WJEC (England) Biology A-level

Topic 3.5: The nervous system

Notes

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 located 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 focuses 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 differ in 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.**

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

In the dark, the rods aren't stimulated as the sodium ions diffuse into the cell through open sodium ions whilst being actively pumped out of the cell by active transport. As a result of that, the **inside of the cell is only slightly more negative compared to the outside**, thus causing the **membrane to be slightly depolarised**. Therefore, the release of neurotransmitter called **glutamate** is released. Glutamate serves **to inhibit the neurones which connect the rod cells to the optic nerve**, as a result **no information is transmitted to the brain.**

In the presence of light, the rhodopsin **splits into retinal and opsin**. **Opsin** binds to the membrane of the cells thus **causing the sodium ion to close without affecting the transport** of sodium ions out of the cell via active transport, therefore the **membrane becomes hyperpolarised** meaning no transmitter is released into the synaptic cleft. Thus an action potential forms and is transmitted to the brain via the optic nerve and subsequently processed by the brain.

Spinal cord

The **spinal cord** is a column of nervous tissue which runs along the back and is protected by the **vertebral column** which is where most peripheral neurones originate from.

The spinal cord is composed of:

- **Grey matter** which lies in the centre, which contains cell bodies of relay and motor neurones.
- **White matter** which surrounds grey matter and contains myelinated axons
- **Central canal** which lies in the centre of grey matter and contains **cerebrospinal fluid**
- **Sensory neurones** enter the spinal cord via the **dorsal route**
- **Motor neurones** leave the spinal cord via the **ventral route**

The function of the spinal cord is to relay information in and out of any point along it as well as up and down the body and to the brain.

The **simple reflex arc** is the basis for rapid, protective involuntary actions, as the information does not reach the brain before a response is carried out.

An example of a reflex is stepping on something sharp:

- **Stimulus** – mechanical stimulus from the object
- **Receptor** – stimulus is detected by mechanoreceptors in the skin which respond to the stimulus by sending a nerve impulse to sensory neurone
- **Sensory neurone** – passes nerve impulse to spinal cord via the dorsal route
- **Relay neurone -** passes the information the impulse to the motor neurone
- **Motor neurone** – carries the nerve impulse via the ventral route of the spinal cord to the muscle
- **Effector** – Muscles are the effectors which carry out a response to prevent an injury
- **Response** – immediately moving away from the sharp object

Cnidarians possess a very simple nervous system in the form of a **nerve net** which consist of interconnected neurones. The nervous net allows them to respond to a limited number of stimuli such as mechanical force.

Neurone structure

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

The **structure of neurones is similar**, as they all have **a cell body composed of the nucleus** as well as **organelles such as mitochondria within the cytoplasm**. 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 them in the opposite direction, that is away from the cell body.

There are three types of neurones, **sensory, motor and relay** with 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 the **relay neurones** which are located within the central nervous system are involved in transmitting the electrical impulses from sensory neurones to motor neurones.

The structure of neurones, that is the length of axons as well as the **polarised** nature of the neurone membrane in the resting state where the **outside of the membrane is positively charged** and the **inside is negatively charged** 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 insulator of axons and dendrons produced by **Schwann cells**. The mechanism by which the speed is increased is known as **salutatory conduction** where the action potential jumps between gaps in the myelin sheath called **nodes of Ranvier.**

Nerve impulse conduction

As previously mentioned, 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. 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**.

This resting potential is generated as well as maintained with the help of **sodium-potassium pump** which **moves sodium ions out of the neurone** thus creating an electrochemical gradient as the **concentration of sodium ions is higher outside the cell** because the **membrane is not permeable to sodium ions**.

The sodium-potassium pump is also involved in **transporting the potassium ions into the neurone**. However, the **potassium ions diffuse back out due to the presence of potassium ion channels**. As a result of that, the **outside of the cell is positively charged** due to the imbalance of positively charged ions.

Upon stimulation, the neurone cell membrane becomes **depolarised**. This occurs as following:

- Firstly, the excitation of neurone cell triggered by stimulus **causes the sodium ion channels to open**, as a result **making it more permeable to sodium ions** which subsequently **diffuse into the neurone** down the electrochemical gradient, thus **making the inside less negative**.
- Upon reaching the threshold of **-55mV**, even **more sodium channels open** eventually giving a potential difference of **+30mV** which is the end of the depolarisation and start of **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.

The action potential travels along the neurone as a **wave of depolarisation** where the **sodium ions move to the adjacent resting region** where they **trigger a change in potential difference**, thus **stimulating another action potential**.

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 only pass in one direction as discrete signals**.

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**. In the case of **inhibitory neurones,** chloride ions open, 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**. Apart from this, the **presence of receptors on one side of the synapse only,** that is the post-synaptic side serves to ensure that the **action potential can only travel in one direction only.**

The effect of chemicals on transmission of impulses

Psychoactive drugs are chemical substances which affect brain function which in turn leads to changes in mood as well as perception. Drugs can either **amplify synaptic transmission** or **inhibit it**. For instance, certain inhibitory drugs mimic the action of neurotransmitters, thus blocking the receptors on the post-synaptic membrane.

Examples of substances which affect the transmission of impulses include:

- **Organophosphates** which inhibit the action of the enzyme involved in the breakdown of neurotransmitters, thus meaning that continual stimulation of the post-synaptic membrane occur and this is exhibited through repeated muscle contraction

- **Excitatory drugs** such as a psychoactive drug amphetamine which stimulates the release of neurotransmitters such as noradrenaline