# Nervous System

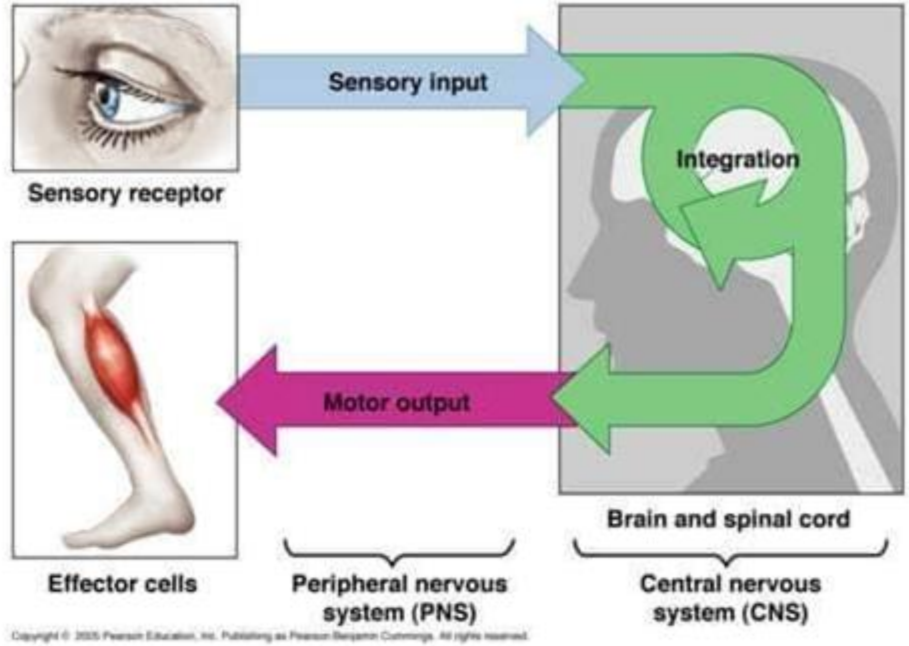
# OBJECTIVES

*At the end of the lecture, students should be able to:*

- ✓ List the subdivisions of the nervous system.
- ✓ Define the terms: grey matter, white matter, nucleus, ganglion, tract and nerve.
- ✓ Define neurons and neuroglia.
- ✓ List the major parts of the brain.
- ✓ Identify the external and internal features of spinal cord.
- ✓ Enumerate the cranial nerves.
- ✓ Describe the parts and distribution of the spinal nerve.
- ✓ Define the term dermatome.
- ✓ List the structures protecting the central nervous system.

# The nervous system has 3 functions:

- **Collection of Sensory Input**
  - Identifies changes occurring inside and outside the body by using sensory receptors. These changes are called stimuli
- **Integration**
  - Processes, analyses & interprets these changes and makes decisions
- **Motor Output**
  - It then effects a response by activating muscles or glands

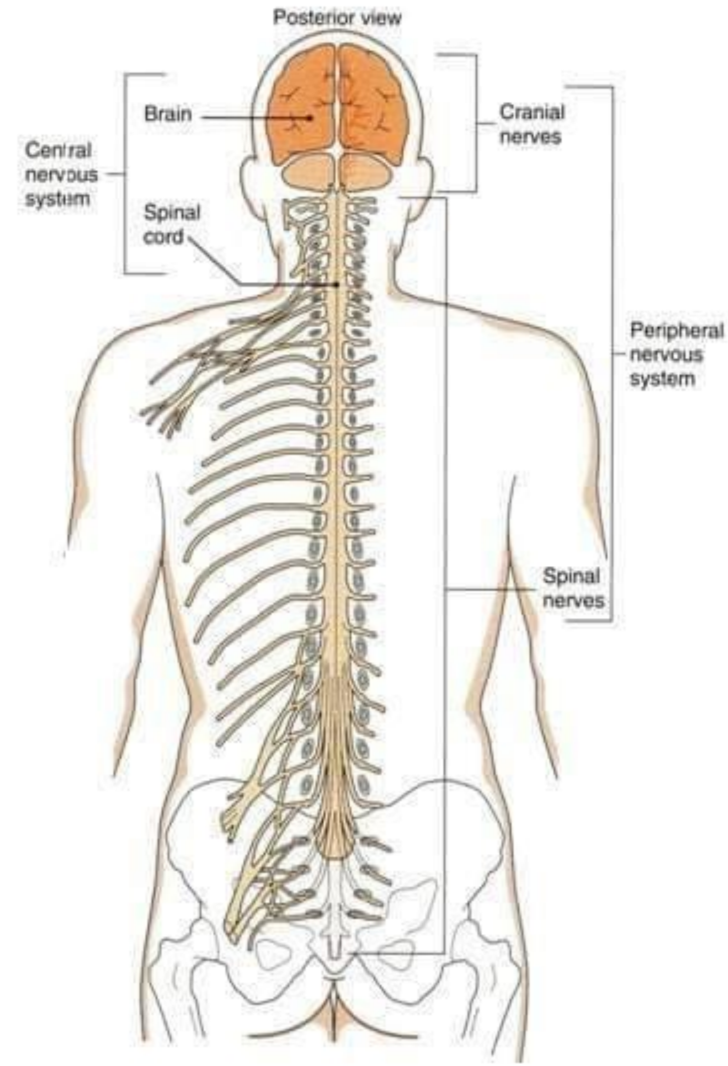



Activating Muscle or glands

# ORGANIZATION

## STRUCTURAL

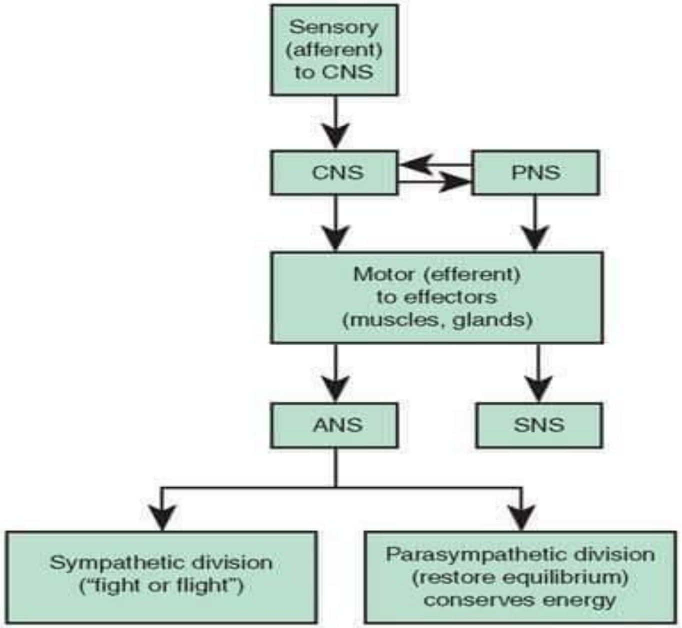
- Central Nervous System (CNS)
  - Brain & Spinal Cord
- Peripheral Nervous System (PNS)
  - Nerves & Ganglia
    - Cranial nerves
    - Spinal nerves



# ORGANIZATION

## FUNCTIONAL

- Sensory Division (Afferent)
- Motor Division (Efferent)
  - Autonomic
  - Somatic



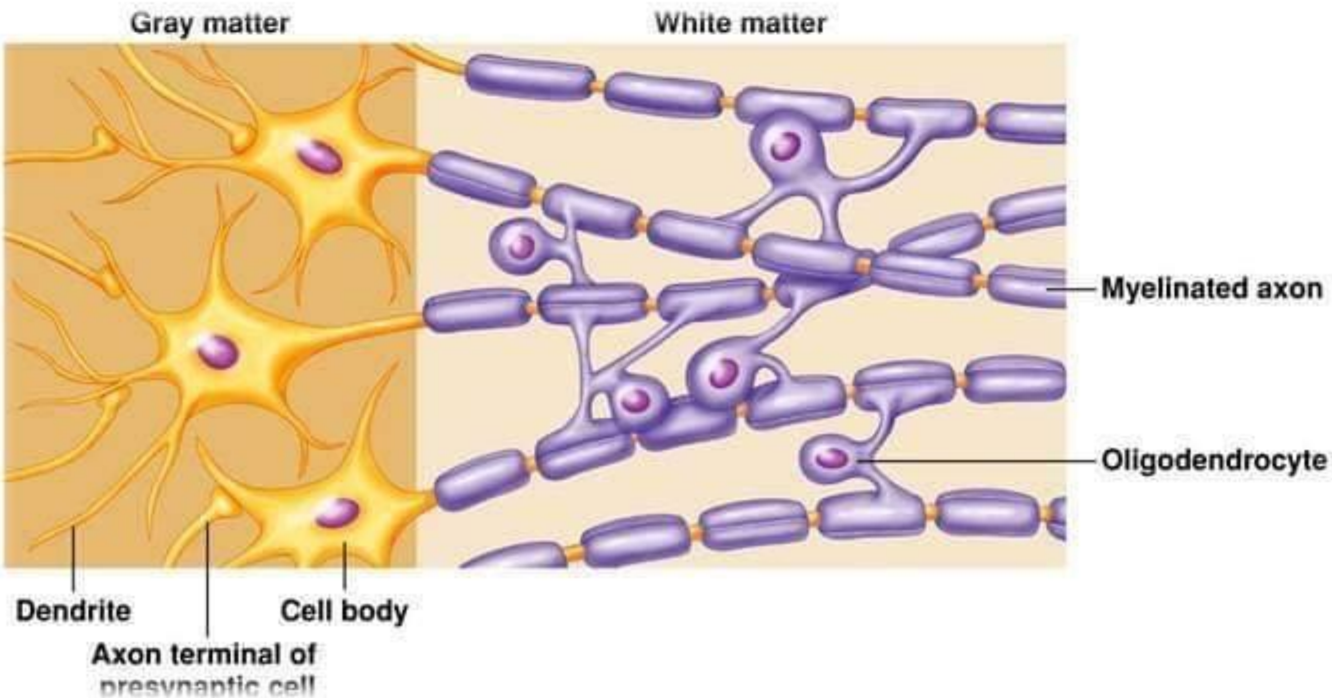

CNS = Central nervous system
PNS = Peripheral nervous system
ANS = Autonomic nervous system
SNS = Somatic nervous system

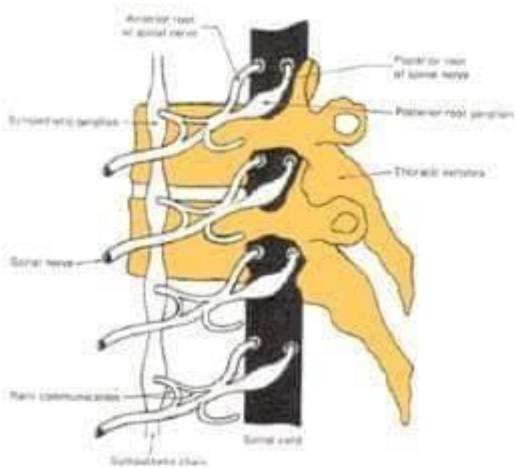
# NERVOUS TISSUE

Nervous tissue is organized as:

**Grey matter:** which contains the cell bodies & the processes of the neurons, the neuroglia and the blood vessels.

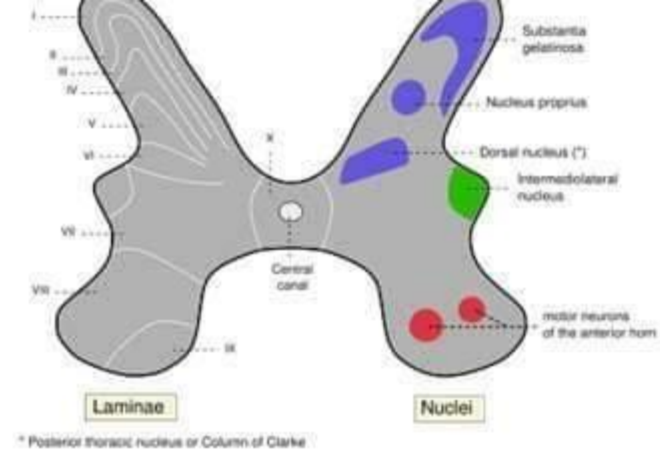
**White matter:** which contains the processes of the neurons (no cell bodies), the neuroglia and the blood vessels.





# Ganglion

A group of neurons outside

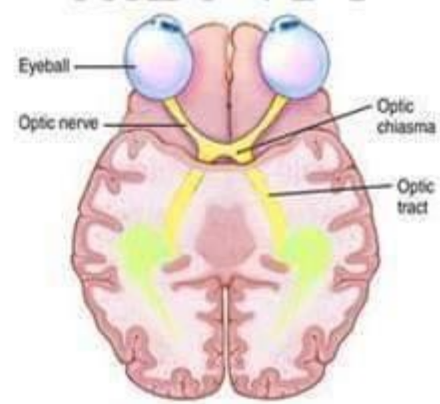



# Nucleus

A group of neurons within the CNS


# Nerve

A group of nerve fibers (axons) outside the CNS

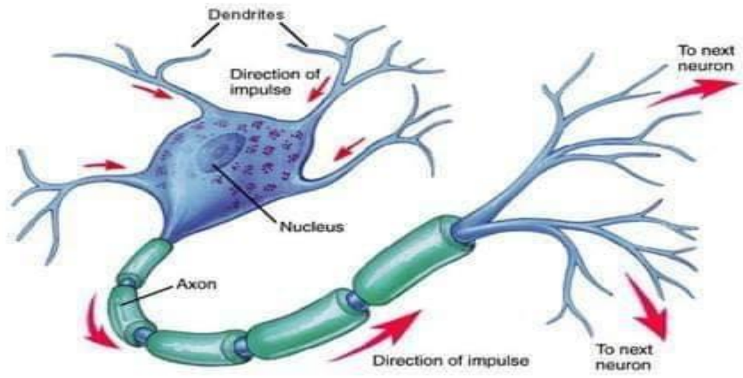



# Tract

A group of nerve fibers (axons) within the CNS

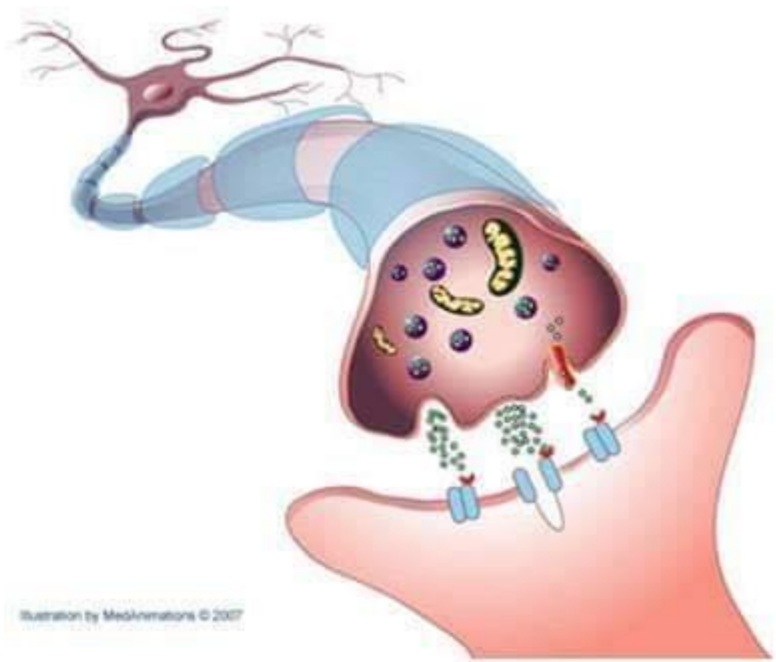
# NEURONS

- It is the basic structural (anatomical), functional and embryological unit of the nervous system.
- The human nervous system is estimated to contain about $10^{10}$.
- The functions of the neuron is to receive incoming information from sensory receptors or from other neurons and to transmit information to other neurons or effector organs.



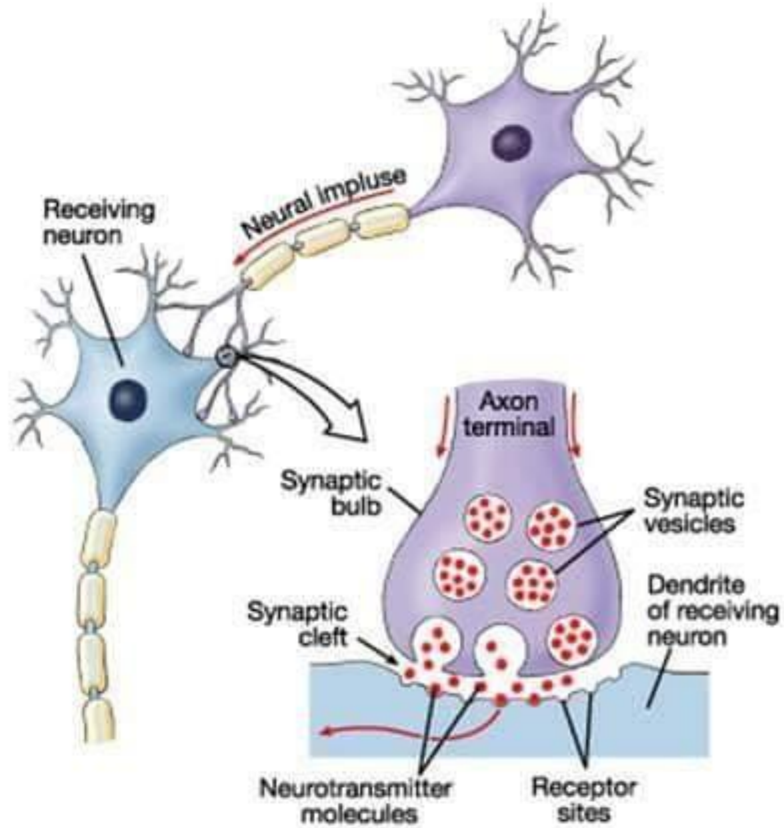
# NEURONS

- Information is passed between neurons at specialized regions called synapses
- There is a single cell body from which a variable number of branching processes emerge.
- Most of these processes are receptive in function and are known as dendrites.
- One of the processes leaving the cell body is called the axon which carries information away from the cell body.
- At the end of the axon, specializations called terminal



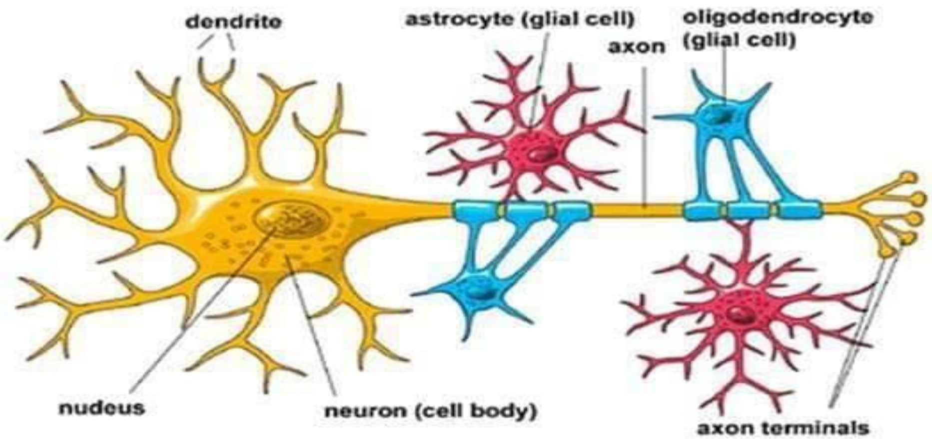
# NEURONS

- Transmission of information between neurons almost always occurs by chemical rather than electrical means.
- Action potential causes release of specific chemical that are stored in synaptic vesicles in the presynaptic ending.
- These chemicals are known as neurotransmitters and diffuse across the narrow gap between pre- and postsynaptic membranes to bind to receptors on the postsynaptic cell.



# NEUROGLIA

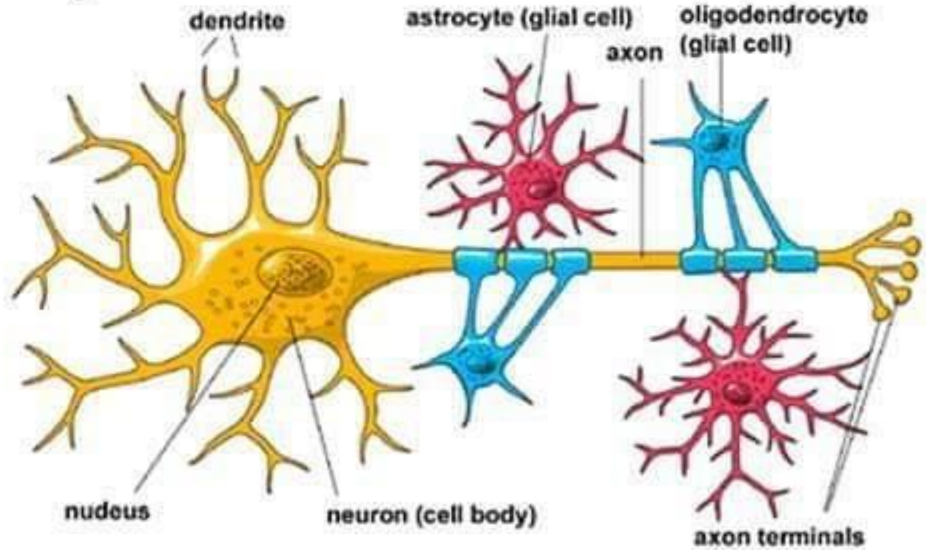
- Neuroglia, or glia cells constitute the other major cellular component of the nervous system.
- It is a specialized connective tissue for the nervous system.
- Unlike neurones, neuroglia do not have a direct role in information processing but they are essential for the normal functioning of nerve cells.



# NEUROGLIA

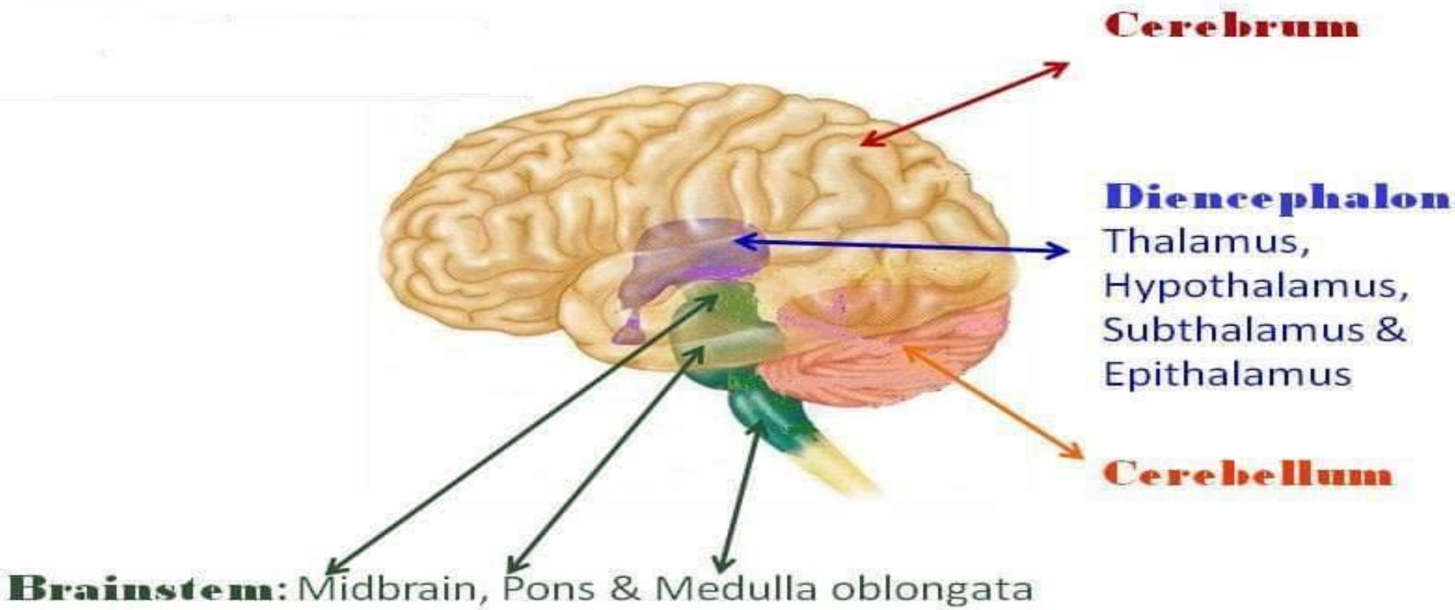
**Three main types of neuroglial cell are recognized:**

- **Oligodendrocytes**
  - they form the myelin sheath that surrounds many neuronal axons, which increase the rate of conduction.
- **Microglia**
  - have a phagocytic role in response to nervous system damage.
- **Astrocytes**
  - provide biochemical support for endothelial cells that form the blood–br



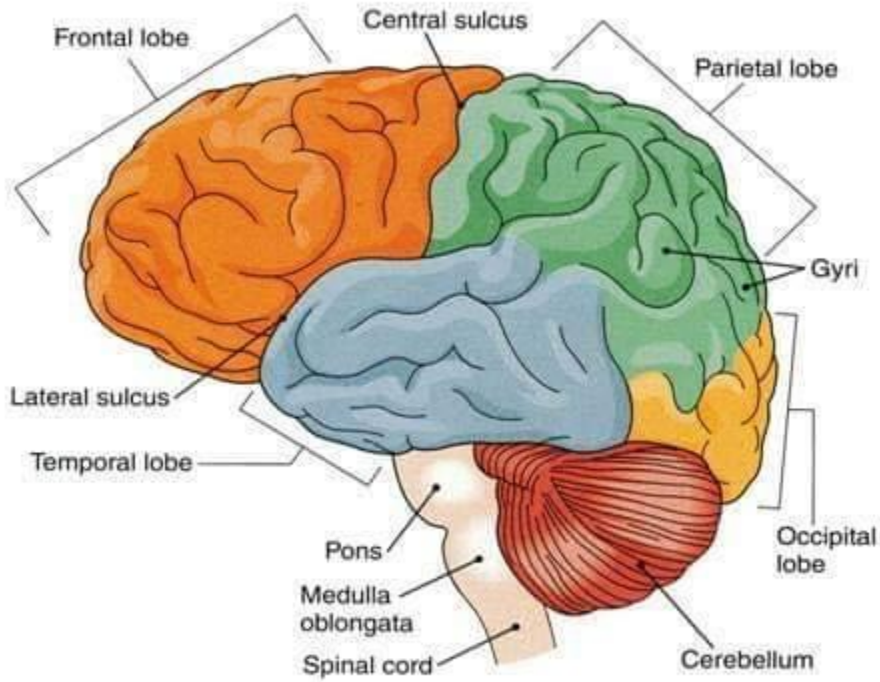
# THE BRAIN

- Large mass of nervous tissue located in the cranial cavity.
- Has four major regions.

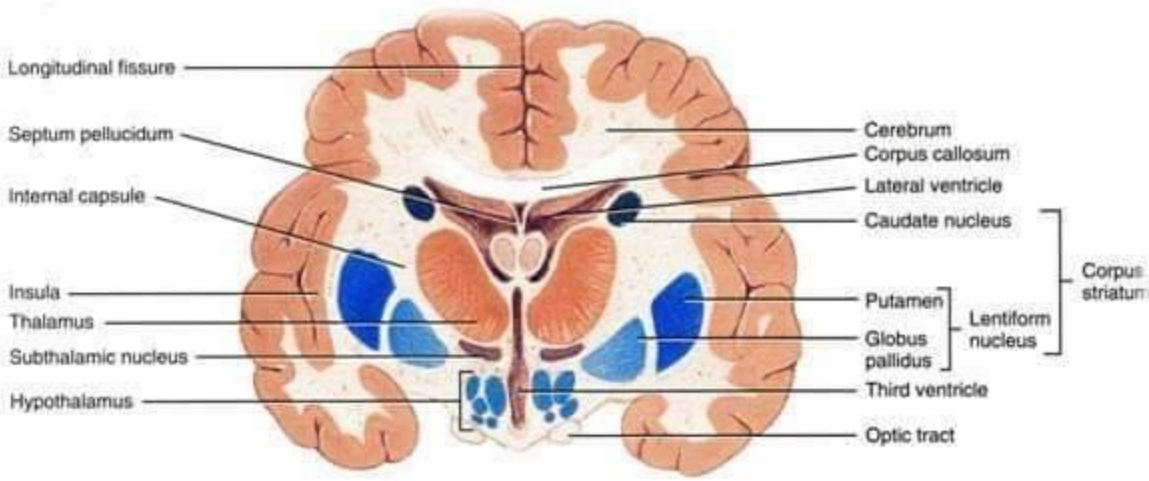


# CEREBRUM

- The largest part of the brain, and has two **hemispheres**.
- The cerebral hemispheres are connected by a thick bundle of nerve fibers called **corpus callosum**.
- The surface shows ridges of tissue, called **gyri**, separated by grooves called **sulci**.
- Divided into **4 lobes** by deeper grooves.



# Tissue of Cerebral Hemispheres

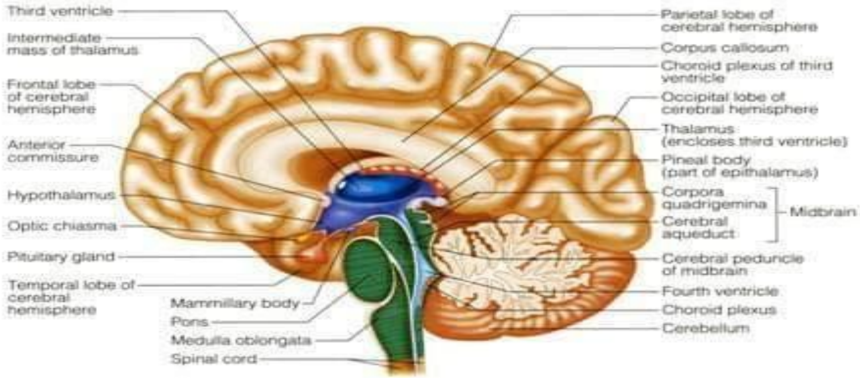



(b) Anterior view of frontal section

- The outermost layer is called gray matter or cortex.
- Deeper is located the white matter, composed of fiber tracts (bundles of nerve fibers)
  - Carrying impulses to and from the cortex.
- Located deep within the white matter are masses of grey matter called the basal nuclei .
  - They help the motor cortex in the regulation of voluntary motor activities

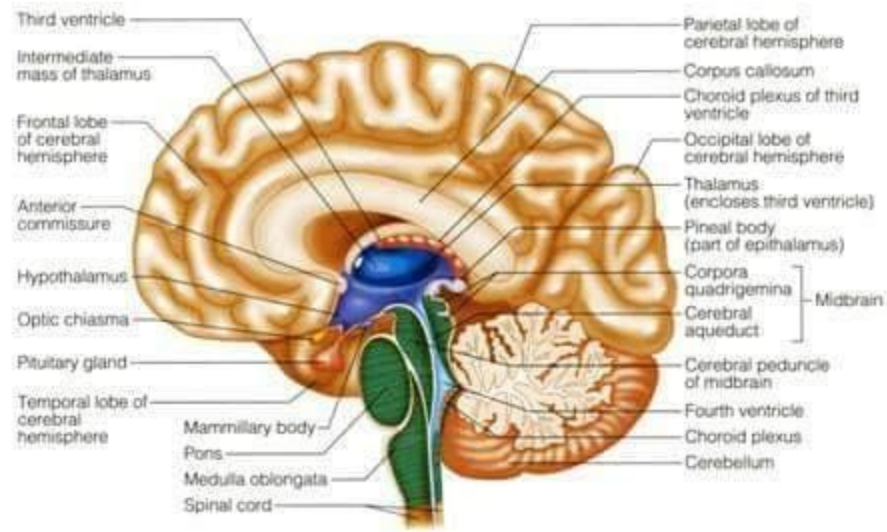
# CEREBLLUM

- The cerebellum has 2 hemispheres and a convoluted surface.
- It has an outer cortex made from gray matter and an inner region of white matter.
- It provides precise coordination for body movements and helps maintain equilibrium.



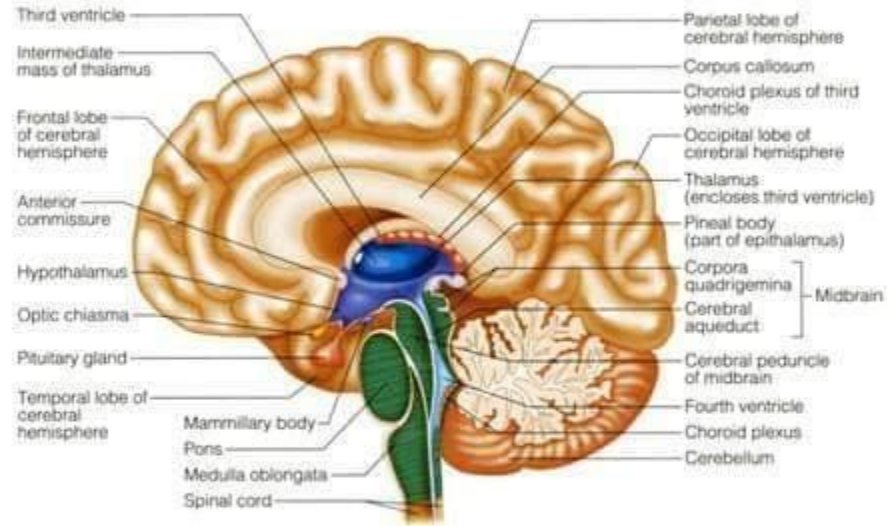
# DIENCEPHALON

- Consists of four parts;
  - Thalamus
  - Hypothalamus
  - Subthalamus
  - Epithalamus
- Lies between the cerebrum and the brain stem.
- Regulates visceral activities and the autonomic nervous system.



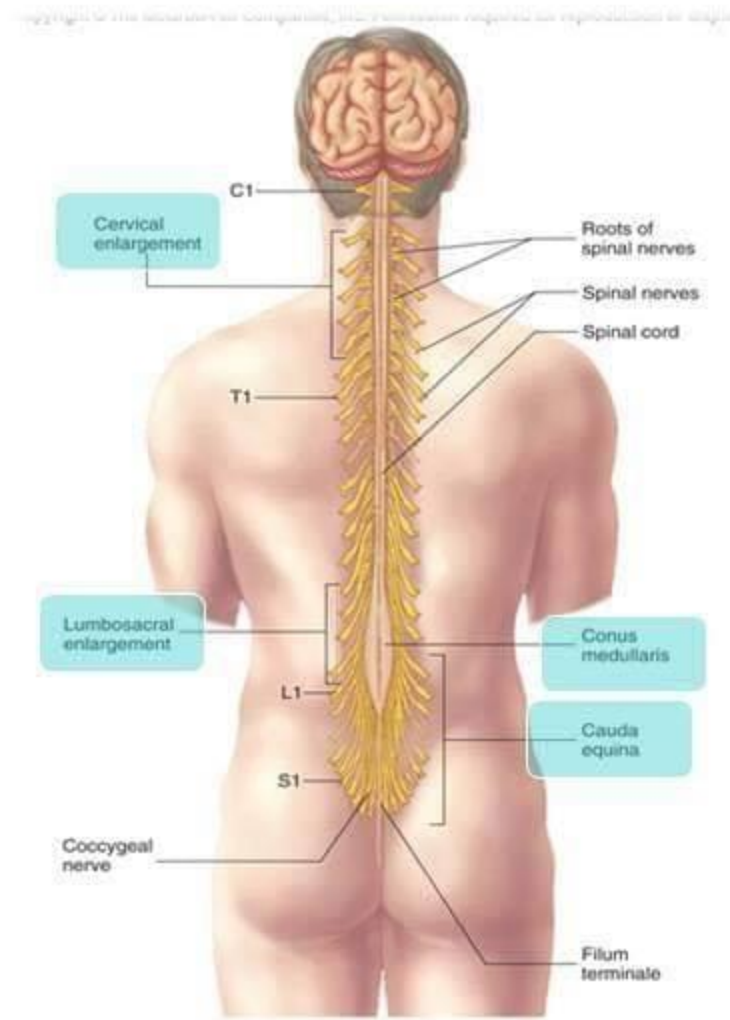
# BRAIN STEM

- Consists of three parts;
  - Midbrain
  - Pons
  - Medulla Oblongata
- Produces the rigidly programmed, autonomic behaviors necessary.
- Provides the pathway for fibers tracts running between higher and lower neuronal centers.



# SPINAL CORD

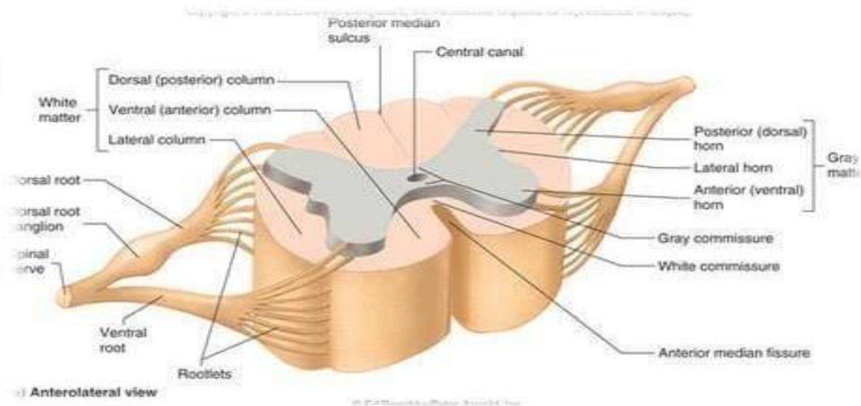
- It is a two-way conduction pathway to the brain & a major reflex center
- 42-45 cm long, cylindrical in shape, lies within the vertebral canal.
- Extends from **foramen magnum** to **L2 vertebra**
- Continuous above with medulla oblongata
- Caudal tapering end is called **conus medullaris**
- Has 2 enlargements: **cervical** and **lumbosacral**
- Gives rise to 31 pairs of **spinal nerves**
- Group of spinal nerves at the end of the spinal cord is called **cauda equina**



# CEREBLLUM

## CROSS SECTION OF SPINAL CORD

- The spinal cord is incompletely divided into two equal parts, **anteriorly** by a short, shallow median fissure and **posteriorly** by a narrow septum, the posterior median septum.
- Composed of **grey matter** in the centre surrounded by **white matter**.
- The arrangement of grey matter resembles the shape of the letter H, having two posterior, two anterior and two lateral horns/columns.



# PEREPHERAL NERVES

- **May be SENSORY, may be MOTOR or could be MIXED**
- **Two TYPES:**

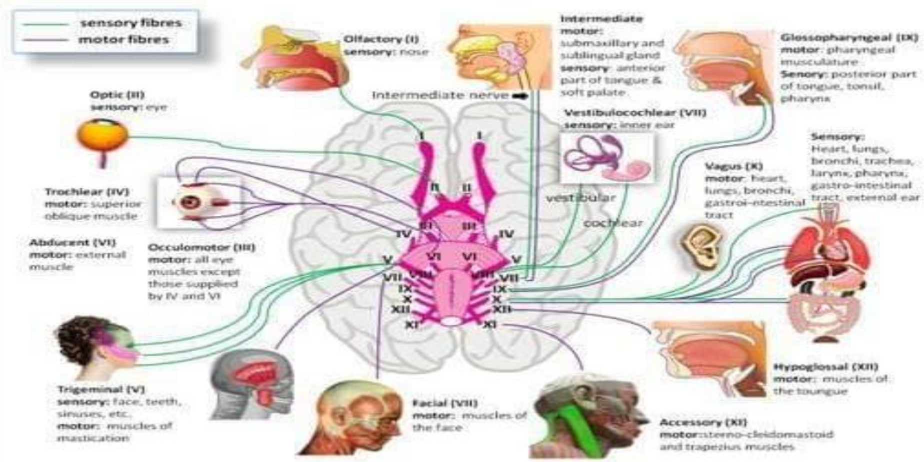
❖ **Cranial:** 12 pairs, attached to brain, named, and numbered from1-12

❖ **Spinal:** 31 pairs, attached to spinal cord named and numbered according to the region of the spinal cord

# CRANIAL NERVES

## 12 Pairs

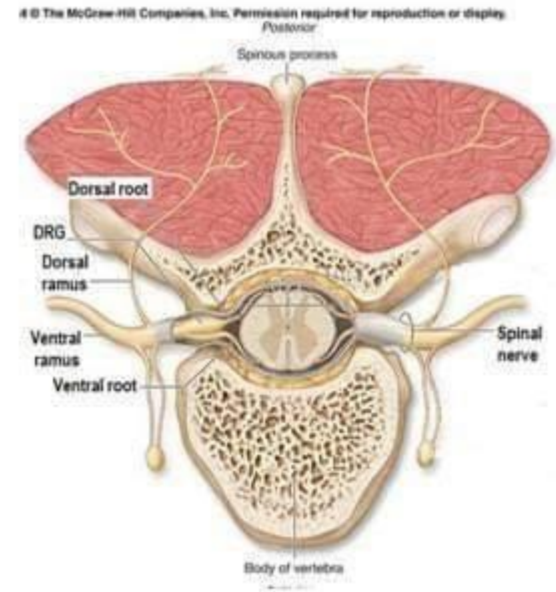
- 4 pairs are mixed
  - trigeminal n. (5th)
  - facial n. (7th)
  - glossopharyngeal n. (9th)
  - vagus n. (10th)
- 5 pairs are motor
  - occulomotor n. (3rd)
  - trochlear n. (4th)
  - abducent n. (6th)
  - accessory n. (11th)
  - hypoglossal n. (12th)
- 3 pairs are sensory
  - olfactory n. (1st)
  - optic n. (2nd)
  - vestibulocochlear n.

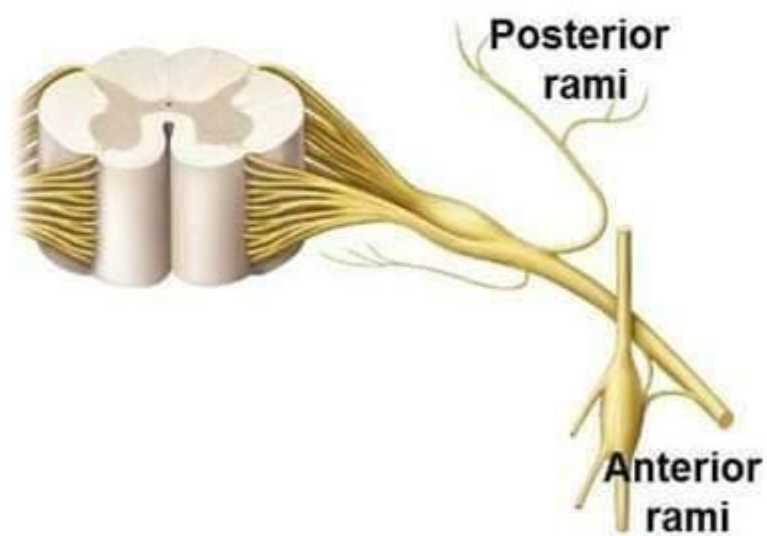


# SPINAL NERVES & NERVE PLEXUES

❖ 31 Pairs

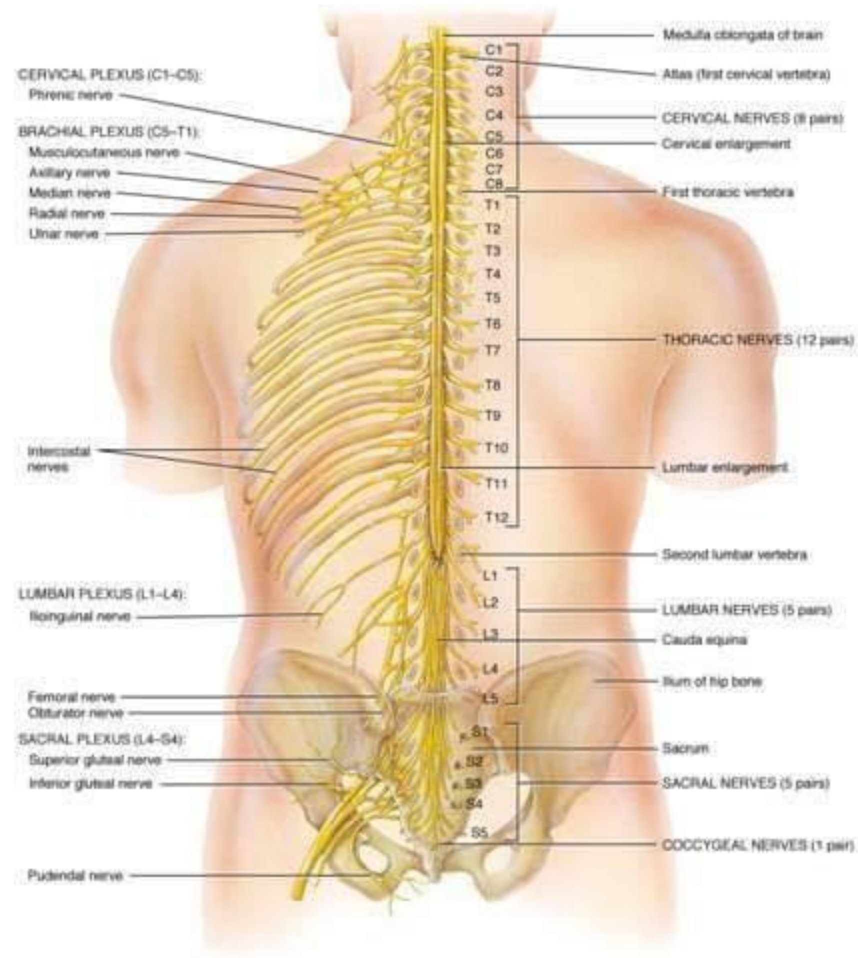
- Each spinal nerve is attached by two roots:
  - Dorsal (sensory)
  - Ventral (motor)
    - ✓ Dorsal root bears a sensory ganglion
- Each spinal nerve exits from the intervertebral foramen and divides into a dorsal and ventral ramus
- The rami contain both



# SPINAL NERVES & NERVE PLEXUES

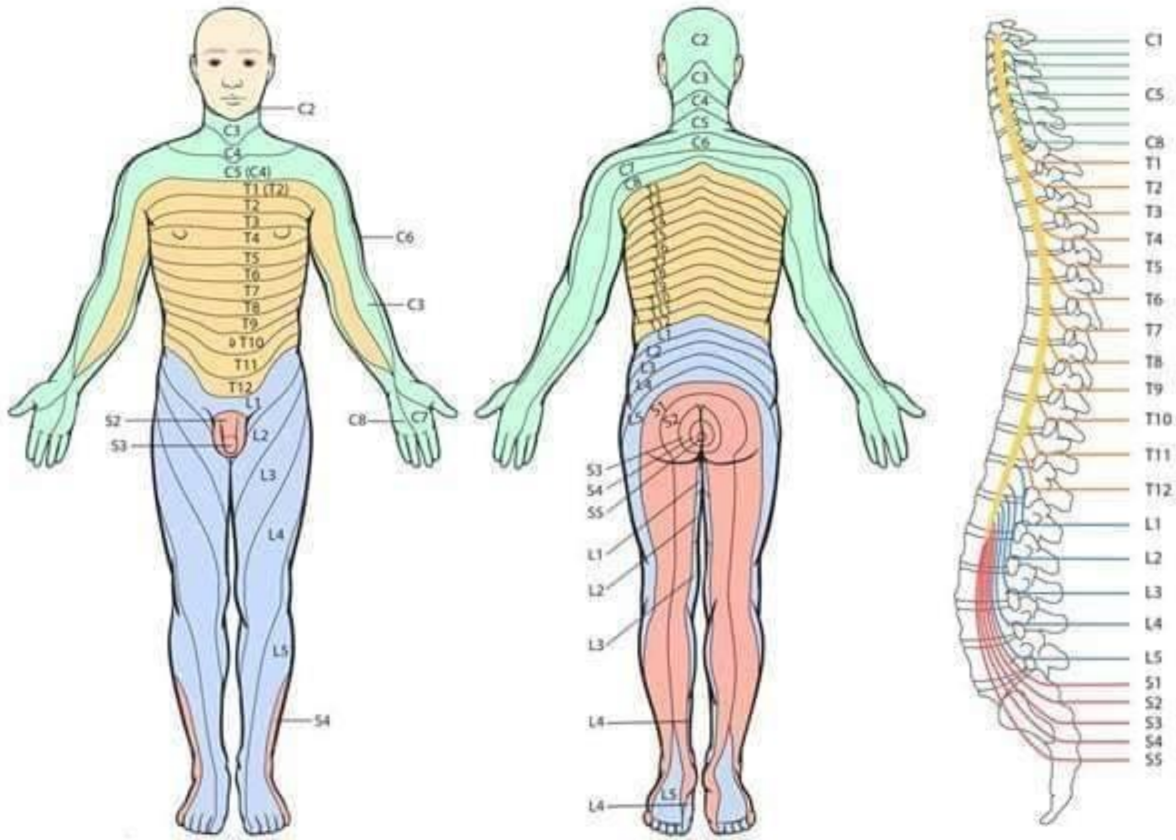
- The **dorsal rami** are distributed individually.
  - Supply the skin and muscles of the back
- The **ventral rami** form **plexuses**
  - Except in thoracic region where they form the intercostal nerves
  - Supply the anterior part of the body




Posterior view of entire spinal cord and portions of spinal nerves and their branches

# DERMATOME

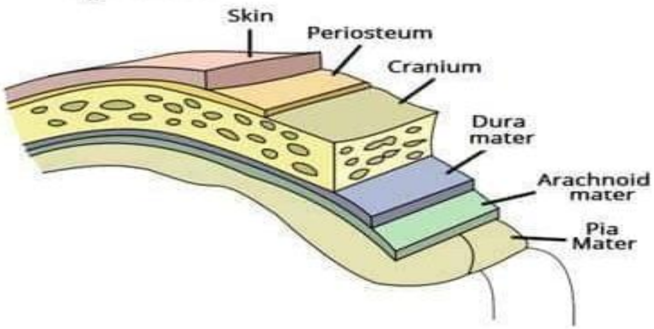
Dermatome is a segment of skin supplied by one spinal nerve.

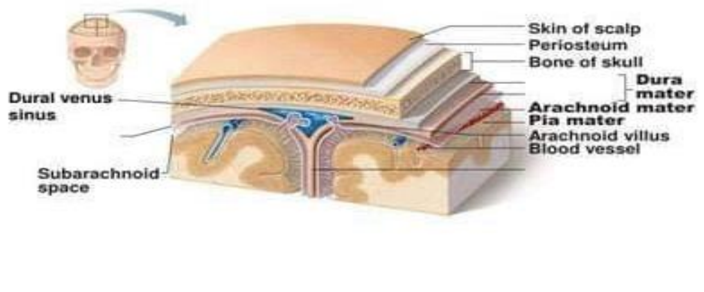


# PROTECTION OF CNS

**THE CNS IS PROTECTED BY:**

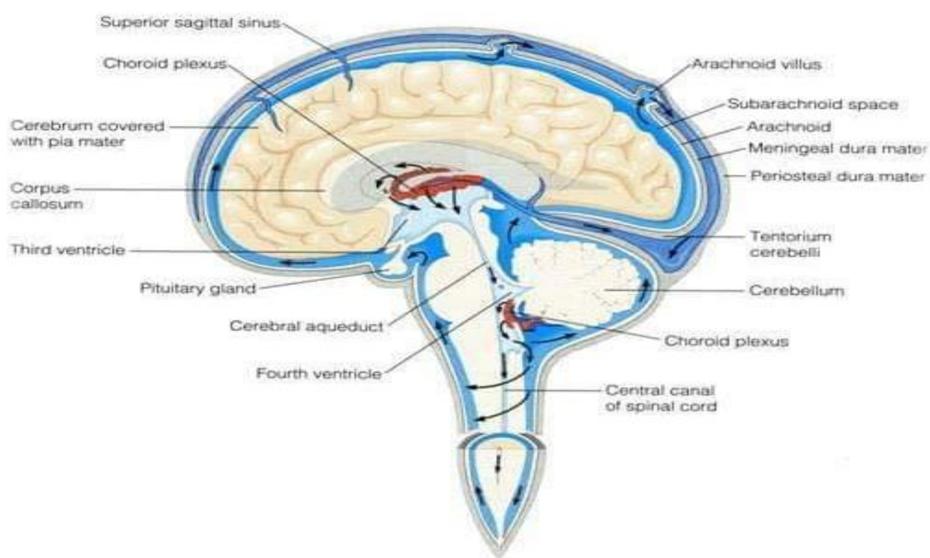
- **Skull** and the **vertebral column** (bone)
- **Meninges** (membranes): 3 layers
  - dura mater (outermost)
  - arachnoid mater (middle
  - pia mater (innermost)
- **Cerebrospinal fluid** in the subarachnoid space



# CEREBRAL FLUID

- CSF is constantly produced by the choroid plexuses inside the ventricles of brain.
- CSF is constantly drained into the dural sinuses through the arachnoid villi.
- Most of the CSF drains from the ventricles into the subarachoid space around the brain and spinal cord. A little amount flows down in the central canal of the spinal cord



## Which statement(s) of the following is TRUE?

1. Nucleus is a group of neurons within the PNS
2. In the Brain, grey matter located in the centre and surrounded by white matter.
3. Oligodendrocytes they form the myelin sheath that surrounds many neuronal axons, which increase the rate of conduction.
4. Diencephalon provides the pathway for fibers tracts running between higher and lower neuronal centers.
5. Information is passed between neurons at specialized regions called synapses
6. Cerebrum provides precise coordinatio movements and helps maintain equilibriun

# The Nervous System

The nervous system is made up of neurons and nervous tissue. It is master controlling and communicating system of body. Its objective is to keep conditions controlled within limits to maintain life. The nervous system carries out a complex array of tasks. It also controls our emotions, perceptions, behavior, memories and initiates voluntary movements. It allows us to sense various smells, produce speech, remember past events, control body movements and regulates the operation of internal organs. The nervous system includes **Brain, Cranial nerves and its branches, Spinal cord, Spinal nerves and its branches, Ganglia, Enteric plexus** and **Sensory receptors**. It detects the changes (stimuli) inside or outside the body and acts accordingly. Nervous system communicates with the body cells through electric signals called nerve impulses.

## Functions of Nervous System:

The functions of nervous systems can be grouped into three basic functions

- **Sensory function:** Sensory receptors detect internal stimuli (such as an increase in blood acidity) and external stimuli (such as a raindrop landing on your arm). This sensory information is then carried into the brain and spinal cord through cranial and spinal nerves.
- **Integrative function:** The nervous system integrates (processes) sensory information by analyzing and storing some of it and by making decisions for appropriate responses.
- **Motor function:** Once sensory information is integrated, the nervous system produces an appropriate motor response by activating effectors (muscles and glands) through cranial and spinal nerves. Stimulation of the effectors causes muscles to contract and glands to secrete.

## Organization of the Nervous System:

The nervous system consists of two main subdivisions:

**A. Central Nervous System:** The central nervous system (CNS) consists of the brain and spinal cord. The CNS processes many different kinds of incoming sensory information. It is also the source of thoughts, emotions and memories. Most nerve impulses that stimulate muscles to contract and glands to secrete originate in the CNS.

**B. Peripheral Nervous System:** The peripheral nervous system (PNS) includes all nervous tissue outside the CNS. Components of the PNS include cranial nerves and their branches, spinal nerves and their branches, ganglia, and sensory receptors. The PNS may be subdivided further into:

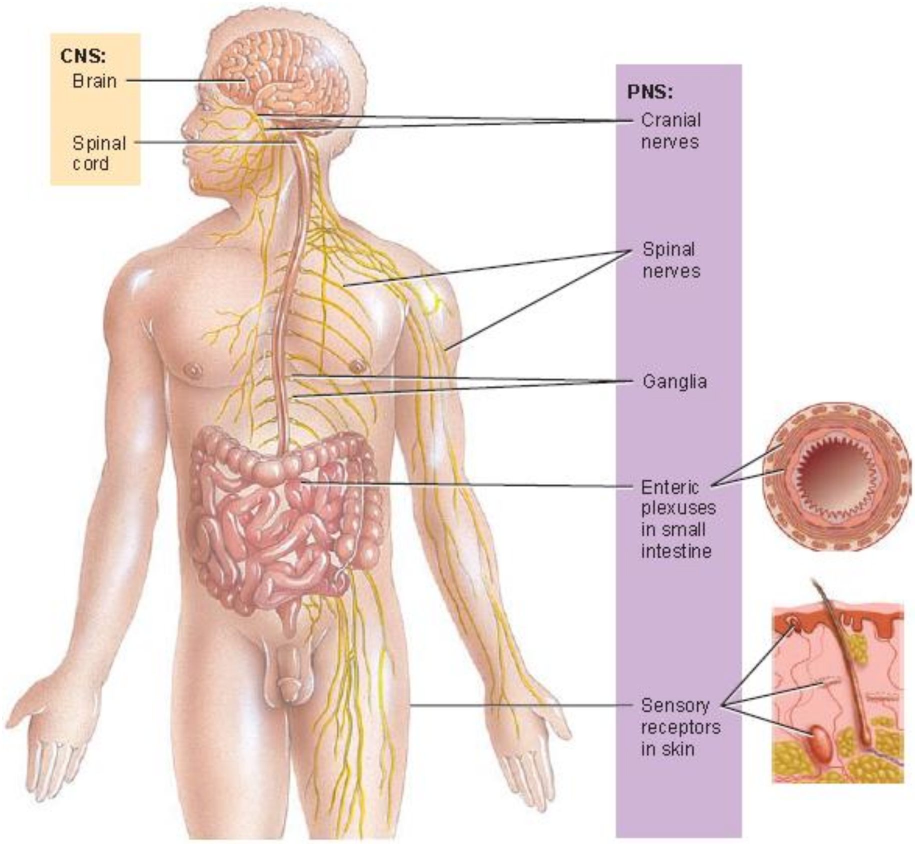
**Somatic nervous system (SNS): (soma = body):** It consists of:

1) Sensory neurons that convey information from somatic receptors in the head, body wall, and limbs and from receptors for the special senses of vision, hearing, taste and smell to the CNS.
2) Motor neurons that conduct impulses from the CNS to skeletal muscles only. Because these motor responses can be consciously controlled, the action of this part of the PNS is voluntary.

**Autonomic nervous system (ANS) (auto = self):** The ANS consists of:

1) Sensory neurons that convey information from autonomic sensory receptors, located primarily in visceral organs such as the stomach and lungs, to the CNS.
2) Motor neurons that conduct nerve impulses from the CNS to smooth muscle, cardiac muscle, and glands. Because its motor responses are not normally under conscious control, the action of the ANS is involuntary. The motor part of the ANS consists of two branches, the sympathetic division and the parasympathetic division. Usually the two divisions have opposing actions. For example sympathetic neurons increase heart rate, and parasympathetic neurons slow it down. In general, the sympathetic division helps support exercise or emergency actions, so it is called "fight-or-flight" responses and the parasympathetic division takes care in resting conditions, so it is called "rest-and-digest" response.

**Enteric nervous system (ENS) (ent = intestines):** The ENS consists of neurons in enteric plexuses of the gastrointestinal (GI) tract. Sensory neurons of the ENS monitor chemical changes within the GI tract as well as the stretching of its walls. Motor neurons control contraction of GI tract to propel food through the GI tract, secretions of the GI tract organs such as acid from the stomach, and activity of GI tract endocrine cells, which secrete hormones. The operation of the ENS, the "brain of the gut," is involuntary.




## Nervous Tissue:

Nervous tissue consists of two types of cells: **neurons** and **neuroglia**.

**Neurons** provide most of the unique functions of the nervous system, such as sensing, thinking, remembering, controlling muscle activity, and regulating glandular secretions.

**Neuroglia** are the cells which support, nourishes and protect the neurons. Neuroglia of the CNS can be classified into four types: astrocytes, oligodendrocytes, microglia, and ependymal cells. Neuroglia of the PNS completely surrounds axons and cell bodies and includes two types of cells *i.e.* Schwann cells and satellite cells.

## Neuron or Nerve Cell:

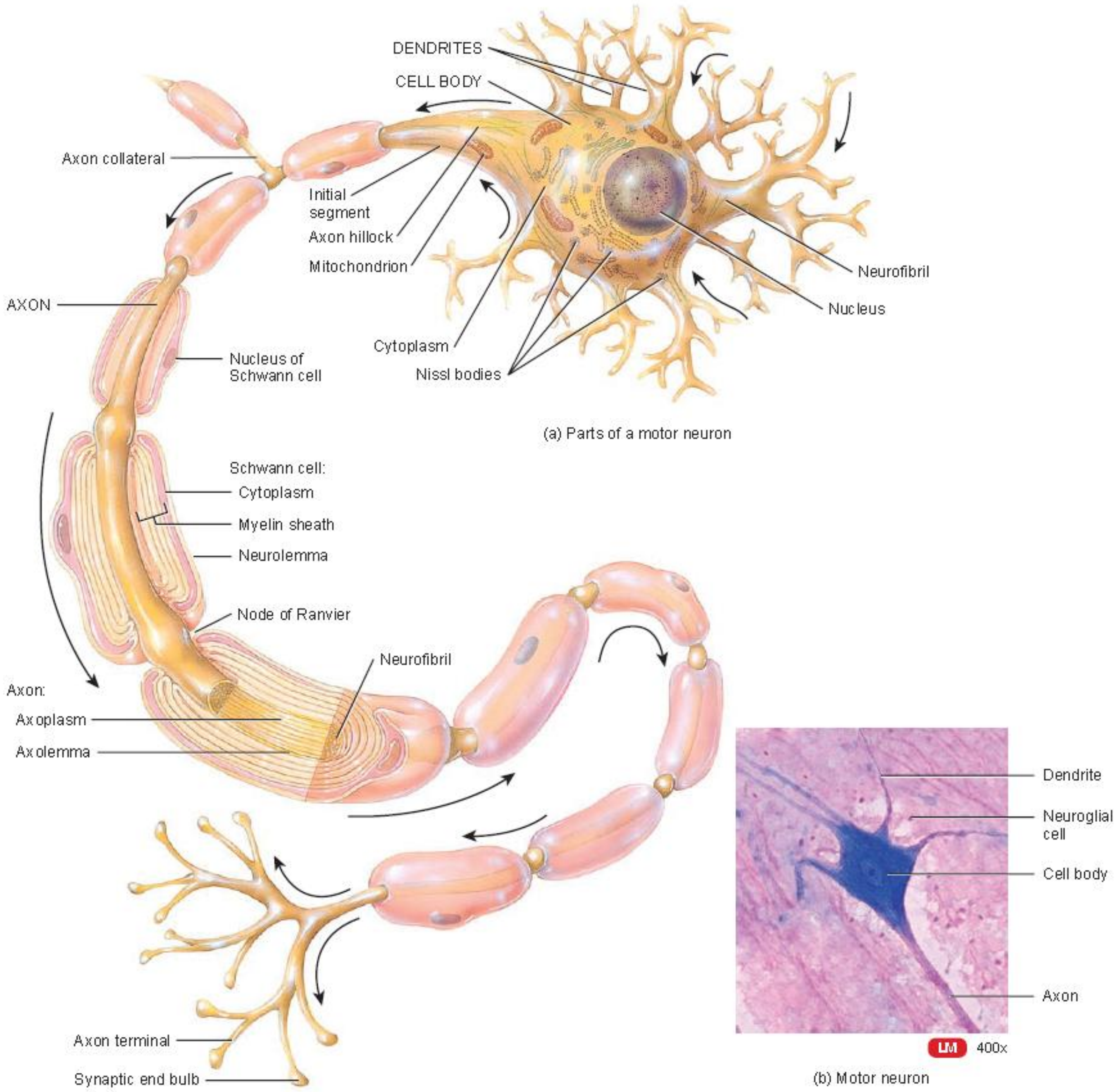
It is a single cell of nervous system. It possesses electrical excitability *i.e.* the ability to respond to a stimulus and convert it into an action potential. A **stimulus** is any change in the environment that is strong enough to initiate an action potential. An **action potential** (nerve impulse) is an electrical signal that propagates (travels) along the surface of the membrane of a neuron. It begins and travels due to the movement of ions (such as sodium and potassium) between interstitial fluid and the inside of a neuron through specific ion channels in its plasma membrane.

**Parts of Neuron:**

Most neurons have three parts: (1) a cell body (2) dendrites (3) axon.

1) **The cell body**: The cell body contains a nucleus surrounded by cytoplasm that includes typical cellular organelles such as lysosomes, mitochondria, ribosomes, endoplasmic reticulum and a Golgi complex. A cluster of neuronal cell bodies located in the PNS is called ganglion (plural is ganglia) and a cluster of neuronal cell bodies located in the CNS is called nucleus (plural is nuclei).

2) **Dendrites**: Dendrites (little trees) are the receiving or input portions of a neuron. They usually are short, tapering, and highly branched and form a tree-shaped array of processes extending from the cell body.



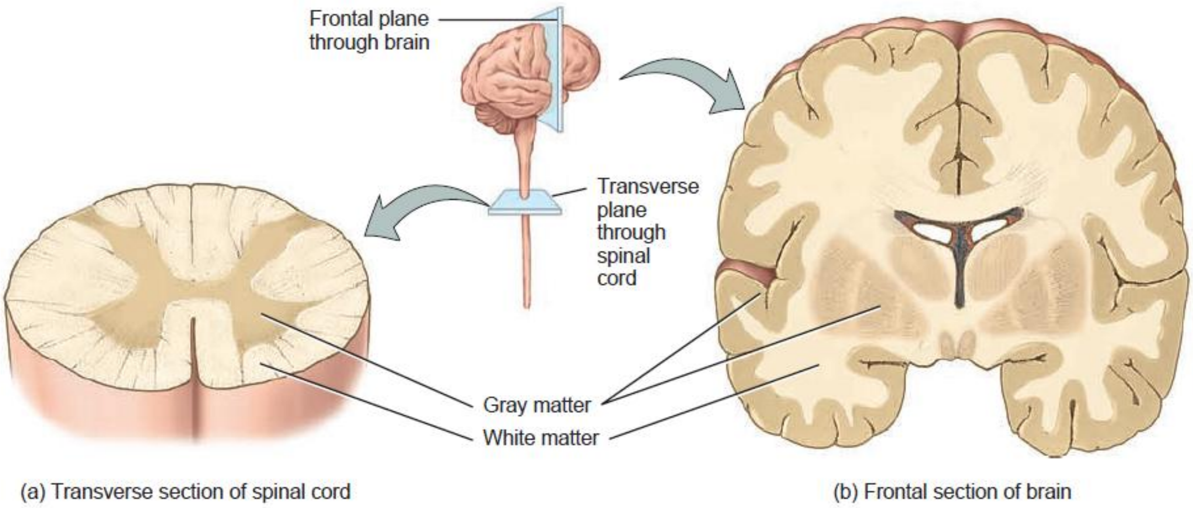

(a) Parts of a motor neuron

(b) Motor neuron

3) **Axon:** An axon is a long, thin, cylindrical projection that carries nerve impulse to other neuron, muscle or glands. It is often joined to the cell body at a cone-shaped elevation called the axon hillock (small hill). The part of the axon closest to the axon hillock is the initial segment. In most neurons, nerve impulses arise at the junction of the axon hillock and the initial segment, an area called the trigger zone, from which they travel along the axon to their destination. The axon of a neuron propagates nerve impulses toward another neuron, a muscle fiber, or a gland cell. Axon can have side branches (at right angle to axon) which are called **axon collaterals**. At the ends, the axon divide into many fine processes called **axon terminals (telodendria)**. The tips of axon terminals swell into bulb-shaped structures called **synaptic end bulbs**. Synaptic end bulbs contain many tiny membrane-enclosed sacs called synaptic vesicles that store a chemical **neurotransmitter**. Many neurons contain two or even three types of neurotransmitters, each with different effects on the postsynaptic cell. When neurotransmitter molecules are released from synaptic vesicles, they excite or inhibit other neurons, muscle fibers, or gland cells. The site of communication between two neurons or between a neuron and an effector cell is called a **synapse**. Bundle of axons located in the PNS is called a Nerve. Cranial nerves connect the brain to the periphery, whereas spinal nerves connect the spinal cord to the periphery. A bundle of axons located in the CNS is called Tract. Tracts interconnect neurons in the spinal cord and brain.

**Myelination:** Axons of some neurons are covered by layers of lipid and protein. This covering is called the **myelin sheath** and the neurons having this covering are called **myelinated**. Axons without such a covering are said to be **unmyelinated**. The sheath electrically insulates the axon of a neuron and increases the speed of nerve impulse conduction. Myelin sheaths are produced by Schwann cells (in the PNS) and oligodendrocytes (in the CNS). Gaps in the myelin sheath appear at intervals along the axon. These gaps are called **nodes of Ranvier**.

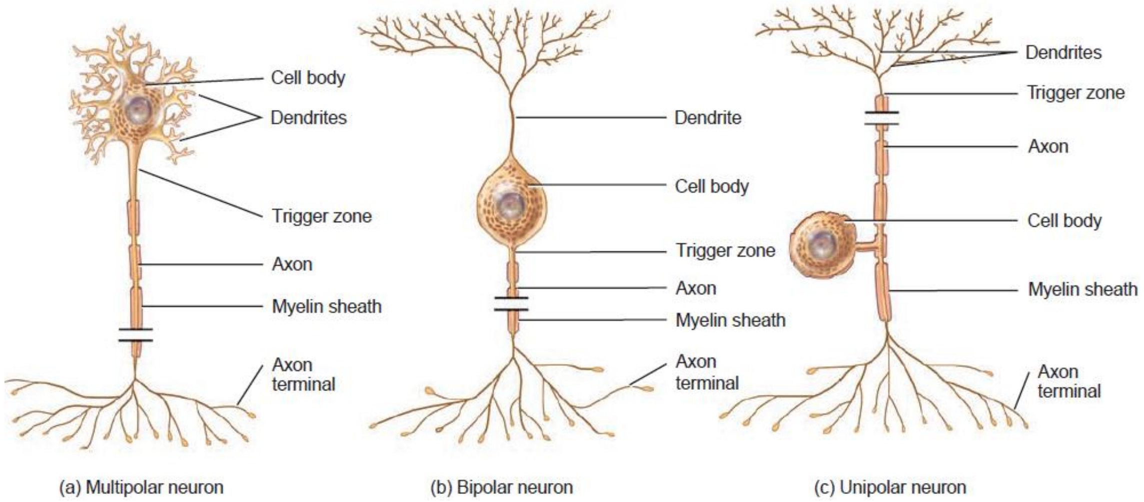
In a freshly dissected section of the brain or spinal cord, some regions look white and glistening, and others appear gray. White matter is called so because it is composed of myelinated axons which appear white in color. The axons present in gray matter lack myelin sheath that is why they appears greyish in color. In the spinal cord, the grey matter is present in central part in shape of letter ‘H’ surrounded by white matter. In the brain white matter is present inside and a thin layer of gray matter is present on outer surface of the brain.




## Classification of neurons:

1. **On Structural Basis:** On the basis of number of processes extending from the cell body.

- **Multipolar neurons:** usually have several dendrites and one axon. Most neurons in the brain and spinal cord are of this type.
- **Bipolar neurons:** have one main dendrite and one axon. They are found in the retina of the eye, in the inner ear, and in the olfactory area of the brain.
- **Unipolar neurons:** have a single process emerging from cell body that divides into a dendrites and an axon. The dendrites of most unipolar neurons function as sensory receptors that detect a sensory stimulus such as touch, pressure, pain, or thermal stimuli.




2. **On Functional Basis:** On basis of the direction in which the nerve impulse (action potential) is conveyed with respect to the CNS.

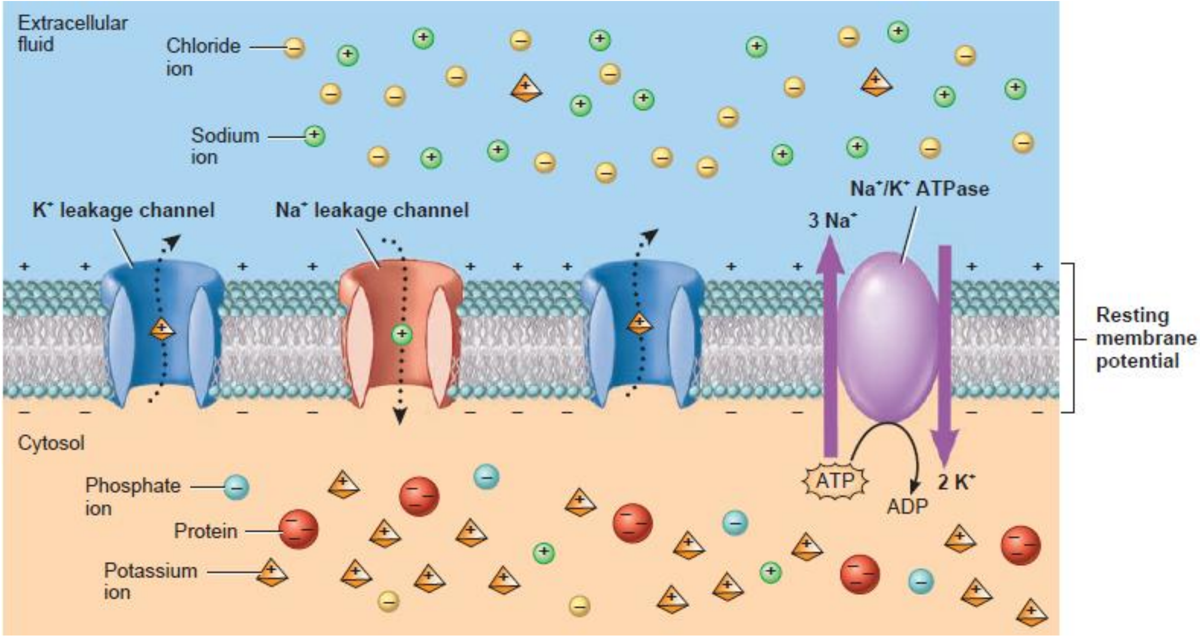
- **Sensory or afferent neurons** (af = toward; ferrent = carried) either contain sensory receptors at their distal ends (dendrites) or are located just after sensory receptors that are separate cells. Once an appropriate stimulus activates a sensory receptor, the sensory neuron forms an action potential in its axon and the action potential is conveyed into the CNS through cranial or spinal nerves. Most sensory neurons are unipolar in structure.
- **Motor or efferent neurons** (ef = away from) convey action potentials away from the CNS to effectors (muscles and glands) in the periphery (PNS) through cranial or spinal nerves. Most motor neurons are multipolar in structure.
- **Interneurons or association neurons** are mainly located within the CNS between sensory and motor neurons. Interneurons integrate (process) incoming sensory information from sensory neurons and then elicit a motor response by activating the appropriate motor neurons. Most interneurons are multipolar in structure.

## Electrical Signals in Neuron/ Physiology of nerve impulse:

Neurons have two functional properties; a) **Electrical excitability** *i.e.* ability to produce electric signal (nerve impulse) in response to a stimuli b) **Conductivity** or propagation *i.e.* ability to transmit the impulse to other neuron, muscle or glands.

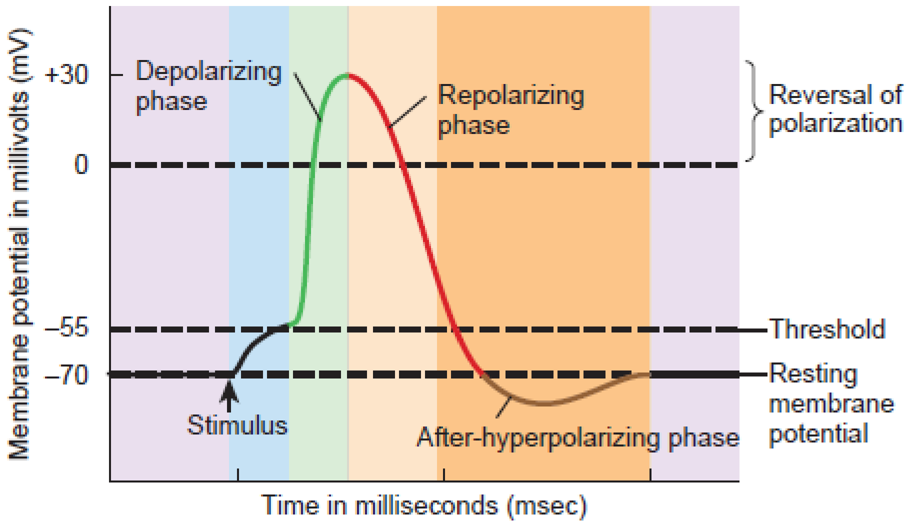
**Production of nerve impulse occurs as follow:**

- At resting position, there are fewer +ve ions present at inner side of neuron's plasma membrane than outside of it. In other word there is –ve environment in cytosol as compared to extracellular fluid present outside of plasma membrane. In this state the neuron is said to be **polarized**.
- Due to difference in concentration of ions across plasma membrane, there is voltage difference. This voltage difference is called **Membrane potential** or **Resting membrane potential.** In neurons, the resting membrane potential ranges from -40 mV to -90 mV. An average value is **-70 mV**.
- The major +ve ions present inside the cell are $K^+$ while $Na^+$ ions are present outside in extracellular fluid. As long as inside (cytosol) remains more –ve than extracellular fluid, neurons remains in resting or polarized state.




- Different types of stimuli excite neuron to become active and generate nerve impulse. *E.g.* Light stimulates photoreceptors in eyes, sound stimulates auditory receptors *etc.*
- Due to stimuli, the permeability of cell's plasma membrane changes for very brief period of time and causes opening of $Na^+$ ion channels present in membrane. As a result $Na^+$ ions diffuse (move) in rapidly. This inward movement of $Na^+$ ions decreases the –ve charge inside. This process is called **depolarization** and the neuron is said to be **depolarized**.
- When a stimulus is weak, it causes opening of less number of $Na^+$ channels and thus less diffusion of sodium ions inside neuron. As a result there is production of graded potential. A **graded potential** is a small deviation from the resting membrane potential that makes the membrane less polarized (inside less negative). So in other words a little depolarization produces a weak graded potential. The signal (impulse) produced by graded potential travels a small distance and gradually dies off. Graded potential is used for short distance communications.
- But when stimulus is strong, it causes opening of more number of $Na^+$ ion channels and more diffusion of $Na^+$ inside neuron. As a result, there is generation of Action potential. An **action potential** (AP) or **impulse** is a sequence of rapidly occurring events that decrease and reverse the resting membrane potential and then eventually restore it to the resting state. An action potential has two main phases: a **depolarizing phase** and a **repolarizing phase**. During the depolarizing phase, the negative membrane potential becomes less negative, reaches zero and then becomes positive. During the repolarizing

phase, the membrane potential is restored to the resting state of -70 mV. An action potential occurs in the membrane of the axon of a neuron when depolarization reaches a certain level termed the **threshold** (about -55 mV in many neurons). An action potential will not occur in response to a **subthreshold** stimulus, a stimulus that is a weak depolarization that cannot bring the membrane potential to threshold. Action potential is used for long distance communications. Action potential in a neuron (nerve cell) is called a nerve action potential (nerve impulse).



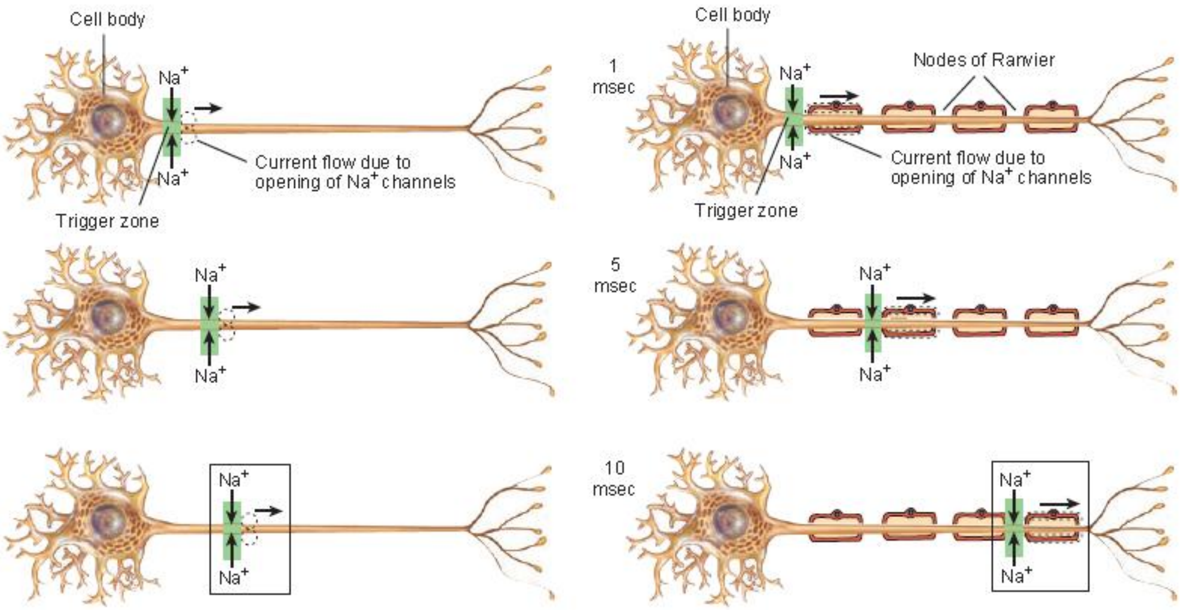

- **Depolarization phase:** During depolarization phase the membrane of the axon depolarize to threshold and voltage-gated $Na^+$ channels open rapidly. This results in fast inward movement of $Na^+$ ion which causes the depolarizing phase of the action potential. The inflow of $Na^+$ ions changes the membrane potential from -55 mV to +30 mV. At the peak of the action potential, the inside of the membrane is 30 mV more positive than the outside.
- **Repolarization phase:** When $Na^+$ ions move inside, the permeability of plasma membrane changes again. It becomes permeable to $K^+$ ions and impermeable to $Na^+$ ions. Thus $K^+$ ions diffuses out rapidly and cell regains its electrical conditions to resting state or polarized state (-70 mV). This process is called **Repolarization** and neuron is called to be in **Repolarized state.** After repolarization, the inside and outside concentration of $K^+$ and $Na^+$ ions is restored by activation of $Na^+$/ $K^+$ ATPase pumps. These pumps use ATP to pump excess $Na^+$ ions out of neuron and $K^+$ ions inside the neuron. A neuron cannot conduct another impulse until repolarized to its resting potential.

- Once begun, these sequential events spread along the entire neuronal membrane *i.e.* opening of one $Na^+$ ion channel assists opening of adjacent $Na^+$ ion channels in membrane.
- **Refractory Period:** It is the time period after an action potential during which a neuron cannot produce another action potential in response to a normal threshold potential. So in other words, it is the time gap between production of two nerve impulses.

**Conduction/ Propagation of nerve impulse occur as follow:**

To communicate information from one part of the body to another, action potentials in a neuron must travel from trigger zone of the axon to the axon terminals. This mode of conduction is called **propagation**. There are two types of propagation: continuous conduction and saltatory conduction.

- **Continuous conduction** involves step by step depolarization and repolarization of each adjacent segment of the plasma membrane. In continuous conduction, ions flow through their channels in each adjacent segment of the membrane. Continuous conduction occurs in unmyelinated axons and in muscle fibers.




- **Saltatory conduction:** It is special mode of action potential propagation that occurs along myelinated axons. It occurs because of the presence of ion channels only at nodes of ranvier. The action potential moves from node to node and hence it travels much faster than it would in an unmyelinated axon of the same diameter. Opening a smaller number of channels only at the nodes, rather than many channels in each adjacent segment of membrane makes it a more energy-efficient mode of conduction.

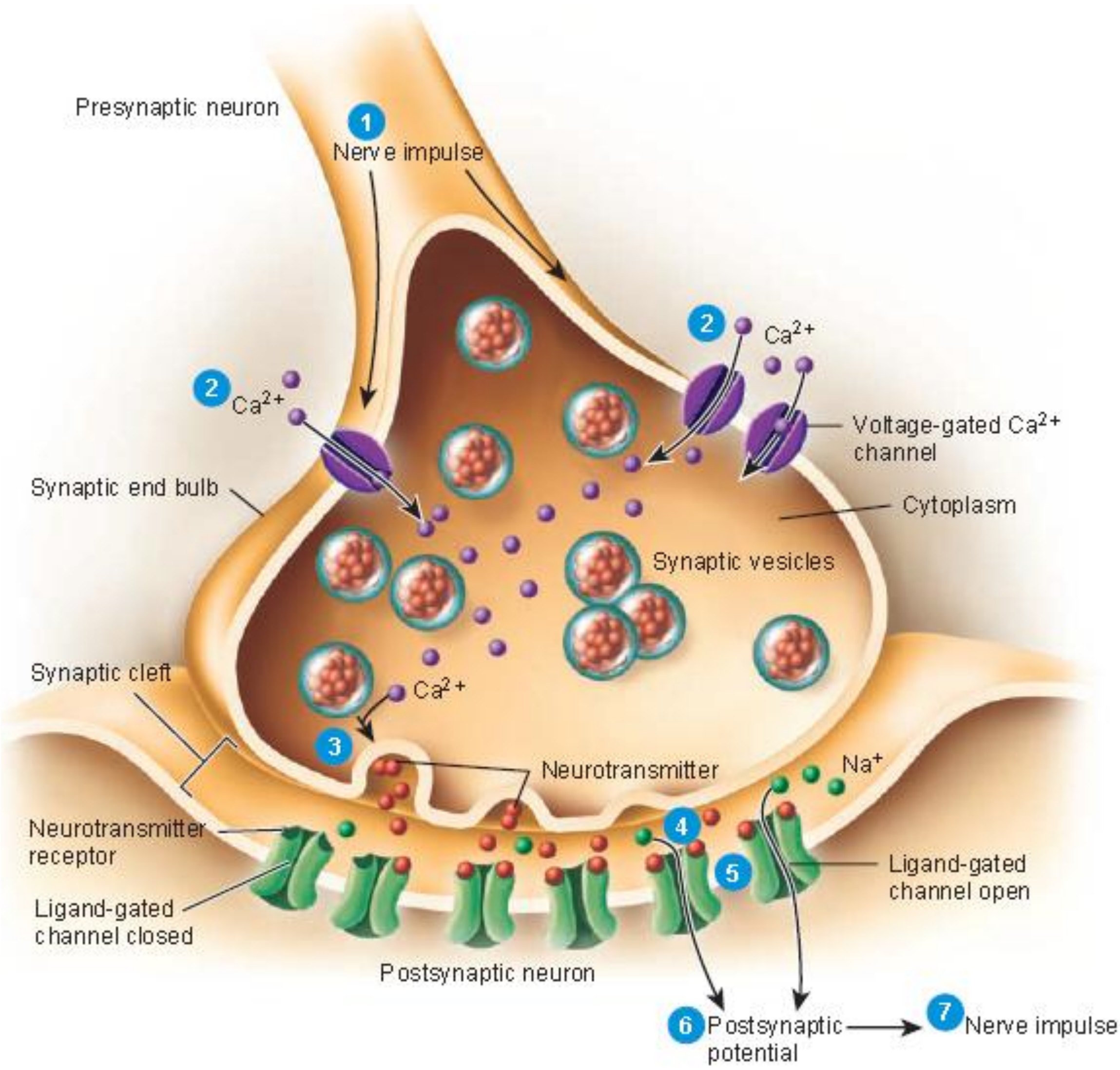
## Signal transmission at synapse/ Neuromuscular junction (NMJ)/ Neurohumoral junction:

**Synapse** is a region where communication occurs between two neurons, or between a neuron and a target cell. **Neuromuscular transmission** is transmission of nerve impulse at neuromuscular junction i.e. from neuron to muscles. **Neurohumoral transmission** is the transmission of a nervous impulse at neurohumoral junction i.e. from neuron to neuron or from neuron to effector organ. At synapses a small gap separates the two cells and that gap is called the **synaptic cleft**. At a synapse between neurons, the neuron sending the signal is called the **presynaptic neuron** and the neuron receiving the message is called the **postsynaptic neuron**. Most synapses are either axodendritic (from axon to dendrite), axosomatic (from axon to cell body), or axoaxonic (from axon to axon). There are two types of synapses; **electrical** and **chemical**.

**A) Electrical Synapses:** In an electrical synapse nerve impulse passes directly from one cell to another cell through gap junctions. Gap junction act like tunnels to connect the cytosol of the two cells directly. As ions flow from one cell to the next through the gap junction, the action potential spreads from cell to cell. Gap junctions are common in visceral smooth muscle, cardiac muscle, and the developing embryo. They also occur in the CNS. Electrical synapses have two main advantages:

- **Faster communication:** Because action potentials conduct directly through gap junctions, electrical synapses are faster than chemical synapses.
- **Synchronization:** Electrical synapses can synchronize (coordinate) the activity of a group of neurons or muscle fibers. In other words, a large number of neurons or muscle fibers can produce action potentials at same time if they are connected by gap junctions. E.g. in heart or smooth muscles.

**B) Chemical Synapse:** Although the plasma membranes of presynaptic and postsynaptic neurons in a chemical synapse are close, they do not touch. They are separated by the synaptic cleft, a space of 20–50 nm that is filled with interstitial fluid. Because the cells do not physically touch each other at synapse, the first cell communicates with the second by releasing a chemical called a neurotransmitter. At the end of the motor neuron (called the axon terminal), it divides into a cluster of synaptic end bulbs. Within each synaptic end bulb, there are hundreds of membrane-enclosed sacs called **synaptic vesicles**. Inside each synaptic vesicle are thousands of molecules of the neurotransmitter. In response to a nerve impulse, the presynaptic neuron releases a neurotransmitter that diffuses through the fluid in the synaptic cleft and binds to receptors in the plasma membrane of the postsynaptic neuron. The postsynaptic neuron receives the chemical signal and in turn produces a postsynaptic potential. Thus, the presynaptic neuron converts an electrical signal (nerve impulse) into a chemical signal (released neurotransmitter). The postsynaptic neuron receives the chemical signal and in turn generates an electrical signal (postsynaptic potential). The time required (0.5 msec) for these processes at a chemical synapse are the reason that chemical synapses relay signals more slowly than electrical synapses.



A typical chemical synapse transmits a signal as follows:

- A nerve impulse arrives at a synaptic end bulb of a presynaptic axon.
- The depolarizing phase of the nerve impulse opens voltage gated $Ca^{2+}$ channels, which are present in the membrane of synaptic end bulbs. Due to which $Ca^{2+}$ flows inward through the opened channels.
- An increase in the concentration of $Ca^{2+}$ inside the presynaptic neuron serves as a signal that triggers exocytosis of the synaptic vesicles. As vesicle membranes merge with the plasma membrane and release neurotransmitter molecules within the vesicles into the synaptic cleft.
- The neurotransmitter molecules diffuse across the synaptic cleft and bind to neurotransmitter receptors in the postsynaptic neuron's plasma membrane. Binding of neurotransmitter molecules to their receptors opens the channels and allows particular ions to flow across the membrane.
- As ions flow through the opened channels, the voltage across the membrane changes. This change in membrane voltage is a postsynaptic potential. Depending on which ions the channels admit, the postsynaptic potential may be a depolarization or a hyperpolarization.
- When a depolarizing postsynaptic potential reaches threshold, it triggers an action potential in the axon of the postsynaptic neuron.

**Excitatory and Inhibitory Postsynaptic Potentials:** A neurotransmitter causes either an excitatory or an inhibitory graded potential.

A neurotransmitter that depolarizes the postsynaptic membrane is excitatory because it brings the membrane closer to threshold. For example, opening of $Na^+$ channels allows inflow of $Na^+$, which causes depolarization. A depolarizing postsynaptic potential is called an excitatory postsynaptic potential (EPSP).

A neurotransmitter that causes hyperpolarization of the postsynaptic membrane is inhibitory. Opening of $Cl^-$ or $K^+$ channels causes hyperpolarization. Opening $Cl^-$ channels permits $Cl^-$ to move into the cell, while opening the $K^+$ channels allows $K^+$ to move out. In both events, the inside of the cell becomes more negative. During hyperpolarization, generation of an action potential is more difficult than usual because the membrane potential becomes inside more negative and thus even farther from threshold than in its resting state. A hyperpolarizing postsynaptic potential is termed an inhibitory postsynaptic potential (IPSP).

## Neurotransmitters:

These are the chemicals which are released from synaptic vesicles and bind to receptors on postsynaptic neurons. Some of them bind to receptor and open the ion channels in the membrane. Some act via secondary messenger system to influence enzymatic reactions inside cell. These can be divided into two classes:

**a) Small molecule neurotransmitter:**

- **Acetylcholine:** It is released by many neurons in PNS and some neurons in CNS. It can act as either excitatory (in NMJ) or inhibitory neurotransmitter (slows HR).
- **Amino Acids:** glutamate and aspartate are having excitatory effect and present in half of the synapse of brain. GABA (gama aminobutyric acid) and glycine are inhibitory neurotransmitters.
- **Biogenic Amines:** These are modified and decarboxylated amino acids. Depending upon receptors, they can cause excitation or inhibition. E.g. Dopamine is involved in emotional response and regulation of skeletal muscle tone. Nor epinephrine and epinephrine help in dreaming and mood control. Serotonin help in sensory perception, temperature regulation, mood control and sleep induction.
- Others include ATP and Nitrix oxide.

**b) Neuropeptide:** Neurotransmitters consisting of 3-40 amino acid linked by peptide bond are called neuropeptides. These are present in both CNS and PNS and have both inhibitory and excitatory action.

- **Enkephalins:** They have potent analgesic effect.
- **Endorphins and Dynorphins:** These also have analgesic activity along with activities like improved memory, euphoria, control of body temperature, regulation of hormones etc.
- **Substance P:** It transmits pain related impulses to CNS.