



STEMpathy

OCR A Level Biology

A (H420)

Revision Notes for Year 2

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Module 5: Introduction to Communication Systems



Cell signalling

Cell signalling is the process by which cells **detect, process, and respond** to signals.

Cell signalling can be **chemical** (e.g. hormones, neurotransmitters) or **electrical** (e.g. action potentials).

- **Intercellular** (between cells) signalling is almost always **chemical**.
- **Intracellular** (within a cell) signalling can be **chemical or electrical**.

The table below outlines **intercellular** and **intracellular cell signalling**, with **examples** you will encounter at A level:

Type	Chemical signalling	Chemical Examples	Electrical signalling	Electrical Examples
Intracellular	Signalling molecules or ions act inside the cell to transmit information from a receptor to a response pathway.	- cAMP as a second messenger. - Ca^{2+} triggering muscle contraction.	Changes in membrane potential or ions within a cell signal a stimulus.	β -cell depolarisation in pancreas in response to glucose uptake.
Intercellular	One cell releases signalling molecules that bind to receptors on another cell, triggering a response.	- Hormones (e.g. insulin, histamine, auxin). - Neurotransmitters (e.g. acetylcholine).	- Electrical impulses do not directly pass between cells. - Electrical impulses are converted to chemical ones.	Depolarisation during a neuron's action potential $\rightarrow$ neurotransmitter released at a synapse.

The Importance of Cell Signalling

Cell signalling allows organisms to **respond** to changing external and internal **conditions** by detecting stimuli with receptors and producing a **behavioural** or **physiological response**.

- A **behavioural response** is a **movement** (towards or away from a stimulus).
- A **physiological response** is a change in **cellular function**.

Responding to changes in internal conditions allows for the maintenance of **optimal conditions** for cellular processes.

Responding to **external conditions** allows organisms to **avoid**, or minimise the effect of, unfavourable **abiotic factors** (e.g. extreme temperature, low pH, water stress) and **hazardous biotic factors** (e.g. predators, competition for food).



Module 5: Introduction to Communication Systems



Communication Systems

Communication systems are how multicellular organisms **coordinate** the **responses** of their **tissues** and **organs**.

Communication systems can be electrical (**neuronal**) or hormonal (**endocrine**).

- **Neuronal system:** Neurones conduct **electrical impulses** rapidly, enabling fast responses to stimuli. At synapses, **neurotransmitters** act as the **cell signalling molecules**.
- **Endocrine system:** Hormones are secreted into the **blood** and transported throughout the body, acting only on **target cells** with **complementary receptors**.

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Module 5: Homeostasis and Feedback Systems



Homeostasis

Homeostasis is the maintenance of a **constant** internal environment **around** an optimal **set point**, despite changes in external or internal conditions.

The table below **outlines** some of the **internal conditions** that must be maintained at the **organism level**:

Factor	Importance	Typical Set Point (in humans)	Controlled By
Blood Glucose Concentration	Essential for cellular respiration and osmotic balance.	$\sim 4\text{--}6\text{ mmol dm}^{-3}$	Pancreas (islets of Langerhans), liver, insulin and glucagon.
Blood Water Potential	Maintains osmotic balance between blood plasma and cells.	$\sim -750\text{ kPa}$	Hypothalamus (osmoreceptors), posterior pituitary, kidneys.
Body Temperature	Affects enzyme and metabolic efficiency.	$\sim 37\text{ }^{\circ}\text{C}$	Hypothalamus, effectors in skin and muscles.

Negative Feedback

The mechanism of action for homeostasis is **negative feedback**.

Negative feedback takes action to **reverse changes** away from the **set point**.

Negative feedback typically follows the following **pathway**:

Stimulus → Receptor → Control Centre* → Effector → Response

* Also called the coordinator.

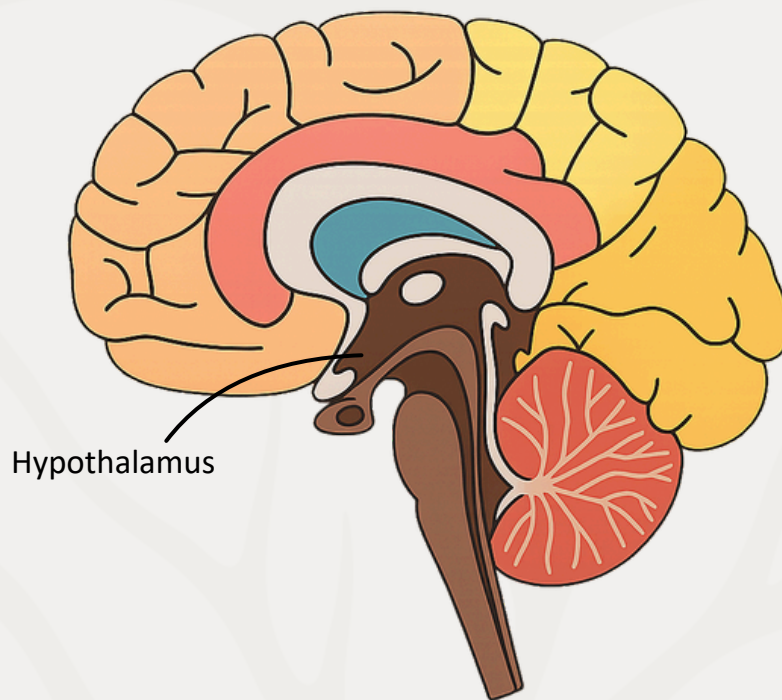
It is useful to know that the control centre for many homeostatic responses in animals is the hypothalamus, a small, central region of the brain.



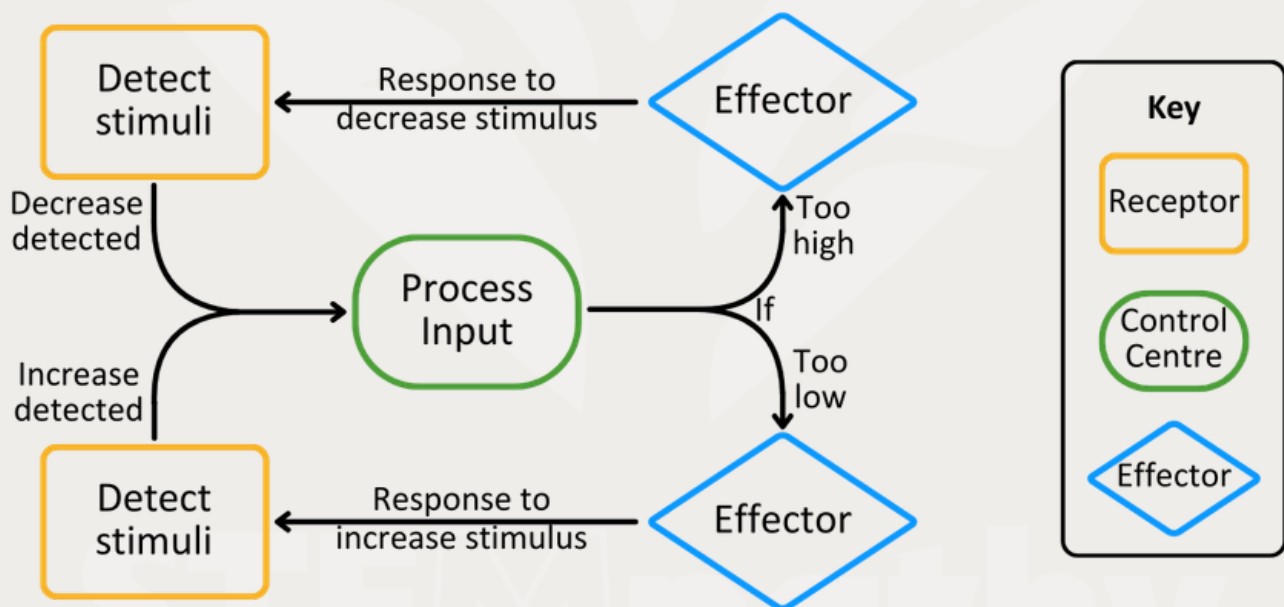
Module 5: Homeostasis and Feedback Systems



The diagram below shows the **position** of the **hypothalamus**:



The diagram below **shows** a typical **flowchart** showing the process of **negative feedback**:



Module 5: Homeostasis and Feedback Systems



The table below outlines some **examples** of **receptors** involved in **homeostatic processes**:

Receptor	Stimulus Detected	Location	Homeostatic Process
Thermoreceptors	Core body/blood temperature	Hypothalamus	Thermoregulation
Chemoreceptors	CO ₂ concentration, pH of blood	Carotid bodies and medulla oblongata	Control of ventilation rate and depth
Osmoreceptors	Blood water potential (solute concentration)	Hypothalamus	Osmoregulation
Glucose receptors	Blood glucose concentration	Pancreas (islets of Langerhans)	Blood glucose regulation

All of the examples above measure internal stimuli. **Receptors** which detect **external** stimuli are **less** directly involved in homeostatic mechanisms.

The table below outlines some **examples** of **effectors** involved in **homeostatic processes**:

Effector	Type	Main Actions	Homeostatic Process
Skeletal muscle	Muscle	Contracts rapidly to generate heat.	Thermoregulation.
Cardiac muscle	Muscle	Adjusts rate and force of contraction.	Heart rate regulation via the autonomic nervous system and hormones (e.g. adrenaline).
Pancreatic cells	Endocrine gland	- β cells secrete insulin. - α cells secrete glucagon.	Blood glucose regulation.
Collecting duct cells	Epithelial tissue	Insert/remove aquaporins to alter water reabsorption rate.	Osmoregulation.
Adrenal gland	Endocrine gland	Secretes adrenaline: - Increasing heart rate. - Stroke volume. - Ventilation rate. - Causes glycogenolysis. - Causes vasodilation/vasoconstriction.	Fight-or-flight response; short-term stress response.



Module 5: Homeostasis and Feedback Systems



Positive Feedback

Positive feedback takes action to **amplify any change** away from the **set point**, stopping only when a limiting factor is reached or an external event occurs.

Positive feedback processes are uncommon in biological systems, as they are **destabilising**; however, they have their uses.

The table below outlines three **examples of positive feedback**:

Example	Stimulus	Response	Stopping Point
Labour	Cervical stretch during childbirth.	Hypothalamus signals the posterior pituitary to release oxytocin, causing stronger uterine contractions and more stretching.	More stretch → more oxytocin → stronger contractions until baby is delivered.
Blood clotting	Platelet activation at the site of vessel damage.	Platelets release clotting factors, which activate more platelets and trigger an enzyme cascade.	Rapid amplification of clotting until a stable clot forms.
Action potential	Initial depolarisation of the membrane.	Voltage-gated Na ⁺ channels in the axon open, Na ⁺ influx depolarises the membrane further.	More Na ⁺ channels open until full depolarisation is reached.

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Module 5: Thermoregulation: Ectothermy and Endothermy



Thermoregulation

Thermoregulation is the maintenance of a **stable** internal body **temperature**, despite changes in the external environment, around an **optimal set point**.

Organisms have evolved different ways to regulate their internal body temperature, each with **advantages** and **disadvantages**, making them well adapted to their ecological niche. Broadly, they are classified as either **ectotherms** or **endotherms**, depending on their main source of heat.

- **Ectothermy**: Regulation of body temperature using external heat sources.
- **Endothermy**: Regulation of body temperature using internal metabolic heat.

Ectotherms are organisms that use **ectothermy**, such as reptiles, amphibians and fish; their **body temperature changes** with the environment's temperature.

Endotherms are organisms that use **endothermy**, such as mammals and birds; their **body temperature remains stable**.

Ectotherms

Ectotherms depend largely on **behavioural mechanisms** to control their body temperature.

The table below outlines some **examples of ectotherms** and their **adaptations**:

Organism	Adaptation	Effect
Crocodile	- Basks in the sun. - Gapes with an open mouth to release heat.	- Absorbs heat directly. - Cooling by evaporation.
Lizard	Uses burrows.	Burrow cooler in the day, warmer at night.
Locust	- Side-on sun-facing to maximise surface area in the morning. - Face-on sun-facing to reduce surface area in the afternoon. Increases breathing rate.	- Heat gain in the morning. - Reduced overheating in the afternoon. - Cooling by evaporation.



Module 5: Thermoregulation: Ectothermy and Endothermy



Endotherms

Endotherms can maintain their body **temperature above** that of the **environment** due to more heat being released by metabolic reactions (exergonic) than being taken in (endergonic).

Endotherms use both **physiological** and **behavioural** mechanisms to maintain their body temperature around a set point.

Behavioural responses in endotherms are similar to those seen in ectotherms.

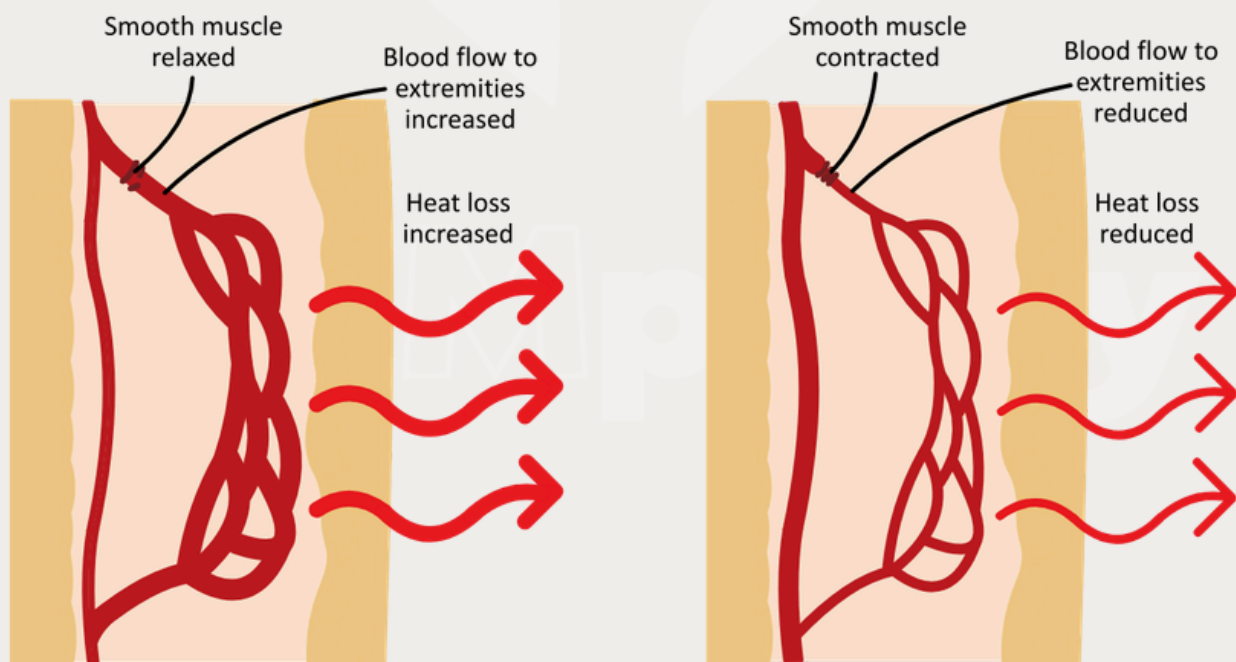
Physiological responses require communication systems to monitor stimuli and coordinate effectors. Consequently, their mechanism of action is that of a negative feedback process.

The **hypothalamus** measures inputs on temperature changes in the internal and external temperature from the receptors, and **coordinates** the response by **signalling effectors**.

The **effectors** which are signalled by the hypothalamus vary depending on the **condition**:

- **If too hot:** Arterioles dilate, sweat glands activate, hair erector muscles relax, and skeletal muscles relax.
- **If too cold:** Arterioles constrict, sweat glands are inactive, hair erector muscles contract, skeletal muscles contract (shivering), respiration rate of liver increases, and the adrenal medulla and thyroid gland secrete metabolism-raising hormones.

The diagram below illustrates the dilation and constriction of **arterioles** to control the release or retention of excess heat during **vasodilation** and **vasoconstriction**:



Module 5: The Importance of Excretion



Excretion

Excretion is the **removal** of **metabolic waste** from the body.

Metabolic waste is the unwanted and potentially **harmful byproducts** of cellular metabolism.

If **metabolic byproducts** can accumulate to significant levels, then reactions can slow down as **enzyme activity is affected**, or cellular damage can occur if they are **toxic**.

The table below outlines some **examples** of the **harmful impacts of metabolic waste on cellular activity**:

Harmful Effect	Metabolic Waste	Mechanism
Enzyme activity decreases as changes in pH disrupt their tertiary structure.	Carbon dioxide (CO ₂).	Forms carbonic acid and releases H ⁺ ions, lowering pH.
Enzymes and structural proteins denature, halting metabolic reactions.	Ammonia (NH ₃).	Highly toxic and alkaline; interferes with hydrogen bonding.
Oxygen transport efficiency falls, reducing aerobic respiration rates.	Carbon dioxide (CO ₂).	Reduces haemoglobin's affinity for oxygen.
Cells lose water by osmosis, leading to dehydration and reduced metabolic efficiency.	Urea / Excess ions.	Lowers tissue water potential, causing water loss from cells.

The Importance of Excretion

Excretion is essential for **maintaining homeostasis** within an organism.

Because **metabolic by-products** are continuously produced by cellular reactions, they must be removed efficiently to avoid them accumulating.

The table below **outlines** some examples of **metabolic wastes**:

Metabolic Waste	Excretory Organ	Excretory Importance
Carbon dioxide (CO ₂)	Lungs	Excess CO ₂ forms carbonic acid, lowering pH and reducing haemoglobin's oxygen affinity.
Ammonia (NH ₃)	Liver → Kidneys	Highly toxic; converted to urea for safe excretion.
Urea	Kidneys	Nitrogenous waste is removed in urine; it controls osmotic balance.



Module 5: The Importance of Excretion



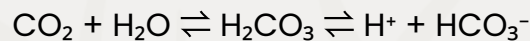
Importance of Excreting Carbon Dioxide

Aerobically respiring cells produce CO_2 , which diffuses into the **bloodstream** and forms **carbonic acid** (H_2CO_3).

Carbonic acid can then **dissociate** into **hydrogencarbonate ions** and **hydrogen ions** ($\text{H}^+ + \text{HCO}_3^-$).

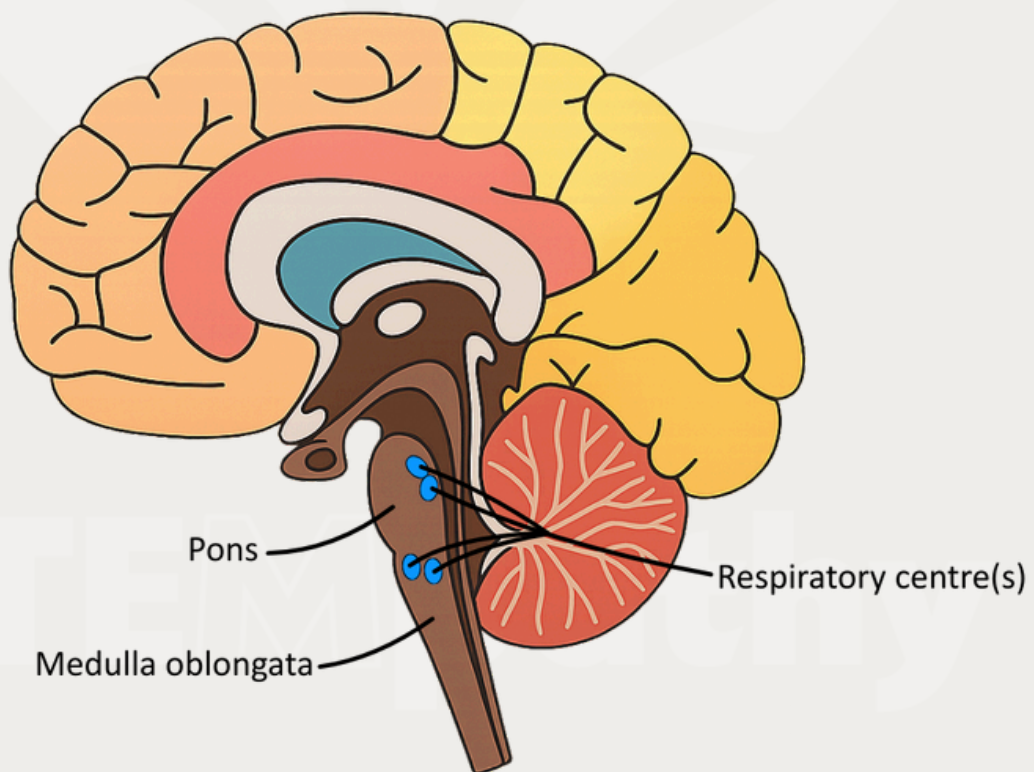
Most carbonic acid dissociates inside **red blood cells** (being catalysed by carbonic anhydrase), but some dissociation still occurs (slowly) in the blood plasma.

The process is **outlined** below:



Small increases in the **hydrogen ion concentration** of the blood plasma are **detected** by the respiratory centre in the medulla oblongata of the brain (as a change in blood plasma pH), which **increases the breathing rate** to remove more carbon dioxide.

The diagram below shows the **position** of the medulla oblongata:



It is useful to know that the respiratory centre is not a centralised area, and is instead several clusters of neurones dispersed across the medulla oblongata and the pons; you are **not expected** to know this.



Module 5: The Importance of Excretion

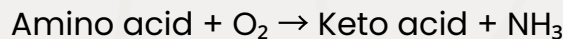


Importance of Excreting Nitrogenous Waste: Ammonia/Urea

The **digestion** of **proteins** produces **amino acids**, which are useful for protein synthesis but, in excess, cannot be stored for later use. Because amino acids are also a source of energy, excreting them directly would be wasteful.

The **liver** metabolises amino acids, **removing** the **amine group** (NH_2) in deamination to produce a keto acid and ammonia (NH_3).

The process is **outlined** below:



Keto acids can be used in **respiration** or converted into a carbohydrate or fat for **storage**. The **ammonia** (NH_3) formed from the amine group (NH_2) is **highly soluble** and **toxic*** and must be converted into a **safer** and **less soluble** compound before it accumulates: **urea**.

Urea, made by the liver, can circulate more safely in the blood before being **filtered** from the blood plasma by the **kidneys** and excreted in urine.

*It is useful to know that, whilst the amine group is commonly described as toxic, it is itself not toxic, and will quickly form ammonia (toxic) in solution, or bind to an organic compound (not in itself toxic).

Importance of Excreting Water

Although water is essential for hydration and as a **solvent** for biochemical reactions, water in excess causes **dilution** of the blood and tissue fluids. This decreases the solute concentration of the blood plasma, disrupting **osmotic balance** and affecting **enzyme activity**.

The **kidneys** are the main organs involved in regulating water levels. They **filter** the blood and **reabsorb** the appropriate amount of water to maintain a stable **blood water potential**.

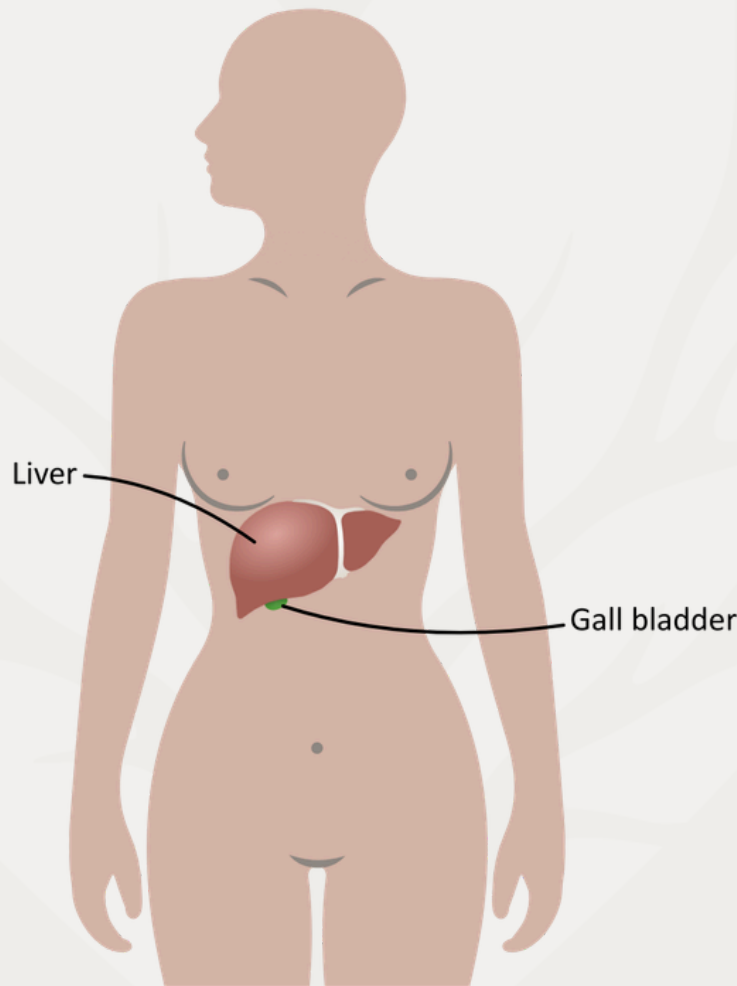
Osmoregulation is coordinated by the **hypothalamus**, which detects changes in blood osmotic potential using **osmoreceptors** and alters the activity of the **kidney** accordingly.





The Liver

The **liver** is the largest internal organ in the human body, located in the upper right of the **abdominal cavity**, just beneath the diaphragm.



The liver **minimises** potentially harmful **changes in blood composition** when nutrient* levels fluctuate, toxins are absorbed, or metabolic wastes are produced, contributing to an optimal internal environment.

The main roles of the liver are:

- **Storage of glycogen** and the regulation of blood glucose concentration.
- **Detoxification** of harmful substances such as alcohol and drugs.
- **Detoxification of ammonia** by converting it into urea in the ornithine cycle.

*A note on the word nutrient. It is vague, general and all-encompassing – appropriate for the varied functions of the liver, but rarely appropriate to be used in an exam response.





Storage of Glycogen

The **liver** contributes to the **homeostatic control** of **blood glucose concentration** by acting as an **effector**; it can increase or decrease blood glucose levels in the blood in response to **pancreatic coordination**.

The liver **stores** excess **glucose as glycogen** when blood glucose levels are **too high**. The **conversion** of glucose into glycogen is controlled by the release of **insulin** from the **pancreas**.

When blood glucose levels are **too low**, glycogen is **broken down** into glucose, which is controlled by the release of **glucagon** from the **pancreas**.

Detoxification

The **liver protects** the body from **toxic substances** that could **disrupt** enzyme-driven metabolism or cause cellular **damage**.

Ammonia is the main example studied in OCR A level biology, and is a highly **toxic** byproduct of the deamination of amino acids.

The liver **converts** ammonia into **urea** – a less toxic and more easily excreted substance – in the **ornithine cycle**.

The **ornithine cycle** is a cyclical enzyme-driven reaction that occurs within individual **hepatocytes** (liver cells).

You are **not** expected to know the details of the ornithine cycle, but you are expected to understand it.

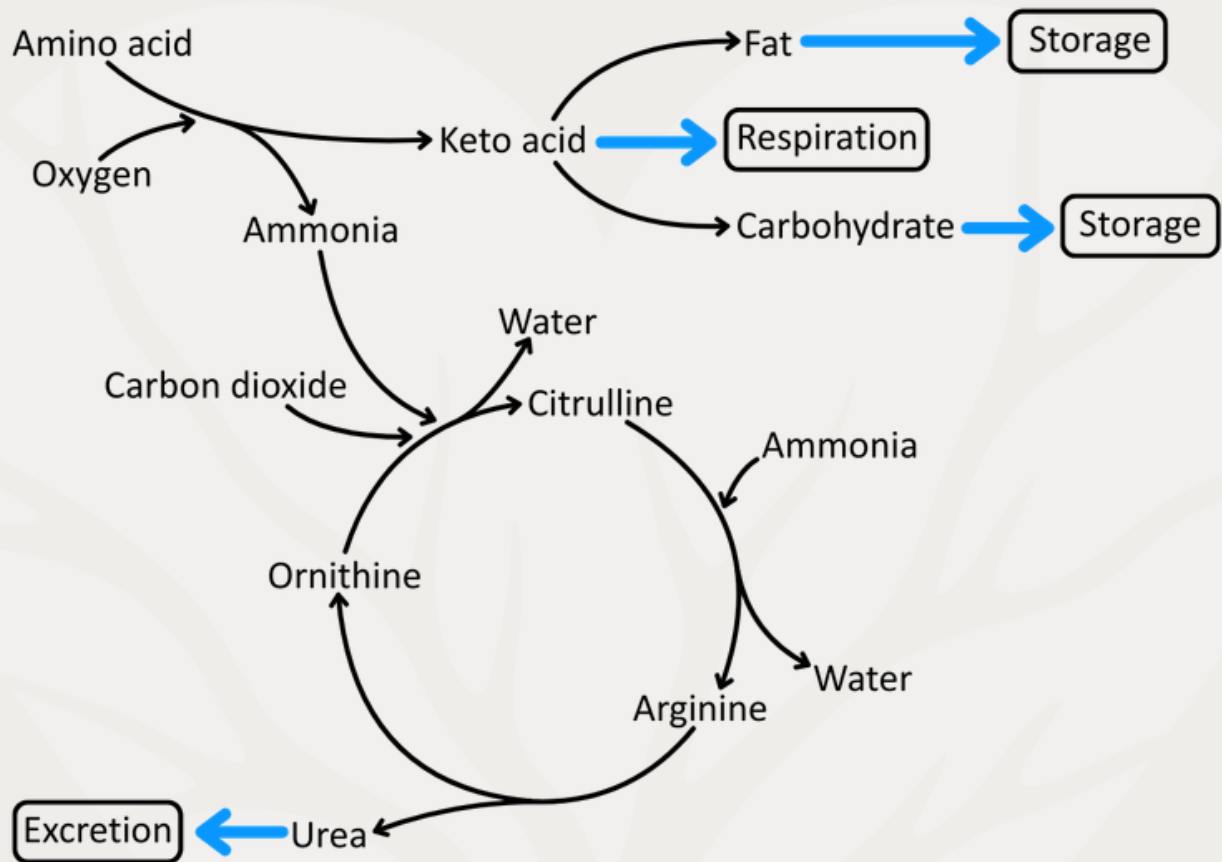
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Module 5: Functions of the Liver



The **diagram** below shows the **ornithine cycle** in hepatocytes:



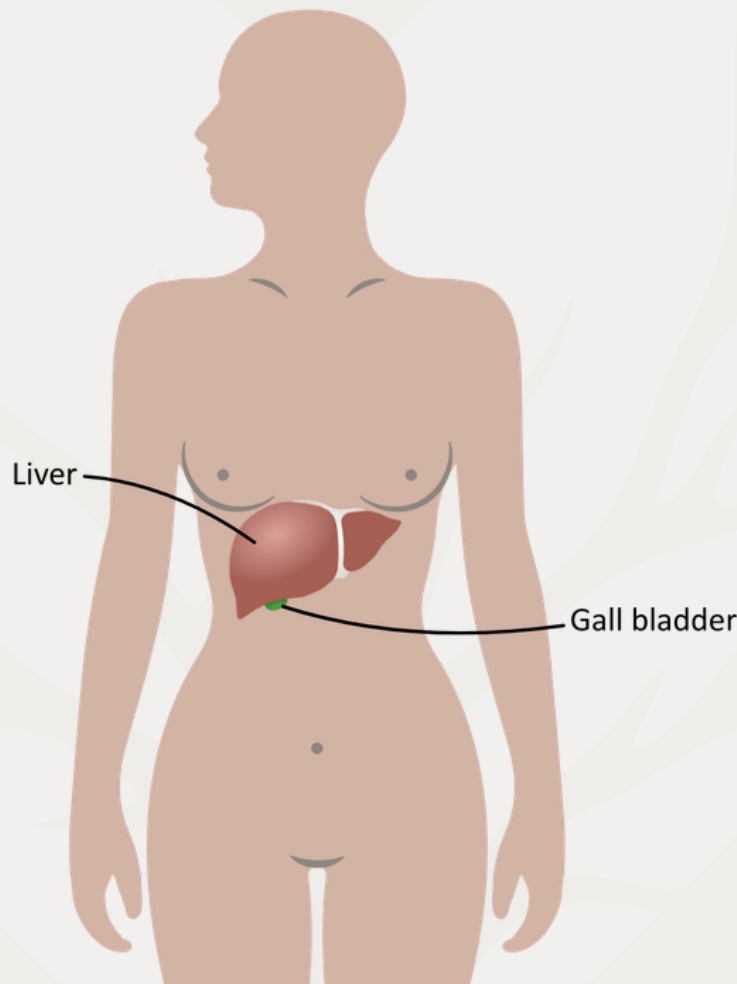
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Gross Anatomical Structure of the Liver

The diagram below **shows** the **position** of the **liver**:



Anatomically, the liver has a **large right lobe** and a **smaller left lobe** (and two smaller subdivisions on the underside of the larger one), both of which are connected to the gall bladder and the small intestine via the **bile duct**, and have an extensive blood supply.

The **gall bladder** is located beneath the right lobe and is connected to the liver by the **bile duct**, which carries bile to the **small intestine**.

Histology of the Liver

The **liver** is divided into **functional units** called **lobules**.

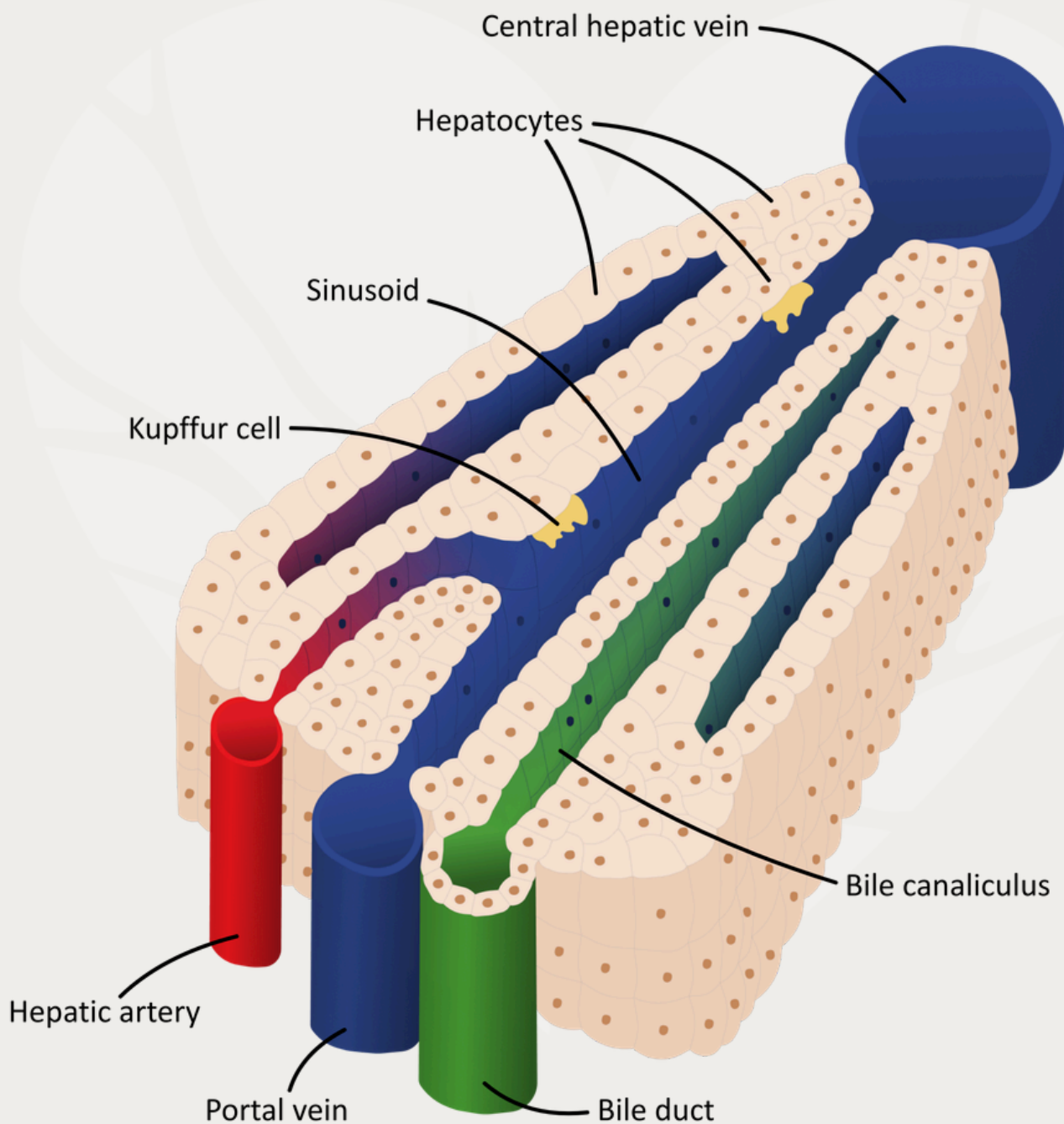
Lobules are a (roughly) cylindrical mass of **hepatocytes** (liver cells) arranged around a **central hepatic vein**, with blood vessels and bile ducts clustered around the outer edges.



Module 5: Liver Anatomy and Histology



The diagram below **shows** the idealised **structure** of a single **lobule**:



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Detoxification: Liver processing of blood

Hepatocytes continuously alter the **composition** of the **blood** by removing, breaking down, and adding substances to it as it passes through the **liver lobule**.

Step-By-Step: Liver processing of blood

1. Oxygenated blood from the **hepatic artery** and nutrient-rich blood from the **hepatic portal vein** enter the liver and flow into the **sinusoids**.
2. Substances move in and out of the **hepatocytes** and are **metabolised**, stored and/or released.
3. The **blood flows** towards the **central hepatic vein** in the middle of each lobule.
4. The **central hepatic veins** carry the processed blood to the vena cava for transport around the body.

Moving among the hepatic cells of the sinusoids are **Kupffer cells**.

Kupffer cells are specialised **macrophages** that break down and recycle the components of haemoglobin from red blood cells (such as bilirubin), which may be **excreted** as a component of **bile**.

The Gall Bladder

The **gall bladder** is a small, muscular sac located beneath the right lobe of the liver.

It acts as a **storage organ for bile**, and plays an important role in **lipid digestion** by **emulsifying fats**, increasing their surface area for enzyme action.

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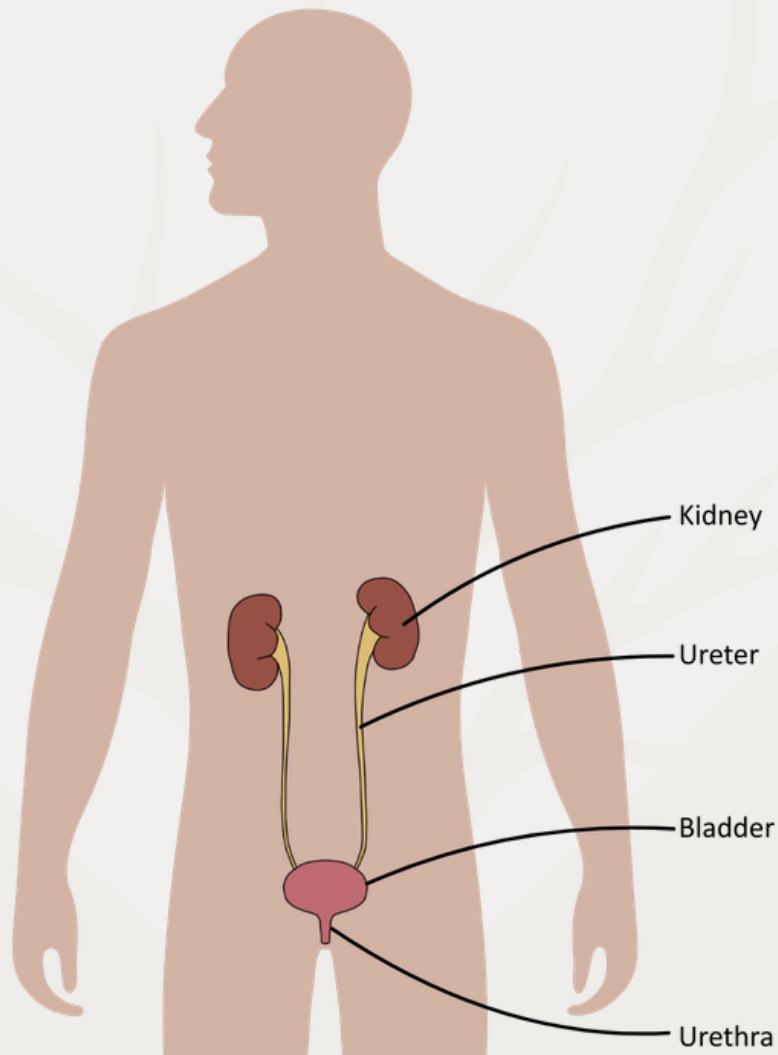




The Kidney

Humans have **two kidneys**, located on either side of the vertebral column, just below the lowest rib.

The diagram below **shows** the **position** of the **kidneys**:



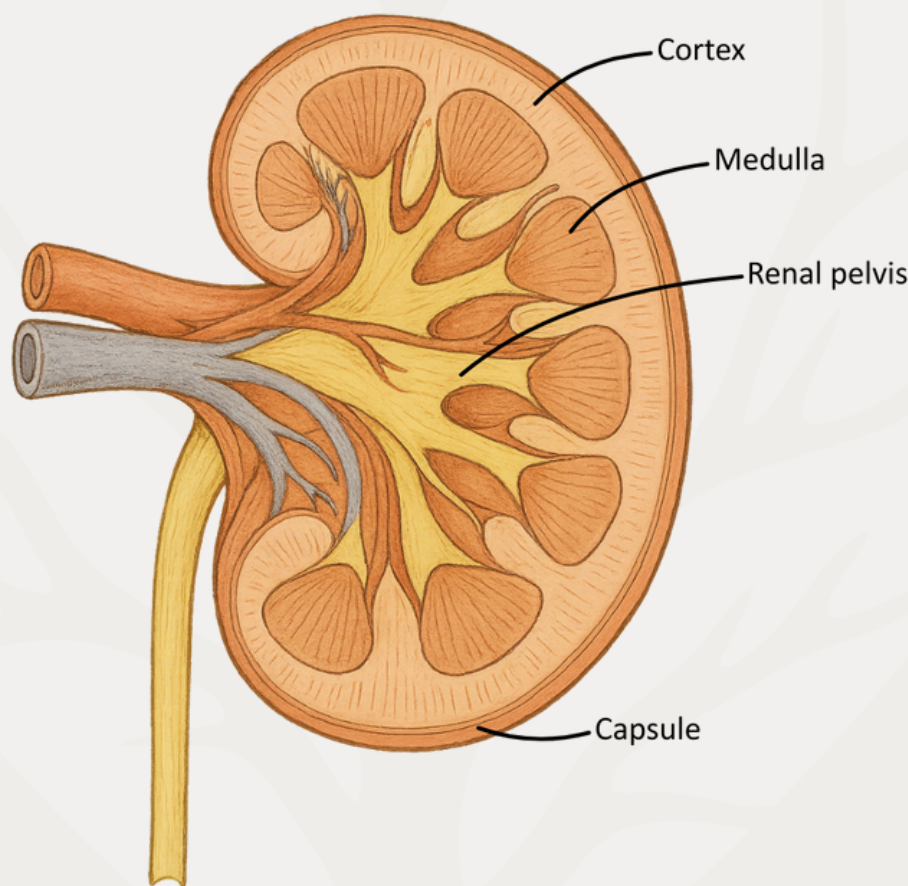
Kidneys are the main organs for **excretion** and **osmoregulation**, and play a central role in **homeostatic processes** that maintain the optimal composition of the blood plasma and tissue fluid, including:

- **Excretion:** Removal of metabolic wastes such as urea and creatinine from the blood.
- **Water balance:** Regulation of blood water potential through the controlled reabsorption of water and production of urine.



Anatomy of the Kidney(s)

The kidney has 3 tissue areas arranged around a central region (the **renal pelvis**), which collects urine before it enters the ureter. Surrounding the renal **pelvis** is the **medulla**, and surrounding that is the **cortex**.



The table below **outlines** the **regions** of the **kidney** and their **role(s)**:

Region	Description	Main Function
Cortex	The outer region contains renal corpuscles and convoluted tubules.	Site of ultrafiltration and the selective reabsorption of most useful solutes.
Medulla	The inner region is composed of renal pyramids, containing loops of Henle and collecting ducts.	Establishes an osmotic gradient to enable water reabsorption.
Renal pelvis	The central region where the collecting ducts drain into the ureter.	Funnels urine to the bladder.

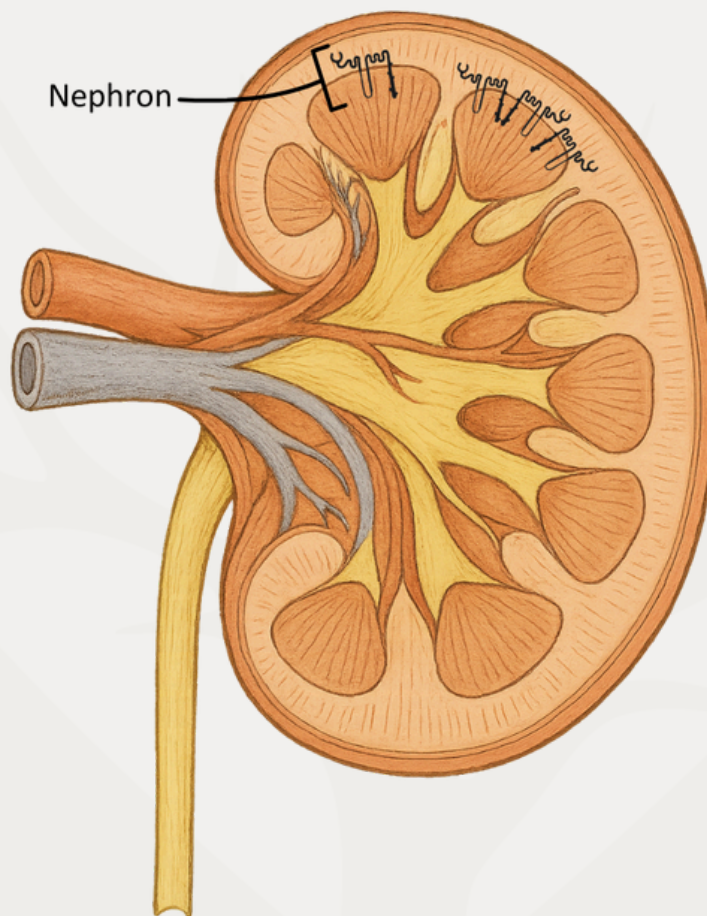




Histology of the Kidney(s)

A **nephron** is a tubular structure responsible for **filtering** the **blood** and **forming urine**. The **nephron** is a **functional unit** of the kidney, with approximately 1 million of them arranged radially across the **cortex** and **medulla**, converging toward the **pelvis**.

The diagrams below **show** the position of a **single** and **many nephrons** in the kidney:



It is important to note that the collecting duct is **not a component** of the **nephron**; however, in A level materials, it is usually referred to as such.

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Module 5: Kidney Nephrons: Filtering the Blood

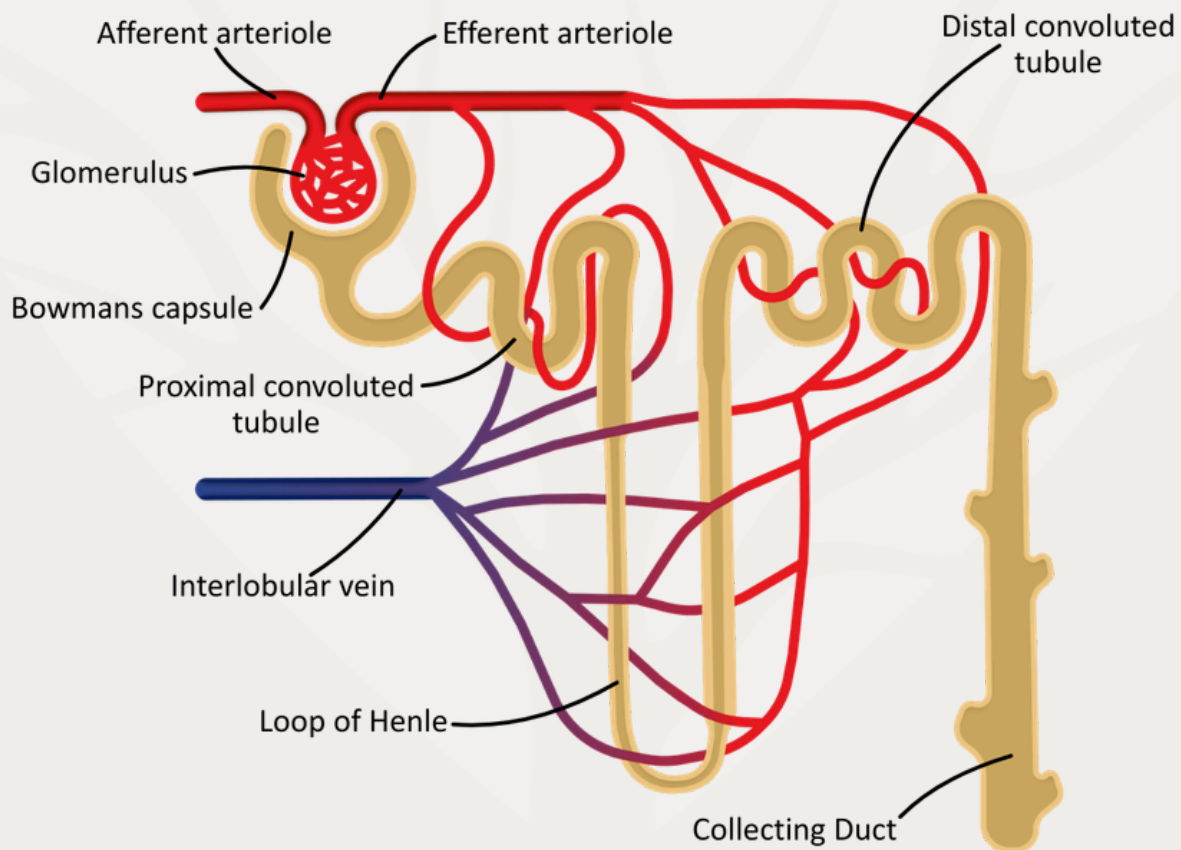


Nephrons

A **nephron** is a tubular structure responsible for **filtering the blood** and **forming urine**.

The **nephron** consists of a number of structures that work together. Their arrangement with respect to each other, a **dense capillary network**, and their position in the kidney set up **concentration gradients** for the effective **filtration** and reabsorption of **substances**.

The diagram below **shows** the **structures** of a single **nephron** and their relative positions in the kidney tissues:



It is important to note that the collecting duct is **not** a **component** of the **nephron**; however, in A level materials, it is usually referred to as such, and for simplicity, it will be included with the nephron.



Module 5: Kidney Nephrons: Filtering the Blood



Blood Filtration: The Nephron

The nephron's structures are **adapted** for their own function; together, they can **filter blood** and **reabsorb substances** in the needed quantities.

The table below **outlines** the **function** of each **structure**:

Nephron Structure	Function
Bowman's capsule and glomerulus	Ultrafiltration: Filtration of small molecules from the blood plasma under pressure.
Proximal convoluted tubule (PCT)	Selective reabsorption: Recovery of useful solutes and most of the water.
Loop of Henle	Creation of a steep osmotic gradient.
Distal convoluted tubule (DCT)	Homeostatic balancing of ions and pH.
Collecting duct	Osmoregulatory water reabsorption in response to ADH.

Ultrafiltration

Ultrafiltration takes place in the **renal corpuscle** and is the **first stage** of blood filtration, leading to urine production.

Blood enters the glomerulus from the **afferent arteriole**, which is **larger** than the exiting **efferent arteriole**. This creates a **higher hydrostatic pressure** in the knot of capillaries than in the surrounding Bowman's capsule, forcing out water and solutes from the blood, which form the **glomerular filtrate**.

Glomerular filtrate is essentially blood plasma **without large proteins or cells**, consisting of:

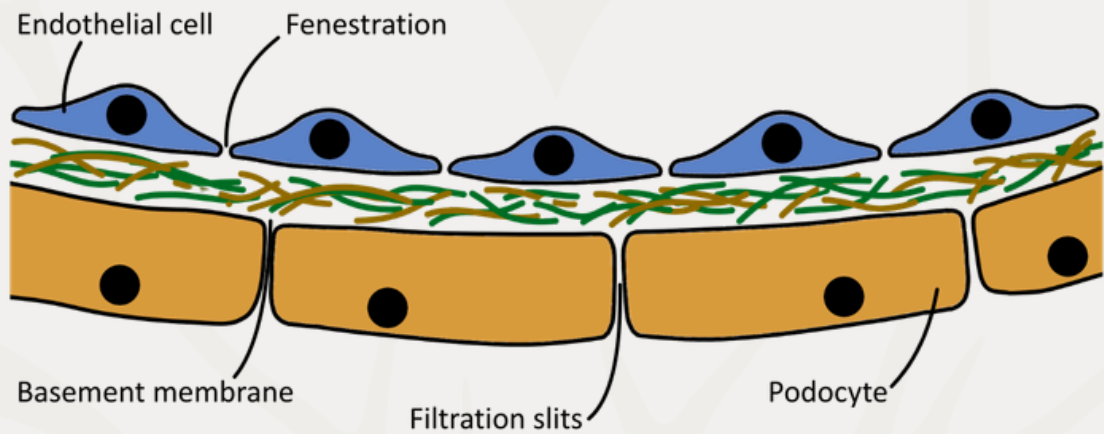
- Water
- Glucose
- Amino acids
- Urea
- Ions (Na^+ , Cl^- , K^+ , HCO_3^-)

The blood plasma leaving the glomerulus (via the efferent arteriole) has a **low (negative) water potential**, which is essential for reabsorption later in the nephron.



Red and white blood cells, and **plasma proteins**, remain in the blood because they are **too large** to cross the **filtration barrier** into the Bowman’s capsule.

The diagram below **shows** the structure of the **filtration barrier**:



The table below **outlines** the **structures** of the **filtration barrier**:

Filtration Barrier Structure	Description
Capillary endothelium	Single layer of cells lining the glomerular capillaries, with small pores called fenestrations.
Basement membrane	Collagen and glycoprotein mesh* located between the capillary and podocyte layers.
Podocyte layer	Epithelial cells (of the Bowman’s capsule) form narrow filtration slits with membrane extensions called major processes, which have smaller extensions called minor processes.

***Molecules** with a relative molecular mass **larger** than **69,000** are **unable** to pass through the mesh of the **basement membrane**, such as **albumin, antibodies, and fibrinogen**.

Selective Reabsorption (in the PCT)

Selective reabsorption takes place in the **proximal convoluted tubule** (PCT), and is the **second stage** of blood filtration in the kidneys.

Selective reabsorption is the process by which **useful substances** from the glomerular filtrate are **reabsorbed** back into the blood through both **active transport** and (passive) **co-transport** mechanisms.

Module 5: Kidney Nephrons: Filtering the Blood



The table below **outlines** the key **substances selectively reabsorbed** from the filtrate in the PCT:

Substance	Mechanism of Reabsorption
Amino acids	Co-transported with Na ⁺ ions into epithelial cells, then diffuse into capillaries.
Cl ⁻	Follow Na ⁺ diffusion down an electrochemical gradient.
Glucose	Co-transported with Na ⁺ ions into epithelial cells, then diffuse into capillaries.
Na ⁺	Actively transported out of epithelial cells into the tissue fluid/blood via Na ⁺ /K ⁺ ATPase pumps.
Small proteins and peptides	Reabsorbed by endocytosis into epithelial cells.
Water	Diffuses down the water potential gradient (osmosis) established by solute reabsorption.

Mechanism of Selective Reabsorption

1. **Sodium-potassium pumps** on the epithelial cell surface membrane actively transport Na⁺ ions out into the surrounding tissue fluid.
2. **Sodium ions diffuse in** from the filtrate in the PCT into the epithelial cells down a concentration gradient. **Glucose or amino acids** are moved with Na⁺ through **co-transport proteins**.
3. **Water** moves **out** of the PCT and into the epithelial cells by **osmosis** down the water potential gradient.
4. **Na⁺ are actively transported** out of the epithelial cells into the **blood** of the capillary.
5. **Water** diffuses down the **water potential gradient** established by the movement of **Na⁺** into the blood of the capillary by osmosis.
6. **Amino acids** and **glucose diffuse** into the bloodstream down the **concentration gradient** maintained by the capillary network.

The PCT reabsorbs nearly **all glucose** and **amino acids**, and around 85% of water and sodium ions from the filtrate.

The Hairpin Countercurrent Multiplier System

The **hairpin countercurrent multiplier system** is a process arising from the structure and function of the **Loop of Henle**.

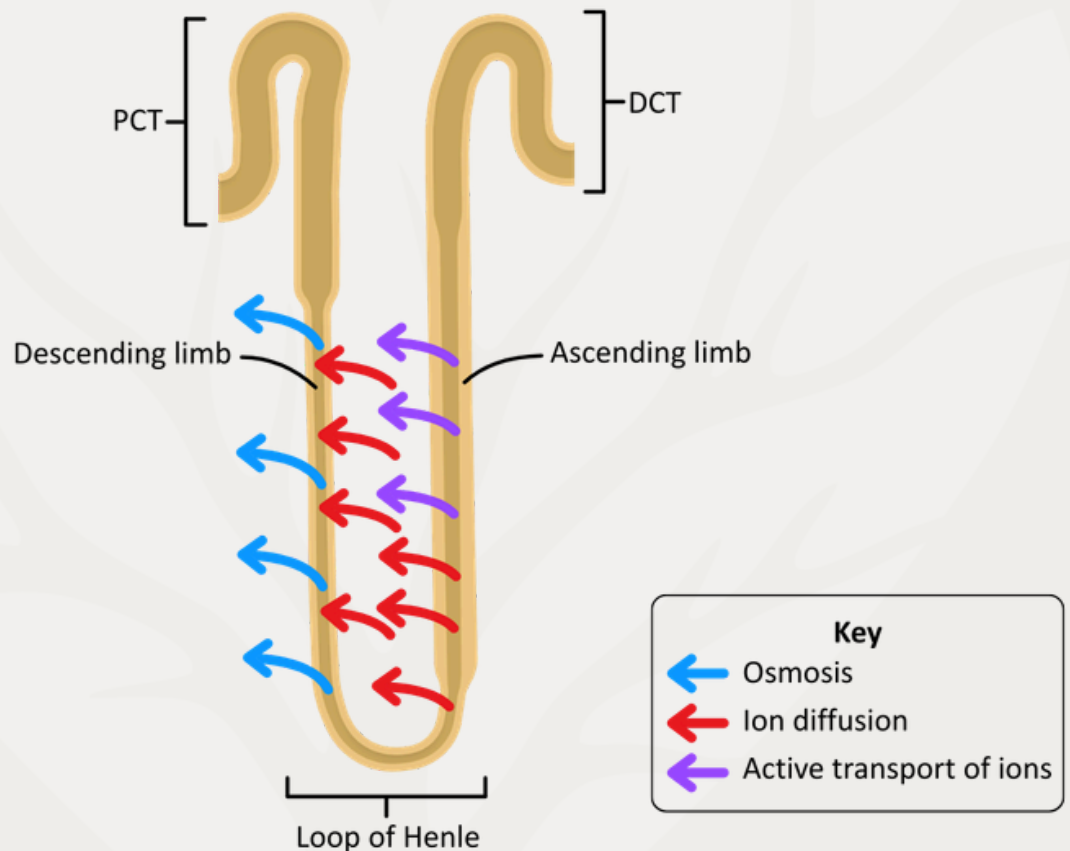


Module 5: Kidney Nephrons: Filtering the Blood



The Loop of Henle works to **create** a steep **osmotic gradient** in the medulla of the kidney, so that **water** will move out of the loop of Henle (and later the collecting duct) as it passes through the nephron, being **reabsorbed** back into the blood.

The diagram below **shows** the **structure** of the **Loop of Henle** and the movement of substances:



The descending limb is permeable to water, but the ascending limb is not.

Mechanism of the Hairpin Countercurrent Multiplier System

1. **Water moves out** of the **descending limb** by osmosis into the medulla because the water potential is **lower**.
2. **Sodium** and **chloride ions diffuse** into the **descending limb** from the medulla, down their **concentration gradient**.
3. **Sodium** and **chloride ions diffuse out** of the **lower ascending limb** into the medulla.
4. **Sodium** and **chloride ions** are **actively transported** out of the **upper ascending limb** into the medulla, further **lowering the water potential** of the medulla.
5. **Water remains** in the filtrate because the **ascending limb** is **impermeable** to water, so the filtrate becomes **more dilute** as ions are transported out.
6. The accumulation of sodium and chloride ions in the **medulla** establishes a **steep water potential gradient** from the cortex down to the base of the medulla, allowing **water** to be **reabsorbed** later from the **collecting duct** by osmosis.





When the **filtrate** reaches the top of the ascending limb, and the end of the loop of Henle, its water potential has increased (become less negative) as most sodium and chloride ions have been removed into the medulla.

Selective Reabsorption (in the DCT)

In OCR A Level Biology the distal convoluted tubule's role in blood filtration is often skimmed over.

The **distal convoluted tubule** (DCT) is located in the **cortex**, and is the final section of the nephron (because the collecting duct is not actually a part of the nephron), connecting the ascending limb of the loop of Henle to the collecting duct.

The **DCT** adjusts the **composition** of the **filtrate** by **selectively reabsorbing ions** and secreting **hydrogen** or **potassium** ions to **regulate** pH and electrolyte balance in the blood.

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Module 5: Osmoregulation: The Collecting Duct and ADH



Osmoregulation

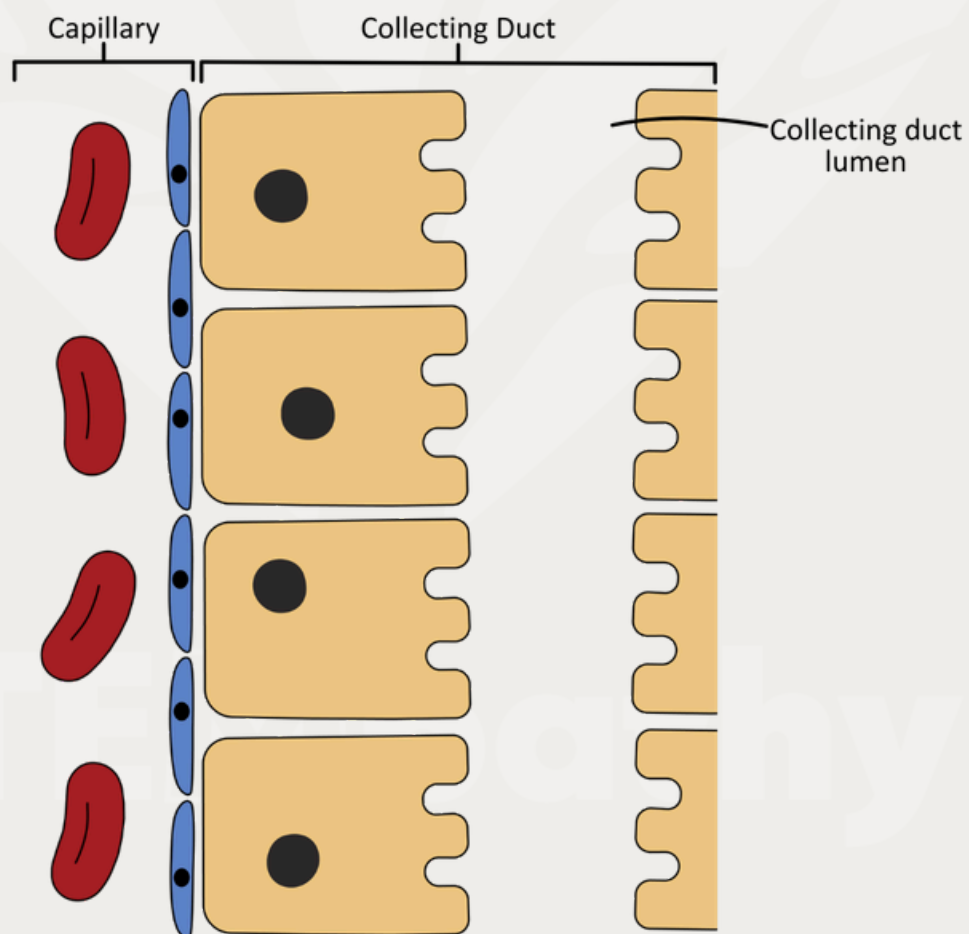
Osmoregulation is the **homeostatic control** of the **water potential** of the blood and the body fluids to minimise cell **shrinking** or **swelling**.

Osmoregulation is under the control of **negative feedback** processes in the **hypothalamus**, which controls the **reabsorption** of water in the **collecting duct**.

The **collecting duct** goes down into the **medulla** towards the renal pelvis, passing through regions of **increasingly low water potential**, enabling **water** to move out of the collecting duct and into the blood of the capillaries by **moving down its water potential gradient**.

To **control the reabsorption** of water, the epithelial cells can adjust the **permeability** of their cell surface membranes to **water** in response to levels of **ADH**.

The diagram below **shows** the **structures** involved in **reabsorption** of **water** from the **collecting duct**:



Module 5: Osmoregulation: The Collecting Duct and ADH



Control of ADH Secretion

The concentration of **ADH** in the bloodstream is controlled by **negative feedback** in the **hypothalamus** using **osmoreceptors** and **neurosecretory** cells working together.

Osmoreceptors are specialised cells in the hypothalamus that **monitor** the blood's **water potential**, **shrinking** in response to **lower blood water potential**, and expanding in response to higher blood water potential.

When **osmoreceptors shrink** (due to a **low water potential** in the blood), they **stimulate** the **neurosecretory cells**, which release ADH into the bloodstream by **exocytosis**.

ADH travels through the **bloodstream** before arriving at the **kidneys** and binding to **complementary receptors** on the cell surface membrane of the **collecting duct's epithelial cells**. This causes the collecting ducts to **increase permeability**.

When the blood **water potential rises** (becomes less negative), osmoreceptor cells gain water and swell, **inhibiting ADH** release, signalling the collecting ducts to **reduce permeability**.

Mechanism of Water Reabsorption in the Collecting Duct

Aquaporins are present in the cell surface membrane of the collecting duct's epithelial cells, through which water is **reabsorbed** by **osmosis**.

When **ADH** levels **increase** (when the water potential of the blood is low):

1. **ADH** binds to **complementary receptor proteins** on the cell surface membranes of the collecting duct epithelial cells.
2. **Cell signalling** causes **vesicles** containing **aquaporins** to move towards and **fuse** with the **cell surface membrane** facing the lumen of the collecting duct.
3. More **aquaporins** in the membrane increase the **permeability** of the collecting duct walls to **water**.
4. Water moves out of the filtrate by **osmosis** through the aquaporin channels into the **medulla**, where the **water potential is lower**.
5. **Water** diffuses into the **bloodstream of the capillaries**, increasing the blood water potential.
6. A **smaller volume** of **concentrated urine** is produced.

The **increase** in **blood water potential** is detected by **osmoreceptors** in the **hypothalamus**, and if it returns to its set point, the release of **ADH** is **reduced**.



Module 5: Kidney Failure



Kidney failure is the **loss** of the kidneys' **ability** to **filter waste** effectively.

The **effect** of kidney failure on the **bloodstream** is the **loss** of effective **regulation** of **water potential**, electrolyte balance, and/or pH of the blood, causing serious **dysfunction** and **illness** if left untreated.

Causes of kidney failure

It is important to note that in OCR A you **do not** need to know the causes of kidney failure, only its effects and treatment; however, causes of kidney infection provide opportunities for examiners to test you on your **understanding** of renal function.

All forms of **kidney failure** will **reduce nephron function** by **damaging** the **filtration barrier** and/or impairing **tubular reabsorption**.

The table below **outlines** some **causes** of **kidney failure** and their specific **mechanisms** and **health effects**:

Cause	Mechanism of failure	Health Effect
Type 2 Diabetes mellitus	- Glucose filtrate levels exceed the reabsorptive capabilities of the PCT, leading to glucose passing into the urine. - Hyperglycaemia also damages PCT epithelial cells.	- Glucose is lost in the urine. - Protein in urine.
Hypertension	Persistently high arterial and glomerular pressure damages the glomerular filtration barrier, so proteins with an M_r larger than 69,000 pass into the urine.*	Protein in urine.
Infection	Inflammation of renal tissue damages the filtration barrier and tubular epithelium, so proteins with an M_r larger than 69,000 pass into the filtrate, and selective reabsorption is lowered.*	- Fever and lower back discomfort (if acute). - RBCs in urine. - Protein in urine.

* M_r stands for relative molecular mass.

Assessing Kidney Function: Glomerular Filtration Rate

Glomerular filtration rate (GFR) is the **volume** of filtrate entering the **nephrons** each **minute** ($\text{cm}^3 \text{min}^{-1}$).

GFR provides a quantitative **estimate** of renal function.



Module 5: Kidney Failure



The table below **outlines** the typical **glomerular filtration rates** discussed in clinical settings:

GFR ($\text{cm}^3 \text{min}^{-1}$)	Inferred Kidney Function
90–120	Expected range (interpret with age and context)
< 60	Suggests chronic kidney disease (CKD)
< 15	Kidney failure; urgent intervention

It is useful to know that GFR is used in conjunction with clinical observations to make an accurate diagnosis.

Treating kidney failure

Treatments for kidney failure aim to **restore** the **control** of **solutes** and **water**, or at least temporarily restore them to **optimal levels**.

The **primary treatment** options are **renal dialysis** and/or **kidney transplants**:

- **Renal dialysis** replaces the kidney's filtering role by using **partially permeable membranes** to exchange excess substances from the blood for those that are lacking.
- **Kidney transplants** implant a **donor kidney** to restore (nearly) normal renal function.

Renal Dialysis

Renal dialysis relies on **diffusion** across a **partially permeable membrane**.

Dialysis fluid contains the **optimal concentrations** of the substances that should be found in the **blood**, so that during dialysis, substances that are in excess will move down their **concentration gradients**.

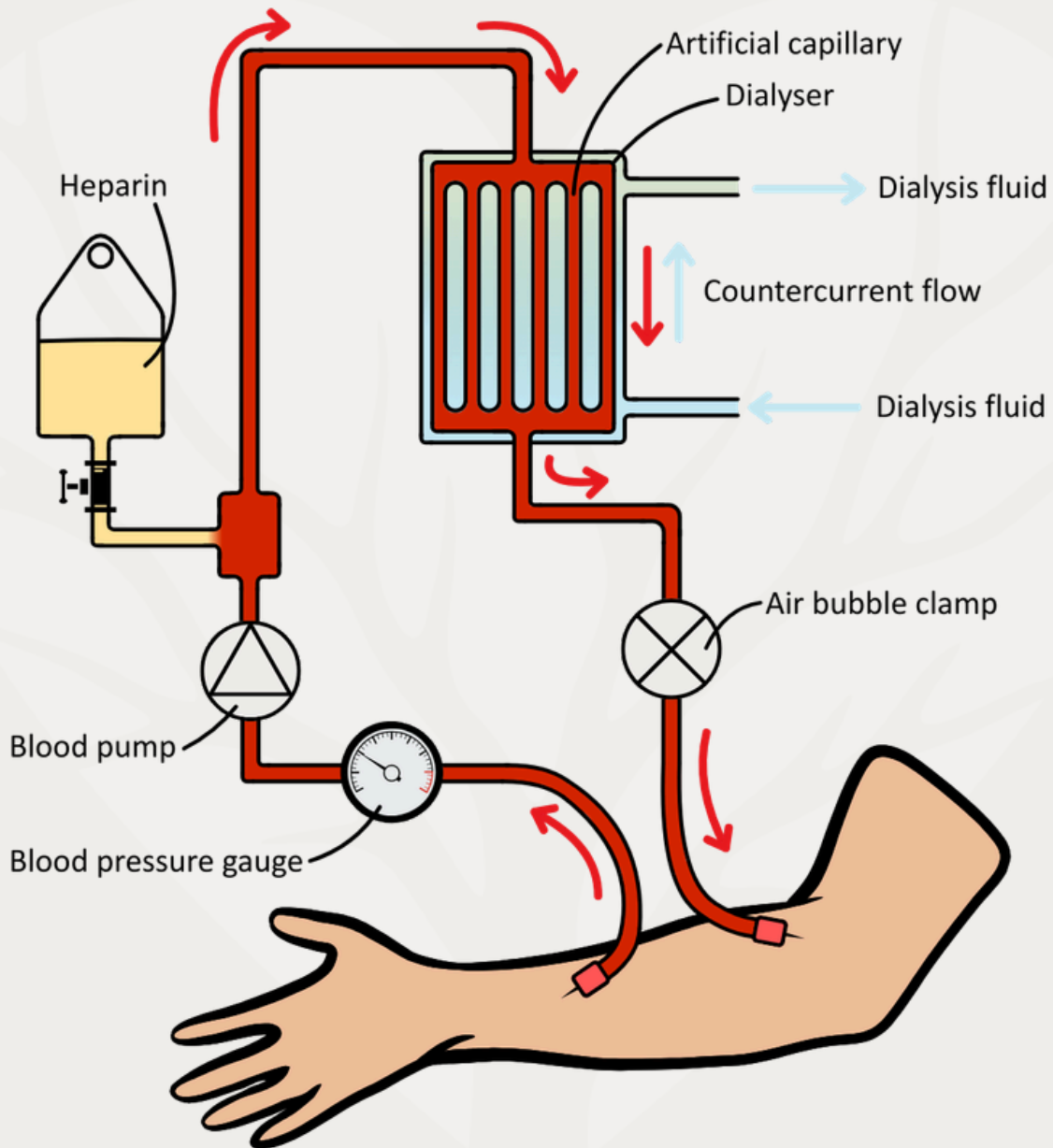
Renal dialysis comes in two forms, but **haemodialysis** is the only one required for OCR A level Biology.



Module 5: Kidney Failure



The diagram below **shows** a simplified diagram for **haemodialysis**:



Take note of the **countercurrent flow** of the dialysis solution and blood.



Kidney transplants

Kidney transplants typically allow patients to feel physically healthy as the concentrations of substances in the blood are **steadily maintained**, and **wastes** are **effectively excreted**.

The table below **compares** the **advantages** and **disadvantages** of different **kidney failure treatments**:

Treatment	Advantages	Disadvantages
Haemodialysis	- Effective removal of waste and excess water. - Typically supervised with a schedule.	- Time-consuming sessions. - Carefully monitored diet and fluid limits. - Access to blood vessels needed.
Kidney transplant	- Better health and well-being. - Freedom from lengthy dialysis sessions. - Greater freedom of travel.	- Immunosuppressant drugs and risk of rejection. - Risks of major surgery. - Side-effects of immunosuppression (infection).

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Module 5: Urine Analysis



Urine analysis detects and measures the presence of **substances** in urine that have passed through the kidney tubules **without being reabsorbed**.

Substances with a relative molecular mass (RMM) **less than 69,000** can typically **appear in urine**, but an **unusual concentration** of these smaller substances can indicate **renal dysfunction** or another **health condition** affecting the blood.

Common Screening Tests

The table below **outlines** some common **urinary screening tests**:

Screen for	Test for	Use	Technique	Cause
Diabetes	Glucose	Screen/monitor glycaemia	Dipstick glucose/enzymatic	- PCT reabsorption exceeded. - Proximal damage.
Glomerular damage	Protein/ albumin	Detect filtration barrier damage	Dipstick protein/ albumin or ACR	Larger molecules are allowed to pass through the filtration barrier.
Pregnancy	hCG	Pregnancy testing	Lateral-flow hCG (urine)	Small hormones are detected by monoclonal antibodies.
Recreational drugs	Drug metabolites	Workplace/ safety/ clinical screening	Urine immunoassay screen	Small, water-soluble metabolites.
Anti-doping (steroids)	Anabolic steroid metabolites	Ensure fair competition	Targeted lab screen	Small metabolites.





The **nervous system** is a **fast** and highly coordinated **communication network** that allows multicellular organisms to **detect changes** in their internal and external **environments** and produce rapid, short-term **responses**.

Neuronal communication consists of **three** main **components**:

- **Sensory receptors** detect changes (**stimuli**) and convert the energy of a stimulus into electrical signals (**transduce**).
- **Neurones** transmit **electrical impulses** to specific components of the body.
- **Synapses** transfer and **coordinate** electrical signals **between neurones** using chemicals (**neurotransmitters**).

The Nervous System as an Effective Communication System

The table below **outlines** the **features** of an effective **communication system**, and the **features** of the **nervous system** that **make it effective**:

Feature	How the Nervous System Enables this
Coverage	The central and peripheral nervous systems link all areas of the body, and their receptors and effectors, through sensory, relay and motor neurones.
Speed	Action potentials transmit information quickly along neurones.
Specificity	Sensory receptors respond to specific stimuli, and complementary receptors in synapses ensure electrical impulses are directed to specific cells.
Coordination	Coordinators (e.g. brain, spinal cord) process sensory input and signal appropriate effectors.
Duration of Response	Effectors signalled by the nervous system typically produce immediate and short-lived responses (compared to the endocrine system).



Module 5: Sensory Receptors



Sensory Receptors

Sensory receptors are specialised cells or sensory nerve endings that **detect a change** (stimulus) in the internal or external **environment**.

Receptors are biological **transducers**.

Transducers **convert** one form of **energy** (such as light, pressure, or chemical energy) into an **electrochemical signal** in the form of a **small, local change** in **potential difference** called a **generator potential**.

If enough **generator potentials** result in the sensory receptor's **threshold potential** being reached, then an **action potential** will be initiated, leading to an electrical impulse.

The table below **outlines** the key **terms** referring to **sensory receptors**:

Term	Definition
Stimulus	A detectable change in the internal or external environment.
Sensory receptor	A specialised cell or sensory nerve ending that detects a stimulus.
Transducer	A structure that converts stimulus energy (e.g. light, pressure, chemical, or temperature) into electrochemical energy.
Generator potential	A small, local depolarisation of the receptor membrane is caused by ion movement when a stimulus is detected.
Threshold potential	The level of depolarisation needed to trigger an action potential.

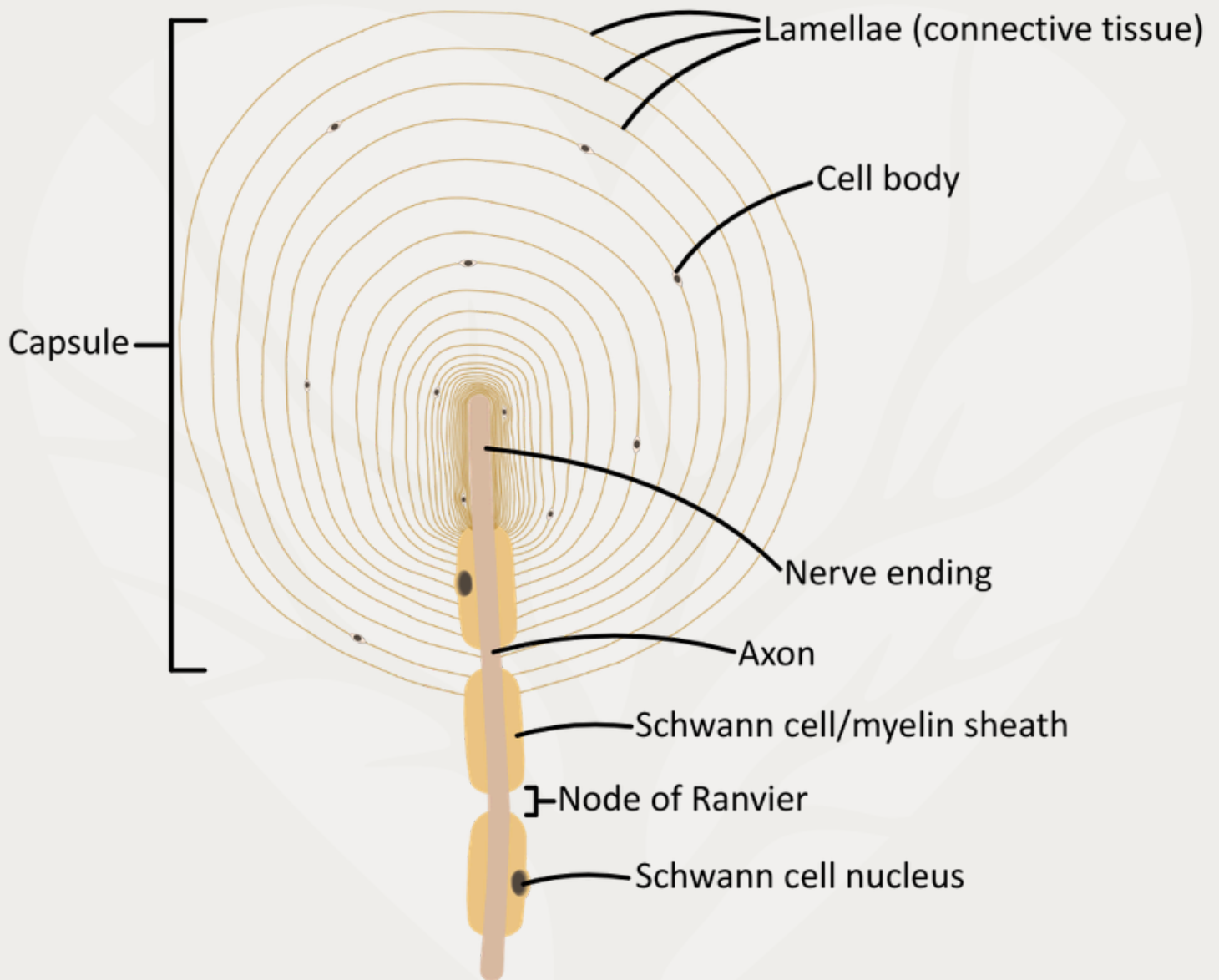
The Pacinian Corpuscle

The **Pacinian corpuscle** is a **mechanoreceptor** (detects pressure) in the skin and around joints that detects **changes in pressure**.

Pacinian corpuscles are the given **examples** of **receptors** in the OCR A Level Biology course.

The Pacinian corpuscle itself is an oval-shaped structure around the nerve ending; the oval shape is formed from layers of connective tissue, which, when pushed, **deform** the membrane.





When the axon membrane is **deformed**, stretch-gated Na^+ channels **open**, creating a **generator potential**.

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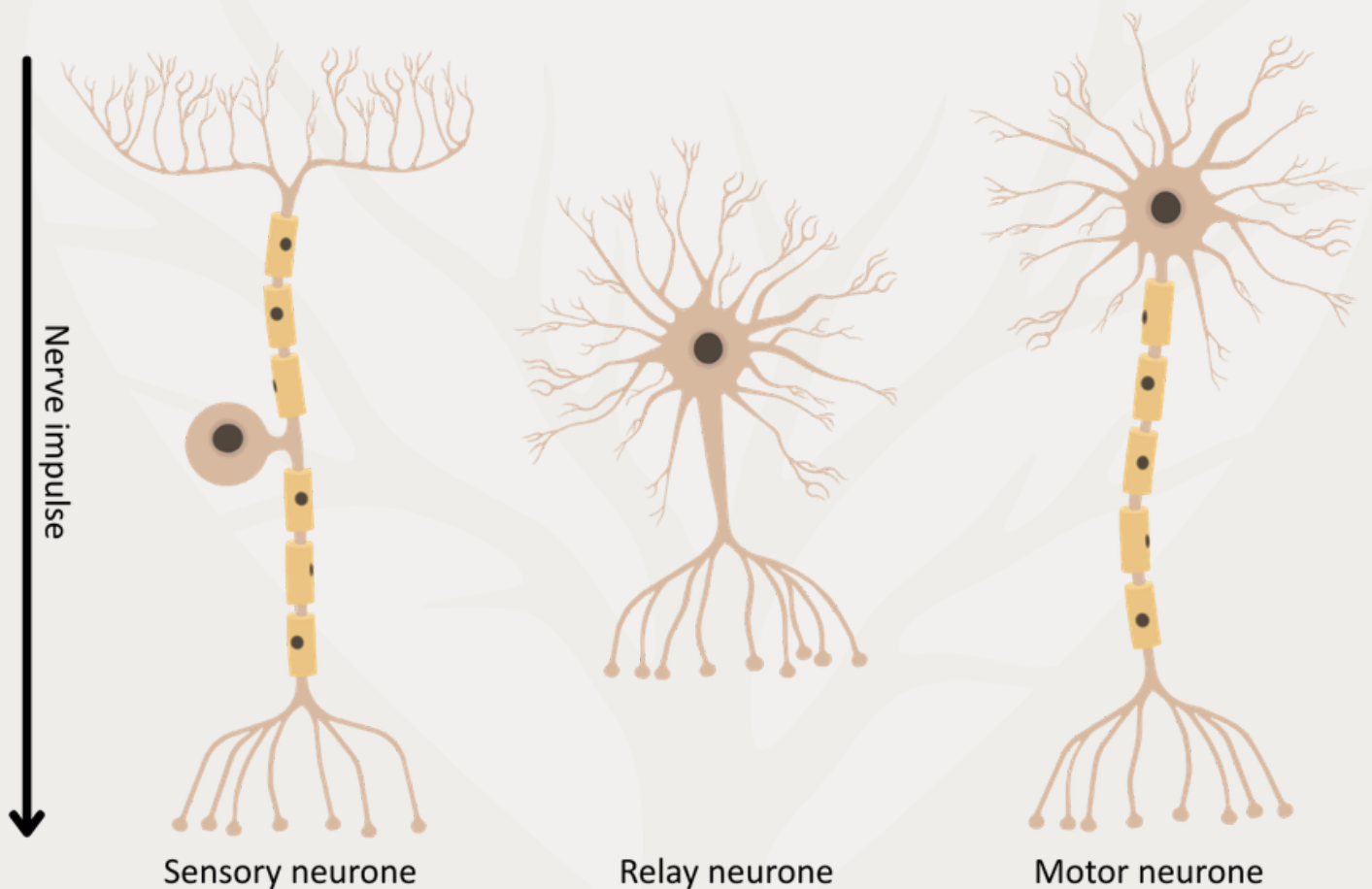




Neurones

Neurones are specialised cells that **transmit information** rapidly throughout the nervous system.

All neurones share the same **basic structure** but are specialised into different types for different roles; at A level we examine generic **sensory, relay** and **motor neurones**.



It is also important to note that most neurones are separated from each other by a **microscopic intercellular gap** known as the **synaptic cleft***. Synapses are junctions that chemically transmit signals with **neurotransmitters**, which then **trigger** electrical changes in the **postsynaptic cell**.

*Also known as the **synaptic gap**.



Common Structural Features

The table below **outlines** some of the key **structures** found in a typical **neurone** and their **functions**:

Structure	Description and Function
Axon	A long extension of the membrane that carries electrical impulses away from the cell body towards other neurones or effectors.
Axon terminals (synaptic end)	Swellings at the end of the axon that form synapses with other neurones or effector cells, releasing neurotransmitters.
Dendrites	Thin, branched extensions from the cell body that receive impulses from other neurones or from sensory receptors.
Myelin sheath	A fatty insulating layer, typically made of Schwann-cell membranes wrapped around the axon. Increases the speed of impulse transmission and prevents signal loss.
Nodes of Ranvier	Gaps between Schwann cells, where the axon membrane is exposed, allow for action potentials to be propagated quickly in saltatory conduction.

Types of Neurone

The three main types of neurone are **sensory** neurones, **relay** neurones and **motor** neurones:

- **Sensory neurones** carry impulses **from sensory receptors to the CNS**.
- **Relay neurones** carry impulses **within the CNS**, linking sensory neurones to motor neurones, and processing information and coordinating responses.
- **Motor neurones** carry impulses **from the CNS to effectors** to produce a response.

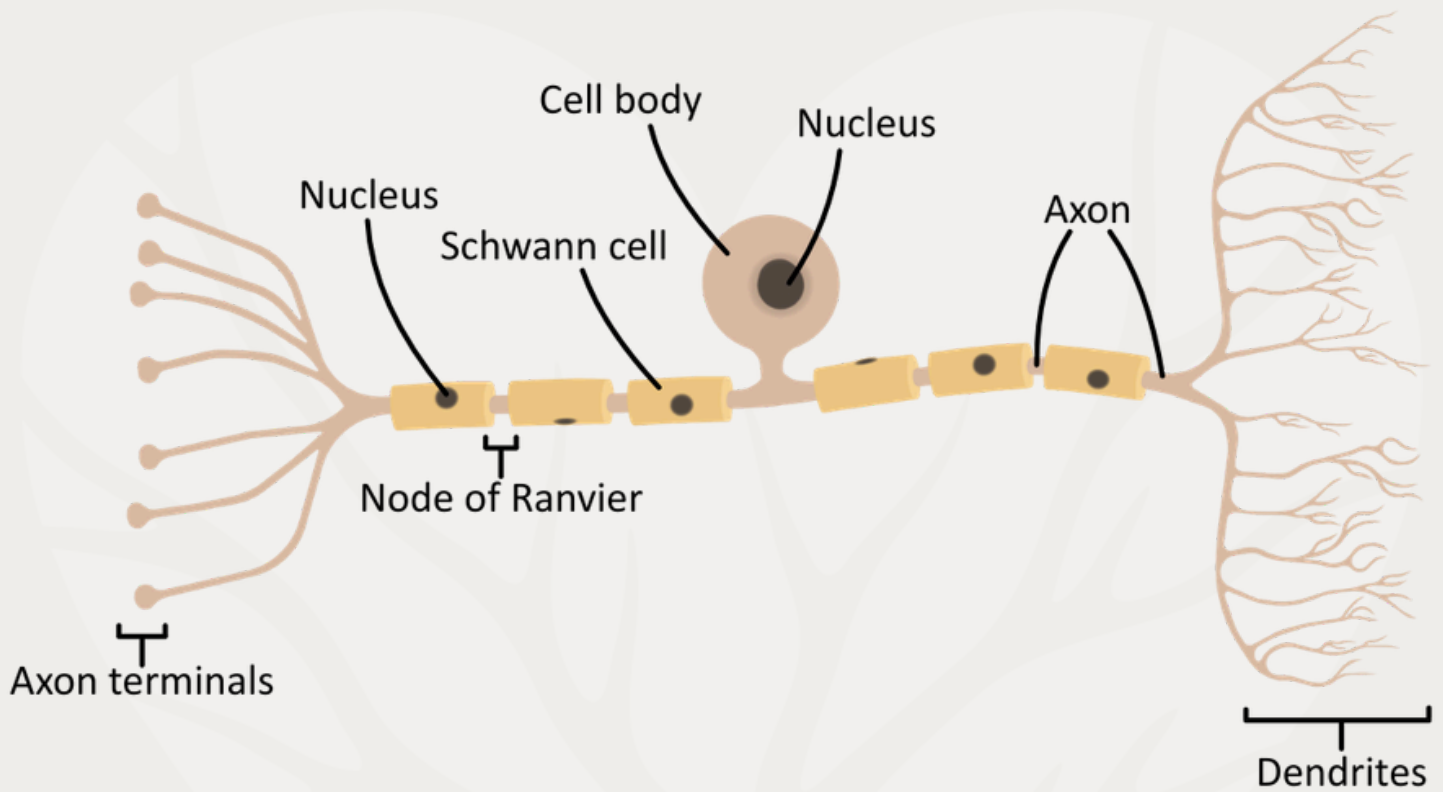
Sensory and **motor** neurones primarily make up the **peripheral nervous system (PNS)**, whilst **relay** neurones make up the **central nervous system (CNS)**.

Each **type** of neurone is **specialised** for its specific role, which is reflected in its **cellular structure**.

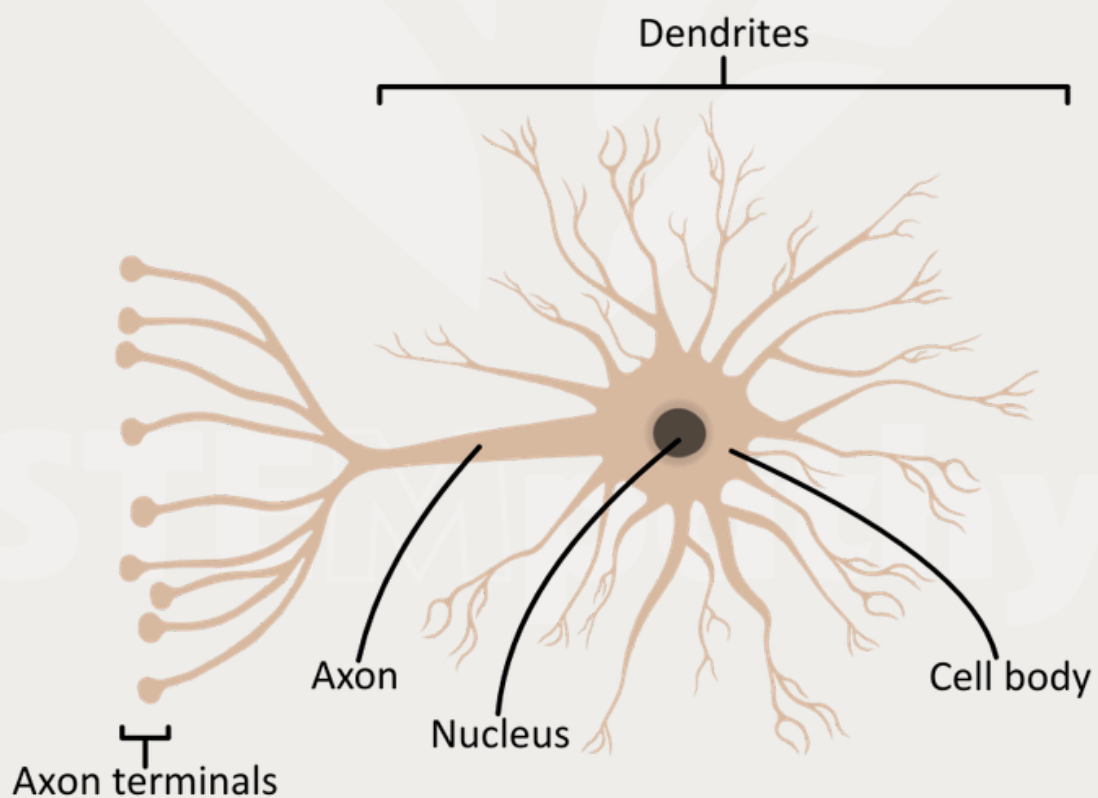




Sensory Neurones

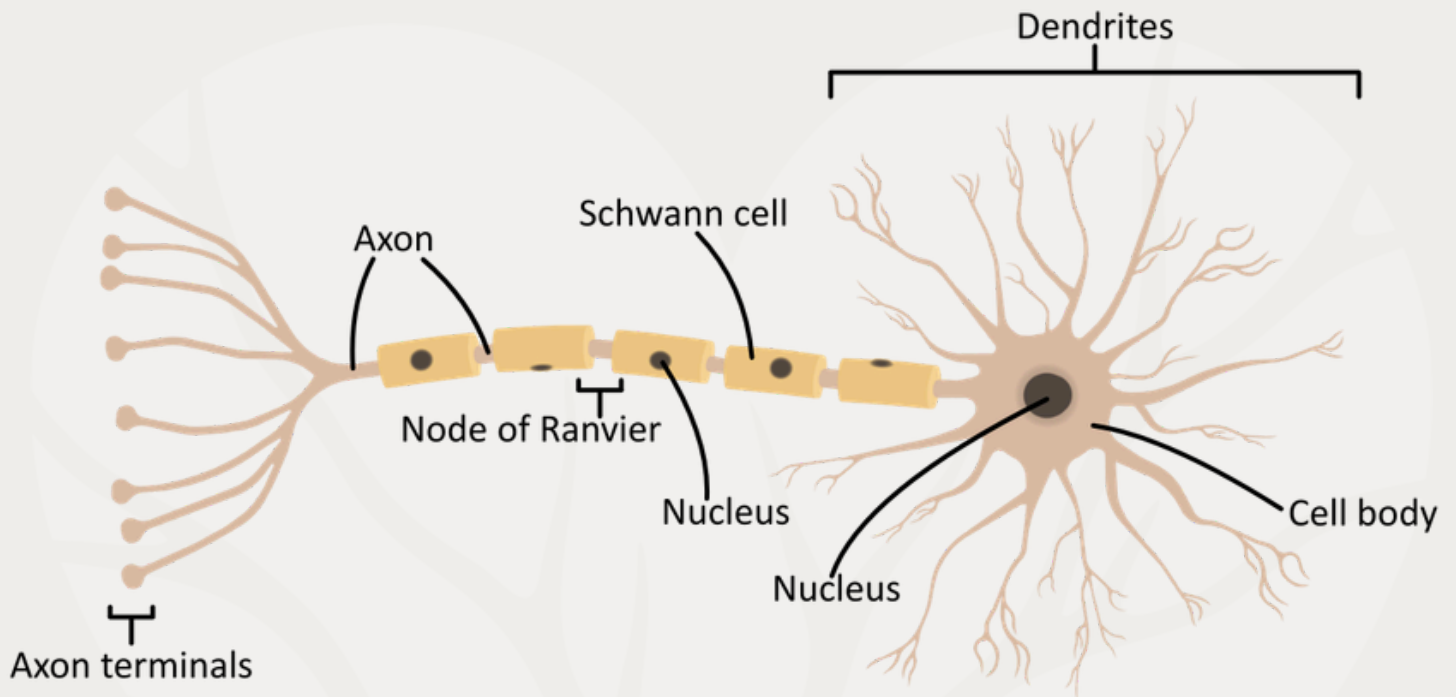


Relay Neurones





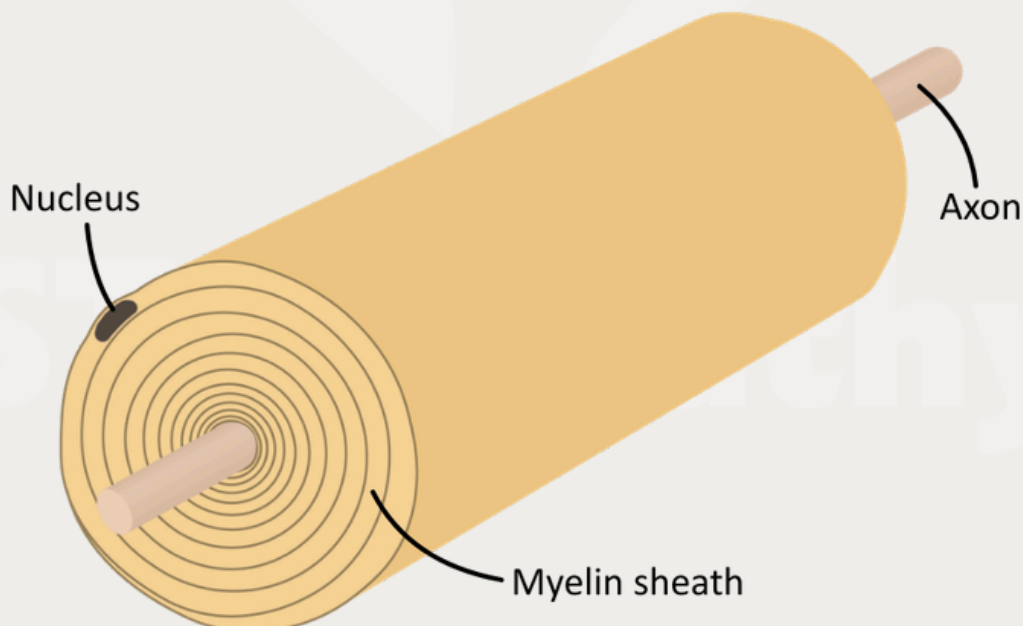
Motor Neurones



Myelination

It is important to note that neurones can be either **myelinated** or **unmyelinated**, which will affect the **speed** of the **electrical impulses** they carry.

Between adjacent **Schwann cells** are small **gaps** exposing the axon plasma membrane called **nodes of Ranvier**.





Because the **myelin sheath prevents ions** from **moving** across the axon membrane where it is covered, **depolarisation** and **repolarisation** can **only occur** at the **nodes of Ranvier**.

The table below **compares** the **structural** and **functional features** of **myelinated** and **unmyelinated** neurones:

Features	Myelinated Neurone	Unmyelinated Neurone
Schwann-cells	Single axon tightly wrapped by many layers of Schwann-cell membrane (myelin).	Sometimes present. If present, one Schwann cell may surround more than one axon.
Nodes of Ranvier	Present at regular intervals.	Absent.
Site of ion movement	Only at nodes of Ranvier.	Along the entire axon plasma membrane.
Conduction	Saltatory conduction, electrical impulse 'jumps'.	Continuous conduction, depolarisation travels as a wave along the membrane.



Module 5: Nerve Impulses



Nerve Impulses

Neurones transmit information as **electrical impulses**.

A **nerve impulse** is a **series of action potentials** travelling along the plasma membrane of a neurone (such as an axon).

The table below **outlines** the key **events** of each **stage** in the action potential:

Stage	Potential Difference	Active/Open Proteins	Ion movement
Resting (polarised)	-60 mV	- Na ⁺ /K ⁺ pump - Leaky K ⁺ channel	- 3 Na ⁺ out for 2 K ⁺ in - K ⁺ leak out
Depolarisation	-60 mV → +40 mV	Voltage-gated Na ⁺ channel	Na ⁺ influx
Hyperpolarisation	-60mV → -70mV	K ⁺ channels closing slowly	Some K ⁺ efflux
Refractory Period	-70mV → -60 mV	- Na ⁺ /K ⁺ pump - Leaky K ⁺ channel	- 3 Na ⁺ out for 2 K ⁺ in - K ⁺ leak out
Repolarisation	+40 mV → -60 mV	Voltage-gated K ⁺ channel	K ⁺ efflux

Electrochemical gradients are **established** and maintained by **carrier proteins** moving specific ions to one side of the plasma membrane.

Resting Potential

When a **neurone** is **not sending** an **electrical impulse**, it is said to be at **rest**.

At **rest**, neurones **maintain** a **potential difference** of approximately **-60 mV***. The inside of the neurone is **negative** compared to the outside.

*It is important to note that OCR A Level Biology specifies the resting potential at **-60 mV**, whilst it is **more commonly** cited at or around **-70 mV**.

Depolarisation

Depolarisation is when the **potential difference** of the cell is **decreased**.

Depolarisation is **important** because if a neurone **depolarises sufficiently** (reaches its threshold potential), then it will **trigger** an electrical impulse; **the action potential**.





Action Potential

An **action potential** is the series of **changes in potential difference** across a membrane, which occurs after a neurone is sufficiently **excited** (stimulated so that it reaches its threshold potential).

During an action potential, the **potential difference** across the plasma membrane **changes** from **-60 mV to +40mV**, then **reverses** temporarily beyond the resting potential (**-65 mV to -70mV**) in a phenomenon known as hyperpolarisation, before **repolarising** to the resting potential of **-60 mV**.*

*It is important to note that these values are true of post-synaptic neurones as they are presented in OCR A Level Biology, but may not be true of other cells, or in other courses. All **action potentials** in the neurone are the **same size**, peaking at about **+40 mV**.

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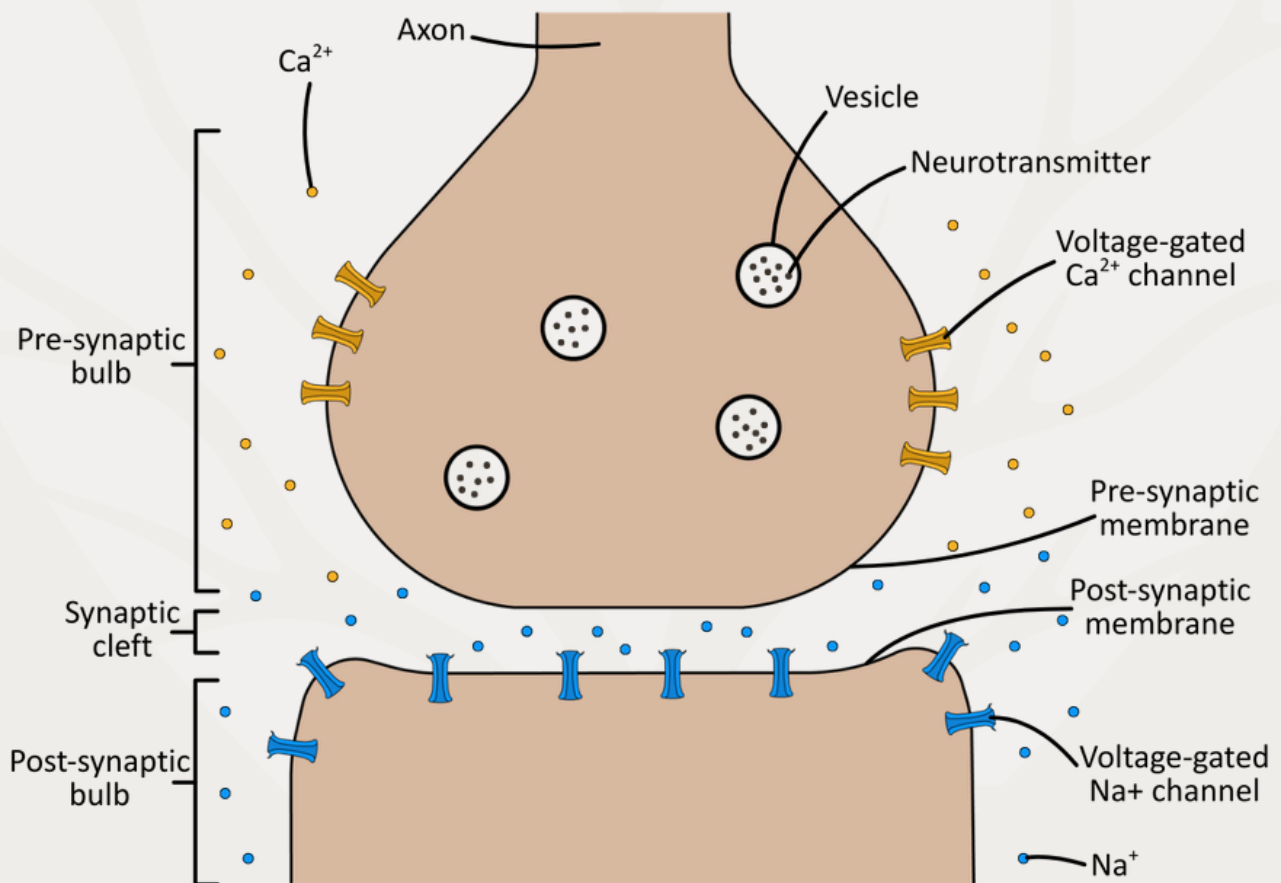


Module 5: Synapses



A **synapse** is the **junction** between a **neurone** and a **postsynaptic cell** (usually another neurone), over which action potentials cannot propagate.

The diagram below **shows** the **synaptic cleft** between the **presynaptic bulb** and the opposing **dendritic membrane** of a postsynaptic neurone:



Neurones communicate across this gap **chemically**, releasing **neurotransmitters** from the presynaptic membrane that **diffuse** across the **synaptic cleft**, and bind to **receptors** on the postsynaptic membrane.

Types of Synapse

There are two main types of synapse, **inhibitory** and **excitatory**:

- **Inhibitory synapses hyperpolarise** postsynaptic membranes, **increasing** the potential difference away from the threshold potential and making an **action potential less likely**.
- **Excitatory synapses depolarise** postsynaptic membranes, **decreasing** the potential difference towards the threshold potential and making **action potentials more likely**.





Additionally, synapses use **different neurotransmitters**, depending on their function. For example, **cholinergic** synapses use **acetylcholine**, dopaminergic synapses use dopamine, and GABAergic uses γ -aminobutyric acid. In OCR A Level Biology **cholinergic synapses** are the named example you are required to know.

Summation

Summation is the **accumulative effect** of postsynaptic potentials at the postsynaptic membrane, which, when combined, can **generate an action potential** if they reach the threshold potential.

It is important to note that the postsynaptic potentials can be either **excitatory** or **inhibitory**:

- **Excitatory**: A small **depolarisation** of the postsynaptic membrane, known as an **EPSP** (excitatory postsynaptic potential).
- **Inhibitory**: A small **hyperpolarisation** of the postsynaptic membrane, known as an **IPSP** (inhibitory postsynaptic potential).

The EPSPs and IPSPs **combine** (so can cancel each other out), and the firing of an action potential is **dependent** upon the threshold potential being reached.

How Synapses Work

Presynaptic neurones release neurotransmitters stored in **vesicles** into the synaptic cleft via **exocytosis**, which then **diffuse** across to the postsynaptic membrane.

Postsynaptic membranes have specific **receptors** to which **neurotransmitters** can **bind**, that **open** their **ion channels**, resulting in an **excitatory** (depolarising) or **inhibitory** (hyperpolarising) effect on the postsynaptic membrane.

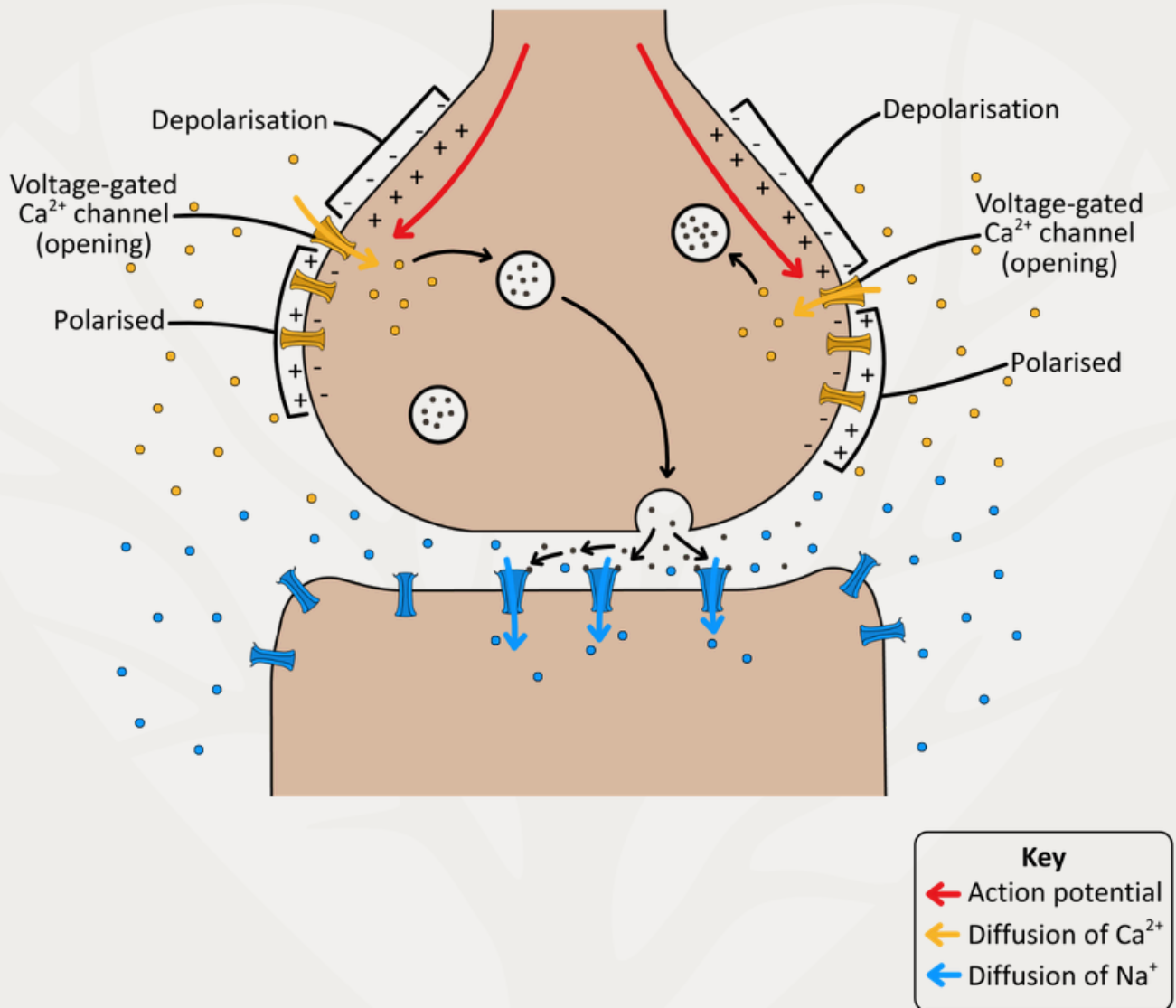
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Module 5: Synapses



The diagram below **shows** the **mechanism** of excitatory **synaptic action**:



Neurotransmitter in the synaptic cleft is either **broken down by enzymes** in the synaptic cleft or **reabsorbed** by the **presynaptic bulb**, which ensures that the transmission of an impulse from one neurone to the next is brief and discrete.

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Module 5: Introduction to the Endocrine System



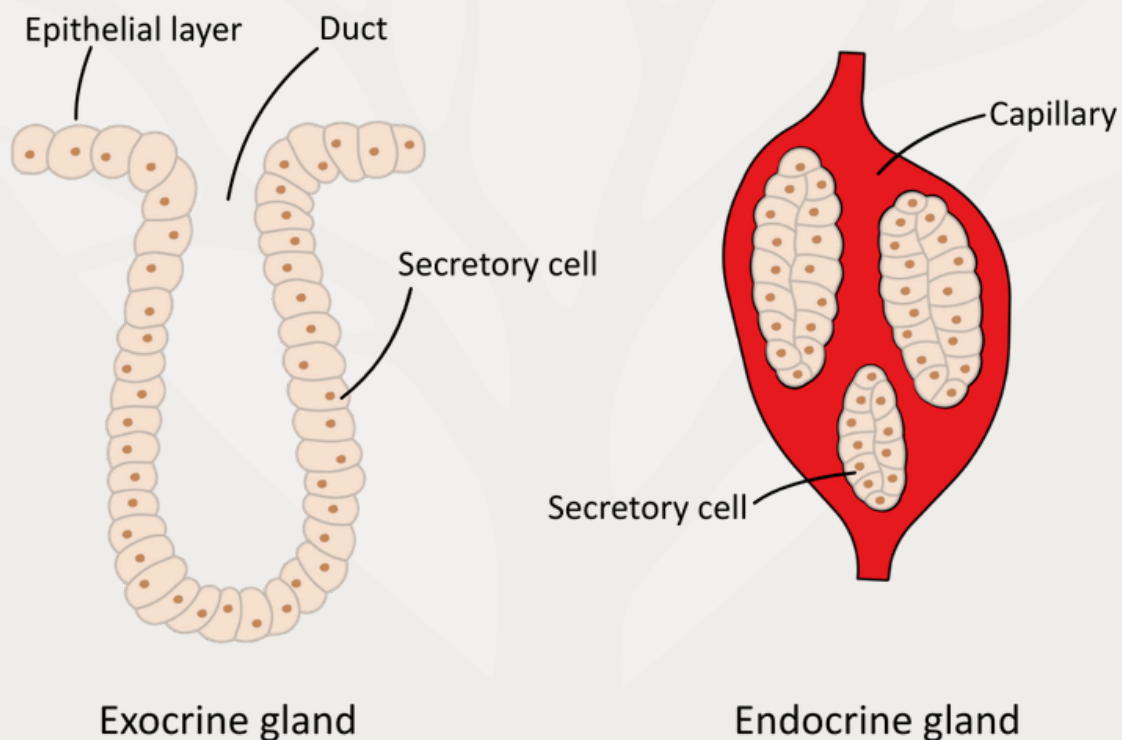
The **endocrine system** is a long-lasting (compared to the neuronal system) **communication** network that **coordinates** the activity of organs and tissues using **chemical messengers** (hormones).

These chemical messengers are **released** from **endocrine glands**.

There are **two** main **types of glands**:

- **Endocrine** glands are **ductless**, releasing **hormones** into the **bloodstream**.
- **Exocrine** glands release **non-hormonal** secretions onto bodily surfaces or into lumens through ducts.

The diagram below **shows** the typical **structure** of **endocrine** and **exocrine glands**.



It is important to note that exocrine glands are **not** a part of hormonal communication.

Module 5: Introduction to the Endocrine System



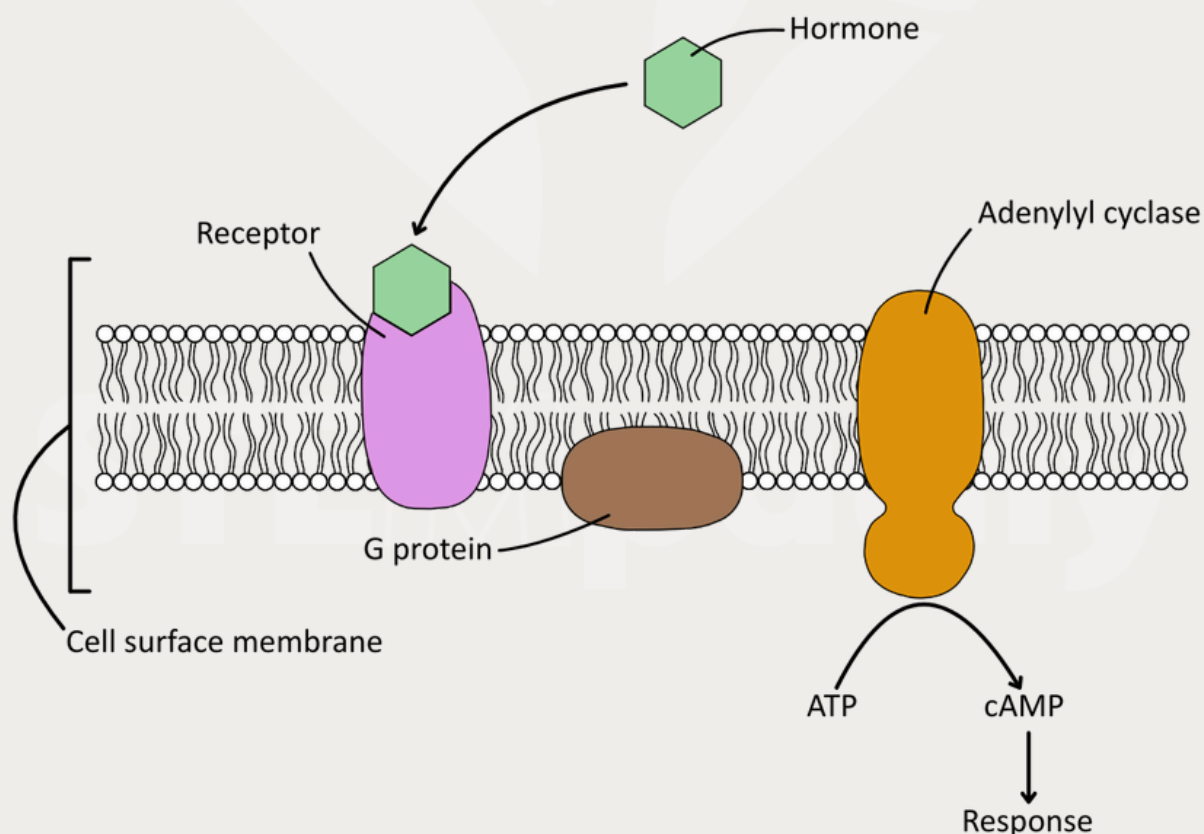
The table below **outlines** some of the different **endocrine glands** and the **role(s)** of their **secreted hormones**:

Endocrine Gland	Main Hormone(s)	Endocrine Gland Role(s)
Adrenal cortex (on kidneys)	- Aldosterone (mineralocorticoid) - Cortisol (glucocorticoid) - Androgens	- Aldosterone: regulates Na⁺ and K⁺ balance, maintaining blood pressure and volume. - Cortisol: controls metabolism under stress, has anti-inflammatory effects. - Androgens: precursors for sex hormones.
Adrenal medulla (on kidneys)	- Adrenaline - Noradrenaline	Triggers fight-or-flight responses: - Increases heart rate. - Increase ventilation. - Increases Blood glucose. - Increases blood flow to muscles.
Pancreas (islets of Langerhans)	- Insulin (β cells) - Glucagon (α cells)	- Insulin: lowers blood glucose (uptake/storage). - Glucagon: raises blood glucose (glycogenolysis, gluconeogenesis).

Hormones are **transported** to target cells in the **bloodstream**.

A **target cell** (or tissue) is one that has a **complementary receptor** (usually on its cell surface membrane) for a **specific hormone** to bind to.

The diagram below **shows** how **hormones act** on specific **target cells**:



Module 5: Introduction to the Endocrine System



The **three types** of hormones are **amino-acid derivatives**, **peptides/proteins**, and **steroids**:

- **Amino-acid derivatives** are **hydrophilic** and water-soluble, typically binding to receptors on the **cell surface membrane**.
- **Peptide/Protein** hormones are **hydrophilic** and water-soluble, binding to receptors on the **cell surface membrane**.
- **Steroid hormones** are not water-soluble, but can cross the **lipid bilayer** of plasma membranes to bind to receptors **inside** the cell's cytoplasm or nucleus.

Hormones: First Messengers and Second Messengers

All types of endocrine hormones travel to their target cells via the **bloodstream** to transmit information. What distinguishes them is whether they bind to **external** or **internal receptors**.

Steroidal hormones are able to pass through the **lipid bilayer** and bind directly to **receptors inside** the cytoplasm or nucleus.

Non-steroidal hormones (amino acids and peptide/protein hormones) are unable to do this, and instead **bind** to **external receptors** on the **cell surface membrane**.

First messengers are hormones, because they carry information directly to the **target cells**.

Second messengers are substances produced or activated in **response to hormones** binding to external receptors.

Adrenaline and **cAMP** are the **named examples** of a **first** and **second messenger** (respectively) in OCR A Level Biology.

The full overview of **adrenaline's mechanism of action** is outlined below:

Adrenaline → binds to receptor → G protein activated → adenylyl cyclase activated → ATP converted to cAMP → cAMP activates PKA → Enzymes phosphorylated by PKA → Enzymes carry out metabolic responses

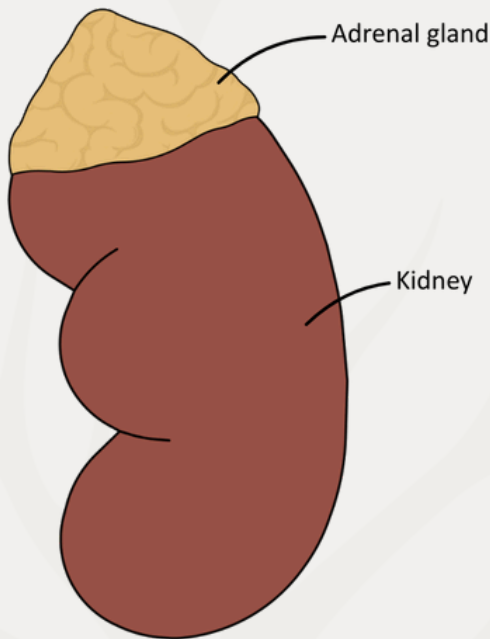




The Adrenal Glands

The **adrenal glands** are a pair of **endocrine** glands that sit just above the **kidneys**.

The diagram below shows the **position** of the **adrenal glands** above the kidneys:



Each gland has a thin outer capsule surrounding an **outer** (the adrenal cortex) and an **inner** (the adrenal medulla) region of **tissue**:

- **Adrenal cortex:** The **outer** layer of the adrenal gland that makes **steroid hormones**.
- **Adrenal medulla:** The **inner** layer that releases **adrenaline** and **noradrenaline**.

The Adrenal Cortex

The **adrenal cortex** consists of **three regions** (called zones), each producing different hormones with their own roles.

The table below **outlines each zone** of the adrenal gland, its **primary hormone(s)**, and their **role(s)**:

Zone	Hormones secreted	Role
Zona glomerulosa (outermost)	Mineralocorticoids (e.g. aldosterone)	Ion/ water balance
Zona fasciculata (middle)	Glucocorticoids (e.g. cortisol)	Metabolism/ stress
Zona reticularis (innermost)	Androgen precursors (e.g. DHEA, androstenedione)	Sex hormone precursors





The Adrenal Medulla

The **adrenal medulla** consists of a single region that secretes **adrenaline** and **noradrenaline** into the bloodstream.

It is important to note that the adrenal medulla is the site of synthesis and release of **adrenaline**, which is the **named example** of a hormone involved in coordinating responses in the OCR A level Biology specification.

The full overview of adrenaline's **mechanism of action** is **outlined** below:

Adrenaline → binds to receptor → G protein activated → adenylyl cyclase activated → ATP converted to cAMP → cAMP activates PKA → Enzymes phosphorylated by PKA → Enzymes carry out metabolic responses

The table below **outlines** some of **adrenaline's** main **effects** on its **target tissues** and the **response**:

Effect on target tissue(s)	Response
Increases heart rate and stroke volume	Raises cardiac output and blood pressure
Vasoconstriction	Raises systemic blood pressure
Vasodilation in skeletal muscles	Directs blood flow to active tissues
Vasoconstriction in the skin and gut	Redirects blood away from non-essential areas
Dilates bronchioles	Increases airflow and oxygen delivery

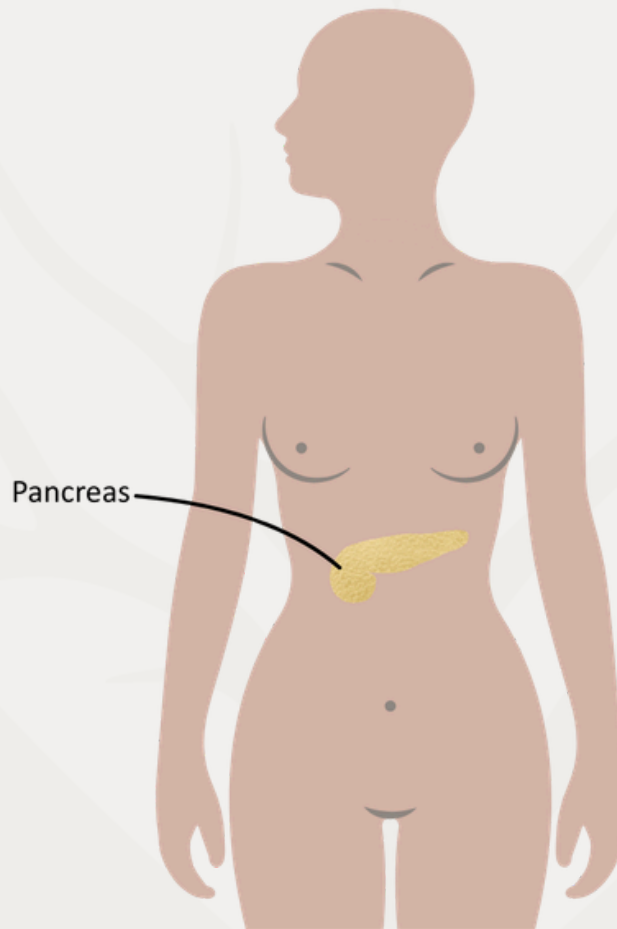




The Pancreas

The **pancreas** is located behind the stomach, where it is connected to the duodenum of the small intestine by the **pancreatic duct**.

The diagram below shows the **position** of the **pancreas**:



The pancreas has **exocrine** and **endocrine** tissue.

Exocrine Glands

The exocrine glands (acini) secrete the pancreatic juices into the duodenum through the pancreatic ducts:

Acini → Intercalated ducts → Intralobular ducts → Main pancreatic duct → Duodenum





Endocrine Glands

The **endocrine glands (islets of Langerhans)** secrete hormones directly into the **bloodstream**:

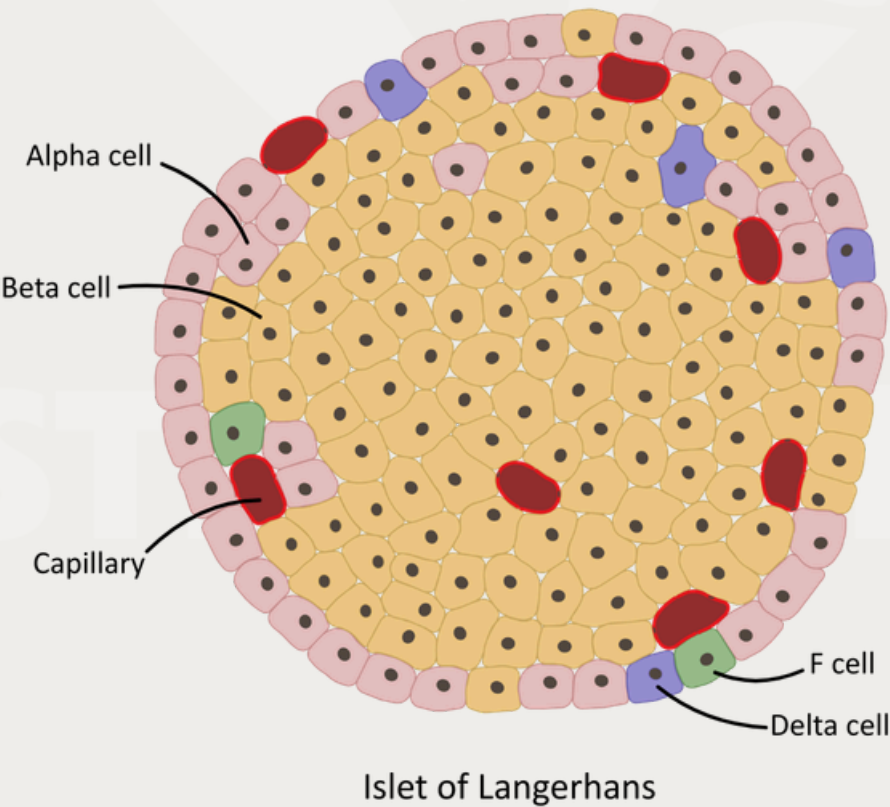
Islet cells → Capillaries → Portal venules → Hepatic portal vein → Liver first

The **islets of Langerhans** produce **insulin** and **glucagon** to control blood glucose concentration.

The table below **outlines** the **effects** that **insulin** and **glucagon** have on **target cells**:

Hormone	When Released	Main Effects
Insulin	When blood glucose rises (e.g. after eating)	- Glycogenesis ↑ - Glucose uptake/use ↑ - Glycogenolysis ↓ - Gluconeogenesis ↓
Glucagon	When blood glucose falls (e.g. fasting, exercise)	- Glycogenolysis ↑ - Gluconeogenesis ↑ - Glycogenesis ↓

The diagram below **shows** the **arrangement** of **alpha** and **beta** cells in the **Islet of Langerhans**:



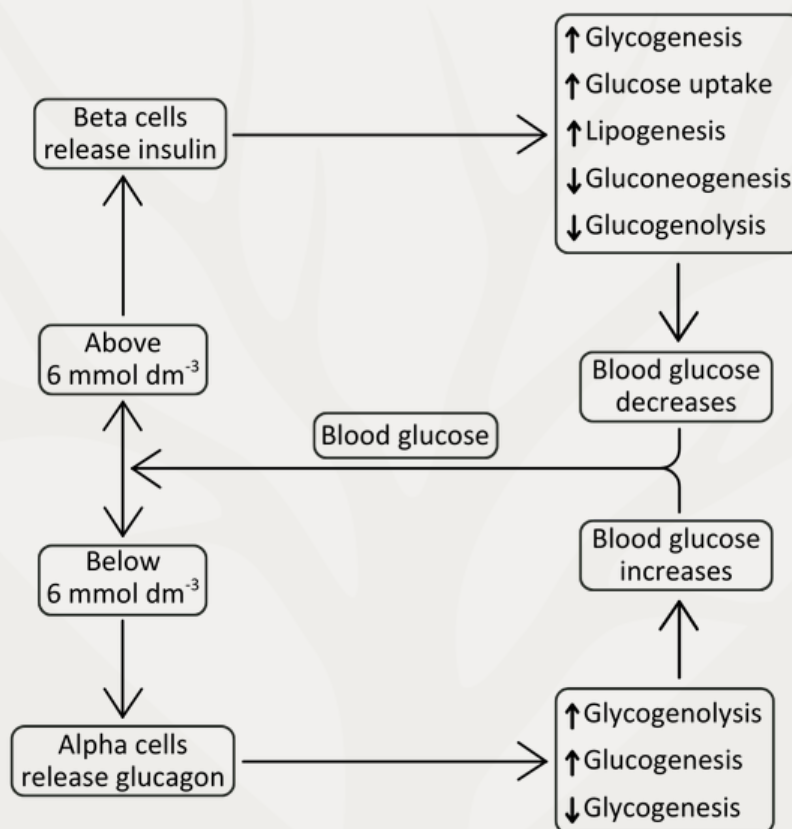


Control of Blood Glucose

Blood glucose concentration is maintained around an **optimal** set point by **negative feedback**.

Alpha and **beta cells** in the **islets of Langerhans** monitor blood glucose concentration, which affects the rate at which they secrete **glucagon** and **insulin** (respectively).

The diagram below shows the **negative feedback flowchart** for blood glucose concentration:



Beta (β) Cells

β cells **release insulin** into the bloodstream in response to **high levels of blood glucose**.

Blood glucose is **measured** indirectly with the use of a **glucose sensor, glucokinase**, which alters the metabolic functioning of β cells.





When blood glucose concentration is **high**:

1. Glucose **diffuses into** the β cell down its concentration gradient by facilitated diffusion.
2. **Glucokinase phosphorylates glucose** into glucose-6-phosphate (G6P).
3. G6P enters glycolysis and is oxidised into **ATP**.
4. Many ATP molecules cause many **K⁺ channels to close**.
5. **K⁺ builds up** inside the cell, **reducing** the potential difference.
6. The β cell **depolarises** as the inside becomes **less negative**.
7. Voltage-gated Ca²⁺ channels **open**.
8. Ca²⁺ **diffuses into** the β cell down its concentration gradient.
9. Ca²⁺ causes **vesicles** containing insulin to move **towards** the cell surface membrane.
10. Insulin is **released** from the β cell by **exocytosis**.

Insulin travels through the bloodstream and binds to a **complementary receptor** on the cell surface membrane of **target cells**.

STEMpathy





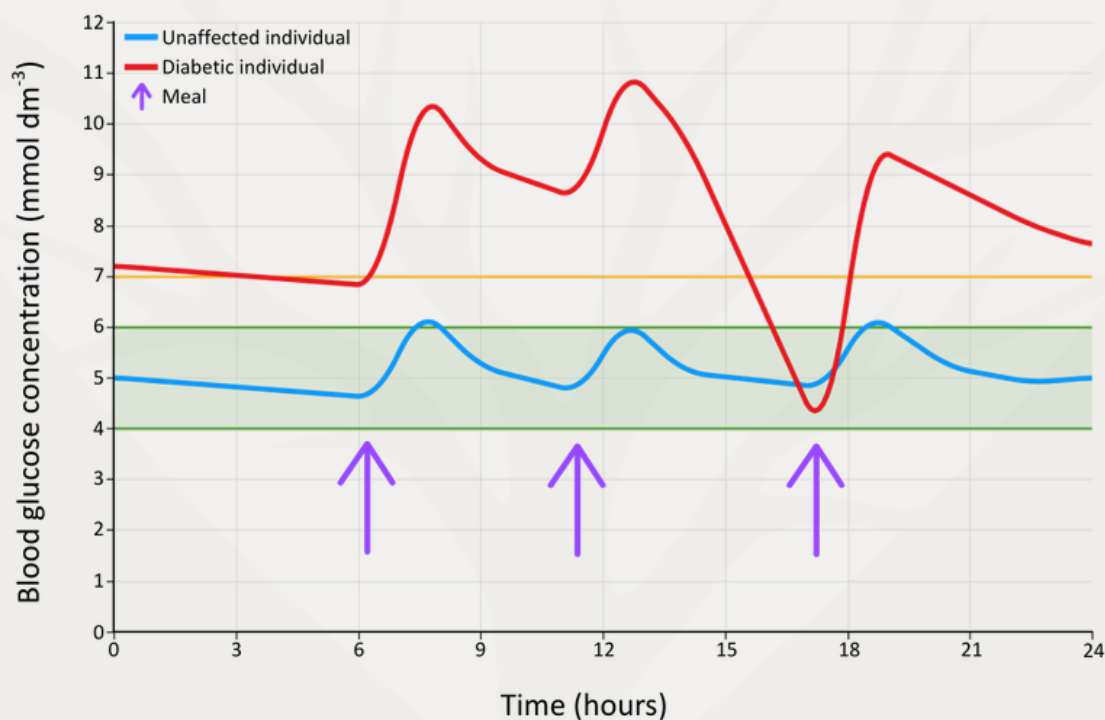
Diabetes Mellitus

Diabetes mellitus is a disorder in which **blood glucose concentration cannot be controlled** effectively, regularly moving outside the optimal range of $4 - 6 \text{ mmol dm}^{-3}$.

Blood glucose concentrations which are continuously **above 7 mmol dm^{-3}** are indicative of **diabetes mellitus**.

The graph below **shows** the changes in **blood glucose levels** of an **unaffected person** and a **diabetic person**:

Blood Glucose Concentration over 24 hours



The **green band** represents an **optimal concentration** of blood glucose. The **orange line** represents the diagnostic **threshold** for **diabetes mellitus**.

Diabetes

There are **two** main types of diabetes, **type 1** and **type 2**.

What distinguishes type 1 and type 2 diabetes is **why the action of insulin fails**:

- **Type 1**: Caused by the autoimmune **destruction** of pancreatic β cells. Sufferers **respond** to insulin, **but** are **deficient** in it.
- **Type 2**: Caused by target tissues being **resistant** to the effects of insulin. Sufferers are **less responsive** to insulin, but do **produce** it.





Treating Diabetes

Diabetes requires careful **management** throughout life to **prevent damage** to organs and tissues from accumulating.

Treating Type 1 Diabetes

The blood glucose concentration of type 1 diabetes must be **monitored frequently**, requiring a balance of carbohydrate intake and physical activity.

The table below **compares** the **advantages** and **disadvantages** of some of the **treatments** for **type 1 diabetes**:

Treatment	Advantages	Disadvantages
Insulin injections	- Simple, widely available.	- Multiple daily injections. - Peaks/troughs in insulin levels.
Insulin pump	- Smaller blood glucose fluctuations. - Fewer injections.	- Device cost and maintenance. - Requires training.
Stem cell therapy	- Restores insulin secretion. - Regenerated β cells restore glucose control.	- Experimental; long-term effectiveness/safety not established. - Cost.

Treating Type 2 Diabetes

Type 2 diabetes is usually managed with lifestyle interventions **first**, before introducing medical options.

The blood glucose concentration of type 2 diabetes must be **monitored frequently**, ensuring a balance of carbohydrate intake and physical activity.

The table below **outlines** the **advantages** and **disadvantages** of some of the **lifestyle interventions** taken to manage **type 2 diabetes**:

Intervention	Advantages	Disadvantages
Regular physical activity	- Increases glucose uptake by muscle. - Improves insulin sensitivity. - Cardiovascular health.	- Needs consistency. - Hypoglycaemia risk.
Balanced carbohydrate diet	- Reduces the size of blood glucose fluctuations. - Manage weight.	- Meal planning. - Social/food-environment challenges.





Medicines are used when lifestyle changes are **insufficient**.

The table below **outlines** the **advantages** and **disadvantages** of the main **medical treatment** for **type 2 diabetes**:

Treatment	Primary Effect	Advantages	Disadvantages
Insulin injections	↑ tissue uptake and storage of glucose	Rapid glucose lowering.	- Monitoring needed. - Hypoglycaemia risk.

Insulin

Historically, insulin was extracted from the pancreas of **pigs** or cattle, as their **insulin** is **similar** to human insulin.

Today, insulin is produced more **safely** and **efficiently** using **genetically modified** (GM) bacteria, such as Escherichia coli, to produce **human insulin** in **bulk**.

The table below **compares insulin** sourced from **animal** and **GM bacteria**:

Source	Description	Effectiveness
Animal	Extracted from animal pancreas.	Similar to human insulin, but may cause allergic or immune reactions.
GM Bacteria	Produced by genetically modified bacteria (e.g. E. coli) using recombinant DNA technology*.	- Cheaper and scalable. - Fewer ethical concerns. - Minimal immune response.

*Recombinant DNA technology is when a gene from one organism is transferred into the genome of another.





Introduction to Plant Responses

Unlike animals, **plants** are **immobile** and unable to respond to both abiotic and biotic stimuli by moving towards (if it is beneficial) or away (if it is harmful) from them. Instead, **plants** must **adapt** to environmental changes by **altering** their **physiology** and **growth**.

Plant responses are **coordinated** by chemicals, such as **hormones**, which are transported slowly (compared to the nervous systems found in animals) by transport processes within a plant.

Plant responses can be **directional**, or **non-directional**, **movements**, or **chemical responses**.

Directional Responses: Tropisms

Tropisms are **responses** to a stimulus in the form of a **directional response**.

Tropic responses involve **differential growth**, where **cells** on one side of an organ **elongate or divide more** than those on the other side over time (making it a slow response). This usually results in the stimulus increasing (if desirable) or decreasing (if undesirable).

The table below **outlines** some of the main **types of tropism**:

Tropism	Description	Example
Geotropism	Growth in response to gravity.	- Roots grow downwards. - Shoots grow upwards.
Phototropism	Growth in response to light.	- Shoots bend towards a light source. - Roots bend away from a light source.
Thigmotropism	Growth in response to touch or contact.	- Tendrils coil around a support. - Root grows around an obstacle.



Module 5: Introduction to Plant Responses



Non-directional Responses: Nastic Movements

Nastic responses are **non-directional movements**, unrelated to the direction of the stimulus. The most commonly encountered example is **thigmonasty**.

The table below **outlines thigmonasty**, and its **survival advantage**:

Nastic Response	Description	Advantage
Thigmonasty	Leaves or leaflets fold in response to touch or vibration.	Deters herbivores, limits water loss by shading leaves.*

*It is useful to know that scientists do not definitely know why *Mimosa pudica*'s leaves fold, only that it has situational advantages and disadvantages. The OCR A Biology specification highlights its role in deterring herbivory.

Physiological Responses

Physiological responses alter how plant tissues function and result in the **production of chemicals**.

The table below **outlines** some of the major **physiological responses** and their **survival advantage**:

Physiological Response	Description	Advantage
Stomatal closure	ABA-induced ion loss from guard cells reduces turgor and closes stomata.	Reduces water loss by transpiration.
Seed germination	Gibberellin (GA) stimulates enzyme production in the aleurone layer.	Provides glucose for respiration and embryo growth.
Leaf abscission	Decrease in auxin and subsequent increase in ethene levels weakens the abscission layer (connection point).	Reduces water loss.
Stress-induced defence chemistry	Increased production of chemical defences (e.g. tannins, alkaloids).	Reduces further herbivore feeding and tissue loss.

Plant hormones are widely used in **agriculture** to control **growth, ripening, development and storage**.

The most commonly used **hormones** in **agriculture** include **auxin** and **ethene**:

- Auxin is used as a herbicide (weed killer) and to encourage the development of roots in plant cuttings.
- Ethene is used to ripen fruit so as to make it more appealing to consumers.



Module 5: Hormonal Control of Stem Elongation



Elongation and **growth responses** depend on changes in cellulose **cell wall extensibility** (stretchiness) and the **rate of cell division** in specific tissues.

Gibberellins (GAs) are **synthesised in young leaves** and **root tips**, and **transported** in both the **xylem** and **phloem** to elongating tissues.

Gibberellins **stimulate growth** by **increasing** the **rate** of:

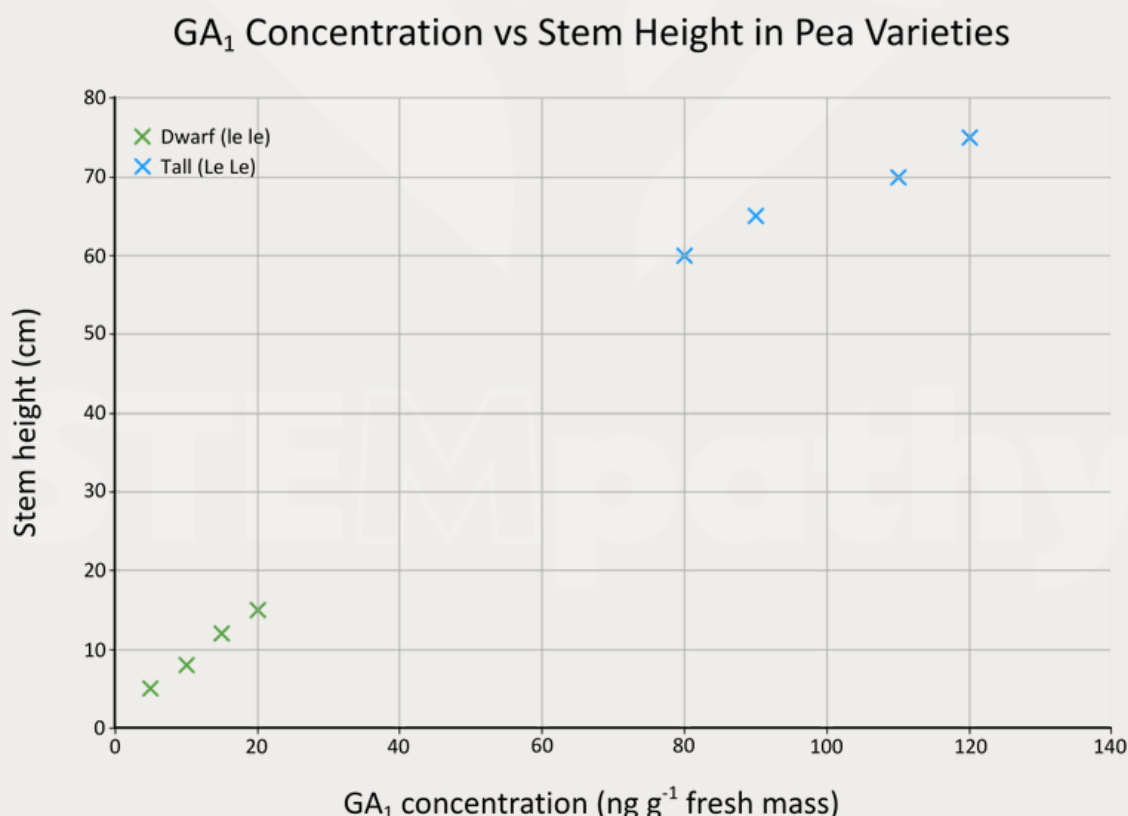
- **cell elongation** (through wall-loosening proteins)
- **cell division** (via activation of cell-cycle genes)

It is important to note that **GA₁** (Gibberellin A₁) is the **main gibberellin** controlling stem elongation in pea plants, and **GA₃** (gibberellic acid*) is a **fungal gibberellin** originally identified from infected rice seedlings (which causes “foolish seedling disease”).

It is useful to know that GA₃ is known specifically as gibberellic acid because it was discovered before the other types of gibberellins were discovered.

Higher concentrations of gibberellins correlate with **increased** plant stem **elongation**, but they **do not** demonstrate the same **inhibitory effect** that auxin does when reaching relatively high concentrations.

The graph below **illustrates** the **correlation** between pea plant **stem height** and **GA₁ concentration** in two different **pea plant varieties** (le le and Le Le):



Module 5: Hormonal Control of Stem Elongation



The **dwarf pea plant** (le le) is **unable** to produce normal levels of **GA₁**, and so **elongation is reduced**, and overall growth is stunted. le le represents its genotype, which transcribes a faulty enzyme in the metabolic pathway for synthesising GA₁. Le Le is the genotype for the **tall pea plant variety**, which produces a **functional enzyme** capable of synthesising GA₁.

Experimental Evidence that GA₁ Causes Stem Elongation

In OCR A Level Biology you need to be able to use your general understanding of the mechanisms of gibberellin to interpret experimental investigations. You are **not required** to learn or recall any specific experiments (although the Le/le mutation is the most commonly taught one).

The table below **outlines** some **examples** of **experiments** or **natural observations**, relating to the **effect of gibberellin** on **stem elongation** and what we can **infer** from them:

Experiment/ Observation	Mechanism	Observation	Inference
Foolish seedling disease	Pathogenic fungus produces GA ₃ .	- Excessive stem elongation. - Seedlings collapse.	GA strongly promotes stem elongation.
Grafting a tall 'Le' plant tip onto a dwarf 'le' plant stem.	Gibberellin diffused down from the tip.	Dwarf plants grow tall after grafting.	GA ₁ is made in the shoot.
GA concentration-response curves	Different concentrations of GA applied to observe the effects.	- Higher GA correlates with longer internodes. - Growth plateaus at high GA.	GA's effect is concentration dependent.

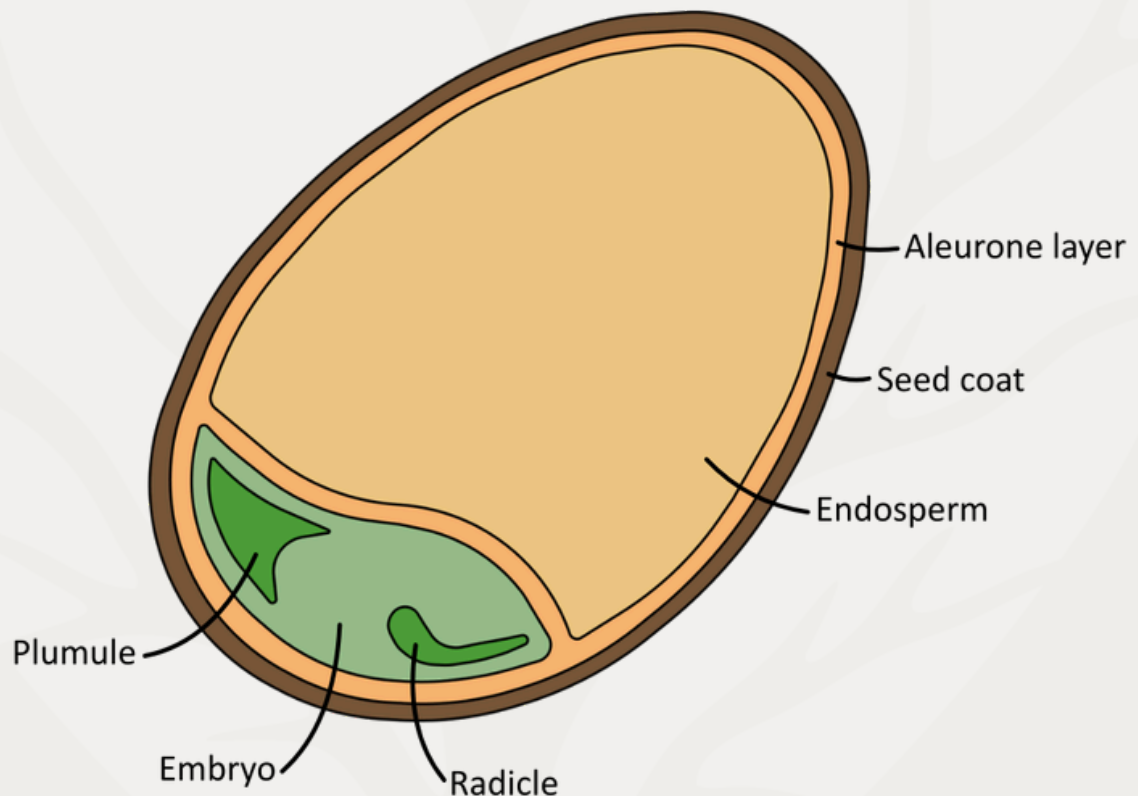


Module 5: Hormonal Control of Seed Germination



Germination typically depends on the ability of an **embryo** to synthesise and **release gibberellin** after water uptake, so that **seed tissues** can **release** the stored **nutrients** needed for **early growth**.

The diagram below **shows** the typical **structure** of a **cereal grain**:



Cereal grains (such as barley and wheat) are characterised by an **aleurone layer** which **surrounds** a **starchy endosperm**.

Gibberellins promote the gene expression of **hydrolytic enzymes** that release **nutrients** for the growth of the radicle and shoot during **germination**.

Gibberellin's mechanism of stimulation in seed germination can be summarised as:

1. **Water** enters the seed, **rehydrating the embryo**, which begins **synthesising gibberellin (GA)**.
2. GA **diffuses** from the embryo into the **aleurone layer** and binds to complementary **receptors**, triggering an intracellular **enzyme cascade**.
3. **Genes are switched on** that **synthesise** digestive enzymes (e.g. **amylase**), which are **secreted** into the **endosperm**.
4. **Nutrient stores** are **hydrolysed**, such as starch turning into maltose and glucose, for use in respiration and metabolism.



Module 5: Hormonal Control of Seed Germination



Experimental Evidence that GA Controls Seed Germination

In OCR A Level Biology you need to be able to use your general understanding of the mechanisms of gibberellin to interpret experimental investigations. You are **not required** to learn or recall any specific experiments.

The table below **outlines** some **examples** of **experiments** or **natural observations**, relating to the **control of germination** by **gibberellin**, and what we can **infer** from them:

Experiment/ Observation	Mechanism	Observation	Inference
GA inhibitor applied to seeds	Blocks early GA synthesis steps.	- Seeds fail to germinate. - Application of GA restores normal germination.	Internal GA synthesis is required to initiate germination.
GA restores germination in GA-deficient mutant seeds	Genetic defect blocks the GA metabolic pathway.	- Mutant seeds do not germinate. - Application of GA restores normal germination.	- Confirms that GA is required for germination. - The defect is in GA metabolism.

STEMpathy



Module 5: Hormonal Control of Apical Dominance



Control of Apical Dominance

Apical dominance is the process by which the **shoot tip** (apical bud) **suppresses** the growth of **lateral buds** lower down the stem.

Apical dominance is **controlled** primarily by **auxin**, which **influences** the concentration of **cytokinins** and **ABA** in the **lateral buds**.

How Apical Dominance Works

The **interaction** between **auxin** and **cytokinins** regulates whether lateral buds remain dormant or begin to grow.

- The process of **apical dominance** can be **summarised** as:
1. **Auxin** is **synthesised** in the **apical bud** and transported down the stem and **accumulates** in the **lateral buds**.
 2. **High auxin** levels **suppress** their **growth** by **reducing** the movement of **cytokinins** into the buds and **promoting ABA accumulation**.
 3. Lateral buds **remain dormant**.

- If the **apical bud** is **removed** (decapitation):
1. **Auxin levels drop** rapidly in the stem below.
 2. **Cytokinin** levels **increase** in **lateral buds**.
 3. **ABA levels fall**.
 4. **Lateral buds** become activated, divide, and **grow** into side shoots.

Experimental Evidence for Apical Dominance

In OCR A Level Biology you need to be able to use your general understanding of the mechanisms of auxin, cytokinin and ABA interactions to interpret experimental investigations. You are **not required** to learn or recall any specific experiments (although variations of apical bud decapitation are the most common).

The table below **outlines** several **examples** of **experiments** or **natural observations** of **apical dominance**, and what we can infer from them:

Experiment / Manipulation	Observation	Inference
Shoot tip removed	Lateral buds grow and form branches.	Apical bud provides a signal that inhibits lateral buds.
Auxin applied to cut surface after tip removal	Lateral buds remain inhibited.	Auxin from the apex maintains apical dominance.



Module 5: Introduction to Communication Systems in Animals



Introduction to Communication Systems in Animals

Animals must **continuously respond** to **changes** in both their **internal** and **external environments** so they can feed, regulate their internal conditions, avoid danger, and **maintain homeostasis**.

The two main **communication systems** in animals are the **nervous** and **endocrine systems**:

- The **nervous system** uses **electrical impulses** along **neurons** and **neurotransmitters** across **synapses**. This produces extremely fast, targeted and short-lived responses ideal for movement, reflexes and rapid changes in heart rate or ventilation.
- The **endocrine system** uses **hormones** released into the **bloodstream**. Hormonal responses develop more slowly but last longer, supporting processes such as metabolic control, growth, development and long-term stress responses.

Coordinating Responses

The **nervous system** and **endocrine systems** often work together, and are (typically) **coordinated** by the **hypothalamus**.

The Fight-or-Flight Response

The **fight-or-flight response** to stress is the required example of **coordination** by the **nervous** and **endocrine systems** in the OCR A level Biology course:

- The **hypothalamus stimulates** the **sympathetic nervous system** (SNS), causing pupils to dilate, bronchial tubes to widen, an increased heart rate, and redirection of blood flow to muscles.
- The **hypothalamus** also **signals** the **pituitary gland** to **secrete ACTH***, which in turn **stimulates** the **adrenal cortex** to **secrete corticoid hormones** that increase metabolism, blood glucose and blood pressure.

*Adrenocorticotrophic hormone.

The SNS also signals the adrenal medulla to release adrenaline and noradrenaline.

The Control of Heart Rate

Heart rate is **controlled** by **both** the **autonomic nervous system** (via the cardiovascular centre in the medulla oblongata) and the **endocrine system** (via the hypothalamus).



Module 5: Introduction to Communication Systems in Animals

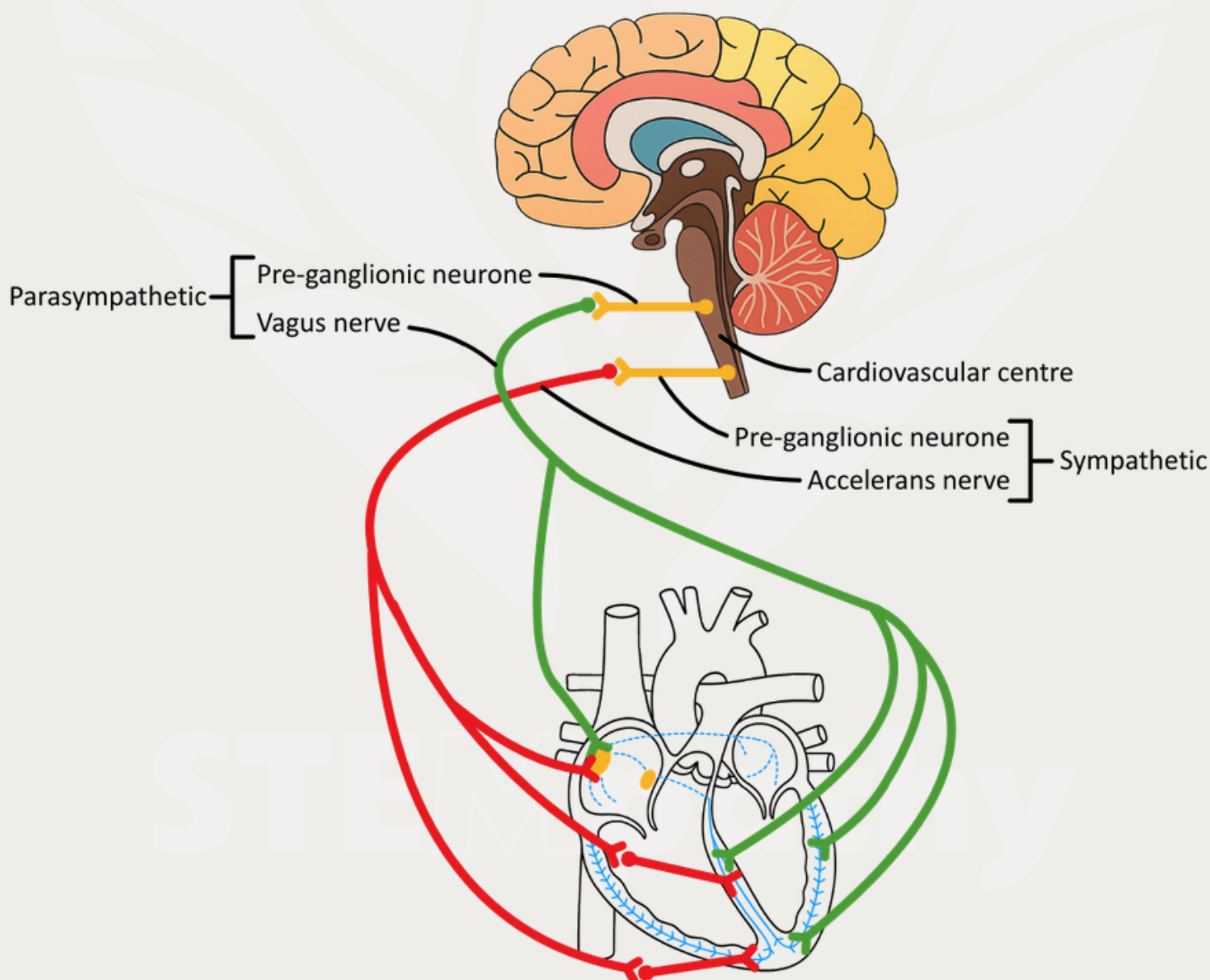


Nervous Control of Heart Rate

The **cardiovascular centre** can **control** the activity of two separate nerves, the **accelerans nerve** and the **vagus nerve**:

- The **accelerans nerve** is a part of the **sympathetic division** of the nervous system, and **releases noradrenaline** to increase the SAN's activity, **increasing the heart rate**.
- The **vagus nerve** is a part of the **parasympathetic division** of the nervous system, and **releases acetylcholine** to reduce the SAN's activity, **reducing the heart rate**.

The diagram below **shows** how the **accelerans** and **vagus nerve** link the **cardiovascular centre** to the **heart**:



Module 5: Introduction to Communication Systems in Animals



Hormonal Control of Heart Rate

The **hypothalamus** can **stimulate** the **adrenal medulla**, which responds by **releasing adrenaline** (a first messenger hormone).

Adrenaline's **mechanism of action** can be summarised as:

- **Adrenaline binds** to its **complementary receptor** on the cell surface membrane of its **target cells** in heart tissue, which **stimulates adenylyl cyclase**.
- **Adenylyl cyclase converts ATP** into **cyclic AMP (cAMP)**, which acts as the second messenger inside the cell, causing metabolic changes to **increase heart rate**.

STEMpathy



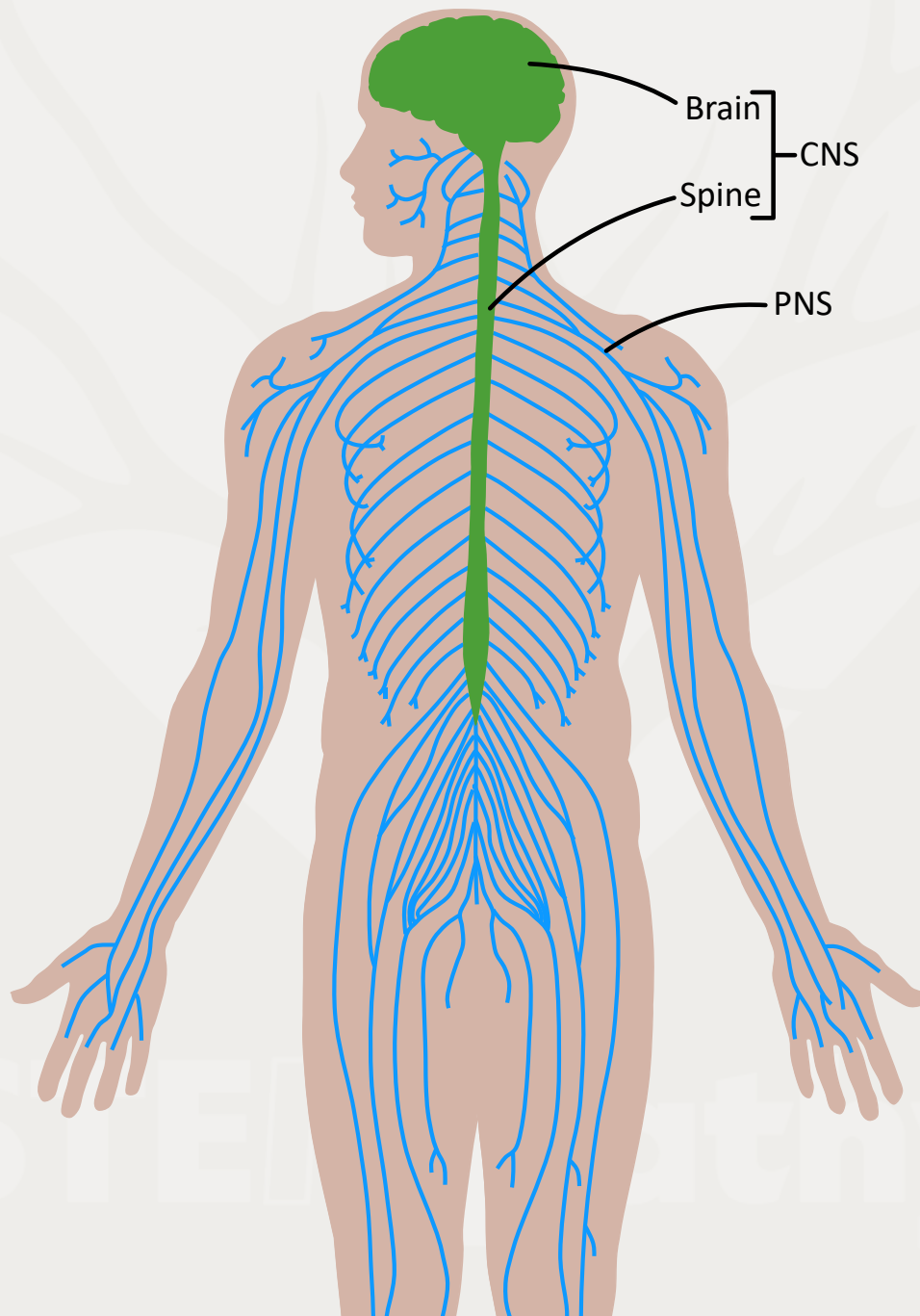
Module 5: The Mammalian Nervous System



Animals must **detect changes** in their **internal** and **external environments** and **coordinate** appropriate **responses**.

The **mammalian nervous system** is organised into a **central nervous system** (the brain and spinal cord) and a **peripheral nervous system**.

The diagram below shows the location of the CNS and PNS:

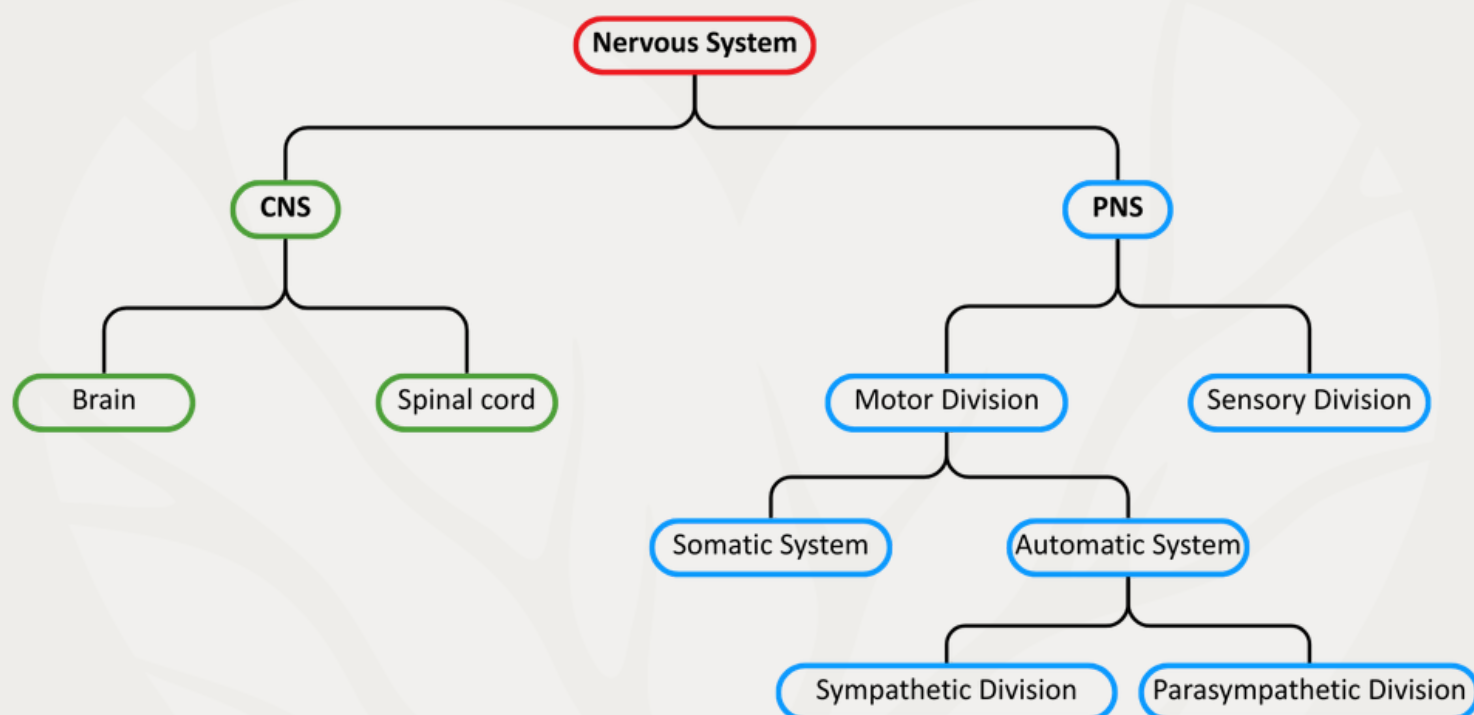


The **CNS** and **PNS** are **organised** into **divisions**, each with specific roles.

Module 5: The Mammalian Nervous System



The diagram below **outlines** the main **divisions** of the **nervous system**:



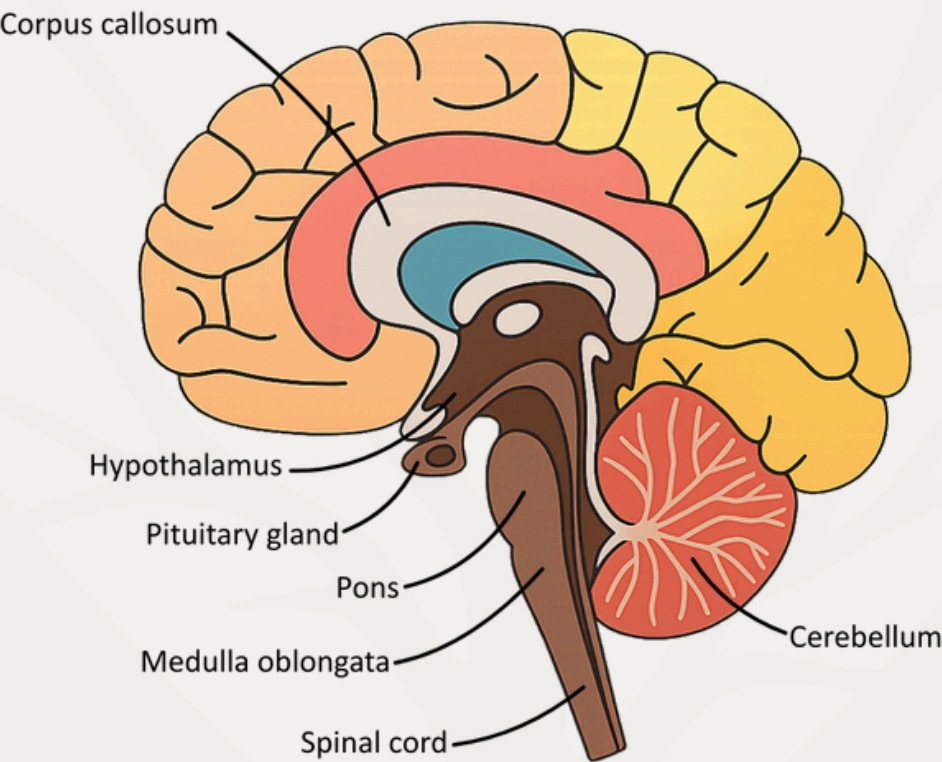
STEMpathy



The Brain

The **brain** is the **primary coordination centre** of the mammalian **nervous system**, **receiving sensory information** from the body, **processing** it, and sending **coordinated** instructions to **effectors**.

The diagram below **shows** a **cross-section** of the **human brain**, and the **regions** and **structures** within:



The table below **outlines** the **location** and some of the **functions** of some of the **major regions** of the brain:

Region	Functions
Cerebrum	- Conscious thought - Reasoning - Memory
Cerebellum	- Balance - Motor learning
Hypothalamus	Coordinates homeostatic processes
Pituitary gland	Secretes hormones to control the endocrine system’s homeostatic activity.
Medulla oblongata	Coordinates the autonomic control of cardiac muscle, involuntary smooth muscle and glands.



Reflex Actions

Reflex actions are **rapid, involuntary** and **automatic responses** to changes in the internal or external environment.

Reflexes often occur to **prevent harm** to the organism.

Reflex actions are **rapid** because they **do not** involve any **processing** by the **brain's higher centres** before the movement occurs.

A **typical reflex arc** consists of:

Receptor → Sensory neurone → Relay neurone* → Motor Neurone → Effector

*The **relay neurones** will be located in the **CNS**.

Some spinal reflexes, such as the **knee-jerk reflex**, are **unusual** in that their reflex arc consists of **only a motor neurone and a sensory neuron**. The lack of a relay neurone means that the brain cannot consciously inhibit the response.

STEMpathy





Mammalian Muscle

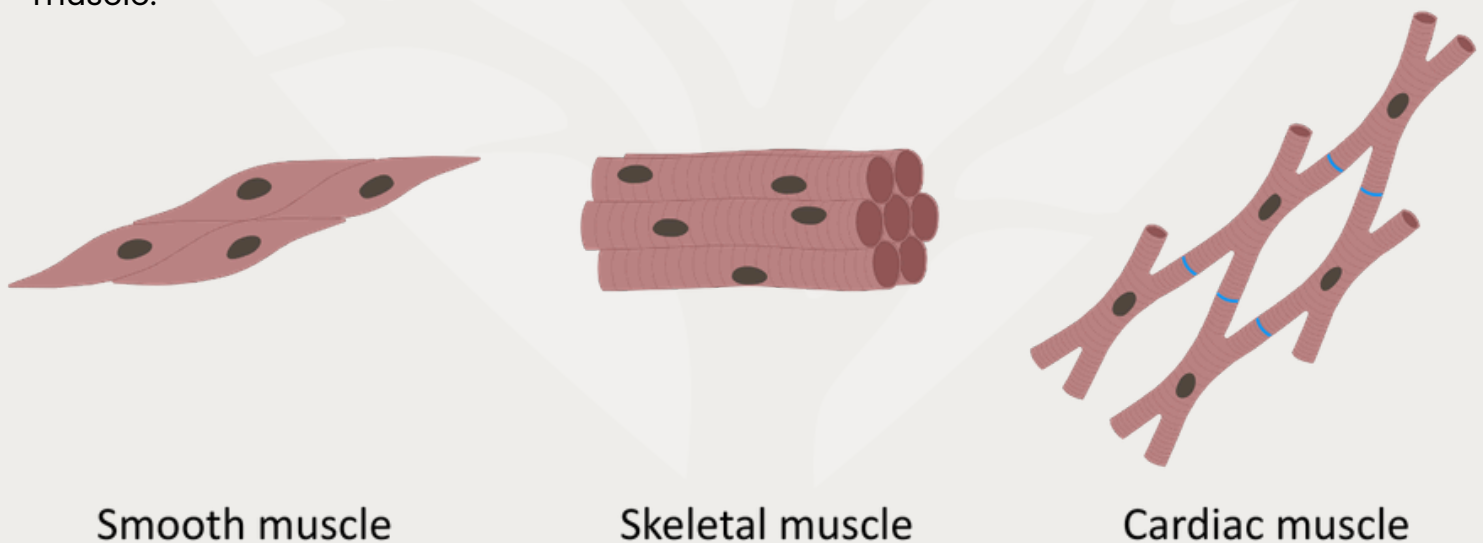
Muscles are **effectors** that produce **movement responses** in animals.

The **3 main types** of muscle in mammals are **cardiac**, **skeletal** and **smooth**:

- **Skeletal muscle*** is connected to the skeleton by tendons, contracting in response to **conscious stimulation** from the **somatic nervous system**.
- **Cardiac muscle*** is found in the **heart** and contracts rhythmically without becoming fatigued.
- **Smooth muscle** is found in **tubular structures**, contracting slowly and rhythmically in response to **unconscious stimulation** from the **autonomic nervous system**.

*Both **cardiac** and **skeletal muscle** are types of **striated muscle** (skeletal often being **incorrectly** treated as synonymous with striated muscle). Cardiac muscle is often (and **misleadingly**) treated as its own separate type at A level for simplicity, as we have done here.

The diagram below **shows** the typical **appearance** of **skeletal**, **cardiac** and **smooth** muscle:



Skeletal Muscle

A **skeletal muscle** fibre is a highly specialised cell formed from the fusion of several cells to form an **elongated cell** with **many nuclei** along its length.

The **cell surface membrane** of a skeletal muscle cell is **known** as a **sarcolemma**.



Module 5: Mammalian Muscle Structure



The **sarcolemma** is a specialised cell surface membrane with several **features adapted** to its role in **muscle contraction**:

- **Motor end plates**: Regions of the membrane **facing** the axon terminals of **motor neurones**, with **acetylcholine receptors** that can initiate **depolarisation** of the sarcolemma.
- **T-tubules**: The **sarcolemma folds inwards**, forming deep transverse tubules (T-tubules) that can **propagate** an action potential deep **into a muscle fibre**, allowing the **entire fibre to contract** (almost) simultaneously.

The **cytoplasm** of a skeletal muscle cell is known as the **sarcoplasm**, and is **highly specialised**:

- **Many myofibrils**: **Contractile elements** made up of the proteins **actin and myosin**.
- **Many mitochondria**: Perform **aerobic respiration** to make lots of **ATP** for contraction.
- **Extensive sarcoplasmic reticulum**: A highly **specialised smooth endoplasmic reticulum** wrapped around the myofibrils, which **releases stored Ca^{2+}** in response to neuronal stimulation of the muscle fibre.

Cardiac Muscle

The **structure** of a cardiac muscle cell is that of a **short cell** with **branches** to join with other cardiac muscle cells. It usually has one nucleus, but sometimes has two.

It is important to note that **cardiac muscle cells** have **many similarities** with **skeletal muscle cells**, and that many details set out in the OCR A Level Biology endorsed textbook relating to skeletal muscles are **also true** of cardiac muscle.

Smooth Muscle

Smooth muscle is a **type of involuntary muscle** found mainly in the walls of tubular organs (such as blood vessels, the digestive system, uterus), where it can control the **movement of substances** through the body.

Smooth muscle **contracts slowly**, but can **maintain** its state of **contraction** for a long time, making it **resistant to fatigue**.

It is important to note that you are **not expected** to know the structure of a smooth muscle cell.





Comparing Types of Mammalian Muscle

The table below **compares** some of the **key features** of each **type** of **muscle cell**:

Feature	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Control	Voluntary	Involuntary	Involuntary
Cell shape	Long, cylindrical fibres	Short, branching cells	Spindle-shaped
Striations	Present (has sarcomeres)	Present (has sarcomeres)	Absent (no sarcomeres)
Intercalated discs	Not present	Present	Not present
Presence of sarcomeres	Yes	Yes	No

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Module 5: Neuronal Control of Striated Muscle



Neuronal Control of Striated Muscle: Neuromuscular Junctions

Skeletal muscle contracts only when **stimulated** by a **motor neurone**.

The specialised **synapse** between a **motor neurone** and a **muscle fibre** is known as a **neuromuscular junction**.

The **region** of the **muscle fibre membrane** (the sarcolemma) that **faces the synaptic terminal** is known as the **muscle end plate**.

A neuromuscular junction's **mechanism of action** can be **summarised** as:

1. An **action potential** arrives at the **synaptic terminal**.
2. **Voltage-gated Ca^{2+} ion channels open**, allowing **Ca^{2+} ions** to **diffuse in down their concentration gradient**.
3. **Ca^{2+} ions** cause **vesicles** containing acetylcholine to **undergo exocytosis**.
4. **Acetylcholine diffuses across the synaptic gap** and **binds to receptors** on the **sarcolemma**.
5. **Na^+ channels open**, allowing **Na^+** to **diffuse into the muscle fibre**, **depolarising it**.
6. **Ca^{2+} ions are released** from the sarcoplasmic reticulum, **initiating muscle contraction**.

Acetylcholine is quickly broken down by acetylcholinesterase to prevent continuous stimulation of the neuromuscular junction and avoid unneeded contractions.

Muscle Contraction: Myofibrils and the Sliding Filament Theory

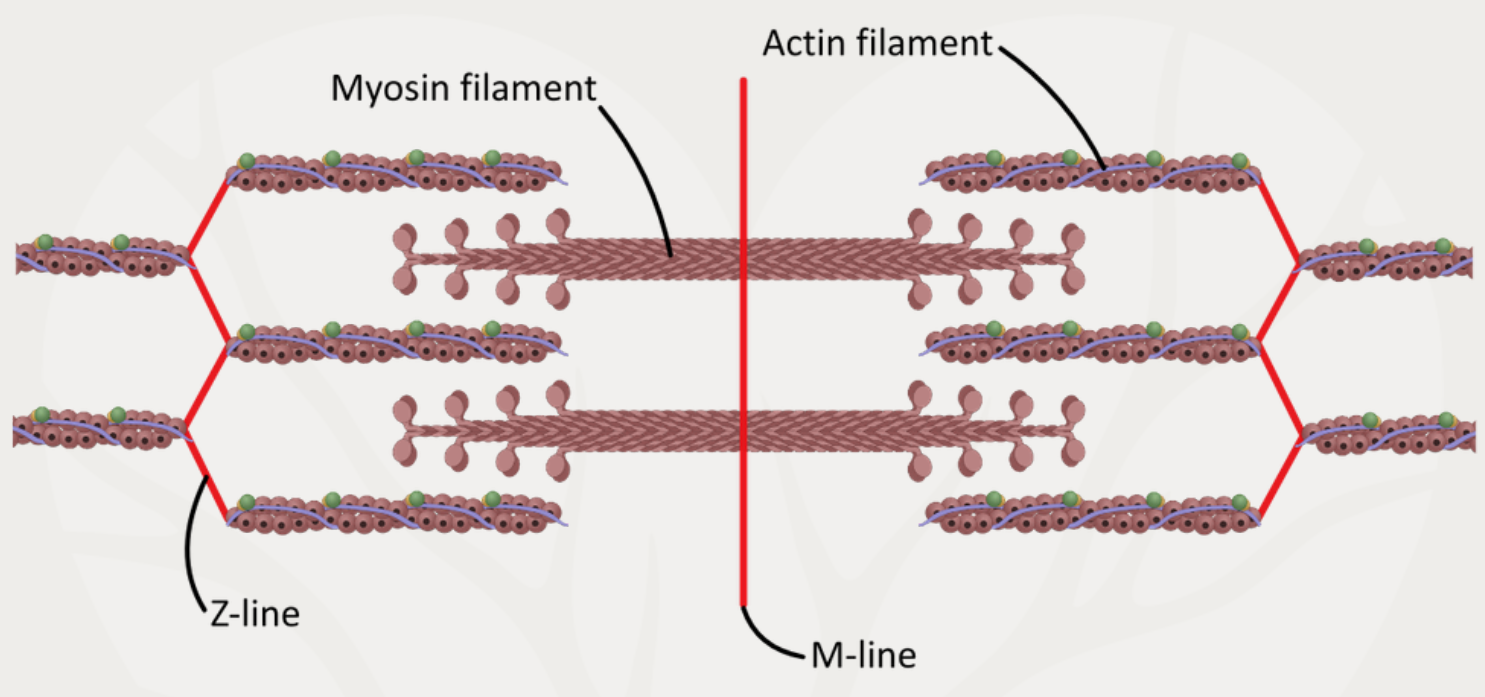
The **sliding filament theory** (also known as the sliding filament model, or hypothesis) is the **mechanism** by which **skeletal muscle fibres contract**.

Sarcomeres are the **contractile elements** of a muscle fibre, consisting of the proteins **actin** and **myosin**.

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The diagram below **shows** the overlapping **structure** of **actin** and **myosin**:



During **contraction**, the actin and myosin **filaments overlap**, which **changes the size** of the light and dark **regions**.

The table below **outlines** the **features** which can be **observed** in **skeletal muscle tissue** under an **optical microscope** and their **significance**:

Feature	Appearance	Significance
A-band	Dark band	Thick myosin filaments, which can overlap with actin
H-zone	Lighter region in the centre of the A-band	Thick filaments only
I-band	Light band	Thin filaments only
Z-line	Thin dark line	Sarcomere boundary

Module 5: Neuronal Control of Striated Muscle



The Sliding Filament Model

The process can be **summarised** as:

1. **Ca²⁺ ions** are released from the **sarcoplasmic reticulum** and **bind to troponin**.
2. Troponin's conformational **shape changes**, moving **tropomyosin away** from the **myosin-binding sites on actin** and **exposing them**.
3. **Myosin heads bind** to the **myosin-binding site** on **actin**, forming a **cross-bridge**.
4. **Myosin heads** move by **tilting, sliding** the **thin filament** along the **myosin filament**, and **releasing ADP** and an **inorganic phosphate (P_i)**.*
5. **ATP binds** to the **myosin head**, causing the **cross-bridge to break** and the myosin head to **detach from actin**.
6. **ATP** is then **hydrolysed** by myosin **ATPase**, providing the energy to **return the myosin head** to its high-energy '**cocked**' position**.

*This is known as the **powerstroke**.

Described in some sources as **re-cocking.

Creatine phosphate is a **store** of **phosphate groups** in the sarcoplasm that can be used to regenerate **ATP quickly** for use in sarcomere contraction.

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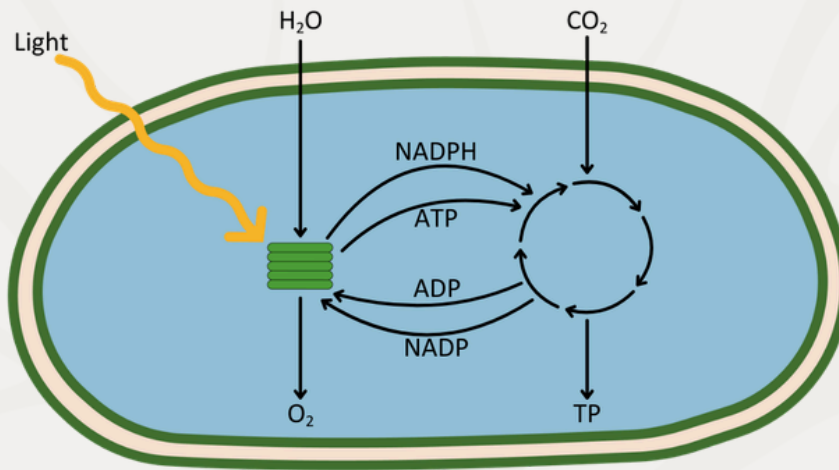


Introduction to Photosynthesis

Photosynthesis consists of **two** distinct **stages** linked together:

- The **light-dependent reactions**: **Light energy** is **absorbed** and **converted** into chemical energy in the form of **ATP** and **reduced NADP** (NADPH).
- The **light-independent reactions**: **ATP** and **reduced NADP** are used to **capture carbon dioxide** and attach it to organic molecules (**carbon fixation**).

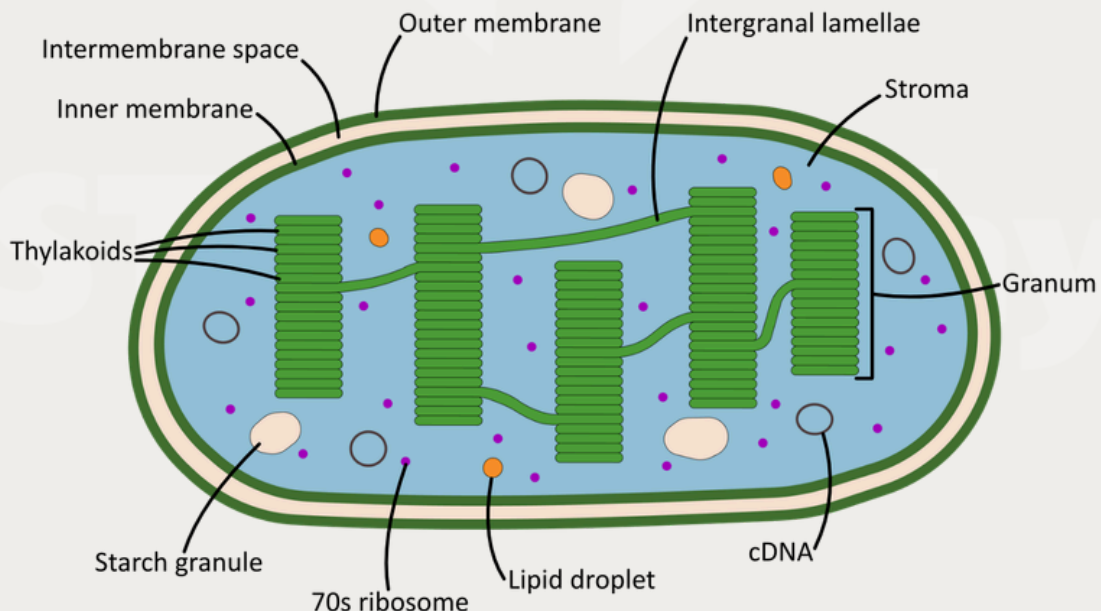
The diagram below **shows** how the **light-dependent** and **light-independent** reactions are **linked**:



Chloroplast Structure and Function

Photosynthesis in eukaryotic organisms **occurs within chloroplasts**.

The diagram below **shows** the typical **structure** of a **chloroplast**:



Module 5: The Light-Dependent Reactions



The **light-dependent reactions convert light energy** into chemical energy in the form of **ATP and reduced NADP** in a process known as **photophosphorylation**.

There are **two types of photophosphorylation: non-cyclic and cyclic**.

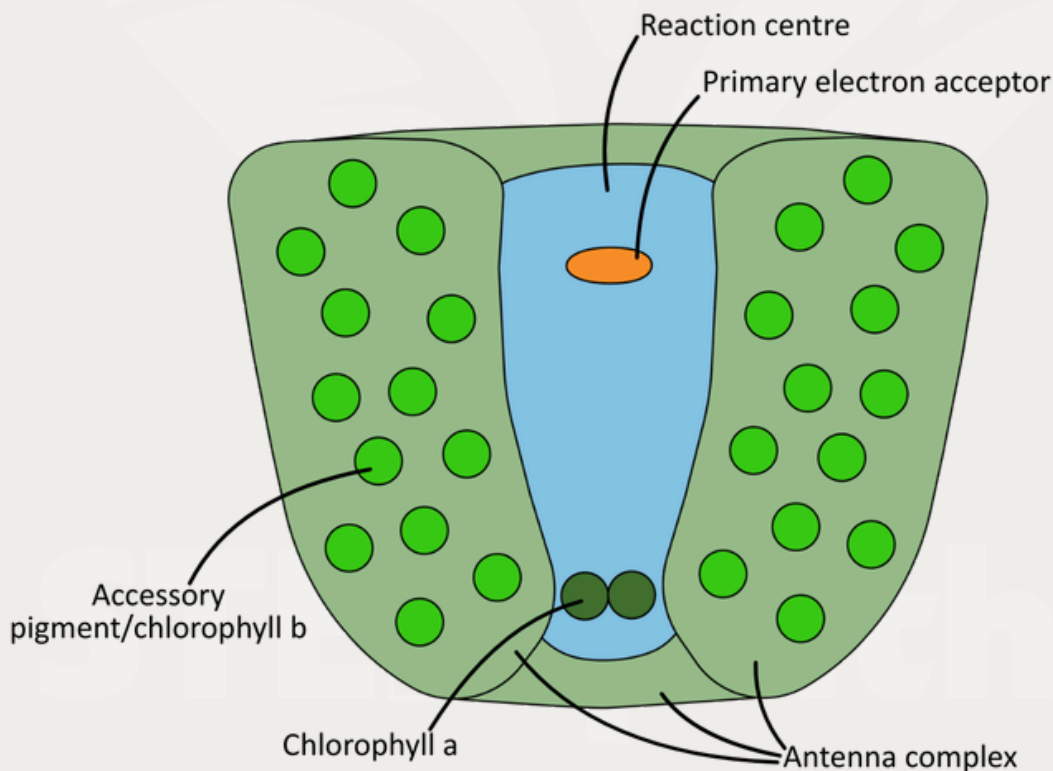
Both pathways depend on the structural arrangement of **photosystems, electron carriers** and **ATP synthase** in the thylakoid membrane.

Photosystems

Photosystems consist of an **antenna complex** and a **reaction centre**:

- The **antenna complex** contains many **chlorophyll b** and **accessory pigments** that **absorb light energy** and **transfer** it towards the **reaction centre**.
- The **reaction centre** contains a pair of **chlorophyll a** molecules* and a primary electron acceptor that uses harvested **light energy** to **excite an electron** to a **higher energy level** for use in non-cyclic photophosphorylation.

The diagram below **shows** the generic **structure** of a **photosystem**:



Module 5: The Light-Dependent Reactions



There are **two types** of **photosystems**, distinguished by the **type** of **chlorophyll a** in their **reaction centre**:

- Photosystem II (**PSII**) has a chlorophyll a molecule **absorbing** light around **680nm**.
- Photosystem I (**PSI**) has a chlorophyll a molecule **absorbing** light around **700nm**.

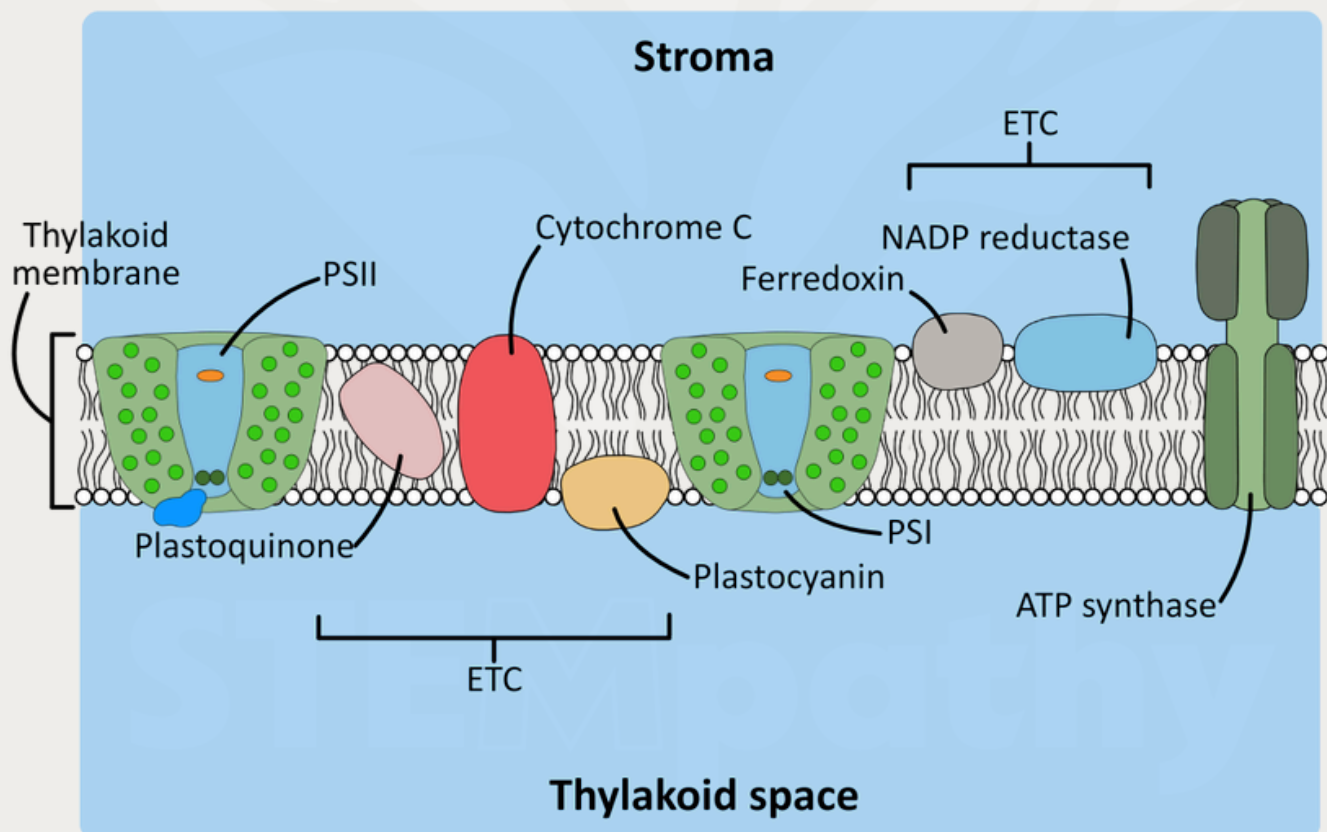
It is useful to know that **PSII** is located at the **start** of the ETC (instead of in second place), simply because it was discovered after PSI.

The Electron Transport Chain

The **electron transport chain** (ETC) is a **series of electron carriers** embedded in the **thylakoid membrane**, located **between PSII and PSI**.

The **carriers accept** and **donate electrons**, which **releases energy** that is used to **actively transport H^+** (protons) **into the thylakoid lumen** from the stroma, generating an electrochemical gradient.

The diagram below **shows** the **structure** of the **electron transport chain**:



The **electrochemical gradient** between the thylakoid lumen and the stroma causes **H^+** to **diffuse down** their **electrochemical gradient* through ATP synthase** (a channel protein associated with an enzyme), which **makes ATP**. This process is known as **chemiosmosis**.



Module 5: The Light-Dependent Reactions



Non-cyclic Photophosphorylation

Non-cyclic photophosphorylation relies on the transfer of electrons **from water** to **NADP**.

As the **electrons** move along the ETC, they **release energy** harvested from photons for use in setting up a **H⁺ concentration gradient** for making **ATP** in **chemiosmosis**.

The **process** can be **summarised** as:

1. **Light energy** absorbed by the **antenna complex** in **PSII** is used to excite an electron to a **higher energy state**.
2. The **electron** is **transferred along** the **electron carriers** in the ETC, **releasing energy** for active transport, before arriving at PSI.
3. **H⁺** are **pumped** into the **thylakoid space**, creating a **concentration gradient** between the **thylakoid space** and the **stroma**.
4. **Light** is **absorbed** by PSI and **re-excites electrons** to a higher energy state in **P700**, being transferred to **ferredoxin**, and then **NADP reductase**, which uses **2 e⁻** and **2 H⁺** to make **reduced NADP**.
5. **H⁺** **diffuse** out of the thylakoid space via **ATP synthase**, which uses P_i to **phosphorylate ADP into ATP**.
6. **Photolysis splits water** into oxygen, 2H⁺, and an e⁻ that **replaces** the one lost from **PSII**.

Cyclic Photophosphorylation

Cyclic photophosphorylation **releases** some additional **energy** for the **active transport** of **H⁺** to produce ATP in **chemiosmosis**, but does not 'lose' electrons to NADP.

The **process** can be **summarised** as:

1. **Light energy** is **absorbed** by **accessory pigments** in **PSI** and **transferred** to **P700** in the **reaction centre**.
2. An **electron** in P700 is **excited** to a higher energy state and **transferred to the electron transport chain**.
3. **Energy released** from electron transfer is used for the **active transport of H⁺** into the thylakoid space, creating an **electrochemical gradient**.
4. The electrons **return to PSI** to replace those lost from P700.



Module 5: The Light-Independent Reactions



The **light-independent reactions** (also known as the **Calvin Cycle**) occur in the **stroma** of the chloroplast.

The Calvin cycle is a cyclical **series of enzyme-controlled reactions** that use **ATP** and **reduced NADP** from the light-dependent reactions to **fix carbon dioxide**.

The **fixation** of carbon dioxide produces **triose phosphate (TP)**, a 3-carbon molecule, which can be used to **produce** larger and more complex organic molecules (e.g. **glucose, amino acids, lipids**).

2 TP (3C) molecules are **required** to make **1 glucose** (a 6C molecule), combining after the Calvin cycle.

The **production of 2 TP molecules**, needed to produce **1 glucose molecule**, requires the **Calvin cycle to turn 6 times**.

The process of **6 CO₂** being **used** to produce **2 TP** for a whole glucose molecule (6 turns of the Calvin cycle) can be **summarised** as:

1. **RuBisCO catalyses** the reaction of **6 RuBP** and **6 CO₂** in the **stroma** to form 6 unstable intermediate 6 carbon compounds.
2. The **6 intermediate** 6C compounds break down to **form 2 3C GP** molecules each (12 GPs in total).
3. **12 GPs** are **reduced using 1 ATP, and 1 reduced NADP each**, producing **12 TPs** (using 12 ATP and 12 reduced NADP in total).
4. **10 TP** molecules are used to **regenerate 6 RuBPs** using **6 ATPs**.
5. **2 TPs leave** the **Calvin cycle** to be used in the formation of glucose, amino acids, fatty acids or glycerol.

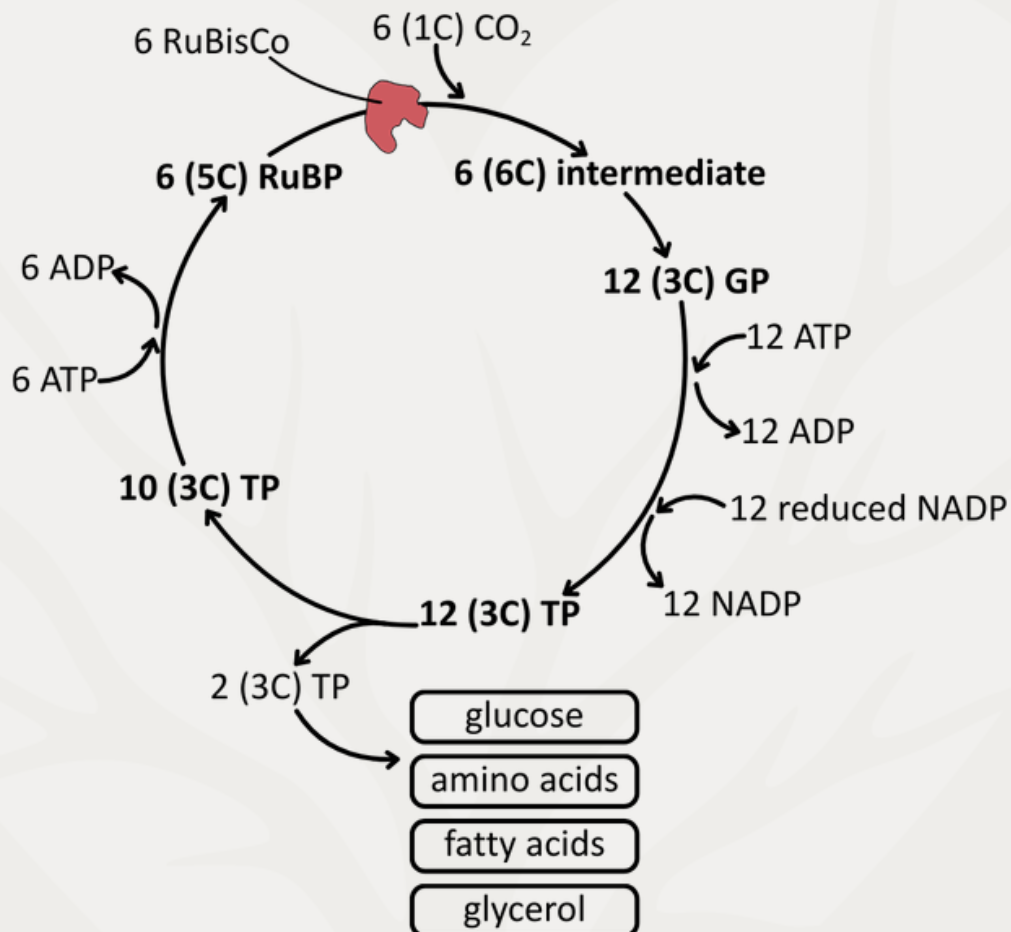
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Module 5: The Light-Independent Reactions



The diagram below **outlines** the roles of the **substances** used in **6 turns** of the **Calvin cycle**:



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Module 5: Factors Affecting the Rate of Photosynthesis



The **rate of photosynthesis** is affected by many **environmental factors**, which can **limit** the **light-dependent reactions** and the **Calvin cycle**.

Some of the main **factors** that **affect** the **rate of photosynthesis** are:

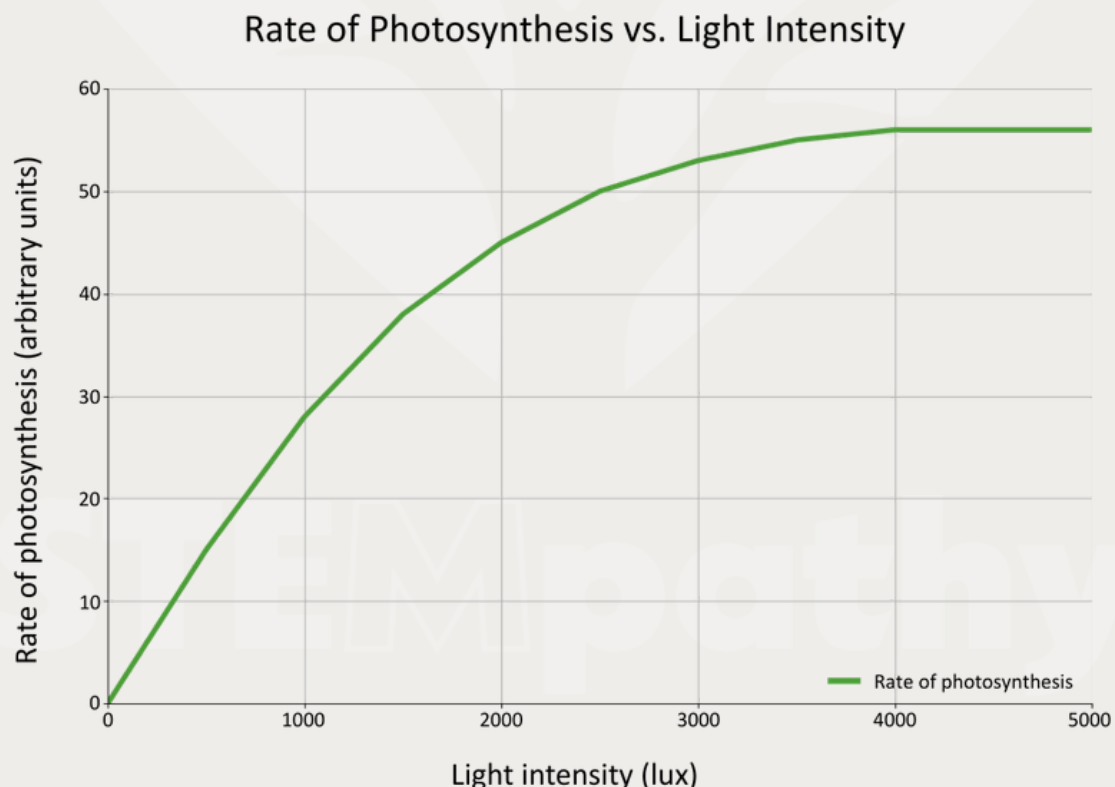
- **Light intensity:** Determines the **rate** of **ATP** and **reduced NADP production** in the **light-dependent reactions**.
- **Carbon dioxide concentration:** Required for **carbon fixation** by RuBisCO in the **Calvin cycle**.
- **Temperature:** Affects **enzyme activity** in the Calvin cycle.

Water stress indirectly **reduces** the **rate of photosynthesis** by **closing stomata** and **limiting CO₂ uptake**.

Light Intensity

Light provides the **energy** for the **light-dependent reactions**, and at **low light intensities**, **ATP** and **reduced NADP** production will **decrease**.

The graph below **shows** how **light intensity** **affects** the **rate of photosynthesis**:



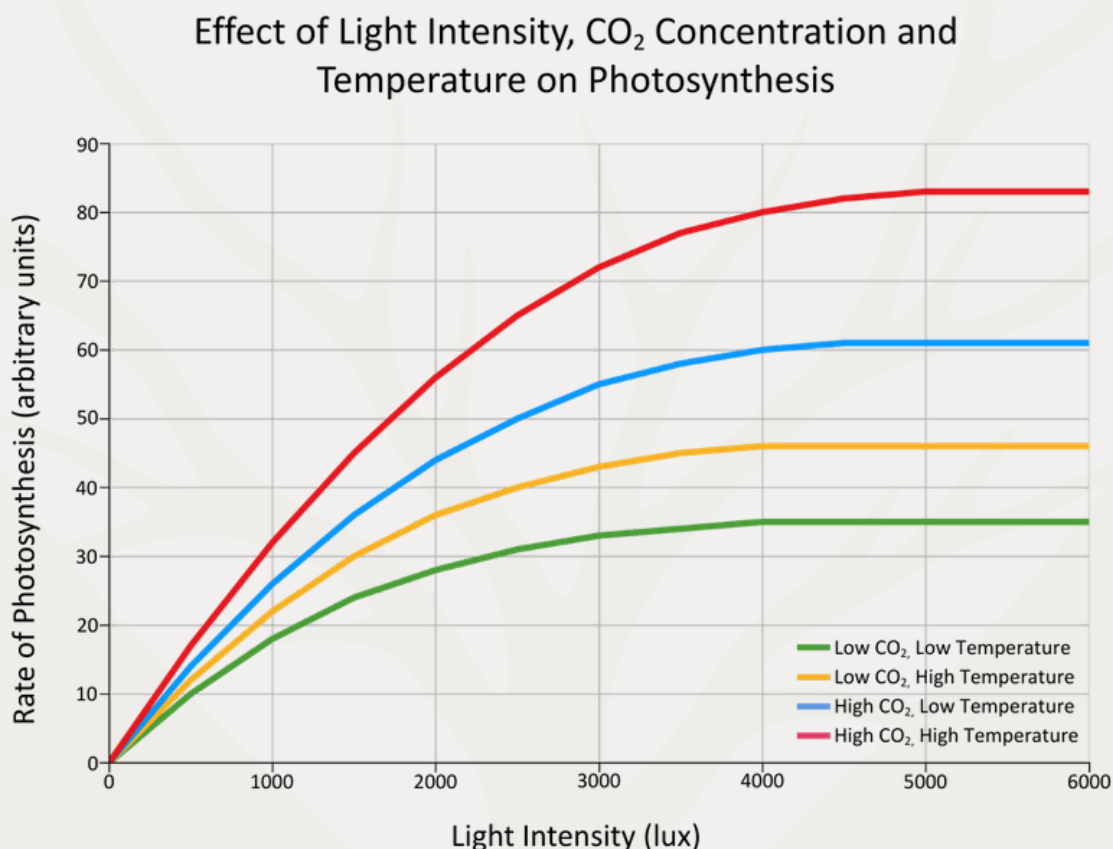
Module 5: Factors Affecting the Rate of Photosynthesis



Carbon Dioxide Concentration

Carbon dioxide is the **substrate** for **carbon fixation** in the Calvin cycle, and at **low** carbon dioxide concentrations, the **rate** at which RuBP can **accept carbon dioxide** is **reduced**.

The graph below **shows** how **carbon dioxide concentration** affects the **rate of photosynthesis** at **different light intensities** and **temperatures**:



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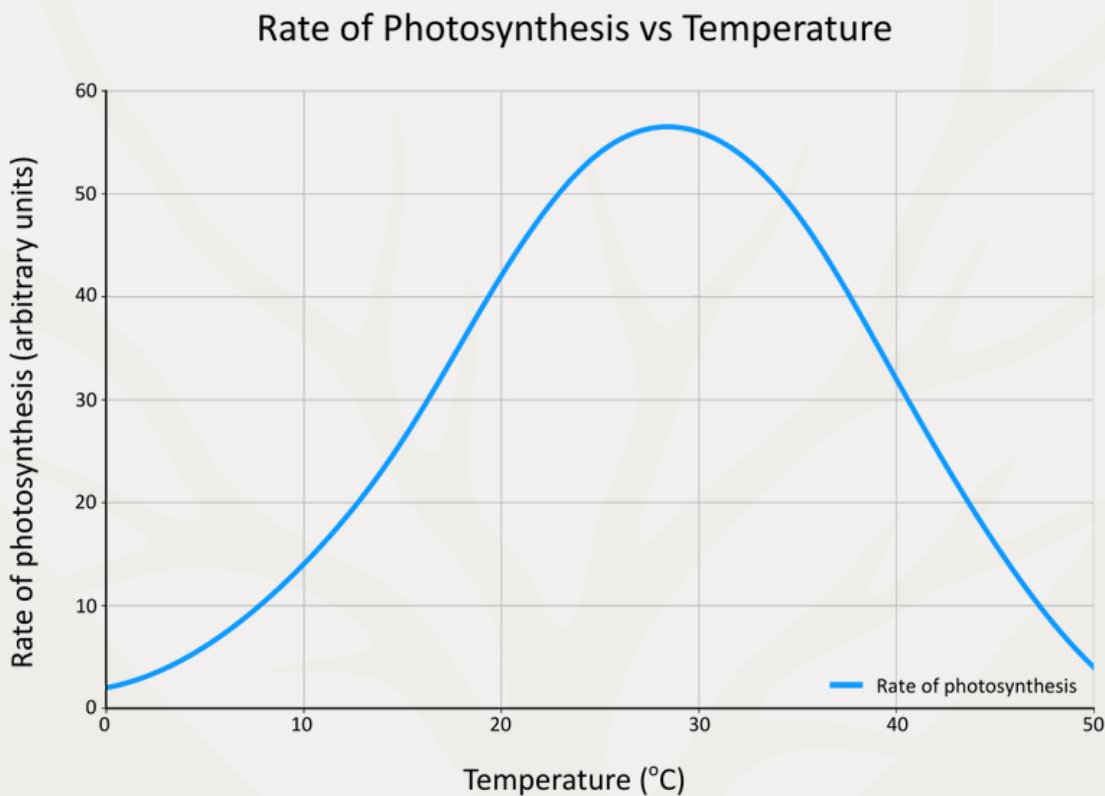
Module 5: Factors Affecting the Rate of Photosynthesis



Temperature

Temperature affects the **rate of photosynthesis** because the Calvin cycle relies on **enzyme-controlled reactions**.

The graph below **shows** how **temperature affects** the **rate of photosynthesis**:



The table below **outlines** the effect of **each environmental factor** on the **products** of the **Calvin cycle**:

Factor	GP	TP	RuBP	Reason
Low light	↑	↓	↓	Less ATP & reduced NADP available to reduce GP into TP.
Low CO ₂	↓	↓	↑	RuBP cannot fix CO ₂ , so RuBP accumulates.
Low temperature	↓	↓	↓	All enzyme reactions slow down.
High temperature	↓	↓	↑ then ↓	- Enzymes denature. - Oxygen increasingly competes with CO₂ at RuBisCO.



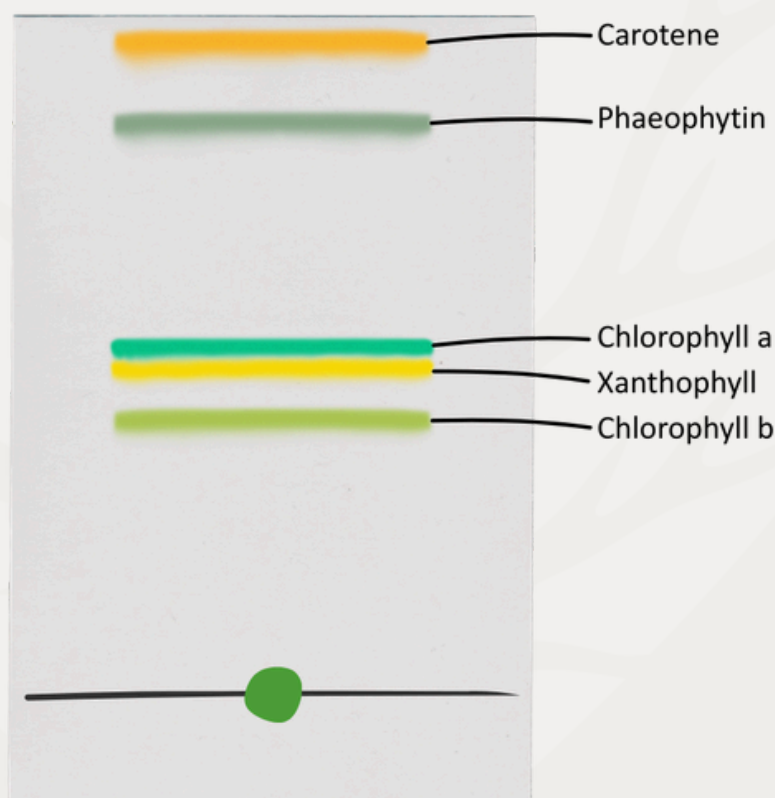
Module 5: Thin-Layer Chromatography of Plant Pigments



Thin-layer chromatography (TLC) is used to separate and **identify photosynthetic pigments** from plant extracts.

The **technique separates pigments** based on their **solubility** in the mobile phase and their affinity for the stationary phase.

The diagram below **shows the distribution of typical pigments** on a TLC plate that can be extracted from photosynthetic plant tissue:



To **calculate** the **Rf value** for each pigment, we use the following **equation**:

$$R_f = \text{Distance moved by pigment} \div \text{Distance moved by solvent front}$$

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Module 5: Respiration and Mitochondria



Respiration is the process by which all living organisms **transfer energy** stored in organic molecules **into ATP**, enabling the release of energy for biological processes.

ATP (adenosine triphosphate) is the immediate source of energy for biological processes, which can be quickly **hydrolysed** to release energy where and when it is needed.

Respiration has different **pathways** depending on the type of organism and whether oxygen is available.

At A level, **respiration** is studied in animals (particularly mammals), plants, and microorganisms (particularly yeast), in terms of **aerobic** and **anaerobic respiration**:

- **Aerobic respiration** is the same in all eukaryotic organisms using **glycolysis**, the **link reaction**, the **Krebs cycle**, and **oxidative phosphorylation**.*
- **Anaerobic respiration** varies between organisms, as different organisms have evolved different pathways in the **absence of oxygen**.

*It is useful to know that **prokaryotes** (bacteria) **also** carry out **aerobic respiration**, but the process occurs differently because they lack membrane-bound organelles.

Introduction to Aerobic Respiration

Aerobic respiration uses **oxygen** as a **final electron acceptor**.

Aerobic Respiration consists of four distinct stages linked together:

- **Glycolysis:** **Glucose** is **phosphorylated** and split into **two** molecules of **pyruvate**, producing a small yield of **ATP** and **reduced NAD** (NADH).
- The **link reaction:** Pyruvate is **decarboxylated** and **dehydrogenated** and combined with coenzyme A to form **acetyl-CoA** and **reduced NAD**.
- The **Krebs cycle:** Acetyl CoA is oxidised in a **series of enzyme-controlled reactions** that produce **ATP** through **substrate-level phosphorylation**, and reduce coenzymes.
- **Oxidative phosphorylation:** **Reduced coenzymes** are oxidised, and the **energy released** is used to generate a large yield of **ATP** through **chemiosmosis**.

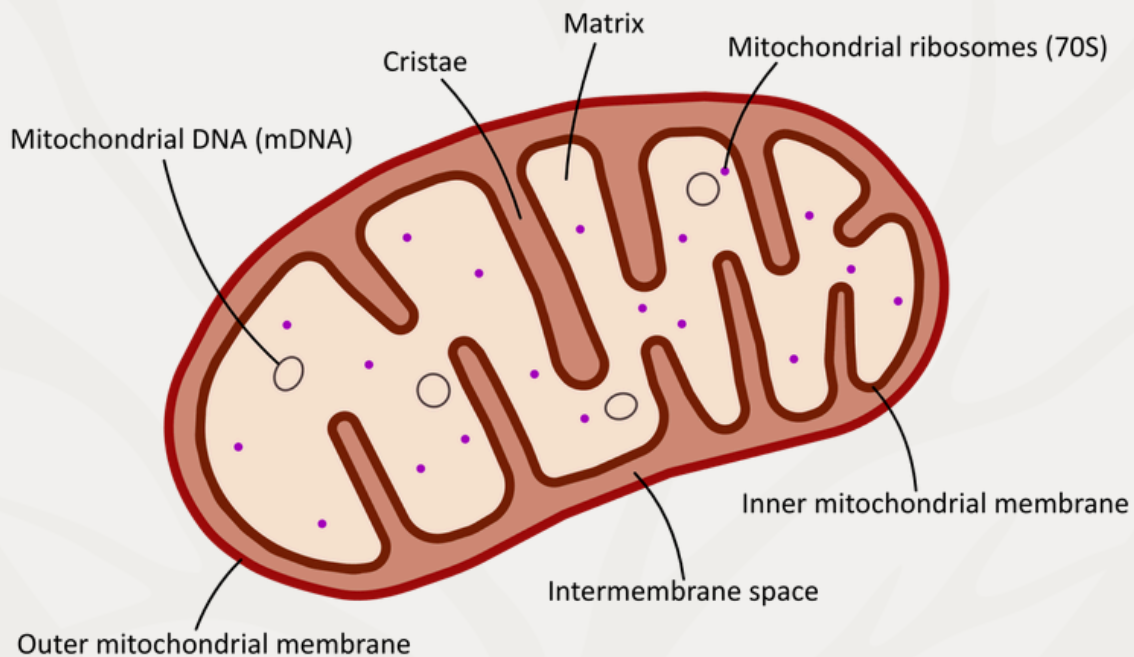




Mitochondria Structure and Function

Aerobic respiration occurs in **mitochondria**.

The diagram below **shows** the typical **structure** of a **mitochondrion**:



Introduction to Anaerobic Respiration

Anaerobic respiration (also known as fermentation) occurs when **oxygen is unavailable** as the final electron acceptor for the aerobic respiration pathway, or when **additional ATP is needed** to supplement ATP production in aerobic respiration.

Anaerobic respiration occurs in the **cytoplasm**.

There are **two** main **types** of anaerobic respiration, **lactate fermentation** and **ethanol fermentation**:

- **Lactate fermentation**: Occurs in mammals and many other animals. **Pyruvate** is reduced to **lactate**. This is **reversible** when oxygen becomes available.
- **Ethanol fermentation***: This occurs in yeast and some plants. **Pyruvate** is decarboxylated to ethanal, which is reduced to **ethanol**. This is **not reversible**.

*Also known as alcohol fermentation.



Module 5: Aerobic Respiration

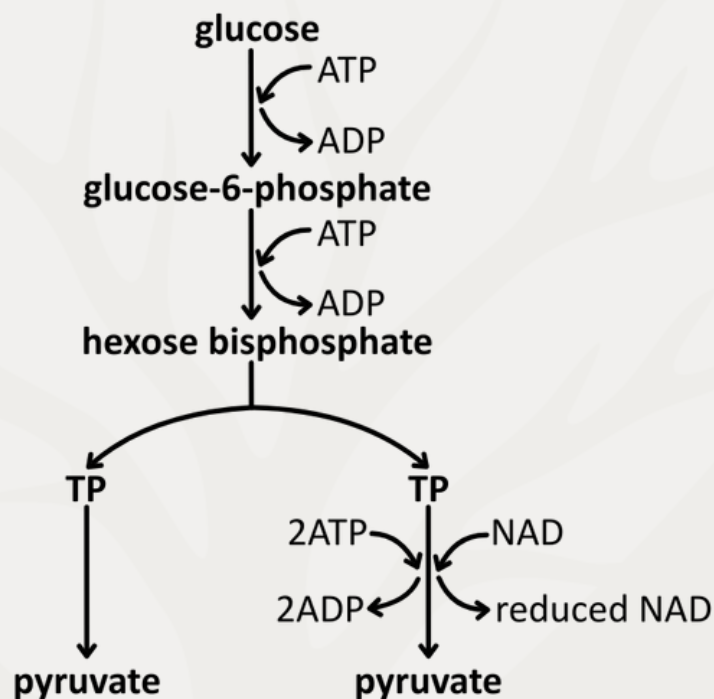


Glycolysis

Glycolysis is the **first stage** of both anaerobic and aerobic respiration (so it does not use oxygen) and occurs in the **cytoplasm** of all living cells.

Glycolysis is a **series of enzyme-controlled reactions** that **phosphorylate** and break down **one** molecule of **glucose** (6C) into **two** molecules of **pyruvate** (3C), producing a **small yield of ATP** and **reduced NAD** that can be used in subsequent stages of respiration.

The diagram below **outlines** the process of **glycolysis**:



It is useful to know that glycolysis is **simplified** at A level, with many intermediate substances and enzymes omitted for simplicity. You **are not** required to learn them.

The **pyruvate** and **reduced NAD**, which are produced in glycolysis, either remain in the **cytoplasm** to enter **anaerobic respiration** pathways or enter the **mitochondria** to be used in **aerobic respiration**.



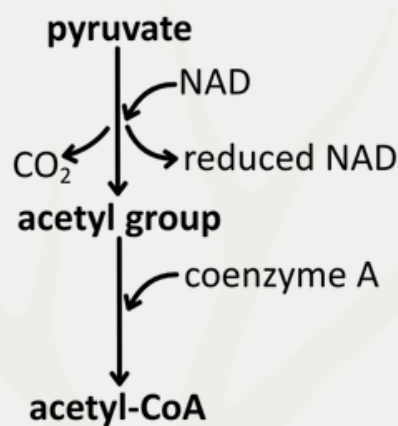


The Link Reaction

The **link reaction** occurs in the **matrix** of the mitochondrion, utilising pyruvate from glycolysis to **produce acetyl-coenzyme A** and **reduced NAD**.

During the link reaction, **pyruvate** (3C) is **decarboxylated into acetyl-CoA** (2C), and **NAD** is **reduced** into **reduced NAD**.

The diagram below **outlines** the process of the **link reaction**:



It is important to note that **coenzyme A** acts as a **carrier molecule**, transferring the acetyl group (2C) from the link reaction to the Krebs cycle.

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Module 5: Aerobic Respiration



The Krebs Cycle

The **Krebs cycle** (also known as the citric acid cycle) occurs in the **matrix** of the mitochondrion.

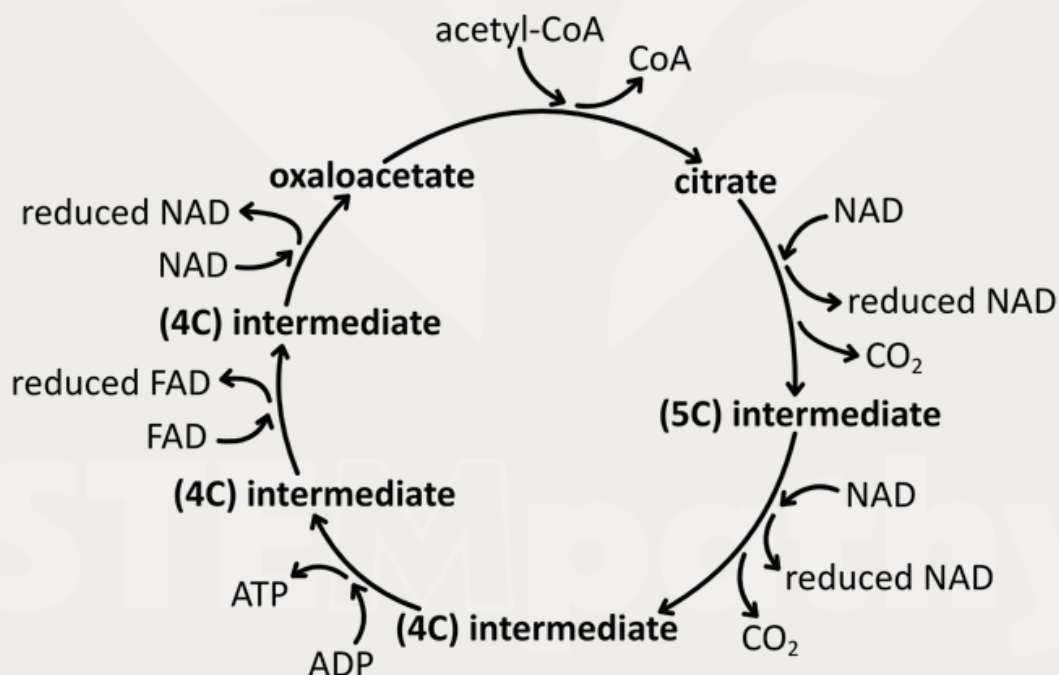
The Krebs cycle is a **series of cyclical enzyme-controlled reactions** that oxidise the acetyl group from acetyl-CoA into **carbon dioxide**, producing reduced **coenzymes** (NAD and FAD) and **ATP**.

The **role** of the Krebs cycle is to complete the oxidation of glucose by **removing hydrogen atoms** (which are carried by reduced NAD and reduced FAD) for use in **oxidative phosphorylation** and to produce **ATP** through **substrate-level phosphorylation**.

The Krebs cycle begins when the **acetyl group** (2C) from acetyl CoA **combines** with **oxaloacetate** (4C) to **form citrate** (6C). This also **regenerates CoA** for use in the link reaction.

Through a series of oxidation and decarboxylation reactions, **citrate is converted back into oxaloacetate**, allowing the cycle to continue.

The diagram below **outlines** the process of the **Krebs cycle**:



Module 5: Aerobic Respiration

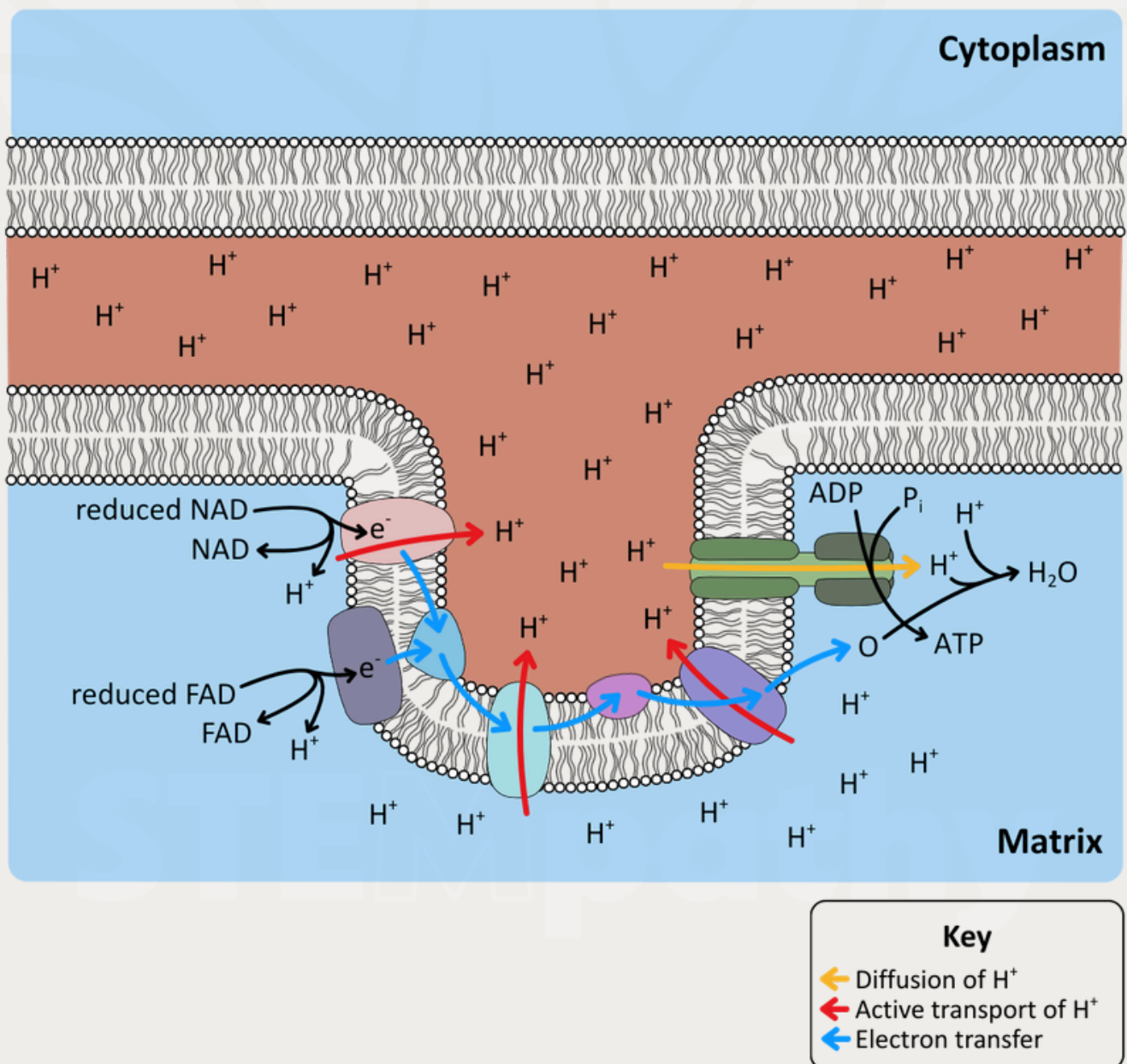


Oxidative Phosphorylation

Oxidative phosphorylation is the final stage of aerobic respiration and occurs on the **inner mitochondrial membrane** (cristae).

Oxidative phosphorylation generates a large amount of ATP using an **electrochemical gradient** established by the **electron transport chain (ETC)** using the reduced coenzymes from glycolysis, the link reaction and the Krebs cycle.

The diagram below **shows** the **processes** that occur on the **cristae** during **oxidative phosphorylation**:



Module 5: Aerobic Respiration



The process can be **summarised** as:

1. **Reduced NAD** and **reduced FAD** are both **oxidised** at the ETC, **releasing electrons and H^+** , which regenerates NAD and FAD for the earlier stages of respiration.
2. **Electrons** are transferred along the **ETC**, releasing energy that is used to **actively transport H^+** from the matrix into the intermembrane space.
3. H^+ accumulate in the intermembrane space, creating an **electrochemical gradient**.
4. H^+ diffuse **down** their **electrochemical gradient** through **ATP synthase**, which uses the energy to phosphorylate $ADP + P_i$ into **ATP**, and into the matrix.
5. **Electrons** and H^+ are accepted by **oxygen** (the final electron acceptor), forming **water**.

The overall **yield** for **ATP** from **aerobic respiration** is between **30 – 32 ATP**.

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Module 5: Anaerobic Respiration



Anaerobic respiration occurs when **oxygen is not available** as the final electron acceptor in the electron transport chain.

Anaerobic respiration allows **glycolysis to continue producing ATP** in the absence of oxygen by **regenerating NAD from reduced NAD**.

Anaerobic respiration's (indirect) **yield of ATP** is only 2.

The Importance of Anaerobic Respiration

Anaerobic respiration is important to organisms because it **enhances their survival**:

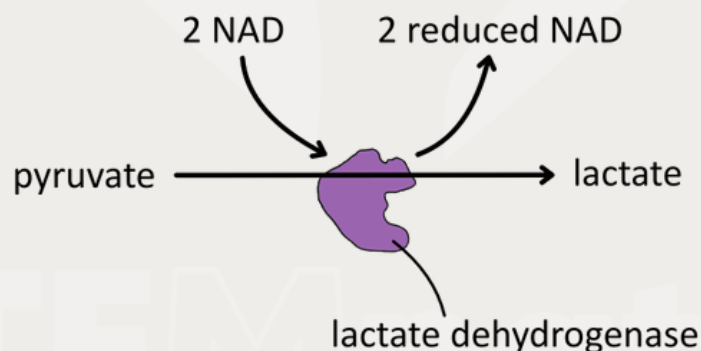
- Survive short periods **without oxygen** (e.g. diving mammals, waterlogged plant roots).
- Produce **additional ATP** during intense activity when aerobic respiration cannot supply enough.
- Provide **faster ATP production** through glycolysis than aerobic respiration.

Anaerobic Respiration in Mammals

In **mammals**, anaerobic respiration (also known as **lactate fermentation**) occurs in **muscle tissue**, providing additional ATP during **strenuous activity**.

Lactate fermentation **converts pyruvate into lactate**.

The diagram below **outlines** the process of **lactate fermentation**:



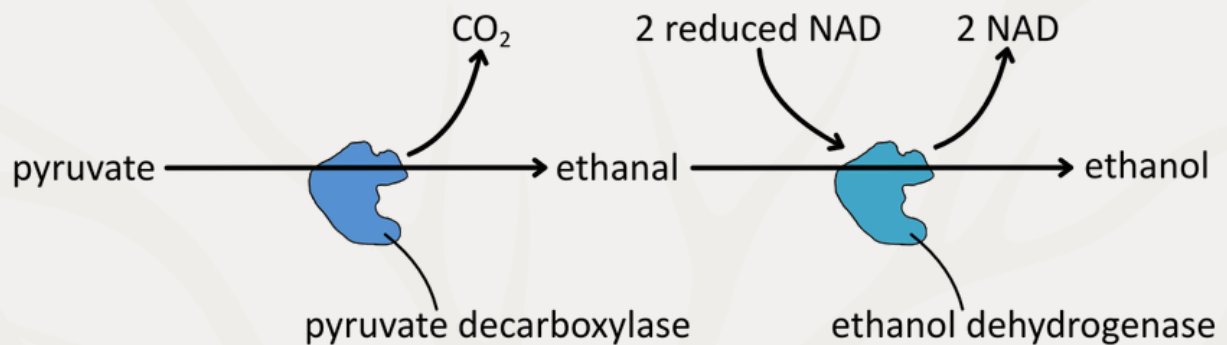


Anaerobic Respiration in Yeast

In **yeast**, anaerobic respiration (also known as **ethanol fermentation**) occurs when oxygen is unavailable, allowing ATP production to continue.

Ethanol fermentation converts **pyruvate** into **ethanol** and **carbon dioxide**.

The diagram below **outlines** the process of **ethanol fermentation**:



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Module 5: Respiratory Quotient



The **respiratory quotient** (RQ) is a **ratio** reported as a single number that **indicates** which **respiratory substrate** is (most likely) being used by an organism.

The **RQ ratio** represents how much **carbon dioxide** is produced **relative** to how much **oxygen** is used.

The **RQ** is **calculated** using the **formula**:

$$RQ = CO_2 \text{ produced} \div O_2 \text{ consumed}$$

The table below **shows** typical **RQ values** for different **respiratory substrates**:

Respiratory Substrate	RQ Value	Explanation
Carbohydrates	1.0	Equal amounts of CO ₂ produced and O ₂ consumed.
Lipids	~0.7	More O ₂ is required to oxidise hydrogen-rich lipids.
Proteins	~0.9	Depends on the amino acid.

Uses of RQ Values

RQ values can be **used** to:

- **Identify** the respiratory substrate being used (e.g. carbohydrates, lipids, proteins).
- **Detect** the presence of anaerobic respiration.
- **Monitor** metabolic shifts during exercise, starvation, medical treatment or fasting.

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Module 5: The Interrelationship Between Photosynthesis and Respiration



Photosynthesis and respiration are **interdependent** processes.

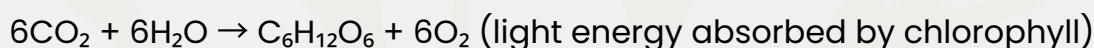
Carbon dioxide and water, which are **products of respiration**, are the **raw materials for photosynthesis**.

Glucose and oxygen, which are **products of photosynthesis**, are the **raw materials for aerobic respiration**.

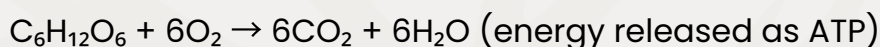
As a result, the same substances are continuously **recycled between the two processes**.

The **overall equations for photosynthesis and aerobic respiration** show this interrelationship:

Photosynthesis:



Aerobic respiration:



The Compensation Point

The **compensation point** is the light intensity at which the **rate of photosynthesis equals the rate of respiration**. At this point, there is no net gain or loss of carbohydrate in the plant.

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Module 5: The Interrelationship Between Photosynthesis and Respiration



Comparing Photosynthesis and Aerobic Respiration

Due to the **shared principles** by which photosynthesis and aerobic respiration work (such as such as oxidation–reduction reactions, electron transport chains, and chemiosmosis), questions **comparing** the two **processes** are common and likely.

The table below **compares** the **key features** of **photosynthesis** and **respiration**:

Feature	Photosynthesis	Respiration
Overall purpose	Converts light energy into chemical energy (glucose)	Transfers chemical energy (glucose) into ATP
Reactants	$\text{CO}_2 + \text{H}_2\text{O}$	Glucose + O_2
Products	Glucose + O_2	$\text{CO}_2 + \text{H}_2\text{O} + \text{ATP}$
Organelle(s)	Chloroplast	Mitochondria and cytoplasm
Coenzymes	- NADP - ATP	- NAD - FAD - CoA - ATP
Chemiosmosis	Thylakoid membrane	Inner mitochondrial membrane

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Module 5: Factors Affecting the Rate of Respiration



Factors Affecting the Rate of Respiration

The main **factors** that **affect** the **rate of respiration** are:

- **Temperature:** affects **enzyme activity** across all stages of respiration.
- **Substrate concentration:** determines the availability of **glucose for glycolysis**.
- **Oxygen availability:** determines if **aerobic respiration can occur**.

Temperature

The **effect of temperature** on respiration depends on if it is **below, above,** or at the **optimum**:

- **Below:** Molecules have **lower kinetic energy**, which **reduces** the frequency of **successful collisions** between enzymes and their substrates.
- **Above:** Molecules have **excessive kinetic energy**, which **disrupts** the hydrogen and ionic bonds that maintain the **tertiary structure** of proteins.
- **Optimal:** Molecules have the **right level of kinetic energy** to maximise the frequency of enzyme-substrate collisions without damaging the structure of the protein.

It is useful to know that respiration rates can be manipulated for **commercial** purposes. For example, fruits and vegetables are stored at **low temperatures** to **prevent** them from **ripening**, sprouting, or otherwise **spoiling**. This **maximises** businesses' **profit margins**. The table below **outlines** a set of **example respiration rates** for **fruits** and **vegetables** stored at **different temperatures**:

	Respiration Rate (mg CO ₂ kg ⁻¹ h ⁻¹)				
Organism	0 °C	5 °C	10 °C	15 °C	20 °C
Apple	3.0	5.0	9.0	15.0	30.0
Asparagus	60.0	95.0	197.0	244.0	388.0
Cauliflower	18.0	21.0	34.0	46.0	81.0
Onion	3.0	3.5	7.5	10.5	16.5
Potato	2.0	6.0	9.0	12.0	28.0



Module 5: Factors Affecting the Rate of Respiration



Substrate Concentration

The **concentration** of respiratory substrate (primarily **glucose**) affects the **rate of glycolysis**, which in turn determines the **production** of **pyruvate**, **reduced NAD**, and **acetyl-CoA**, which is required for later stages.

The **effect of substrate concentration** on the rate of respiration depends on whether it is **low**, **high**, or **saturated**:

- **Low substrate concentrations**: The **rate of glycolysis is limited** because enzymes have fewer substrate molecules available, producing **less pyruvate** and **reduced NAD**.
- **High substrate concentration**: The **rate of respiration increases**, as more **enzyme-substrate complexes** can form, producing **more pyruvate** and **reduced NAD**.
- **Saturating concentrations**: The **rate of respiration plateaus** at its **V_{max}**, because all **enzyme active sites** are **occupied**; adding more substrate has **no further effect**.

Oxygen Availability

Oxygen availability **determines** whether **aerobic or anaerobic respiration** occurs.

The **effects** of **reduced** or absent **oxygen** are due to its effect on the **ETC**, and the subsequent effects of its limitation:

- The **ETC stops** as **electrons cannot** be **transferred to oxygen** as the final electron acceptor.
- **Chemiosmosis** and **oxidative phosphorylation reduce** or **stop** as the electrochemical **gradient** decreases.
- The **link reaction** and the **Krebs cycle stop** as their inputs of **NAD** and **FAD** are **no longer regenerated** at the ETC.

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Module 5: Investigating the Rate of Respiration



Respirometers

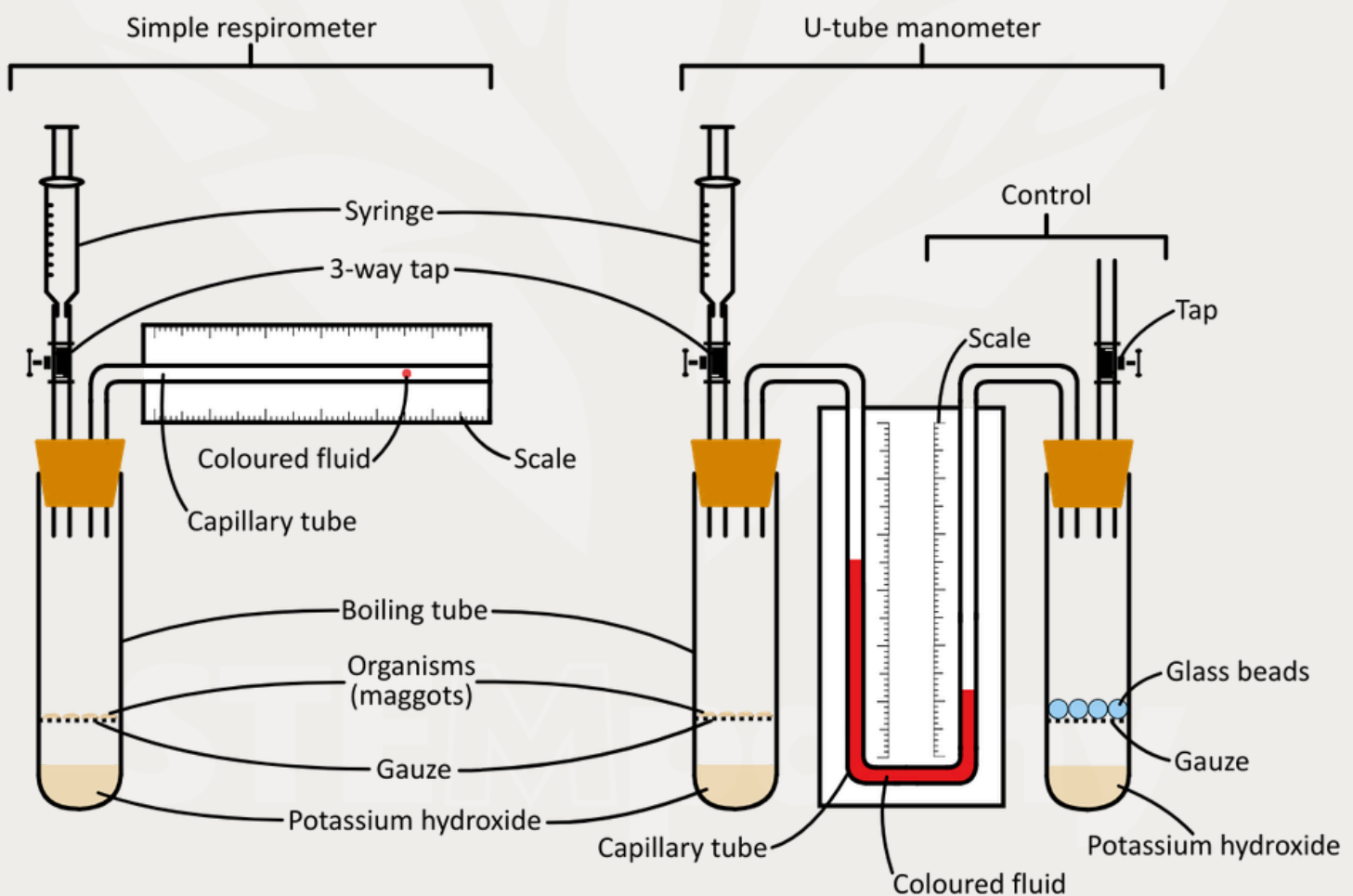
A **respirometer** is a device that can be used to **measure oxygen uptake**.

Respirometers work by **measuring** the **decrease in volume** of a sealed gas chamber containing the air that an organism takes in oxygen from and releases carbon dioxide into.

The decrease in volume is due to the **carbon dioxide** from respiration being **absorbed** by a chemical (such as **soda lime** or **potassium hydroxide solution**).

The **syringe** and the **U-tube manometer** are the two most commonly encountered **respirometers** used at A level biology.

The diagram below **shows** examples of both types of **respirometer**:



The carbon dioxide absorber is **separated** from the **organisms** using a wire mesh or muslin cloth to prevent harm to the organisms.



In both experiments, the **distance moved** by the **coloured fluid** along the capillary tubing allows for the **volume** of carbon dioxide to be **calculated** using the following equation:

$$Volume = \pi \times radius^2 \times length \text{ (distance travelled)}$$

Practical Investigations into Respiration in Yeast

In OCR A Level Biology you need to be able to use your general understanding of **aerobic and anaerobic respiration in yeast** to interpret experimental investigations. You are **not required** to learn or recall any specific experiment.

- Respiration in yeast can be investigated under both **aerobic and anaerobic conditions**:
- **Aerobic respiration** in yeast **occurs** when **oxygen is available**, producing **CO₂**, **water**, and a **high yield of ATP**.
 - **Anaerobic respiration** (ethanol fermentation) occurs in the **absence of oxygen**, producing **CO₂** and **ethanol** with a low yield of ATP (**2 ATP** per glucose).

The **rate of aerobic respiration** can be **measured** by **O₂ consumption**, **CO₂ production**, or **redox indicator decolourisation**.

The **rate of anaerobic respiration** can be **measured** by **CO₂ production** or **ethanol detection**.

The table below **outlines** two examples of **practical investigations** for investigating **respiration in yeast suspensions**, and what can be **inferred** from the **observations** of each:

Experiment	Observation	Inference
Yeast suspension is placed in a respirometer. The effect of temperature or glucose concentration is investigated.	Coloured fluid moves towards the experimental tube.	The rate of fluid movement reflects the rate of O ₂ consumption, allowing the rate of aerobic respiration in different conditions to be calculated.
Yeast suspension with oxygen excluded is placed alongside hydrogencarbonate indicator solution. The effect of temperature, glucose concentration, or substrate type is investigated.	Indicator changes from red towards yellow as the CO ₂ concentration increases.	Rate of colour change reflects the rate of CO ₂ production in anaerobic respiration in different conditions.

Module 6: Cellular Control of Gene Expression



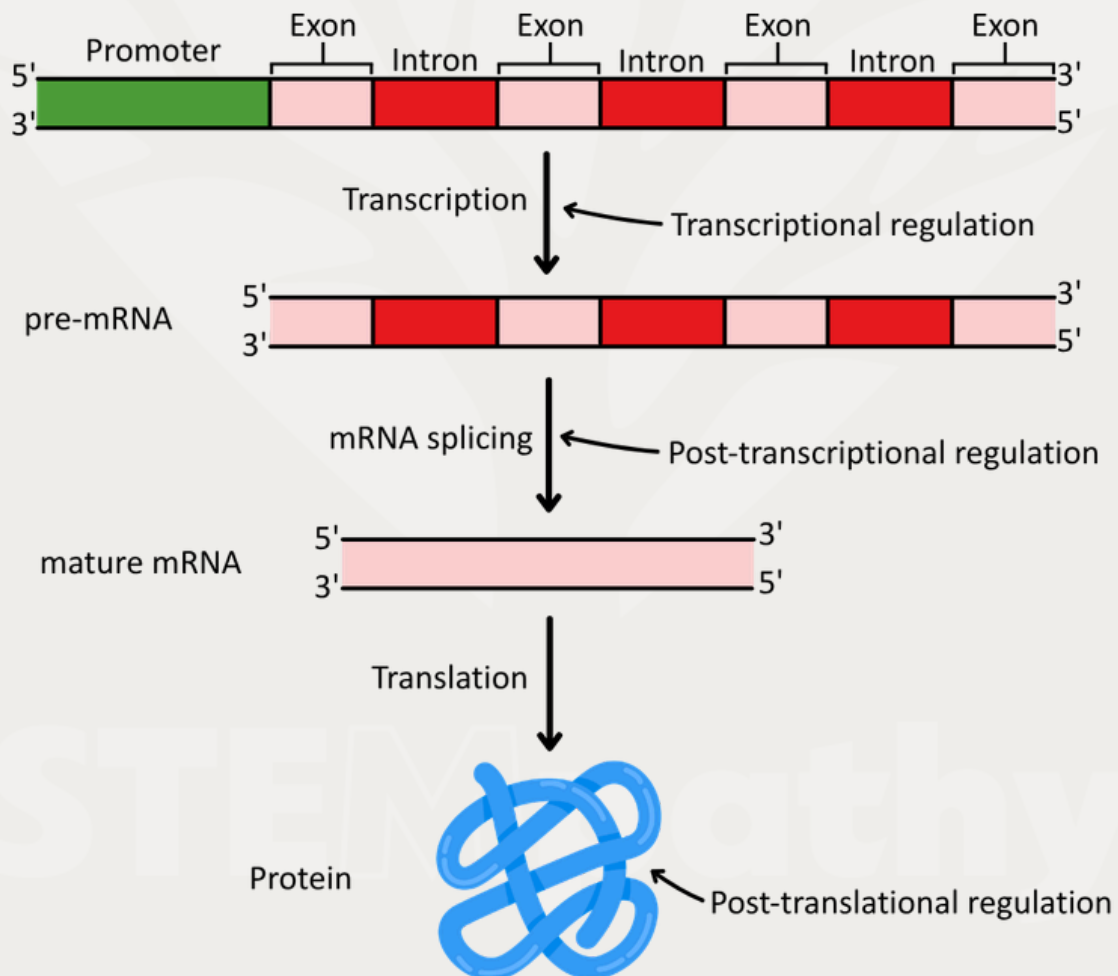
Cellular control refers to the **regulatory mechanisms** by which **cells regulate** their **metabolic activities, development, structure and function**.

Regulatory mechanisms involved in cellular control work by **controlling gene expression**.

Regulatory mechanisms are categorised as either **transcriptional, post-transcriptional, or post-translational**:

- **Transcriptional regulation** is whether a **gene** is **transcribed** into **mRNA**, and how often.
- **Post-transcriptional regulation** is the **editing** of the **mRNA** copy of the gene produced in transcription.
- **Post-translational regulation** determines **whether the protein** produced by translation is **activated**.

The diagram below **shows the stages in gene expression** at which **different regulatory mechanisms** act:





Transcriptional regulation

Transcriptional regulation **controls whether a gene is transcribed into mRNA**, and is **controlled by** proteins called **transcription factors**, which turn genes on, off, or influence the rate at which they are transcribed.

Post-transcriptional regulation

Post-transcriptional regulation **modifies** the **mRNA** produced in **transcription**.

Transcription produces a **full copy of the gene** known as **primary mRNA**.

Primary mRNA* (and the gene it is a copy of) is made up of **sections** that can be categorised as either **introns** or **exons**:

- **Introns** are **non-coding regions** of the gene (and primary mRNA copy) that do **not code** for the **amino acid** sequence in the final protein product; however, they may have roles in regulating gene expression.
- **Exons** are **coding regions** of the gene (and primary mRNA copy) that **do code** for the **amino acid** sequence in the final protein product.

*It is useful to know that primary mRNA is also known as pre-mRNA.

Introns are **cut out** of the primary mRNA, and the remaining **exons** are **joined together** to **form mature mRNA** (or just 'mRNA').

Post-translational regulation

Post-translational regulation **controls** the **activation of proteins produced in translation**.

cAMP (cyclic AMP) is an example of post-translational regulation, it is a **secondary messenger** involved in an enzyme cascade that **activates enzymes and proteins**.

cAMP is **produced from ATP** following the binding of a signalling molecule (such as glucagon) to a complementary receptor on the cell surface membrane.



Module 6: The Lac Operon



An **operon** is a **group of genes** that are **transcribed together** by RNA polymerase binding to a **single promoter region**.

Grouping genes into **operons** allows a microorganism to **switch** several related **genes on or off together**, so that the proteins they code for are only produced when they are actually needed.

The *lac* Operon

The ***lac* operon** is a cluster of **2 genes*** in *Escherichia coli* involved in **expressing proteins** associated with **metabolising lactose**.

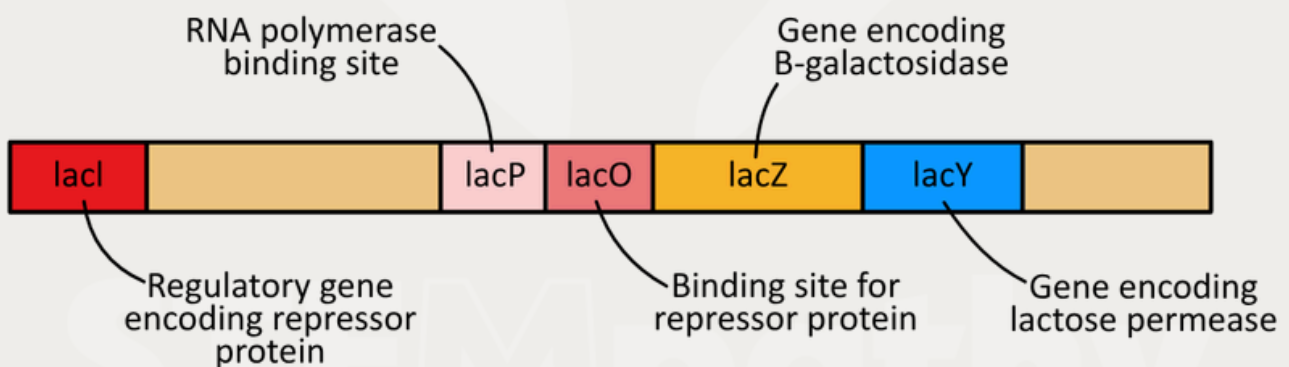
*It is actually 3 genes, but some components of the *lac* operon are (typically) omitted for simplicity.

The **genes** in the *lac* operon are **only expressed** when **lactose is present**.

It is important to note that the *lac* **operon** is the required example of an operon given in the OCR A Level Biology specification.

The *lac* operon is **under the control** of a **regulatory gene** called ***lacI***, located upstream of the activator binding site.

The diagram below **shows** the **positions** of ***lacI*** and the **components** of a simplified ***lac* operon**:



It is useful to know that in educational materials, 'empty' sections of DNA are often added between *lacI* and the components of the operon to emphasise that *lacI* is not a part of the operon.

***LacI* encodes a transcription factor** (a repressor) that **binds** to the **operator (*lacO*)** and **prevents RNA polymerase** from binding to the promoter and transcribing *lacZ* and *lacY*.



Module 6: The Lac Operon



The *lac* operon can be described as 'on' when RNA polymerase **can transcribe** *lacZ* and *lacY* due to the presence of lactose.

Lactose inhibits the repressor molecule, allowing **RNA polymerase** to bind to the promoter region and **transcribe the genes** involved in digesting lactose.

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Module 6: Controlling the Development of Body Form



In order for an organism to assume its particular shape and size (its morphology), **mitosis**, **differentiation** and **apoptosis** must be **coordinated** between different cells to ensure these processes proceed at the **correct rate**, and at the **right time**.

The **coordination** of **mitosis**, **differentiation** and **apoptosis** ensures that:

- **Mitosis** produces **sufficient cells** during periods of growth, and replaces cells at a sufficient rate **without** tissues **atrophying** or **tumours** forming.
- **Differentiation** occurs at the **appropriate time** in an organism's development, so that specialised cells arise in the **correct location**.
- **Apoptosis** allows for tissues to be sculpted (such as **separating toes**), and safely **removes unneeded** or **defective cells** (such as defective T-lymphocytes, or in the formation of a lumen) during organ system development.

It is important to note that OCR A Level Biology highlights the **importance** of **apoptosis** in **shaping the morphology** of a developing organism.

The image below **shows** the **separation of digits** in the paw of a developing kitten foetus over time due to **apoptosis**:

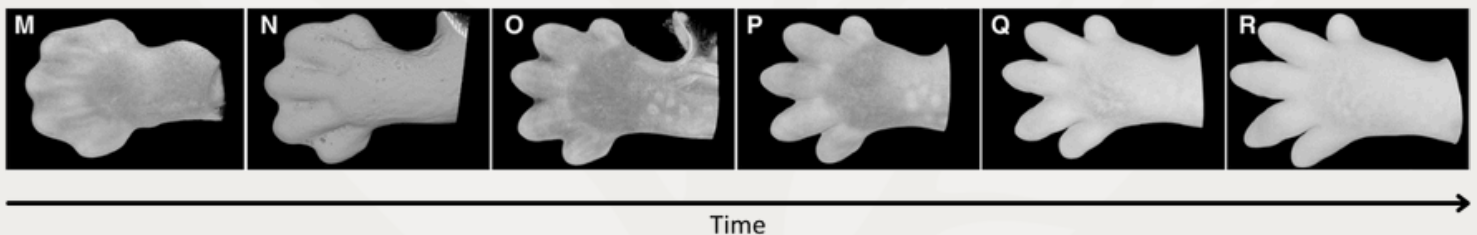


Image by Geyer et al., 2017

The **coordination** of mitosis, differentiation and apoptosis is **controlled by genes**.

Hox Genes

Hox genes **control the development of the body plan** along the anterior–posterior axis (**front to back**), which goes in the direction of the **head to the tail** in the **embryo** of animals, and determine **where anatomical structures develop**.

Hox genes are arranged in clusters (of up to 10) on the chromosomes, and their **order** along the cluster **reflects** the **relative location** in the embryo **in which they are expressed**.



Module 6: Controlling the Development of Body Form



Homeobox Sequence

The homeobox sequence is a **180-base pair-long*** section of DNA **found in** many (but not all) **genes** which **control the morphological development** of most organised multicellular organisms, including **animals, plants, and fungi**.

*Once any introns have been removed.

The homeobox sequence **codes** for an **amino acid sequence** that **folds** into a **DNA-binding domain** that allows it to act as a **transcription factor**.

The **homeodomain** enables the proteins it is a part of to **bind to DNA**, allowing them to act as **transcription factors** that can **bind to genes**, allowing for the **control of their gene expression**.

The **homeobox gene's conservation** in animals, plants, and fungi is **molecular evidence** for the **common ancestry** between these types of organisms.

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Module 6: Generating Genetic Variation



Genetic variation is mainly **caused by mutation** and **sexual reproduction**.

Mutations generate **new alleles** and can alter the **arrangement of genes** on a chromosome.

Sexual reproduction generates **new genotypes** as a result of **meiosis** and **fertilisation**.

The table below **outlines** different **sources of genetic variation and their mechanism**:

Source	Contribution to genetic variation
Mutation	- Produces new alleles by changing DNA base sequences. - Changes the number of copies of genes by altering the number or structure of chromosomes.
Crossing over	Produces chromosomes with new allele combinations by producing recombinants when non-sister chromatids exchange DNA at the chiasmata.
Independent assortment	Produces many chromosome combinations by allowing maternal and paternal chromosomes to be distributed randomly into gametes from homologous pairs as they align randomly at the equator in metaphase I.
Random fertilisation	Produces new combinations of chromosomes by allowing any male gamete to fertilise any female gamete.

Mutation

A mutation is a **random change** to the **genetic material** of an organism.

A mutation can be (typically) **harmful**, (sometimes) **harmless**, or (rarely) **beneficial**:

- **Harmful** mutations **alter** the structure of a **protein** in such a way that its **function is negatively impacted**, interfering with normal cell functioning.
- **Harmless** mutations don't affect the structure of a protein, so it **functions as normal**.
- **Beneficial** mutations **alter** the structure of a **protein** in such a way that its **function is improved**, positively affecting normal cell functioning.

Gene mutations are either **deletions**, **insertions**, or **substitutions**:

- **Insertion**: One or more **nucleotides** are **added** to the DNA sequence.
- **Substitution**: One **base pair*** is **replaced** with another.
- **Deletion**: One or more **nucleotides** are **removed** from the DNA sequence.

*Sometimes a single nucleotide in the template strand can be replaced, and will not pair correctly with its opposite on the coding strand (which remains unchanged).



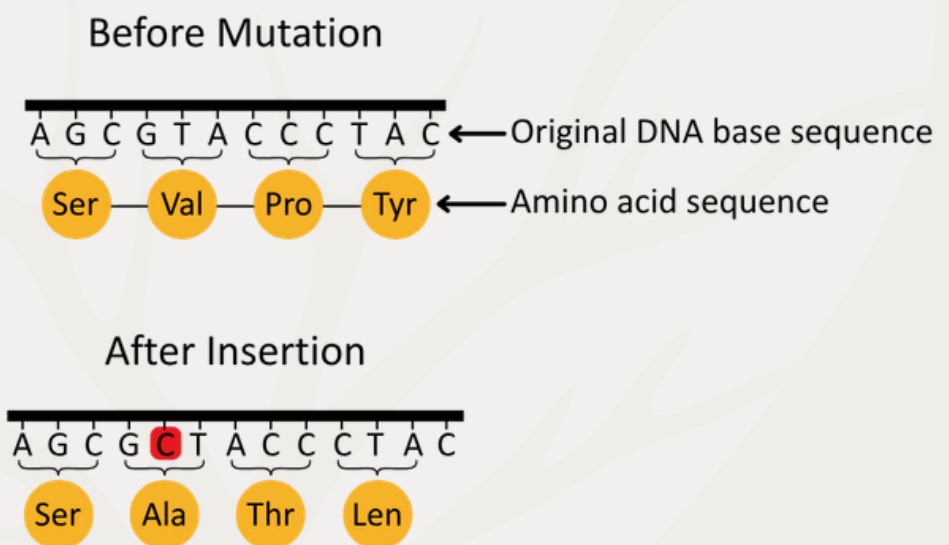


Frameshift

Insertions and **deletions** can cause a **frameshift**.

A frameshift occurs when the **number of bases** inserted or deleted is **not a multiple of three**.

The diagram below **shows** the **effect** of **frameshift** on the **DNA sequence**, and the **polypeptide chain** that it codes for:



It is important to note that **insertions** or **deletions** of **three bases** (or any multiple of three) **do not cause a frameshift**, but instead **add** or **remove whole amino acids** from the protein.

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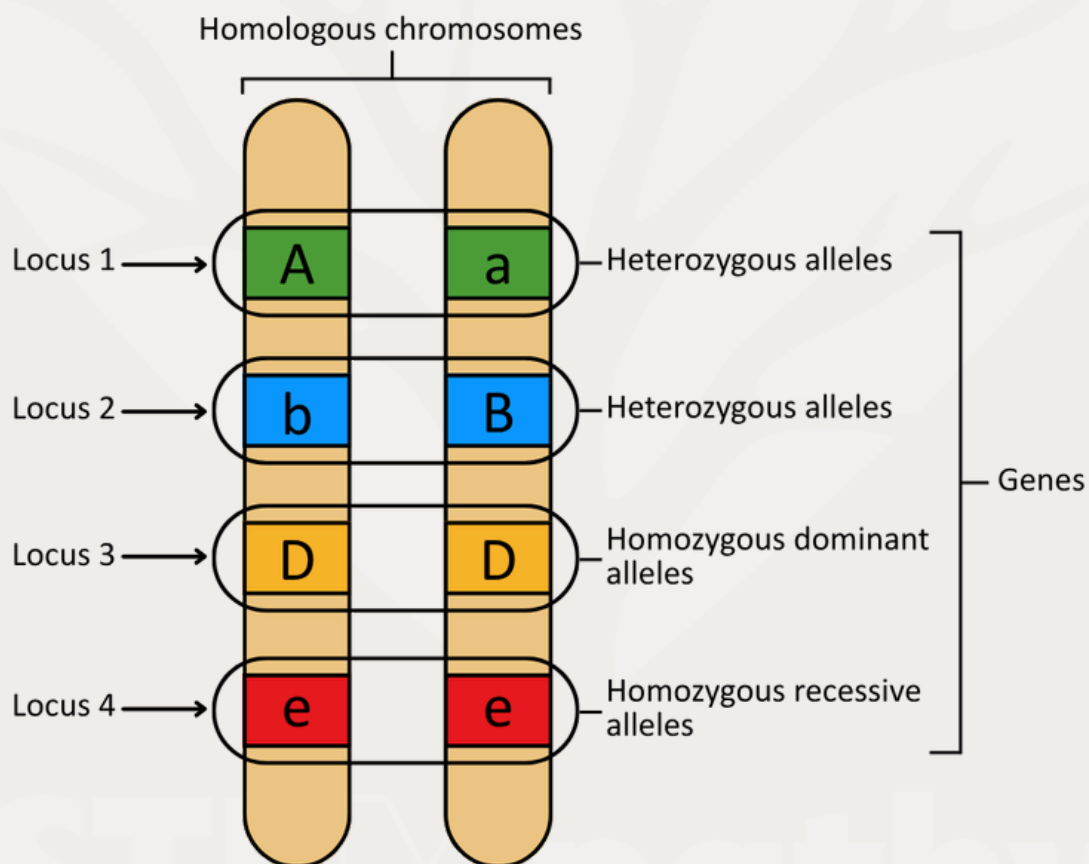
Principles of Genetic Inheritance

The **inheritance** of a genetic trait is **dependent** on the section of DNA that codes for it (the **gene**, or genes), the variants involved (**alleles**), and its position on the chromosome (the **locus**):

- **Genes** are the **sections of DNA** that **code** for **proteins** or **RNA**.
- **Alleles** are slightly **different versions** of a **gene** with slightly **different base sequences**, which code for **different versions** of the **gene's product**.
- **Loci*** are the **gene's positions** on the **chromosomes**.

*'Loci' is plural, 'locus' is singular.

The diagram below **shows** the **relationship** between **genes**, **alleles** and their **loci**:





Alleles: Genotypes and Phenotypes

Diploid organisms have **two copies of each gene**, but the two copies **may not be identical**.

Different **versions of a gene** are known as **alleles**.

The **combination** of **alleles** at each locus **determines** the **characteristics** of an organism.

An individual **organism's combination** of **alleles** is called its **genotype**.

A **genotype** can be either **homozygous** or **heterozygous**:

- **Homozygous** genotypes have the **same alleles** at a particular gene locus on a pair of homologous chromosomes.
- **Heterozygous** genotypes have **different alleles** at a particular gene locus on a pair of homologous chromosomes.

The **characteristics** which a **genotype** gives rise to are known as the **phenotype**.

Phenotype is **determined** by the **interaction between the two alleles*** in an organism's genome.

*As well as any other genes that may also interact with each other.

Alleles are typically **categorised** by their relationship with other alleles, in terms of being either **dominant** or **recessive**:

- A **dominant** allele is **expressed** over another allele.
- A **recessive** allele is **only expressed** when the individual is **homozygous** for it (e.g. aa).

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Module 6: Principles of Mendelian Inheritance



Mendelian inheritance is the system of **inheritance principles** deduced by **Gregor Mendel** from his experiments with the garden pea plant, which **describes how alleles pass from parents to offspring** and produce **predictable phenotypic ratios** in their offspring.

Mendelian Inheritance: Unmodified Phenotypic Ratios

A **cross** between **two heterozygous individuals**, for traits determined by genes whose inheritance is true of these assumptions, will produce **predictable phenotypic ratios**:

- **3:1: Two heterozygous individuals** for a single gene locus (e.g. $Aa \times Aa$).
- **1:1: One heterozygous individual and one homozygous recessive individual**, for a single gene locus (e.g. $Aa \times aa$).
- **9:3:3:1: Two heterozygous individuals for two gene loci** (e.g. $AaBb \times AaBb$).
- **1:1:1:1: One heterozygous individual for both gene loci, and one homozygous recessive individual for both gene loci** (e.g. $AaBb \times aabb$).

If the **ratios** for these crosses **change**, then it is due to a **modifying phenomenon*** which breaks one of the assumptions about how genes and alleles are inherited.

*Typically, gene interactions.

Gene Interactions: Modifying Phenomena

Mechanisms which break these assumptions **produce modified phenotypic ratios** from what is expected, and are collectively known as '**non-Mendelian inheritance**'.

Non-Mendelian inheritance breaks the primary assumptions of Mendel's Laws due to:

- **Multiple alleles:** Although diploid organisms still inherit only two alleles, **more alleles** produce **more genotypes and phenotypes** than allele pairing assumes.
- **Codominance:** Some **alleles** in a heterozygous genotype are **not fully dominant** over each other, and can **both be expressed** to produce a new phenotype.
- **Disjunction:** Meiosis can (rarely) **fail to separate homologous chromosomes** (and the alleles on them) into different gametes.
- **Sex linkage:** Where a gene is located on a sex chromosome, the **pattern of inheritance is modified** by the **offspring's sex** due to their **combination of sex chromosomes**, which breaks the assumption of random fertilisation.
- **Autosomal linkage:** Where **two genes** are located on the **same chromosome**, they are **inherited together** as a single unit rather than assorting independently, unless separated by crossing over during meiosis.
- **Epistasis:** When **one gene masks the expression of another gene**, then the assumption that genes (and the characteristics they code for) are assorted independently is broken.



Module 6: Genetic Diagrams and Punnett Squares



Genetic Diagrams and Punnett Squares

A **genetic diagram** is used to **predict** the **genotypes** and **phenotypes** of the offspring of a cross* between two organisms.

*The breeding of two organisms.

The table below **provides** the **definitions** of the **terms** used in **genetic diagrams**:

Term	Description
Parental phenotype(s)	The observable characteristic(s) of the two parents being crossed.
Parental genotype(s)	The combination of alleles each parent carries at the gene locus (or loci).
Possible gametes	The different allele combinations * each parent can produce in their gametes through meiosis .
F1 genotype(s)	All possible allele combinations * that can result from the fusion of parental gametes at fertilisation.
F1 phenotype(s)	The observable characteristic(s) produced by each possible offspring genotype.
(F1) Phenotypic ratio**	The proportions in which the different offspring phenotypes are expected to appear.

*Allele combinations become relevant when the inheritance of two (or more) genes is being predicted.

**At GCSE, percentages were typically given, but ratios are more appropriate at A level.

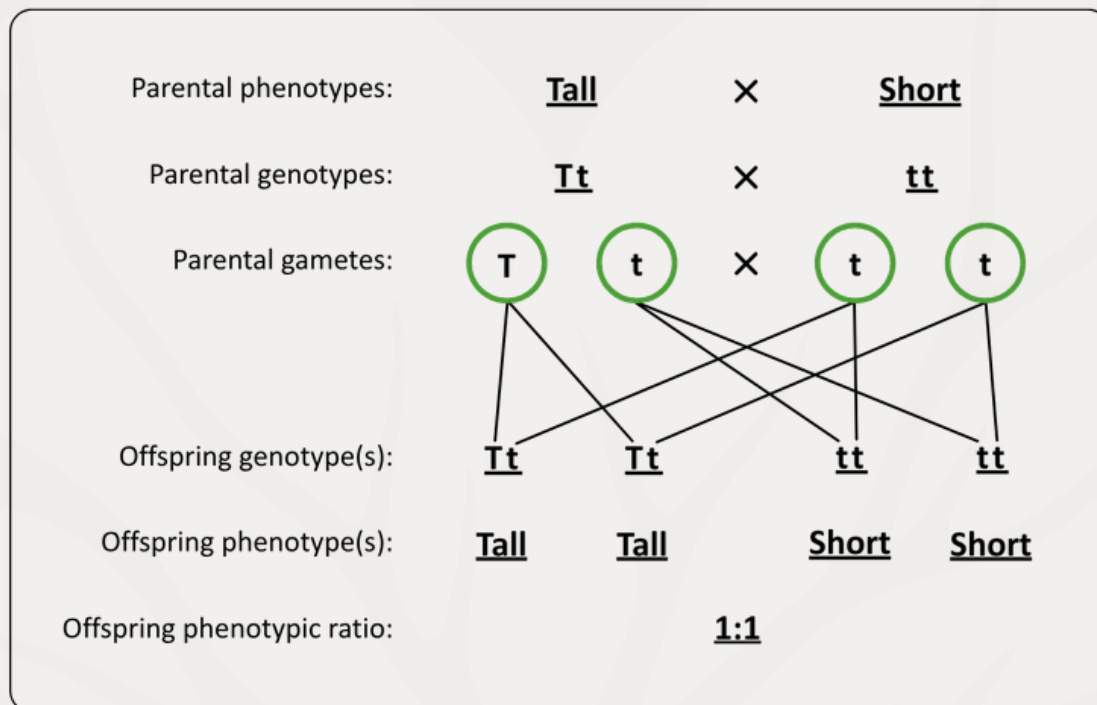
It is important to note that **F1** refers to the **first generation** produced from crossing the parents, so **F2** would refer to the **second generation**.



Module 6: Genetic Diagrams and Punnett Squares



The diagram below **shows** the **layout** of an **example cross** between a tall **heterozygous** pea plant and a short **homozygous** recessive pea plant:



The diagram above **shows** how the **possible combinations of alleles** can be **worked out** by drawing lines between them.

Monohybrid and Dihybrid Crosses

Two types of crosses are commonly investigated with genetic diagrams (and encountered at A level), which depend on whether the inheritance of **one or two characteristics** is being observed.

Investigating the inheritance of **one characteristic** involves a **monohybrid cross**, whilst **two characteristics** involve a **dihybrid cross**:

- **Monohybrid crosses** involve the inheritance of a **single monogenic trait***.
- **Dihybrid crosses** involve the **simultaneous inheritance** of **two monogenic traits**.

*This is the type of cross investigated with (usually) Punnett squares at GCSE, typically with only two alleles involved (one dominant, and one recessive).

Punnett squares are often used in dihybrid crosses to **determine** and show the **possible zygotes** that can be **formed** from gametes.



Module 6: Genetic Diagrams and Punnett Squares



Worked Example

In pea plants, seed shape and seed colour are determined by unlinked genes at different loci:

- Seed shape can be round (**R**) or wrinkled (**r**)
- Seed colour can be yellow (**Y**) or green (**y**)

Two pea plants, which produce round and yellow seeds and are **heterozygous for both gene loci**, are crossed:

P phenotypes: Yellow Round × Yellow Round

P genotypes: YyRr × YyRr

P gametes: YR Yr yR yr × YR Yr yR yr

F₁ genotypes:

	YR	Yr	yR	yr
YR	YYRR	YYRr	YyRR	YyRr
Yr	YYRr	YYrr	YyRr	Yyrr
yR	YyRR	YyRr	yyRR	yyRr
yr	YyRr	Yyrr	yyRr	yyrr

F₁ phenotypes:

- Yellow round: YYRR, YYRr, YyRR, YyRr
- Yellow wrinkled: YYrr, Yyrr
- Green round: yyRR, yyRr
- Green wrinkled: yyrr

F₁ phenotypic ratio: 9:3:3:1

It is important to note that the **9:3:3:1 phenotypic ratio** (typically) produced by two individuals who are heterozygous at both gene loci in a **dihybrid cross** can be used to **infer the parental genotypes** (as being heterozygous) if they are **unknown**.



Module 6: Multiple Alleles



Diploid organisms have **two homologous chromosomes**, which give them **two copies*** of each gene.

*With the **exception of some genes on sex chromosomes**.

When a gene locus has **three or more alleles**, then it is **defined** as having '**multiple alleles**'.

Worked Example

Coat colour in rabbits is determined by a **single gene** with **four alleles**, which produce four distinct coat colours:

- **C** produces an **agouti** coat.
- **C^{ch}** produces a **chinchilla** coat.
- **C^h** produces a **Himalayan** coat (white, with black extremities)
- **c** produces the **albino** coat (no pigment)*

***Albinism**, which is the **absence of pigment**, making an organism appear white, must not be **confused** with a **white phenotype** from the **production of white pigment**.

The **alleles for coat colour** in rabbits have the following **dominance hierarchy**:

- Agouti (**C**) is **dominant to all** other alleles.
- Chinchilla (**C^{ch}**) is **dominant to Himalayan (C^h) and albino (c)**.
- Himalayan (**C^h**) is **dominant to albino (c)**.
- Albino (**c**) is **recessive** to all other alleles.

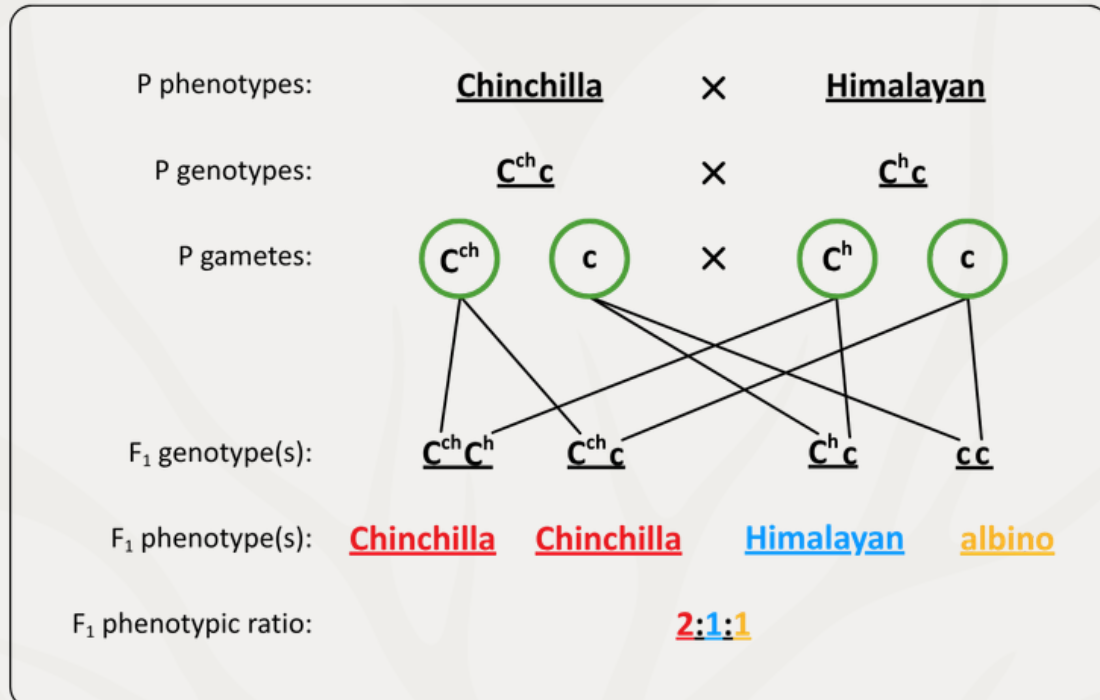
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Module 6: Multiple Alleles



A **heterozygous** chinchilla rabbit ($C^{ch}c$) and a **heterozygous** Himalayan rabbit (C^hc) are crossed:



The example dihybrid cross above demonstrates how a **new** (and third) **phenotype emerges** in the offspring, because the recessive **c** allele is **masked in both heterozygous parents**, but is **expressed** in some offspring when **two recessive alleles combine** during fertilisation to form the offspring's genotype.

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Module 6: Codominance



When **two alleles** at the **same gene locus** on two homologous chromosomes are different, but **neither is dominant over the other**, then **both will be expressed**.

When **both alleles** in a genotype can **express** their own phenotype, then it is known as '**codominance**'.

Worked Example

Coat colour in shorthorn cattle is determined by a **single gene** with **two codominant alleles**:

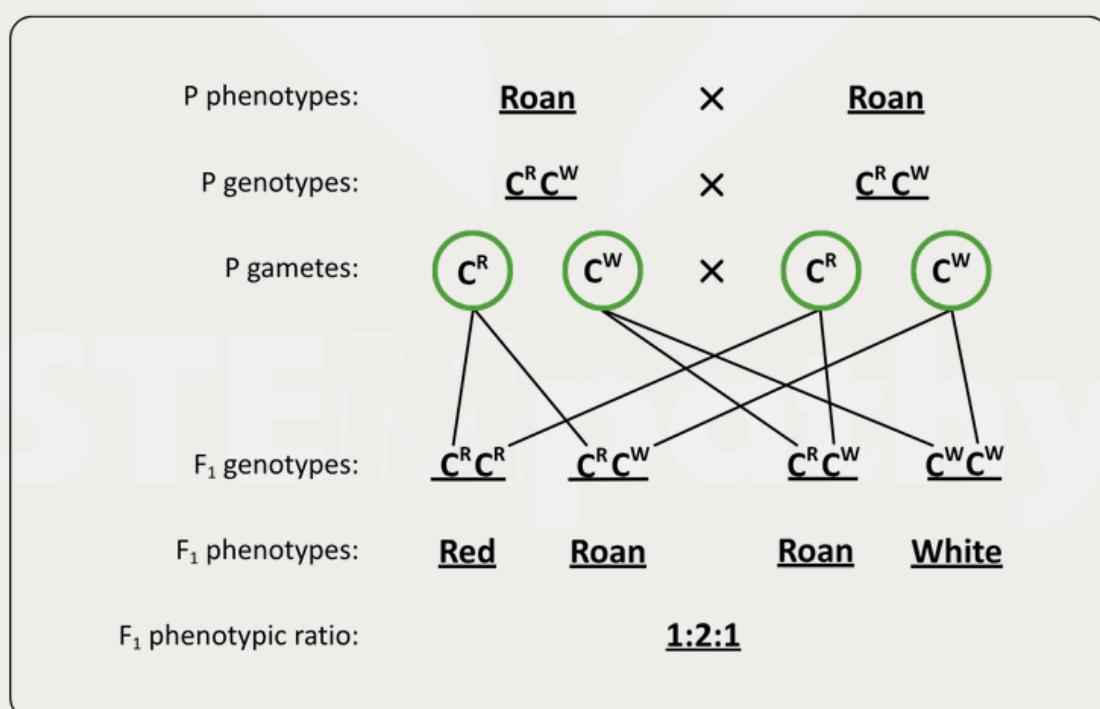
- C^R produces **red hair**.
- C^W produces **white hair**.

The three **possible genotypes** each produce their **own distinct phenotypes**:

- $C^R C^R$ cattle have a **red coat**.
- $C^W C^W$ cattle have a **white coat**.
- $C^R C^W$ cattle have a **roan coat**, with both **red and white hairs** present.

It is important to note that the roan coat can be **mistaken** for an intermediate phenotype produced by incomplete dominance, but is in fact an example of codominance as both alleles are fully expressed, and the visual mixture of red and white hairs gives the illusion of a blended phenotype.

Two roan shorthorn cattle, which are **heterozygous**, are crossed:



Module 6: Autosomal Linkage and Sex Linkage



Diploid organisms have **two types of chromosomes**:

- **Autosomes**: Fully homologous chromosomes with all of the **same gene loci**.
- **Allosomes***: Partially homologous chromosomes, where some gene loci are missing on one type.

*More commonly known as **sex chromosomes**.

Diploid organisms have **two homologous chromosomes*** of each type, which carry many **different genes** at **different loci**.

*With sex chromosomes being the exception.

Genes located on the **same chromosome** are **inherited together**, because the chromosome (not the individual genes) is the unit of transmission during reproduction.

Autosomal Linkage

When two or more genes are located on the same autosome, they are described as being **autosomally linked**.

Worked Example

Flower colour and **pollen grain shape** in sweet pea plants are determined by **two genes** located on the **same chromosome**:

- Locus 1: **P** produces **purple flowers**, **p** produces **red flowers**.
- Locus 2: **L** produces **long pollen grains**, **l** produces **short pollen grains**.

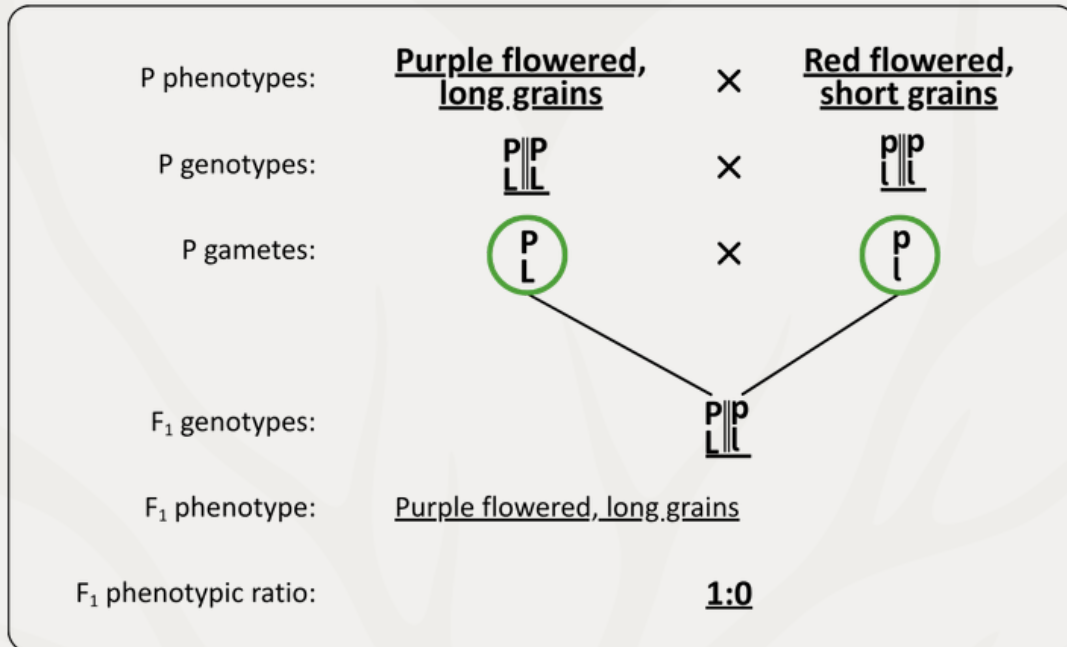
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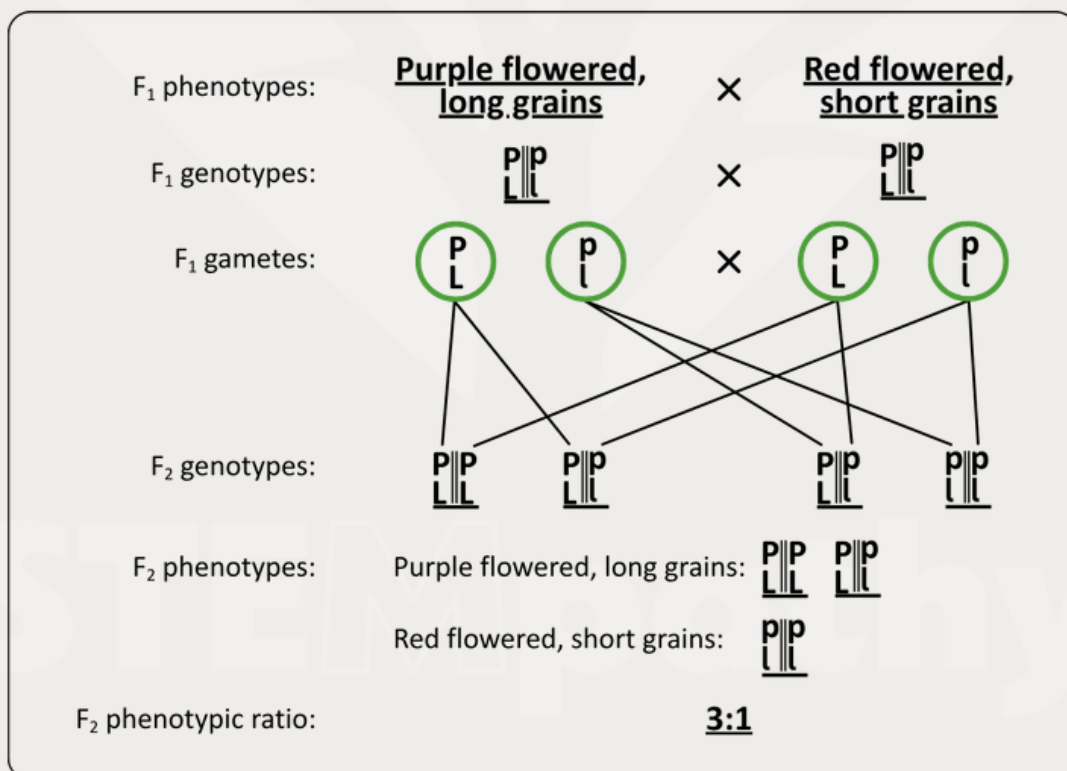
Module 6: Autosomal Linkage and Sex Linkage



A **homozygous** purple-flowered, long-grained plant is crossed with a **homozygous** red-flowered, short-grained plant to produce the F₁ generation:



The F₁ generation is then **interbred** to produce the F₂ generation:



The **3:1 phenotypic ratio** arising from a dihybrid cross between two heterozygous individuals can be **indicative** of **autosomal linkage**.





Sex Linkage

Genes for traits **located** on one of the **sex chromosomes** are described as being **sex linked**.

Sex linkage causes the **pattern of inheritance** for traits to **vary between males and females**.

In **humans**, **sex is determined** by the 23rd pair of chromosomes, composed of **X and Y**.

Most **sex linked traits** are located on the **X chromosome**, and affect the **inheritance patterns** of **females and males** differently:

- **Females** inherit **two copies** of the gene, and so can inherit one recessive allele, and have it masked by a dominant allele.
- **Males** inherit **one copy** of the gene (from their mother), and will express that gene.

Sex-linked genotypes are written with the **alleles** shown as **superscripts on the X chromosome** (e.g. X^H and X^h), to denote that the gene is sex-linked.

Worked Example

Haemophilia A is a **blood-clotting disorder** caused by an abnormal gene on the **X chromosome**, which codes for factor VIII (8), a blood-clotting protein:

- X^H codes for a **normal**, functioning factor VIII.
- X^h codes for **non-functioning** factor VIII.

The **phenotypes** produced **depend** on the **sex** of the individual and the **alleles inherited**:

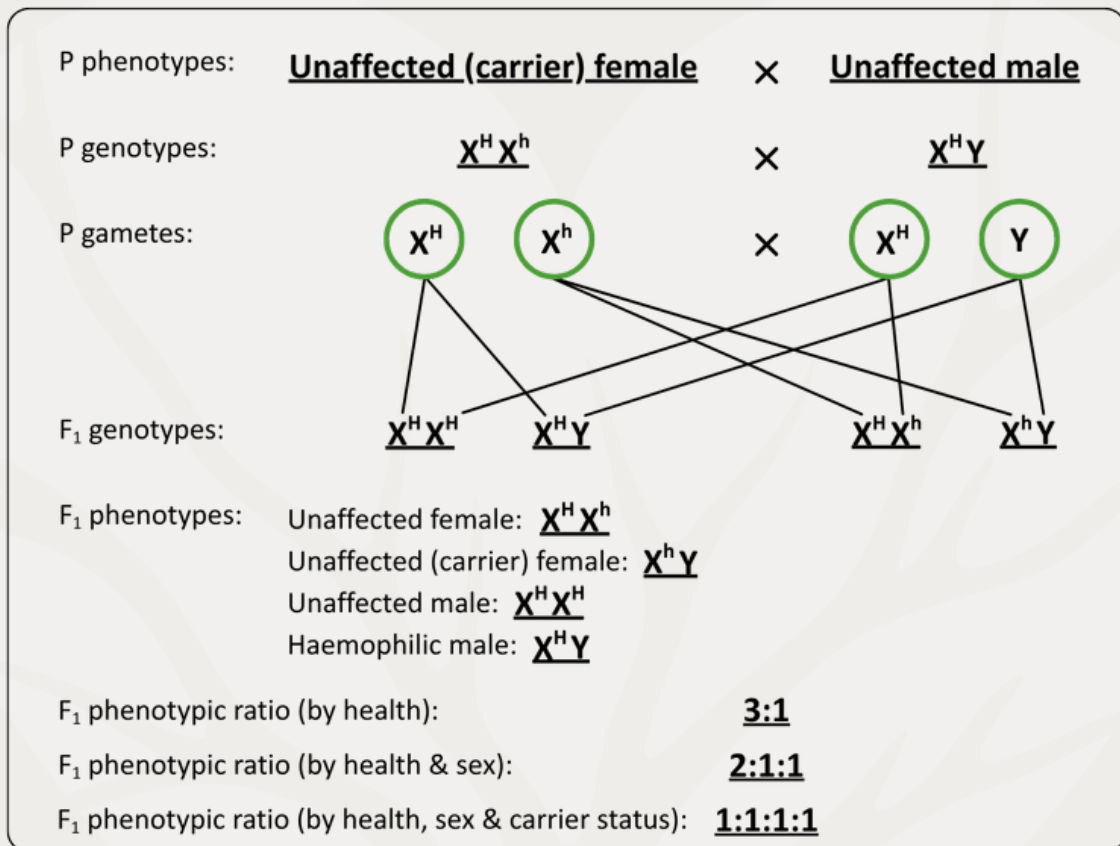
- A **female** who is $X^H X^H$ only produces functional factor 8, so her blood clots **normally**.
- A **female** who is $X^H X^h$ produces enough factor 8 to clot **normally**, but is a **carrier** of the disease.
- A **female** who is $X^h X^h$ has no functioning allele and **suffers** from haemophilia A.
- A **male** who is $X^H Y$ produces enough factor 8 to clot **normally**.
- A **male** who is $X^h Y$ has no functioning allele and **suffers** from haemophilia A.



Module 6: Autosomal Linkage and Sex Linkage



A symptomless **carrier mother** and an **unaffected father** are crossed:



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Module 6: Epistasis



The **interaction** between two genes, where the phenotypic expression of one is modified or masked, is **known as epistasis**.

There are **two types of epistasis**, distinguished by whether the genotype at the epistatic locus, which modifies or masks the hypostatic locus, is **recessive** or **dominant**:

- **Recessive epistasis** is when a **homozygous recessive genotype** at the **epistatic gene** locus **prevents** the **expression** of the **hypostatic gene**; at least one dominant allele at the epistatic gene locus is required for the hypostatic gene locus to be expressed.
- **Dominant epistasis** is when a **dominant allele** at the **epistatic gene** locus **prevents** the **expression** of the **hypostatic gene**; a homozygous recessive genotype at the epistatic gene locus is required for the hypostatic gene to be expressed.

How **epistasis modifies** the **expected phenotype ratios** of a cross between heterozygotes depends on if it is **recessive** or **dominant**:

- **Recessive epistasis** produces a **9:3:4 ratio**.
- **Dominant epistasis** often produces a **13:3** or **12:3:1** ratio.

The exact phenotypic ratio from any epistatic interaction will depend on the underlying mechanisms and the phenotypes involved.

The **mechanism** by which the **epistatic gene** can mask or modify the expression of the hypostatic gene is sometimes described as **antagonistic** or **complementary**:

- **Antagonistic** gene interaction is where the epistatic gene actively **prevents the hypostatic gene's** phenotype from being **expressed**.
- **Complementary** gene interaction occurs when **both genes' protein products are required** for the phenotype to be expressed, so the absence of one gene's product masks the phenotype of the other.

Worked Example: Complementary Recessive Epistasis

Flower colour in sweet peas is produced in a **multi-step reaction** catalysed by two enzymes, each expressed at separate gene loci.

The **first gene locus** codes for an **enzyme** which converts a colourless precursor molecule into a colourless intermediate product; the **recessive allele** codes for a **non-functional enzyme**.

The **second gene locus** codes for an **enzyme** which converts the colourless intermediate product into a **coloured pigment**.



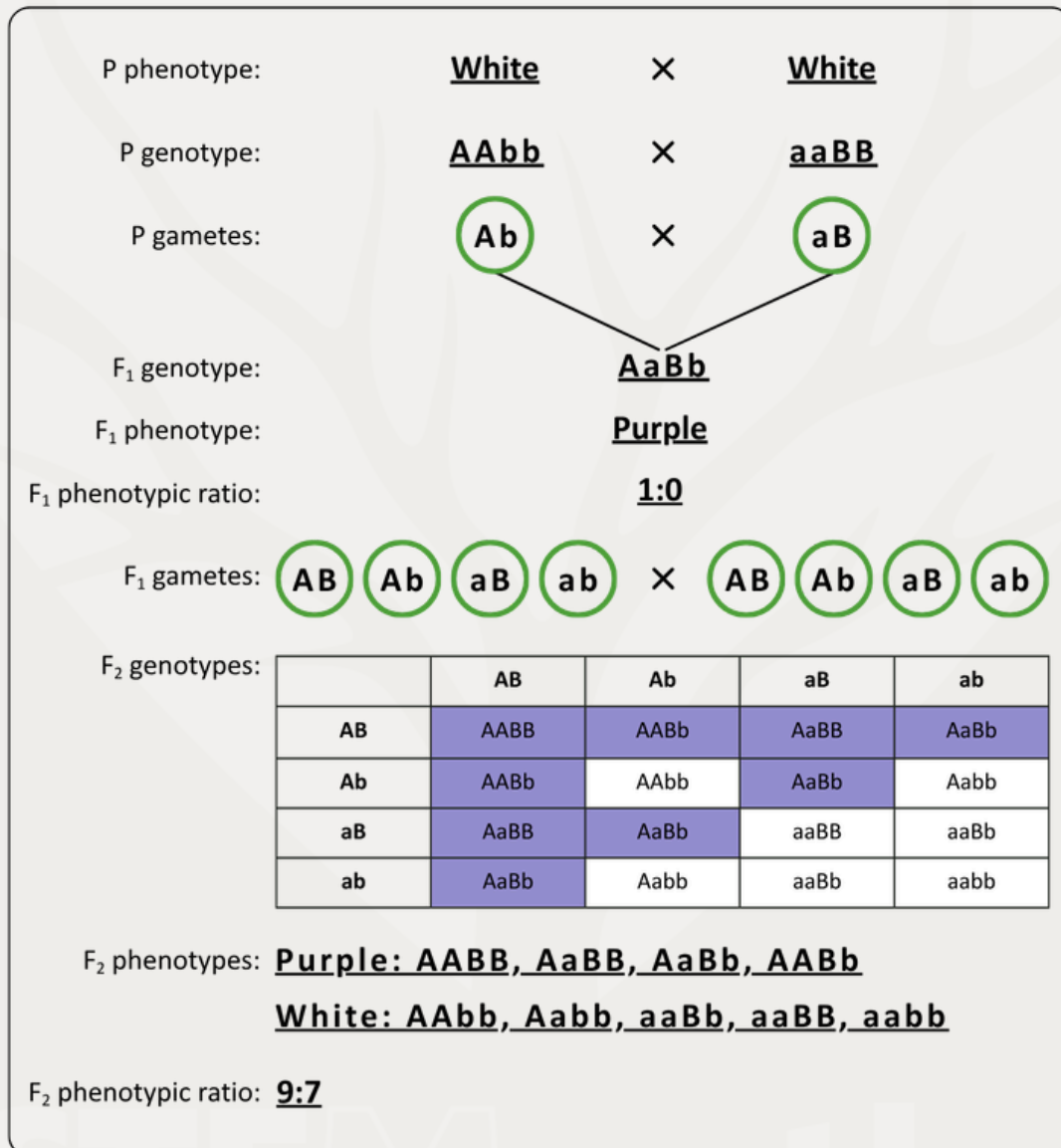
Module 6: Epistasis



The genes involved are located on two different chromosomes:

- **A/a** is the **first gene locus**, where **aa** prevents pigment production.
- **B/b** is the **second gene locus**, where **B** produces **purple**, and **b** produces **white**.

A pure-breeding **white-flowered** variety (**AAbb**) is crossed with a pure-breeding **white-flowered** variety (**aaBB**), and the F₁ generation is interbred to produce the F₂ generation:



The homozygous genotype (**aa**) at the epistatic gene locus masks the **B** gene, so any plant that is **aa** at the epistatic locus is white, regardless of the genotype at the second locus. This modifies the expected phenotypic ratio of **9:3:3:1** to **9:7**.



Module 6: Continuous and Discontinuous Variation



Characteristics can demonstrate either **continuous** or **discontinuous variation**:

- **Continuous variation** is when individual characteristics range across **many intermediate phenotype values**, with **no natural divisions**.
- **Discontinuous variation** is when individual characteristics can be organised into **separate, non-overlapping phenotypes**, with **no intermediates**.

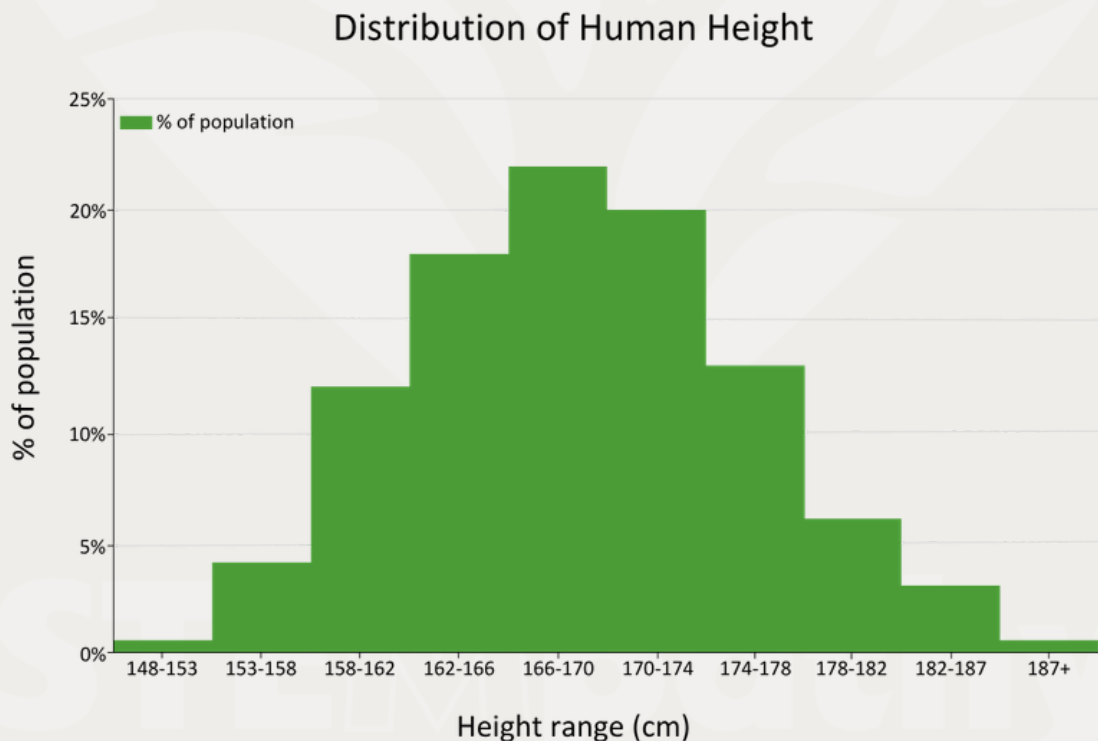
Continuous and discontinuous variation is **determined by how many gene loci control a characteristic's phenotype**.

Continuous Variation

Characteristics that show **continuous variation** are typically **polygenic**, with **many alleles** each contributing a small amount to the phenotype through an **additive effect**.

The **greater the number of gene loci** involved, the **wider range of phenotypes** produced.

The diagram below **shows the distribution of adult height** in a sample **population**, as an example of **continuous variation**:



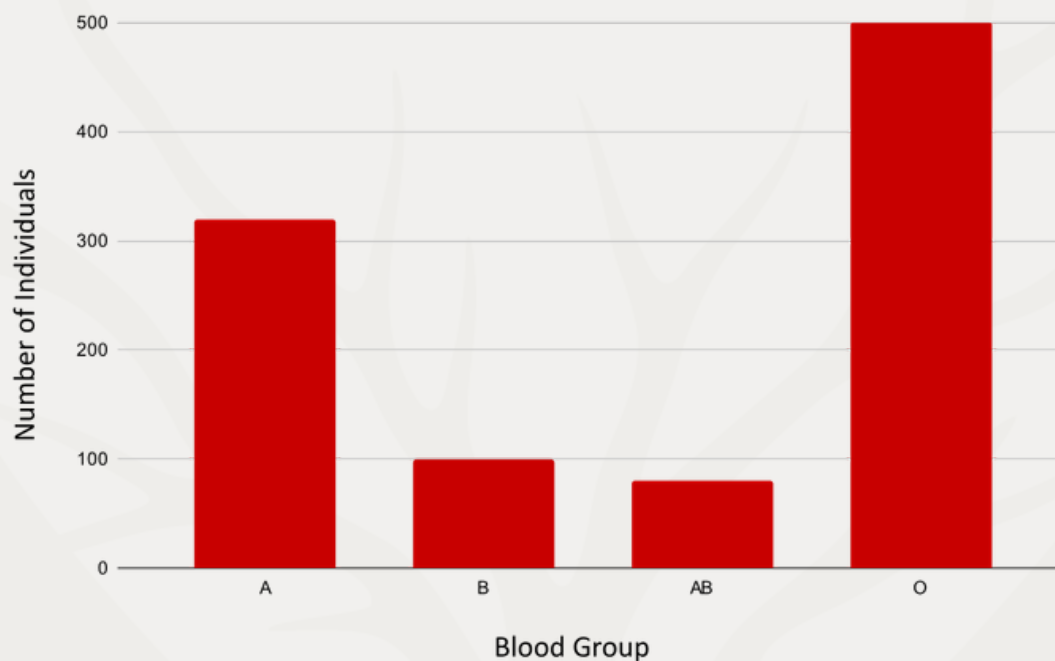
Module 6: Continuous and Discontinuous Variation



Discontinuous Variation

Characteristics that show **discontinuous variation** are typically **monogenic**, with alleles having a large or all-or-nothing effect on the phenotype.

The diagram below **shows** the **distribution** of **ABO blood group** in a sample **population**, as an example of **discontinuous variation**:



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Module 6: Chi-squared Test



The **chi-squared (χ^2) test** is a statistical test used to **determine** whether the **difference between observed and expected results** is statistically significant, or whether it is **due to chance**.

Calculating the **chi-squared value** from the observed results and the expected results allows for the difference between them to be determined as being either statistically significant or due to chance.

A **statistically significant** result has a high chance of being caused by an underlying mechanism (and **not due to random chance**), whilst a result that is **not significant** has a high chance of being **due to random chance** (and not due to an underlying mechanism).

The **chi-squared test tests the null hypothesis**, and accepts it if there is no significant difference, and **rejects it if there is a significant difference**. The alternative hypothesis is rejected in the former outcome and accepted in the latter outcome.

The Chi-Squared Formula

The **value of chi-squared (χ^2)** is **calculated** using the **formula**:

$$\chi^2 = \sum (O - E)^2 / E$$

The **formula** is **also shown** like this:

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Where:

- **O** = the **observed value** in each category
- **E** = the **expected value** in each category
- **Σ** = the **sum of**
- **χ^2** = the **chi-squared value**

It is useful to know that the smaller the value of χ^2 , the better the fit between the observed and expected data.



Module 6: Chi-squared Test



Worked Example

288 F₂ generation plants were grown from a **dihybrid cross** between **two heterozygous individuals**, investigating the inheritance of **seed colour** and **seed shape**.

The **predicted ratio** is **9:3:3:1**, so the **expected values** are:

- **9/16** of 288 = **162 yellow and round**
- **3/16** of 288 = **54 green and round**
- **3/16** of 288 = **54 yellow and wrinkled**
- **1/16** of 288 = **18 green and wrinkled**

χ^2 is **calculated** using the **formula**:

$$\chi^2 = \sum (O - E)^2 / E$$

For convenience, the **calculation** is typically **processed** in the following **format**:

Phenotype	Observed (O)	Expected (E)	O - E	(O - E) ²	(O - E) ² / E
Yellow, round	169	162	7	49	0.30
Green, round	54	54	0	0	0.00
Yellow, wrinkled	51	54	-3	9	0.17
Green, wrinkled	14	18	-4	16	0.88
				Sum (Σ)	1.35

The **calculated value of χ^2** is **1.35**.

The **degrees of freedom** are required to **read the correct critical value** from a **chi-squared probability table**.

There are **4 phenotype categories**, so the **degrees of freedom** are:

$$df = 4 - 1$$

$$df = 3.$$



Module 6: Chi-squared Test



A **significance level** of **0.05** is expected as standard unless otherwise stated.

In this case, the **significance level** at 3 degrees of freedom for $p = 0.05$ is **7.82**.

Because **1.35 is less than the critical value of 7.82**, the **difference** between observed and expected results is **not statistically significant**. The **null hypothesis is accepted**, and the **difference** between the observed counts and the predicted 9:3:3:1 ratio is attributed to chance. There is a **greater than 5% probability that the difference is due to chance**.

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Evolution is a **change** in the characteristics of a **species over time**.

Evolution occurs when the **frequencies of alleles** in a **population's gene pool** change over time.

When the **allele frequencies** in a population **change significantly** from those of the ancestral population so that **reproduction no longer produces fertile offspring**, they are considered to have evolved into a **new species**.

The evolution of a new species is known as **speciation**.

The Role of Natural Selection

Natural selection is the **process** by which organisms with advantageous characteristics are **more likely to survive and reproduce**, passing on their **alleles** for these advantageous traits to the **next generation**.

Types of natural selection

The 3 primary **types of natural selection** are **directional selection**, **disruptive selection** and **stabilising selection**:

- **Directional selection** favours phenotypes at **one extreme**, shifting the population mean in that direction.
- **Disruptive selection*** favours **both extremes** simultaneously, **reducing** the frequency of **intermediate phenotypes**.
- **Stabilising selection** favours **intermediate phenotypes** and selects **against extremes**, maintaining the population mean.

*Disruptive selection, unlike directional selection and stabilising selection, is **not** on the OCR A Level Biology specification; **however**, its effect has appeared in official OCR A Level Biology question papers and been named in the official mark scheme.

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Random Mechanisms

Genetic drift is the **random change in allele frequency** caused by chance events that **prevent** organisms from **passing on their alleles**.

Genetic drift can be **caused** by the **following events**:

- **Chance events** like extreme weather (e.g. lightning strikes) or accidents (e.g. being crushed in a landslide).
- **Random reproduction success** (e.g. seeds land on bare rock).
- **Genetic bottleneck events** (a catastrophic event drastically reduces the population, greatly reducing the genetic diversity in the surviving population).
- **Founder effect** (a small group colonises a new area, carrying only a random subset of alleles).

Speciation

Speciation occurs when a population becomes genetically distinct enough from its ancestral population that it can **no longer interbreed to produce fertile offspring**.

Speciation is caused by evolution occurring within an isolated population, which leads to **changes in allele frequencies**.

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Module 6: Geographical and Reproductive Isolation



Isolating Mechanisms

Factors that **prevent gene flow** between populations are called **isolating mechanisms**.

Isolating mechanisms allow **allele frequencies** in separate populations to **diverge** over time and (potentially) give rise to a new species.

The **isolating mechanisms** which can give rise to a new species **include geographical and reproductive isolation**:

- **Geographical isolation** prevents individuals from reproducing due to a **physical barrier** between populations, resulting in **allopatric speciation**.
- **Reproductive isolation** prevents individuals in the same geographic area from interbreeding due to **biological or behavioural differences**, resulting in **sympatric speciation**.

If the two **populations experience different selection pressures**, then the **allele frequencies** within their gene pools will **change over generations** and may **evolve into separate species**.

Allopatric speciation is when **two new species evolve** from one original species due to **geographical isolation**.

Sympatric speciation is when **two new species evolve** from one original species due to **reproductive isolation**.

Reproductive isolation can arise through several **distinct mechanisms**:

- **Temporal isolation** occurs when populations **reproduce at different times** of day or year, preventing individuals from the two groups from meeting to mate.
- **Chromosome number changes** prevent gene flow when a change in chromosome number means **gamete fusion is prevented**, **zygotes are not viable**, or **hybrid offspring** have an odd number of chromosomes, which makes them **infertile**.
- **Behavioural isolation** occurs when **divergence in courtship displays, mating calls** or other behaviours means individuals from the two groups **do not recognise one another as suitable mates**.
- **Structural isolation** occurs when **differences in the morphology** of animal genitalia or plant flower structure **prevent successful mating or pollination**.



Module 6: Hardy-Weinberg



The **proportion of genotypes** in a population can be **calculated** using the **Hardy-Weinberg equation**.

The **Hardy-Weinberg** principle **predicts** expected **genotype frequencies** within a **non-evolving population** (allele frequencies do not change across generations).

The Hardy-Weinberg equation is:

$$p + q = 1$$

$$p^2 + 2pq + q^2 = 1$$

Where:

- **p** = frequency of the dominant allele (A)
- **q** = frequency of the recessive allele (a)
- **p²** = homozygous dominant (AA)
- **2pq** = heterozygous (Aa)
- **q²** = homozygous recessive (aa)

Because $p + q = 1$, knowing one allele, or genotype, frequency allows the rest to be calculated.

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Module 6: Artificial Selection



Artificial selection is carried out in order to **enhance the desirable characteristics** of organisms.

The Process of Artificial Selection

The **process of artificial selection** can be simplified into the **following stages**:

1. **Individuals** within the population who have the **best version** of the desired **characteristic** are **identified** and selected.
2. **Selected individuals are crossed** (bred) with each other to produce offspring.
3. **Offspring** with the **best version** of the desired characteristic are **identified** and selected.
4. **Selected individuals are crossed** (bred) with each other to produce offspring.
5. The process is **repeated over many generations**.

The process of artificial selection **utilises a small breeding population**, which leads to a significant **reduction in genetic diversity**.

Conserving Genetic Variation

Artificial selection reduces genetic variation over successive generations, so breeders must take active steps to **conserve and maintain the genetic diversity** of the population in order to **maintain its adaptive capacity and overall health**.

Genetic variation within a breeding population can be **maintained** through **management or preservation**:

- **Management** of selective breeding programs **minimises the chances of inbreeding and genetic drift**.
 - **Preserving** genetic material allows for **alleles to be stored** within gene banks and other repositories so that they can be introduced into the population as and when needed.
-

Ethical Considerations of Artificial Selection

The **effects of artificial selection** on organisms that undergo artificial selection raise **ethical concerns** relating to their **genetic diversity** and **survival**:

- **Genetic diversity**: Breeding from a limited number of individuals reduces their genetic variation, **increasing susceptibility to disease** and **reducing adaptability**.
- **Survival**: Selectively bred organisms may have a **reduced ability to defend themselves** and a **reduced tolerance to environmental conditions**.





DNA sequencing is the process by which the **nucleotide base sequence of a gene*** is **determined** so that it can be read.

*Or any other section of DNA.

Types of DNA Sequencing

The **principles** of DNA sequencing are demonstrated in **Sanger sequencing** and in **high-throughput sequencing**:

- **Sanger sequencing** was effective, but **slow and labour-intensive**.
- **High-throughput sequencing** refers to many modern approaches which improve upon Sanger sequencing with chemical and technical methods that allow for DNA to be sequenced **faster and more cheaply** with the use of computers.

Sanger Sequencing

Sanger sequencing utilises many single-stranded DNA copies of the section of DNA being sequenced.

The **single-stranded DNA copies** are used as templates for **DNA polymerase** to carry out **DNA replication** (turning the single-strands into double-strands), but the experiment is set up so that DNA replication is **terminated randomly**, resulting in double-stranded DNA molecules of **varying lengths**.

Gel electrophoresis is used to **separate** the **DNA fragments by length** after they are produced.

The **terminal** (end) **nucleotide** on the DNA fragments is **identified by its marker**, and its relative position to the other fragment's markers is noted to **work out the sequence of nucleotide bases** in the DNA fragment.

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The **process of Sanger sequencing** can be **summarised** as:

1. The **DNA** being sequenced is **amplified by PCR***, and **heated to 94–96 °C** to **break the hydrogen bonds** between the DNA strands to **produce single-stranded DNA****.
2. A **primer** is added to the DNA that binds to the template strands, which **allows DNA polymerase to bind** and **add nucleotides** to the 3' end of the strand being synthesised.
3. The DNA is divided between **4 separate reaction vessels** containing a high proportion of **unmodified nucleotides** and a small proportion of **one of the 4 types of modified nucleotides** in each.
4. **DNA polymerase** is added, **synthesising** many complementary strands using the free activated nucleotides in the **5' → 3' direction**.
5. Whenever a **modified nucleotide** is added onto a DNA strand, DNA polymerase **stops DNA synthesis**.
6. Many **fragments of different lengths are synthesised** in each reaction vessel, each ending with the specific modified nucleotide in its respective reaction vessel.
7. Once no more reactions are occurring, the **fragments are separated by gel electrophoresis**.
8. The **base sequence is determined** by **identifying** the fluorescent/**radioactive label** of each fragment from **smallest to largest**.

*The polymerase chain reaction is studied in greater detail later on.

Breaking the hydrogen bonds between complementary bases with heat is known as 'denaturing**' the DNA.

High-Throughput Sequencing

High-throughput sequencing refers to a range of modern DNA sequencing technologies that allow DNA to be **sequenced faster**, more **cheaply**, and on a much **larger scale** than Sanger sequencing.

It is important to note that you are **not** expected to know the details of the techniques relating to high-throughput sequencing (such as pyrosequencing). However, you should **be aware** of them as examples of techniques that have improved upon Sanger sequencing.



Module 6: DNA Sequencing



The table below **outlines** the **key developments** that have **increased** the **speed** and **reduced the cost** of **DNA sequencing**:

Development	Improvement
Fluorescent labelling	Eliminating manual reading of DNA sequences from gel electrophoresis, enabling automated laser-scanning reading of the DNA sequence.
Pyrosequencing	Enabled DNA sequences to be determined in real-time as computers detect the light signals produced as nucleotides are added .
Shotgun sequencing	Enabled the simultaneous DNA sequencing of an entire section of DNA, rather than sequencing it from beginning to end.
Massive parallel sequencing	Increased DNA sequencing to a scale that made whole genome sequencing fast and affordable .

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Module 6: The Polymerase Chain Reaction



The Polymerase Chain Reaction (PCR)

Gene sequencing uses many identical copies of a section of DNA in order to determine the order of bases.

PCR (polymerase chain reaction) is a technique that **replicates DNA rapidly** using the same principles as biological DNA replication.

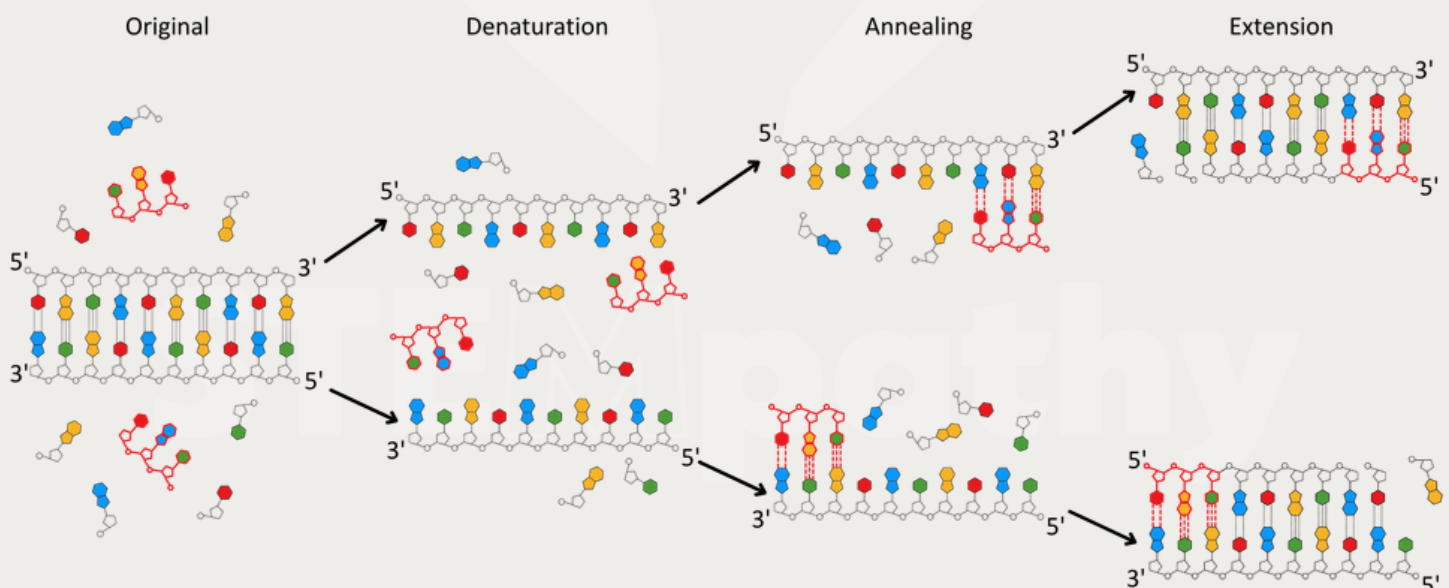
PCR consists of **3** distinct **phases** known as **denaturation**, **annealing**, and **extension**:

1. **Denaturation heats** the DNA to **~95 °C*** to **break the hydrogen bonds** between the two strands, **producing single-stranded DNA**.
2. **Annealing cools** the reaction down to **~68 °C*** to allow **primers to anneal** (bind) to the single-stranded DNA**.
3. **Extension heats** the reaction up to **~72 °C*** to allow **DNA polymerase** to synthesise a complementary strand by **adding free activated nucleotides in the 5' to 3' direction** from the primer.

*Temperatures provided beyond OCR A level Biology are typically ranges, and can vary from the approximate values commonly cited in official OCR exam questions and mark schemes.

When two strands of nucleic acid join together via hydrogen bonds, it is known as **annealing.

The diagram below **shows** the phases of **denaturation**, **annealing** and **extension** in **PCR**:



The diagram above **shows** how **PCR doubles the number of DNA strands** present at the start of the cycle.



Module 6: Electrophoresis



Electrophoresis is a technique used to **separate DNA fragments**, RNA, or proteins (typically) **by size** using an electrical field.

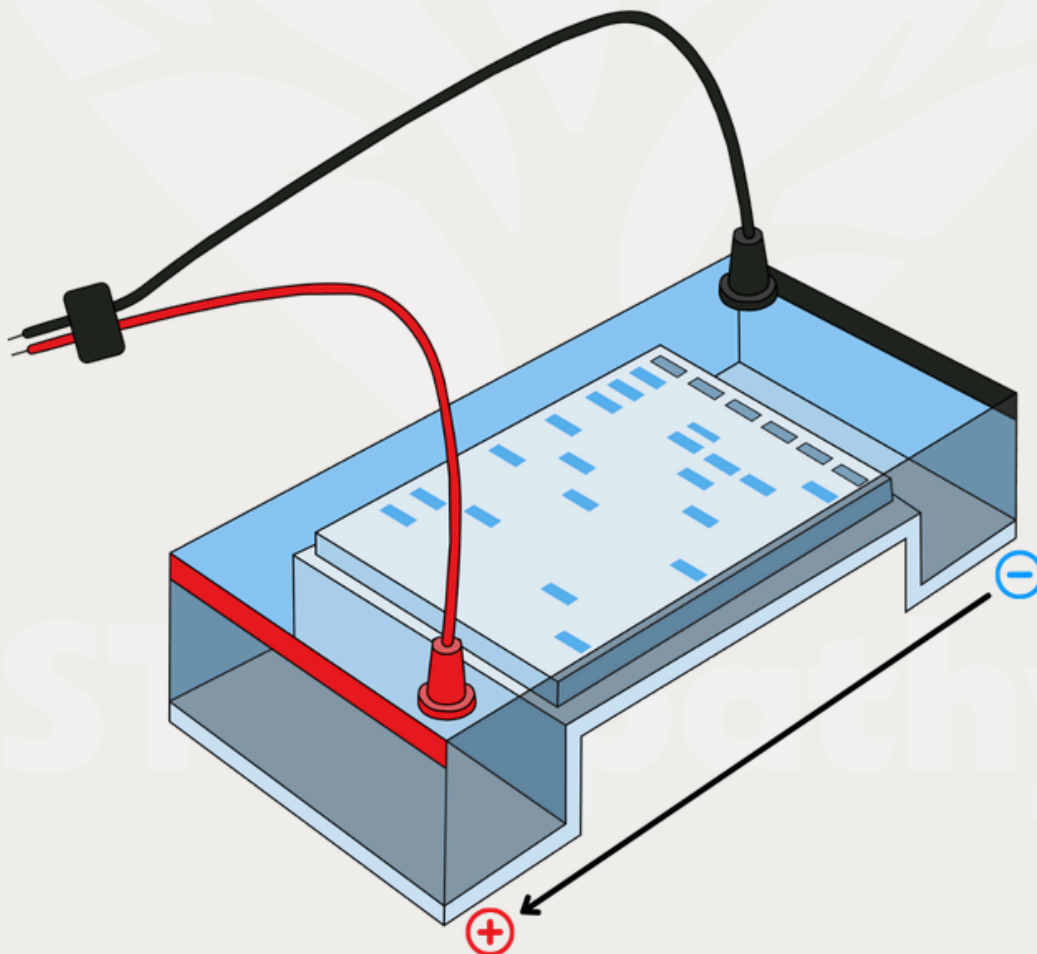
Electrophoresis generates an **electric current** that causes the **negatively charged molecules to move** through the matrix (its structure) of an agarose gel **towards the anode** (positive electrode).

The degree of **separation between fragments** is determined primarily by their **size**:

- **Smaller fragments** experience **less resistance** moving **through the agarose gel** matrix, so they **move faster**, travelling a **greater distance** during electrophoresis.
- **Larger fragments** experience **more resistance** moving **through the agarose gel** matrix, so they move **more slowly**, travelling a **shorter distance** during electrophoresis.

Gel electrophoresis is carried out inside a **gel electrophoresis tank**.

The diagram below **shows a gel electrophoresis tank** with the positions of **DNA bands** made **visible** towards the **end of the run**:



Module 6: Electrophoresis



The table below **outlines examples** for **using gel electrophoresis** on different **molecules**:

Molecule separated	Examples
DNA fragments	- Identifying base sequences in Sanger sequencing. - DNA profiling. - Assessing restriction enzyme digestion in genetic engineering.
RNA	- RNA profiling. - Analysing gene expression via mRNA abundance. - RNA virus identification.
Proteins	- Analysing haemoglobin types to diagnose conditions (e.g. sickle cell anaemia). - Checking protein purity (e.g. food products).

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Module 6: DNA Profiling



DNA profiling* is a technique that produces a **banding pattern from DNA** fragments of the individual's genome known as a **DNA profile****.

*Also known as genetic fingerprinting.

**Also known as a genetic fingerprint.

DNA Profiling: Method

DNA profiling uses **PCR** to amplify a sample of DNA, and **gel electrophoresis** to separate out the STRs based on their size.

The **process** of **DNA profiling** can be **summarised** as:

1. A **DNA sample is obtained** from the individual (e.g. mouth swab, blood).
2. If the sample is small, the **DNA is amplified by PCR** to produce sufficient quantities.
3. The **DNA is digested with restriction enzymes**, which cut it at specific recognition sites* into **fragments** that **vary in length** between individuals.
4. The **fragments are separated by gel electrophoresis** according to their length, producing a pattern of bands.
5. The agarose gel is **stained** to make the **bands of DNA visible**.
6. The **banding patterns** of the samples are **compared** to identify matching bands.

*Also known as **recognition sequences** in reference to the DNA sequence that the **restriction enzyme binds** to.

Uses of DNA Profiling

DNA profiling is used in **forensic science**, **determining relatedness**, and analysing the **risk of disease**:

- **Forensic science** uses DNA profiles to determine if an individual is a **match** for a biological **sample** obtained from a **crime scene**.
- **Determining relatedness** is when the DNA profiles of individuals are used to establish if they are **biologically related** (e.g. paternity testing).
- **Analysis of disease risk** may involve identifying **DNA sequences, mutations, or STRs** linked with **disease-associated alleles**.



Module 6: Bioinformatics and Computational Biology



Two interdisciplinary fields have developed to enable **scientists to practically use** the huge quantities of **data** being generated by **DNA sequencing**, known as **bioinformatics** and **computational biology**:

- **Bioinformatics** is the use of computers to **organise, retrieve and store data**.
- **Computational biology** is the use of computers to **analyse and interpret biological data**.

Bioinformatics

DNA sequencing **data** is stored in **searchable databases** in a **standardised format**, allowing for universal understanding for researchers who are accessing it across the world.

Data generated from DNA sequencing and **stored in databases** includes:

- DNA and amino acid sequences.
- Protein structures.
- Metabolic pathways.

Computational Biology

Computational biology involves the effective **analysis and interpretation** of the **data** stored by bioinformatics.

Scientists can **research and utilise** the information stored in databases including:

- **Identifying patterns, similarities and differences between DNA sequences and organisms' genomes** so that comparisons can be made.
- **Predict the amino acid sequence of a protein** from a gene's base sequence and use this information to **model its three-dimensional structure**.
- **Design new proteins and metabolic pathways**, and determine the needed DNA sequences an organism would need to produce them in protein synthesis (synthetic biology).

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Module 6: Genetic Modification



Genetic modification is the intentional **modification** of an **organism's genome** using **genetic engineering**.

Genetic Engineering

Genetic engineering refers to the **techniques and tools** used to **change an organism's DNA**.

Traditional approaches to genetic engineering involve the **isolation of a desired gene** and its **incorporation into a vector** (e.g. a plasmid) using restriction enzymes.

The **process of forming a recombinant DNA plasmid** can be simplified into the **following stages**:

1. The **desired gene** and the **plasmid** are **cut** with the **same restriction enzyme**, producing **complementary sticky ends**.
2. The cut **gene** and opened **plasmid** are mixed, and their **sticky ends pair up**, held **together** by **hydrogen bonds**.
3. **DNA ligase** joins the **gene with the plasmid** by **forming phosphodiester bonds**, producing a recombinant plasmid.

Transformation of the host cell involves getting the desired **gene into the target cell**. The table below **outlines** some of the **techniques** used to **introduce the recombinant DNA or its vector** into the **target cell**:

Technique	Description
Agrobacterium tumefaciens	This bacterium naturally transfers part of its plasmid into plant cells and is used as a vector to introduce genes into plant cells.
Electroporation	A high-voltage pulse is applied to the target cells to create temporary pores in the cell surface membrane through which DNA can enter .
Transduction*	A bacteriophage** is used to deliver the DNA into the host cell.

*The official OCR A Level Biology textbook refers to the use of bacteriophages as an example of 'transfection'. Historically, 'transfection' **was** used to describe using bacteriophages to deliver recombinant DNA into bacteria. However, contemporarily this is known as 'transduction', whilst 'transfection' refers to the use of chemical or physical methods (e.g. electroporation) to introduce non-viral DNA or RNA into eukaryotic cells.

**A virus that infects bacteria.





Gene therapy is the use of genetic engineering to **treat genetic disorders** by **correcting, replacing, or modifying faulty genes**.

Techniques used in **gene therapy** involve:

- **Restoring gene function: Replacing or correcting a defective gene** enables a functional or absent protein to be made (e.g. cystic fibrosis).
- **Reducing or eliminating harmful gene activity: Disabling, suppressing, or silencing a faulty gene** prevents the production of a harmful protein (e.g. Huntington's disease).
- **Giving cells a new therapeutic function: Adding a new gene** gives a target cell a new function (e.g. T-cells recognising cancers).

Gene therapy can be **categorised** into **two types**, depending on the **type of cell** that is modified:

- **Somatic cell** gene therapy, which **modifies** the **body cells** of the patient, and is not inheritable.
- **Germline* cell** gene therapy, which **modifies** the **gametes or a fertilised egg**, and is inheritable.

*Germline therapy is predominantly written as 'germ line' in the official OCR A Level Biology textbook, and appears in this form as well as 'germ-line' in official exam questions and mark schemes. 'Germline' is the scientifically accepted form, but it will not matter for marking which way it is written.

Ethical Issues in Gene Therapy

The table below **outlines** some of the **ethical issues** associated with **somatic cell gene therapy**:

Ethical issue	Explanation
High cost	Treatments are extremely expensive, so access may be limited to wealthier patients or healthcare systems.
Long-term effects	Many treatments are new, so long-term safety and efficacy may not be fully understood .
Therapeutic benefit	Can treat or reduce symptoms of genetic disorders, improving the quality of life.



Module 6: Gene Therapy



The table below **outlines** some of the **ethical issues** associated with **germline cell gene therapy**:

Ethical issue	Explanation
Heritable genetic modification	Genetic modifications are inheritable: - Elimination of health disorders in potential children. - May create unforeseen mutations. - Unknown long-term safety and consequences for offspring and the future population's gene pool.
Lack of consent from future generations	Offspring of patients cannot give consent to the genetic modifications they will inherit.
Unequal access	Gene therapy is expensive, creating inequality between socioeconomic groups and countries.

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Genetic Modification of Animals: Ethical Issues

The table below **outlines** some of the **benefits and risks** of using **genetically modified animals**:

Benefits	Risks
Animals can be modified so their organs are less likely to be rejected when transplanted into humans, increasing the supply of potential donor organs .	Inserting human genes into animals raises concerns about the long-term effects of transferring genes between species .
Animals can be modified to produce human pharmaceutical proteins in their milk (e.g. proteins too complex for bacteria to synthesise).	Using animals for human uses raises ethical objections .

The **ethical issues** relating to the **genetic manipulation of humans** are described in the **Gene Therapy** topic as they relate to germline cell and somatic cell modification.

Genetic Modification of Microorganisms: Ethical Issues

The table below **outlines** some of the **benefits and risks** of using **genetically modified microorganisms**:

Benefits	Risks
Microorganisms can be modified to produce medicines (e.g. insulin, human growth hormone) and vaccines .	Modified microorganisms could escape and transfer genes (e.g. antibiotic-resistance marker genes) to wild populations, with potential impacts on disease prevention .
Modified microorganisms are used as model organisms for research and as vectors for transferring genes into other organisms.	



Genetic Modification of Plants: Ethical Issues

The table below **outlines** some of the **benefits and risks** of using **genetically modified plants**:

Benefits	Risks
Crops (e.g. Golden Rice) can be modified to produce nutrients (e.g. β -carotene, a vitamin A precursor) to reduce dietary deficiencies in populations .	Genes (e.g. for herbicide tolerance) could transfer to wild plants, potentially producing herbicide-resistant weeds .
Crops (e.g. soya) can be modified to produce insecticidal proteins (e.g. Bt toxin), which kill pests that feed on the plant, reducing the need for insecticide sprays .	Genetically modified seeds and the genes they contain can be patented, restricting farmers' access through licensing costs.



Natural Cloning in Plants

Natural cloning occurs more frequently in plants than in animals because they **retain** more tissues with **undifferentiated cells** throughout their lives.

Undifferentiated plant tissues are called **meristems**.

Vegetative propagation* is the development of a **new plant from meristematic tissue**, producing offspring that are genetically identical to the parent.

***Vegetative** refers to the **non-reproductive parts** of a plant (e.g. roots, stem, leaves). The diagram below **shows** examples of vegetative propagation structures:



Corm



Rhizome



Tuber



Bulb



Sucker



Plantlets



Runner

Artificial cloning in plants is used to produce **large numbers of genetically identical plants**.

Techniques used to **artificially clone plants** include **cuttings, tissue culturing** and **micropropagation**.



Cuttings

Taking **plant cuttings** is the simplest technique to artificially clone a plant because it **exploits** the plant's own **vegetative propagation abilities** and does not require a sterile environment.

A simple **method** for **cloning a plant** by taking **stem cuttings** is **outlined** below:

1. Select a **healthy shoot** from the parent plant and remove any flowers and excess leaves.
2. **Cut the stem at an angle** between two leaf joints (just **below a node**).
3. **Apply rooting powder**, which contains auxin, to the cut end to stimulate root growth.
4. Plant the cutting in **moist compost**.

Tissue Culturing and Micropropagation

Tissue culturing is a range of techniques used for stimulating small pieces of plant tissue (**explants**) or whole plant tissues to **grow into calluses**, which can then be stimulated to **grow into plantlets**.

A simplified **method** for **tissue culturing** is **outlined** below:

1. **Cut the meristematic tissue** from the parent plant to form **explants**.
2. **Sterilise** the explants using **bleach or alcohol**.
3. Place the explants on a **sterile agar gel** containing **nutrients, auxin and cytokinin**, so that they **develop into a callus** (a mass of undifferentiated cells).
4. **Divide the callus** into small clumps of undifferentiated cells.
5. Transfer the clumps to a **4:1 cytokinin to auxin** solution to **promote stem formation**.
6. Transfer the clumps to a **100:1 auxin to cytokinin** ratio to **promote root formation**.
7. Transfer the plantlets to compost and grow in a greenhouse or propagator under optimal conditions.

Micropropagation involves the **use of tissue culturing** techniques to culture **large numbers** of genetically identical plants*.

*Typically for commercial purposes.



Module 6: Cloning in Plants



Arguments For and Against Artificial Cloning in Plants

The table below **outlines** the **advantages** of **artificial cloning in plants**:

Advantage	Explanation
Rapid production	Large numbers of plants can be produced quickly and independently of seasonal reproduction, especially using methods such as tissue culture and micropropagation.
Overcomes limitations of sexual reproduction	Allows propagation of seedless, sterile, or slow-reproducing plants and bypasses unreliable germination and vulnerable seedling stages.
Desirable traits retained	Plants are genetically identical , ensuring that commercially valuable traits such as yield, disease resistance and appearance are retained .
Uniformity	Produces genetically identical crops with predictable size, quality and yield, making cultivation and harvesting easier on a commercial scale.

The table below **outlines** the **disadvantages** of **artificial cloning in plants**:

Disadvantage	Explanation
Labour intensive	Requires skilled labour , particularly for techniques such as tissue culture that involve sterile technique and careful handling of explants.
Expensive	High initial costs due to the need for specialised equipment, sterile facilities, and trained personnel.
No genetic variation	Populations have very low genetic diversity , with variation arising only from mutation, reducing adaptability .
Disease and infection risk	Genetically identical populations are more vulnerable to the same pathogens and environmental changes because of their low genetic diversity.

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Module 6: Natural and Artificial Cloning in Animals



Natural Cloning in Animals

Natural cloning in animals can occur through **modifications** to **embryo formation or development** (e.g. identical twins), **budding** (e.g. hydra), or **fragmentation** (e.g. planarians).

Artificial Cloning in Animals

Artificial cloning is used to produce genetically identical **cells, tissues, organs or whole organisms**.

Artificial cloning in animals may be **reproductive or non-reproductive**:

- **Reproductive cloning** produces **whole**, genetically identical **animals**.
- **Non-reproductive cloning*** produces genetically identical **cells and tissues** for medical uses.

*Also known as **therapeutic cloning**.

Reproductive Cloning

Reproductive cloning can be carried out by **artificial embryo twinning** and **somatic cell nuclear transfer**:

- **Artificial embryo twinning** involves **splitting an early embryo** to produce two or more genetically identical embryos.
- **Somatic cell nuclear transfer (SCNT)** involves **transferring the nucleus of a somatic cell into an egg cell** whose own nucleus has been removed.

Artificial Embryo Twinning

Artificial embryo twinning involves manually **splitting an embryo** into two (or more) clusters of cells to create two (or more) genetically identical embryos.

A simplified **method** for **artificial embryo twinning** is **outlined** below:

1. Produce a **zygote by in vitro fertilisation (IVF)**.
2. Allow the zygote to **divide by mitosis** into a small ball of cells, **forming** an early **embryo** whose cells are still totipotent.
3. **Split the embryo** into two or more smaller embryos.
4. **Implant each embryo**** into a surrogate mother, where it develops into an individual. The resulting offspring are genetically identical to one another.

**One embryo can be saved to be further divided into more embryos while its cells remain totipotent, allowing additional genetically identical embryos to be produced.



Module 6: Natural and Artificial Cloning in Animals



Somatic Cell Nuclear Transfer (SCNT)

Somatic cell nuclear transfer (SCNT) produces a **clone** from a single **somatic cell** of the animal to be copied.

The **somatic cell** contains the genome of the organism to be cloned within its **nucleus**, which is **removed** and **fused with an egg cell** that has been enucleated (**had its nucleus removed**).

A simplified **method** for **somatic cell nuclear transfer** is **outlined** below:

1. **Remove the nucleus from an egg cell.**
2. **Remove a nucleus from a somatic cell** of the animal being cloned.
3. **Fuse** the somatic cell nucleus with the enucleated egg cell using an **electric shock***.
4. The electric shock **stimulates the egg cell to begin dividing**.
5. Allow the cell to divide and **develop into an embryo**.
6. **Implant the embryo** into a surrogate mother and allow it to develop.

*The electric shock also stimulates the egg cell to begin dividing.

Arguments For and Against Artificial Cloning in Animals

The table below **outlines** some of the **advantages** of **artificial cloning** in **animals**:

Advantage	Explanation
Medical treatment	Genetically identical tissues or organs could be grown to treat injuries or diseases in patients, eliminating the risk of rejection .
Reproduction of high-value animals	Large numbers of identical, high-value animals can be produced by selective breeding (e.g. a cow with a high milk yield), or genetic modification, and then cloned.

The table below **outlines** some of the **disadvantages** of **artificial cloning** in **animals**:

Disadvantage	Explanation
Expensive	High costs due to the need for trained personnel and the low success rate.
Poor health	Cloned animals have a much higher risk of health issues and a shorter lifespan .



Module 6: Introduction to Biotechnology



Biotechnology is the use of **living organisms**, or their components, to produce pharmaceuticals, food, and other products.

The types of **microorganisms commonly** used in **biotechnology** include **algae, bacteria and fungi**:

- **Algae** are primarily used for producing **biofuels, environmental products, food supplements** and **pigments**.
- **Bacteria** are widely used for producing **enzymes, fermented foods, industrial chemicals** and **pharmaceuticals**.
- **Fungi** are primarily used for producing **enzymes, food products** and **pharmaceuticals**.

Using **microorganisms to produce substances** is more efficient than using animals or plants, which gives them significant **advantages**.

The table below **outlines** some of the **advantages** of using **microorganisms for producing substances**:

Advantage	Explanation
Economic considerations*	- Microorganisms are cheap and easy to grow. - Low growing temperatures reduce energy costs. - Microorganisms can be grown on cheap or waste materials from other industries.
Healthier food	Microbial protein (e.g. mycoprotein) is high in protein and fibre , but low in fat , and has no cholesterol , making it healthier and more nutritious than protein derived from animals.
Optimisation	Conditions inside a bioreactor can be closely controlled to maximise the organism's rate of reproduction and/or productivity .
Short life cycle*	Microorganisms have short life cycles and reproduce very rapidly, so large quantities of product can be produced in a short time.

*These are the advantages **specifically named** in the OCR A Level Biology specification.



Module 6: Introduction to Biotechnology



The table below **outlines** the **disadvantages** of using **microorganisms** for **producing substances**:

Disadvantage	Explanation
Consumer acceptability	Some people may be reluctant to eat food made from microorganisms , especially when it is grown on waste materials .
Contamination	Growth cultures can be contaminated by other microorganisms, reducing productivity or producing toxins, so sterile conditions must be maintained, which increases the cost .

It is important to note that you are **not expected** to know specific examples of products made by microorganisms. Earlier editions of the specification included baking, brewing, bioremediation, cheese making, yoghurt production, penicillin production and insulin production as examples of food production processes with microorganisms that you were expected to learn. Although they appeared in the first official OCR A Level Biology textbook, the official OCR A Level Biology specification was updated to remove them.

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Module 6: Culturing Microorganisms



Microorganisms can be **cultured** (grown) intentionally for **commercial and research purposes** under controlled conditions.

Microorganisms are typically cultured in a **culture medium*** containing the required **nutrients** (e.g. carbohydrates, nitrogen) that is **sterilised** before the inoculation (introduction) of the desired microorganisms.

*Also referred to, informally, as a growth medium.

Culturing microorganisms involves **sterilisation, inoculation and incubation**:

- **Sterilisation kills** all **microorganisms** present in the culture medium or on the equipment.
- **Inoculation transfers** the **microorganisms** to the culture medium.
- **Incubation** maintains the microorganisms at a **suitable temperature** so that they **grow and reproduce**.

Aseptic technique is used throughout the process of setting up cultures to **ensure the sterility** of the **equipment** and **culture medium** is maintained.

Aseptic technique refers to a **set of procedures** that **prevent** the culture from being **contaminated with unwanted microorganisms**.

A simple **method** for setting up a **bacterial culture** on **agar** using **aseptic technique** is **outlined** below:

1. **Disinfect** the work **surface**, **wash hands**, and **light a Bunsen burner** near the working area.
2. **Sterilise** the **culture medium** and all **equipment** in an **autoclave** at **121 °C for 15 minutes**.
3. **Pour** the **molten agar** into a **Petri dish** and allow it to **set**.
4. Remove the lid of the bottle containing the bacteria and **flame the neck of the bottle**.
5. Sterilise the **inoculating loop** in the Bunsen flame until it is **red-hot**, then allow it to **cool**.
6. **Dip the loop** into the bacterial culture, then **flame the neck** of the bottle again and replace the lid.
7. Lift the **Petri dish lid slightly**, and quickly **streak** the loop gently across the surface of the agar.
8. **Flame** the inoculating loop after use to sterilise it.
9. **Tape** the lid of the Petri dish **without sealing it airtight**, and **label** it.
10. **Incubate** the dish **upside down** at a suitable temperature (e.g. 25 °C) for an appropriate time.



Module 6: Growth Curve of Microorganisms

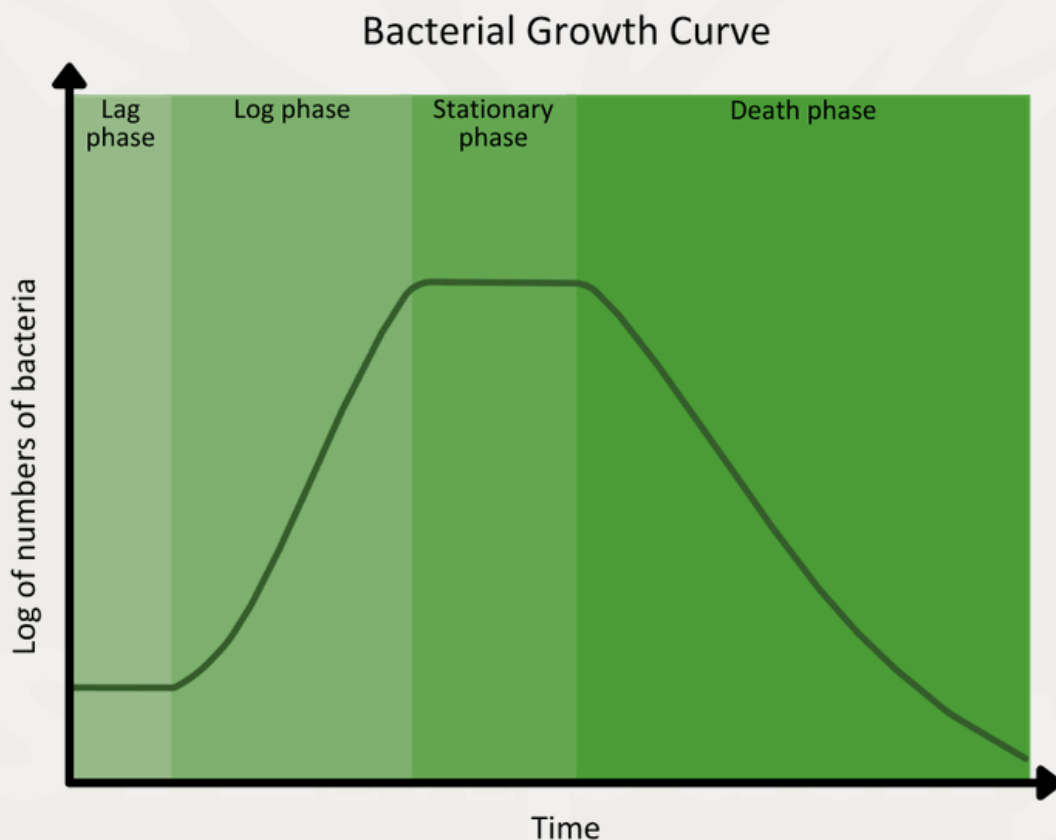


A **standard growth curve** describes the distinct **changes in population growth** which a population of microorganisms goes through **in a closed culture**.

Population growth occurs over **four** distinct **growth phases** known as the **lag** phase, **log** phase, **stationary** phase, and **death** phase:

1. **Lag** phase is when the inoculated microorganisms **adjust** to their new **environment**, **taking up nutrients** and **synthesising proteins** (e.g. enzymes). **Population growth is slow**.
2. **Log** (exponential) phase is when the microorganisms **rapidly divide** in large amounts of space and available nutrients. **Population growth is exponential**.
3. **Stationary** phase is when available **nutrients are low**, **space is limited**, and **metabolic wastes accumulate**. **Population growth stays constant**.
4. **Death** (decline) phase is when **nutrients run out**, and the concentration of **metabolic waste products** becomes **lethal**. **The population declines**.

The graph below **shows** the **standard growth curve** of a population of microorganisms in a **closed culture**:



Population growth in microorganisms is typically **exponential** during the **log phase** of a growth curve.



Module 6: Growth Curve of Microorganisms



The **number of microorganisms** in a population undergoing exponential growth can be **calculated** using the **formula**:

$$N = N_0 \times 2^n$$

Where:

- **N** = the **final number** of microorganisms.
- **N₀** = the **initial number** of microorganisms.
- **n** = the **number of generations** that have taken place.
- **2ⁿ** = the **doubling** of the population after each generation.

The **number of divisions** is **calculated** using the **formula**:

$$n = \text{total time} \div \text{mean generation time}$$

Serial Dilutions

A **serial dilution** is a stepwise sequence of dilutions that **lowers the concentration by the same** factor (e.g. 10).

For example, adding **1 cm³** of a solution to **9 cm³** of water **dilutes** it by a **factor of 10***.

*Sometimes described as tenfold.

Serial dilution reduces the concentration of microorganisms enough so that the colonies they give rise to are **unlikely to overlap** and can be **clearly counted**.

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Module 6: Batch and Continuous Fermentation

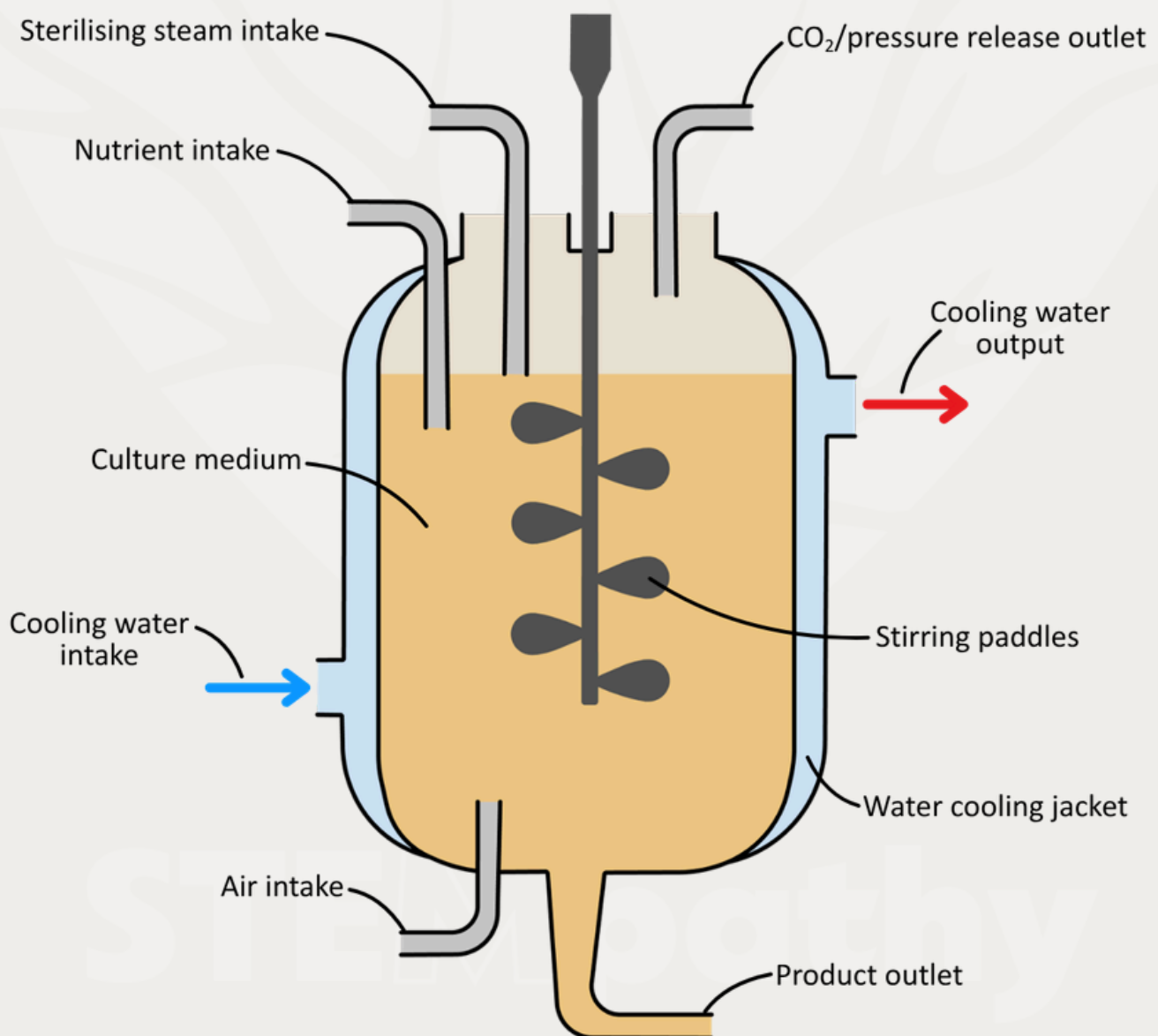


Industrial fermentation is the **growth** of microorganisms at a **large scale** within **bioreactors** so that the product **yield is maximised**.

A **bioreactor** is a large vessel that **maintains the environment** of the microorganism being grown at **optimal conditions** for a desired product.

A **fermenter** is a **type of bioreactor**.

The diagram below **shows** a typical **fermenter**:



It is useful to know that the microorganisms being grown within a fermenter may not always undergo fermentation as part of the production process, despite what its name indicates.



Module 6: Batch and Continuous Fermentation



The table below **outlines** some of the environmental **conditions** that a **fermenter** is designed to **control** and **how** it does it:

Environmental Condition	How it is controlled
Nutrients	Inlets allow sufficient nutrients (e.g. carbohydrate, nitrogen) to be added to the tank.
Oxygen	Inlets allow sterile air containing oxygen to be bubbled through the culture medium.
pH	pH probes monitor the pH, which can be corrected by adding acidic or alkaline substances to maintain an optimal pH .
Temperature	A cooling jacket removes the excess heat released by the microorganisms' metabolism, keeping the temperature at an optimum .

Continuous and Batch Fermentation

Fermentation can be carried out as either **batch fermentation** or **continuous fermentation**:

- **Batch fermentation** involves growing microorganisms within a **fixed volume of culture medium**, and then emptying the fermenter to harvest the product.
- **Continuous fermentation** involves growing microorganisms within a **culture medium that continuously has nutrients added** and products and wastes removed.

Batch fermentation allows a population to develop through **all phases of the growth curve** (lag, log, stationary, death), whilst **continuous fermentation** causes a population to be **maintained in the log or stationary phase**.

Microorganisms may **produce different substances in different phases of the growth curve**, due to different environmental conditions affecting their metabolic activity.

Deciding whether to use **batch or continuous fermentation** is determined by the **type of metabolite** the desired product is:

- **Batch fermentation** is used to produce **secondary metabolites** (e.g. antibiotics) that are only produced during the **stationary** and/or **death phase**.
- **Continuous fermentation** is used to produce **primary metabolites** (e.g. amino acids, ethanol, enzymes) and/or biomass, by maintaining the population in the **log and/or stationary phase**.





Investigating Factors Affecting the Growth of Microorganisms

The **growth of a microorganism's** population is affected by many different **factors**, which can be **investigated** by growing the microorganisms in a broth and **measuring the population density over time**.

The table below **outlines** the main **factors** that **affect microbial growth**:

Factor	Effect on growth
Nutrient availability	- A greater supply of nutrients leads to faster population growth. - A limited supply of nutrients slows, or reverses, population growth.
Oxygen availability	- Aerobic microorganisms need oxygen to respire and grow. - Anaerobic microorganisms are inhibited by oxygen and may grow less.
pH	- An optimal pH increases the rate of enzyme-driven reactions, increasing population growth. - A too low or too high pH denatures enzymes and may damage the microorganism, slowing or reversing population growth.
Temperature	- An optimal temperature increases the rate of enzyme-driven reactions, increasing population growth. - A temperature too low decreases kinetic energy, whilst too high temperatures denature enzymes and may damage the microorganism, which decreases population growth.

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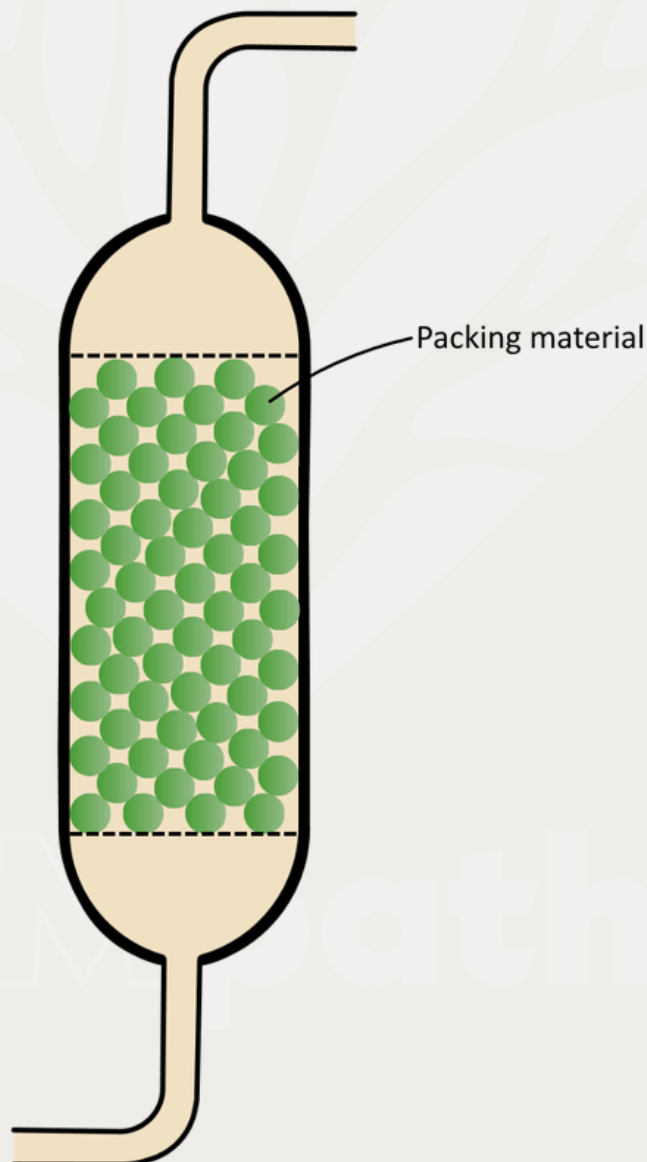
Immobilised Enzymes

Enzyme immobilisation is a **technique** which **prevents the free movement of enzymes** within a reaction mixture containing a substrate.

Enzymes are **immobilised** by **trapping them within, or binding them to**, a material that is then packed into a **reaction column**.

Reaction columns are used in chemical immobilisation to provide a **vessel** in which the material to which the enzyme is bound can be packed.

The diagram below **shows** a typical **reaction column** containing **immobilised enzymes**:



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Module 6: Immobilised Enzymes



Methods of Immobilisation

Enzymes can be **immobilised** either **chemically** or **physically**:

- **Chemically binding** enzymes with **chemical bonds to the surface** of a solid material.
- **Physically trapping** enzymes involves allowing the substrate to diffuse through a material that **binds the enzymes within a matrix** or keeps the **enzymes separate** by acting as a **partially permeable membrane**.

Chemical Immobilisation

The **two types** of **chemical immobilisation** are **adsorption** and **covalent bonding**:

- **Adsorption** binds enzyme molecules to the surface of an **inert supporting material** (e.g. clay, glass beads) by **weak hydrogen bonds, hydrophobic interactions, or ionic bonds**.
- **Covalent bonding** binds enzyme molecules to a support by **strong covalent bonds**.

The table below **outlines** some of the **advantages** and **disadvantages** of the different types of **chemical immobilisation**:

Method	Advantage(s)	Disadvantage(s)
Adsorption	- Enzymes can be reused, lowering costs. - The active site is exposed to the reaction mixture containing the substrate.	The enzyme-surface bonding is weak , so the enzyme may detach and leak into the mixture.
Covalent bonding	- Enzymes can be reused, lowering costs. - Strong covalent bonds prevent enzymes from detaching and leaking into the reaction mixture.	- Expensive to covalently bind enzymes to the surface. - The enzyme-surface bonding is strong, so the enzyme's active site may be distorted, reducing the rate of reaction.

Physical Immobilisation

The two types of physical immobilisation are **entrapment** and **membrane separation**:

- **Entrapment** holds enzymes **inside a matrix or gel** (e.g. calcium alginate beads) that they cannot leave, but the **substrate** and product molecules can **diffuse in and out** of the matrix or gel.
- **Membrane separation** holds enzymes on one side of a **partially permeable membrane**, which **separates** them from the reaction mixture containing the substrate.



Module 6: Immobilised Enzymes



It is useful to know that adsorption is more commonly classified as a form of physical immobilisation.

The table below **outlines** the **advantages** and **disadvantages** of the different types of **physical immobilisation**:

Method	Advantage(s)	Disadvantage(s)
Entrapment	- Enzyme active site is unaffected and fully active. - Enzymes can be reused, lowering costs.	The need for diffusion limits the rate of reaction .
Membrane separation	- Enzyme active site is unaffected and fully active. - Enzymes can be reused, lowering costs.	- Need for diffusion limits the rate of reaction. - The substrate and product must be small enough to diffuse through the partially permeable membrane, limiting its use to certain reactions.

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Module 6: Ecosystems



An **ecosystem** is a **community of organisms** together with the **physical and chemical environment** with which they interact.

The **environment** is all of the **factors surrounding an organism** that can affect it.

An **environment** consists of **abiotic and biotic factors**:

- **Abiotic factors** are the non-living components of an ecosystem (e.g. pH, temperature, humidity and light intensity).
- **Biotic factors** are the **living components** of an ecosystem (e.g. predation, disease and competition).

The **environment influences** the **abundance, behaviour and location of organisms** within an ecosystem due to its abiotic and biotic factors.

Abiotic factors

Some examples of abiotic factors from the **environment which can affect organisms** include:

- **Humidity**, the amount of water vapour in the air, **affects the rate of water loss from organisms**.
- **Light intensity** affects the **rate of photosynthesis** and, therefore, the **food available** to a community.
- **Oxygen availability**, which is needed **for aerobic respiration**, can be limited in water or waterlogged soil.
- **Temperature** affects the **rate of enzyme-controlled reactions** and, therefore, the **activity and survival of organisms**.

Biotic factors

Some examples of biotic factors arising from **organisms interacting with each other** include:

- **Competition**: When organisms compete for the same **limited resources**, such as **food, light, water, mineral ions** or **space**.
- **Disease**: When **pathogens** infect organisms and can **reduce the size of a population**.
- **Herbivory**: When an animal **feeds on a plant**.
- **Predation**: When one organism **hunts, kills and eats another**.





Dynamic Ecosystems

The components of an **ecosystem change over time** as a result of internal and external factors interacting with each other, which makes them **dynamic**.

The table below **outlines** the main **dynamic changes** affecting **example ecosystems**:

Rock pool	Large Tree	Playing field	African grassland
- Tides alternately cover and expose the pool, and conditions change seasonally. - Erosion increasingly shrinks the rock pool. - Unpredictable changes from storms.	- Gradual changes from seasonal weather. - Habitat enlarges as the tree grows. - Unpredictable changes from storms.	Gradual changes from seasonal weather.	- Seasonal changes from wet and dry seasons that determine herbivore migration. - Climate change increasingly changes the average climate. - Unpredictable changes from droughts and wildfires.





Biomass

Biomass is the **total dry mass of organic material** in living organisms within a given area at a particular time.

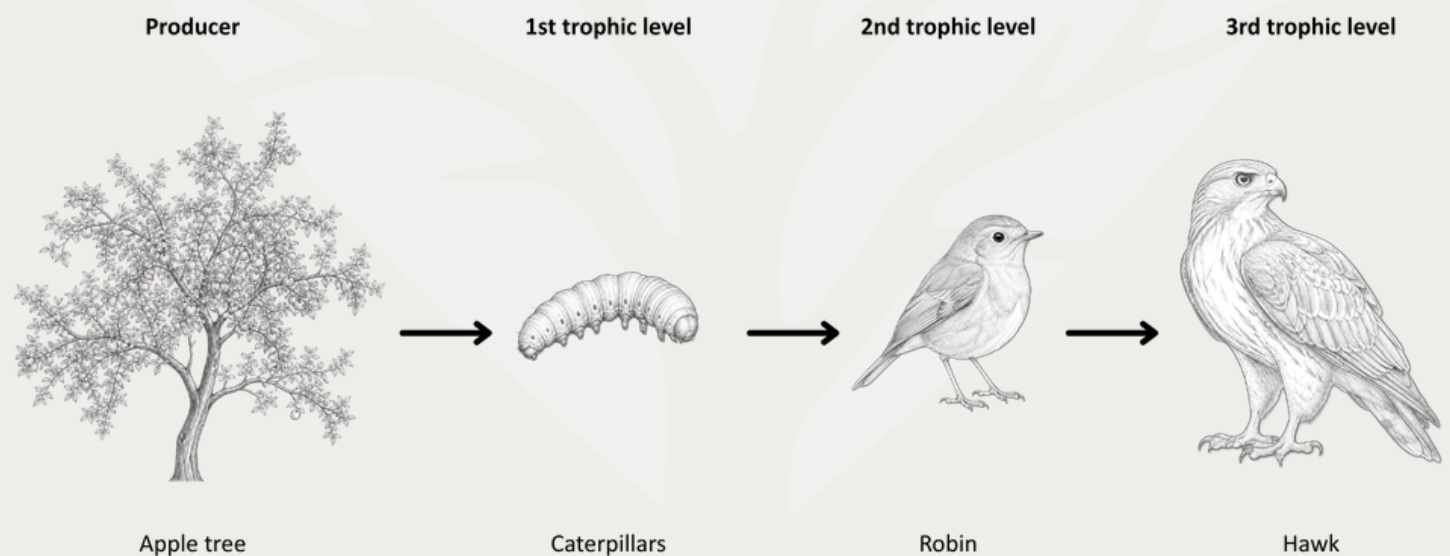
All **biomass** in an ecosystem **originates from producers**, which can **capture energy** from their environment (e.g. light in photosynthesis), store it as chemical energy, and **use it to synthesise organic molecules**.

Biomass Transfers Through Trophic Levels

When one **organism is eaten** by another, its **biomass** and the **energy** stored within it are **transferred to the consumer**, a process called **biomass transfer**.

Biomass transfer occurs **through trophic levels**.

The diagram below shows the trophic levels of a food chain:



When biomass is transferred from one organism to another along a food chain, a significant **proportion of biomass is lost**.

Reasons why biomass is lost from one trophic level to the next include:

- **Death:** Biomass in dead organisms will often be **consumed by decomposers**.
- **Indigestible parts:** Some biomass (e.g. bones, hair) **cannot be digested**.
- **Respiration:** Some biomass is **broken down to release energy** during respiration.





Calculating the Efficiency of Biomass Transfer

The **efficiency of biomass transfer** between trophic levels can be **calculated using the following equation**:

$$\text{efficiency} = (\text{biomass transferred} \div \text{biomass intake}) \times 100$$

The values used in the efficiency of biomass transfer equation may be masses (e.g. g m⁻²) or quantities of energy (e.g. kJ m⁻²).

It is important to note that you **are expected** to learn and recall this equation from memory. It will **not be provided** in the exam.

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Module 6: Manipulating Biomass Transfers



Manipulating the Transfer of Biomass

Farming aims to **maximise the productivity of biomass production**, so biomass transfers will be **manipulated to increase the yield** of food produced from crops and livestock.

Biomass transfers can be **manipulated** at either the **primary productivity** or **secondary productivity** level:

- **Primary productivity** is manipulated by **reducing the limiting factors for photosynthesis**, so that the rate of biomass production in the first trophic level is increased.
- **Secondary productivity** is manipulated by **reducing energy loss and usage from consumers**, so that more biomass goes into growth.

Increasing Primary Productivity

Improving primary productivity in farming involves **increasing the rate of photosynthesis** in plants and **reducing the biomass lost** to disease, fungi and pests.

The table below **outlines** how some of the **factors** that **limit photosynthesis** are **manipulated to increase primary productivity**:

Factor	Manipulation
Fungal diseases	Applying fungicides or growing disease-resistant varieties keeps leaves healthy and prevents the loss of photosynthetic tissue .
Light availability	Plants grown in a greenhouse can be grown under artificial light , or shading can be removed by removing competing plants or thinning crops so that more light can be absorbed for the light-dependent reaction.
Mineral ions/nutrients	Applying fertilisers , or carrying out crop rotation with nitrogen-fixing legumes, supplies the mineral ions needed to build biomass (e.g. nitrate for amino acids, magnesium for chlorophyll).
Weeds	Removing weeds with herbicides , by hand, or through biological control reduces the competition for light, water and mineral ions .

Increasing Secondary Productivity

Improving secondary productivity in farming involves **increasing the efficiency of animals converting consumed plant biomass** into new animal biomass.



Module 6: Manipulating Biomass Transfers



The table below **outlines** how the **factors** that reduce the **efficiency** of **secondary productivity** are **manipulated**:

Factor	Manipulation
Disease	Controlling the spread of diseases with hygiene, or using antibiotics or medicines , reduces the energy lost to the immune response.
Feed quality	High-quality, easily digestible feed increases the proportion of consumed biomass that is absorbed and incorporated into animal biomass, as it reduces the biomass lost in faeces.
Temperature	Keeping animals at an optimal temperature reduces energy loss through maintaining body temperature.
Movement	Restricting animal movement reduces the energy lost through respiration.

It is important to note that many farming practices which increase the efficiency of secondary productivity **raise ethical issues** due to poor animal welfare. This is because the unnatural conditions animals may be kept in **reduce the opportunity for them to express normal behaviours (e.g. moving around, socialising)**, and **increase the prevalence of disease**.

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Recycling within Ecosystems

The **chemical elements** that make up living things are **recycled continuously** between the biotic and abiotic components of an ecosystem.

Two elements recycled in this way are **carbon** and **nitrogen**, each through its **own cycle**:

- **The carbon cycle:** Carbon is **cycled** between the **atmosphere**, where it exists as carbon dioxide, and **living things**, driven mainly by photosynthesis and respiration.
- **The nitrogen cycle:** Nitrogen is **cycled** between the **atmosphere**, where it exists as nitrogen gas, **soil**, and **living things**, mainly through the action of bacteria.

The Carbon Cycle

The **carbon cycle** describes how **carbon atoms** move through the different **components of an ecosystem**.

Carbon is transferred between the abiotic and biotic components of an ecosystem through several **different processes**, including:

- **Combustion:** **Burning** biomass and fossil fuels **releases CO₂** back into the atmosphere.
- **Decomposition:** Decomposers **respire** whilst **breaking down the biomass** in dead organisms and waste, **releasing CO₂** back into the atmosphere.
- **Feeding:** **Consumers eat** other organisms, **moving the carbon** stored within biomass **along food chains**.
- **Sequestration:** The **removal of carbon from circulation** within the carbon cycle for long periods of time **in carbon sinks** (e.g. dissolved deep in the ocean, formation of carbonate rocks).
- **Photosynthesis:** **Producers take in CO₂** from the atmosphere and fix it into organic molecules to **form biomass**.
- **Respiration:** Organisms **break down organic molecules** during respiration and **release CO₂** back into the atmosphere.

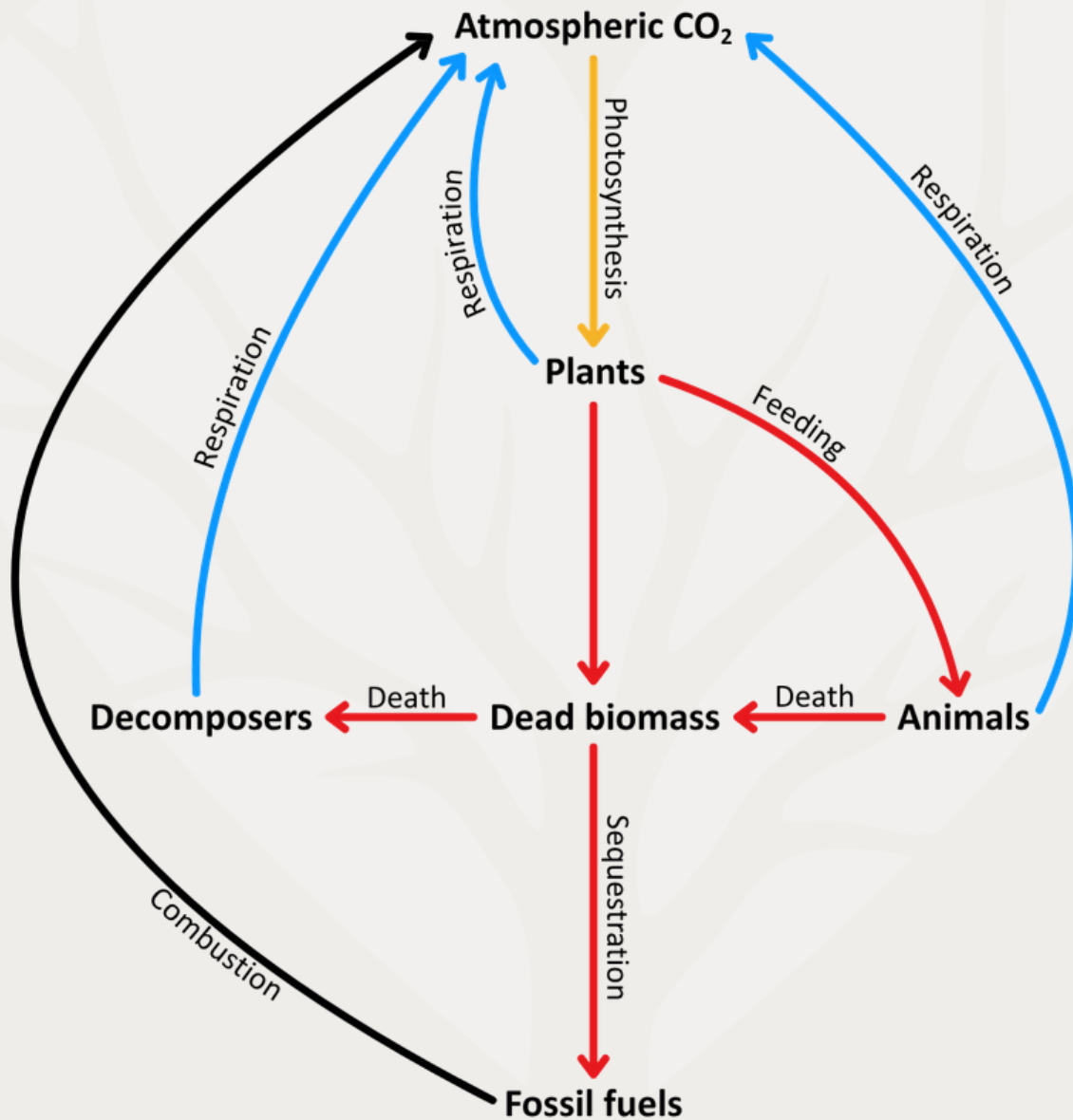
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Module 6: Recycling in Ecosystems



The diagram below **shows** the **processes** that move carbon around the ecosystem in the **carbon cycle**:



The Nitrogen Cycle

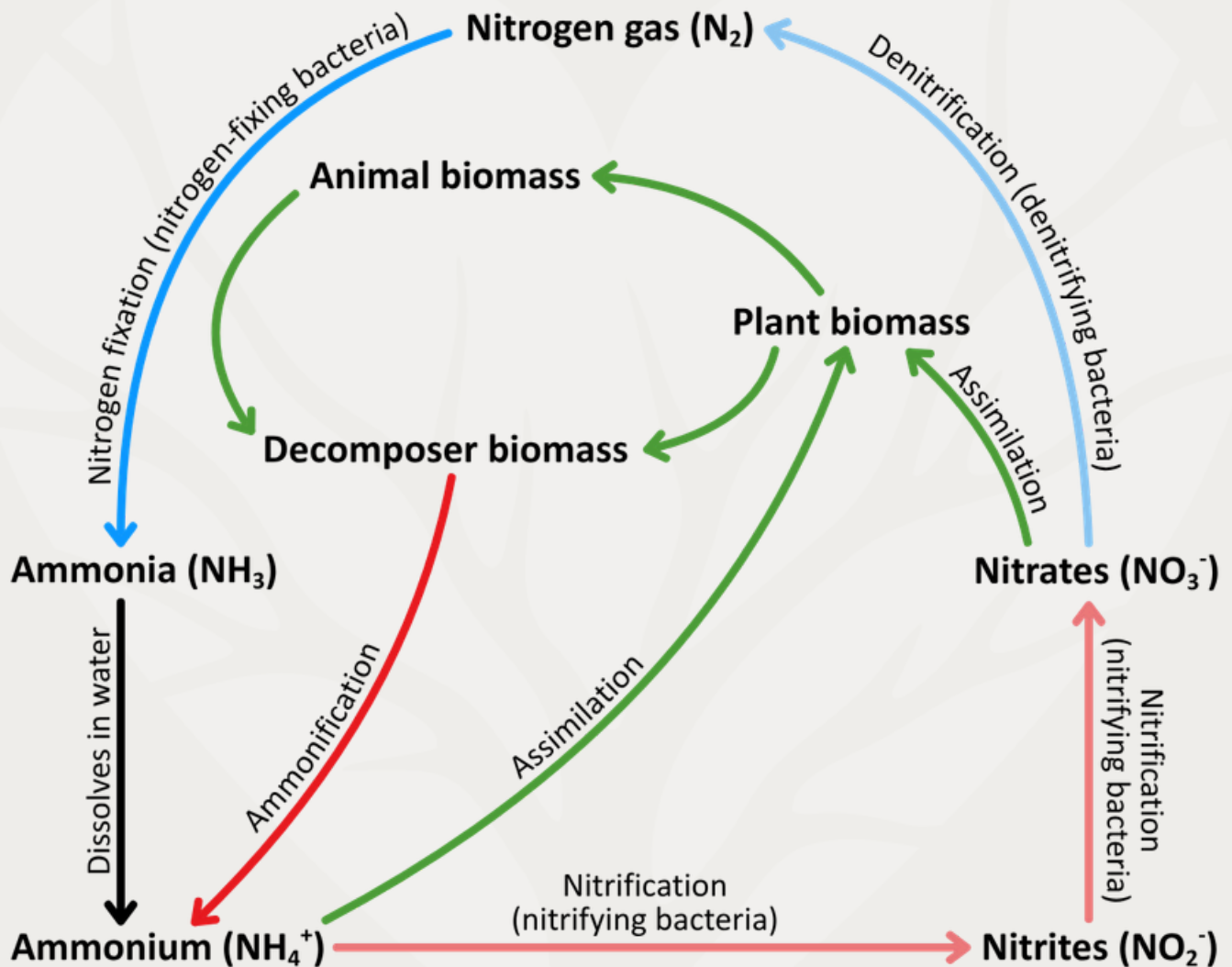
The **nitrogen cycle** describes how **nitrogen atoms** move through the different **components of an ecosystem**.



Module 6: Recycling in Ecosystems



The diagram below **shows** the **processes** that move nitrogen around the ecosystem in the **nitrogen cycle**:



It is useful to know that lightning causes N_2 to react with oxygen to produce NO_3^- , which can be absorbed by plants from the soil.

Roles of Organisms in the Nitrogen Cycle

Organisms have many **different roles in cycling nitrogen** through the nitrogen cycle.

Nitrosomonas, *Nitrobacter*, *Azotobacter* and *Rhizobium* are the named examples of microorganisms involved in the nitrogen cycle in the OCR A Level Biology specification. You **are expected** to recall them and know their roles in the nitrogen cycle.



Module 6: Recycling in Ecosystems



The table below **outlines** the **roles** that **these organisms** have in the **nitrogen cycle**:

Organism	Role in the nitrogen cycle
Nitrogen-fixing bacteria (e.g. Rhizobium, Azotobacter)	Convert atmospheric nitrogen gas (N_2) into ammonia (NH_3) or ammonium ions (NH_4^+), making nitrogen available to other organisms.
Consumers (e.g. caterpillars, foxes)	Obtain nitrogen by feeding on other organisms , and use it to build proteins and nucleic acids.
Detritivores (e.g. earthworms, woodlice)*	Feed on dead organisms and waste , physically breaking them into smaller pieces and increasing the surface area available to saprotrophs.
Saprotrophs (e.g. fungi, bacteria)*	Break down the organic nitrogen in dead organisms and waste during ammonification, releasing ammonia (NH_3) , which may turn into ammonium (NH_4^+).
Nitrifying bacteria (e.g. Nitrosomonas, Nitrobacter)	Oxidise ammonium (NH_4^+) to nitrite (NO_2^-) , then nitrite to nitrate (NO_3^-) .

***Decomposers** are organisms which break down dead biomass or waste, allowing the nutrients to return to the environment. Decomposers either break down biomass and waste physically, as **detritivores**, or chemically, as **saprotrophs**.

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Succession is defined as the gradual **change in a community of organisms over time**. Succession (typically) follows similar patterns of change over time, although the species involved and the climax community vary between habitats.

The **process of succession** can be **simplified** into the **following stages**:

1. **Pioneer species colonise** a bare or disturbed surface.
2. **Soil begins to form** from the weathering of rocks by pioneer species and the decomposition of their dead biomass after they die.
3. The **soil becomes deeper** and retains more water and nutrients, making the **habitat less hostile**.
4. **Plants colonise** the habitat, **outcompeting the pioneer species** for resources such as light, water and mineral ions.
5. **Successive generations** of organisms **develop the soil** as decomposers break down dead biomass and release nutrients.
6. The **community** gradually **becomes larger** with more biomass, biodiversity, and larger food webs, as earlier species are outcompeted by newer species.
7. A **stable climax community** is reached, in which the **community** is in **dynamic equilibrium** with its **environment**.

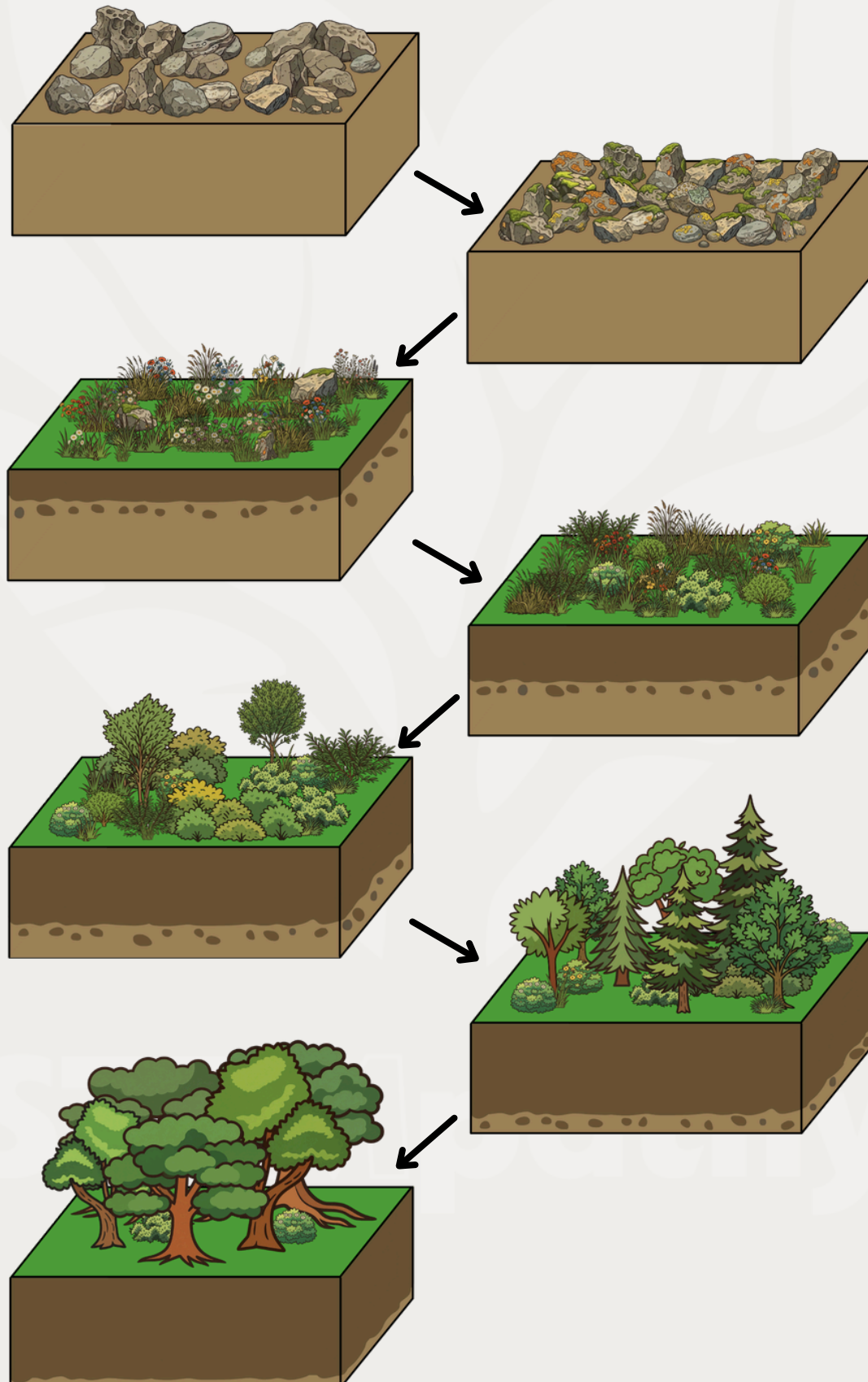
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Module 6: Succession



The diagram below **shows** the typical **stages of succession**, from a bare or disturbed surface to a **climax woodland**:





It is important to note that the animal community also undergoes succession, as the changing plant community creates new niches, eliminates old ones, and can support a food web with greater biomass.

Primary and Secondary Succession

Succession is categorised as either **primary** or **secondary**:

- **Primary succession** occurs when a **newly exposed surface, lacking soil**, is colonised.
- **Secondary succession** is when land that has **already been colonised is disturbed** (e.g. a fire or a flood), but the soil remains.

You are **only expected** to know about **primary succession**.

Primary Succession

Primary succession occurs where there is **no soil**, which makes the **environmental conditions very harsh**, such as little water, nutrients, and extremes of temperature.

Deflected Succession

Succession is sometimes **stopped before** it reaches the **climax community stage**.

Deflected succession is when the process of **succession is interrupted** at a particular stage by a disturbance which **maintains an intermediate community**.

Deflected succession can occur as a result of **abiotic or biotic factors**:

- **Abiotic factors**, such as **drought, fire, and flooding**, **prevent species** involved in the later stages of succession from **colonising** the habitat, allowing the intermediate community to dominate.
- **Biotic factors**, such as **herbivore grazing and trampling**, only **allow certain species** to persist, maintaining the community at an intermediate stage of succession.

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Measuring Abundance

Abundance is the **number of individuals** of a species in a defined area.

Abundance can be determined using **random**, **opportunistic** or **stratified sampling** to decide where **quadrats** can be placed for **counting** or estimating **percentage coverage**.

Opportunistic Sampling

Opportunistic sampling is used to **collect data quickly**, so that a preliminary judgement can be made before proceeding with a more valid investigation, such as establishing that a **species is present** in an area of interest.

Opportunistic sampling is inherently **biased** because the **sampling locations** are **chosen** for their **accessibility**, **convenience**, or **prior knowledge** of the likely presence of organisms of interest. This produces **unrepresentative experimental results**.

The table below **outlines examples** of **investigations** that would use **opportunistic sampling**:

Investigation	Approach	Observation	Results
Confirming the presence of bluebells in a woodland	Use opportunistic sampling by walking accessible paths and recording locations where bluebells are observed.	Locations containing bluebells are identified.	Bluebells are confirmed as being present in certain areas, informing where more valid investigations can be conducted.
Investigating red squirrels in a woodland	Use opportunistic sampling by placing camera traps in accessible locations where red squirrels are likely to occur.	Images of red squirrels are captured at some locations.	Red squirrels are confirmed as being present in the woodland, informing the relevance of a future investigation into their abundance.



Module 6: Measuring Abundance



Random Sampling

Random sampling is used to **estimate** the **abundance** of plants or slow-moving animals in a habitat.

The table below **outlines examples** of **investigations** that would use **random sampling**:

Investigation	Approach	Observation	Results
Comparing clover cover between two lawns	Conduct random sampling in each field by placing 1 m ² quadrats at random coordinates, estimating the percentage cover of clover in each.	One lawn shows a consistently higher percentage cover of clover than the other.	Calculate a mean for each lawn's percentage cover and compare to determine if one lawn has a greater abundance of clover.
Estimating plantain cover in a field	Use random sampling by placing a 50 cm point frame at random coordinates, recording how many pins touch a plantain.	Plantains are recorded by approximately half of all pins.	The number of pins that touched a plantain is divided by the total number of pins deployed, then multiplied by 100 to give the estimated percentage cover.

Stratified Sampling

Stratified sampling is used to **estimate** the **abundance** of species across a **habitat** that contains clearly **different areas** (strata), such as the layers of a forest canopy.

The table below **outlines examples** of **investigations** that would use **stratified sampling**:

Investigation	Approach	Observation	Results
Estimating marram grass abundance across a sand dune system	Use stratified sampling by dividing the dune system into different strata, and placing 1 m ² quadrats at random coordinates within each stratum.	Marram grass abundance varies within different strata.	A mean number of marram grass plants per 1 m ² is calculated for each stratum, multiplied by the area of each stratum, and combined to estimate the total abundance across the dune system.
Surveying the heather cover on a heath with wet and dry areas	Use stratified sampling by dividing the reserve into wet and dry strata, and placing 1 m ² quadrats at random coordinates within each stratum.	Heather percentage cover is higher in the dry stratum than in the wet stratum.	A mean percentage cover is calculated for each stratum, and strata are compared across the heath.





Measuring Distribution

Distribution is the **range of locations** at which the individual organisms of a **species can be found** across a habitat.

Distribution can be determined using **systematic sampling** to take measurements **along a transect** whilst taking abiotic measurements at the same locations, producing paired data that may show a **correlation** between an **abiotic factor** and the **abundance of a species**.

Systematic Sampling

Systematic sampling can make use of **belt transects** or **line transects**:

- **Belt transects** use **quadrats** placed at **set intervals** along the transect line to record the abundance* of each species.
- **Line transects** only record the species **touching the transect line at set intervals** to produce a quicker, but less representative, distribution of each species.

*Or coverage.

The table below **outlines examples** of **investigations** that would use **systematic sampling**:

Investigation	Approach	Observation	Results
Investigating seaweed distribution up a rocky shore	Use systematic sampling by placing a line transect from the low-tide to the high-tide mark, recording the species touching the tape at set intervals and measuring the height below high-tide.	Different seaweed species occur at different heights up the shore.	Species occurrence is plotted against submersion depth.
Investigating plant abundance along a light gradient from a woodland edge	Use systematic sampling by placing 1 m ² quadrats at 5 m intervals along a belt transect from the woodland edge into a field, recording the abundance of each species and the light intensity.	Light-demanding species in the open ground replace shade-tolerant species near the woodland edge.	The abundance of each species is plotted against light intensity. The abundance of each species may also be plotted against distance on a kite diagram.



Module 6: Populations and Limiting Factors



Population size is the **number of individuals of a species** present in a habitat.

The **size of a population** is **determined** by the environment's **carrying capacity** and the species' rate of **population growth**:

- **Carrying capacity** is the **maximum number of individuals** that a habitat can support.
- **Population growth** is the **rate** at which the **number** of individuals **changes over time**.

Population growth and an environment's **carrying capacity** are **determined** by **limiting factors** in the **environment**.

Limiting Factors

Limiting factors **lower** the **rate of reproduction** (and growth rate) and **raise the mortality rate** (which lowers the carrying capacity).

Limiting factors affect the **rate of population growth** by:

- **Decreasing reproduction**: If there are limited resources, then organisms will be less likely to mate and produce live offspring.
- **Increasing mortality**: If there are limited resources, then organisms will be less likely to compete successfully and survive.
- **Decreasing immigration**: If a habitat has limited resources, then organisms will be less likely to travel to, and remain, in an area.
- **Increasing emigration**: If a habitat has limited resources, then organisms will be more likely to disperse to other habitats.

The table below **outlines** some examples of **abiotic factors** that can **limit population size**:

Abiotic factor	Effect On Population
Light intensity	Low light intensity reduces photosynthesis , limiting the biomass produced by producers and the food available to consumers.
Oxygen availability	Low oxygen availability restricts aerobic respiration.
Soil composition and mineral ions	A shortage of mineral ions limits the biomass producers can make.
Water availability	Lack of water reduces metabolic function.



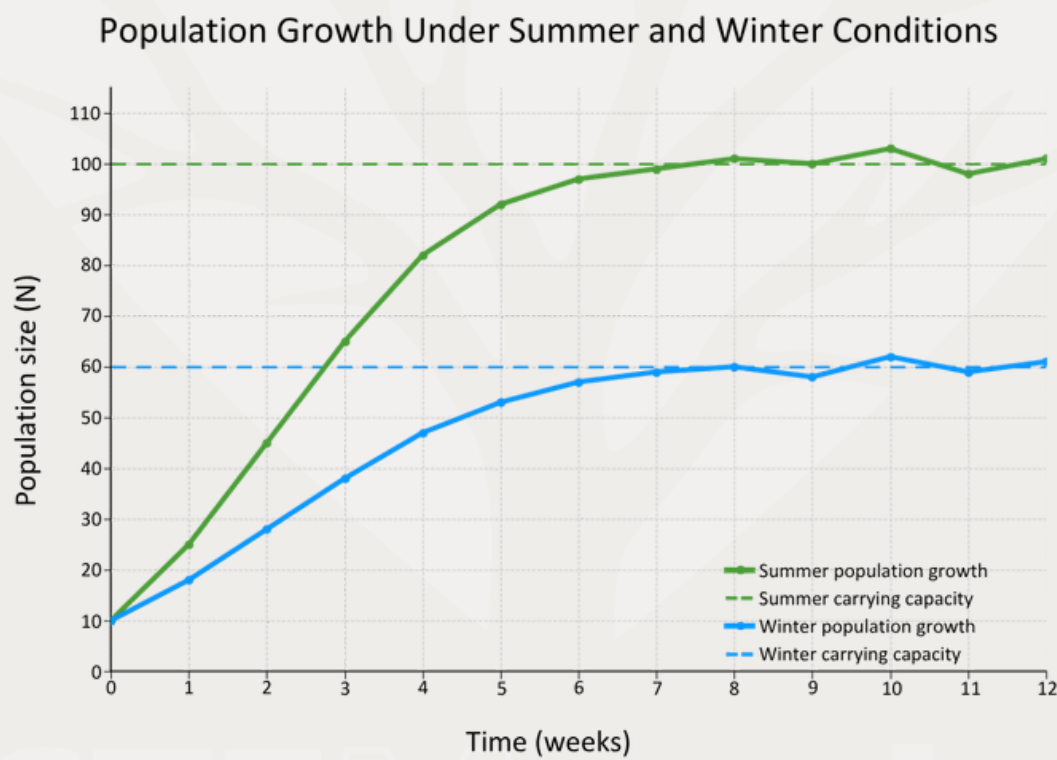
Module 6: Populations and Limiting Factors



The table below **outlines** some examples of **biotic factors** that can **limit population size**:

Biotic factor	Effect on population
Accumulation of waste	Toxic waste products accumulate faster than decomposers break them down, causing harm and disrupting metabolic function .
Disease	Pathogens increase the death rate .
Food availability	The biomass at the trophic level below limits the number of consumers .
Predation	Predators raise the death rate of the prey population .

The graph below **shows** the **carrying capacity** of a woodland **ecosystem** during the **summer** and **winter**:



The graph above **shows** how the **lower temperatures and light intensity** during winter **lower the carrying capacity** of the environment.



Module 6: Interactions Between Populations



Organisms within a habitat **interact** with one another **as they acquire resources**.

Interactions between organisms are **either interspecific or intraspecific**:

- **Interspecific interactions** occur **between populations of different species** as organisms compete for resources (e.g. food, light, space) or engage in predator-prey relationships*.
- **Intraspecific interactions** occur **within the population of a single species** as organisms compete for resources (e.g. food, mates, territory).

***Predator-prey relationships** are **one type of feeding interaction**; other types include herbivory, parasitism, and mutualism. Predator-Prey relationships are the specific example given in the OCR A Level Biology specification.

Competition

Competition **occurs** when organisms require the same **resource that is limited**.

Predation

Predation is when one organism (the **predator**) hunts, **kills and eats another organism** of a different species (the **prey**).

Predator-prey relationships describe the **effect** that this interaction has on the **populations of both the predator and prey species**.

Each population in a predator-prey relationship acts as a **limiting factor on the other**:

- The **prey population is limited by predation**, because predators raise the mortality rate of the prey.
- The **predator population is limited by prey availability**, because a shortage of prey raises the mortality rate of the predator.

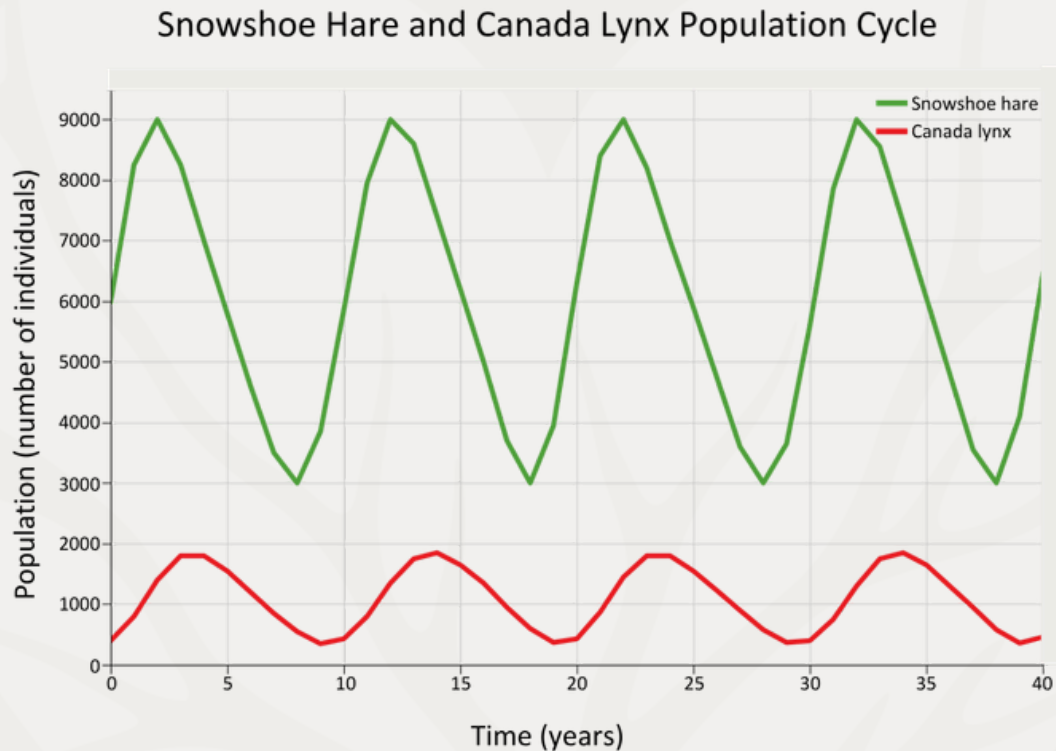
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Module 6: Interactions Between Populations



The graph below **shows** the **cyclical changes** in **population size** observed in a **predator-prey cycle**:



The graph **above demonstrates** the **time delay** between a change in one population and the change it causes in the other.

It is useful to know that scientists have **documented clear predator-prey cycles** in the **Canadian lynx** and the **snowshoe hare** due to long-term data sets **recorded over a century** by fur traders recording the number of pelts from wild animals that were traded.

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Module 6: Conservation and Preservation



Biodiversity can be **protected** by **conservation** and **preservation**:

- **Conservation** is the **active management** of an ecosystem to **maintain or restore its biodiversity** by actively managing it and allowing **humans to live in the area sustainably**.
- **Preservation** is the **protection** of an ecosystem from human activity by **limiting its access and use**.

It is important to note that conservation and preservation can primarily be **distinguished** by whether or not human activity is **permitted** (as with **conservation**) or heavily **restricted** (as with **preservation**).

Reasons for Conservation and Preservation

Conservation and/or **preservation** of biodiversity is **justified** for **economic, social** and **ethical** reasons:

- **Economic** reasons include **products, research** (e.g. **new medicines**), raw **resources**, services (e.g. **ecosystem services, ecotourism**) and the **employment** opportunities they bring.
 - **Social** reasons include its **aesthetic, cultural** and **spiritual value**, as well as its **educational** and **recreational** use.
 - **Ethical** reasons include a sense of human **responsibility** and **stewardship** for the natural world to **preserve species** for their own sake.
-

Conservation

Conservation is the **human activity** undertaken to **maintain biodiversity**.

Conservation is carried out either **in situ** or **ex situ**:

- **Ex situ** conservation is conservation carried out **outside the natural habitat**.
- **In situ** conservation is conservation carried out **within the natural habitat**.

Approaches to conservation are explored in greater detail in Module 4.





Preservation

Preservation is the **maintenance of habitats and ecosystems in their present condition** by **minimising human impact**.

Considering when **preservation** is most **appropriate** includes:

- **Habitat sensitivity:** What degree of human activity would alter the habitat irreversibly.
- **Species vulnerability:** What rare, threatened or endangered species that live there would be irreversibly harmed by a disturbance.
- **Habitat condition:** Is the habitat undisturbed and in an original condition that can be maintained.

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Module 6: Managing Ecosystems and Resources



Human population growth has made human exploitation of ecosystems for resources increasingly **unsustainable** and **damaging** to habitats.

Controlling the Effects of Human Activities

As **awareness increased** about the impact of human activity on the environment over time, so have efforts to reduce it through **conservation increased**.

The table below **outlines** some examples of **measures** used to **control** the effects of **human activity**:

Effect	Measures
Habitat loss and fragmentation	- Degraded habitats are actively repaired (e.g. removing drainage to restore wetlands). - Areas are given legal protection (e.g. national parks, nature reserves, marine conservation zones) to restrict any activity within them. - Habitats are maintained via deflected succession (e.g. coppicing), and wildlife corridors are created to join up isolated populations.
Overexploitation	- No-take zones prohibit fishing entirely, and endangered species are given legal protection (e.g. CITES legally regulates international trade). - Quotas limit the mass of a resource (e.g. fish, timber) that may be taken, closed seasons protect species during breeding, and permits and penalties are used for enforcement.

Managing Conflict Between Human Populations and Conservation Efforts

Conflict arises when **conservation efforts** to protect an ecosystem interfere with the **local human population's needs** to acquire resources.

Conservation projects that do not take into account the needs of the local population are likely to **encounter resistance** or **create conflict** between humans and wildlife.

Examples of successful conservation measures that **balance** the needs of the **local population** include:

- **Regulated use:** Local people continue using natural resources but at a **sustainable rate** (e.g. coppicing, quotas).
- **Investment:** Encourage **ecotourism to create local jobs**, compensate owners for ending environmentally destructive activities or set aside land for conservation.
- **Community involvement:** Involve and **educate local people** so that they know of, have a voice in, and have responsibility for conservation decisions that can affect and benefit them.





Sustainable Management of Ecosystems: Timber

Trees are harvested to produce **timber**, which is **used in construction, manufacturing, and for energy**.

Sustainable timber production considers:

- **Harvest rate:** Trees are **replaced as fast as they are harvested**, either by regrowth from the cut stem (e.g. coppicing) or by replanting.
- **Ecological integrity:** Forest **ecosystems are managed** so that the nutrient content (e.g. mineral ions) of the **soil is not degraded**, and a **range of habitats** are available to support species biodiversity.
- **Local benefit:** Timber production provides **local jobs**.

Examples of some sustainable **management techniques** used in timber production include:

- **Coppicing:** The stem of a deciduous tree is **cut down to just above the ground**, so that the remaining stump produces **many individual stems**.
- **Pollarding:** The stem of a deciduous tree is **cut higher up the tree**, so that **many individual stems** are produced above the height a grazing herbivore (e.g. deer) can reach.
- **Rotational coppicing/pollarding:** The wood is divided into areas, and only **one area is coppiced each year**.
- **Standards:** **Full-sized trees** are left uncut and allowed to grow larger, with **smaller trees managed by coppicing growing under the canopy**.

Sustainable Management of Ecosystems: Fishing

Overfishing has **reduced** many **fish populations** faster than their rate of reproduction. **Fish** are harvested from marine ecosystems to **provide food** for millions of people.

Sustainable fishing considers:

- **Harvest rate:** Fish are **caught at a rate** that ensures the **population** will be able to **return to its original size**.
- **Ecological integrity:** **Fishing is regulated** so that marine **ecosystems are not damaged** by indiscriminate fishing techniques (e.g. bottom trawling).
- **Local benefit:** Fishing provides **local jobs**.

Sustainable management of wild fish populations involves the **regulation of fishing** in ecosystems to **avoid irreversible harm to habitats and/or ocean populations**.





Sustainable fishing regulations consider:

- **Quantity caught:** The **mass of fish** that is and could be caught by fishing vessels.
- **Species and size caught:** **Which fish** are removed by fishing vessels.
- **Time and place:** **When and where** fishing may occur.

The table below **outlines** how **wild capture** is **managed sustainably**:

Sustainable Aspect	Description
Harvest rate	Only adult fish that have been able to breed are caught. Fish are caught at a rate that does not reduce the population's ability to return to its original size. Fishing may be prohibited to give populations time to recover.
Ecological integrity	Fishing is regulated so that habitats are not damaged by indiscriminate fishing techniques (e.g. bottom trawling) and non-target species are not caught (e.g. regulating fishing net sizes), whilst prohibiting fishing during breeding season to allow for reproduction.
Local benefit	Sustainable fishing ensures that jobs will be commercially viable in the long term .

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