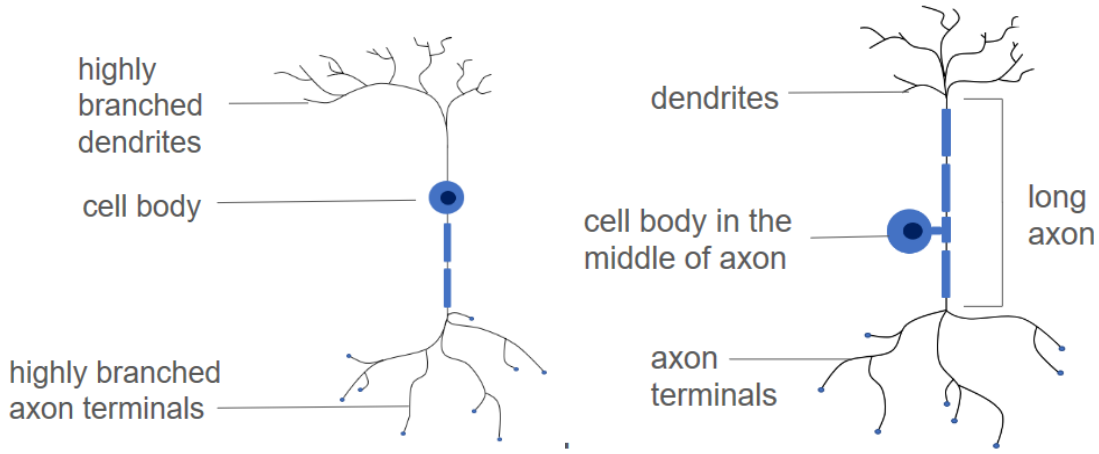
Edexcel (A) Biology A-level

Topic 8: Grey Matter

Notes



Nerve cells called **neurones** play an important role in coordinating communication within the nervous system.

The structure of different types neurones is similar; they all have a **cell body** composed of the nucleus as well as organelles such as mitochondria within the cytoplasm. These provide the energy (in the form of ATP) needed for the active transport of ions into & out of the cell in an impulse (see below). Apart from the essential components, they also contain extensions called **dendrites** involved in conducting impulses towards the cell body, as well as **axons** which conduct impulses away from the cell body.

There are three types of neurone: **sensory, motor and relay. They have** different functions which differ by the position of the cell body within the neurone.

- **Motor neurones** are involved in transmitting electrical signals from the central nervous system to muscles and glands in the body.
- **Sensory neurones** transmit impulses from receptors to the central nervous system whereas
- **Relay neurones** are located within the central nervous system are involved in transmitting the electrical impulses from sensory neurones to motor neurones.

Wider diameter nerve cells transmit impulses more quickly, however this takes up more space within the organisms' body. **Myelination** - a layer of fatty substance formed from Schwann cells wrapped around the neurone - can increase the speed of impulses by acting as an electrical insulator, and allowing impulses to travel by **saltatory conduction** (see below).

Nerve impulse conduction

The structure of neurones, that is the length of axons as well as the polarised nature of the neurone membrane in the resting state, enables the neurones to carry electrical impulses called **action potentials.**

The speed at which the electrical potential is carried can be increased with the help of **myelin sheath** (which serves as an electric insulator of axons and dendrons) - produced by **Schwann cells**. The mechanism by which the speed is increased is known as **saltatory conduction** where the action potential jumps between gaps in the myelin sheath called **nodes of Ranvier.**

Resting Potential

When nerve cells are not actively transmitting an impulse, they are found in the **resting state.** Nerve cells are **polarised** in their resting state. This occurs as a result of imbalance between sodium ions and potassium ions, thus giving the inside of the nerve cell a negative charge in comparison to the external environment. Sodium-ion pumps (cation pumps) constantly and actively remove sodium ions from the cell cytoplasm (across the nerve cell membrane). Potassium ions diffuse out of the cell through ion channels, along their concentration gradient. They also experience an electrostatic force attracting them back into the cell as a result of the negative potential created. When the forces on the potassium ions are balanced, there is no net movement - the resting potential has been reached. As a result of the polarisation, there is a difference in the voltage across the neurone membrane, with a value of **-70mV** known as the **resting potential**.

Action Potential

Upon **stimulation**, the neurone cell membrane becomes **depolarised**. The excitation of neurone cell triggered by stimulus causes sodium ion channels to open, as a result making it more permeable to sodium ions which subsequently diffuse into the neurone, making the inside less negative. The membrane potential becomes less and less negative, until reaching the **threshold potential** of -55mV. This triggers even more sodium channels to open eventually giving a potential difference of +30mV which is the end of the **depolarisation** and start of **repolarisation**.

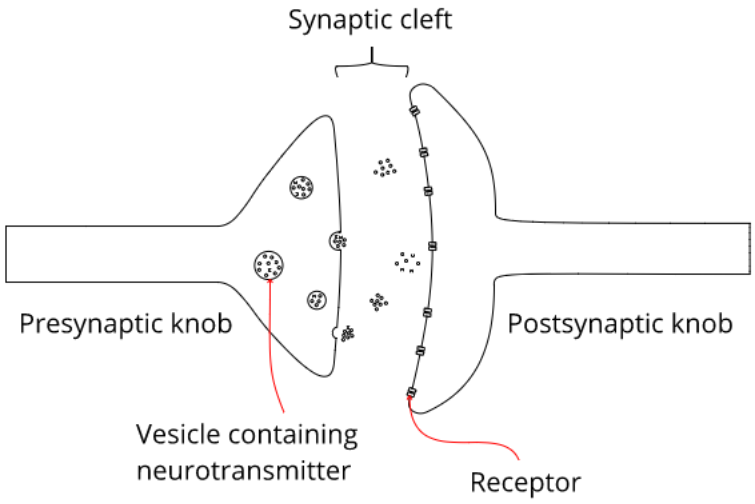
Repolarisation

This is achieved as a result of sodium ion channels closing and potassium ion channels opening. The potassium ions diffuse out of the neurone down the concentration gradient and eventually restore the **resting potential.** However, as the closing of potassium ion channels is slightly delayed, this leads to **hyperpolarisation** i.e. when the potential difference becomes greater than the resting potential. The resting potential is then achieved with the help of sodium-potassium pump which returns the potential difference to the value of **-70mV.**

Afterwards, there is a short period during which the neurone membrane cannot be excited as the sodium channels enter they recovery stage. This period is known as the **refractory period** and serves an important role in ensuring that the action potentials can pass in **one direction only.**

The action potential travels along the neurone as a **wave of depolarisation** - sodium ions move to the adjacent resting region where they diffuse sideways, triggering a change in potential difference, thus creating **local currents** - thus stimulating another **action potential**.

Synapses



Synapses are junctions between two neurones.

Upon the arrival of an action potential, the **presynaptic membrane** depolarises therefore causing the calcium channels to open which subsequently allow calcium ions to enter the neurone.

The presence of calcium ions in the neurone causes the fusion of **synaptic vesicles** filled with a particular **neurotransmitter** such as **acetylcholine** to fuse with the **presynaptic membrane** thus causing the release of neurotransmitter into the **synaptic cleft**, that is the gap between the two neurones.

Afterwards, the neurotransmitter binds to the **receptors** located on the **postsynaptic membrane** therefore stimulating the opening of cation channels which enable sodium ions to enter the neurone. As a result of that, the membrane **depolarises** therefore triggering another **action potential**.

This process only occurs if the neurotransmitter originates from an **excitatory neurone** (creating an **EPSP)**. In the case of **inhibitory neurones** (creating an **IPSP**), chloride ions enter, thus causing hyperpolarisation of the post synaptic membrane therefore triggering a new action potential becomes more difficult.

This sequence of events is controlled with the help of **digestive enzymes** in the synaptic cleft which serve to break down the neurotransmitter to prevent **overstimulation** of the post-synaptic membrane.

Following the breakdown of the neurotransmitter, it is taken up by the pre-synaptic membrane and reused. This, the presence of receptors on one side of the synapse only, and the refractory period serves to ensure that the action potential can only travel in **one direction only**.

Detection of stimuli

Cells specialised for detection of stimuli are known as **receptors**. **Sense organs** such as the eye are composed of groups of receptors.

Photoreceptors are light receptors in the eye. The light enters the eye through the **pupil** and the amount of light entering is controlled by muscles of a structure called the **iris.** The **lens** of the eye focus the light on the retina where the photoreceptors are located, specifically the **fovea**. Subsequently, the nerve impulses received by the photoreceptors cells are then carried via the **optic nerve** to the brain. The point where the optic nerve leaves the eye is known as the **blind spot** as there are no photoreceptor cells located there.

The two types of photoreceptors in the retina are **cones** involved in **colour vision** whereas **rods** can only produce **monochromatic vision**.

Apart from the type of vision they provide, the two photoreceptors different by their level of **sensitivity** – cones can only work in bright conditions whereas rods are much more sensitive and dim light is sufficient for them to work. This is brought about as a result of **convergence** - three rods converge onto a single **bipolar cell** (connecting photoreceptors to the optic nerve) - this acts to amplify the signals triggered by light. Only one cone synapses with each bipolar neurone - so there is no amplification of the signal - making these photoreceptors less sensitive.

Rods contain a light-sensitive pigment called **rhodopsin** which absorbs light energy and subsequently splits into **cis- retinal and opsin**.

In the dark, the rods aren't stimulated: sodium ions diffuse into the cell through open sodium ion channels whilst also being actively pumped out of the cell. As a result, the inside of the cell is only slightly more negative compared to the outside, thus causing the membrane to be slightly depolarised. This enables the release of a neurotransmitter called **glutamate**. Glutamate serves to **inhibit the neurones** which connect the rod cells to the optic nerve, (creating an **IPSP**) as a result **no information is transmitted to the brain.**

In the presence of light, the rhodopsin splits into **cis-retinal and opsin.** Opsin binds to the membrane of the cells thus causing the sodium ion to close without affecting their active removal. The membrane becomes **hyperpolarised** meaning no transmitter is released into the synaptic cleft. Consequently an **action potential** can form and is transmitted to the brain via the optic nerve.

Plants

Plants respond to external stimuli to increase their chance of survival. One example is in **tropisms**, that is growth responses to a **direction stimulus**. An example of tropism is **phototropism** where the direction of growth is determined by the **direction of light.** The shoots of the plant are **positively phototropic** and grow towards the lights whereas roots are **negatively phototropic** and grow away from the light. This allows them to maximise the

light, for photosynthesis, captured by green parts of the plant whilst moving the roots away from the surface in search of minerals & water.

Apart from being affected by light, plants are also affected by **changes in day length**. This kind of sensitivity is known as **photoperiodism** where the plants **flower and germinate** in response to day length. This response is coordinated by a photoreceptor called **phytochrome.** The phytochrome exists in two states, P_R which is the inactive form and P_{FR} which is the active form. Pfr (phytochrome far red) is converted to Pr (phytochrome red) in the dark/low light levels and if exposed to light of **far-red light** wavelengths, whilst the reverse will occur in daylight or if Pr is exposed to **red light**.

Plant growth is also controlled by **indoleacetic acid (IAA)** which is an important **auxin** produced in the **tips and shoots of flowering plants**. The distribution of IAA around the plant controls tropism. IAA causes cell elongation - as opposed to physical growth - brought about by the 'loosening' of cell walls, which go on to take in water by osmosis & stretch (elongate). Protons pumped into the cell wall from the cell cytoplasm disrupt the bonds between cellulose molecules, allowing the cell wall to be stretched.

When the shoot is illuminated from all sides, the auxins are distributed evenly and move down the shoot tip thus causing elongation of cells right across the **zone of elongation**. Whereas if the shoot is only illuminated from one side, the auxins move towards the shaded part of the shoot thus causing elongation of the shaded side only which results in bending of the shoot towards the light.

Brain structure

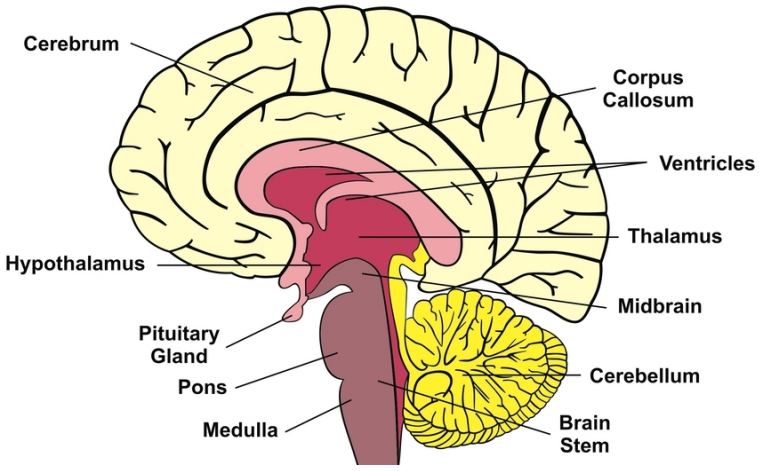


Figure 1 Udaix Shutterstock

- **Cerebrum** is the largest part of the brain composed of two halves known as the **cerebral hemispheres**. The two hemispheres are connected by a band called the **corpus callosum**. The cerebrum is involved in controlling **vision, thinking, learning** and **emotion** as well as **voluntary control** of the body– collectively referred to as **advanced mental activity**. Different parts of the cerebrum have different functions, for instance the **parietal lobe** controls orientation, movement, some types of recognition and memory whereas the **occipital lobe** located at the back of the cerebrum is known as the visual cortex. Auditory information is processed by the **temporal lobe.**
- The **cerebellum** is located underneath the cerebrum and plays an important role in **coordinating muscle movements** as well as **balance**
- **Hypothalamus**, found just beneath the middle part of the brain is involved in **thermoregulation** as well as production of **hormones** involved in control of the **pituitary gland.**
- **Medulla oblongata**, located at the base of the brain controls many **vital body processes** such as breathing, heart rate and blood pressure.

Imaging techniques

MRI – **Magnetic Resonance Imaging** scanners use a **magnetic field and radio waves** for imaging **soft tissues** such as the brain. MRI can be used for diagnosis as **diseased tissue** can be seen, for instance in multiple sclerosis. It can be used to investigate **brain structure and function** as well as medical diagnosis of **tumours** by helping to determine the **exact size and location of the tumour**.

fMRI – a modified version of MRI where the brain **can be seen in action** whilst performing tasks as it monitors the **uptake of oxygen**. It can be used for medical diagnosis of conditions which are caused by **abnormal activity of the brain**, such as seizures.

CT- use radiation in the form of **X-rays** to produce **cross-section** images of the brain. It is based on the idea that denser structures absorb more radiation than the less dense ones therefore they show up lighter on the scan. CT can be used to **investigate brain structure and function**, for instance via studying **damaged brain structure where loss of function is seen.** They can also be used for medical diagnosis which show up **damaged/abnormal areas**, such as where **bleeding in the brain occurs after a stroke**.

PET - Positron Emission Tomography scans use **radioactive isotopes** (such as **Carbon 11** in glucose) with a **short half-life** to monitor areas of activity in the brain. Similar to fMRI, PET follows the flow of blood (thus radioisotopes) through the brain and can be used to monitor activity whilst performing different activities. It is detected by the emission of **positrons** as the radioisotopes **decay**.

Critical windows

Critical windows for development are stages in the lifespan of an organism where it is particularly **sensitive to a specific stimulus** which is required for the organism to develop properly.

The critical windows are supported by various experiments such as **Hubel and Wiesel's experiments on kittens and monkeys**, animals that possess visual systems similar to humans. Hubel and Wiesel's experiments show that there's a period in the early life of these animals where visual stimuli are absolutely necessary for the development of the visual cortex. During the critical period (beginning at around 4 weeks) the presence of synapses allows the transmission of impulses to the visual cortex, therefore enabling the development of the visual cortex.

The development of the human visual system has been studied by looking at abnormalities such as **cataracts** which make the lens in the eye appear cloudy, leading to blurry vision. If a baby is born with a cataract, it needs to be removed as soon as possible to ensure that it is not present during the critical window, as it might potentially cause permanent damage to the visual system. In the case of adults, it causes no permanent damage when it is removed.

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Ethics

The use of animals or humans for research raises many **ethical issues**, with arguments for and against their use in research.

The arguments supporting their use include their **similarity to humans** which has huge potential and enabled us to make important discoveries such as antibiotics. Moreover, many people believe that animals can be used so long as they are treated well and their suffering is avoided. Animals also play an important role in **drug trials** - reducing the (ethical) problems faced if drugs were to be tested on humans alone.

However, many believe that animals should not be used in medical research as it goes against their basic animal rights, as well as prevents them from expressing their natural behaviours. **Absolutism** is the belief that there either animals always should or should not be used. In practice, animals are used in research in the cases where the overall expected benefits of the study outweigh the harm done to the animals. This is known as **Utilitarianism**.

Habituation

Habituation is a phenomenon where an organism becomes **insensitive to repeated stimuli over time** which does not threaten their survival or does not benefit them in any way. It is a

type of **learned behaviour**. Examples include ignoring familiar sounds and responding to unfamiliar ones.

Habituation occurs when the **calcium channels become less responsive**, as a result reducing the amount of calcium ions which cross the presynaptic membrane with the purpose of triggering neurotransmitter release. As a consequence, **less depolarisation of the post-synaptic membrane occurs therefore no action potential is triggered**.

Invertebrates such as snails, sea slugs and tortoises can be used to investigate habituation in a similar way where the animal is repeatedly stimulated for instance by tapping the shell of a tortoise until it stops responding to the stimulus.

A great range of studies can be performed to study important brain functions - including the 'nature-nurture' debate. Methods may include **twin studies** (comparing characteristics shown by identical and non-identical twins), **longitudinal studies** (following individuals through the various events of their lives), **cross-cultural studies** (comparing individuals of different nationalities), and laboratory **experiments** (such as those carried out by Hubel and Weisel).