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Neural Signalling

IB Biology - Revision Notes

Neurones: Function & Structure

Neurones: Function & Structure

The nervous system

- The human nervous system consists of:
  - **Central nervous system** (CNS) – the **brain** and **spinal cord**
  - **Peripheral nervous system** (PNS) – all of the **nerves** in the body
- It allows us to make sense of our surroundings and respond to them, and to **coordinate and regulate body functions**
- Information is sent through the nervous system in the form of **electrical impulses** – these are electrical signals that pass along **nerve cells** known as **neurones**
  - A **bundle of neurones** is known as a **nerve**
- The nerves spread out from the central nervous system to **all other regions of the body** and importantly, to all of the **sense organs**
  - The **CNS** acts as a **central coordinating centre** for the impulses that come in from, and are sent out to, any part of the body

Central Nervous System Diagram

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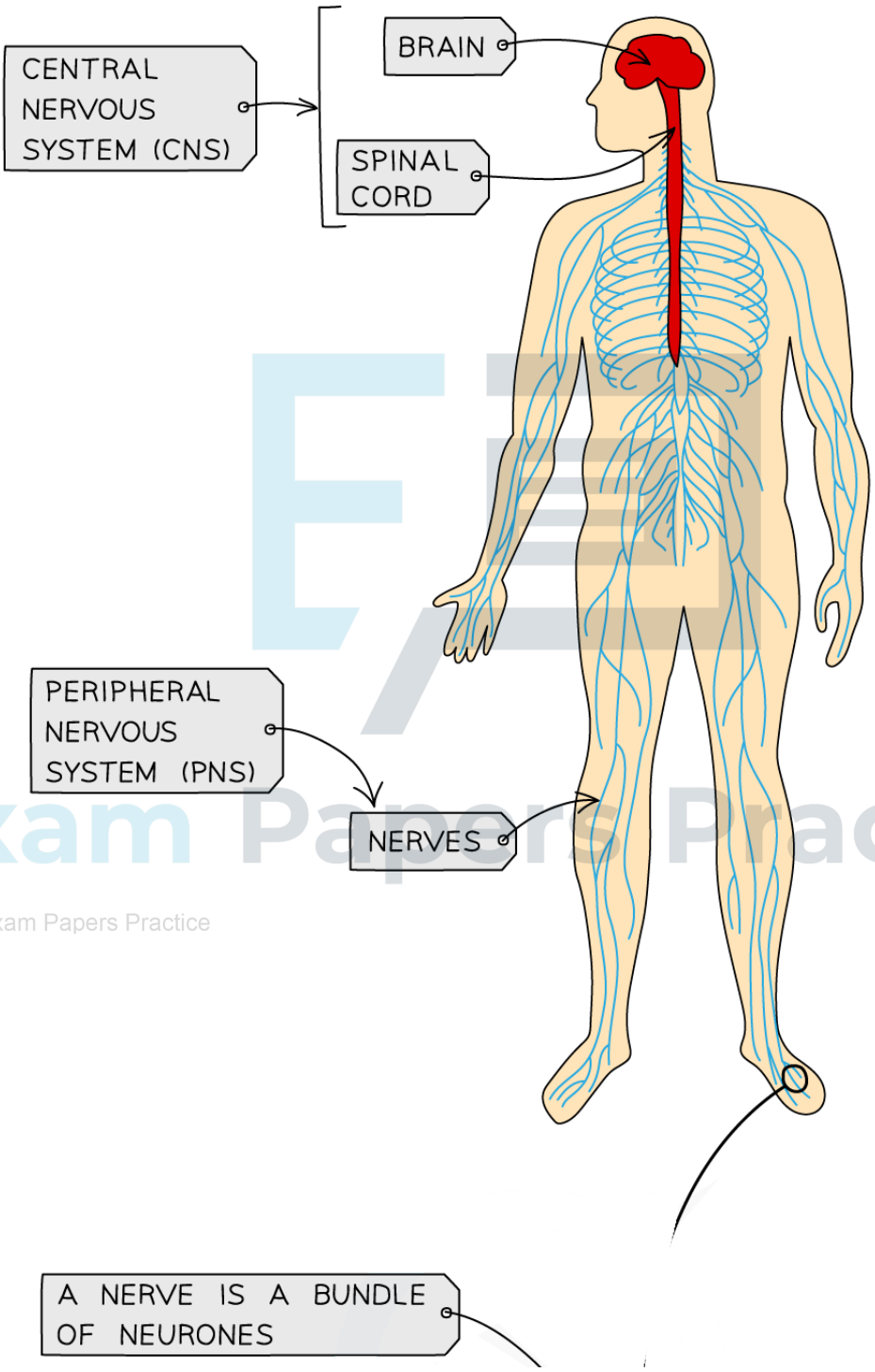

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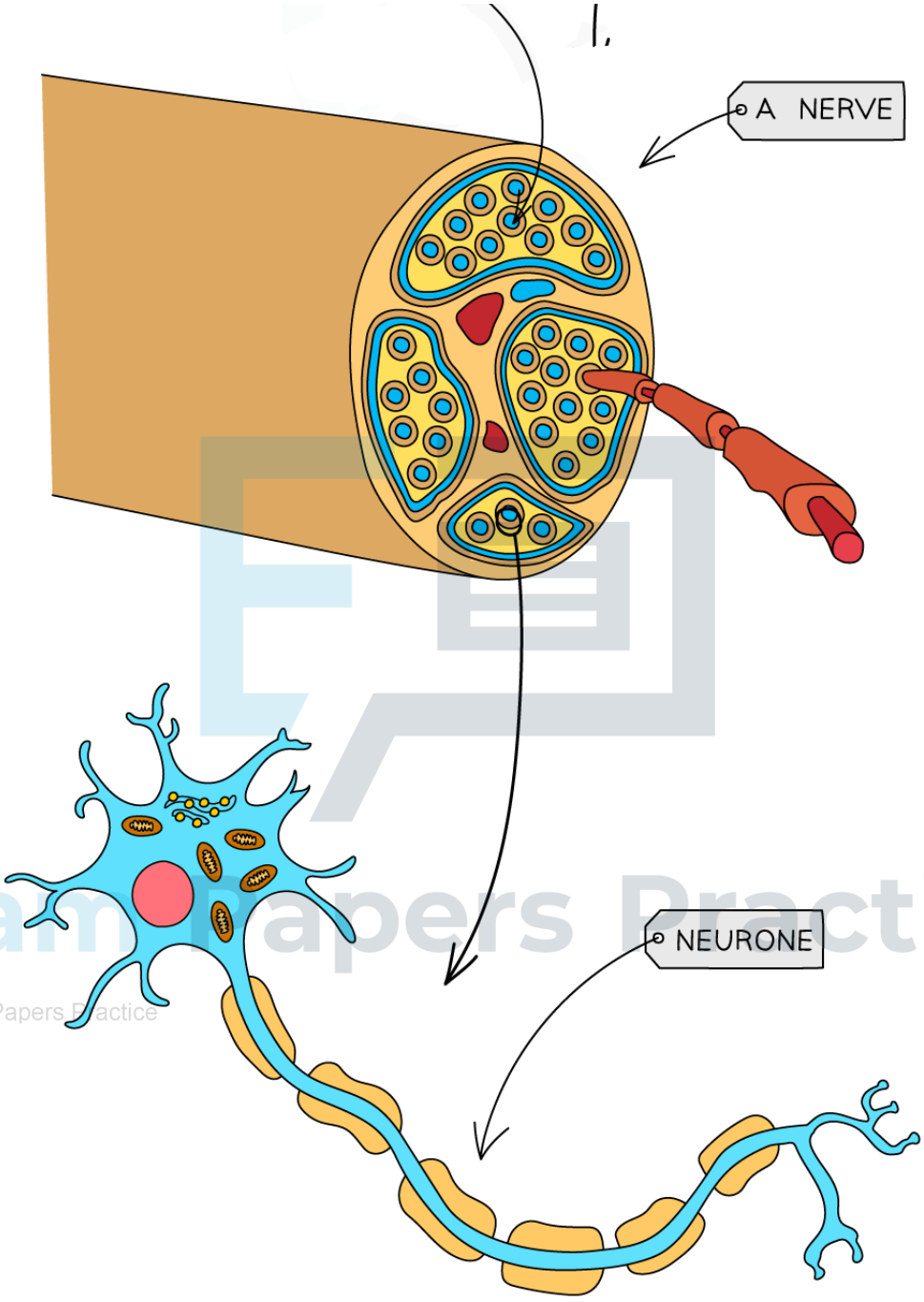

The human nervous system is comprised of the CNS and the PNS

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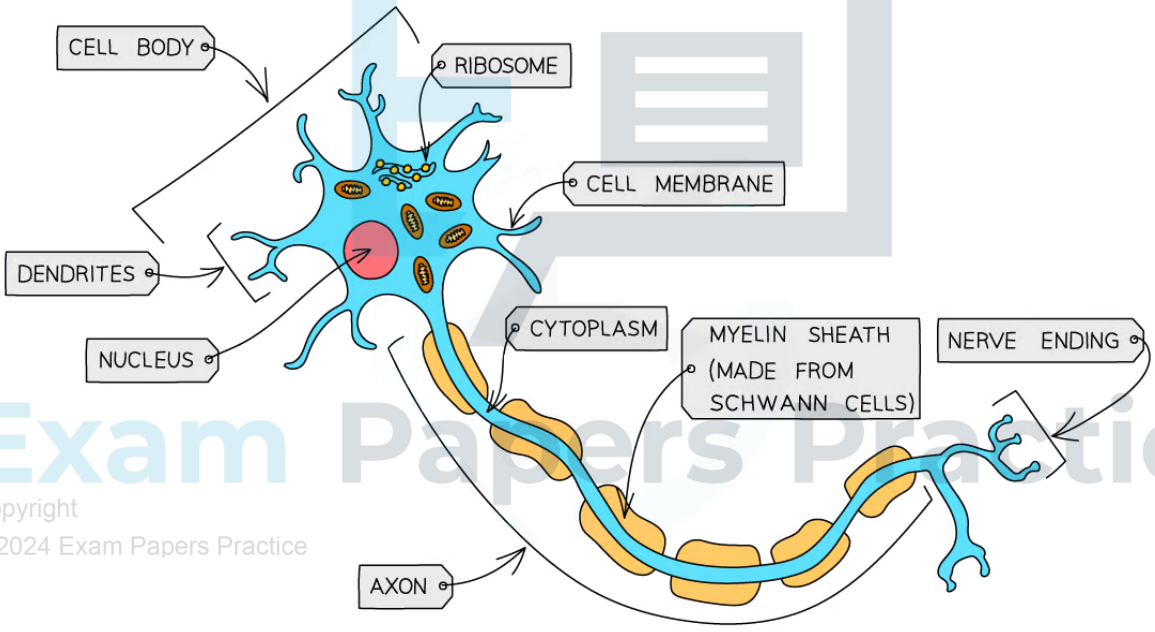
Neurones

- The following features are found in neurones:
  - Neurones have a **main, long, fibre** known as an **axon**
  - The axon is often **insulated** by **Schwann cells** which form the **myelin sheath** which prevents loss of nerve impulses along the axon
  - They have a **cell body** that contains the **nucleus** and other cellular structures
  - Their **cell bodies** and **axon terminals** contain many extensions called **dendrites**
  - These **dendrites** allow them to **connect** to **many other neurones** and receive **impulses** from them, forming a **network** for easy **communication**

Structure of a Neurone Diagram



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Neurones have a characteristically elongated structure which allows them to transfer information between the central nervous system and the rest of the body

Different types of neurone

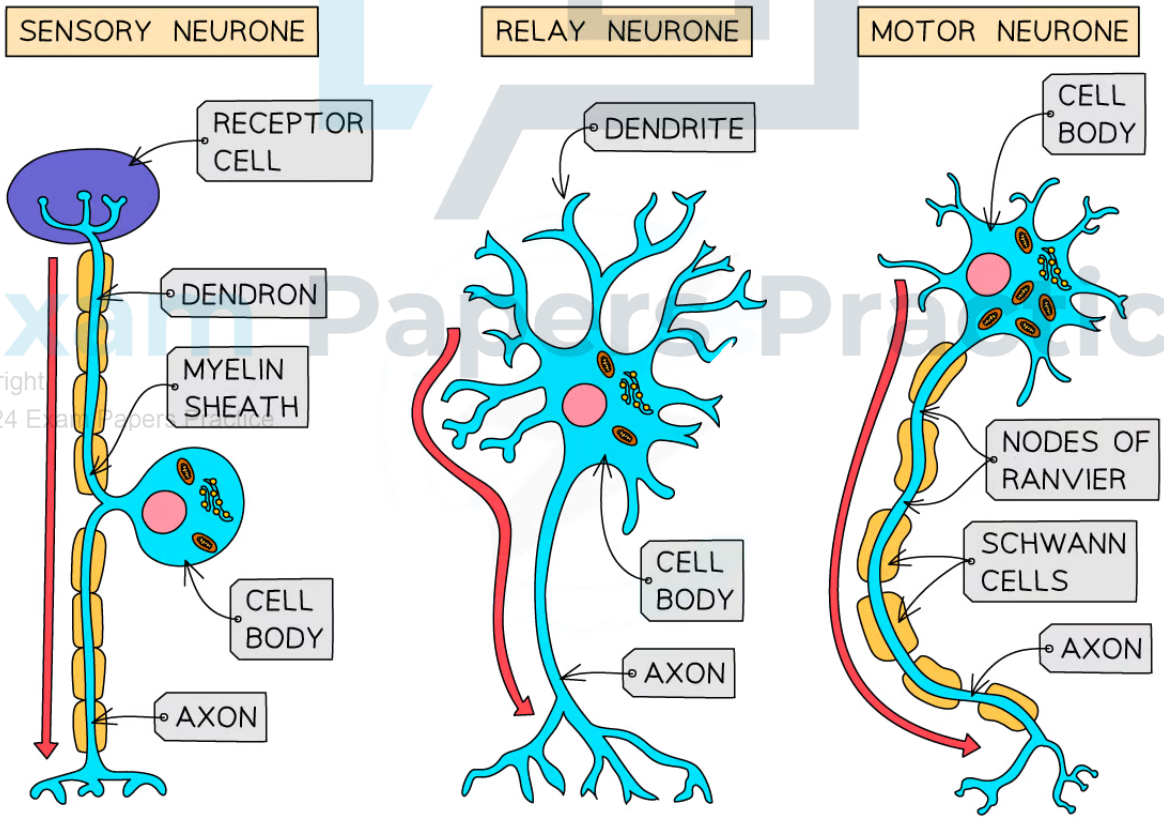
- There are **three main types** of neurone: **sensory, relay and motor**
  - **Sensory** neurones carry impulses from **receptors** to the **CNS** (brain or spinal cord)

- **Relay** (intermediate) neurones are found entirely within the CNS and **connect sensory** and **motor** neurones
- **Motor** neurones carry impulses from the **CNS** to **effectors** (muscles or glands)

- Each type of neurone has a **slightly different structure**
- **Motor neurones** have:
  - A large **cell body at one end** that lies within the spinal cord or brain
  - A nucleus that is always in its cell body
  - Many highly-branched dendrites extending from the cell body, providing a large surface area for the axon terminals of other neurones

  Relay neurones have:
  - Short, but highly branched, axons and dendrites
- **Sensory neurones** have:
  - A **cell body** that branches off in the **middle** of the cell
  - A single long dendron that carries impulses to the cell body and a single long axon that carries impulses away from the cell body

Three Types of Neurone Diagram



The three types of neurone – the red line shows the direction of impulses. Note that the axon always carried impulses away from the cell body.

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Nerve Impulses

Generating the Resting Potential

- **Neurones** transmit information in the form of **impulses**, which travel extremely quickly along the neurone from one end to the other
  - Note that an impulse is **not** an electrical current that flows along neurones as if they were wires
  - Instead, an impulse is a **momentary reversal in the electrical potential difference** across the **neurone cell surface membrane**
    - The electrical potential difference across a membrane can also be described as the **voltage** across a membrane, the **difference in charge** across a membrane, or the **membrane potential**
- In an axon that is **not transmitting an impulse** the **inside** of the axon always has a **negative electrical potential**, or charge, compared to **outside** the axon, which has a **positive electrical potential**
  - This membrane potential in a resting neurone is known as **resting potential**
- The **resting potential** is usually about **-70 millivolts (mV)**
  - This means that the **inside** of the resting axon has a **more negative** electrical charge than the **outside** by about 70 mV
- Two main processes contribute to establishing and maintaining resting potential:
  - **The active transport of sodium ions and potassium ions**
  - **A difference in rates of diffusion of sodium ions and potassium ions**
- In addition to these two main processes, **negatively charged proteins** inside the axon also contribute to the negative resting potential

The active transport of sodium ions and potassium ions

- Carrier proteins called **sodium-potassium pumps** are present in the cell surface membranes of neurones
- These pumps use **ATP** to actively transport **sodium ions** (Na^+) **out** of the axon and **potassium ions** (K^+) **into** the axon
- The two types of ion are pumped at an unequal rate; for every **3 sodium ions that are pumped out** of the axon, only **2 potassium ions are pumped in**
- This creates a concentration gradient across the membrane for both sodium ions and potassium ions

Difference in rates of diffusion of sodium ions and potassium ions

- Because of the concentration gradient generated by the **sodium-potassium pumps**, both sodium and potassium ions will diffuse back across the membrane
  - The neurone cell surface membrane has **sodium ion channels** and **potassium ion channels** that allow sodium and potassium ions to move across the membrane

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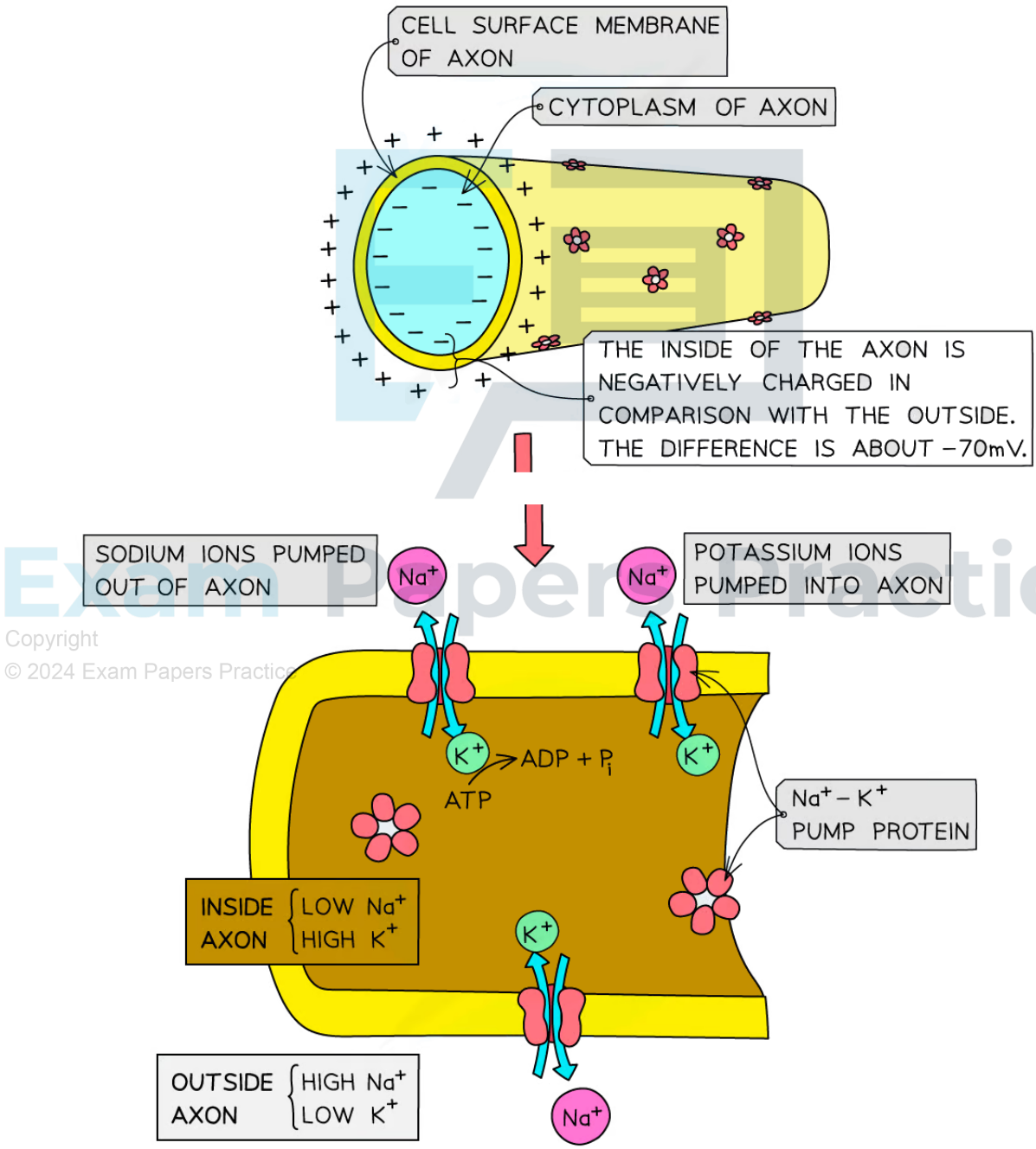
by **facilitated diffusion**

- The neurone membrane is much **less permeable** to sodium ions than potassium ions, so potassium ions inside the neurone can diffuse **out** at a **faster rate** than **sodium ions** can diffuse **back in**
- This results in **far more positive ions** on the **outside** of the neurone than on the inside, generating a **negative charge inside** the neurone in relation to the outside
- The result of this is that the neurone has a **resting membrane potential** of around **-70 millivolts (mV)**

Resting Potential Diagram



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Sodium-potassium pumps in the membrane of a resting neurone generate a concentration gradient for both sodium ions and potassium ions. This process, together with the facilitated diffusion of potassium ions back out of the cell at a faster rate than sodium ions diffuse back into the cell, generates a negative resting potential across the membrane.

Nerve Impulses

- Once resting potential is reached, the neurone membrane is said to be **polarised**
- To initiate a nerve impulse in a neurone, the neurone membrane needs to be **depolarised**
  - Depolarisation is the **reversal of the electrical potential difference** across the membrane
- The depolarisation of the membrane occurs when an **action potential** is generated
  - Action potentials lead to the reversal of resting potential from around **-70 mV** to around **+40 mV**
- Action potentials involve the **rapid movement** of **sodium ions** and **potassium ions** across the **membrane** of the **axon**
- An action potential is the **potential electrical difference** produced across the axon membrane when a neurone is **stimulated** e.g. when an environmental stimulus is detected by a receptor cell

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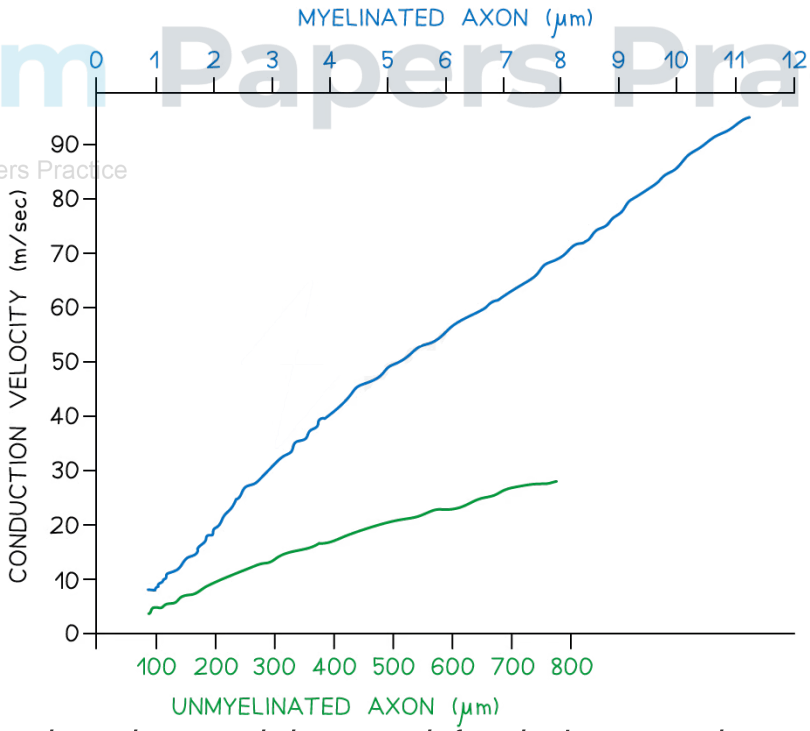
Nerve Impulses: Skills

Speed of Nerve Impulses

Comparing the speed of transmission

- There are well documented correlations between specific **structural features** of neurones and the **speed of transmission**
- Two key features that should be considered include
  - **Myelination** of the neurone
    - **Myelinated** neurones conduct electrical impulses **much more quickly** than unmyelinated fibres
    - This is because of the **insulation** offered by the myelin sheath which allows faster **saltatory conduction** along the neurone
  - **Diameter** of the neuron
    - An axon with a **wider diameter** conducts an electrical impulse **more quickly** than a narrow axon
    - This is because a wider axon offers **less resistance** to the action potential
- **Squid** have giant axons which are **unmyelinated** and can be up to **1 mm** wide, whereas the average diameter of a **human** neurone is somewhere between **4 and 100 µm**
- The graph shows the relationship between axon diameter and speed of transmission in a giant unmyelinated axon from a squid and a 'normal' sized myelinated axon of a mammal
- Despite the axon being significantly wider, the speed of transmission is much faster in the axon which is insulated by a myelin sheath

Comparing Speed of Nerve Transmission Graph



Unmyelinated axons have a much slower speed of conduction compared to a myelinated axon

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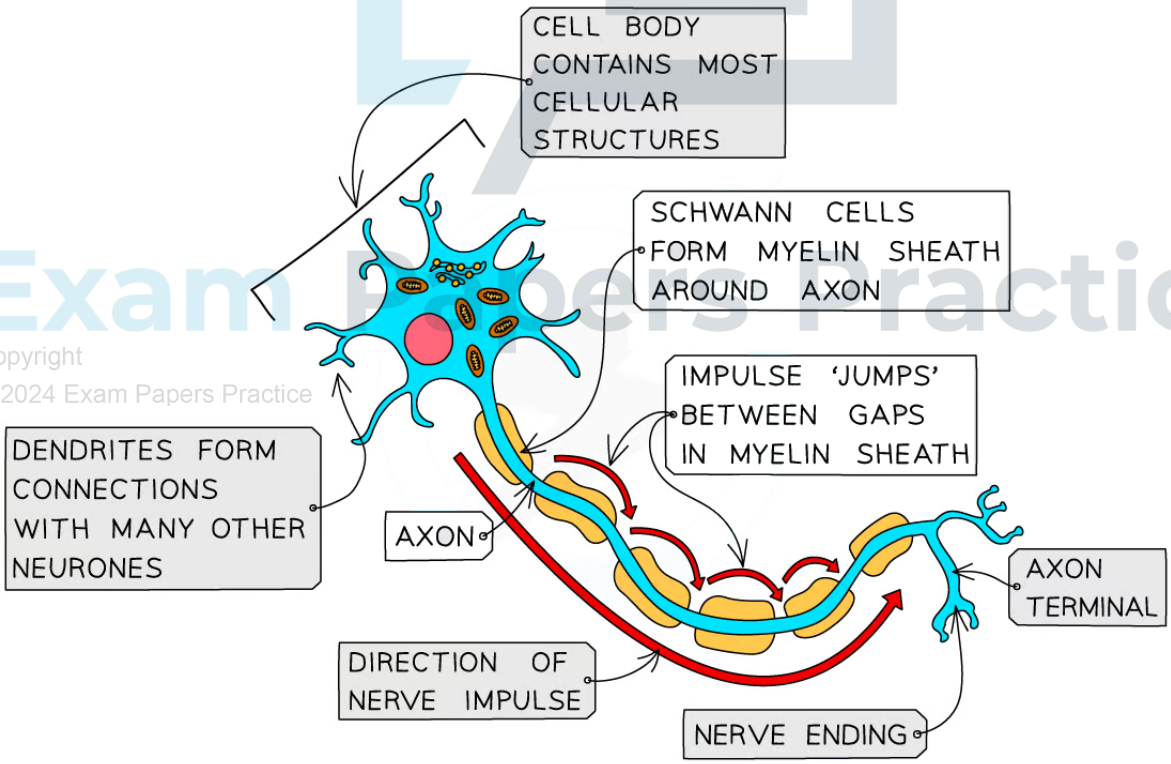
Myelination

- Neurones have a **main, long, fibre** known as an **axon**
- The axons of neurones are **surrounded** by specialised cells called **Schwann cells**
- Schwann cells **wrap themselves around the axon**, forming a structure known as a **myelin sheath**
  - **Myelin** contains the **phospholipids** of the **Schwann cell membranes**; it is built up in layers as the Schwann cells grow around the axon
  - The **lipid** content of the myelin sheath gives it a **high electrical resistance**
- The myelin sheath acts as an **electrical insulator;** impulses cannot pass through the myelin sheath
- The myelin sheath has **small, uninsulated sections** in the gaps between the individual Schwann cells
  - These gaps are called **nodes of Ranvier**
- Electrical impulses effectively **jump** from one node of Ranvier to the next
  - This process is known as **saltatory conduction**
  - It greatly **speeds up the rate of transmission of impulses** along myelinated neurones
  - In non-myelinated neurones the axon is not insulated by myelin, so the impulse travels **more slowly**

Diagram to show the myelination of neurones



An impulse travels down a neurone via saltatory conduction

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Describing a correlation using a correlation coefficient

- When studying the **relationship between two variables** such as diameter or myelination and speed of transmission, it is important to collect data which allows us to analyse the **strength of the correlation**
  - **Correlation** is an association or relationship between variables
  - There is a clear distinction between **correlation** and **causation**: a **correlation does not necessarily imply a causative relationship**
  - **Causation** occurs when one variable has an influence or is influenced by, another
- For the variables discussed here:
  - There may be a correlation **between diameter** of a neurone and the **speed** of impulse conduction
  - There may be a correlation **between the myelination** of a neurone and **speed** of impulse conduction
- The apparent correlation between variables can be analysed using **scatter graphs** and different **statistical tests**

Correlation between variables

- In order to get a broad overview of the correlation between two variables the data points for both variables can be plotted on a **scatter graph**
- The correlation coefficient (r) indicates the **strength of the relationship** between variables
- Perfect correlation occurs when **all of the data points lie on a straight line** with a **correlation coefficient of 1 or -1**
- Correlation can be **positive or negative**
  - Positive correlation: as variable A increases, variable B increases
  - Negative correlation: as variable A increases, variable B decreases
- If there is **no correlation** between variables the **correlation coefficient will be 0**

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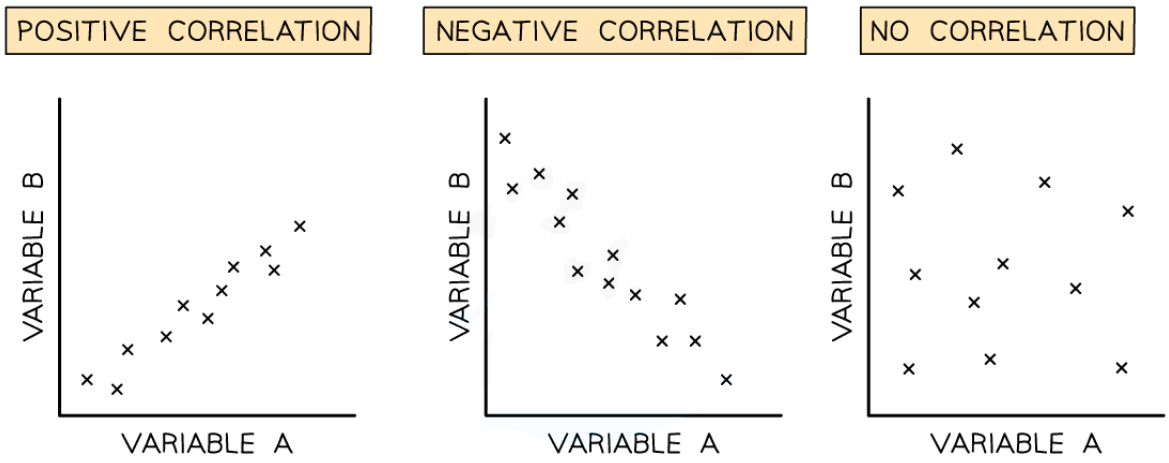

Different types of correlation in scatter graphs

- The **correlation coefficient (R)** can be calculated to determine whether a linear relationship exists between variables and how strong that relationship is
- The **coefficient of determination (R^2)** can then be calculated to test the strength of the association between the variables

Pearson's linear correlation

- Pearson's linear correlation is a **statistical test** that determines whether there is **linear correlation** between two variables
- The data must:
  - Be **quantitative**
  - Show normal distribution
- Method:
  - **Step 1:** Create a **scatter graph** of data gathered and identify if a linear correlation exists
  - **Step 2:** State a null hypthessis
  - **Step 3:** Use the following **equation** to work out Pearson's correlation coefficient *r*
- If the correlation coefficient r is close to 1 or -1 or the then it can be stated that there is a strong linear correlation between the two variables and the **null hypothesis can be rejected**

$$R = n\frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

$\sum x$ = total of the first variable value

$\sum y$ = total of the second variable value

$\sum xy$ = sum of the product of the first and second value

$\sum x^2$ = sum of the squares of the first value

$\sum y^2$ = sum of the squares of the second value

The coefficient of determination

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$$\text{The coefficient of determination } (R^2) = (\text{Pearson correlation coefficient})^2$$

The to find the coefficient of determination...

- Method:
  - **Step 1:** Square the value found for R
  - **Step 2:** Convert the value into a percentage
- An R^2 value of **closer to 1 (or 100%)** shows that the variables have a **strong correlation**, or, you can predict the dependent variable accurately from the independent variable
  - **The null hypothesis can be rejected**
- An R^2 value closer to **0** indicates that there is **no correlation**, or, the dependent variable cannot be predicted from the independent variable

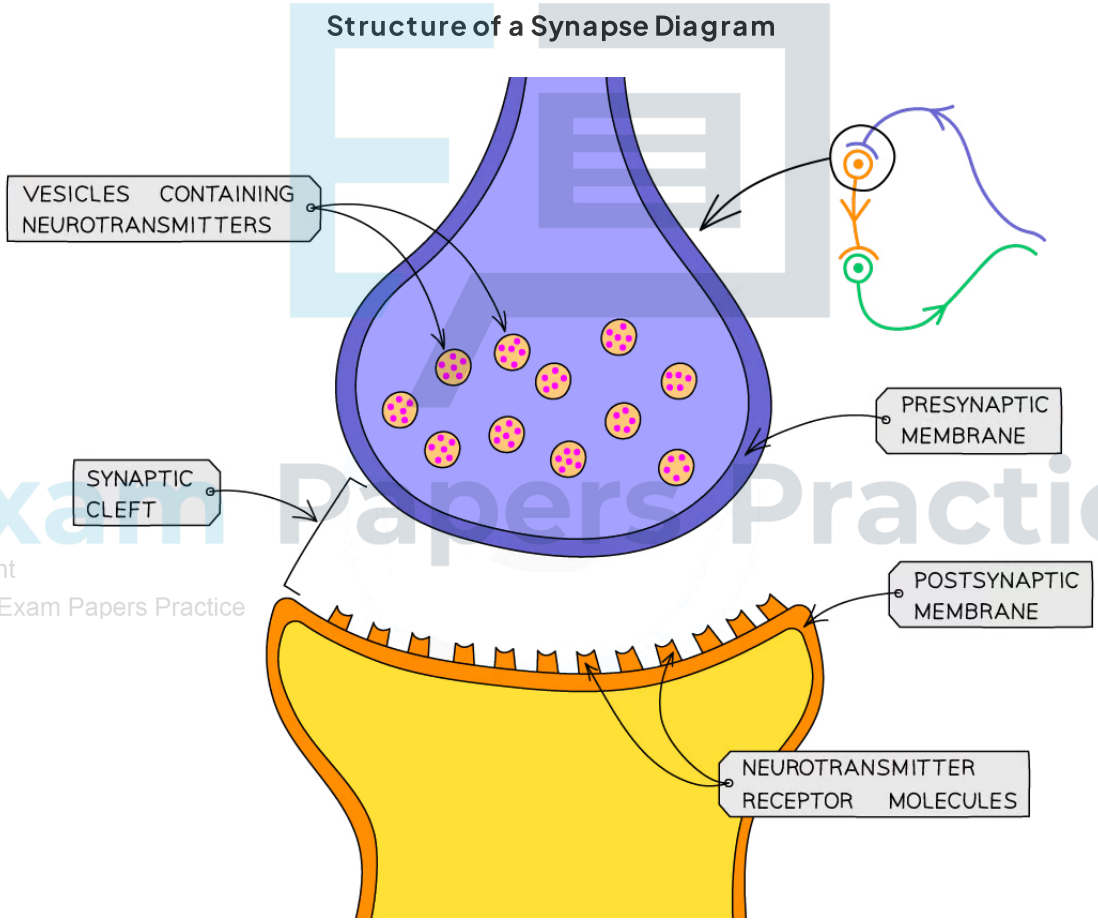
Exam Tip

You will be provided with the formula for Pearson's linear correlation in the exam. You need to be able to carry out the calculation to test for correlation, as you could be asked to do this in the exam. You should understand when it is appropriate to use the different statistical tests that crop up in this topic, and the conditions in which each is valid.

Synapses

Synapses

- Where two neurones meet, they do not actually come into **physical contact** with each other
- Instead, a very small gap, known as the **synaptic cleft**, separates them
- The ends of the two neurones, along with the synaptic cleft, form a structure known as a **synapse**
- Synapses act as the junctions **between any cells in the nervous system**, e.g.
  - In the sense organs, there are synapses between **sensory receptor cells** and **sensory neurones**
  - In muscles, there are synapses between **motor neurones** and **muscle fibres**



A synapse

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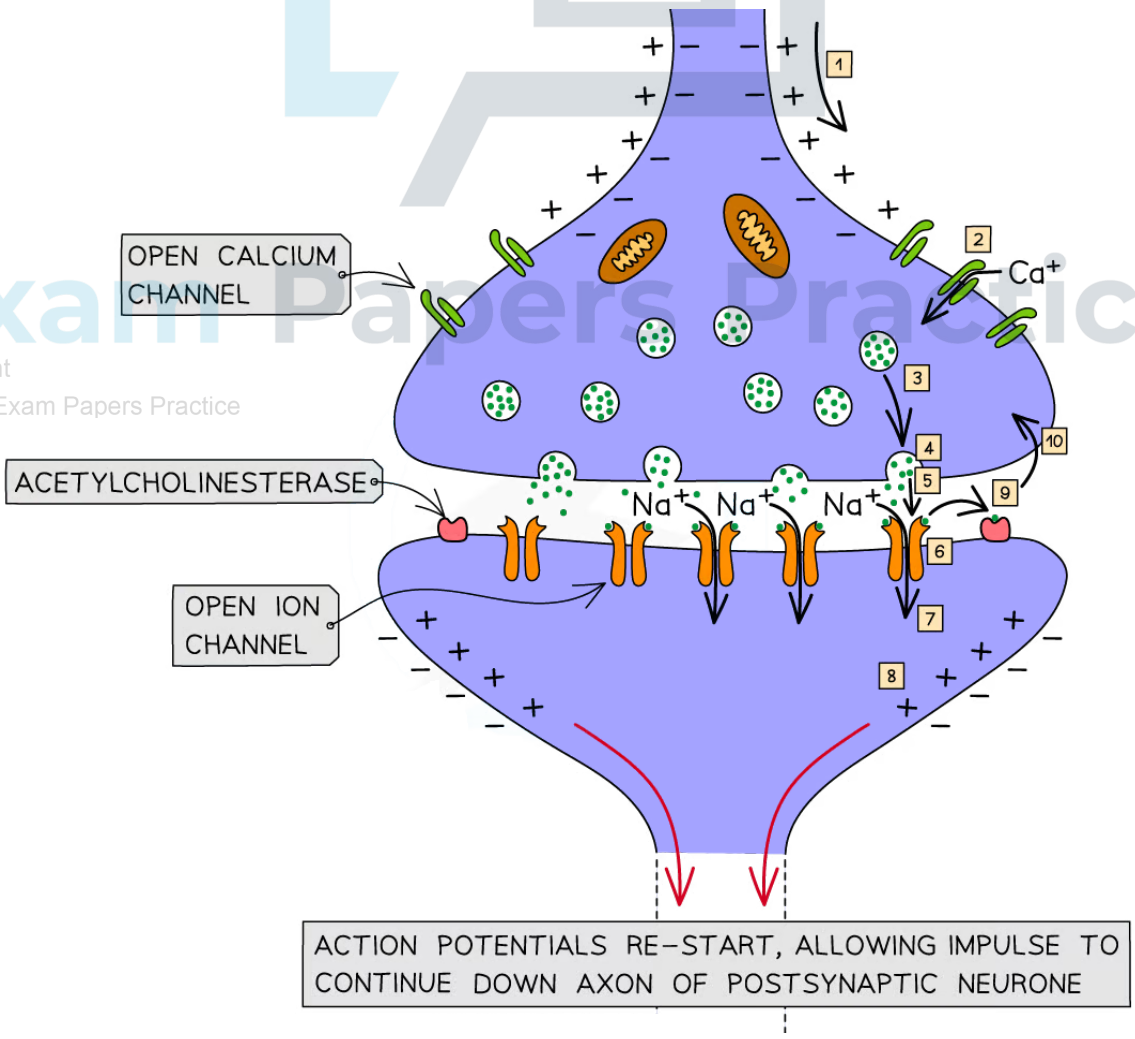
Release of Neurotransmitters

Synaptic transmission: How do synapses work?

- Electrical impulses cannot 'jump' across the synaptic cleft
- When an electrical impulse arrives at the end of the axon on the **presynaptic neurone**, the **membrane** of the presynaptic neurone becomes depolarised, triggering an influx of **calcium ions** into the presynaptic cell via **calcium ion channels** in the membrane
- The calcium ions cause vesicles in the presynaptic neurone to move towards the presynaptic membrane where they fuse with it and **release chemical messengers** called **neurotransmitters** into the synaptic cleft
  - A common neurotransmitter is **acetylcholine**, or **ACh**
- The neurotransmitters **diffuse** across the **synaptic cleft** and **bind with receptor molecules** on the **postsynaptic membrane**; this causes associated **sodium ion channels** on the postsynaptic membrane to open, allowing **sodium ions** to diffuse into the postsynaptic cell
- If enough neurotransmitter molecules bind with receptors on the postsynaptic membrane then an **action potential** is generated, which then travels down the **axon** of the **postsynaptic neurone**
- The neurotransmitters are then **broken down** to prevent continued stimulation of the postsynaptic neurone
  - The enzyme that breaks down acetylcholine is **acetylcholinesterase**

Transmission of a Nerve Impulse Diagram



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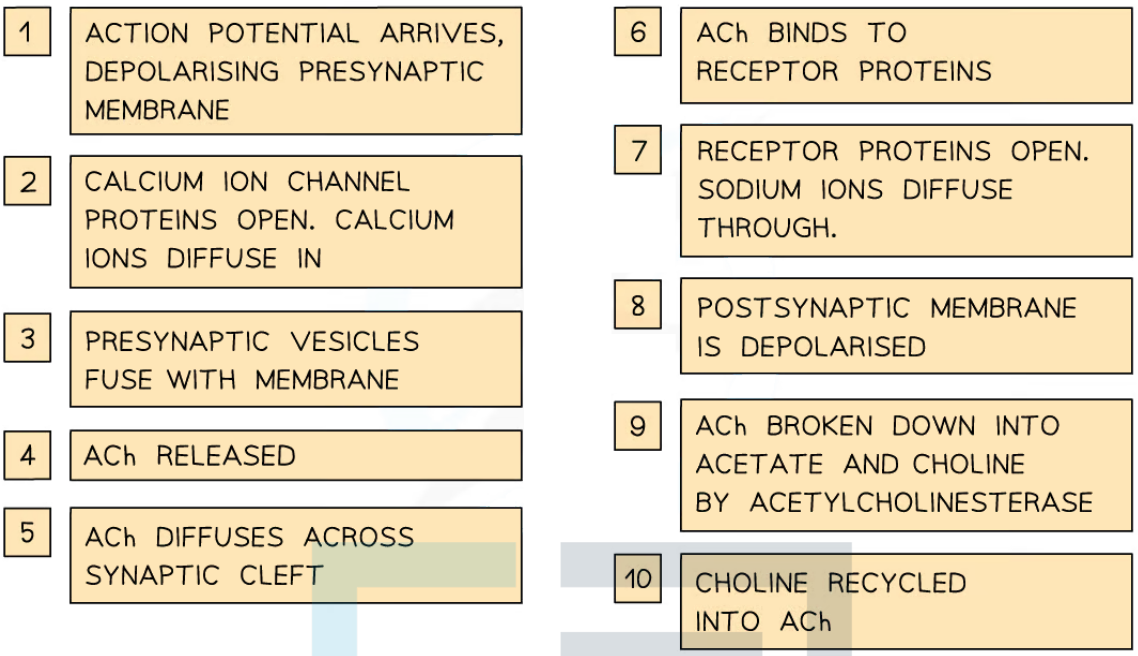

Synaptic transmission using the neurotransmitter acetylcholine

Unidirectionality

- Synapses ensure the **one-way transmission** of impulses
- Impulses can only pass in **one direction** at synapses because **neurotransmitter is released on one side** and its **receptors are on the other** – chemical transmission cannot occur in the opposite direction
- This prevents impulses from travelling the wrong way

Generating a Postsynaptic Potential

- There are over 40 different known **neurotransmitters**
  - Examples include dopamine and noradrenaline
- One of the key neurotransmitters used throughout the nervous system is **acetylcholine (ACh)**
  - ACh is produced in the **presynaptic neurone** by combing **choline** with an **acetyl group**
  - Synapses that use the neurotransmitter ACh are known as **cholinergic synapses**
- Acetylcholine is released into the **synaptic cleft** when **ACh-containing vesicles** fuse with the **presynaptic membrane**, releasing ACh molecules into the **synaptic cleft**
- ACh **binds to specific receptors** on the postsynaptic membrane, where it can **generate an action potential** in the postsynaptic cell by opening **associated sodium ion channels** to allow sodium ions into the cytoplasm of the postsynaptic neurone until the **threshold** level is achieved
- To prevent the sodium ion channels staying permanently open and to stop permanent depolarisation of the postsynaptic membrane, the **ACh molecules are broken down** and **recycled**
  - The enzyme **acetylcholinesterase** catalyses the **hydrolysis** of ACh molecules into **acetate** and **choline**
  - The products of hydrolysis are then **absorbed back into the presynaptic neurone**, and the **active neurotransmitter** ACh is reformed

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Action Potentials (HL)

Depolarisation & Repolarisation

- An action potential is generated when a **stimulus** causes an **influx of positively charged sodium ions** into the axon of the neurone
- This leads to **depolarisation** of the membrane of the neurone, the action potential then moves through the neurone in a wave of **depolarisation** and **repolarisation** events as follows:

Depolarisation

- Some of the ion channels in the membrane of a neurone are **voltage gated**, meaning that they open and close in response to changes in the **electrical potential** across the membrane
  - Voltage gated ion channels are **closed** when the membrane is at rest, but they are involved in the generation and transmission of action potentials
  - Note that not all of the channels in a neurone membrane are voltage gated e.g. some types of potassium ion channel are open when a neurone is at rest to enable potassium ions to diffuse out of the axon and generate resting potential
- When a neurone is stimulated, the following steps occur:
  - A small number of **sodium ion channels** in the axon membrane **open**
  - **Sodium ions** begin to move **into the axon** down their **concentration gradient**
    - There is a greater concentration of sodium ions outside the axon than inside due to the action of sodium-potassium pumps
  - This **reduces** the **potential difference** across the axon membrane as the **inside** of the axon becomes **less negative**
  - If enough sodium ions enter the axon and the potential difference is reduced enough, **voltage gated sodium ion channels** open, leading to a further, large influx of sodium ions
  - Once the charge has been reversed from -70 mV to around +40 mV, **an action potential** is said to have been **generated**

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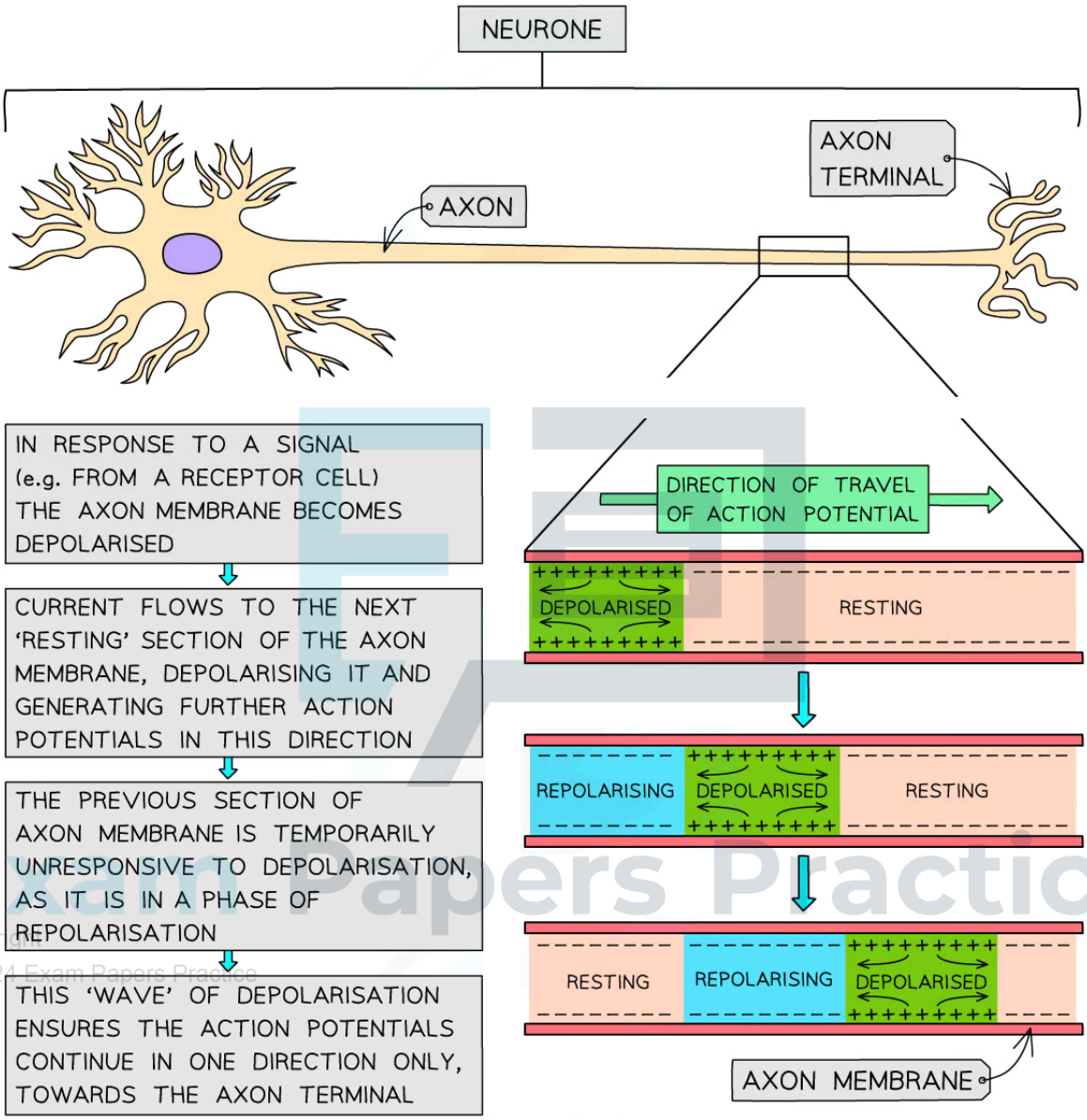
How an action potential is propagated

- Once an action potential has been generated, it can be **propagated**, or transmitted, along the length of the axon
  - The depolarisation of the membrane at the site of the first action potential causes **sodium ions** to diffuse along the cytoplasm into the next section of the axon, **depolarising** the membrane in this new section, and causing voltage gated sodium channels to open
  - This triggers **another action potential** in this section of the axon membrane
  - This process then repeats along the length of the axon
- In the body, this allows action potentials to begin at one end of an axon and then pass along the entire length of the axon membrane

Propagation of Nerve Impulse Diagram



How an impulse is propagated in one direction along the axon of a neurone

Repolarisation

- About 1ms after an action potential is generated, all the **voltage gated sodium channels** in this section of membrane **close**

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- **Voltage gated potassium channels** in this section of axon membrane now **open**, allowing the diffusion of potassium ions **out of the axon**, down their concentration gradient
  - Remember that the sodium-potassium pumps have not stopped working during the action potential; hence the potassium ion gradient is still present
- This movement of potassium ions causes the inside of the axon to become **negatively charged again**, a process known as **repolarisation**
  - There is a short period during which the membrane potential is more negative than resting potential; this is known as **hyperpolarisation**
  - The period during which the membrane is hyperpolarised is known as the **refractory period**
    - The membrane is unresponsive to stimulation during the refractory period, so a new action potential cannot be generated at this time
    - This makes the action potentials **discrete** events and means the impulse can **only travel in one direction**
    - This is essential for the successful and efficient transmission of nerve impulses along neurones
- The voltage gated potassium channels then **close**, and the **sodium-potassium pumps** work to restore **resting potential**
  - Only once resting potential is restored can the membrane be stimulated again

Action Potential Graph

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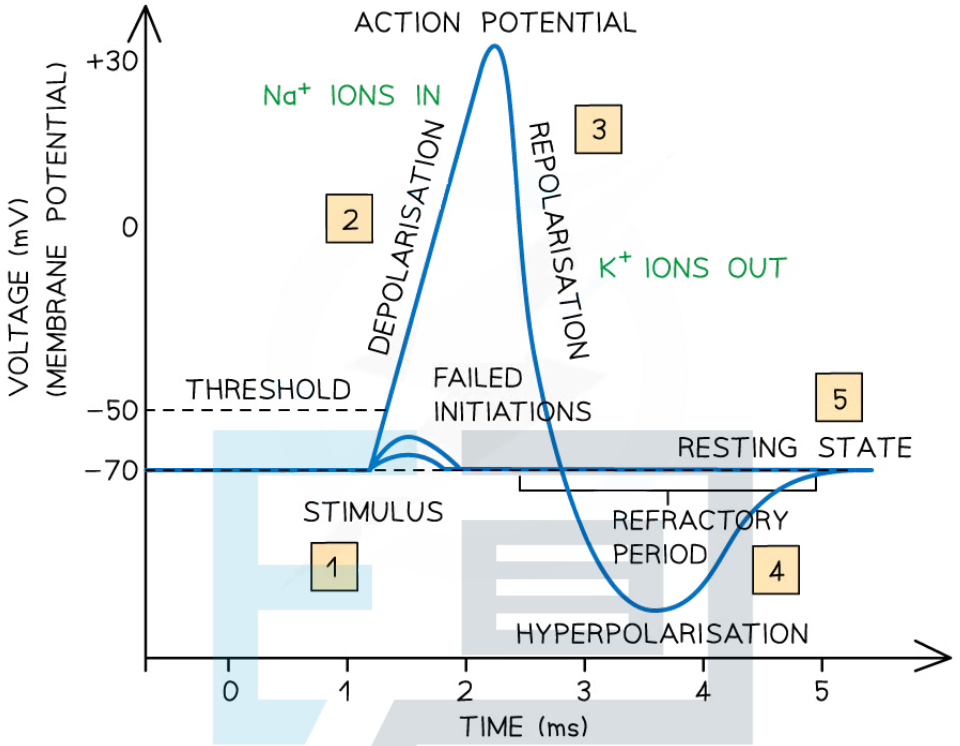

The depolarisation and repolarisation of an action potential can be clearly seen in a graph of membrane potential against time

- An **action potential** is only **initiated** if the **threshold potential** is reached
- When a neurone is stimulated, sodium ion channels in the axon membrane open and sodium ions pass into the axon down their concentration gradient
- This causes the inside of the axon to become **less negative,** but exactly how much less negative it becomes is dependent on the number of sodium ion channels that open
  - A large stimulus will cause more channels to open than a small stimulus
  - If more channels open, then more sodium ions will enter the axon, causing it to become less negative
- If the potential difference reaches around **-50 mV,** known as the **threshold potential**, voltage gated sodium ion channels open and **many more** sodium ions enter the axon
  - This causes the membrane potential to reach around +40 mV
- Once the charge has been reversed from -70 mV to +40 mV, an action potential is generated

The all-or-nothing principle

- Action potentials are either generated or not generated depending on whether the threshold potential is reached; there is **no such thing as a small or large action potential**

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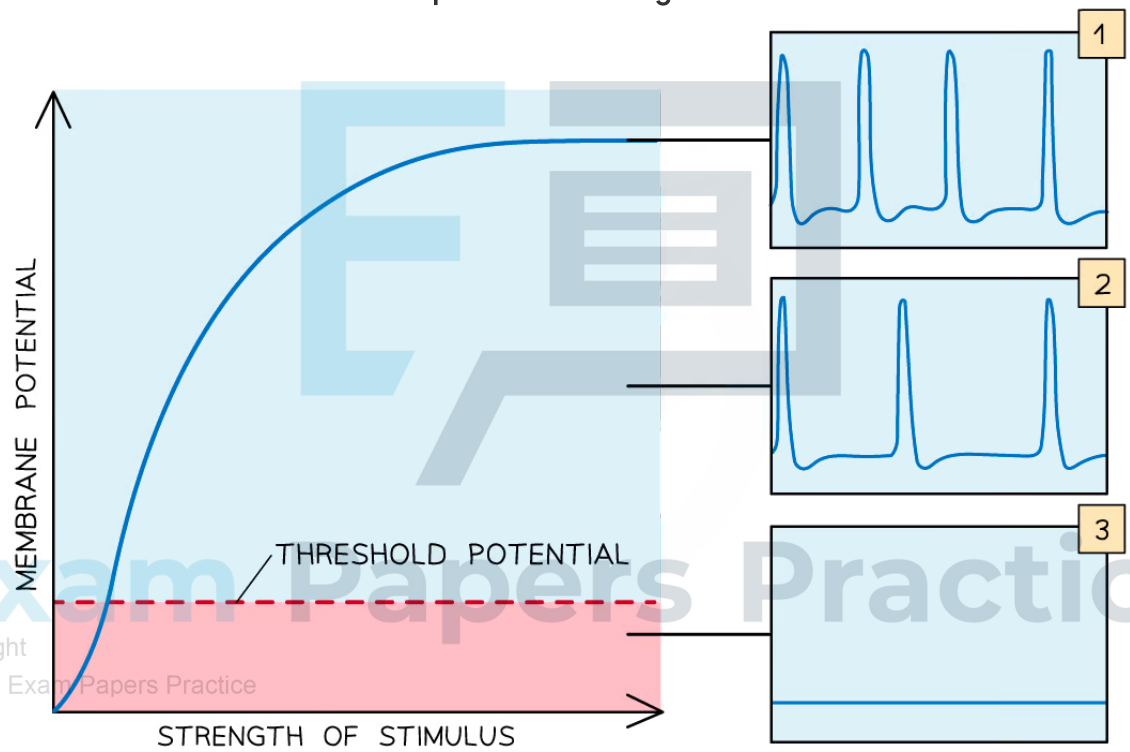
- If a stimulus is **weak,** only a few sodium ion channels will open and the membrane won't be sufficiently depolarised to reach the **threshold potential;** an action potential will not be generated
- If a stimulus is **strong enough** to raise the membrane potential above the **threshold potential** then an action potential will be generated

- This is the **all-or-nothing principle**
  - An impulse is **only transmitted** if the **initial stimulus is sufficient** to increase the membrane potential above a **threshold potential**
- Stimulus size can be detected by the brain because as the **intensity of a stimulus increases**, the **frequency** of action potentials transmitted along the neurone **increases**
  - This means that a small stimulus may only lead to one action potential, while a large stimulus may lead to several action potentials in a row

Depolarisation Diagram



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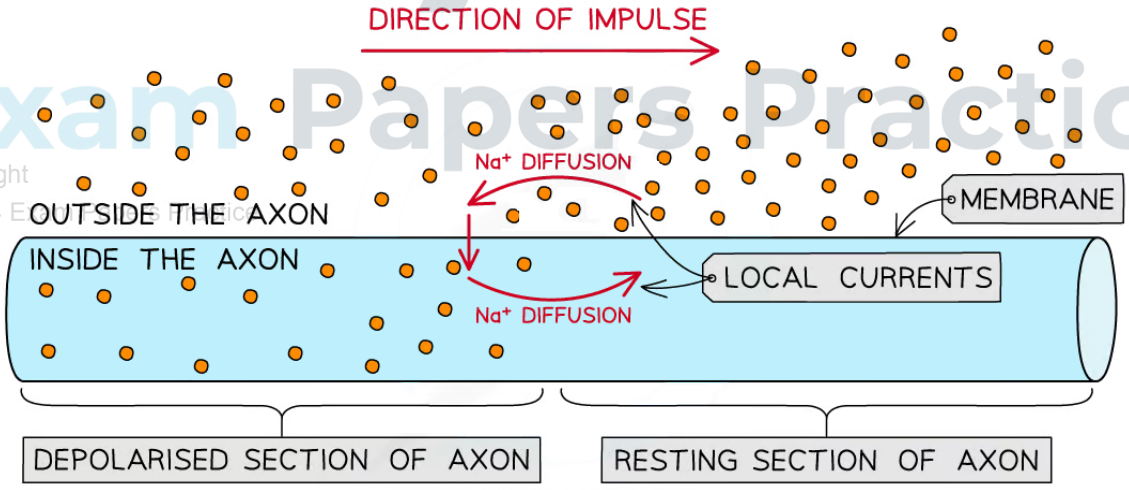
1	THE MEMBRANE IS GIVEN A STRONG STIMULUS WHICH GENERATES A HIGH FREQUENCY OF ACTION POTENTIALS
2	THE MEMBRANE IS GIVEN A WEAK STIMULUS WHICH GENERATE A LOW FREQUENCY OF ACTION POTENTIALS
3	THE MEMBRANE IS GIVEN A VERY WEAK STIMULUS WHICH FAILS TO GENERATE AN ACTION POTENTIAL

As the strength of a stimulus increases beyond the threshold potential, the frequency of action potentials increases

Local Currents

- The propagation of nerve impulses along axons occurs due to **local currents** that cause each successive section of the axon to reach the **threshold potential**
- **Inside** the **depolarised** section of the axon
  - There is a **high concentration** of sodium ions due to their recent **influx**
  - This creates a **concentration gradient** between the section of the axon that has depolarised and the neighbouring section
  - Sodium ions diffuse **within the axon** to the neighbouring section of axon that has not yet depolarised
  - This reduces the negative membrane potential in the new section of axon and, if a threshold is reached, begins the initiation of an action potential
    - This enables the original action potential to be propagated
- On the **outside** of the axon
  - There is a higher concentration of sodium ions outside the section of axon that has **not yet depolarised** due to the diffusion of sodium ions into the depolarised section
  - Sodium ions diffuse from here along the outside of the axon to the section of axon that has just become depolarised
- These movements of sodium ions are known as **local currents**
- These local currents cause a **wave of depolarisation** and **repolarisation** to travel along the axon, resulting in the **propagation of a nerve impulse**

Propagation of Nerves Impulses Diagram



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The propagation of nerve impulses along axons occurs due to local currents created by the diffusion of sodium ions

Interpreting Oscilloscope Traces: Skills (HL)

Interpreting Oscilloscope Traces

- It is possible to **measure membrane potentials** in neurones by placing electrodes on each side of the membrane
  - A membrane potential is the **difference in charge** between one side of a membrane and the other, sometimes described as the potential difference, or the voltage
- The membrane potential can then be **visually represented** and **displayed** using an **oscilloscope**
- An oscilloscope is a type of **electronic test instrument** that **graphically displays varying signal voltages**
- The display produced is **like a graph** with **time** in milliseconds on the **x-axis** and the membrane **potential** in millivolts on the **y-axis**

How to analyse oscilloscope traces showing resting potentials and action potentials

- If there is a **resting potential**, a **straight, horizontal line** should be shown on the display screen of the oscilloscope at a level of **-70 mV**
- If an **action potential** occurs a **spike,** rising up to a maximum voltage of **between +30 and +40 mV,** should be shown on the display
  - The **rising phase** of the spike shows depolarisation
  - The **falling phase** of the spike shows repolarisation
- Often not shown on an action potential graph is the gradual rise in membrane potential just before the membrane rapidly depolarises
  - Before threshold potential is reached, only a small number of sodium channels in the membrane are open, so the membrane depolarises slowly, but when the threshold is reached many more sodium channels open
- Instead of repolarisation causing the membrane potential to return **immediately** to the normal resting potential of -70 mv, the trace often shows a **short period** of **hyperpolarisation**
  - This is when the membrane potential briefly becomes **more negative** than resting potential

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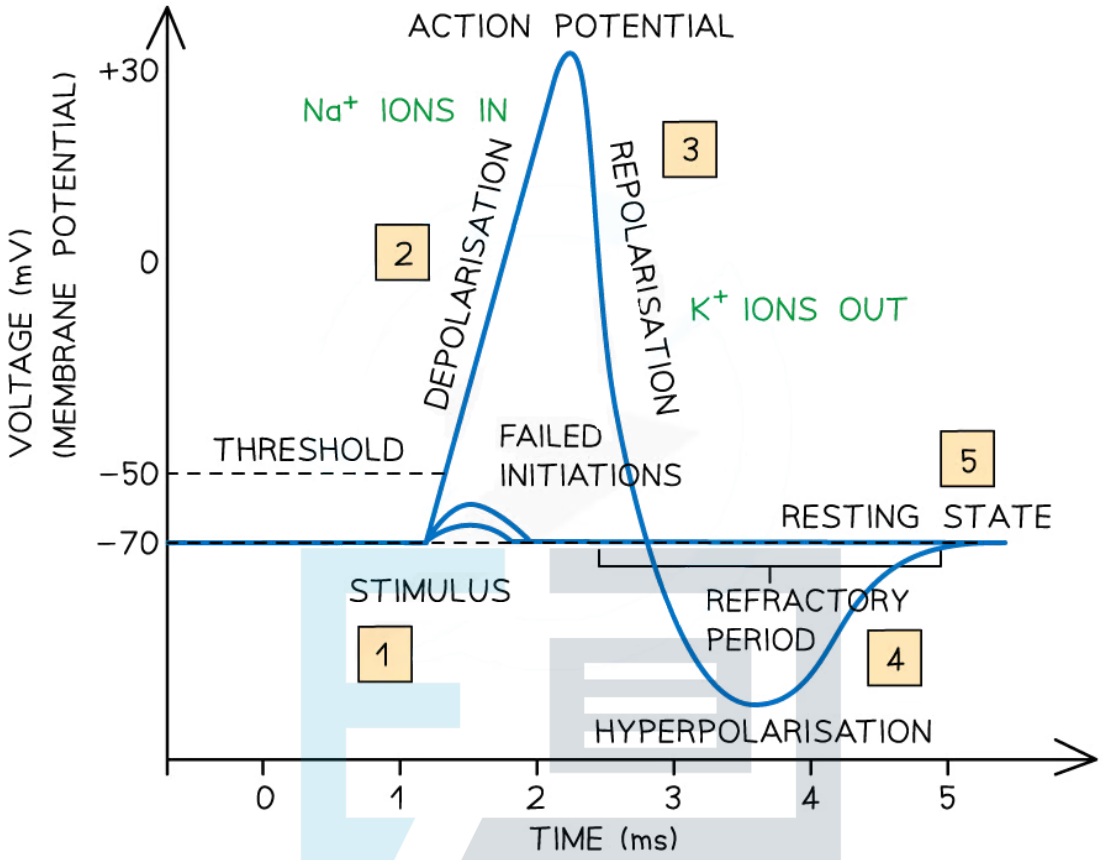
Oscilloscope Trace Graph



An example of an oscilloscope trace showing resting potential and an action potential

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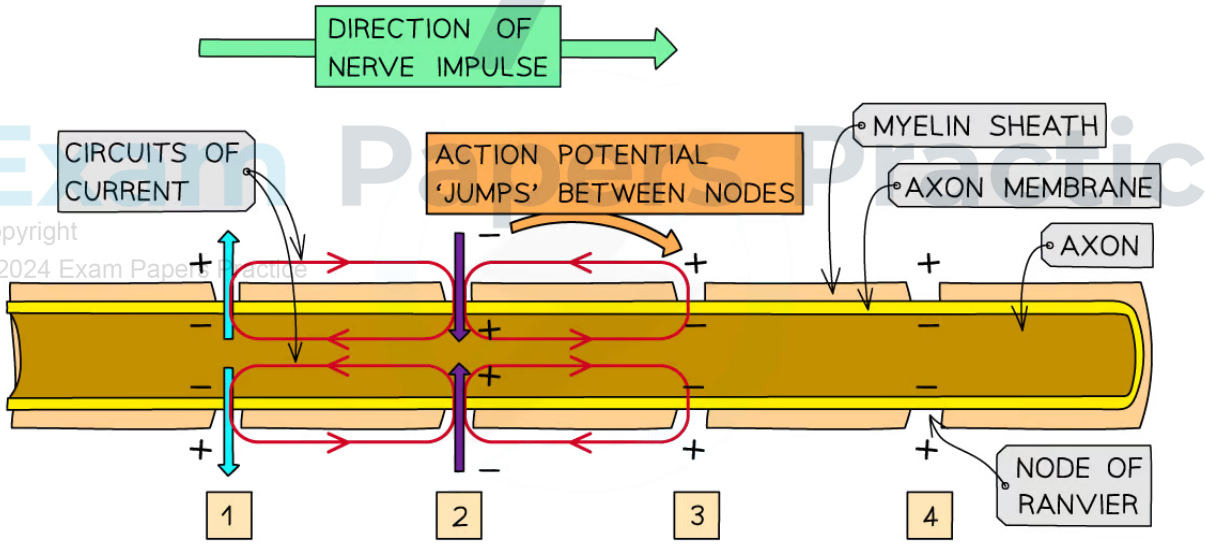
Nerve Conduction Velocity (HL)

Saltatory Conduction

- By insulating the axon membrane, the **presence of myelin increases the speed at which action potentials can travel** along the neurone:
  - The myelin sheath is formed from **Schwann cells**
  - In sections of the axon that are surrounded by a myelin sheath, **depolarisation** (and the **action potentials** that this would lead to) **cannot occur**, as the myelin sheath **stops the diffusion of sodium ions and potassium ions**
  - There are small, **uninsulated sections** of the axon, called the **nodes of Ranvier,** which contain **clusters of ion pumps and channels** which allow the action potential to occur
  - As a result, the **action potentials 'jump' from one node to the next,** this is known as **saltatory conduction**
  - The **local circuits** of current that trigger depolarisation in the next section of the axon membrane exist between the nodes of Ranvier
  - Saltatory conduction allows the impulse to travel **much faster** (up to 50 times faster) than in an unmyelinated axon of the same diameter

Saltatory Conduction Diagram



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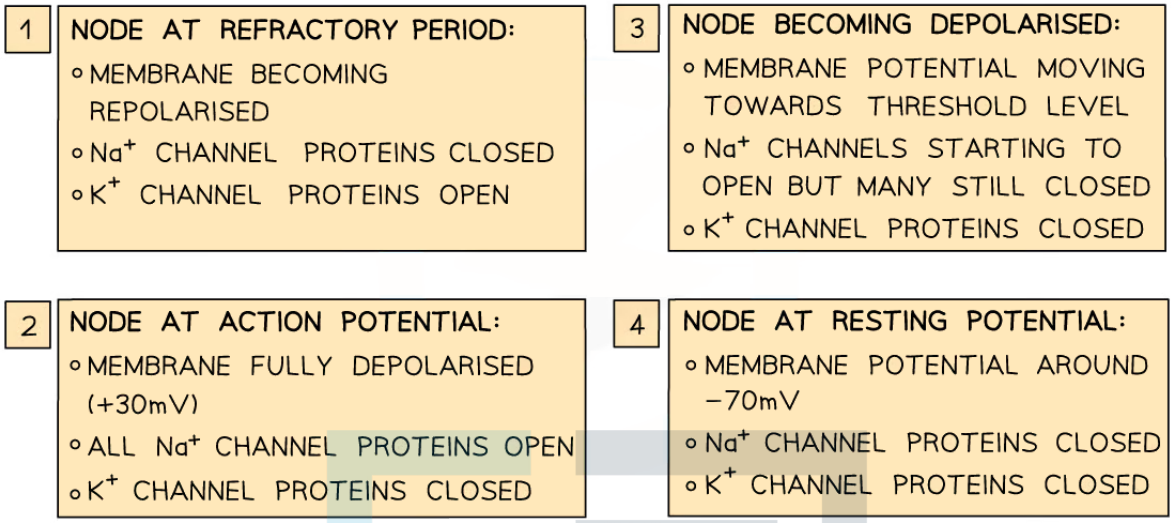

Transmission of an action potential in a myelinated axon by saltatory conduction

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Synaptic Transmission (HL)

Effects of Exogenous Chemicals

Neonicotinoids

- **Neonicotinoids** are synthetic compounds similar to nicotine that are commonly found in **pesticides**
- Neonicotinoids can **block** synaptic transmission at **cholinergic synapses** in **insects** by binding to **acetylcholine receptors**
  - This binding is **irreversible**, as **acetylcholinesterase** cannot break down neonicotinoids
  - As the acetylcholine receptors are blocked, **acetylcholine is unable to bind**, which **stops impulses** from being transmitted across synapses
  - This leads to **paralysis** and **death** in insects
- Neonicotinoids are considered to be especially suitable as pesticides because they're **not toxic to humans and other mammals**
  - A much larger proportion of synapses in insects are cholinergic compared to mammals
  - Neonicotinoids bind much more strongly to acetylcholine receptors in insects
- There is a great deal of controversy over the use of neonicotinoid pesticides because of the impact that they are thought to have on essential pollinators such as bees

Cocaine

- Cocaine is a drug which **blocks the reuptake of neurotransmitters** into the presynaptic knob
- Primarily cocaine affects reuptake of **dopamine** as it binds to the dopamine **transporter protein**
- This prevents dopamine from binding to the transporter so it is not able to move through the membrane back into the presynaptic neurone
- As a result **dopamine builds up in the synapses** which can lead to feelings of pleasure
- Cocaine also blocks the neurotransmitters **serotonin** and **norepinephrine** which enhances feelings of confidence and energy
- In regular users of cocaine, the brain responds by increases numbers of **dopamine receptors** to respond to the high levels of dopamine
  - Once levels return to normal, more dopamine receptors results in increased **sensitivity** and **depression**

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Inhibitory Postsynaptic Potentials

- Some neurotransmitters result in the generation of an action potential in a postsynaptic neurone
- Other neurotransmitters can **prevent** the generation of an action potential in a postsynaptic neurone
  - This is **inhibition** - the impulse stops at the synapse
- One way in which a neurotransmitter can inhibit an impulse is by **opening the gated potassium ion channels** in the membrane so that potassium ions are able to diffuse out of the cell body
  - The result is that the postsynaptic neurone becomes even more negatively charged, or **hyperpolarised**
  - If the neurone is hyperpolarised, the **threshold will not be reached** when the neurone is stimulated and an **action potential cannot be triggered**
- If the cell body of a motor neurone is subject to both excitatory and inhibitory synapses at the same time the following happens:
  - **Sodium ions enter** the cell body following stimulation by the excitatory synapse
  - The stimulation of the inhibitory synapse causes **potassium ions to diffuse out** of the cell body
  - This **cancels out the effect** of the sodium ions entering
  - The **threshold potential is not reached** so no action potential is generated

Inhibitory Synapse Diagram

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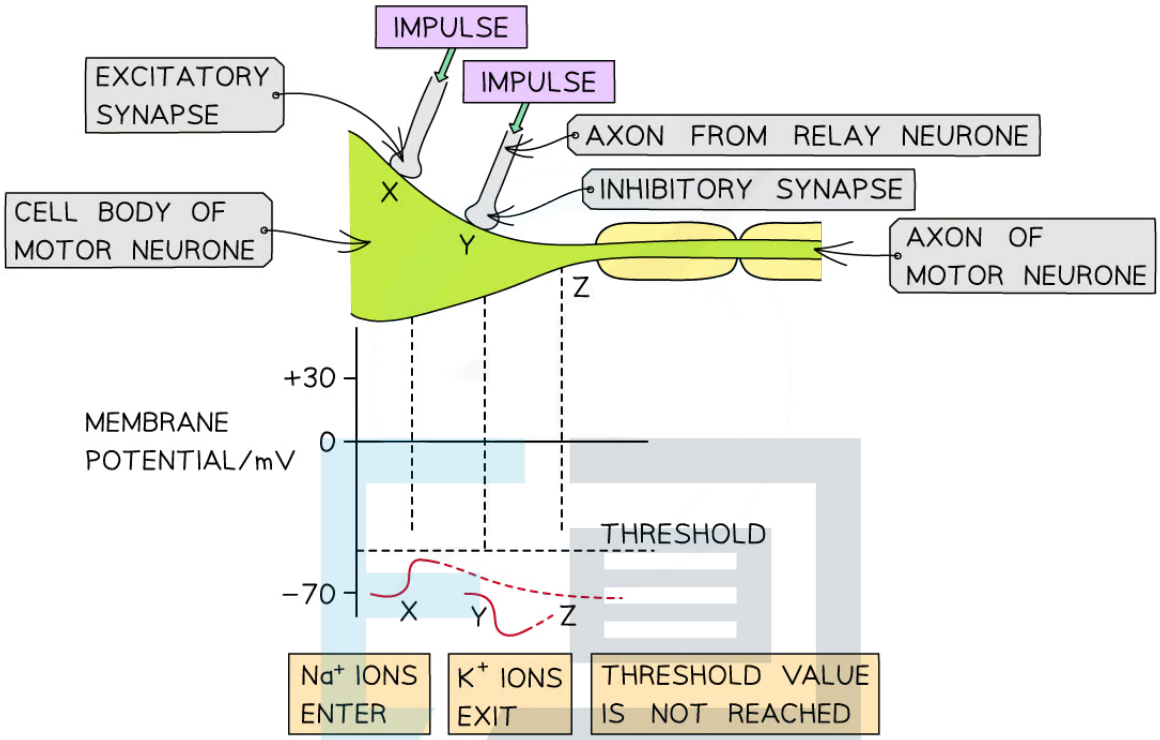

The inhibitory synapse (Y) causes the membrane potential to decrease, cancelling out the effect of the excitatory synapse (X) so that the threshold is not reached and no action potential is generated

- Inhibitory synapses play a vital role in the nervous circuit
- They **prevent random impulses** from being sent around the body
- They allow for **specific** pathways to be stimulated
  - For example, reflex actions should be rapid but specific
  - If an individual grabs a plank of wood that has a nail sticking out they need their arm muscles to pull their hand away
  - It would be unhelpful if their leg muscles contracted and moved their foot away
- Inhibitory pathways can **develop over time**
- These pathways are very important for skills such as painting and drawing
  - Children initially struggle with these skills as their inhibitory pathways have not yet developed to refine their uncontrolled movements

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Summation of Neurotransmitter Effects in Postsynaptic Neuron

- When an impulse arrives at a synapse it **does not always cause impulses** to be generated in the next neurone
- In some cases, a **single impulse** that arrives at a synaptic knob is **insufficient** to generate an action potential in the post-synaptic neurone, for instance
  - Only a **small amount of acetylcholine** is released into the synaptic cleft
  - A **small number of the gated ion channels** are opened in the axon membrane
  - An **insufficient number of sodium ions** pass through the membrane
  - The **threshold potential is not reached**
  - The **small amount of acetylcholine** attached to receptors is broken down rapidly by acetylcholinesterase
- The effect of multiple impulses can be added together to overcome this in a process known as **summation**
- There are two types of summation:
  - Temporal
  - Spatial
- There are several benefits of summation
  - It allows for the effect of a stimulus to be **magnified**
  - A **combination of different stimuli** can trigger a response
  - It avoids the nervous system being **overwhelmed** by impulses
    - Synapses act as a barrier and slow down the rate of transmission of a nerve impulse that has to travel along two or more neurones
    - They only allow the impulses to pass on if there has been input from other neurones and receptors

Temporal summation

- If **multiple impulses arrive within quick succession** the effect of the impulses can be added together to generate an action potential
  - A large amount of acetylcholine is released into the synaptic cleft
  - A large number of the gated ion channels open
  - A sufficient number of sodium ions pass through the membrane

Spatial summation

- Multiple impulses arriving simultaneously at **different synaptic knobs** stimulating the same cell body can also generate an action potential through **spatial** summation
- The multiple impulses result in a large amount of acetylcholine being released into the synaptic cleft which results in the generation of an action potential

Temporal and Spatial Summation Diagram

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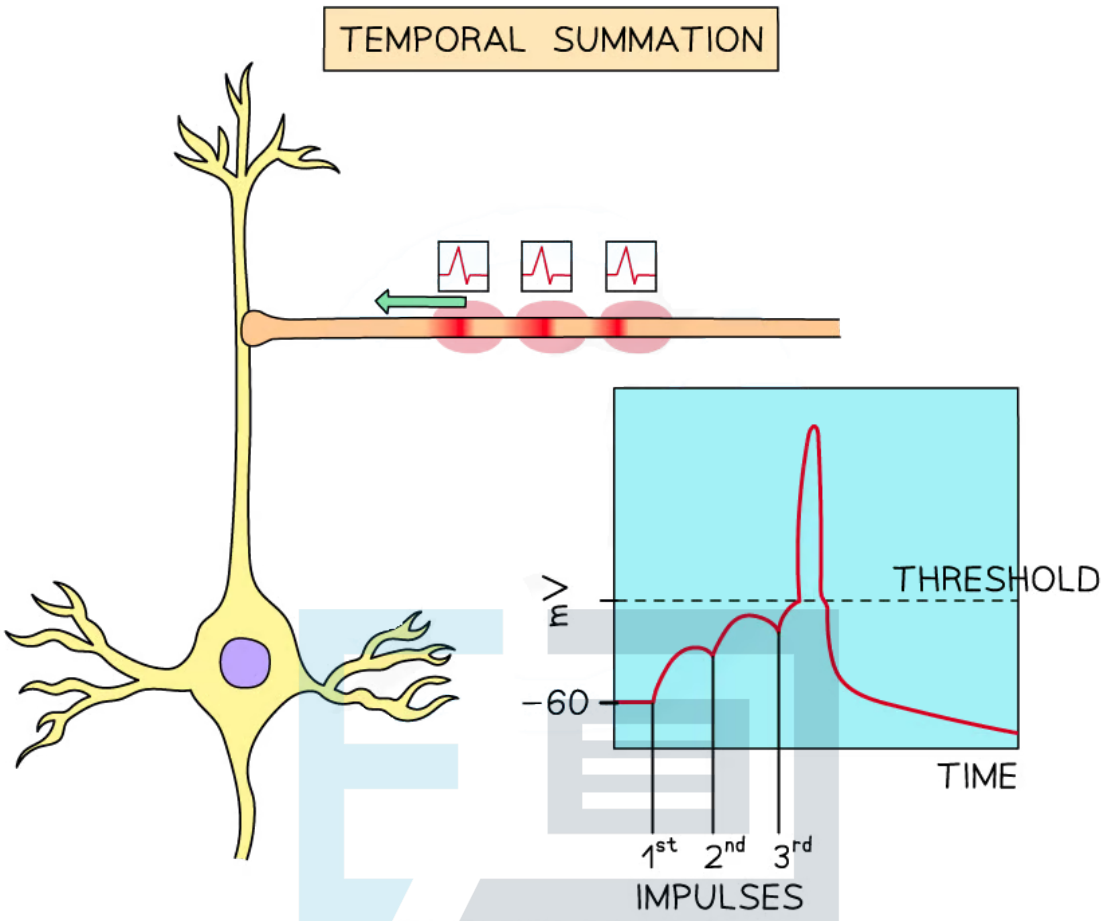

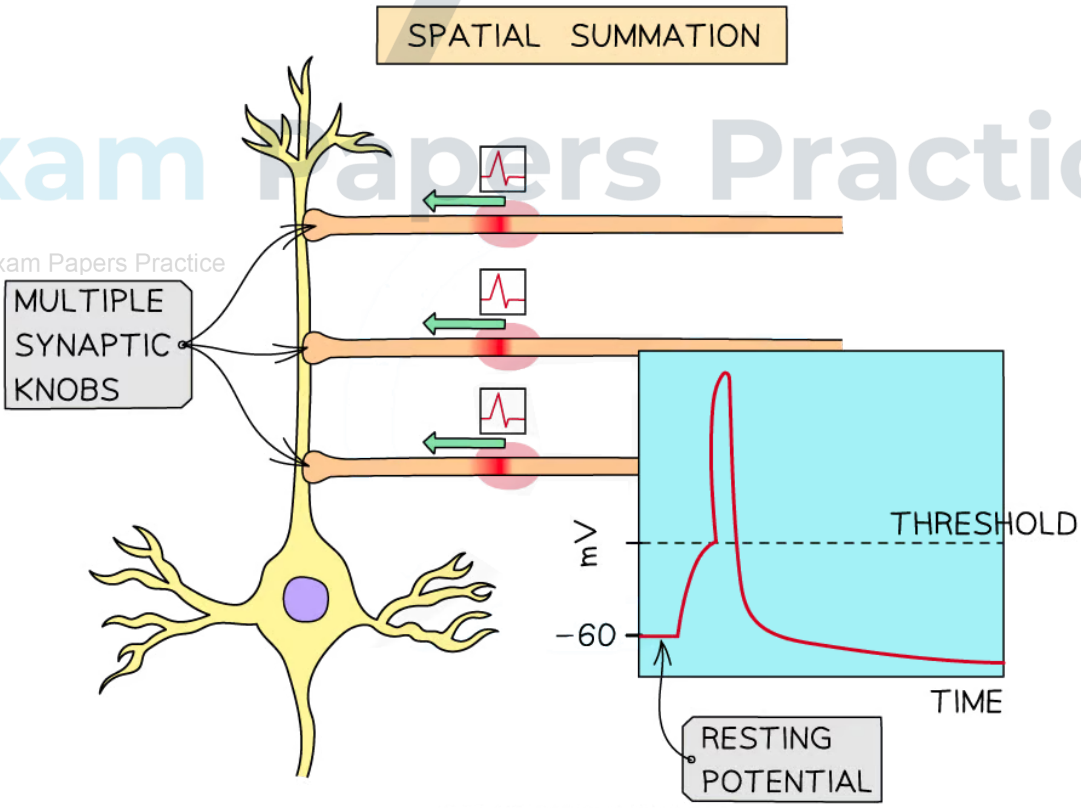

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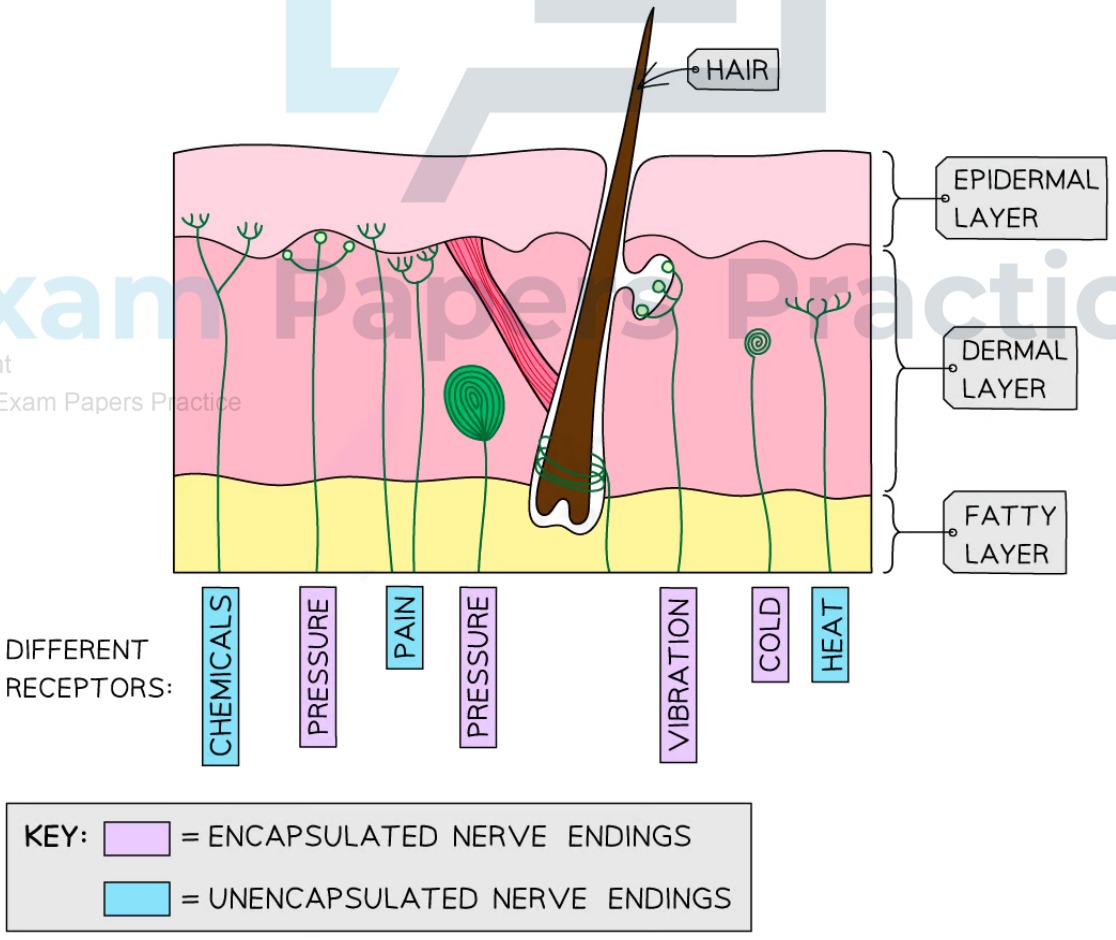
Temporal summation involves only one synaptic knob whereas spatial summation involves multiple synaptic knobs. The different types of summation produce different shaped graphs.

Neurones in the Brain (HL)

Perception of Pain

- Pain receptors (nociceptors) are **sensory receptors**
- These receptors have **free nerve endings** which are **unencapsulated** nerve endings
- The exposed dendrites on these nerves have **transient receptor potential (TRP) channels** which open in response to stimuli which indicate a risk of damaged tissue
- Stimuli might include:
  - High temperature
  - Acid
  - Chemicals e.g. capsaicin in chilli peppers
- Entry of **positively charged ions** causes the **threshold potential** to be reached
- An **action potential** is generated, it moves along the axon of the **sensory neurone** to the central nervous system
- Nerve impulses then pass through the neurones to the cerebral cortex in the **brain,** where pain is **perceived** and a protective response results
- The sensitivity of an organism to these stimuli provides a **survival** and **reproductive** advantage

Pain Receptors Diagram



Pain receptors in the skin can respond to a number of different stimuli as the nerve endings are exposed

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Interaction of Neurones in the Brain

The cerebrum

- **The cerebrum is the largest part** of the brain in humans (accounts for about 80% of the total mass of the brain)
- The cerebrum carries out a large **variety of functions** involved with **conscious** activities, including:
  - Vision
  - Hearing
  - Speech
  - Thinking
  - Memory
- The cerebrum is divided into two hemispheres, each of which have a **thin outer layer** known as the **cerebral cortex** or '**grey matter**'
  - The cerebral cortex consists of the **cell bodies of neurones**
  - It is **highly folded**, which **increases its surface area** and allows it to contain a **greater number of neurones**
  - With more neurones in the brain, **more connections between neurones** can be made
  - This is important, as the more connections between neurones in the brain, the **greater the ability of the brain to carry out more complex behaviours**
  - It is in this part of the brain where **interactions between neurones** lead to **consciousness**
  - This idea of consciousness incorporates **qualitative perception of feelings** associated with colour, temperature, sound as well as communication which results in a **complex awareness** of the environment
- The structure and function of the brain as an organ is covered in more detail here

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