

# Nervous System

---

*"Neurons are indeed lotic  
Impulse carryover has inborn tactic  
Action potential at synapse is just magic  
To comprehend entire cognition is too hectic"*

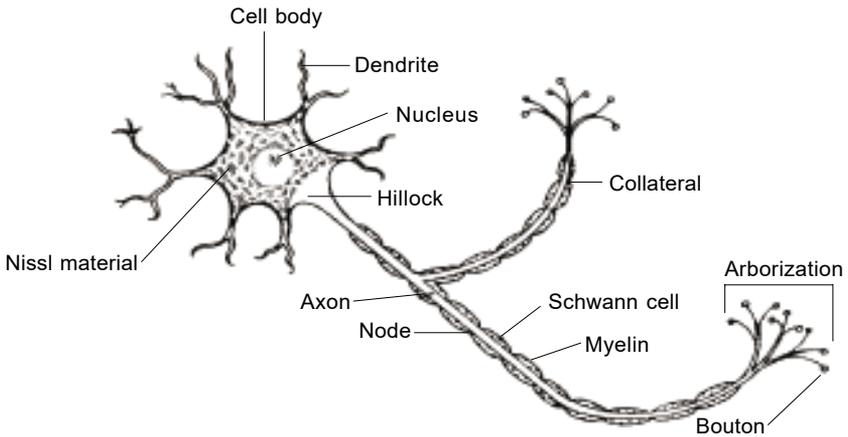
## 2.1 INTRODUCTION

The **nervous system** is a highly specialized network whose principal components are nerves called **neurons**. Neurons are interconnected to each other in complex arrangements, and have the property of conducting, using electrochemical signals, a great variety of stimuli both within the nervous tissue as well as from and towards most of the other tissues. Thus, neurons coordinate multiple functions in organisms. Nervous systems are found in many multicellular animals but differ greatly in complexity between the species.

The *neuron* (nerve cell) is the conducting unit of the nervous system. It is specialized to be irritable and transmit signals, or impulses. The neurons are held together and supported by another nervous tissue known as *neuroglia*, or simply *glia*.

### Parts of Nervous System

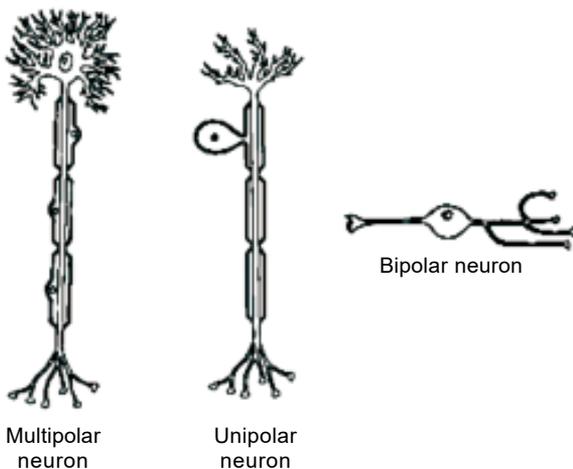
1. The central nervous system (CNS) consisting of brain and spinal cord.
2. The peripheral nervous system (PNS) consisting of all the nerves outside the brain and the spinal cord. It comprises of paired cranial and sacral nerves. The functional parts are the sensory division and the motor division.



**Fig. 2.2: Structure of neuron.**

### 2.3 MORPHOLOGICAL TYPES OF NEURONS

1. **Unipolar Neurons:** The neurons which have only one pole are called the unipolar neurons. From a single pole, both the processes, axon and dendrite arise. This type of nerve cell is present only in embryonic stage in human beings.
2. **Bipolar Neurons:** The neurons with two poles are known as bipolar neurons. Among the two poles, axon arises from one pole and dendrites arise from other pole.
3. **Multipolar Neurons:** These are neurons which have many poles. One of the poles give rise to the axon and all other poles give rise to dendrites.



**Fig. 2.3: Different types of neurons.**

## 2.4 PHYSIOLOGICAL TYPES OF NEURONS

1. **Sensory Neurons:** These are also called afferent nerve cells. These neurons carry the sensory impulses from periphery to the central nervous system. The sensory neurons have a short axon and long dendrites.
2. **Motor Neurons:** These are also known as efferent nerve cells. These neurons carry the motor impulses from central nervous system to the peripheral effector organs like muscles, glands, blood vessels etc. The motor neurons have long axon and short dendrites.

## 2.5 NERVOUS TISSUE

The **human nervous system** consists of billions of nerve cells (or neurons) plus supporting (neuroglial) cells. Neurons are able to respond to stimuli (such as touch, sound, light, and so on), conduct impulses, and communicate with each other (and with other types of cells like muscle cells).

### Properties of nervous tissue

1. **Irritability:** Ability to transmit the impulses from outside. Monitoring of CO<sub>2</sub> concentration and inturn stimulates for reception of oxygen.
2. **Conductivity:** The action potential is transmitted through the nerve fiber as nerve impulse normally, in the body the action potential is transmitted through the nerve fiber in only one direction. However, experimentally the action potential travels through the nerve fiber in either direction.

### Type of Neurons

There are three major classes of neurons: Sensory neurons, internurons and motor neurons.

#### **Sensory neurons**

**Sensory neurones** (*neurons*) are unipolar neuron nerve cells within the nervous system responsible for converting external stimuli from the organism's environment into internal electrical motor reflex loops and several forms of involuntary behavior, including pain avoidance. In humans, such reflex circuits are commonly located in the spinal cord.

In complex organisms, sensory neurons relay their information to the central nervous system or in less complex organisms, such as the hydra, directly to motor neurons. Sensory neurons also transmit information to the brain, where it can be further processed and acted upon. For example, olfactory sensory neurons make synapses with neurons of the olfactory bulb, where the sense of olfaction (smell) is processed.

The term “interneuron” hides a great diversity of structural and functional types of cells. In fact, it is not yet possible to say how many different kinds of interneurons are present in the human brain. Certainly hundreds; perhaps many more.

### **Motor neurons**

These transmit impulses from the central nervous system to the muscles and glands that carry out the response.

Most motor neurons are stimulated by interneurons, although some are stimulated directly by sensory neurons.

### **Function**

At the interface between a motor neuron and muscle fiber is a specialized synapse called the neuromuscular junction. Upon adequate stimulation, the motor neuron releases a flood of neurotransmitters that bind to postsynaptic receptors and trigger a response in the muscle fiber.

- In invertebrates, depending on the neurotransmitter released and the type of receptor it binds, the response in the muscle fiber could be either excitatory or inhibitory.
- For vertebrates, however, the response of a muscle fiber to a neurotransmitter can only be excitatory, in other words, contractile. Muscle relaxation and inhibition of muscle contraction in vertebrates is obtained only by inhibition of the motor neuron itself. Although muscle innervation may eventually play a role in the maturation of motor activity. This is why muscle relaxants work by acting on the motoneurons that innervate muscles (by decreasing their electrophysiological activity) or on cholinergic neuromuscular junctions, rather than on the muscles themselves.

### **Somatic motor neurons**

Somatic motor neurons are further subdivided into two types: *alpha efferent neurons* and *gamma efferent neurons*. (Both types are called *efferent* to indicate the flow of information from the central nervous system (CNS) to the periphery.)

- *Alpha motor neurons* innervate extrafusal muscle fibers (typically referred to simply as *muscle fibers*) located throughout the muscle. Their cell bodies are in the ventral horn of the spinal cord and they are sometimes called **ventral horn cells**.
- *Gamma motor neurons* innervate intrafusal muscle fibers found within the muscle spindle.

In addition to voluntary skeletal muscle contraction, alpha motor neurons also contribute to muscle tone, the continuous force generated by noncontracting muscle to oppose

## Factors Contributing Membrane Potential

Two ions are responsible for contributing membrane potential: sodium ( $\text{Na}^+$ ) and potassium ( $\text{K}^+$ ). An unequal distribution of these two ions occurs on the two sides of a nerve cell membrane because carriers actively transport these two ions: sodium from the inside to the outside and potassium from the outside to the inside. As a result of this active transport mechanism (commonly referred to as the sodium-potassium pump), there is a higher concentration of sodium on the outside than the inside and a higher concentration of potassium on the inside than the outside.

The nerve cell membrane also contains special passageways for these two ions that are commonly referred to as gates or channels. Thus, there are sodium gates and potassium gates. These gates represent the only way that these ions can pass through the nerve cell membrane. In a resting nerve cell membrane, all the sodium gates are closed and some of the potassium gates are open. As a result, sodium cannot diffuse through the membrane and largely remains outside the membrane. However, some potassium ions are able to diffuse out.

Overall, therefore, there are lots of positively charged potassium ions just inside the membrane and lots of positively charged sodium ions plus some potassium ions on the outside. This means that there are more positive charges on the outside than on the inside. In other words, there is an unequal distribution of ions or a resting membrane potential. This potential will be maintained until the membrane is disturbed or stimulated. Then, if it is a sufficiently strong stimulus, an action potential will occur.

## Action Potential

An action potential is a very rapid change in membrane potential that occurs when a nerve cell membrane is stimulated. Specifically, the membrane potential goes from the resting potential (typically  $-70$  mV) to some positive value (typically about  $+30$  mV) in a very short period of time (just a few milliseconds).

What causes this change in potential to occur? The stimulus causes the sodium gates (or channels) to open and, because there is more sodium on the outside than the inside of the membrane, sodium then diffuses rapidly into the nerve cell. All these positively-charged sodiums ions rushing in, causes the membrane potential to become positive (the inside of the membrane is now positive relative to the outside). The sodium channels open only briefly, and then close again.

The potassium channels then open, and, because there is more potassium inside the membrane than outside, positively-charged potassium ions diffuse out. As these positive ions go out, the inside of the membrane once again becomes negative with respect to the outside.

## Threshold Stimulus and Potential

- Action potentials occur only when the membrane is stimulated (depolarized) enough so that sodium channels open completely. The minimum stimulus needed to achieve an action potential is called the **threshold stimulus**.
- The threshold stimulus causes the membrane potential to become less negative (because a stimulus, no matter how small, causes a few sodium channels to open and allows some positively-charged sodium ions to diffuse in).
- If the membrane potential reaches the **threshold potential** (generally 5-15 mV less negative than the resting potential), all the voltage-regulated sodium channels open. Sodium ions rapidly diffuse inward, and depolarization occurs.

**All-or-None Law:** Action potentials occur maximally or not at all. In other words, there is no such thing as a partial or weak action potential. Either the threshold potential is reached and an action potential occurs, or it is not reached and no action potential occurs.

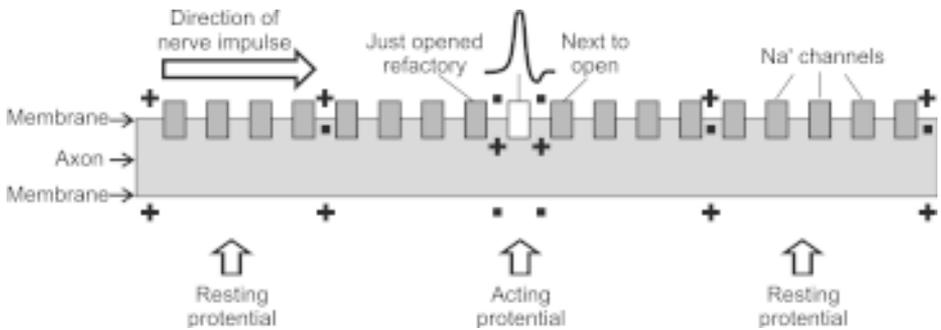


Fig. 2.5: Mode of conduction of nerve impulse.

## 2.7 CENTRAL NERVOUS SYSTEM (CNS)

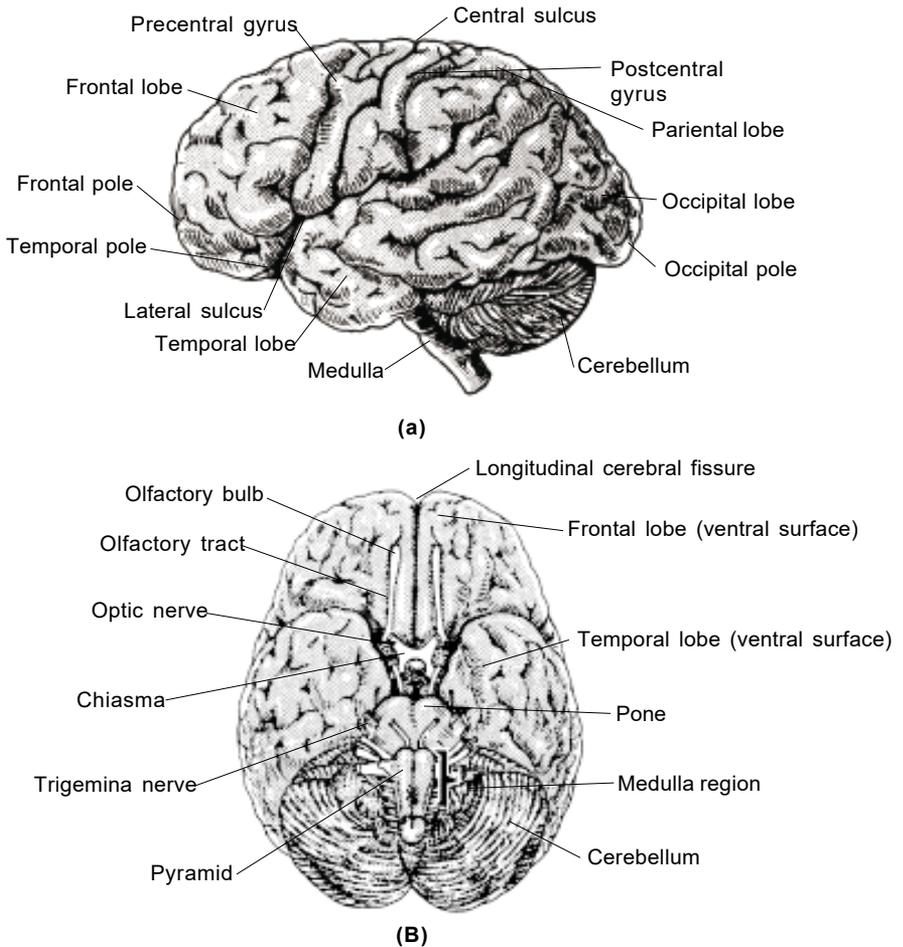
The *central nervous system (CNS)* represents the largest part of the nervous system, including the brain and the spinal cord (Fig.2.6). Together with the peripheral nervous system, it has a fundamental role in the control of behavior. The CNS is contained within the dorsal cavity, with the brain within the cranial cavity, and the spinal cord in the spinal cavity. The CNS is covered by the meninges. The *brain* is protected by the skull, and the spinal cord is also protected by the vertebrae.

**Major Subdivisions:** The fully formed CNS can be considered in two major subdivisions: the **brain** and the **spinal cord**.

**PONS:** They form a bridge between medulla and midbrain. They form a pathway connecting cerebellum with cerebral cortex. The nuclei of 8th, 7th, 6th and 5th cerebral nerves are located in pons. It consists mainly of nerve fibres (white matter) that form the bridge between the two hemispheres of the cerebellum and fibres passing between the higher levels of the brain and spinal cord. Nuclei present within the pons act as relay stations.

**MEDULLA OBLONGATA:** It is the lower most part of the brain situated below pons and continued downward as spinal cord. It forms the main pathway for ascending and descending tracts of the spinal cord. The outer aspect is composed of white matter, which passes between the brain and the spinal cord. And the gray matter lies centrally. It has **respiratory centers** for maintaining normal rhythmic respiration. From here nerve impulses pass to the phrenic and intercostal nerves which stimulate the contraction of diaphragm and intercostal muscles. **Vasomotor centre** is for control of BP and heart rate. Vomiting center induces vomiting during irritation or inflammation of GI tract. Salivatory nuclei control the secretion of saliva which are maintained by **reflux centres**. Vestibular nuclei contain second order neurons of vestibular nerve. It is about 2.5 cm long and it lies just within the cranium above the foramen magnum. **Cardiovascular centre** controls the rate and force of cardiac contraction and blood pressure.

- B. The Cerebellum.** Over the hindbrainstem is the cerebellum. The cerebellum is connected to both the midbrainstem and the hindbrainstem. The cerebellum is the primary coordinating center for muscle actions. Here, patterns of movements are properly integrated. Thus, information is sent to the appropriate muscles in the appropriate sequences. Also, the cerebellum is very much involved in the postural equilibrium of the body.
- C. The Cerebrum.** Attached to the forebrainstem are the two cerebral hemispheres. Together, these two hemispheres make up the cerebrum. Among related species, the cerebrum is the newest development of the brain.
- (1) *Cerebral hemispheres.* The cerebrum consists of two cerebral hemispheres, right and left. They are joined together by a very large fiber tract known as the *corpus callosum* (the *great commissure*).
  - (2) *Lobes:* Each hemisphere can be divided into four lobes. Each lobe is named after the cranial bone it lies beneath—parietal, frontal, occipital, and temporal. (Actually, there are five lobes. The fifth is hidden at the bottom of the lateral fissure. It is known as the *insula* or *insular lobe*. It is devoted mainly to visceral activities.)



**Fig. 2.7: Human brain (a) Side view (b) Bottom view.**

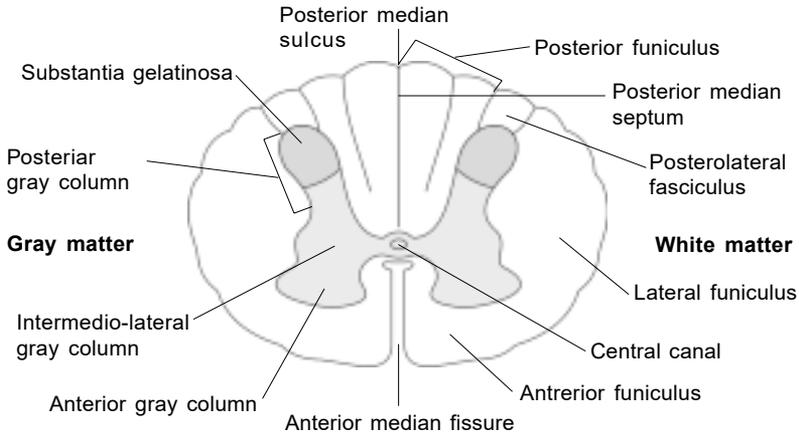
(3) *Gyri and sulci.* The *cerebral cortex*, the thin layer at the surface of each hemisphere, is folded. This helps to increase the amount of area available to neurons. Each fold is called a *gyrus*. Each groove between two gyri is called a *sulcus*.

- (a) The *lateral sulcus* is a cleft separating the frontal and parietal lobes from the temporal and occipital lobes. Therefore, the lateral sulcus runs along the lateral surface of each hemisphere.
- (b) The *central sulcus* is a cleft separating the frontal from the parietal lobe. Roughly, each central sulcus runs from the left or right side of the cerebrum to top center and over into the medial side of the cerebrum.

- (c) There are two gyri that run parallel to the central sulcus. Anterior to the central sulcus is the *precentral gyrus*. Posterior to the central sulcus is the *postcentral gyrus*.

## The Human Spinal Cord

Extending inferiorly from the brain is the spinal cord (Fig. 2.8).



**Fig. 2.8: Cross section of spinal cord.**

### ***A cross section of the spinal cord***

- a. The spinal cord is continuous with the brainstem. Together, the spinal cord and the brainstem are called the *neuraxis*. The *foramen magnum* is taken as the point that divides the brainstem from the spinal cord. Thus, the brainstem is within the cranial cavity of the skull, and the spinal cord is within the vertebral (spinal) canal of the vertebral column.
- b. The spinal cord has a central portion known as the *gray matter*. The gray matter is surrounded by the *white matter*:
  - (1) The *gray matter* is made up of the cell bodies of many different kinds of neurons.
  - (2) The *white matter* is made up of the processes of neurons. The white color is due to their myelin sheaths. These processes serve several purposes: Many make a variety of connections within the spinal cord. Many ascend the neuraxis to carry information to the brain. Many descend the neuraxis to carry commands from the brain.

*The spinal cord has two functions:*

- **Transmission of nerve impulses.** Neurons in the white matter of the spinal cord transmit sensory signals from peripheral regions to the brain and motor signals from the brain to peripheral regions.
- **Spinal reflexes.** Neurons in the gray matter of the spinal cord integrate incoming sensory information and respond with motor impulses that control muscles (skeletal, smooth, or cardiac) or glands.

## **2.8 PERIPHERAL NERVOUS SYSTEM (PNS)**

The **peripheral nervous system (PNS)** has two components: the somatic nervous system and the autonomic nervous system. The PNS consists of all of the nerves that lie outside the brain and spinal cord. **Nerves** are bundles of neuron fibers (axons) that are grouped together to carry information to and from the same structure.

- The **somatic nervous system** is made up of nerves that connect to voluntary skeletal muscles and sensory receptors. It is composed of **afferent** nerves that carry information to the central nervous system (spinal cord) and **efferent** fibers that carry neural impulses away from the central nervous system.
- The **autonomic nervous system** also consists of two components: the sympathetic division and the parasympathetic division. This system mediates much of the physiological arousal (such as rapid heart beat, tremor, or sweat) experienced by a fearful person in an emergency situation.
  - The **sympathetic nervous system** mobilizes the body to respond to emergencies.
  - The **parasympathetic nervous system** generally helps to conserve the body's energy. It controls normal operations of the body such as digestion, blood pressure, and heart rate. It helps the body return to normal activity after an emergency.

PNS connecting the CNS to all parts of the body are individual organs known as nerves. A *nerve* is a collection of neuron processes together and outside of the CNS. *Peripheral nerves* are nerves which pass from the CNS to the periphery of the body. Together, they are referred to as the *peripheral nervous system*.

a. These nerves are bilateral and segmental.

- (1) *Bilateral*. This means that the peripheral nerves occur in pairs. In each pair, there is one nerve to the right and one to the left.

TABLE. 2.1 Characteristics of cranial nerves.

Cranial Nerve	Nerve Type	Major Functions
I. Olfactory	sensory	smell
II. Optic	sensory	vision
III. Oculomotor	primarily motor	eyeball and eyelid movement; lens shape
IV. Trochlear	primarily motor	eyeball movement; proprioception
V. Trigeminal: ophthalmic branch	sensory	sensations of touch and pain from facial skin, nose, mouth, teeth, and tongue; proprioception motor control of chewing
VI. Trigeminal: maxillary branch	sensory	sensations of touch and pain from facial skin, nose, mouth, teeth, and tongue; proprioception motor control of chewing
VII. Trigeminal: mandibular branch	mixed	sensations of touch & pain from facial skin, nose, mouth, teeth, & tongue; proprioception motor control of chewing
VIII. Abducen	sprimarily motor	eyeball movement; proprioception
IX. Facial	mixed	movement of facial muscles; tear and saliva secretion; sense of taste and proprioception
X. Vestibulo-cochlear: vestibular branch	sensory	hearing
XI. Vestibulo cochlear vestibular branch	sensory	sense of equilibrium
XII. Glossopharyngeal	mixed	sensations of taste, touch and pain from tongue and pharynx; chemoreceptors (that monitor O <sub>2</sub> and CO <sub>2</sub> ), blood pressure receptors; movement of tongue and swallowing; secretion of saliva
XIII. Vagus	mixed	parasympathetic sensation and motor control of smooth muscles associated with heart, lungs, viscera; secretion of digestive enzymes
XIV. Accessory	primarily motor	head movement; swallowing; proprioception
XV. Hypoglossal	primarily motor	tongue movement, speech and swallowing; proprioception

stimulate skeletal muscles. In contrast, the ANS consists of motor neurons that control smooth muscles, cardiac muscles and glands. In addition, the ANS monitors visceral organs and blood vessels with sensory neurons, which provide input information for the CNS. The ANS is further divided into the **sympathetic nervous system** and the

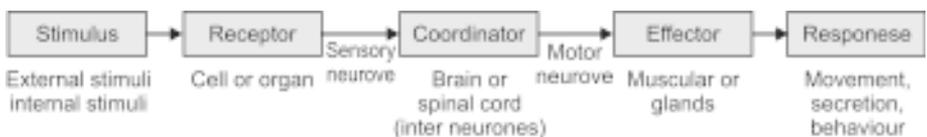
- Terminal (intramural) ganglia receive parasympathetic fibers. These ganglia occur near or within the target organ of the respective postganglionic fiber.

**A comparison of the sympathetic and parasympathetic pathways is as follows:**

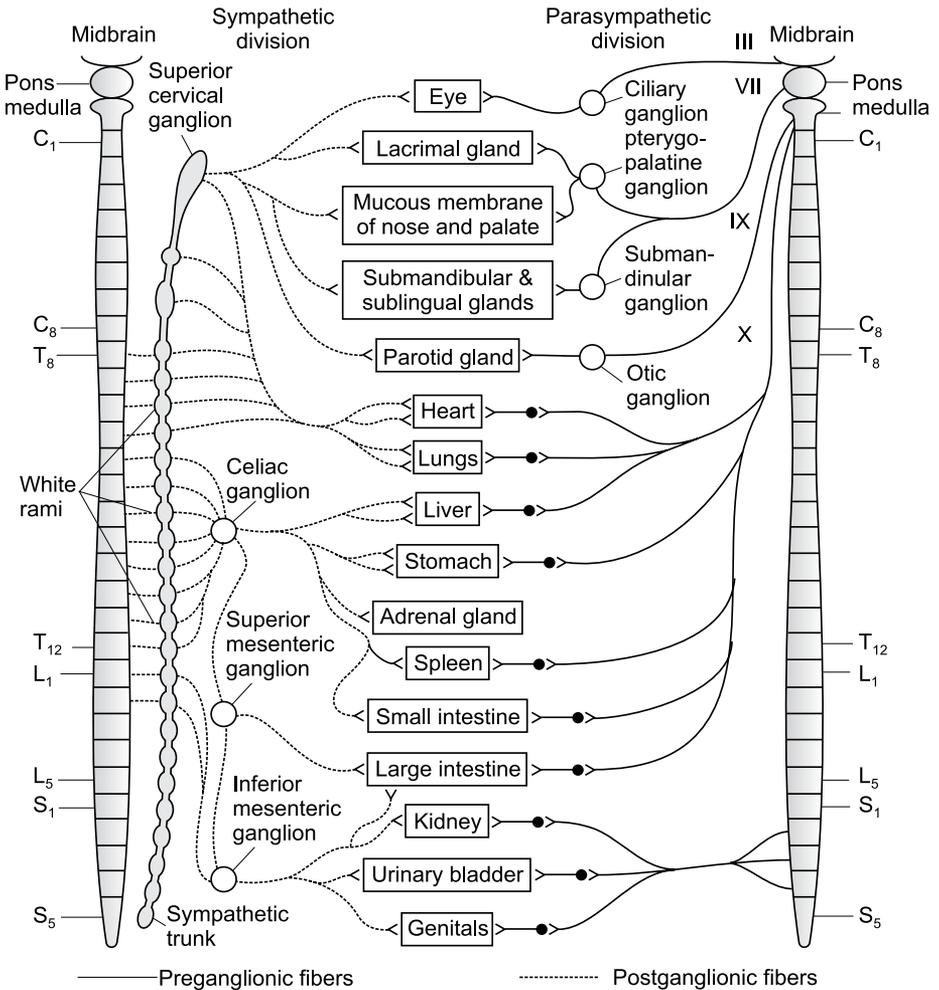
**Sympathetic Nervous System.** Cell bodies of the preganglionic neurons occur in the lateral horns of gray matter of the 12 thoracic and first 2 lumbar segments of the spinal cord. (For this reason, the sympathetic system is also called the **thoracolumbar division**.) Preganglionic fibers leave the spinal cord within spinal nerves through the ventral roots (together with the PNS motor neurons). The preganglionic fibers then branch away from the nerve through white rami (white rami communicantes) that connect with the sympathetic trunk. White rami are white because they contain myelinated fibers. A preganglionic fiber that enters the trunk may synapse in the first ganglion it enters, travel up or down the trunk to synapse with another ganglion, or pass through the trunk and synapse outside the trunk. Postganglionic fibers that originate in ganglia within the sympathetic trunk leave the trunk through gray rami (gray rami communicantes) and return to the spinal nerve, which is followed until it reaches its target organ. Gray rami are gray because they contain unmyelinated fibers.

- Parasympathetic Nervous System:** Cell bodies of the preganglionic neurons occur in the gray matter of sacral segments  $S_2$ - $S_4$  and in the brain stem (with motor neurons of their associated cranial nerves III, VII, IX, and X). (For this reason, the parasympathetic system is also called the **craniosacral division**, and the fibers arising from this division are called the cranial outflow or the sacral outflow, depending upon their origin.) Preganglionic fibers of the cranial outflow accompany the PNS motor neurons of cranial nerves and have terminal ganglia that lie near the target organ. Preganglionic fibers of the sacral outflow accompany the PNS motor neurons of spinal nerves. These nerves emerge through the ventral roots of the spinal cord and have terminal ganglia that lie near the target organ.

Reflex arc can also be represented by a simple flow diagram (Fig.2.9).



**Fig. 2.9: Simple flow diagram of reflex arc.**



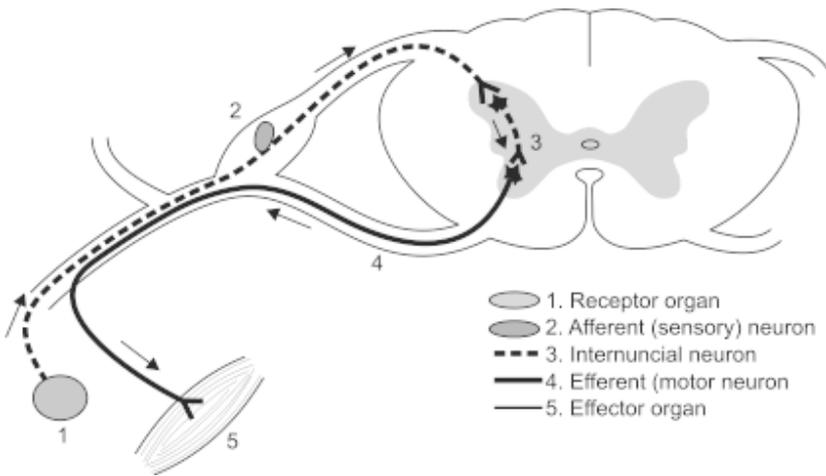
**Fig. 2.10: A comparison of the sympathetic and parasympathetic pathways.**

## 2.10 THE GENERAL REFLEX

The simplest reaction of the human nervous system is the reflex. A reflex is defined as an automatic reaction to a stimulus.

The pathway followed by the stimulus (impulse) from beginning to end is the *reflex arc*. The general reflex arc of the human nervous system has a minimum of five components (Fig. 2.11).

- The stimulus is received by a *receptor organ* specific to that stimulus.



**Fig. 2.11: Components of Reflex arc.**

- b. From the receptor organ, the stimulus is carried to the CNS by way of an *afferent* (sensory) *neuron* within the appropriate peripheral nerve. The cell body of this afferent neuron is located in the posterior root ganglion of a spinal nerve or the individual ganglion of a cranial nerve.
- c. Within the spinal cord or brainstem, the terminal of the afferent neuron synapses with the interneuron, or *internuncial neuron*.

INTER = between

NUNCIA = messenger

In turn, the internuncial neuron synapses with the cell body of the efferent (motor) neuron.

- d. In the spinal cord, the cell bodies of the *efferent* (motor) *neurons* make up the anterior column of the gray matter. In the brainstem, the motor neurons make up the individual nuclei of the cranial nerves. The axon of the motor neuron passes out of the CNS by way of the appropriate peripheral nerve. Command information is thus carried away from the CNS.
- e. The information is then delivered by the motor neuron to the *effector organ*. *Somatic* motor neurons lead to striated muscle fibers, particularly in skeletal muscles. *Autonomic* (visceral) motor neurons lead to smooth muscle tissue, cardiac muscle tissue, or glands.

## 2.11 SPECIAL SENSE

There is no firm agreement among neurologists as to the number of senses because of differing definitions of what constitutes a sense. One definition states that an **exteroceptive sense is a faculty by which outside stimuli are perceived**. The conventional **five senses** are sight, hearing, touch, smell, taste: a classification traditionally attributed to Aristotle. However, humans have at least nine different senses (including interoceptive senses), like thermoception (heat, cold), nociception (pain), equilibrioception (balance, gravity), proprioception and kinesthesia (joint motion and acceleration) and sense of time. There are at least two other senses in other organisms (amongst them are electroreception, echolocation, magnetoception, pressure detection, polarized light detection).

A broadly acceptable definition of a sense would be “a system that consists of a group sensory cell types that responds to a specific physical phenomenon, and corresponds to a particular group of regions within the brain where the signals are received and interpreted.” Disputes about the number of senses arise typically regarding the classification of the various cell types and their mapping to regions of the brain.

### Taste (Tongue)

The sense of taste, or **gustatory sense**, occurs in the taste buds. Located primarily on the tongue, taste buds reside in papillae, the bumps on the tongue that give it a rough texture. The taste bud consists of supporting cells, basal cells, and gustatory (taste) receptor cells arranged in the shape of a glove with an opening, or taste pore, to the outside located at the top. A long microvilli, or gustatory hair, from each gustatory receptor cell within the taste bud projects through the taste pore. Gustatory hairs generate action potentials when stimulated by chemicals that are dissolved in the saliva. Basal cells are actively dividing epithelial cells. The daughter cells of basal cells develop into supporting cells, which subsequently mature into gustatory receptor cells. Since they are easily damaged by the activities that occur in the mouth, gustatory receptor cells are short-lived and replaced about every ten days.

An individual gustatory receptor cell responds to only four taste sensations: sweet, bitter, sour, and salty. All other tastes arise from a mixture of these four tastes in combination with olfactory sensations associated with the substance tasted. Taste buds on certain areas of the tongue seem to specialize for certain tastes. For example, the sensation of sweetness is best detected at the front of the tongue, while bitterness is best detected at the back of the tongue.

### Smell

The sense of smell, or **olfactory sense**, occurs in olfactory epithelium that occupies a small area in the roof of the nasal cavity. The olfactory receptor cells are bipolar

neurons whose dendrites have terminal knobs with hairlike cilia protruding beyond the epithelial surface. The cilia, or olfactory hairs, initiate an action potential when they react with a molecule from an inhaled vapor. However, molecules of the vapor must first dissolve in the mucus that covers the cilia before they can be detected. The action potential is transmitted along the axons of the olfactory receptor cells (which form the olfactory nerves) to the olfactory bulbs, where they synapse with sensory neurons of the olfactory tract. Other cells of the olfactory epithelium include columnar supporting cells and basal cells. The basal cells continually divide to produce new **olfactory receptor cells** that, because of their short life, need regular replacement. The replacement of olfactory receptor cells is unusual because most other nerve cells cannot be replaced.

## Sight (Eye)

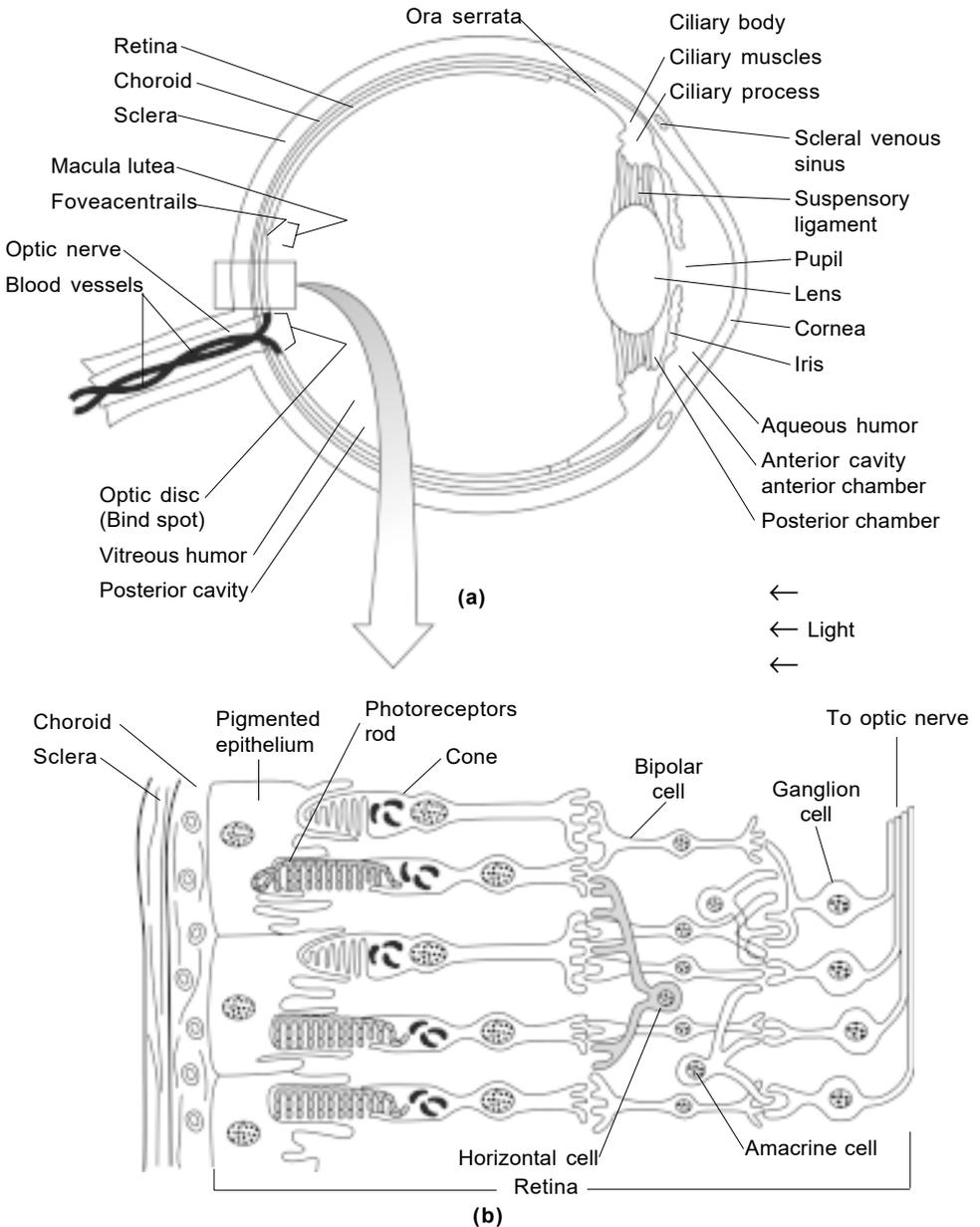
The eye is supported by the following accessory organs:

The eyebrows shade the eyes and help keep away the perspiration that accumulated on the forehead from running into the eyes.

The eyelids (palpebrae) lubricate, protect, and shade the eyeballs. Contraction of the levator palpebrae superioris muscle raises the upper eyelid. Each eyelid is supported internally by a layer of connective tissue, the tarsal plate. Tarsal (Meibomian) glands embedded in the tarsal plate produce secretions that prevent the upper and lower eyelids from sticking together. The inner lining of the eyelid, the conjunctiva, is a mucous membrane, which produces secretions that lubricate the eyeball. The conjunctiva continues beyond the eyelid, folding back to cover the white of the eye.

The eyeball is a hollow sphere whose wall consists of three tunics (layers), shown in Fig. 2.12. The outer fibrous tunic consists of avascular connective tissue. The forward 1/6 portion of this tunic is the cornea, a transparent layer of collagen fibers that forms a window for entering light. The remainder of the fibrous tunic is the sclera. Consisting of tough connective tissue, the sclera maintains the shape of the eyeball and provides for the attachment of the eye muscles. The visible forward portion of the sclera is the white of the eye.

- The **iris** is the colored portion of the eye that opens and closes to control the size of its circular opening, the **pupil**. The size of the pupil regulates the amount of light entering the eye and helps bring objects into focus.
- The ciliary body lies between the iris and the choroids (the remainder of the vascular tunic). The ciliary processes that extend from the ciliary body secrete aqueous humor, the fluid that fills the forward chamber of the eye. The



**Fig. 2.12: Details of the (a) eye (b) retina.**

differences in densities among the aqueous humor, the lens, and the vitreous humor.

- *Lens accommodation.* Light rays from near objects enter the eyeball at more divergent angles than rays from distant objects. Thus, when near objects are

**Pitch is Determined by the Frequency of Vibration:** We perceive fast vibrations as high pitches and slow vibrations as low pitches. When we are young we can hear vibrations from about 20 hertz to about 20,000 hertz.

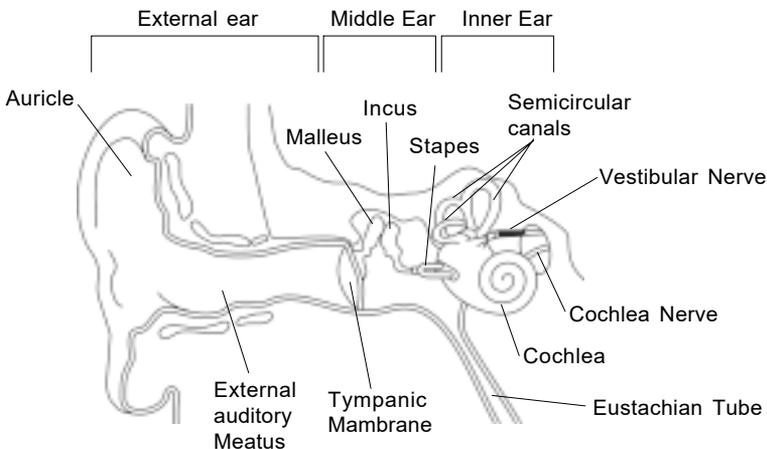
**Sound Intensities Are Measured in Decibels:** The stronger the vibration (the higher the sound pressure) the louder the noise. The scale used for sound intensity is logarithmic because of the very wide range of sound intensities that we encounter. The ear is sensitive to sound. Intensities over a range of a million to one sound intensities are given in decibels (dB). The human ear can respond to a range of sound intensities of about a million to one. For an instance the number of decibels is:

- Decibels =  $20 \times \log (1,000,000/1) = 120$
- Sounds louder than this will be painful and will damage the ear
- A few examples of sound intensities:
  - Threshold of hearing (4000 herz) = 0 dB
  - Soft whisper = 20 dB
  - Conversation = 60 dB
  - Busy traffic = 70 dB
  - Rock band = 120 dB
  - Pain threshold = 130 dB

## Basic Ear Anatomy

The Ear Has 3 Essential Parts (Fig. 2.13)

- mechanism for collecting and amplifying sound



**Fig. 2.13: Structure of ear.**

- a transducer to convert sound vibrations into action potentials
- nerves to deliver the action potential signals to the brain for interpretation

### **The Outer Ear Collects Sound Waves**

- The pinna (auricle) and ear canal funnel the waves inward to the eardrum (tympanic membrane)
- The waves cause the eardrum to vibrate

### **Bones of the Middle Ear (Malleus, Incus, Stapes) Amplify the Sound Waves**

- The eardrum attaches to the malleus (hammer)
- The malleus attaches to the incus (anvil), which in turn attaches to the stapes (stirrup)
- The stapes is attached to the oval window of the cochlea
- Because of the way the bones are attached together, the vibrations in the oval window are 20X larger than those in the eardrum (amplification)
- If the sound is too loud, small muscles attached to the ear bones contract and dampen the vibrations.

### **The Cochlea Converts Sound Vibrations to Action Potentials in the Auditory Nerve**

- Vibration of the oval window causes cochlear fluid (perilymph & endolymph) to vibrate
- The fluid vibrations in turn cause the basilar membrane to vibrate, producing traveling waves
- The basilar membrane vibrations cause hair cells to bend generate potential
- If generator potentials are large enough, they will stimulate fibers of the auditory nerve to produce action potentials
- Different pitches are detected in different parts of the cochlea:
  - High pitches produce traveling waves at the base of the cochlea (near the oval window)
  - Low pitches produce traveling waves at the apex.

### **Balance**

Equilibrium is maintained in response to two kinds of motion: