Structure of Neuron

Dr Krishnendu Das
Material Shared on 13.01.2023

Neurons, communicate information using a combination of electrical and chemical signals. The membranes of most neurons are electrically excitable [that is, signals are generated in and transmitted along them without decrement as the result of the movement of charged particles (ions)].The properties of electrical signals allow neurons to carry information rapidly and accurately to coordinate actions involving many parts, or even all, of an animal's body. All of the neurons in an organism's body, along with supporting cells called **glial cells** (or neuroglia), make up the nervous system, which collects and processes information, analyses it, and generates coordinated output to control complex behaviours.

Unique features of neuron:

(i)Neurons transmit information electrically, which allows scientists to monitor the activity of individual neurons by using various instruments originally developed for the physical sciences. These measurement techniques, have facilitated research on neurons and enormously increased the information available about them.

(ii)Recordings of electrical activity in neurons have revealed that the properties of individual neurons from nearly all animals are very similar. In other words, the mechanisms involved in transmitting information along and between neurons is essentially the same whether the neurons come from an ant or from an anteater.

(iii)Neurons process information in a highly sophisticated manner, but in doing so they rely on a surprisingly small number of physical and chemical processes, making it possible to formulate general principles about their function.

NEURONAL STRUCTURE, FUNCTION, AND ORGANIZATION

(i)Neurons vary greatly in shape and size, every neuron typically has a soma, or cell body, which is responsible for metabolic maintenance of the cell and from which emanate several thin processes
(Figure 1).

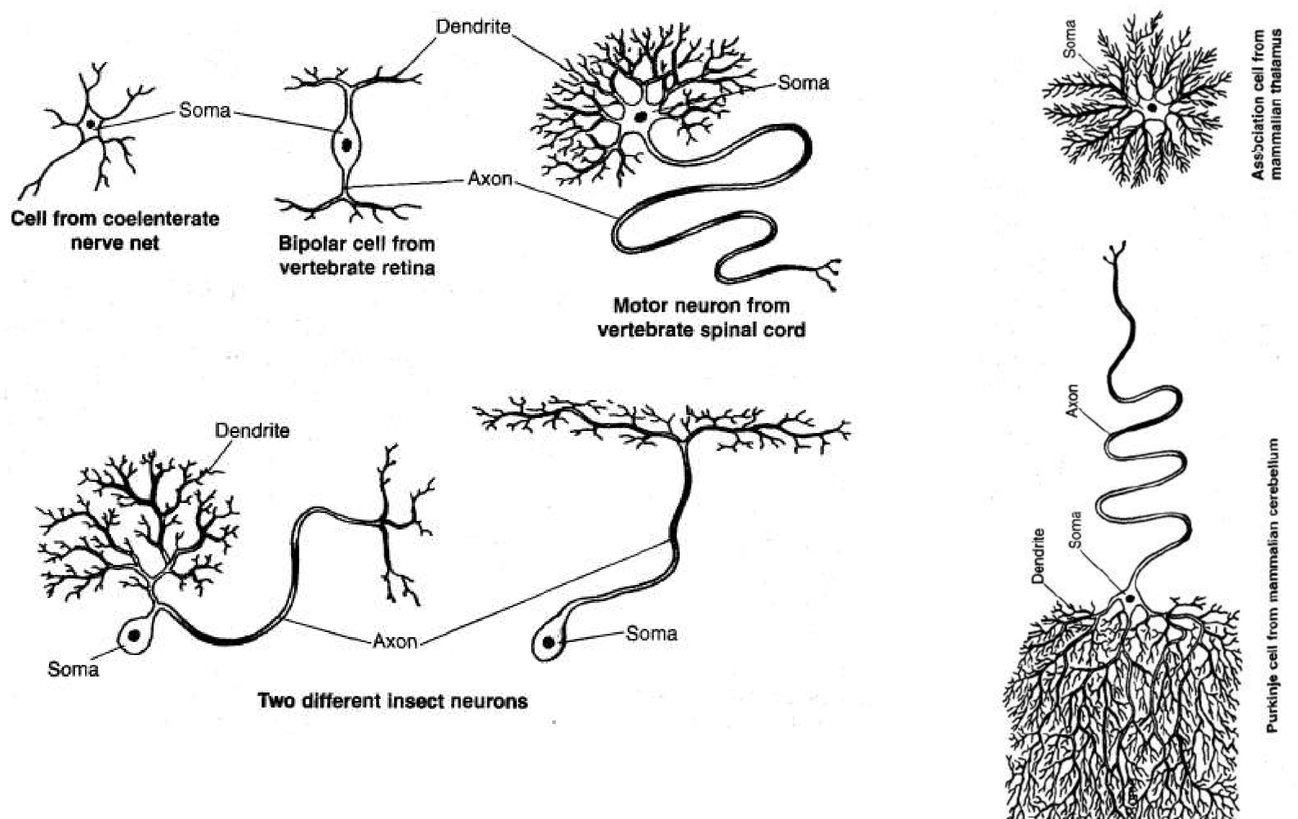


Figure1: The general morphology of neurons varies from simple to very complex, but most neurons have certain identifiable regions, including dendrites, a soma, and an axon. Notice that there is little correlation between phylogeny and the complexity of neuronal structure. Although simple animals have simple neurons (e.g, the coelenterate neuron), some neurons in higher animals also have a simple structure (e.g., the vertebrate retinal bipolar cell). Higher animals also have neurons with a very complex structure (e.g., the Purkinje cell from the mammalian cerebellum),but so do insects and other simpler animals. In some neurons (e.g., cerebellar Purkinje cells and vertebrate motor neurons), the dendrites and the axon are easily distinguished. In other neurons(e.g., retinal bipolar cellsand mammalian association cells), no morphologicfeatures readily distinguish the axon from thedendrites.

***There are two main types of processes*:**

Dendrites and axons. Most neurons possess multiple dendrites and a single axon.

(a)Dendrites

(i)Branched, extend from the cell body, and serve as the receptive surface that brings signals from other neurons toward the cell body.

(ii)Information from other neurons is usually transmitted to the dendrites and soma of a neuron, so neurons with an extensive and complex dendritic tree typically receive many inputs.

(iii)The location and branching pattern of dendrites can reveal from where each neuron gets its information.

(b)Axons

(i)Specialized processes that conduct signals away from the cell body. Although many neurons have relatively short axons, the axons of some nerve cells extend surprisingly long distances.

(ii)Axons have evolved mechanisms that allow them to carry information for long distances with high fidelity and without loss. In a whale, for example, the axon of a single motor neuron (or motoneuron),which carries information from the nervous system out to muscle fibers, may extend many meters from the base of the spine to the muscles that it controls in the tail fin. (Notice that bundles of axons running through the tissues of an animal's body are called nerves.)

(iii)At its termination, each axon may divide into numerous branches, allowing its signals to be sent simultaneously to many other neurons, to glands, or to muscle fibers.

Transmission of Signals in a Single Neuron

A typical vertebrate spinal motor neuron, which has its soma in the spinal cord and carries signals to skeletal muscle fibers, displays the structural and functional features that characterize many neurons (**Figure 2).**

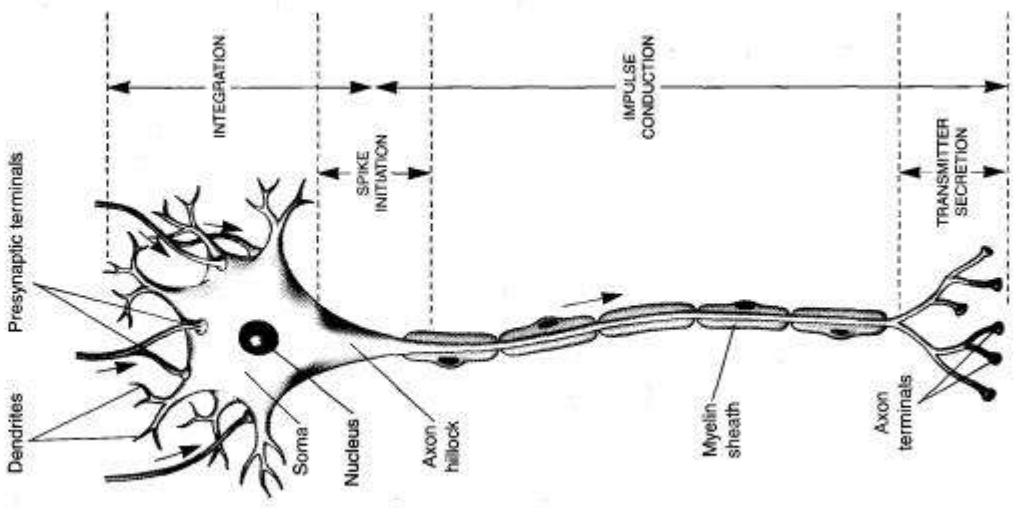


Figure2: A vertebrate spinal motor neuron exemplifies the functionally specialized regions of a typical neuron. The flow of information is indicated by small black arrows. Information is received and integrated by the

membrane of the dendrites. In some neurons the soma also receives information and contributes to integration. In spinal motor neurons, action potentials are initiated at the spike-initiating zone, in or near the axon hillock, and then travel along the axon to the axon terminals, where a chemical neurotransmitter is released to carry the signal on to another cell. In other types of neurons, the spike-initiating zone may have a different location. The axon and surrounding myelin sheath cells are shown in longitudinal section.

(i)The surface membrane of motor-neuron dendrites and the membrane of the soma receive signals from, or are innervated by, the terminals of other nerve cells.

(ii)The soma integrates (sums) messages from the many input neurons to determine whether the neuron will initiate its own response, an action potential (AP), also called a nerve impulse.

(iii)The axon carries an AP from its point of origin, the spike-initiating zone, to the axon terminals, which contact skeletal muscle cells in the case of motor neurons.

(iv)Typically the spike-initiating zone is located near the axon hillock, the junction of the axon and cell body, although in many neurons the spike-initiating zone lies elsewhere.

(v)Many axons are surrounded by supporting cells, which provide an insulating layer called the *myelin sheath*.

(vi)Unlike wires, the membranes of neurons also possess active electrical properties that allow these cells to conduct electrical signals without decrement. The active electrical responses of neurons and other excitable cells depend on the presence of specialized proteins, known as **voltage-gated ion channels**, in the cell membrane.

(vii)Voltage-gated ion channels allow ions to move across the cell membrane in response to changes in the electrical field across the membrane. Neurons possess various types of ion channels, each permitting passage of a particular ionic species.

(viii)The different types of ion channels found in neurons are not distributed uniformly over the surface of the cell. Instead, they are localized in different regions that have specialized signalling functions. For example, the axonal membrane is specialized for the conduction of APs by virtue of its fast-acting, voltage-gated ion channels that selectively allow Na^+ and K^+ to cross the membrane.

(ix)The membrane of axon terminals contains voltage gated Ca^{2+}channels and other specializations that allow neurons to transmit signals to other cells when APs invade the terminals.

(x)Transmission of Signals between neurons information processing by any nervous system begins when sensory neurons collect information and send it to other neurons. The axon of an information-gathering neuron is called an afferent fiber. Sensory neurons pass information on to other neurons, and the signal is transferred from neuron to neuron in the animal's nervous system.

(xi)Information is passed between neurons, or between neurons and other target cells, at specialized locations called **synapses.**

(xii)Neurons that carry information out to effectors are called efferent neurons. Together the afferent neurons and efferent neurons, along with any interneurons that participate in processing the information, make up a neuronal circuit.

(xiv)A cell that carries information toward a particular neuron is said to be presynaptic to that neuron, while a cell that receives information transmitted across a synapse from a particular neuron is said to be postsynaptic to that neuron.

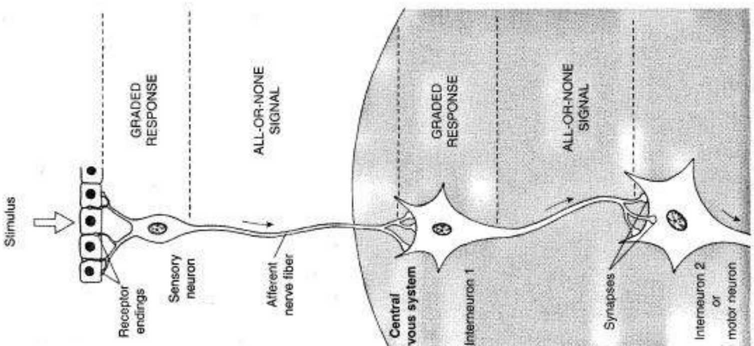


Figure3: A neuronal circuit via electrical action potentials and chemical synaptic potentials.

(xv)Most synaptic transmission is carried by neurotransmitters, which are specific molecules released by the axon terminals of the presynaptic neuron in response to APs in the axon. The membrane of the postsynaptic neuron's dendrites and soma, the part of the postsynaptic cell that typically receives synaptic signals, contains ligand-gated ion channels, which bind neurotransmitters and react to them.

(xvi)The postsynaptic effects of a neuron's numerous synaptic inputs are integrated to produce a net postsynaptic potential in the dendrites, soma, and axon hillock. As indicated in Figure3, information is carried in neuronal circuits via alternating graded and all-or-none electrical signals.

ORGANIZATION OF THE NERVOUS SYSTEM

The nervous system is composed of two basic cells types:

Neurons and supporting glial cells. As we have seen, neurons are classified functionally into three types:

(a)Sensory neurons, which transmit information collected from external stimuli (e.g., sound, light, pressure, and chemical signals) or respond to stimuli inside the body (e.g., the blood oxygen level, the position of a joint, or the orientation of the head)

(b)Interneurons, which connect other neurons within the central nervous system

(c)Motor neurons, which carry signals to effector organs, causing contraction of muscles or secretion by gland cells.

(i)The cell bodies of many-even most-neurons are contained within the central nervous system (CNS),although the cell bodies of some neurons are located in the periphery. In most animals, the CNS consists of **a brain**, located in the head, and a **nerve cord**, which extends posteriorly along the midline of the animal.

Many invertebrates have a brain located in the head and collections of neuronal cell bodies, called ganglia, distributed along the nerve cord; these control local regions of the animal (Figure 5-5).Vertebrates also have ganglia, consisting of peripheral neuronal cell bodies, outside the CNS. In vertebrates the nerve cord, called the spinal cord, is located along the dorsal midline, whereas in many invertebrates (e.g., insects, crustaceans, and annelids), the major nerve cord lies along the ventral midline. Many neurons that have cell bodies in the CNS send processes into the rest of the body (the periphery) to collect sensory information or to deliver motor information to control the activity of muscles or glands.

(ii)The other main cell type in the nervous system, **glial cells,** fills all of the space between neurons, except for a very thin extracellular space (about **20 nm wide**) that separates the glial and neuronal membranes.

(iii)The vertebrate central nervous system, for instance, contains 10-50 times more glial cells than neurons, and these cells occupy about half the volume of the nervous system. *The ratio of glial cells to neurons is considerably smaller in most invertebrates*.

(iv)Glial cells provide intimate structural, and perhaps metabolic, support for neurons. Several different cell types function as glial cells. In vertebrates, for example, oligodendrocytes in the CNS and Schwann cells in the periphery wrap each axon in an insulating myelin sheath, which contributes to assuring reliable and rapid transmission of Aps.

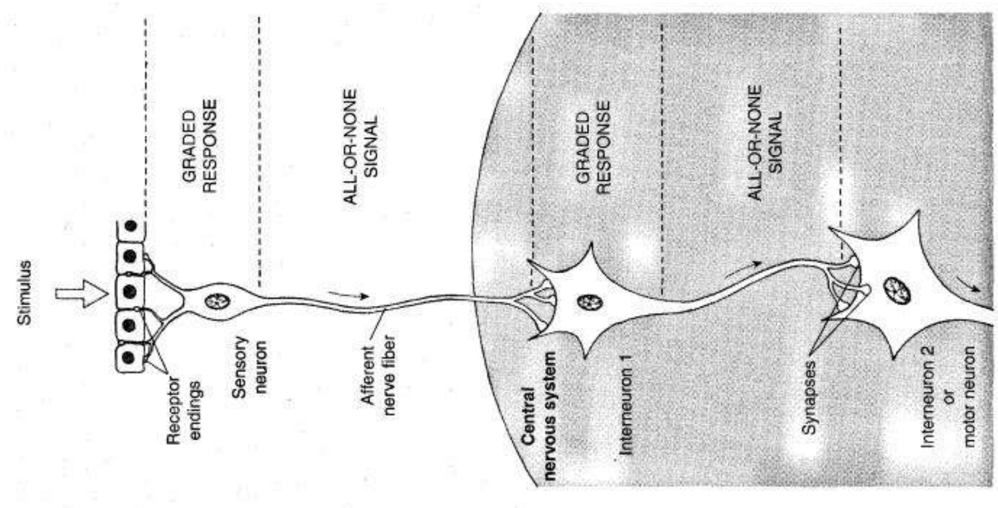
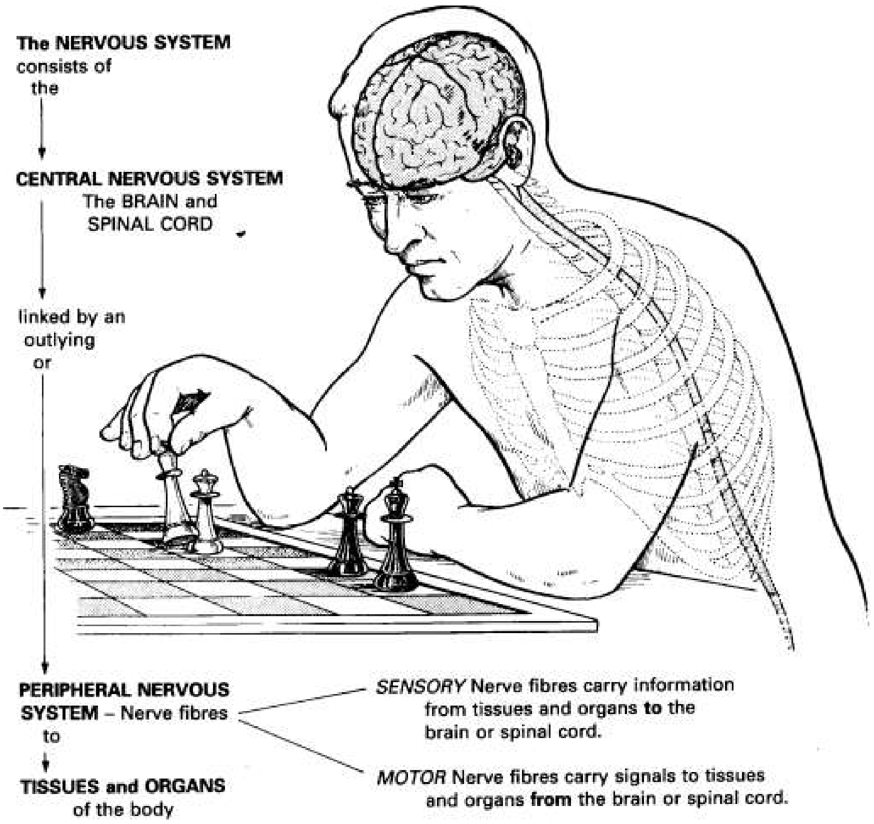


Figure4: Information is typically carried through a neuronal circuit via electrical action potentials and chemical synaptic potentials.



(v)**Nissl bodies** are layers of rough endoplasmic reticulum, whose function is protein synthesis. Neurofibrils are filamentous strands of protein that support the cell body. Microtubules are minute channels that transport material within the cell. Collateral branches are extensions from the axon that may also transmit impulses.

(vi)Axon terminals are the slight enlargements at the ends of the branched axon. Axon terminals contain synaptic vesicles that produce and secrete neurotransmitter chemicals into the synapses.

(vi) Myelin (Gk. myelas, marrow) is an insulating cellular membrane consisting of a fatlike lipid substance known as sphingomyelin. During myelination, the myelin wraps around the neuron, creating a multilayered sheath. In the CNS, oligodendrocytes produce the sheath; in the PNS, neurolemmocytes (Schwann cells) assume this role. In the PNS, there are small gaps called neurofibril nodes nodes of Ranvier between segments of the sheath. The sheath insulates nerve fibers and thereby inhibits the flow of ions between intracellular and extracellular fluid compartments. Two fairly common diseases afflict the myelin sheaths. Multiple sclerosis (MS) is a chronic degenerative disease, marked by remission and relapse, that progressively destroys the myelin sheaths of neurons in multiple areas of the CNS. Tay-Sachs disease is an inherited disease in which the myelin sheaths are destroyed by excessive accumulation of lipids within the membrane.

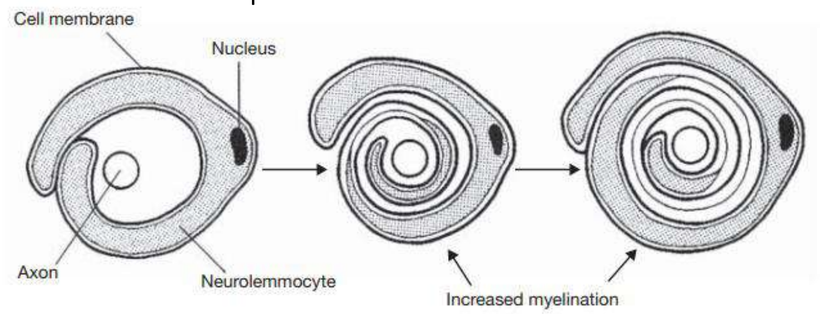


Figure 5: The process of myelination, as viewed in axonal cross section

(vii)There are six categories of **neuroglia**. Also called *glia*, or *glial cells*, these specialized cells of the nervous system physically and physiologically support neurons by assisting in the transfer of nutrients and wastes to and from the neurons. Neuroglia mitotically divides and are estimated to be about five times more abundant than neurons.

TYPES	STRUCTURE	FUNCTION
Astrocytes	Stellate with numerous processes	Form structural support between capillaries and neurons within the CNS; contribute to blood–brain barrier
Oligodendrocytes	Similar to astrocytes but with shorter and fewer processes	Form myelin in CNS; guide development of neurons within the CNS
Microglia	Minute cells with few short processes	Phagocytize pathogens and cellular debris within CNS
Ependymal cells	Columnar cells that may have ciliated free surfaces	Line ventricles and central canal within CNS where cerebrospinal fluid is circulated by ciliary motion
Ganglionic gliocytes (satellite cells)	Small, flattened cells	Support ganglia within PNS
Neurolemmocytes (Schwann cells)	Flattened cells arranged in series around axons of dendrites	Form myelin within PNS

Shape and size: The neuron varies considerably in shape and size in different animals and even in different parts of the animal body. In man, for example, the granule cells of the cerebellum are 5u in diameter while the giant pyramidal cells of the cerebral cortex are as large as 130µ. The axons of the neurons vary from a few microns in length up to 90 cm long 2. Number: The number of nerve cells is almost always fixed for a particular species. In man, the entire nervous tissue comprises some 3000 x 106 nerve cells and it makes up approximately 2 8% of the body weight (Marshall and Hughes, 1972).

3.Structure: A typical neuron has three parts :

(a) Neurocyton:

The cytology of neuronal soma is broadly similar to that of nonneuronal cells. It contains a nucleus and most of the organelles and cytoskeleton elements familiar to cytologists: mitochondria, Golgi apparatus, smooth endoplasmic reticulum, rough endoplasmic reticulum, microtubules, neurofilaments and actin microfilaments.

Neurons are very active in protein synthesis and thus extensive well developed RER, aggregates of which can be stained to appear in light microscopy as Nissl substance.

Each neuron has a cell body called the soma, neurocyton or perikaryon which is about 4 to 25 µ in diameter and comprises a nucleus in the centre. It contains a granular cyloplasm due to the presence of basophil masses or Nissl's granules,mitochondria, a Golgii apparatus and fine long endoplasmic reticulum and neurofibrillae and a few centrioles. A mature neuron, however, does not undergo cell division (Warwick and Williams, 1978)

The Nissl's granules are composed of ribonucleoproteins produced by the nucleus and they play an important role in the metabolism of nerve cell. These granules are also present in the dendrites bat are absent from the axon.

(b) Dendrites or Dendrons:

Dendrites of most neurons have continuously varying diameters and lack myelin sheaths.

In general broader dendritic trunks resemble soma in fine structure, they contain RER, mitochondria, microtubules, neurofilaments and an occasional Golgi apparatus.

Thinner dendritic branches may lack Golgi apparatus and RER.

The dendrites are branched cytoplasmic processes given out from the cyton and are basically meant for bringing impulses into the cell body. Information received by the dendrites can influence the cell body to generate action potential that is then conducted along the axon to the target cell.

The cell bodies and dendrites are usually aggregated into ganglia and the main assemblage of ganglia in animal’s body is the central nervous system (CNS).

(e) Axon :

The larger vertebrate axons are surrounded by myelin sheaths-multiple wrappings of insulating glial cell membranes that increase the speed of impulse transmission.

At the fine structural level, axons contain microtubules, neurofilaments, reticulum.

Axons generally lack RER and Golgi apparatuses.

The axon, neurite or neuraxis is a single but much longer extension that projects from an axon-hillock to the cyton of a nerve cell. It forms the nerve fibre that carries away impulses or signals from the cyton to another neuron forming a synaptic connection between its terminal buttons or synaptic knobs and the dendrites of the following neuron.

The length of an axon varies at different places in the body and generally, there are two main types of axons in vertebrates, the larger axons, 1 to 25 μ in diameter being myelinated and the smaller ones, under 1μ, are non-myelinated. Almost all invertebrates are equipped with non –myelinated fibres, bat some of them differ from vertebrate non-myelinated fibres in being much large, for example, the giant axons of the squid are approximately 1000 μ in diameter.

Axoplasm : In essence, all nerve fibres consist of a long cylinder of cytoplasm, the axoplasm. The axoplasm is a viscous fluid and contains ultramicroscopic extremely fine neurofibrils that serve to trans signals. The axoplasm and the neurofibrils are enclosed in an electrically excitable axolemma or nerve membrane or axon sheath of about 75Å thickness and separated by a pap of 25 Å.

(1)Myelin or Mledullary Sheath :

An axon is not uniformly thick throughout its length. At more or less regular intervals it is constricted to form characteristic nodes of Ranvier, the part between the two successive nodes is called an internode. Continuous into the nodes of Ranvier and just outside the axon sheath, there lies another coat of one-to-many sheathe of lipo-proteins, called the myelin or medullary sheath. The sheath is secreted by large flattened cells, the Schwann cells, whose cytoplasm bathes the myelin sheath. The Schwann cells arise from the embryonic crest and each cell comprises a prominent nucleus and a cell membrane.

Neurilemma : Outside the Schwann cells and the myelin sheath lies a tough and inelastic layer of scleroproteins which is known as the neurilemma or the sheath of Schwann. Outside the neurilemma is yet another thicker layer of collagen fibres, the sheath of Henle, which is continuous with the endoneurium, the connective tissue that binds the axons together in a nerve.

v) Collaterals : A neuron may have small and delicate side branches, termed as collaterals, which may terminate into a synapse like an ordinary axon ending.

(v)Telodendria: At its distal end, an axon breaks up into a number of fine branches called telodendria. Each telodendron ends in a tiny knob-like structure, the terminal button or synaptic button which usually rests on the dendrite and cyton of the following neuron and thus forms a synapse between the two adjacent neurons. At a synapse the two cell membranes are usually thickened and the gap between the two is about 20-60 nm.

Glial cells:

Glial cells support neurons physically and metabolically and collectively referred to as glia or neuroglia ('nerve glue') surround the neurons. Rudolf Virchow discovered and named the neuroglial cells. The ratio of glia to neurons increases with increasing evolutionary complexity, from the brains of fish to mammals. Glial cells are estimated to make half the volume of the mammalian brain and to outnumber neurons by ten to one.

Different types of glial cells play diverse functional roles in the nervous system. In vertebrates ensheathing glial cells called Schwann cells (in the PNS, peripheral nervous system) and oligodendrocytes (in the CNS, central nervous system) envelop the axons of neurons.

The glial sheath can be a simple encircling of an unmyelinated axon or a group of axons or a myelin sheath consisting of multiple concentrically wrapped layers of glial membrane that insulate the axon and increase the velocity of nerve impulse propagation.

Other glial cells called astrocytes line the outside surface of capillaries in the vertebrate CNS and act as metabolic intermediaries between the capillaries and neurons. Astrocytes take up neurotransmitters from extracellular space and help supply metabolic substrate to neurons. They also regulate extracellular ion concentrations and play important roles in nervous system development. Microglial cells mediate immune response n neural tissue and may act as phagocytes, consuming pathogens and cell debris in brain injury.