



STEMpathy

OCR A Level Biology

A (H420)

Revision Notes for Year 2

Created by STEMpathy | March 2026

© STEMpathy 2026. All rights reserved. www.stempathy.co.uk
For personal study use only. Not to be copied, redistributed, or sold.
While accuracy has been checked, STEMpathy cannot guarantee absolute completeness.
Always refer to the official OCR specification and other authoritative sources.



Module 5: Communication, Homeostasis and Energy

1. Introduction to Communication Systems
2. Homeostasis and Feedback Systems
3. Thermoregulation: Ectothermy and Endothermy
4. The Importance of Excretion
5. Functions of the Liver
6. Liver Anatomy and Histology
7. Kidney Anatomy and Histology
8. Kidney Nephrons: Filtering the Blood
9. Osmoregulation: The Collecting Duct and ADH
10. Kidney Failure
11. Urine Analysis
12. Introduction to the Nervous System
13. Sensory Receptors
14. Neurones
15. Nerve Impulses
16. Synapses
17. Introduction to the Endocrine System
18. The Adrenal Glands
19. The Pancreas
20. Control of Blood Glucose
21. Diabetes Mellitus
22. Introduction to Plant Responses
23. Hormonal Control of Stem Elongation
24. Hormonal Control of Seed Germination
25. Hormonal Control of Apical Dominance
26. Introduction to Communication Systems in Animals
27. The Mammalian Nervous System
28. Mammalian Muscle Structure
29. Neuronal Control of Striated Muscle
30. Photosynthesis and Chloroplasts
31. The Light-Dependent Reactions
32. The Light-Independent Reactions
33. Factors Affecting the Rate of Photosynthesis
34. Thin-Layer Chromatography of Plant Pigments
35. Respiration and Mitochondria
36. Aerobic Respiration
37. Anaerobic Respiration
38. Respiratory Quotient
39. The Interrelationship Between Photosynthesis and Respiration
40. Factors Affecting the Rate of Respiration
41. Investigating the Rate of Respiration

Module 6 Coming soon!

STEMpathy



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 → 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**.

STEMpathy



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.	$\sim 4-6 \text{ mmol dm}^{-3}$	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.

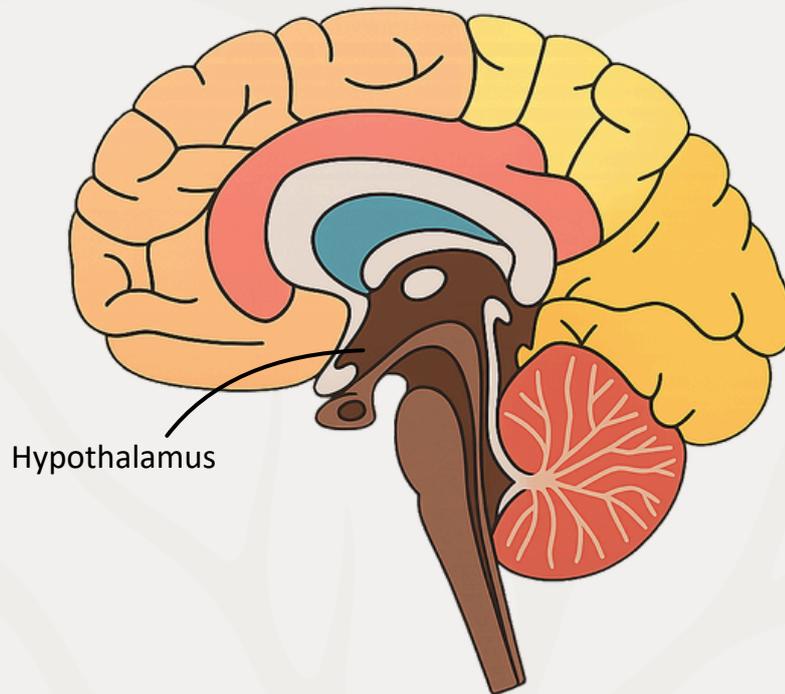
It is useful to know that the control centre for many homeostatic responses in animals is the hypothalamus, a small, central region of the brain.



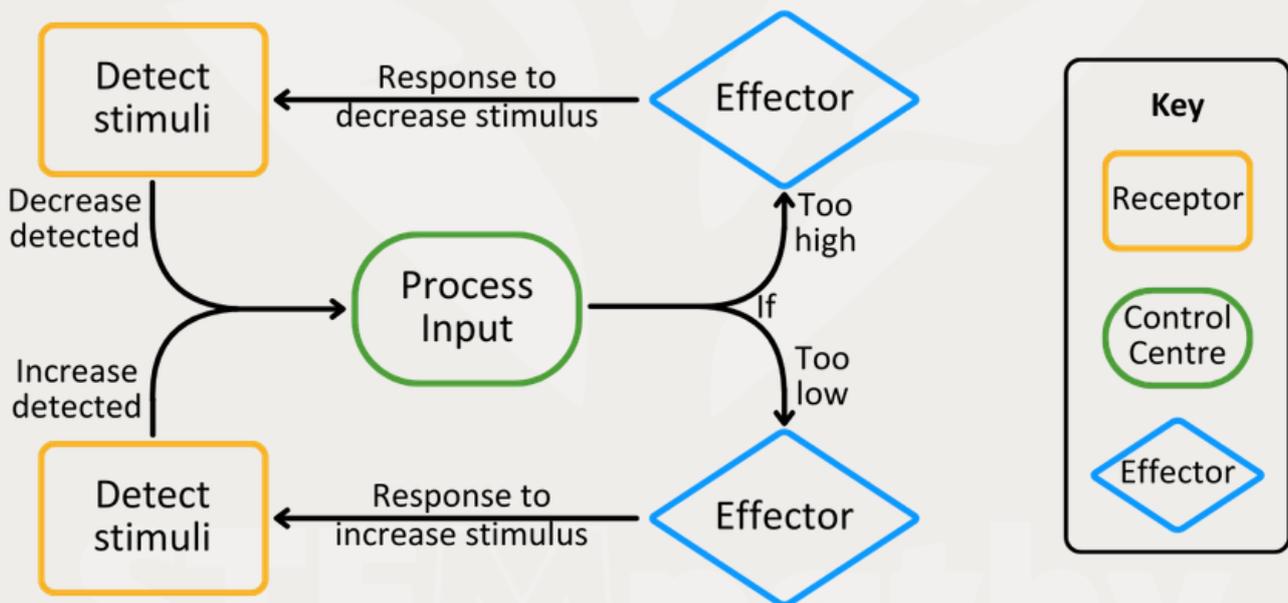
Module 5: Homeostasis and Feedback Systems



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.

STEMpathy



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.

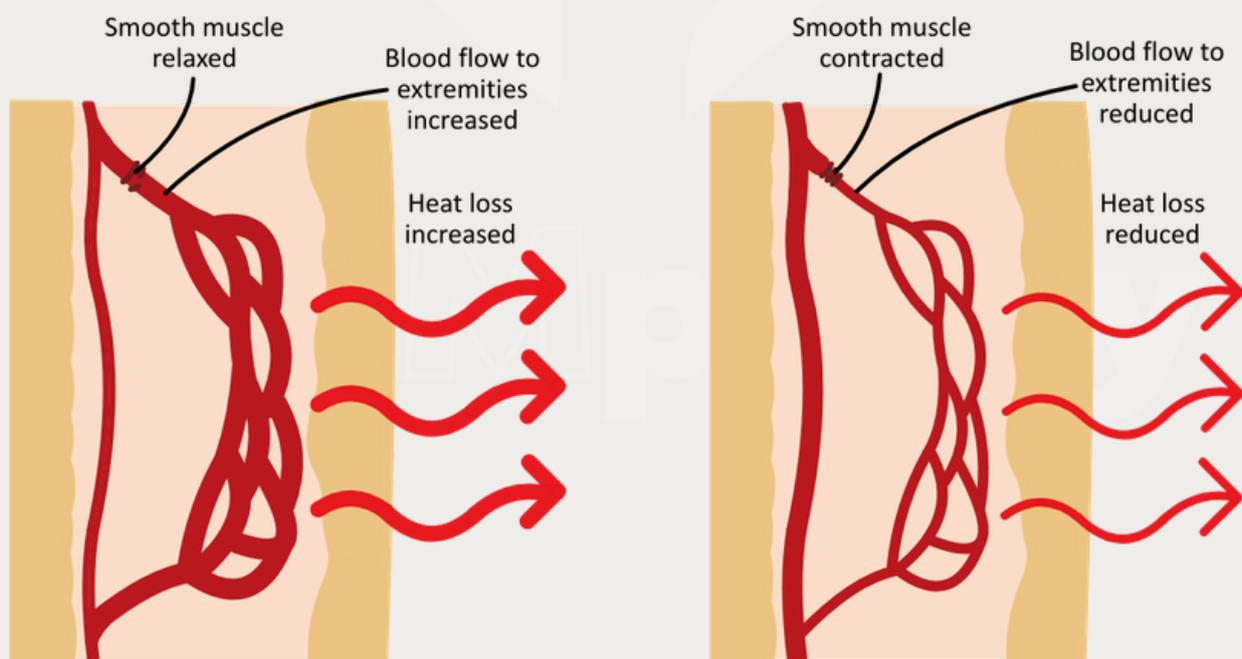
Physiological responses require communication systems to monitor stimuli and coordinate effectors. Consequently, their mechanism of action is that of a negative feedback process.

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.





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** ($\text{H}^+ + \text{HCO}_3^-$).

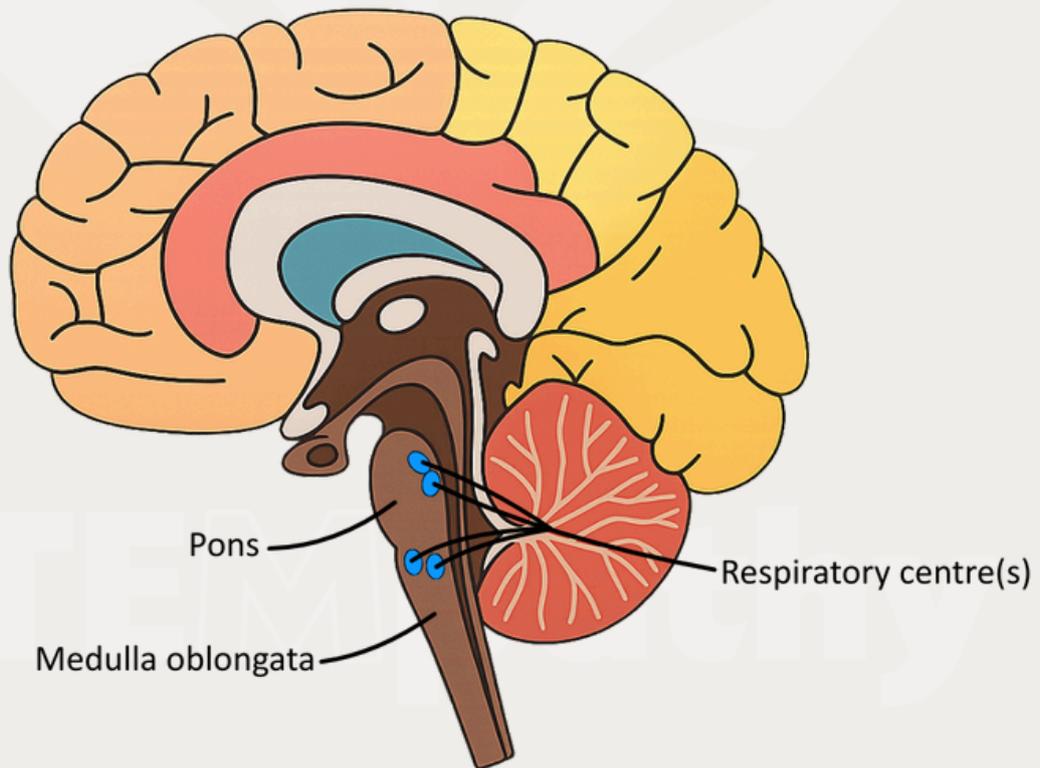
Most carbonic acid dissociates inside **red blood cells** (being catalysed by carbonic anhydrase), but some dissociation still occurs (slowly) in the blood plasma.

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

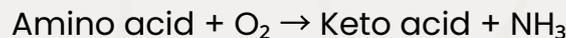


Importance of Excreting Nitrogenous Waste: Ammonia/Urea

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** (NH₂) in deamination to produce a keto acid and ammonia (NH₃).

The process is **outlined** below:



Keto acids can be used in **respiration** or converted into a carbohydrate or fat for **storage**. The **ammonia** (NH₃) formed from the amine group (NH₂) 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**.

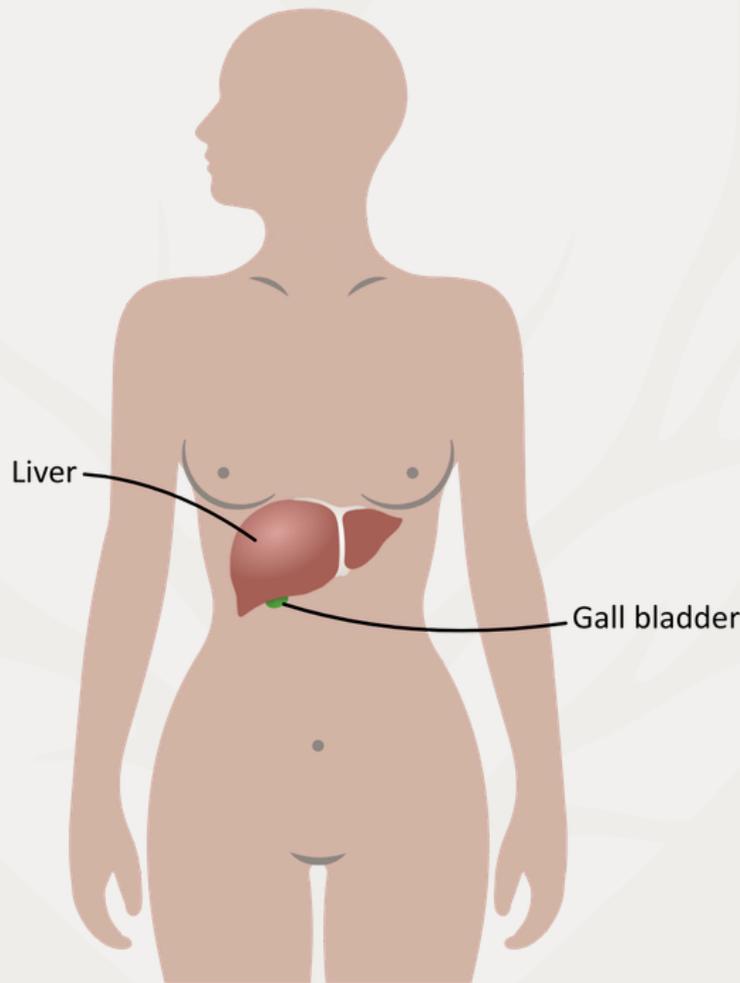
Osmoregulation is coordinated by the **hypothalamus**, which detects changes in blood osmotic potential using **osmoreceptors** and alters the activity of the **kidney** accordingly.





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.

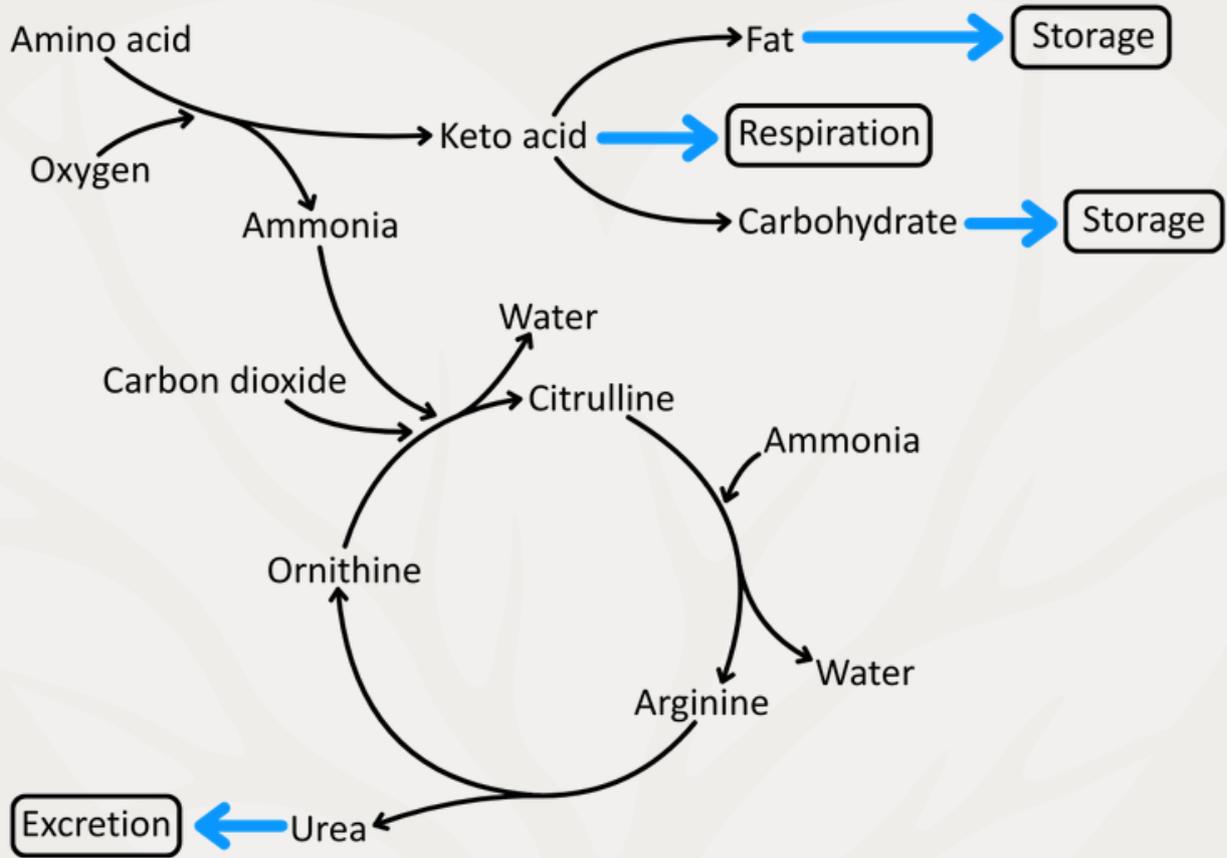
STEMpathy



Module 5: Functions of the Liver



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



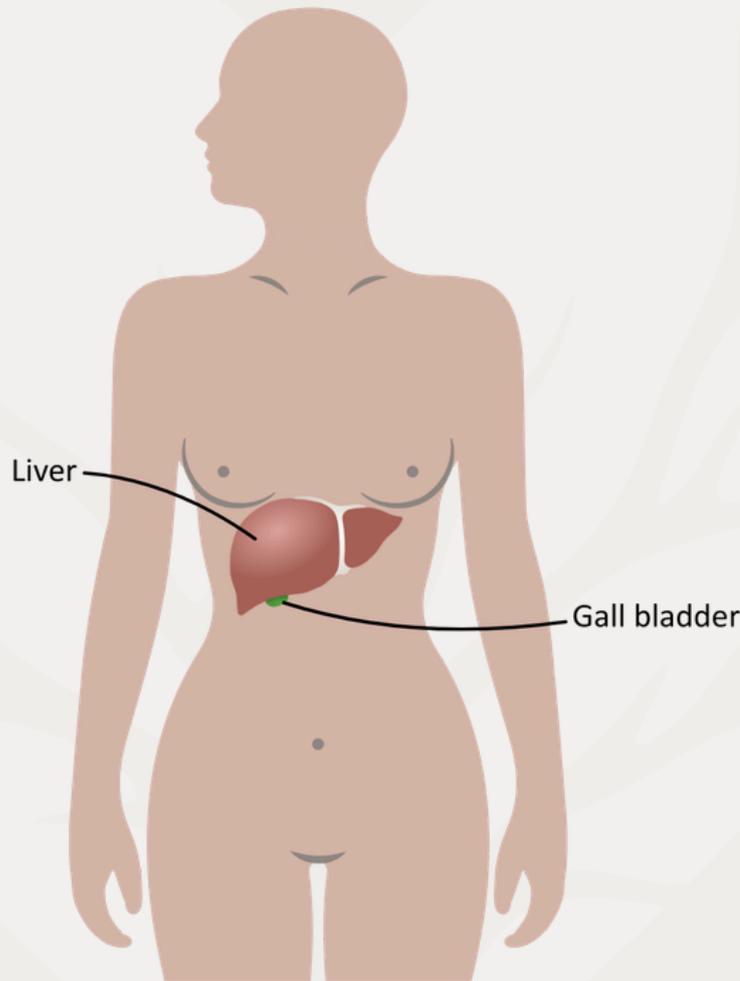
STEMpathy





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**.

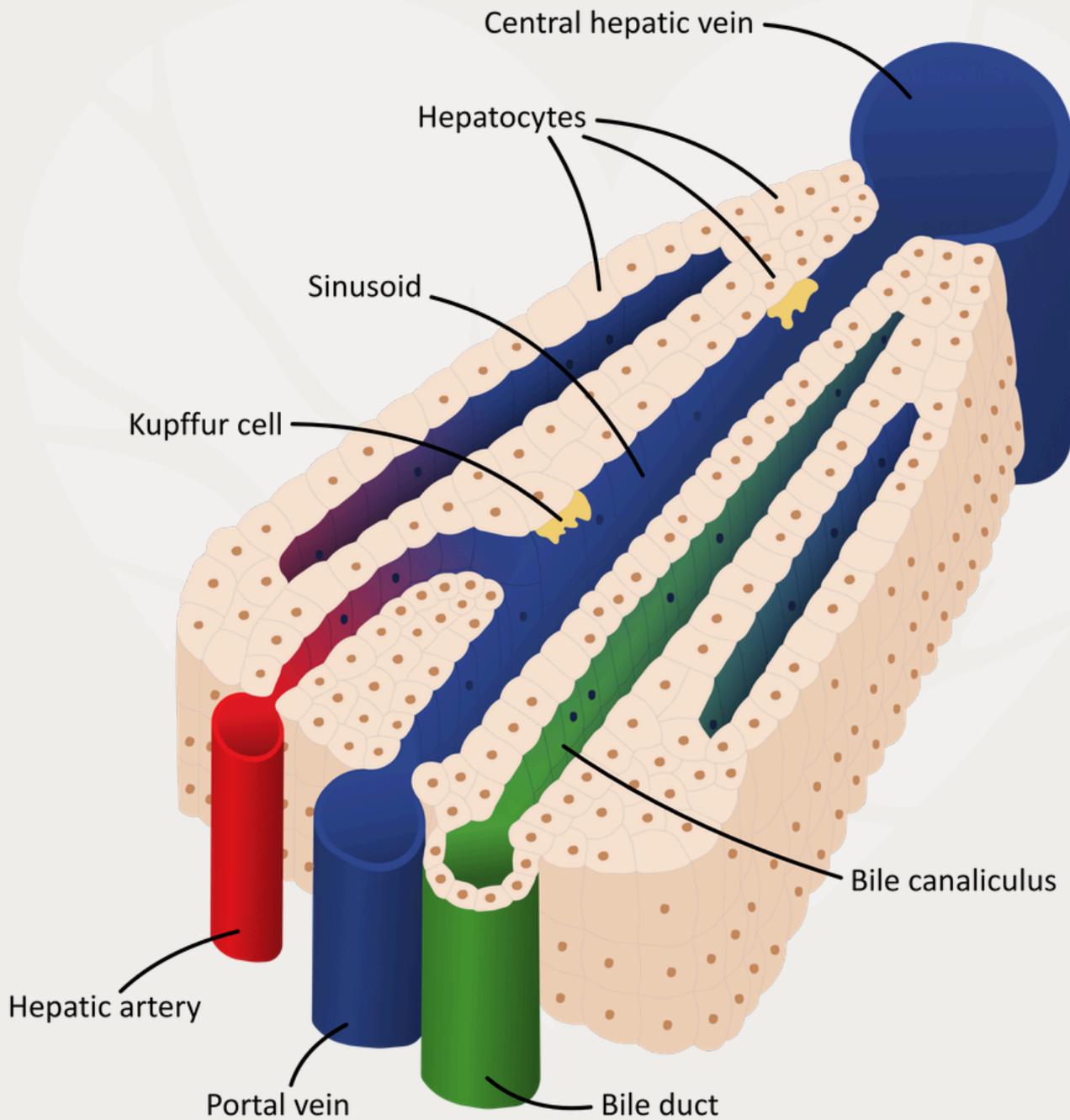
Lobules are a (roughly) cylindrical mass of **hepatocytes** (liver cells) arranged around a **central hepatic vein**, with blood vessels and bile ducts clustered around the outer edges.



Module 5: Liver Anatomy and Histology



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



STEMpathy





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.

STEMpathy

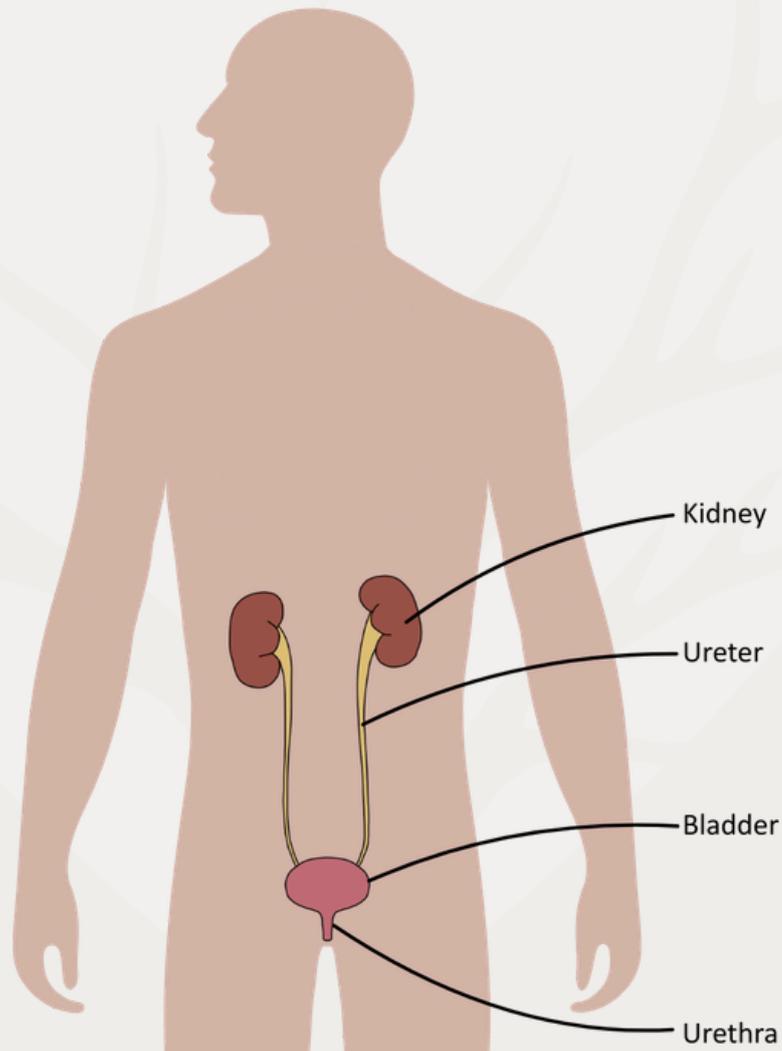




The Kidney

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**:



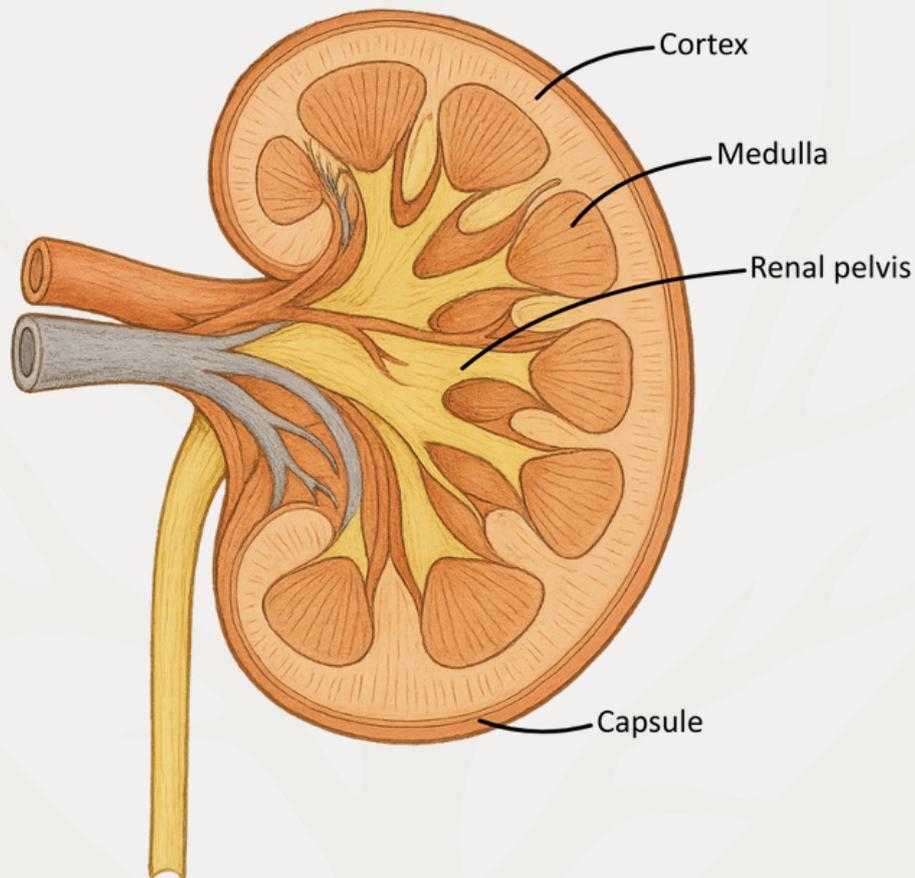
Kidneys are the main organs for **excretion** and **osmoregulation**, and play a central role in **homeostatic processes** that maintain the optimal composition of the blood plasma and tissue fluid, including:

- **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.

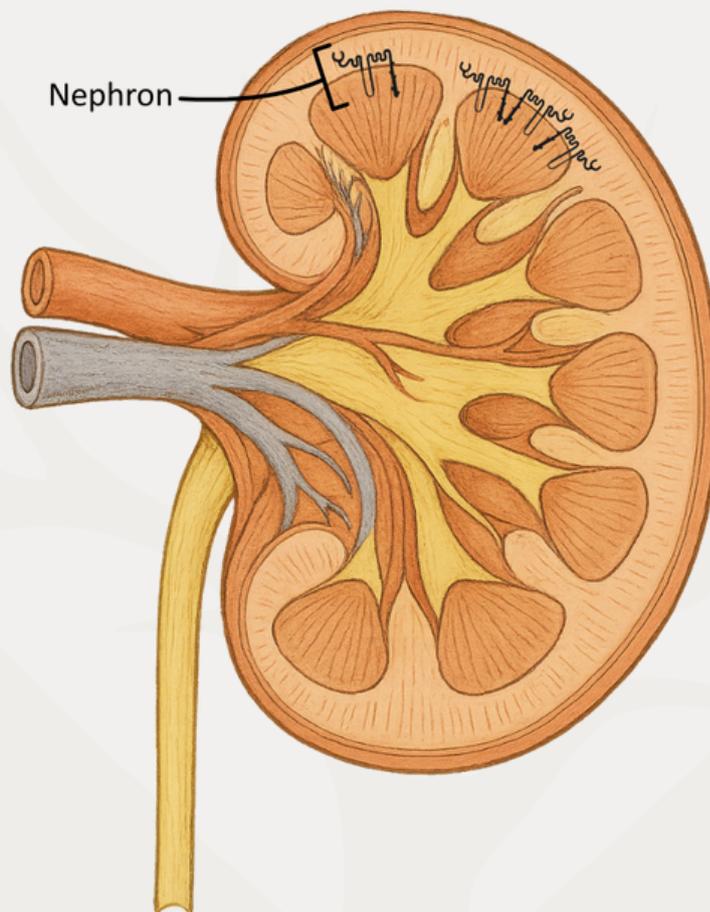




Histology of the Kidney(s)

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.

STEMpathy

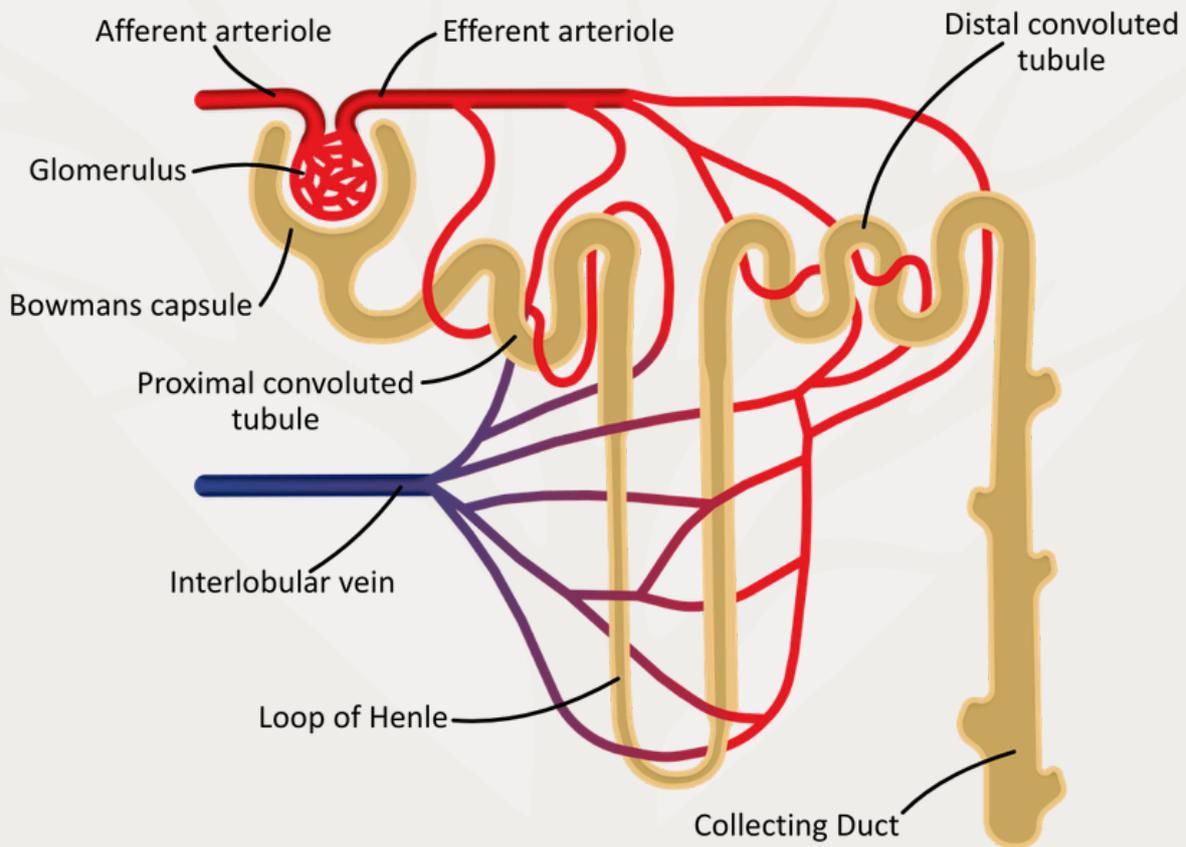


Nephrons

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.





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.

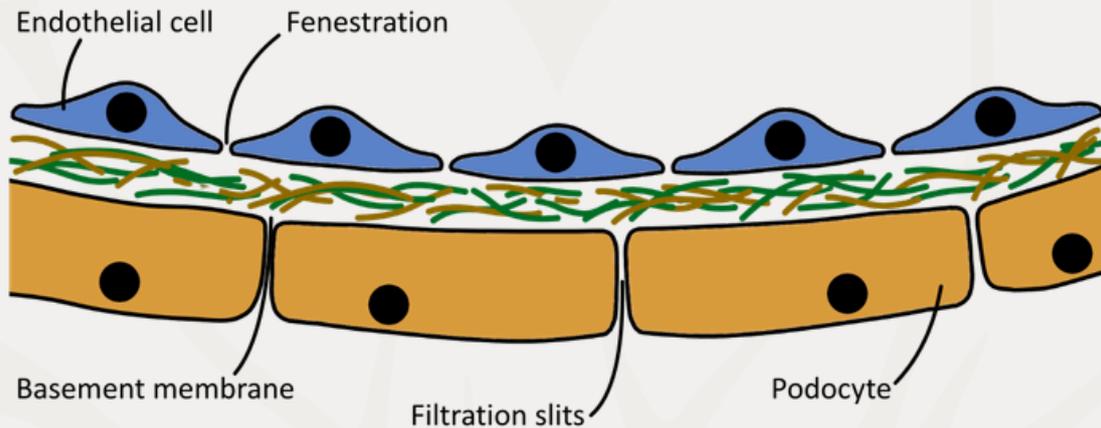


Module 5: Kidney Nephrons: Filtering the Blood



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

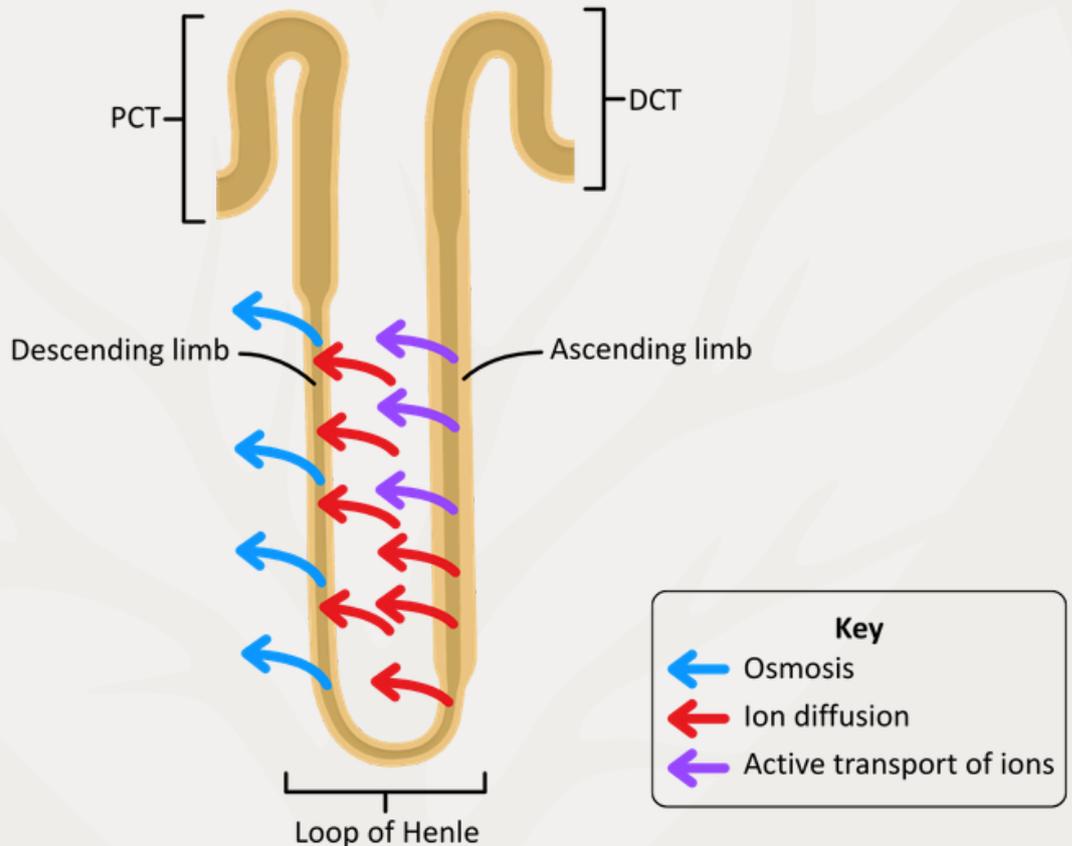
The **hairpin countercurrent multiplier system** is a process arising from the structure and function of the **Loop of Henle**.





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.

STEMpathy



Module 5: Osmoregulation: The Collecting Duct and ADH



Osmoregulation

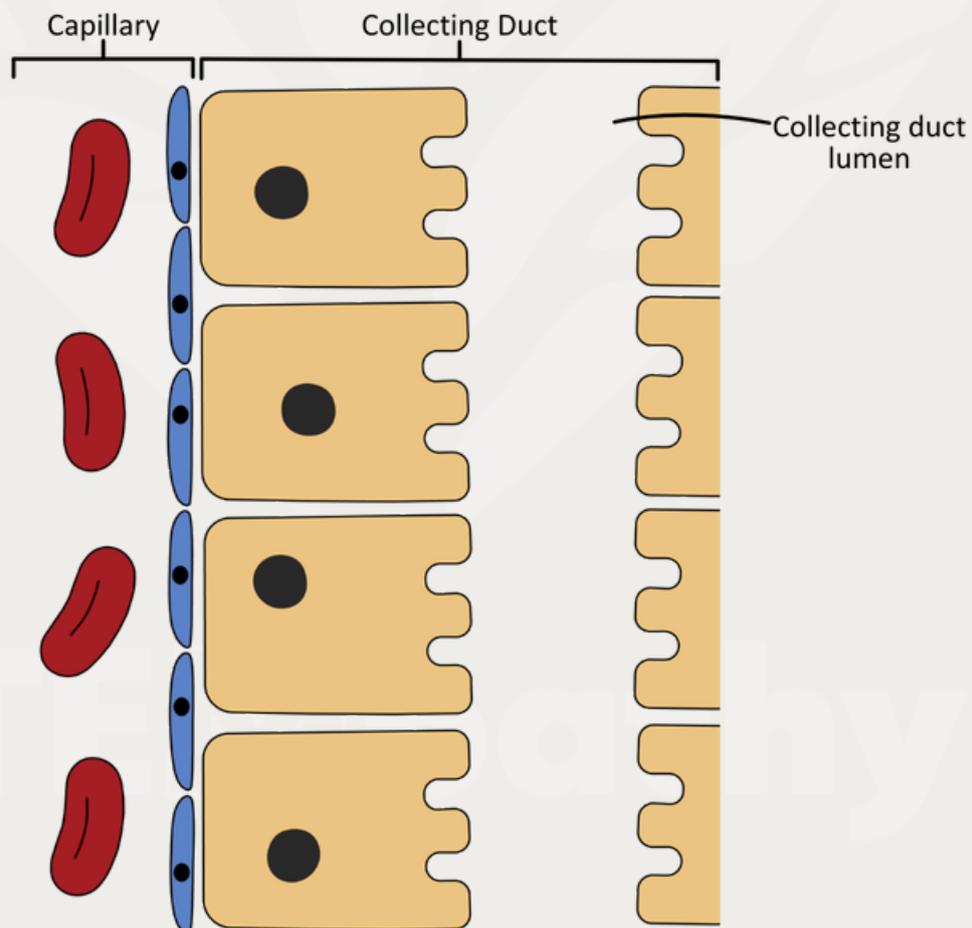
Osmoregulation is the **homeostatic control** of the **water potential** of the blood and the body fluids to minimise cell **shrinking** or **swelling**.

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	<ul style="list-style-type: none">- Glucose filtrate levels exceed the reabsorptive capabilities of the PCT, leading to glucose passing into the urine.- Hyperglycaemia also damages PCT epithelial cells.	<ul style="list-style-type: none">- 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.*	<ul style="list-style-type: none">- 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**.

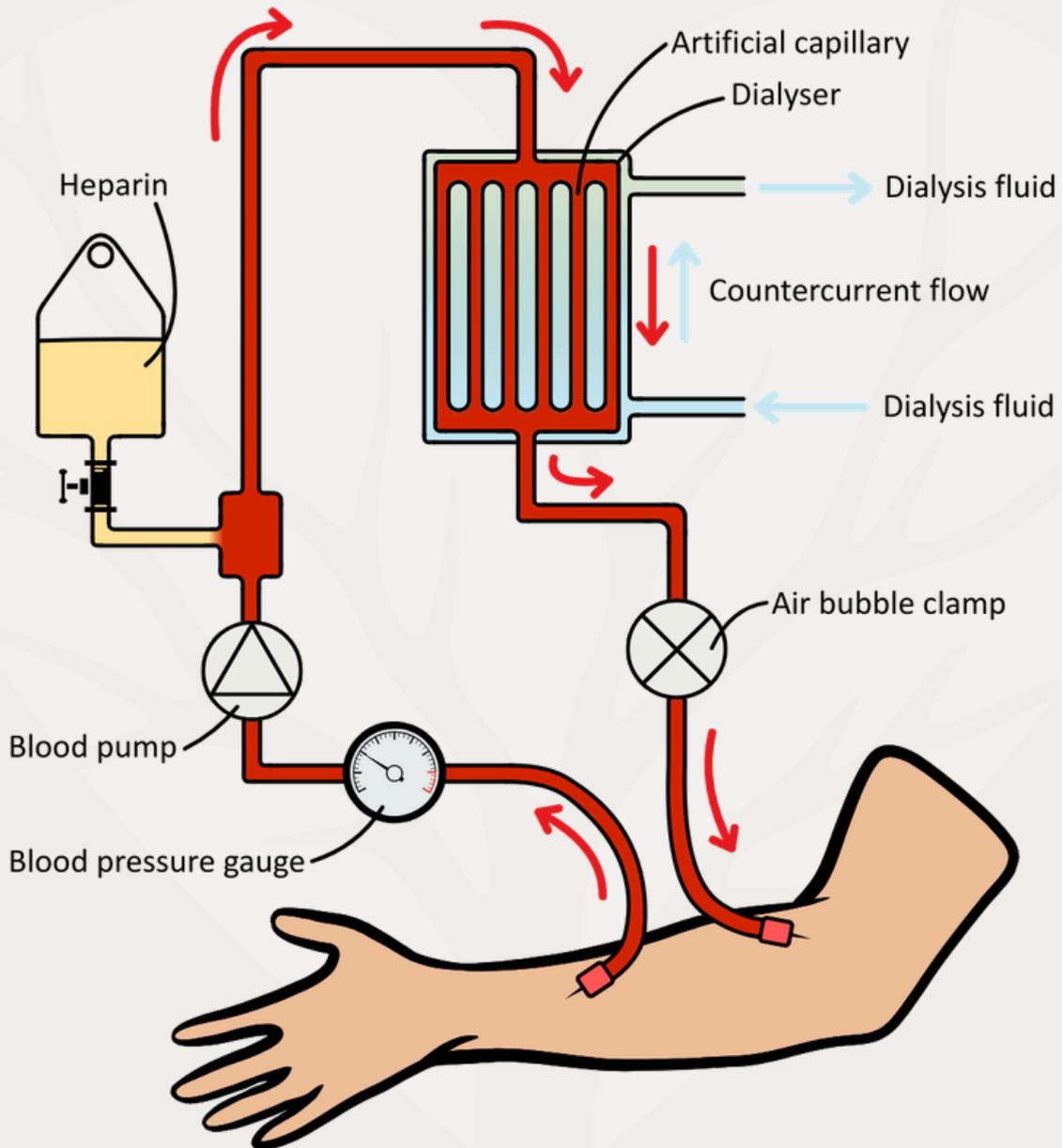
Renal dialysis comes in two forms, but **haemodialysis** is the only one required for OCR A level Biology.



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.

STEMPATHY





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	<ul style="list-style-type: none">- Effective removal of waste and excess water.- Typically supervised with a schedule.	<ul style="list-style-type: none">- Time-consuming sessions.- Carefully monitored diet and fluid limits.- Access to blood vessels needed.
Kidney transplant	<ul style="list-style-type: none">- Better health and well-being.- Freedom from lengthy dialysis sessions.- Greater freedom of travel.	<ul style="list-style-type: none">- Immunosuppressant drugs and risk of rejection.- Risks of major surgery.- Side-effects of immunosuppression (infection).



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.

STEMpathy



Module 5: Introduction to the Nervous System



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).

STEMpathy





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.

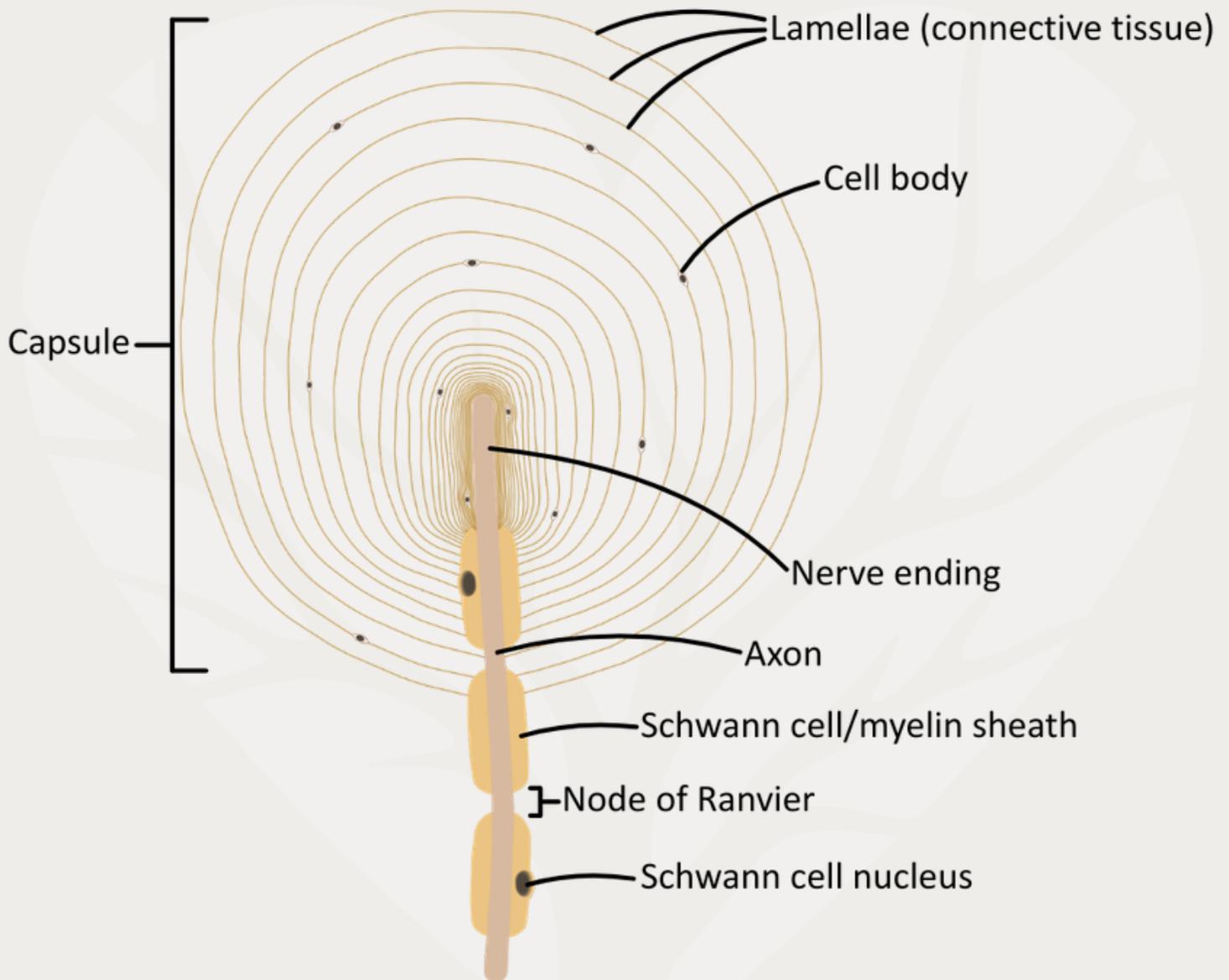
The Pacinian Corpuscle

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**.

STEMpathy

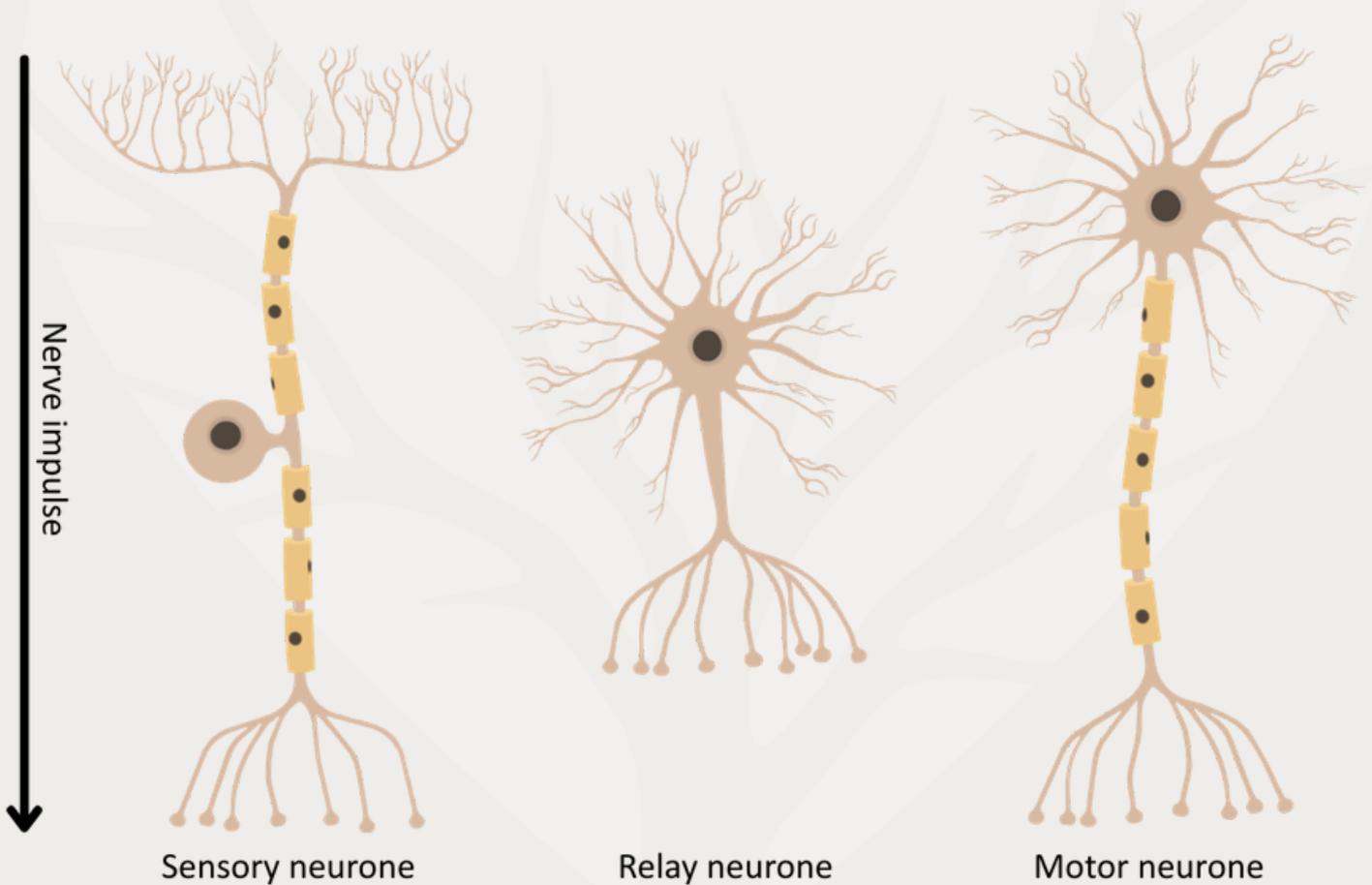




Neurones

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.

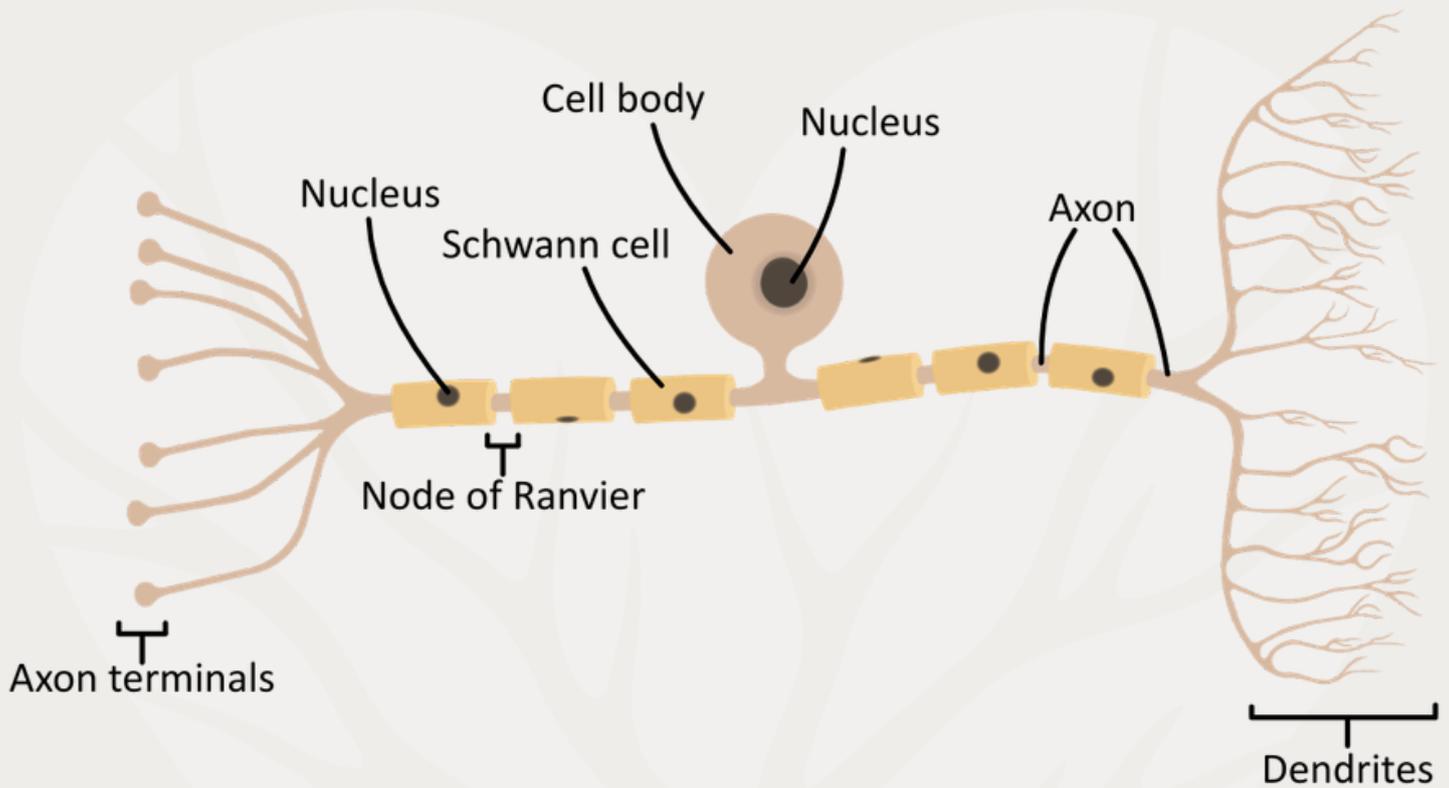
Sensory and **motor** neurones primarily make up the **peripheral nervous system (PNS)**, whilst **relay** neurones make up the **central nervous system (CNS)**.

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

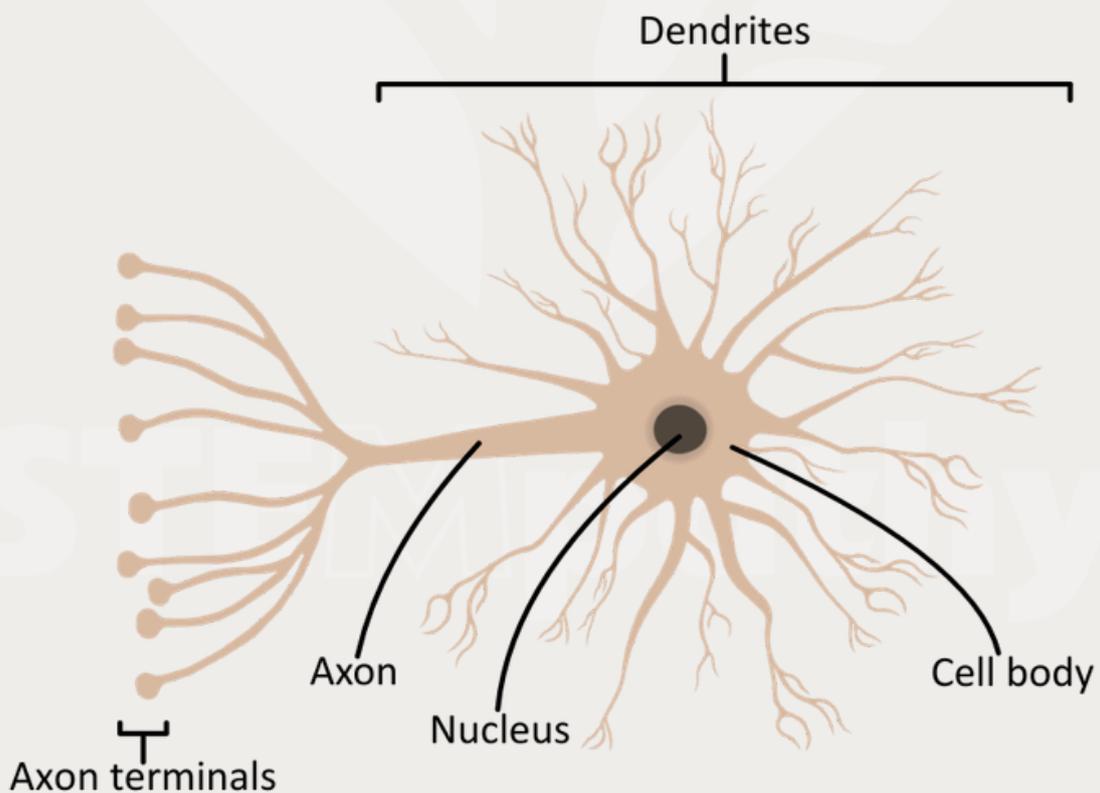




Sensory Neurones

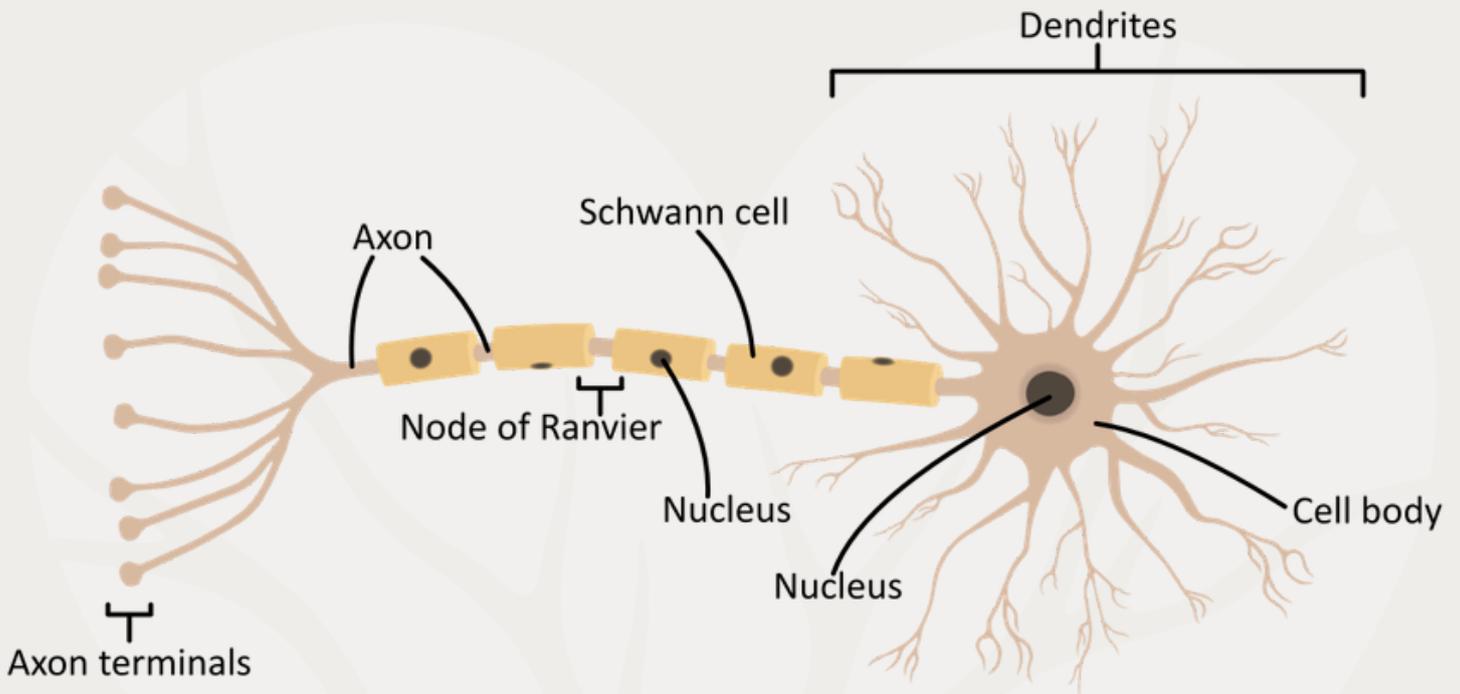


Relay Neurones





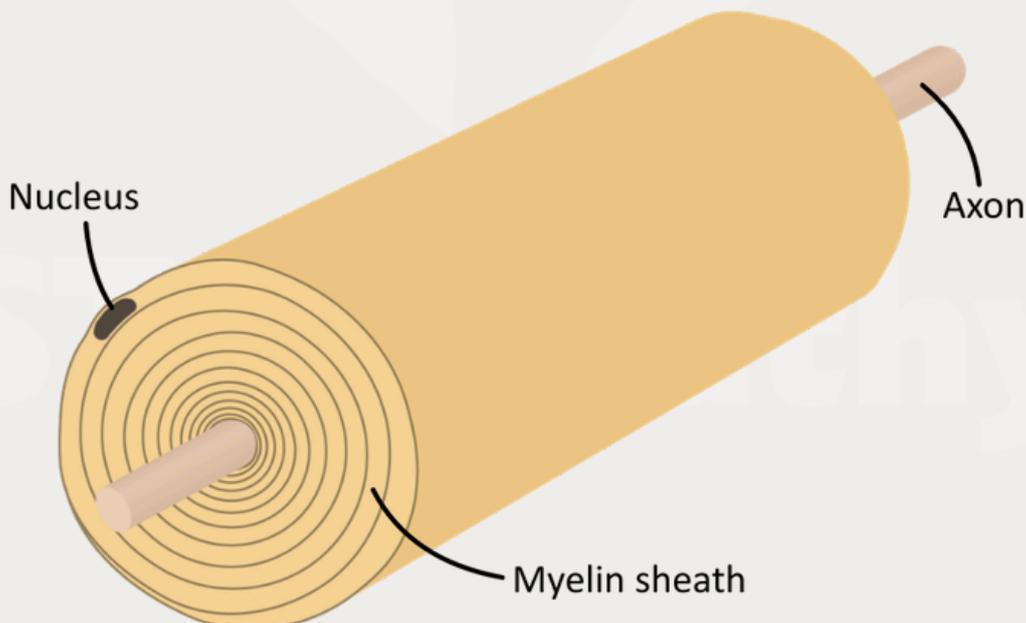
Motor Neurones



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.





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**.

STEMpathy

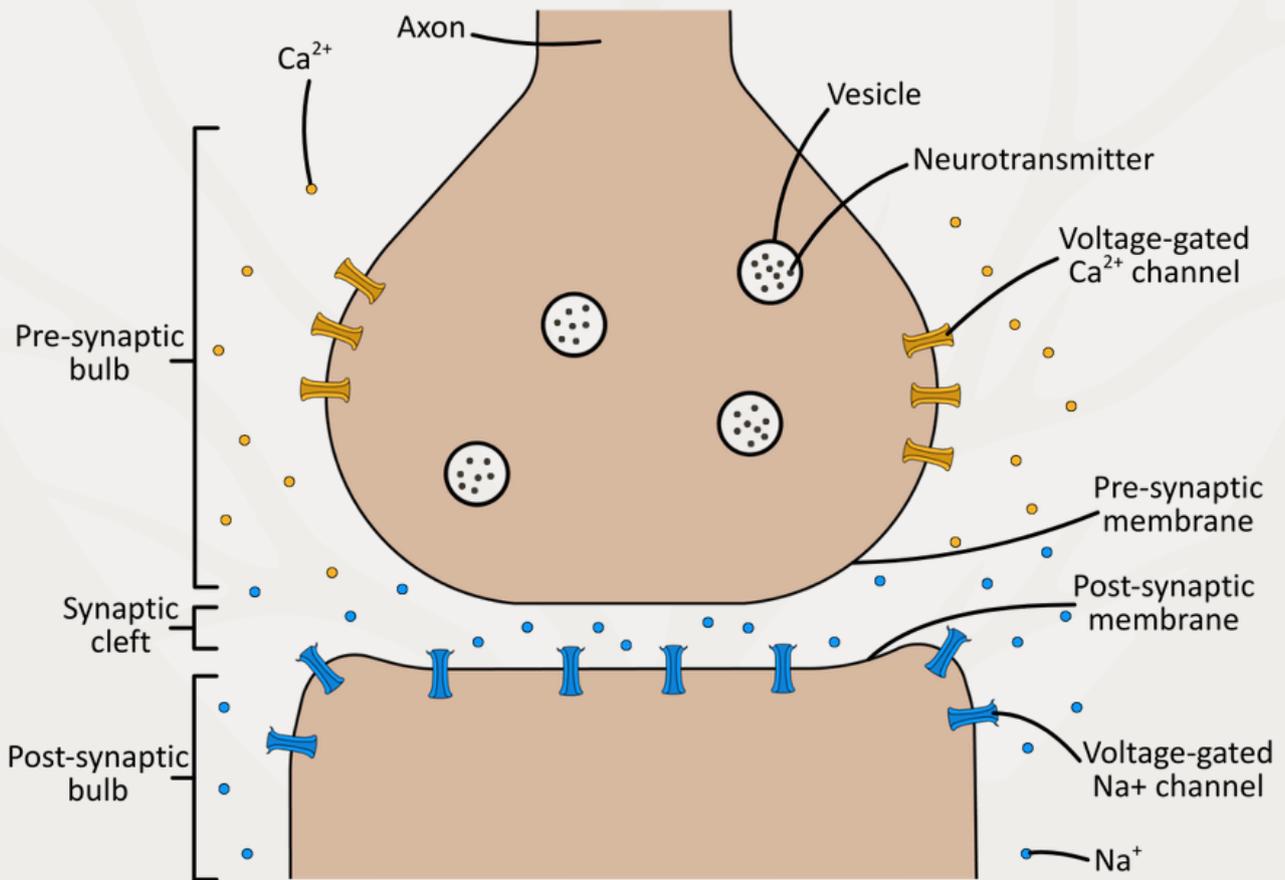


Module 5: Synapses



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.

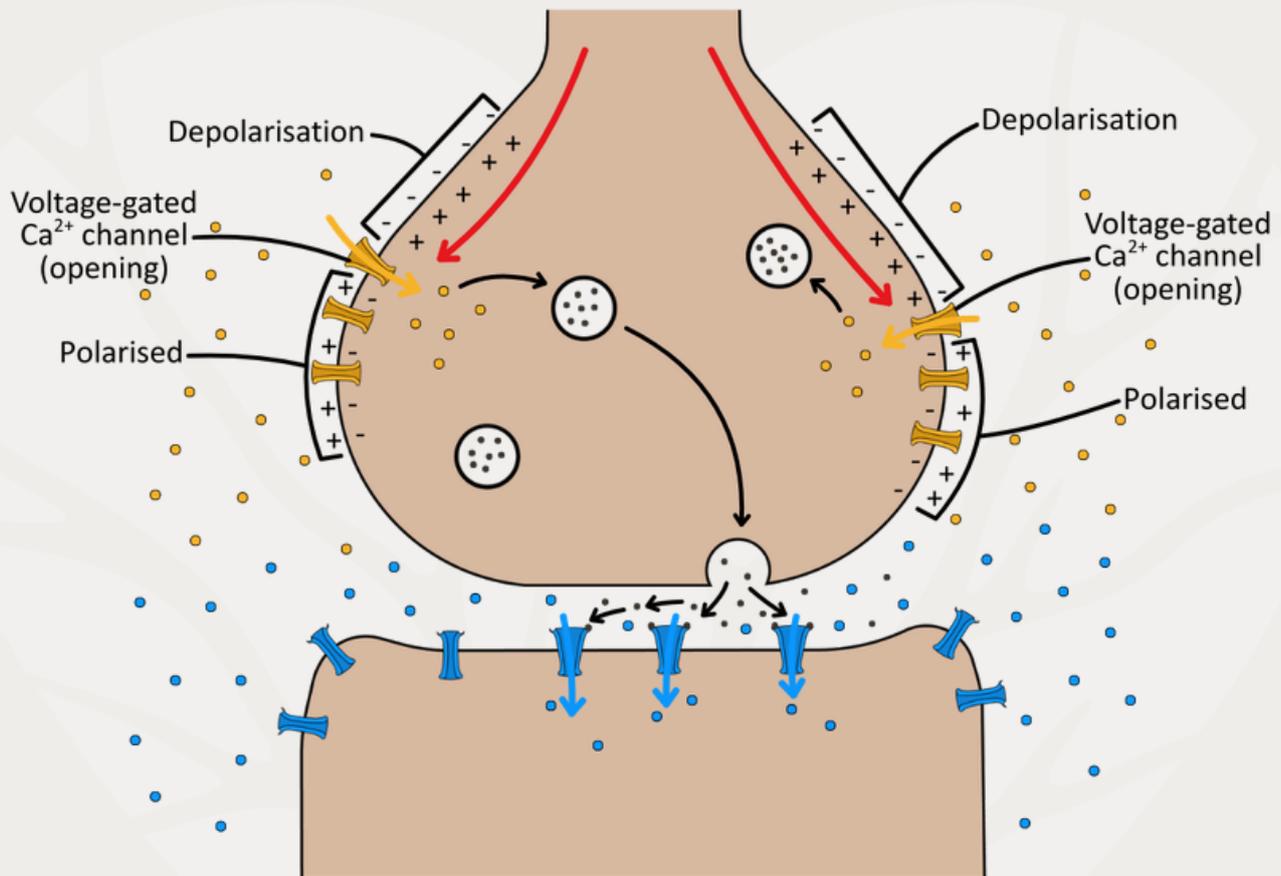
Postsynaptic membranes have specific **receptors** to which **neurotransmitters** can **bind**, that **open** their **ion channels**, resulting in an **excitatory** (depolarising) or **inhibitory** (hyperpolarising) effect on the postsynaptic membrane.

STEMpathy





The diagram below shows the mechanism of excitatory synaptic action:



Key	
	Action potential
	Diffusion of Ca^{2+}
	Diffusion of Na^{+}

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.

STEMpathy



Module 5: Introduction to the Endocrine System



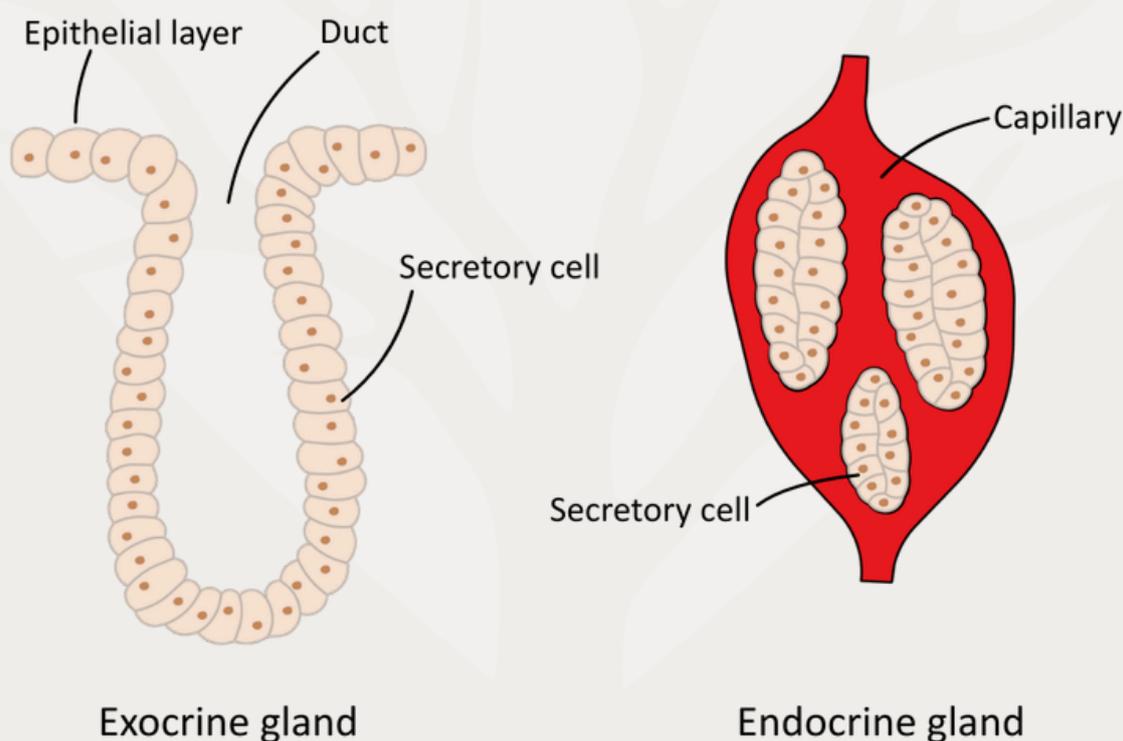
The **endocrine system** is a long-lasting (compared to the neuronal system) **communication** network that **coordinates** the activity of organs and tissues using **chemical messengers** (hormones).

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



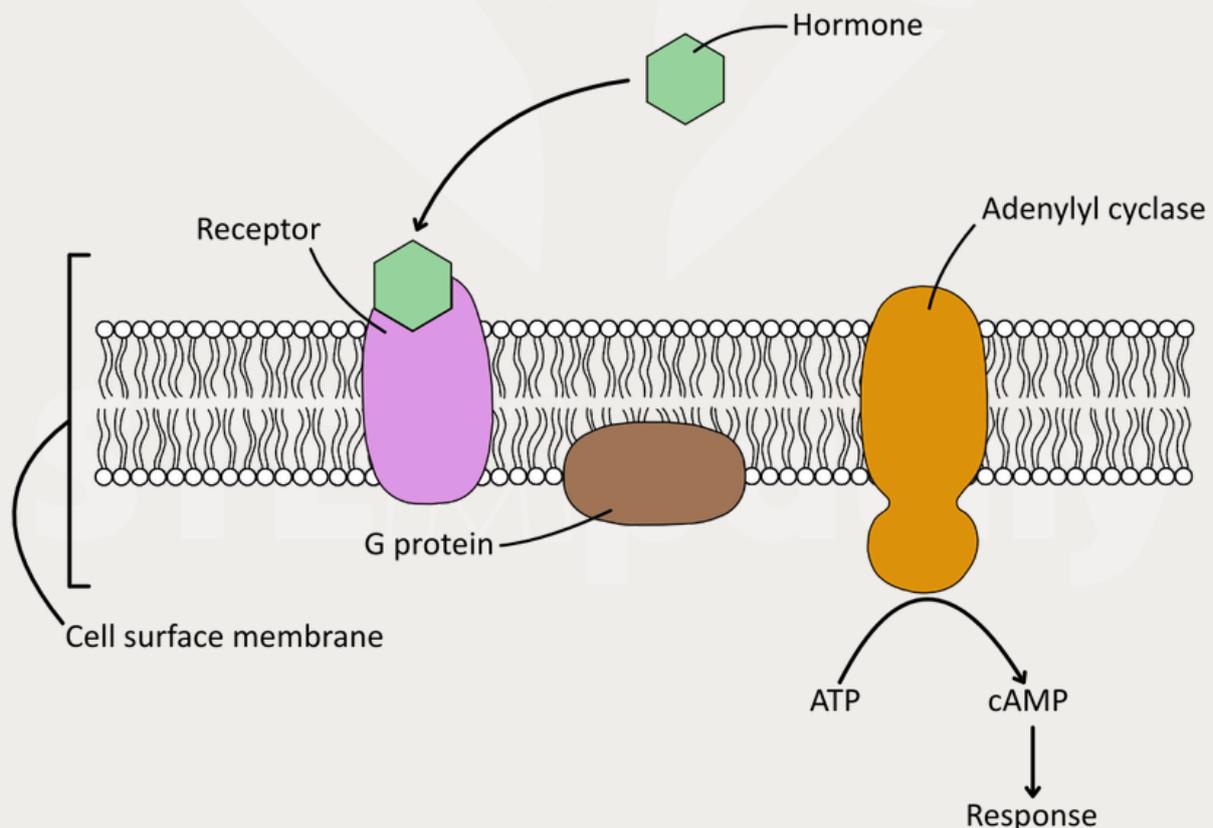
The table below **outlines** some of the different **endocrine glands** and the **role(s)** of their **secreted hormones**:

Endocrine Gland	Main Hormone(s)	Endocrine Gland Role(s)
Adrenal cortex (on kidneys)	<ul style="list-style-type: none"> - Aldosterone (mineralocorticoid) - Cortisol (glucocorticoid) - Androgens 	<ul style="list-style-type: none"> - 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)	<ul style="list-style-type: none"> - Adrenaline - Noradrenaline 	Triggers fight-or-flight responses: <ul style="list-style-type: none"> - Increases heart rate. - Increase ventilation. - Increases Blood glucose. - Increases blood flow to muscles.
Pancreas (islets of Langerhans)	<ul style="list-style-type: none"> - Insulin (β cells) - Glucagon (α cells) 	<ul style="list-style-type: none"> - 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

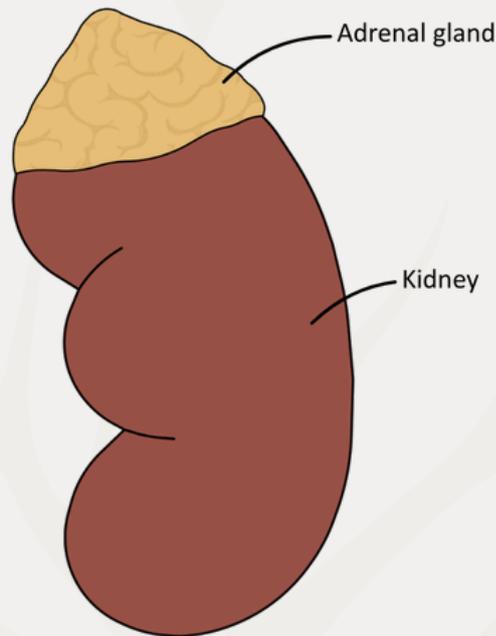




The Adrenal Glands

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

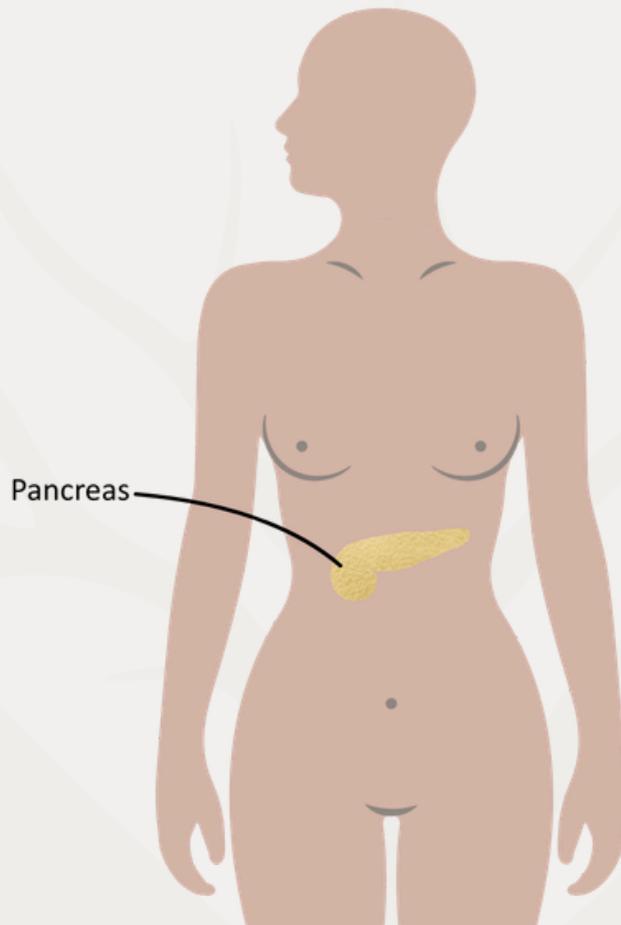




The Pancreas

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**:

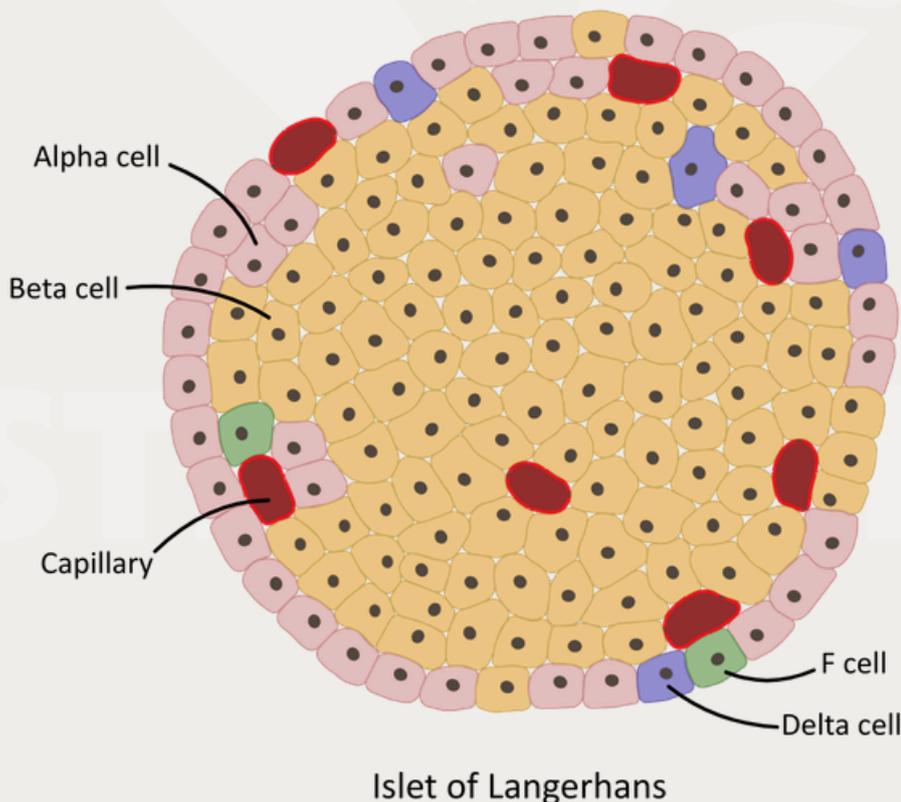
Islet cells → Capillaries → Portal venules → Hepatic portal vein → Liver first

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)	<ul style="list-style-type: none"> - Glycogenesis ↑ - Glucose uptake/use ↑ - Glycogenolysis ↓ - Gluconeogenesis ↓
Glucagon	When blood glucose falls (e.g. fasting, exercise)	<ul style="list-style-type: none"> - Glycogenolysis ↑ - Gluconeogenesis ↑ - Glycogenesis ↓

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



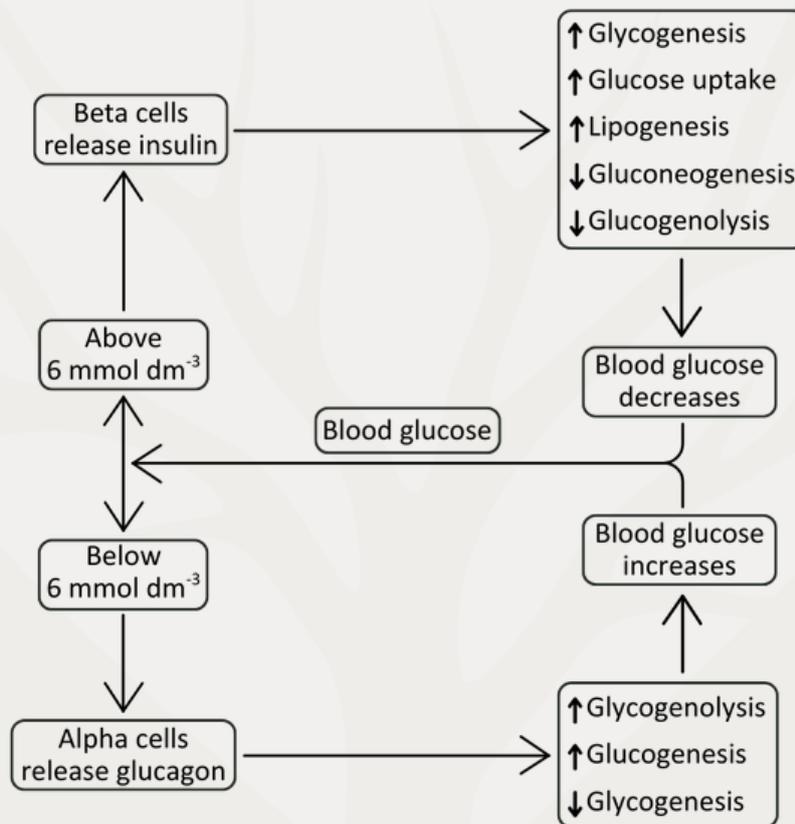


Control of Blood Glucose

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





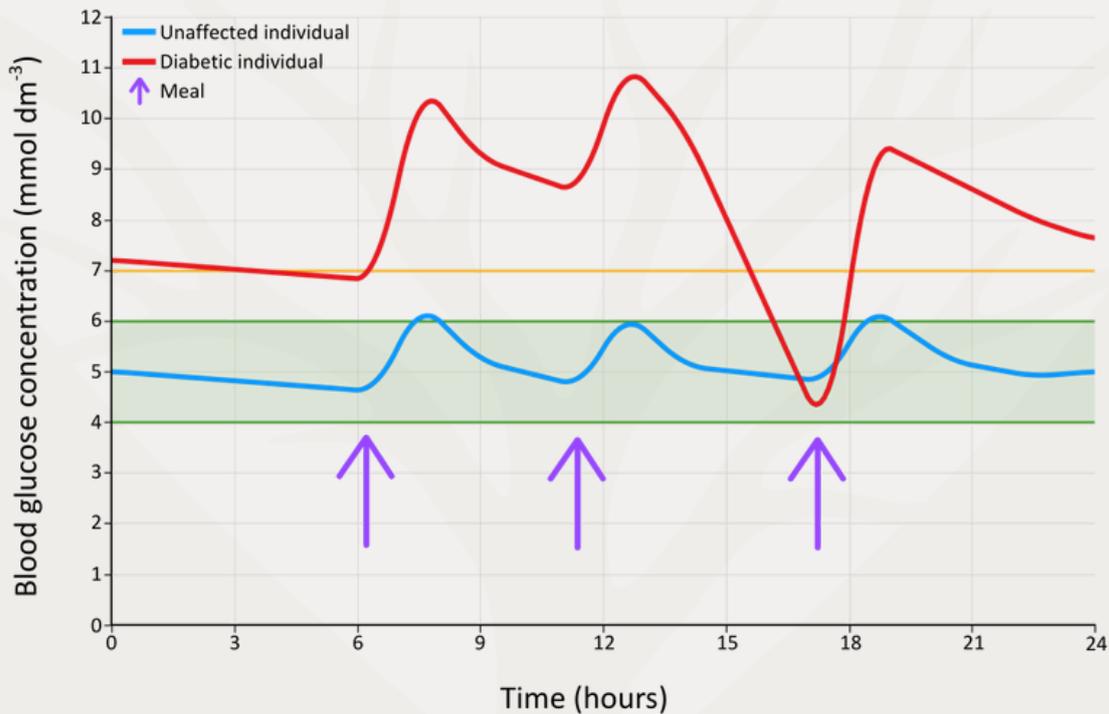
Diabetes Mellitus

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.



Module 5: Diabetes Mellitus



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. <i>E. coli</i>) 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.

STEMpathy



Module 5: Introduction to Plant Responses



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:

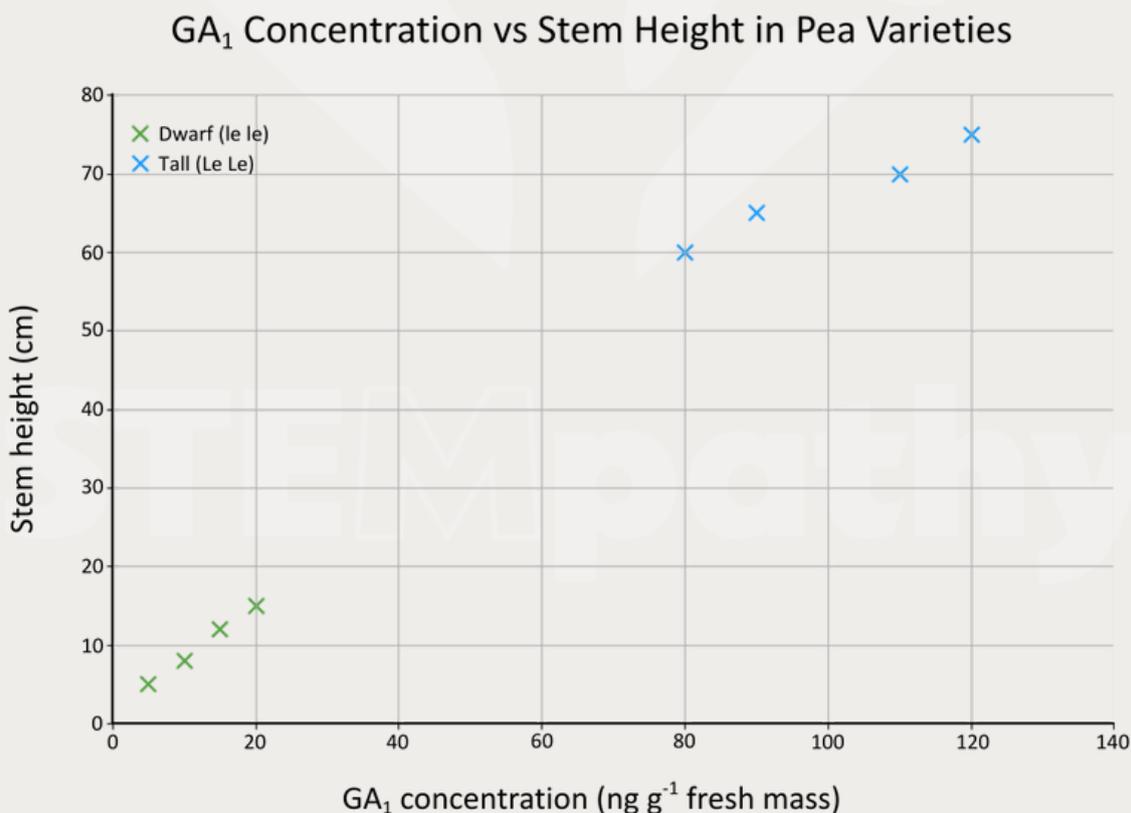
- **cell elongation** (through wall-loosening proteins)
- **cell division** (via activation of cell-cycle genes)

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 GA_1 , 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 GA_1 . $Le\ Le$ is the genotype for the **tall pea plant variety**, which produces a **functional enzyme** capable of synthesising GA_1 .

Experimental Evidence that GA_1 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.

STEMpathy

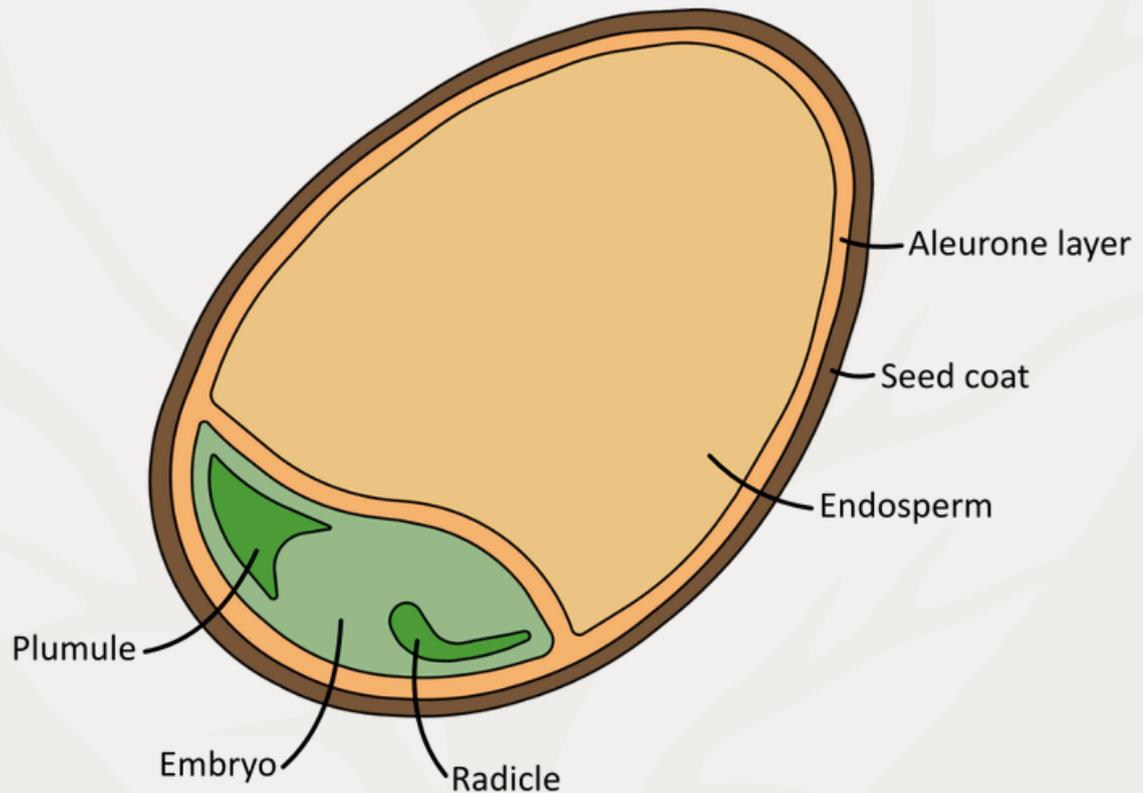


Module 5: Hormonal Control of Seed Germination



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.	<ul style="list-style-type: none">- 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.	<ul style="list-style-type: none">- Mutant seeds do not germinate.- Application of GA restores normal germination.	<ul style="list-style-type: none">- 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 **neurones** 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

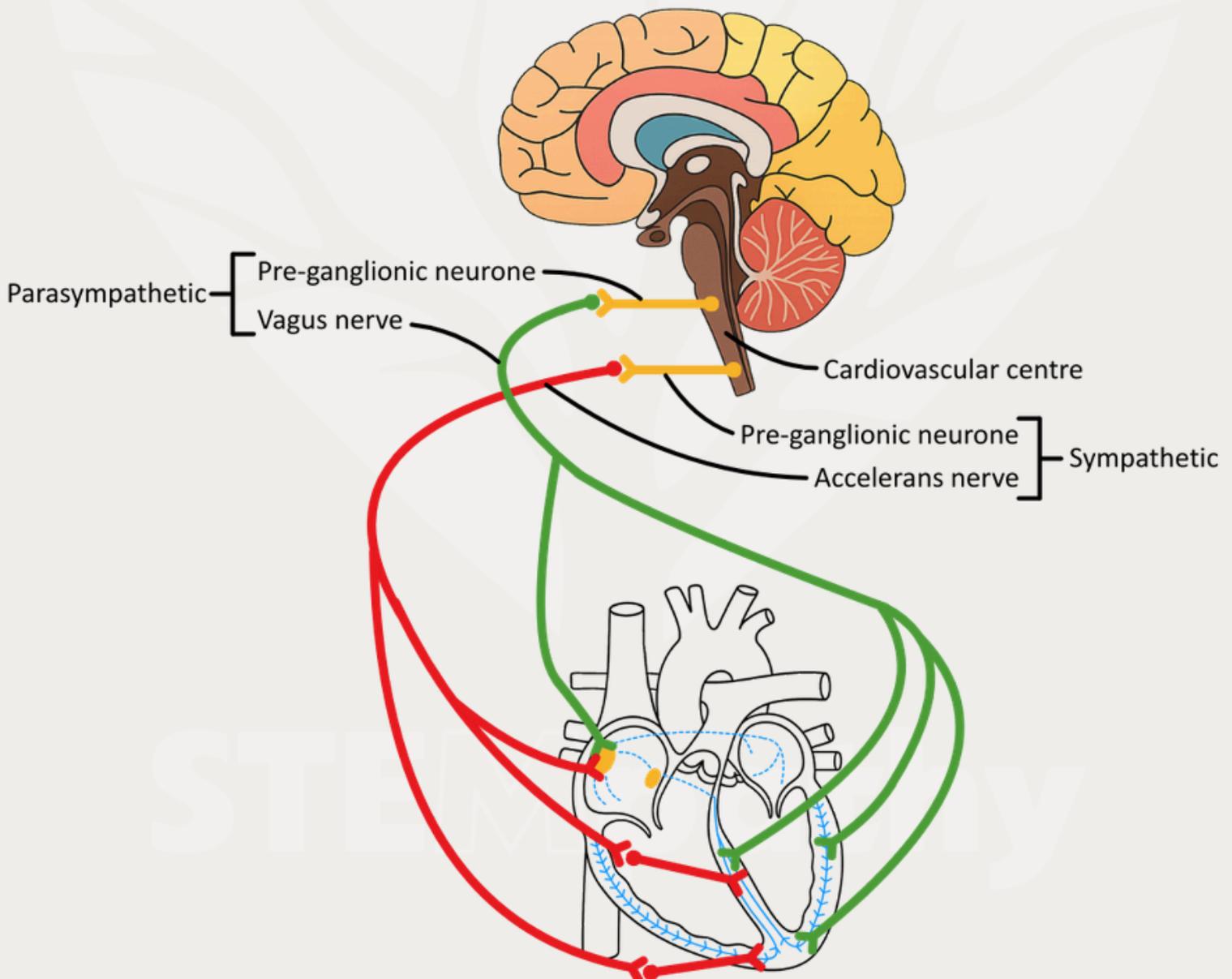


Nervous Control of Heart Rate

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



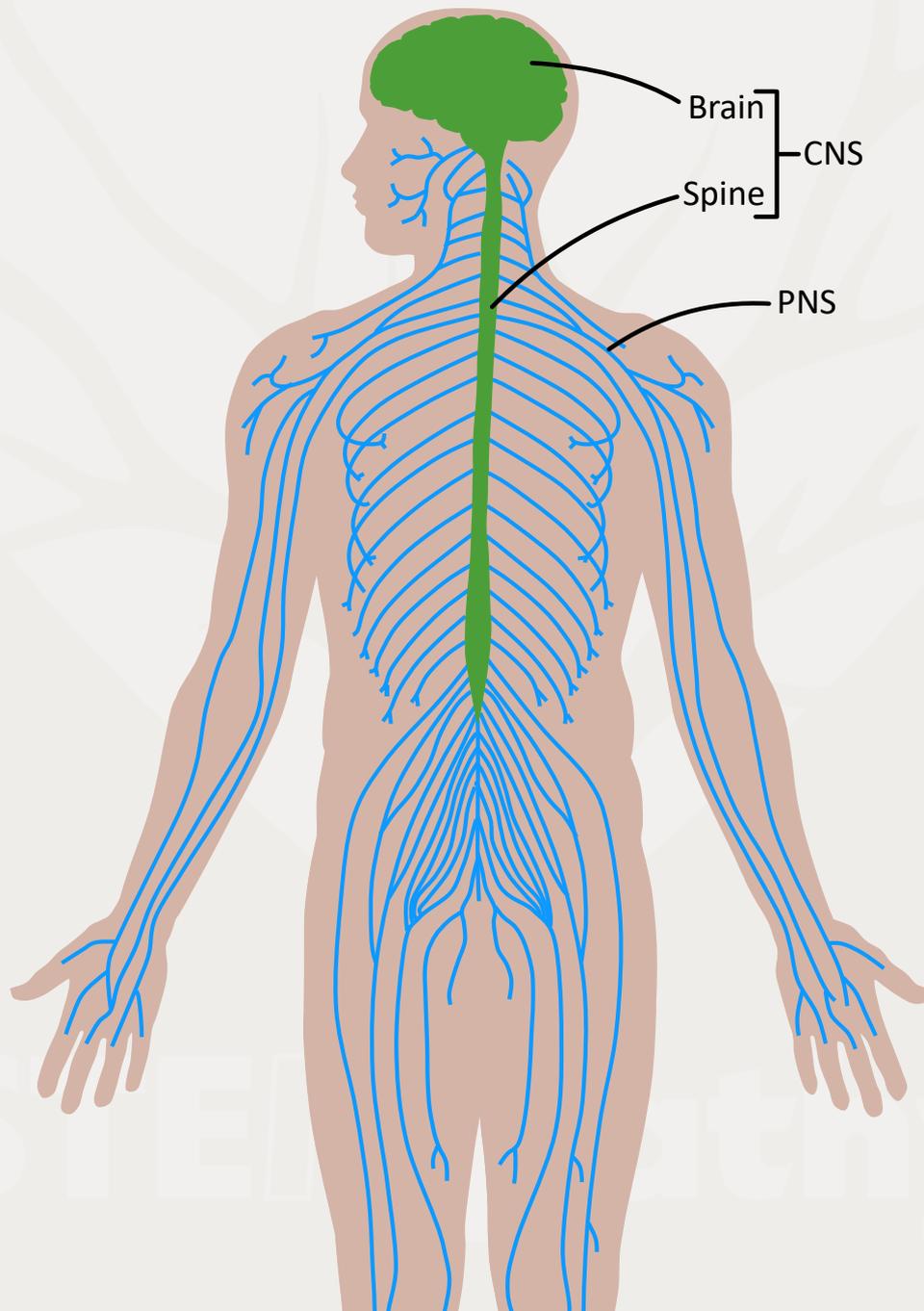
Module 5: The Mammalian Nervous System



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:



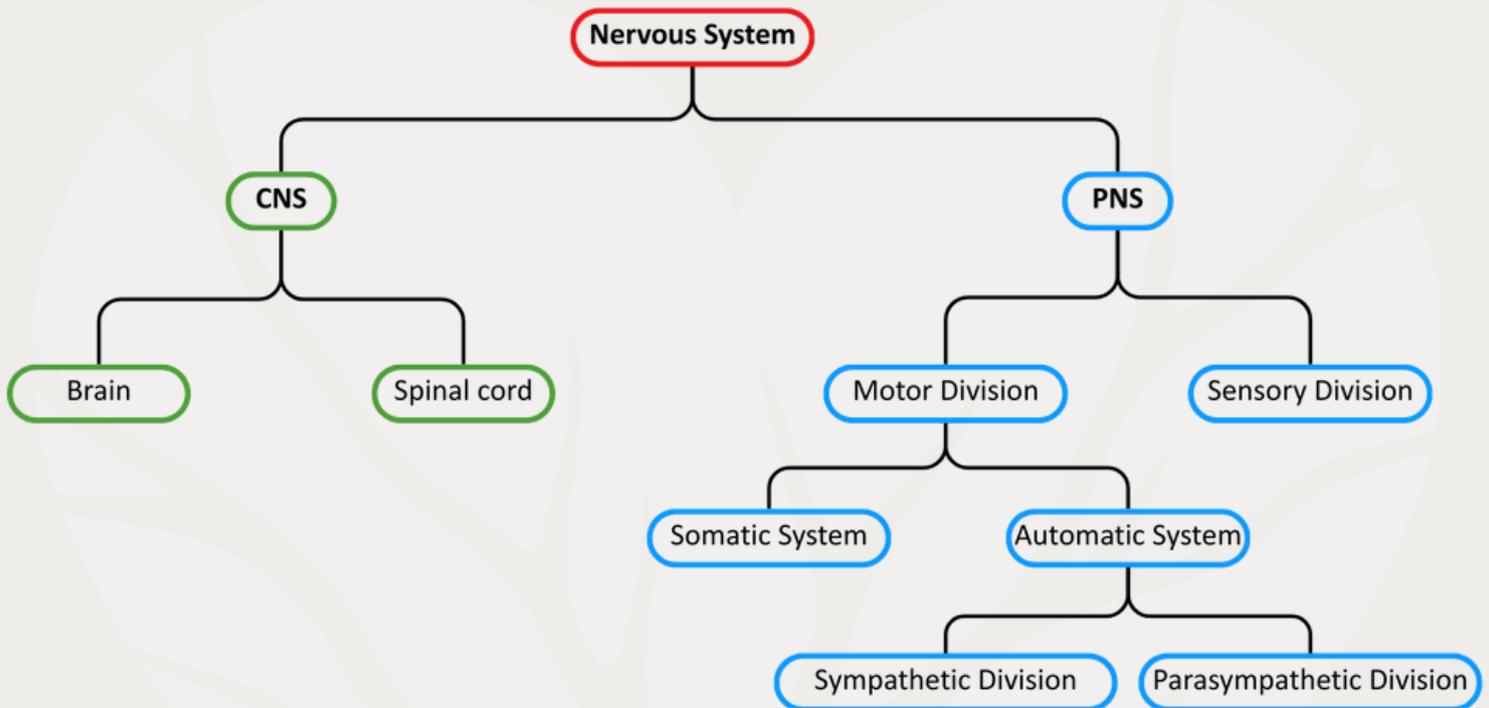
The **CNS** and **PNS** are **organised** into **divisions**, each with specific roles.



Module 5: The Mammalian Nervous System



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



STEMpathy



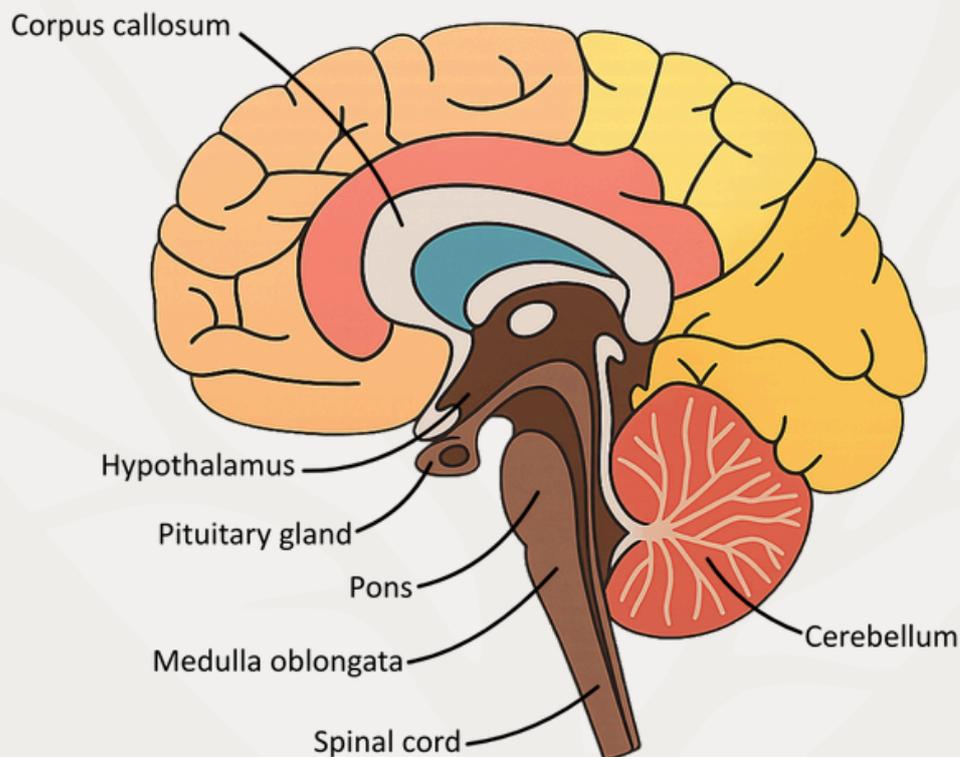
Module 5: The Mammalian Nervous System



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	<ul style="list-style-type: none">- Conscious thought- Reasoning- Memory
Cerebellum	<ul style="list-style-type: none">- 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

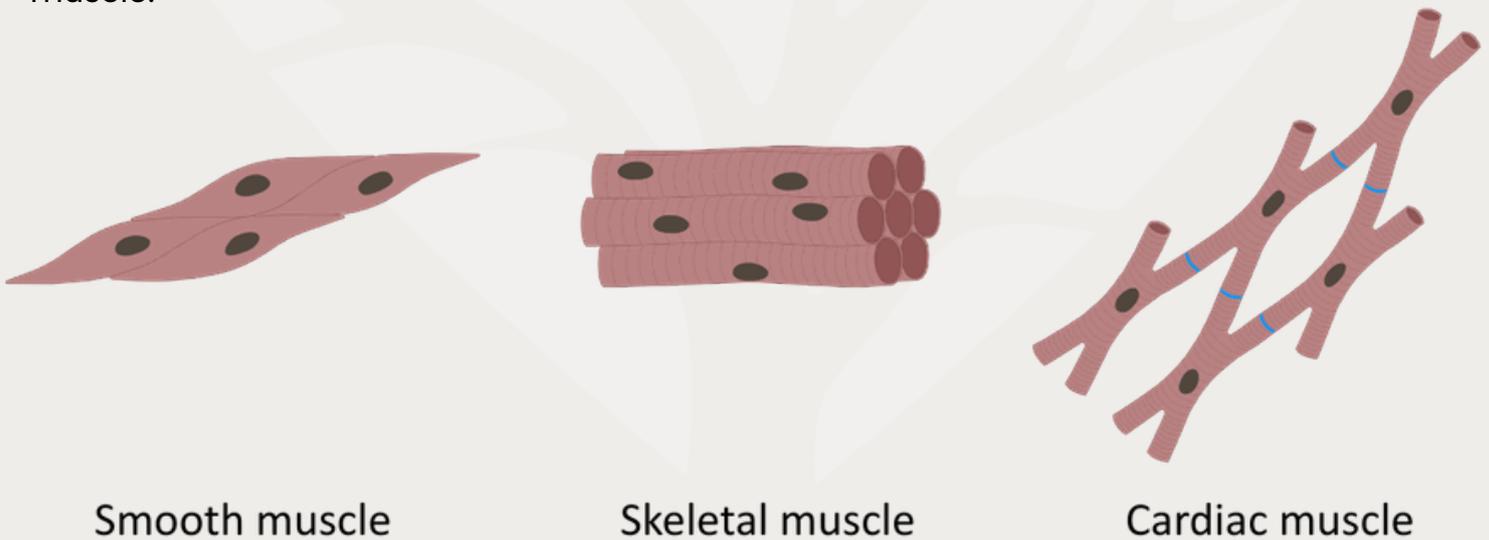
Muscles are **effectors** that produce **movement responses** in animals.

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**.



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

STEMpathy



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**.

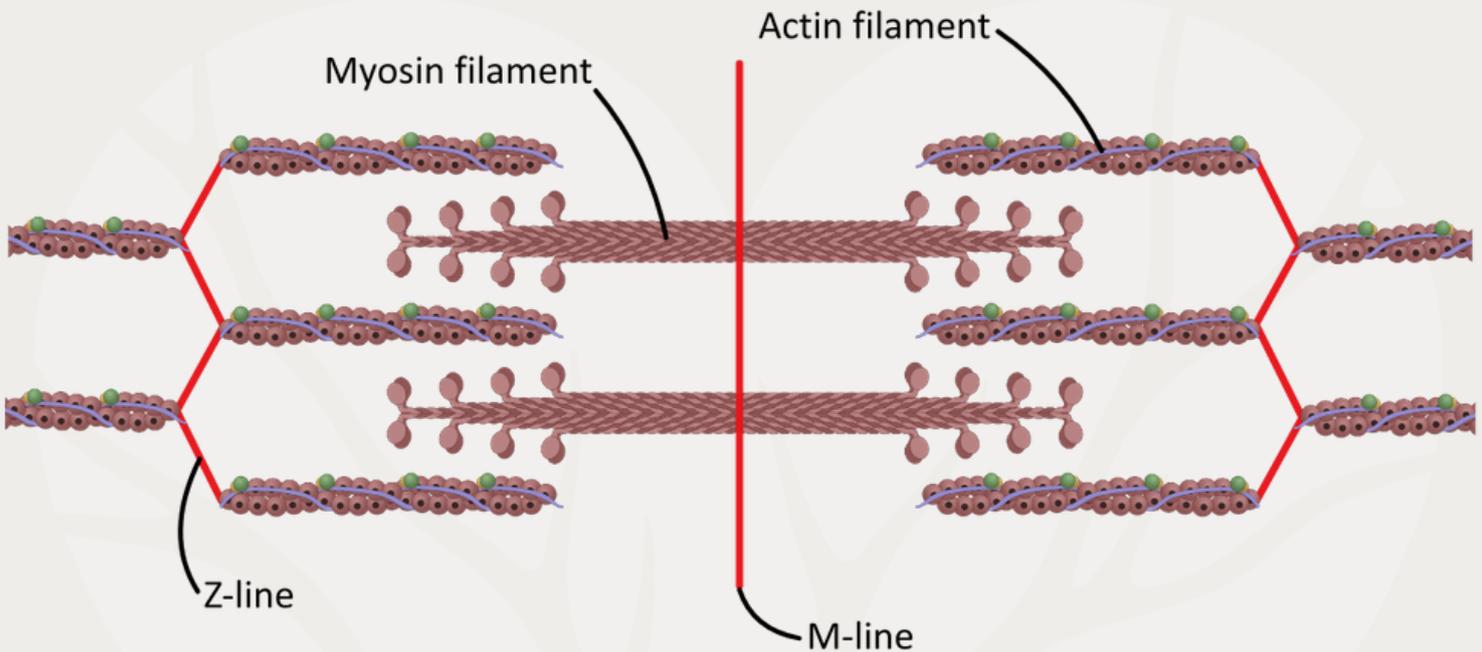
STEMpathy



Module 5: Neuronal Control of Striated Muscle



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

STEMPATHY



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.

STEMpathy



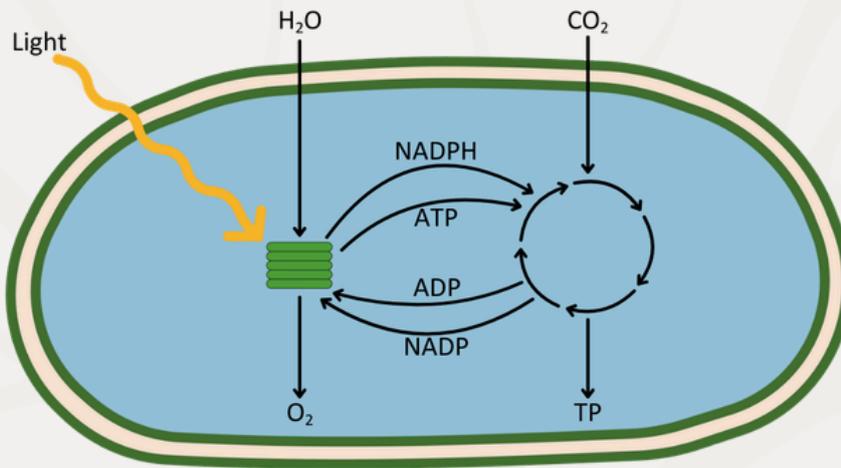


Introduction to Photosynthesis

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**).

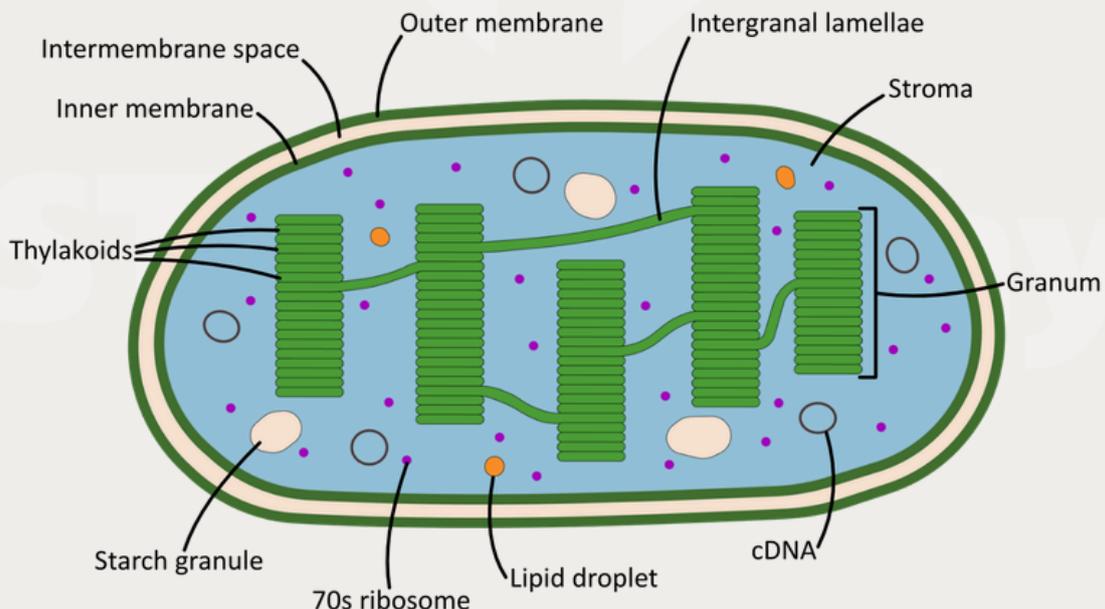
The diagram below **shows** how the **light-dependent** and **light-independent** reactions are **linked**:



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**.

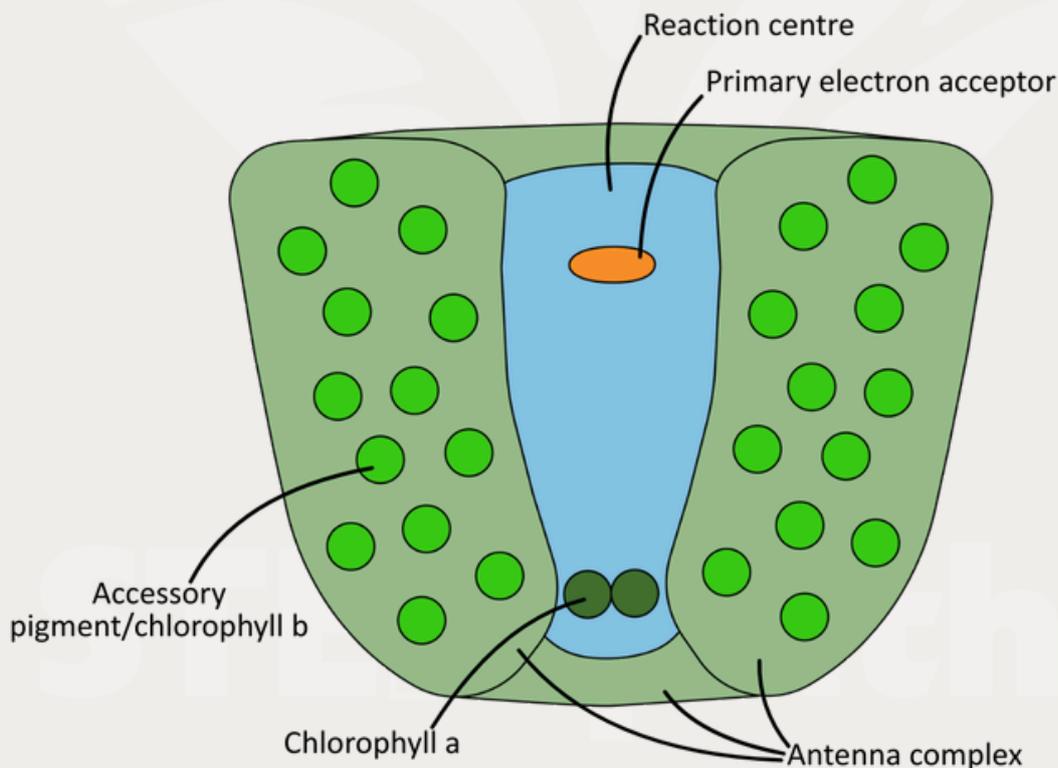
Both pathways depend on the structural arrangement of **photosystems**, **electron carriers** and **ATP synthase** in the thylakoid membrane.

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**.

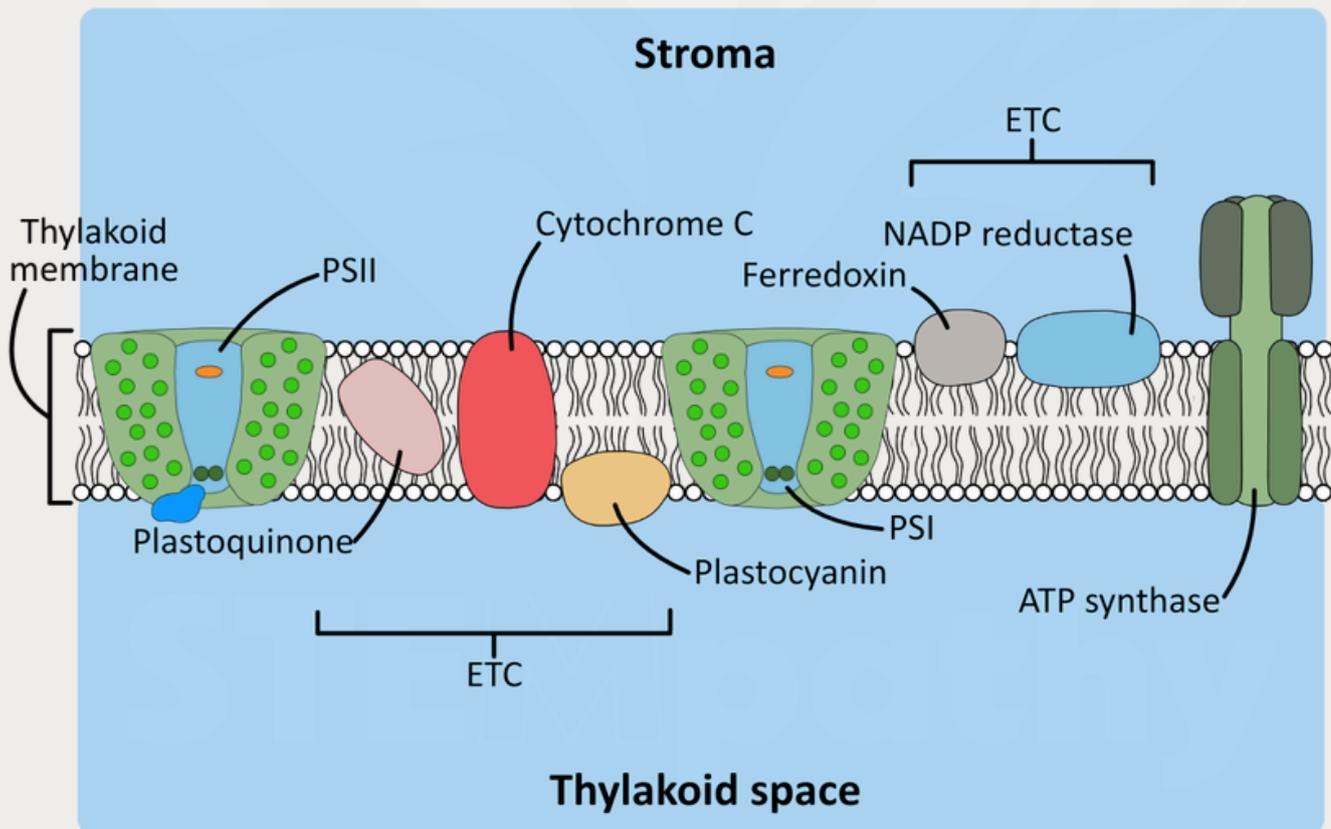
It is useful to know that **PSII** is located at the **start** of the ETC (instead of in second place), simply because it was discovered after PSI.

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**.





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.

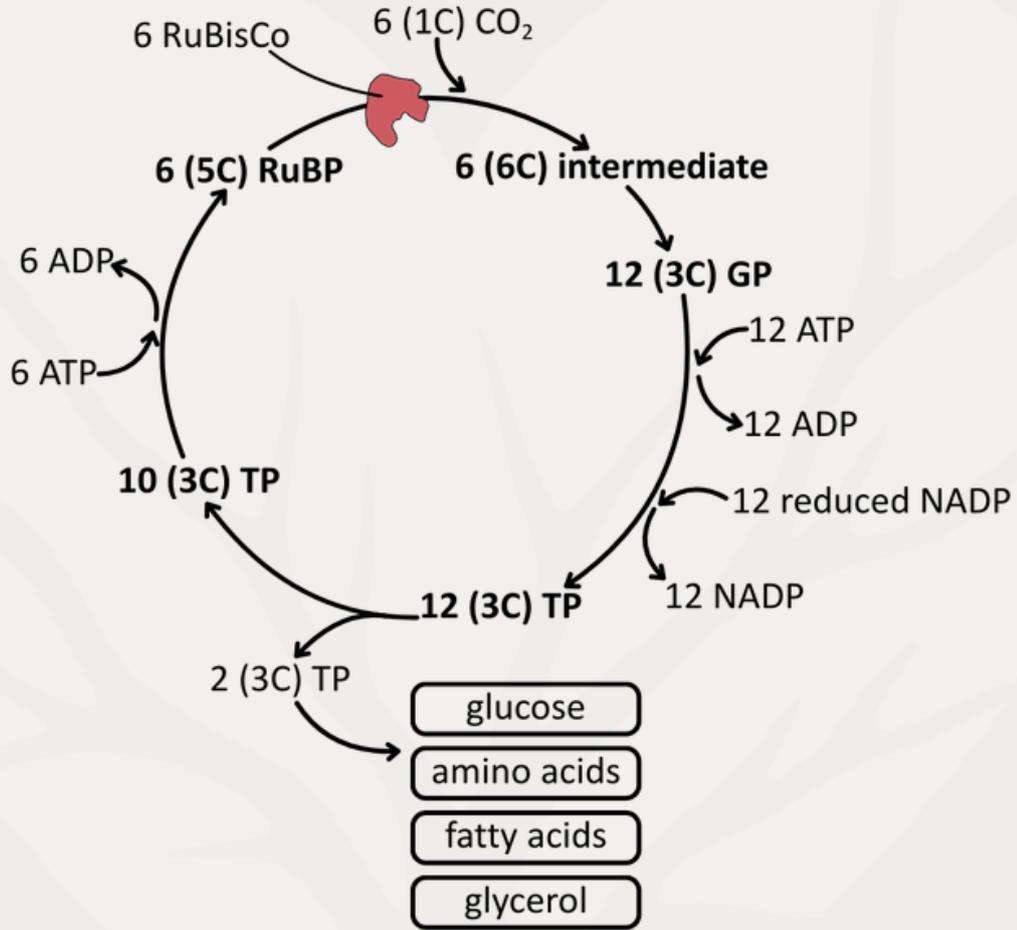
STEMpathy



Module 5: The Light-Independent Reactions



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



STEMpathy



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:

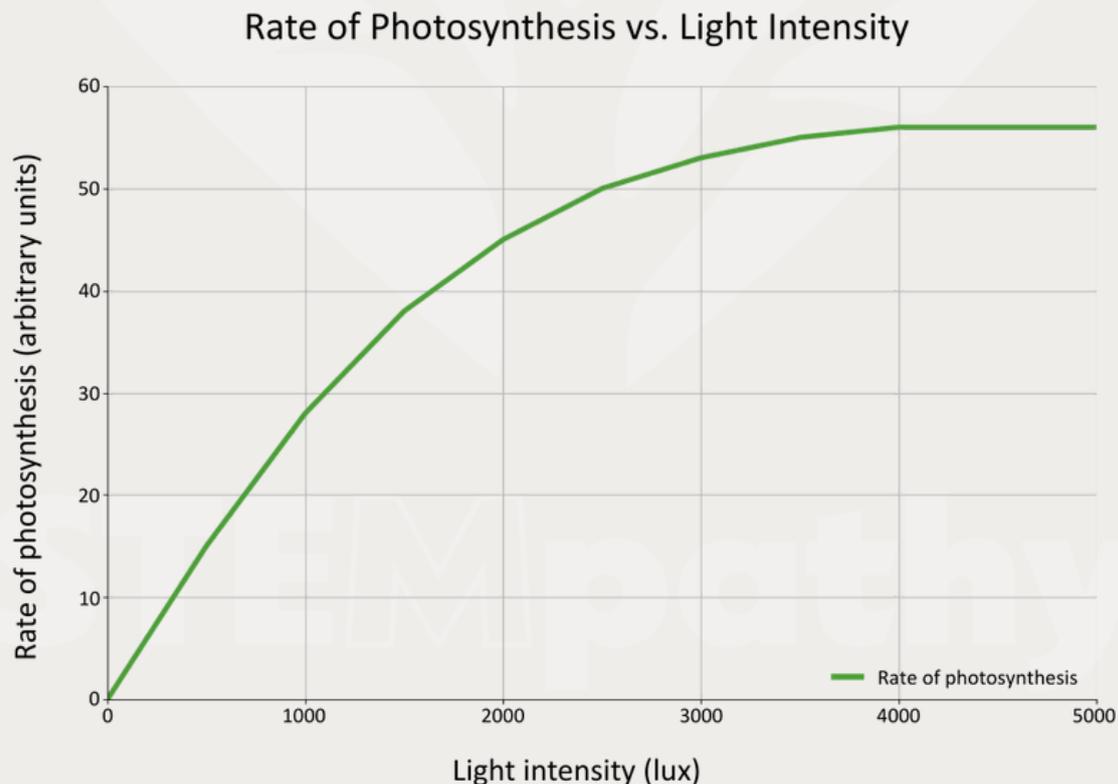
- **Light intensity:** Determines the **rate** of **ATP** and **reduced NADP production** in the **light-dependent reactions**.
- **Carbon dioxide concentration:** **Required** for **carbon fixation** by RuBisCO in the **Calvin cycle**.
- **Temperature:** Affects **enzyme activity** in the Calvin cycle.

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**:



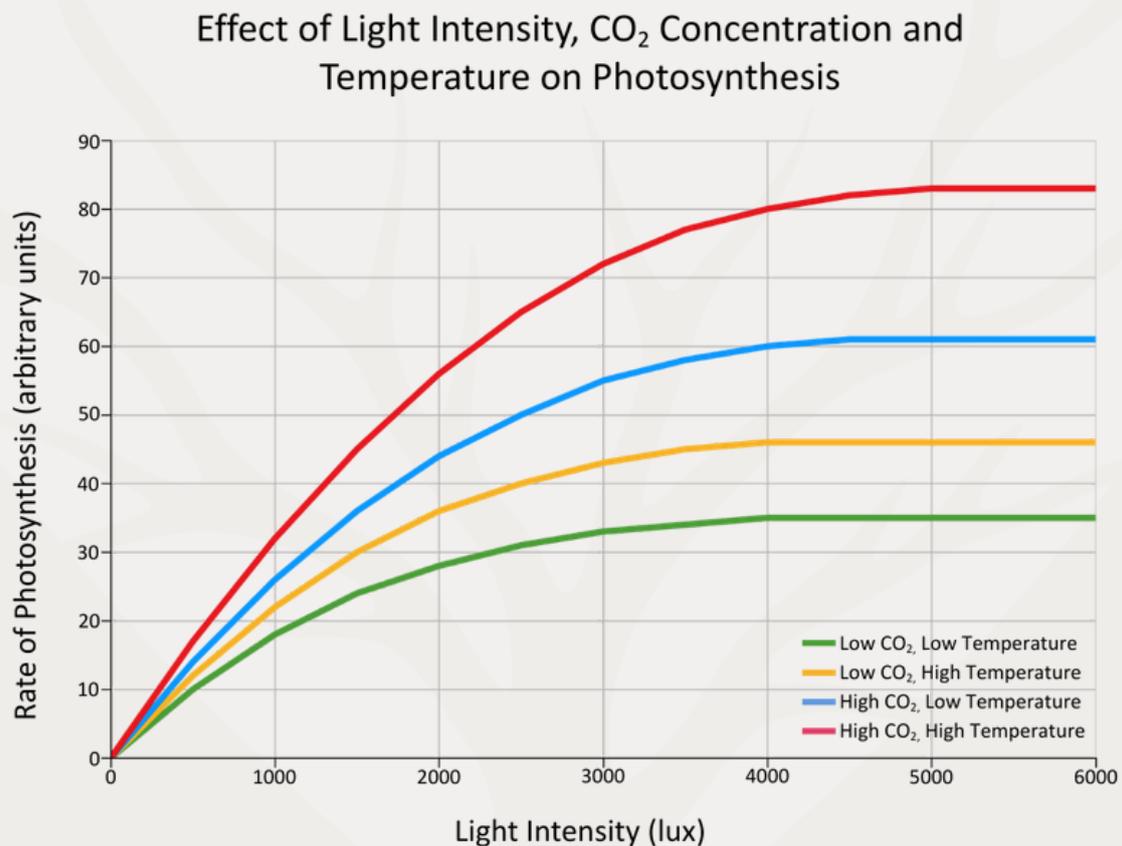
Module 5: Factors Affecting the Rate of Photosynthesis



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**:



STEMpathy



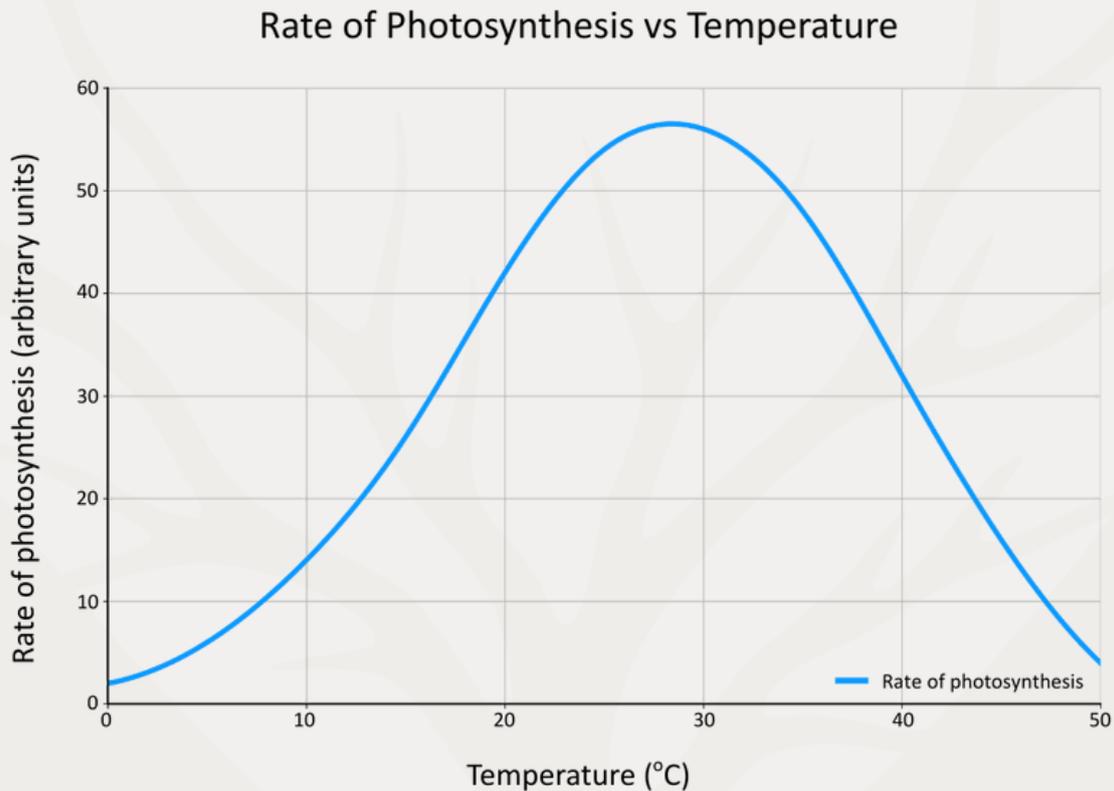
Module 5: Factors Affecting the Rate of Photosynthesis



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 CO ₂ at RuBisCO.



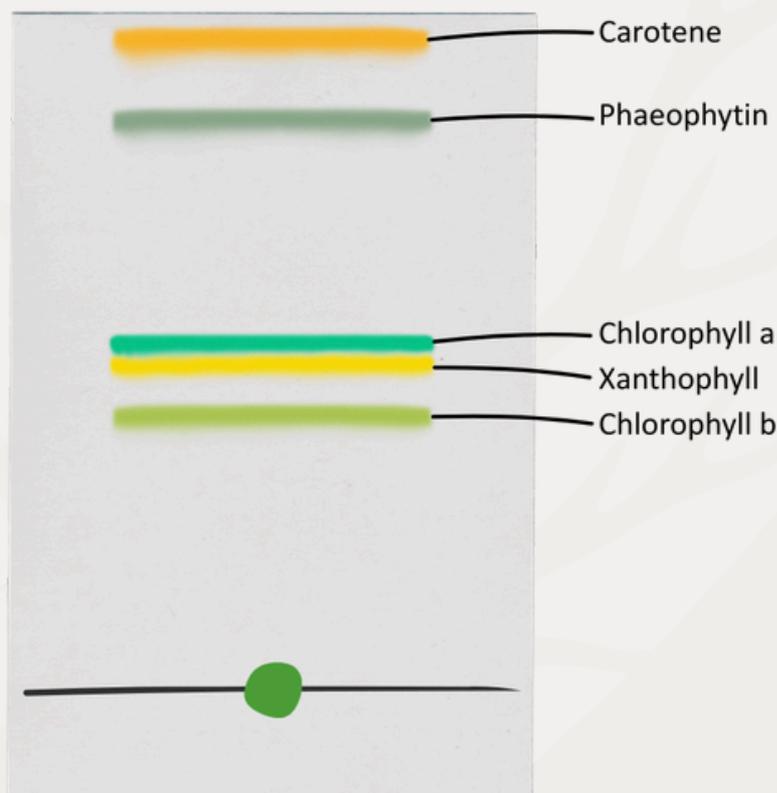
Module 5: Thin-Layer Chromatography of Plant Pigments



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**:

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

STEMpathy



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**.

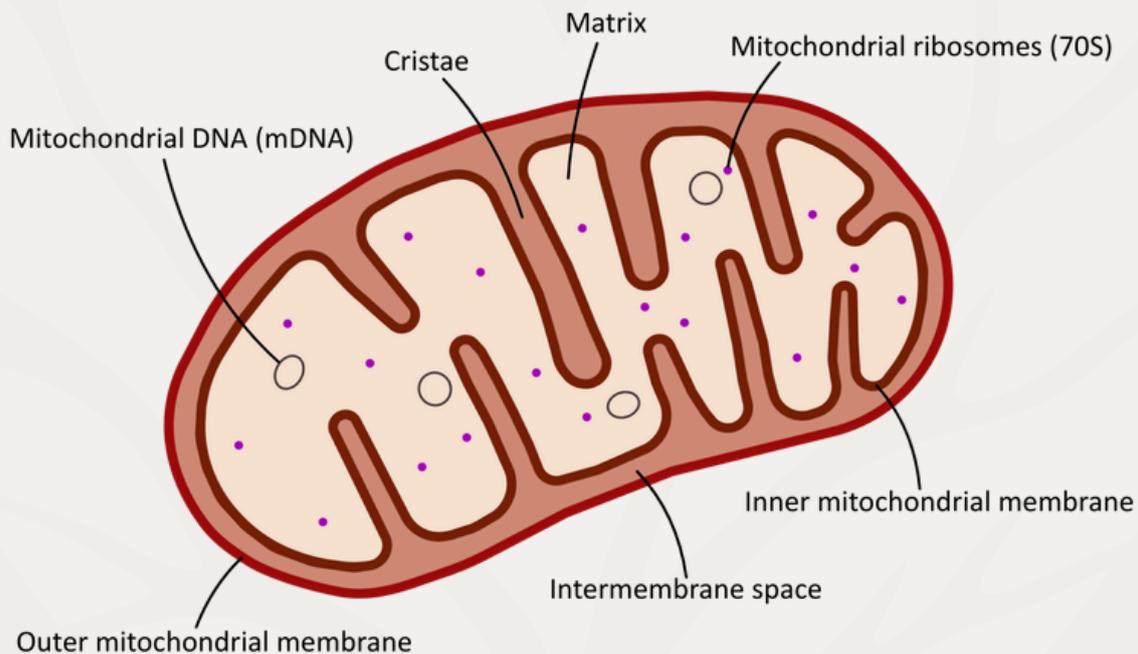




Mitochondria Structure and Function

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

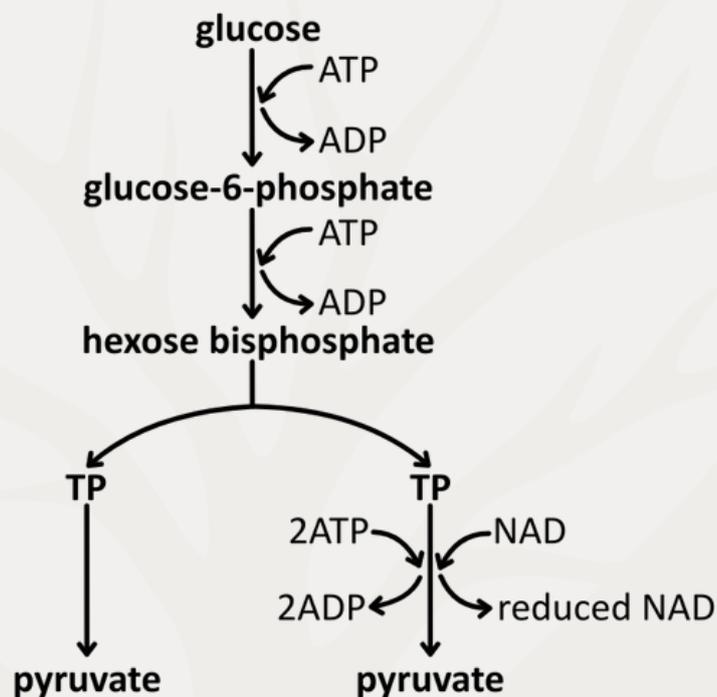


Glycolysis

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**.



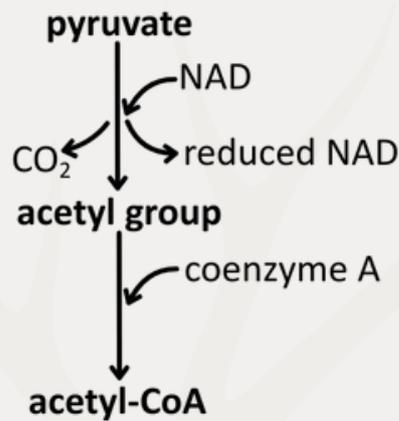


The Link Reaction

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.

STEMpathy





The Krebs Cycle

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

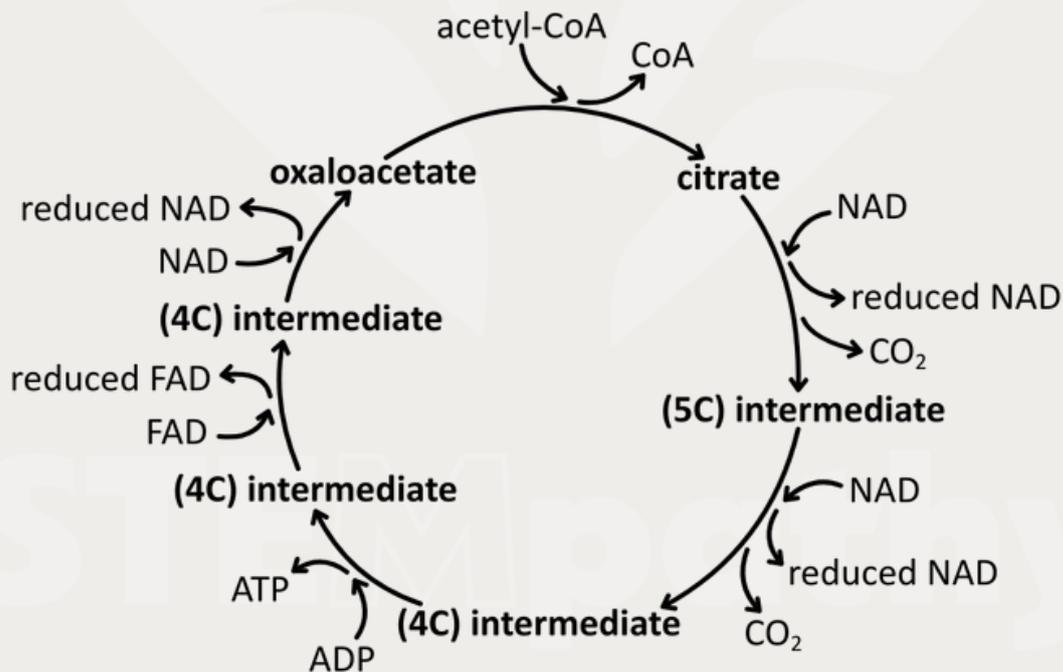
The Krebs cycle is a **series of cyclical enzyme-controlled reactions** that oxidise the acetyl group from acetyl-CoA into **carbon dioxide**, producing reduced **coenzymes** (NAD and FAD) and **ATP**.

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**:



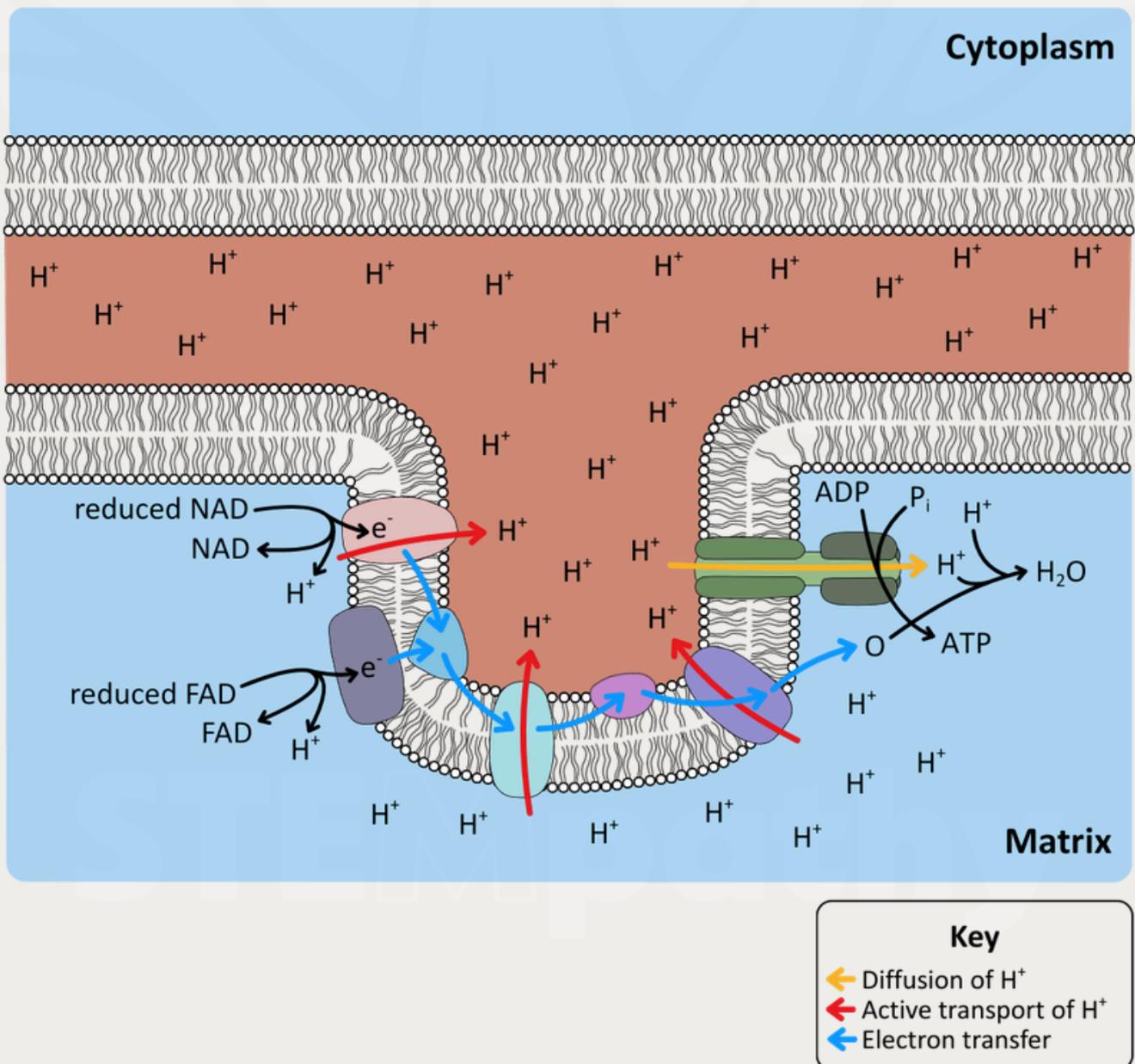


Oxidative Phosphorylation

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**.

STEMpathy



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**:

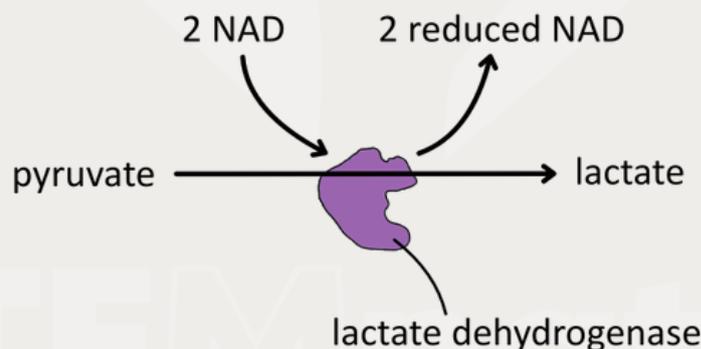
- Survive short periods **without oxygen** (e.g. diving mammals, waterlogged plant roots).
- Produce **additional ATP** during intense activity when aerobic respiration cannot supply enough.
- Provide **faster ATP production** through glycolysis than aerobic respiration.

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**:



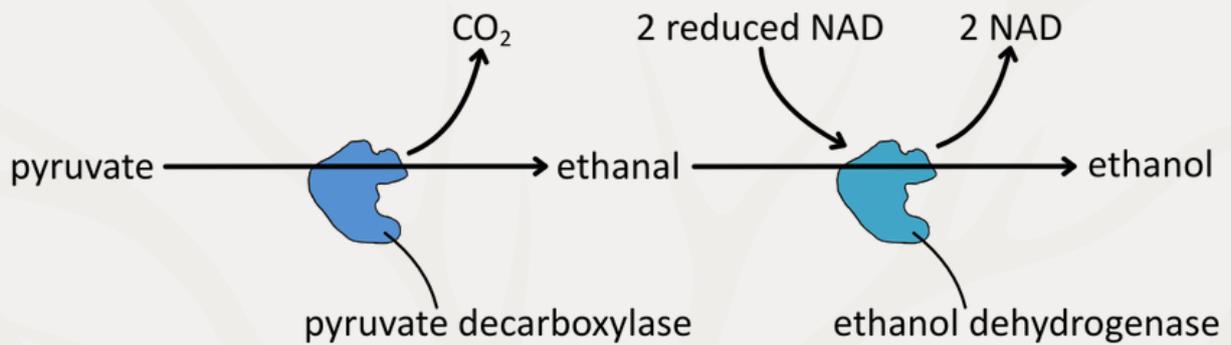


Anaerobic Respiration in Yeast

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**:



STEMpathy

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.

STEMpathy



Module 5: The Interrelationship Between Photosynthesis and Respiration



Photosynthesis and respiration are **interdependent** processes.

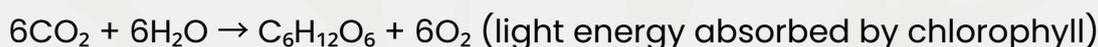
Carbon dioxide and water, which are **products of respiration**, are the **raw materials for photosynthesis**.

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

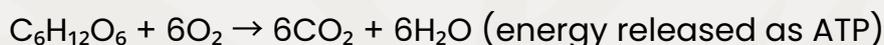
As a result, the same substances are continuously **recycled between the two processes**.

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.

STEMpathy



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	<ul style="list-style-type: none">- NADP- ATP	<ul style="list-style-type: none">- NAD- FAD- CoA- ATP
Chemiosmosis	Thylakoid membrane	Inner mitochondrial membrane

STEMpathy



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:**

Organism	Respiration Rate (mg CO ₂ kg ⁻¹ h ⁻¹)				
	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.

STEMpathy



Module 5: Investigating the Rate of Respiration



Respirometers

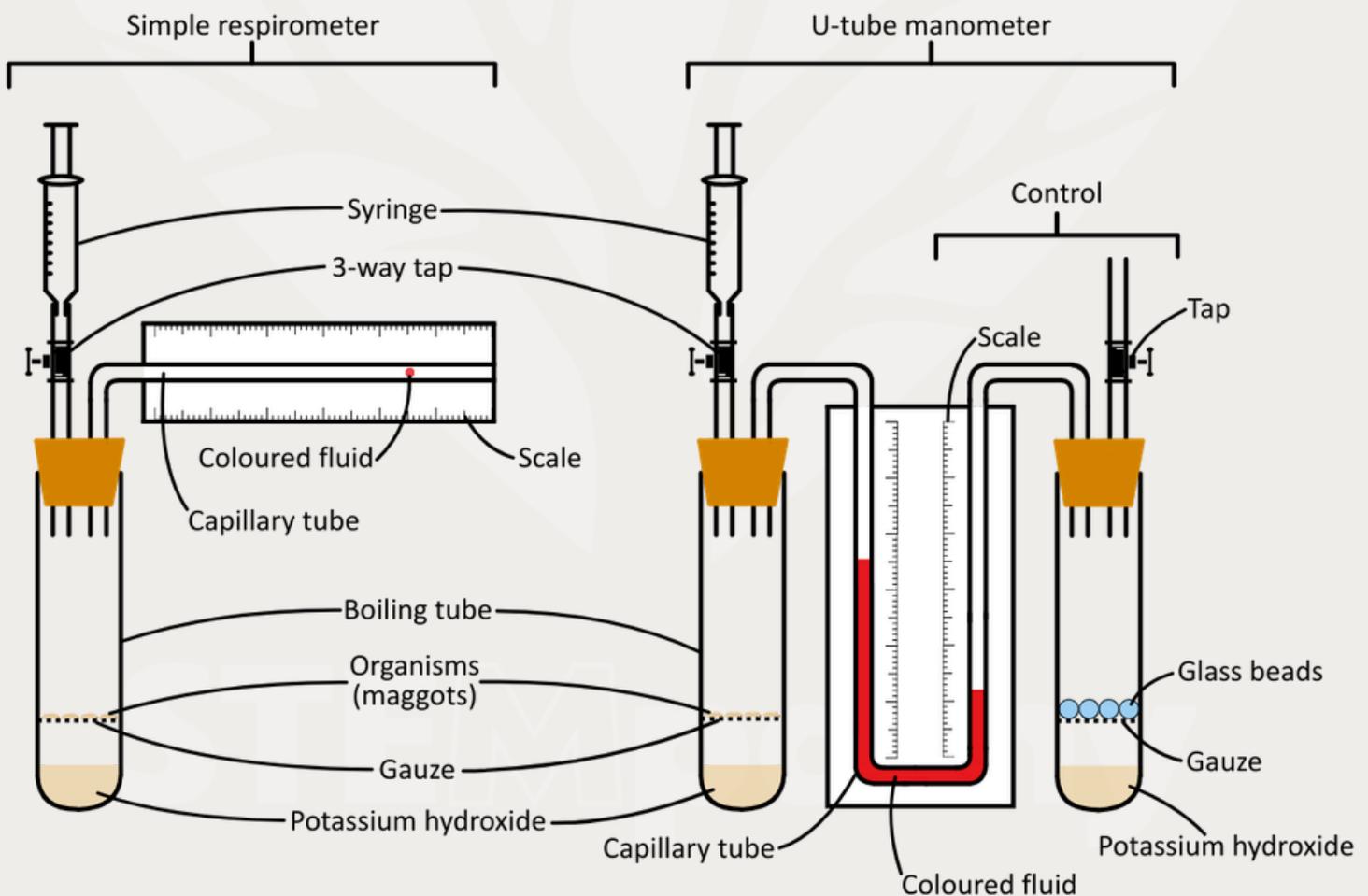
A **respirometer** is a device that can be used to **measure oxygen uptake**.

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.



Module 5: Investigating the Rate of Respiration



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.

