Neuron and Transmission of Nerve Impulse

Content Outline

Introduction

You are sleeping alone in your house. Suddenly there is a noise and you are awakened. Yoga instructor gives instruction and the students follow. The teacher asks the students to write the questions written on the board and students write down. Your awakening or students' following instructions are some examples of the functioning of the nervous system.

Sweating on summer days and shivering on cold winter nights are some other examples of normal functioning of the nervous system. Nervous system along with the endocrine system maintains homeostasis of the body. This is required to sustain life in changing environmental conditions. The objective of the nervous system and endocrine system is the same but their modes of action are completely different.

The nervous system is the master controlling and communicating system of the body. The cells constituting the nervous system communicate by rapid and specific signals which produce immediate responses.The branch of medical science which deals with the normal functioning and disorders of the nervous system is called **neurology.**

There are three overlapping functions in the nervous system. (i) **Sensory input** – The collection of information from inside and outside of the body through sensory receptors is called sensory input. (ii) **Integration -** Its function is to process and interpret sensory input and decide what should be done as response. (iii) **Motor output** is the response created by activating effectors.

Components of the Nervous System

All the above functions are performed by specific cells. These cells are compactly arranged without very less extracellular space. Although the function of the nervous system is very much complicated, it consists of two types of cells: **neuroglia** or **glial** cells and **neurons.**

- **Neuroglia**

These are small sized supporting cells which remain associated with neurons. They make up about half the volume of CNS. Their names arose from the ideas of early biologists who felt that these cells keep nervous tissues together like 'glue'. Recent knowledge reveals that these cells are not passive adhesive cells rather they actively take part in nervous activities.

Neuroglial cells are much smaller in comparison to neurons but their number is 5-50 times more than neurons. Neurological cells do not have excitability like neurons. They have the capacity to divide. During injury or diseases, if neurons are destroyed neuroglial cells divide and fill up the gap. Brain tumours derived from glial cells are called **gliomas** and have the risk to become malignant and grow rapidly.

Types of Neuroglia

There are six different types of neuroglial cells. Four of them are associated with CNS and two are associated with PNS.

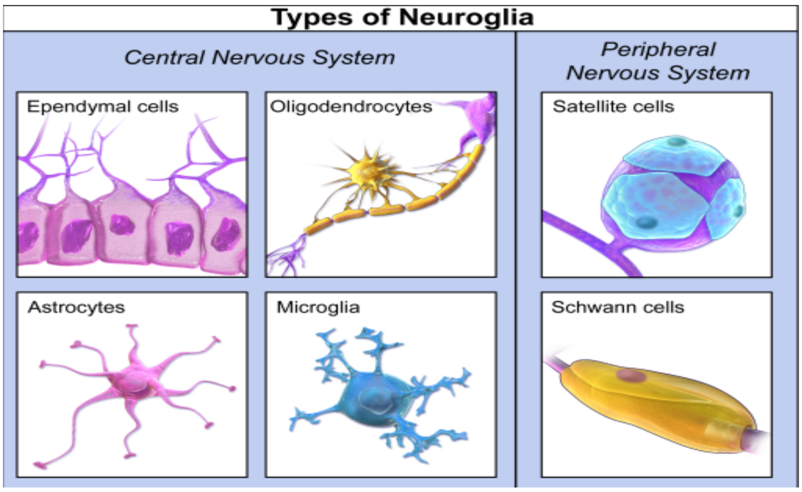


Fig 1. Types of Neuroglia

Neuroglia in CNS

These include astrocytes, microglia, ependymal cells and oligodendrocytes.

Astrocytes are most abundant and most versatile among all the glial cells. Their processes cling to neurons and their synaptic endings. They provide support and supply glucose from capillaries to neurons.

Microglia are small, ovoid cells with processes. These cells detect the presence of microorganisms or dead neurons. On detection they change to special macrophage-like cells and phagocytize microorganisms and neuron debris. This is essential as cells of the immune system are not allowed to enter in CNS. Thus they maintain the health of neurons.

Ependymal cells

They are squamous, columnar or even ciliated cells. They line the central cavities of the brain and spinal cord. Beating of cilia helps to circulate the cerebrospinal fluid.

Oligodendrocyte

They have fewer processes. They wrap around a group of nerve fibres and form myelin sheath.

Neuroglia in PNS

There are two types of neuroglial cells associated with PNS. **Satellite cells** surround neuron cell bodies in ganglia and **Schwann cells** surround and form myelin sheath, an insulating membrane around the longer fibres of PNS.

- **Neuron**

Nervous system consists of billions of neurons also called nerve cells.

Characteristics

(i) Neurons have very great longevity. They can survive their whole lifetime provided the supply of proper nutrition and oxygen is maintained.

(ii) Neurons generally do not divide. They generally do not undergo cell division except a few exceptions. Olfactory epithelium and hippocampal regions possess some stem cells which divide throughout life and produce new neurons.

(iii) They have a very high metabolic rate and require a large and continuous supply of glucose and oxygen. Neurons cannot survive without oxygen for more than a few minutes.

Structure

Most of the neurons possess two parts (i) cell body (ii) processes.

(i) **Cell body** consists of a spherical nucleus with a prominent nucleolus. Cell bodies possess usual cell organelles except centrioles. Absence of centrioles results in their non-dividing entity. Free ribosomes and rough ER involved in protein synthesis and membrane making are scattered in large numbers in cells. They take more stains and look like dark coloured granules called as *Nissl's granules*. Golgi bodies encircle the nucleus. Cytoplasm consists of a large number of microtubules and neurofibrils. Cell bodies of most of the neurons are located in CNS. Clusters of cell bodies in CNS are called **nuclei** and those in PNS are called **ganglia**.

(ii) **Processes** arise from cell bodies. Brain and spinal cord possess both cell bodies and processes whereas PNS mainly possesses neuronal processes. The latter in CNS are called **tracts** and those of PNS are called nerves.The processes of neurons are of two types; dendrites and axons. They differ in their structure and function. The nature of the plasma membrane of these two processes is also different.

Dendrites

Dendrites of motor neurons are highly branched, tapering structures arising from the cell body. They increase the surface area for receiving signals from other neurons. They form close contacts (synapses) with other neurons. Dendrites collect signals and send them to the cell body.

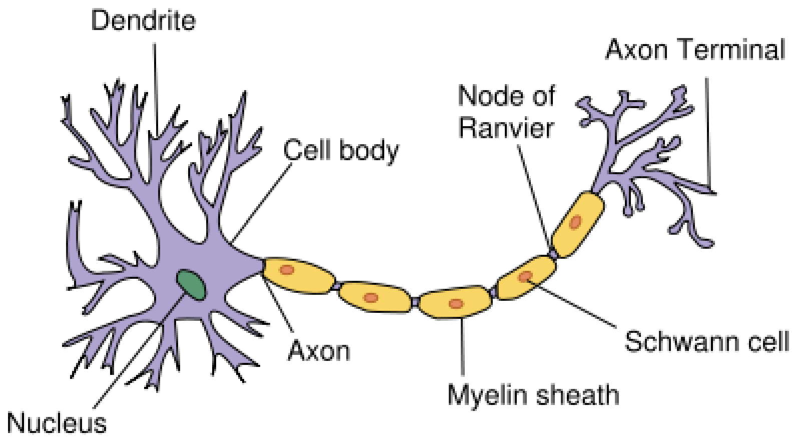


Fig 2. Structure of neuron

Axon

Each neuron has a single axon arising from a cone shaped area called **axon hillock** on the cell body which narrows down to form a thin, fibre-like extension called an axon**.**

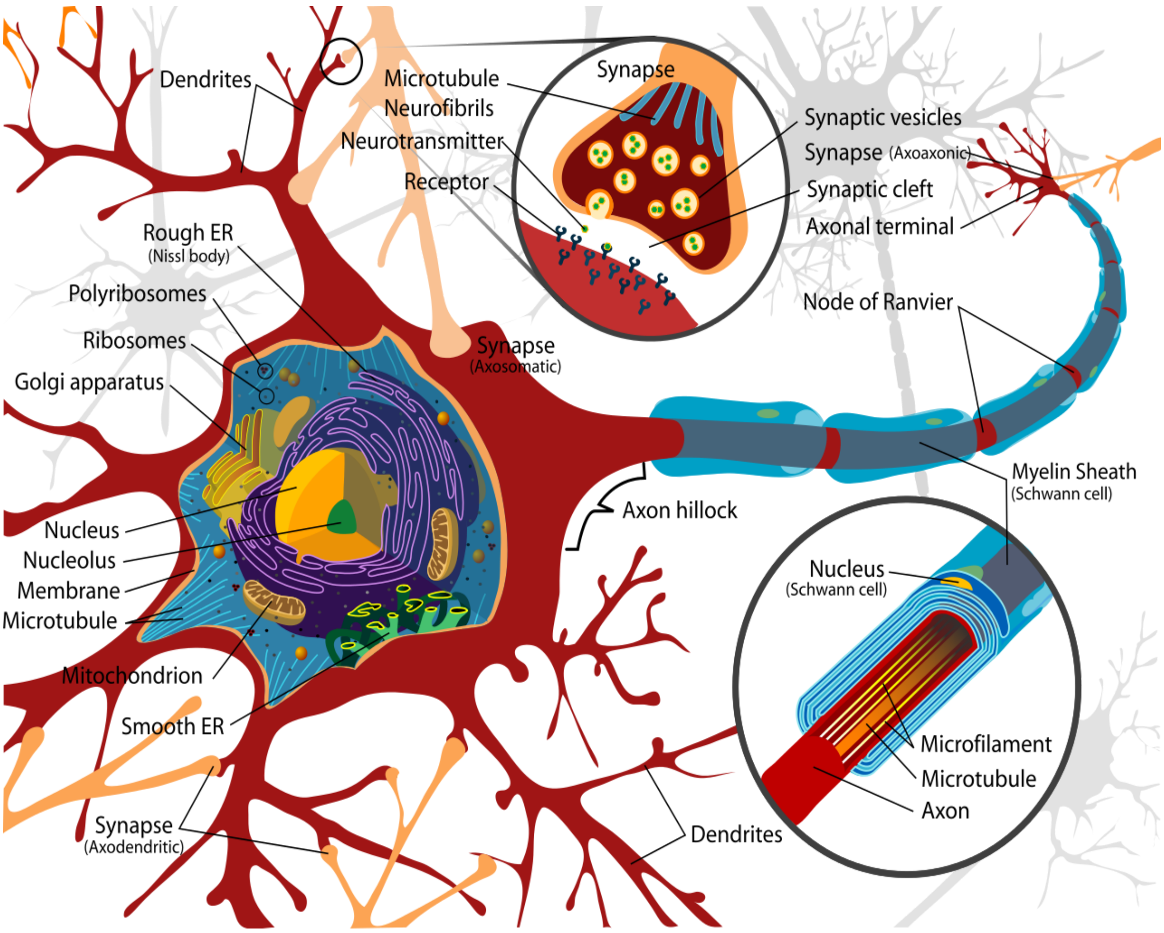


Fig 3. Structure of Neuron

In some cases, axons may give out branches called **collaterals** which arise almost at right angles to the axon. The axon bears branches at its end, called **telodendria** or terminal branches. Axons bearing 10,000 or more telodendria are not uncommon. The end of each terminal branch is swollen and knob-like and is called synaptic **bulbs, boutons** or **axonal terminals.** Membrane enclosed synaptic vesicles store **neurotransmitters.**

The part of the axon close to hillock is called the initial **segment.** In most neurons, nerve impulses arise at the junction of the axon hillock and initial segment known as **trigger zone**. The plasma membrane and cytoplasm of an axon are respectively called axolemma and **axoplasm**. Axoplasm consists of mitochondria, microtubules and neurofibrils. It does not contain rough endoplasmic reticulum. Protein synthesis does not take place in axons. Long axons are called nerve **fibres**.

Differences between neuroglia cells and neurons

Neuroglia	Neuron
1. Exist in very large numbers.	Fewer in number in comparison to neuroglial cells.
2. Cells are smaller in size.	Cells are elongated and some neurons are regarded as the longest cells of the body.
3. Nuclei take darker stains.	Nuclei of neurons are comparatively lightly stained.
4. Do not possess excitability.	Possess excitability.
5. Capable of dividing.	Except few the rest of the neurons cannot divide.
6. Performs many functions like supporting, secretion, supplying nourishment etc.	Associated with generation and transmission of nerve impulse.

Synapse: this is the junction between two neurons, neuron and muscles or neuron and gland. Synaptic cleft is the gap between pre and postsynaptic neurons. Neurotransmitters are released in this space.

Nerve

A nerve is an enclosed, cable-like bundle of nerve fibres (bundle of axons) in the PNS. Each axon within the nerve is an extension of an individual neuron along with other supportive cells such as Schwann cells.

Each nerve is covered on the outside by a dense sheath of connective tissue, the **epineurium.** Beneath this is a layer of flat cells,the perineurium which forms a complete sheath around a bundle of axons. Perineurial septae extend into the nerve and subdivide it into several bundles of fibres. Surrounding each such fibre is **endoneurium**. Nerves are bundled and often travel along with blood vessels. Nerves are bundled and often associated with blood capillaries as neurons have high metabolic rate and require lots of metabolites.

Types of Nerves

(a) Basing on the directions the signals are conducted through nerves are divided into:

- ***Afferent nerves*** - They conduct signals from sensory neurons to the central nervous system(CNS)
- ***Efferent nerves*** - They conduct signals from CNS along motor neurons to their target muscles and glands.
- ***Mixed nerves*** - They contain both afferent and efferent axons and thus conduct both incoming and sensory information and outgoing muscle commands in the same bundle.

(b) Depending on the part from which it arises and to which it ends the nerves are categorised into

- ***Cranial nerves*** - They innervate part of the head and connect directly to the brain. There are 12 pairs of cranial nerves.
- ***Spinal nerves*** - It stimulates much of the body and connects to the spinal cord.

(c) Depending on presence or absence of myelin sheath as protecting and insulating covering they are divided into:

- ***Myelinated nerves*** Nerve fibres which are quite long or large in diameter remain covered by a whitish fatty substance called myelin sheath. Such nerve fibres are called myelinated nerve fibres. In PNS, myelin sheath is formed by Schwann cells. The latter come in contact with axon, wrap around it and form concentric layers of wrapping myelin sheath. This sheath forms an insulating layer around the axon and allows transmission of nerve impulses at a very fast rate. The nucleus and most of the cytoplasm of Schwann cells exist as bulge external to myelin sheath. This exposed part of Schwann cells is called neurilemma. Adjacent Schwann cells do not touch each other and there is a gap between two myelin sheaths called **nodes of Ranvier**. Myelinated and unmyelinated nerve fibres are also found in CNS. In CNS, the myelin sheath of myelinated nerve fibres is formed by oligodendrocytes.

- ***Unmyelinated nerve fibres*** The axon of neuron is not wrapped individually. So does not possess individual myelin sheath.

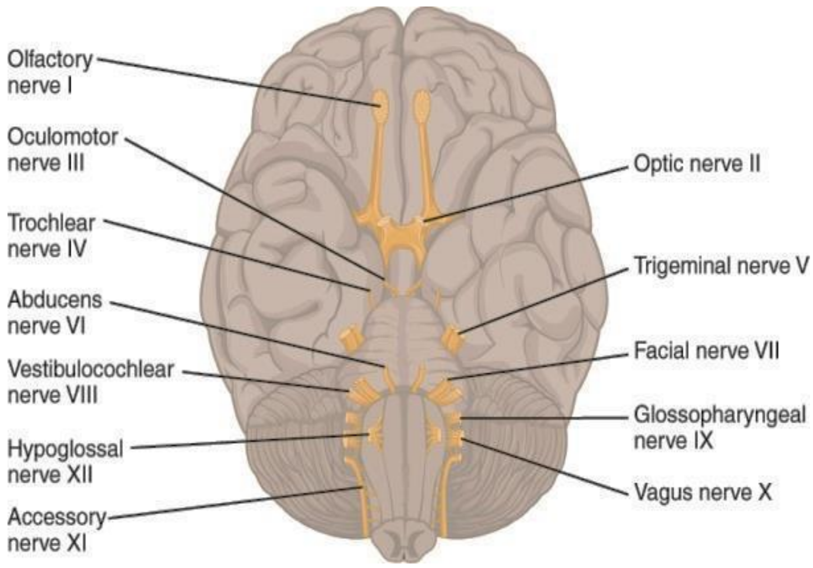


Fig 4. Cranial nerves

Grey Matter and White Matter

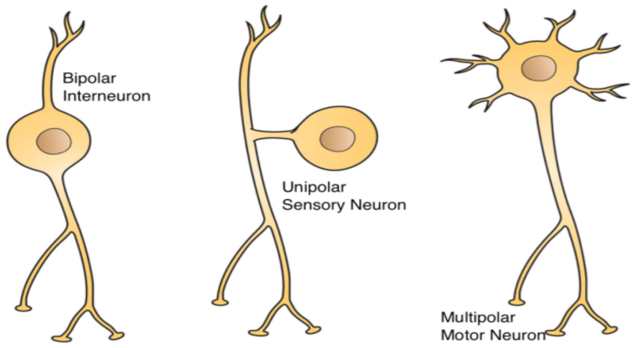
In the fresh section of spinal cord, some parts look grey and some other parts look white and glistening. They are accordingly called grey matter and white matter. Grey matter consists of neuronal cell bodies, unmyelinated axons, axon terminals and neuroglia cells. Grey matter forms a thin layer on the surface of the largest parts of cerebrum and cerebellum. White matter predominantly consists of Myelinated axons.

Types of Neurons

(a) Basing on structural variation neurons are divided into

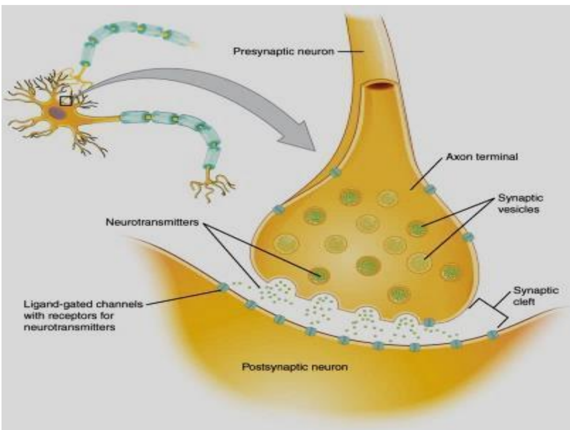
- ***Multipolar neuron*** - They possess one axon and several dendrites. Most of the neurons located in the brain and spinal cord are multipolar types.

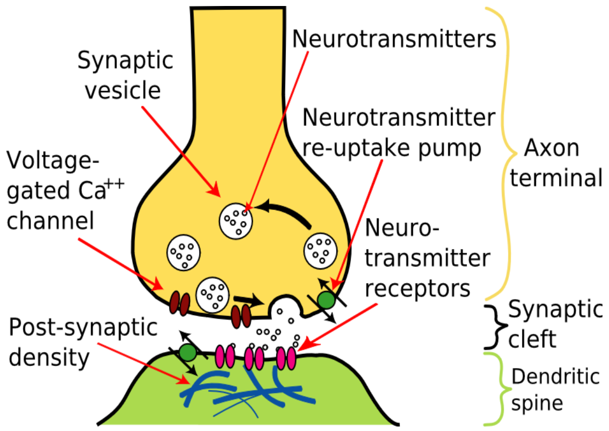
- ***Bipolar neurons*** - These neurons possess one axon and one dendrite. Found in the retina of the eye and in the ear.
- ***Unipolar neuron*** - They have dendrites and an axon which are fused to look like a single process.



(b) Basing on functional differences

- ***Sensory or Afferent neuron*****:** They possess sensory receptors at their distal end.
- ***Motor or Efferent neurons*****:** They carry impulses from CNS to effectors.
- ***Interneurons or Association neurons*****:** They are located in CNS between afferent and efferent neurons.





Neurotransmitters are endogenous chemicals that enable neurotransmission. They are chemical messengers which help in transmission of nerve signals from one neuron to another through synapses or from a neuron to a muscle through neuromuscular junctions or neuron to glands. As these neurotransmitters or chemical messengers are released at the junction

Certain viruses and bacteria utilize axonal route to reach cell bodies and produce toxins. This kind of transport has been detected in rabies, polio, herpes simplex viruses and tetanus bacteria (neuron – neuron or neuron-muscle) so such junctions are also called chemical **synapses**. Neurotransmitters may be amino acids (glutamate, aspartate), monoamines (dopamines, norepinephrines, histamines, serotonin), peptides (oxytocin, somatostatin) etc. apart from these acetylcholine, nitric oxide, carbon monoxide are some other neurotransmitters.

Neurophysiology

Neurons are electrically excitable cells. The membrane of neurons possesses ion channels. Some of these are passive leakage channels and some are gated channels. Gated channels are active channels which possess a molecular gate which opens in presence of a signal. The signals may be mechanical, chemical, electrical or physical. Each of these gated channels acts in the presence of a single signal. Accordingly they are called voltage **gated channels** (opens due to voltage change), **ligand gated channels**(chemical substances like neurotransmitters are the signals acting as gate openers) and **mechanical gated channels** (open due to physical deformities caused due to touch or pressure). Each type of channel is selective and allows only those ions to move which are specific to that channel.

Basic Principles of Electricity

Human body is electrically neutral except at certain areas where a particular charge predominates rendering positive or negative charge to that area. When opposite charges attract there is release of energy. This energy can be utilized for doing work. Energy is consumed when these charges are separated. This energy is called potential energy.

The measure of this potential energy is called **voltage** and measured in terms of volts or millivolts. Voltage is measured in between two points and is called potential difference or **potential**. The flow of charge from one point to another is called current. Voltage and resistance are two factors which decide how much charge will be flown. Resistance is the hindrance offered by the substance through which charge is flowing. If the substance provides a large amount of hindrance then it is called an insulator**.** The substance which provides low hindrance is called **conductor**.

When the potential difference on either side of the membrane of the neuron is measured, it revealed that in resting condition the cytosol side of the membrane possesses comparatively more negatively charged than outside (ECF side) membrane. The potential difference in a resting neuron is called resting potential and the membrane is said to be in a polarised state.

Resting (membrane) potential varies from -40mV to -90mV. Resting potential exists across and close to the membrane. Away from the membrane both the cytosol and extracellular fluid are neutral. In polarised neurons the cytosol near the membrane possesses much less N ions and an abundance of K ions. Although many other ions are present in cytosol but K+ ions play a key role in maintaining resting potential.

Graded Potential: These are temporary changes in membrane potential which may be either depolarisation (decreasing in existing charge and becoming more positive) or hyperpolarization (increasing in existing charge and becoming more negative). Graded potential decreases in strength over distance.

Action Potential: It develops when the membrane potential of a specific cell location rises and falls. Neurons propagate communication in a neuron. The action potential is also called nerve **impulse**.

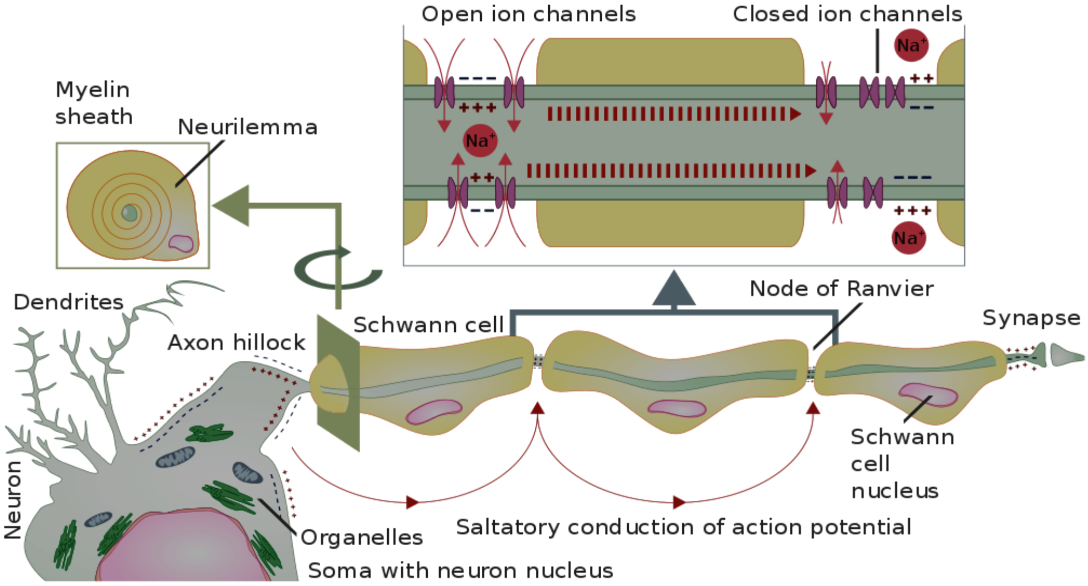
Mechanism of Generation, Propagation and Transmission of Nerve Impulse

Generation of nerve impulse*:* It takes place in following steps

(i) ***Resting state:*** At resting state(-70mV) usually all the voltage gated Na+ and K+ channels are closed. But some K+ diffuse out and fewer number of Na+ diffuse in through leakage channels. At resting state three K+ are expelled and two Na+ are taken in by a sodium potassium pump thus rendering more negative charge inside than outside.

(ii) ***Depolarising state :*** As the axon membrane is depolarised the voltage gated channels open locally which causes entry of Na ions. This results in lowering of negative charge. This causes the opening of more Na+ activated channels. This state is called a depolarised state. When the negative charge reaches to a critical (threshold) level, by a positive feedback more and more channels open up till all the Na+ gates are opened. This results in lowering of membrane potential (upto +30mV). This high rise in depolarisation results in the 'action' of action potential.

(iii) ***Repolarisation:*** High rising phase of action potential persists for a short period. As it becomes positively charged , the membrane resists further entry of Na+. as Na+ entry declines K+ voltage gated channels open and efflux of K+ take place and decreases positive charge and increases internal negativity, restoring repolarisation state.



Propagation of an Action Potential (Nerve Impulse)

Following depolarisation, each adjacent segment of axonal membrane repolarizes thus restoring the membrane potential of that region. As local current is developed due to electrical changes, repolarisation flows just behind repolarisation along the axonal length.

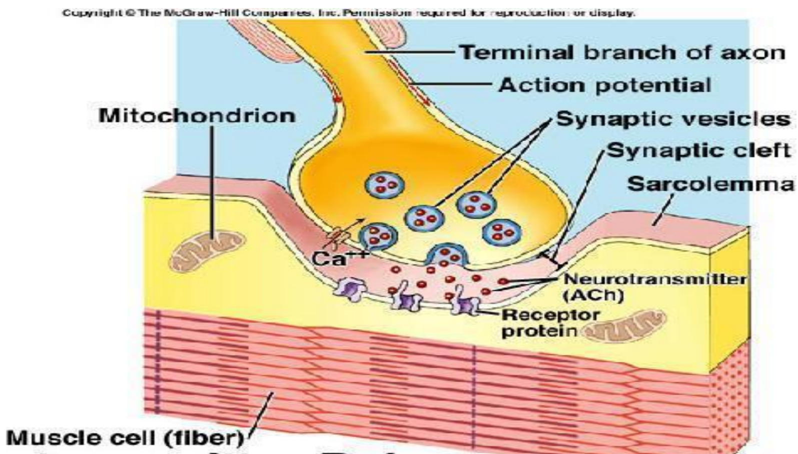
Myelin sheath is a lipid rich fatty substance which forms an insulating layer around the axon. Schwann cells wrap around axons several times to form myelin layer. Myelin layer is basically made up of several layers of plasma membrane which is lipid rich. The winding part of the plasma membrane lacks leakage channels and gated channels. Due to which there is no efflux and influx of ions. As there is no entry or exclusion of ions so the flow of ions takes place uninterruptedly. Entry of Na ions takes place through nodes of Ranvier. The segments of myelinated axons in between Nodes of Ranvier are called internodes.

Specific structure of the myelinated axon allows jumping of action potential from one node to another. Such type of propagation of nerve impulse is called saltatory *conduction.*

Transmission of Nerve Impulse

Nerve impulse is transmitted from one neuron to another neuron through junctions (synapse) present in between two neurons. When the nerve impulse reaches the presynaptic knob, Ca gated channels open up and Ca++ diffuse rapidly in the presynaptic knob. Neurotransmitters are stored in synaptic vesicles. These vesicles remain clustered close to the axon terminals of the presynaptic axon. Entry of Ca++ stimulates synaptic vesicles to fuse with the presynaptic membrane and release neurotransmitters enclosed within them. Neurotransmitters are released into and diffuse across the synaptic cleft where they bind with receptors located on the dendritic membrane of the presynaptic neuron.

Neurotransmitters like acetylcholine diffuse through the synaptic cleft and bind with receptor sites of postsynaptic dendritic membranes. This results in the opening of Na voltage gated channels and lowering of electrical negativity and establishment of depolarisation. Released neurotransmitters are available in synaptic clefts for a very short period. After that it is either reabsorbed in synaptic vesicles of pre synaptic axon terminals or enzymes mediated bound to the receptor of postsynaptic dendrite.



Neurotransmitter Release

The binding of neurotransmitters with postsynaptic dendrites causes generation of nerve impulse. Propagation and transmission of nerve impulse follow as explained.

Summary

- The Central nervous system and Peripheral nervous system consist of basically two types of cells; neuroglia and neurons.
- Four types of neuroglia are associated with CNS and two types of neuroglia are associated with PNS.
- Neurons possess basically two parts: *cell bodies* and *processes.*
- Schwann cells wrap around the axon of the neuron in PNS and form concentric rings around the axon.
- Myelinated nerve fibres transmit nerve impulse more rapidly than unmyelinated nerve fibres.

- White matter consists of myelinated axons and grey matter possesses cell bodies, unmyelinated axons, axon terminals and neuroglia.
- Axons of longer neurons form bundles and are called tracts in the brain and spinal cord and nerves in PNS.
- In the resting state of the neuron, a potential difference exists across the membrane and the neuron is stated to be at a polarised state.
- Difference in charge distribution across the membrane results in generation, propagation and transmission of nerve impulses.