CHAPTER-21

NEURAL CONTROL AND COORDINATION

Introduction

To maintain homeostasis the functions of the organs or organ systems in our body must be coordinated. Coordination is the process through which two or more organs interact and complement the functions of one another. For example, when we do physical exercises, the energy demand is increased for maintaining an increased muscular activity. The supply of oxygen is also increased. The increased supply of oxygen necessitates an increase in the rate of respiration, heartbeat, and increased blood flow via blood vessels. When physical exercise is stopped, the activities of nerves, lungs, heart, and kidney gradually return to their normal conditions. Thus, the functions of muscles, lungs, heart, blood vessels, kidney, and other organs are coordinated while performing physical exercises.

In our body, two systems are responsible for control and coordination. These organ systems are the neural system and the endocrine system. These systems jointly coordinate and integrate all the activities of the organs so that they function in a synchronized fashion.

The neural system provides an organized network of point-to-point connections for quick coordination. The endocrine system provides chemical integration through hormones.

In this chapter, we will learn about the neural system of humans, mechanisms of neural coordination like transmission of nerve impulse, impulse conduction across a synapse, and the physiology of reflex action.

Neural system

The neural system of animals is composed of highly specialized cells called neurons that can detect, receive, and transmit different kinds of stimuli. The neural system is at first appears in phylum Cnidaria. Since in Porifera nerve cells are altogether absent, so these animals are known as the brainless animal. The first organized brain appeared in phylum Platyhelminthes. The brain in this group of animals is very simple. As we move from this phylum to higher animal phylum the complexity of the brain increases. It is highly complex in human beings. The neural organization is very simple in lower invertebrates. For example, in Hydra, it is composed of a network of neurons. The neural system is better organized in insects, where a brain is present along with several ganglia and neural tissues. The vertebrates have a more developed neural system.

Human neural system

The human nervous system is divided into two parts

(a) Central neural system (CNS) - The CNS includes the brain and the spinal cord and is the site of information processing and control.

(b) Peripheral neural system (PNS) – It includes all the nerves of the body associated with the CNS.

- Nerve fibres of PNS - The nerve fibres of the PNS are of two types :

(i) **Afferent fibres** - The afferent nerve fibres transmit impulses from tissues/organs to CNS.
(ii) **Efferent fibres –** These nerve fibres transmit regulatory impulses from the CNS to the concerned peripheral tissues or organs.

- The PNS may be divided into two divisions called

(i) Somatic neural system - The somatic neural system relays impulses from the CNS to skeletal muscles.
(ii) Autonomic neural system - This neural system transmits impulses from the CNS to the involuntary organs and smooth muscles of the body. The autonomic neural system is further classified into the sympathetic neural system and parasympathetic neural system

Neuron as a structural and functional unit of the neural system

- Nerve tissue has consisted of two types of cells- The neuron and glial cells. The glial cells form the packing material of nerve tissue while the neurons form the structural and functional unit of the neural system.
- A neuron is a microscopic structure composed of three major parts, namely, cell body, dendrites, and axon. The cell body contains cytoplasm with typical cell organelles and certain granular bodies called Nissl's granules.
- Short fibres which branch repeatedly and project out of the cell body also contain Nissl's granules and are called dendrites. These fibres transmit impulses towards the cell body.
- The axon is a long fibre, the distal end of which is branched. Each branch terminates as a bulb-like structure called a synaptic knob which possesses synaptic vesicles containing chemicals called neurotransmitters.

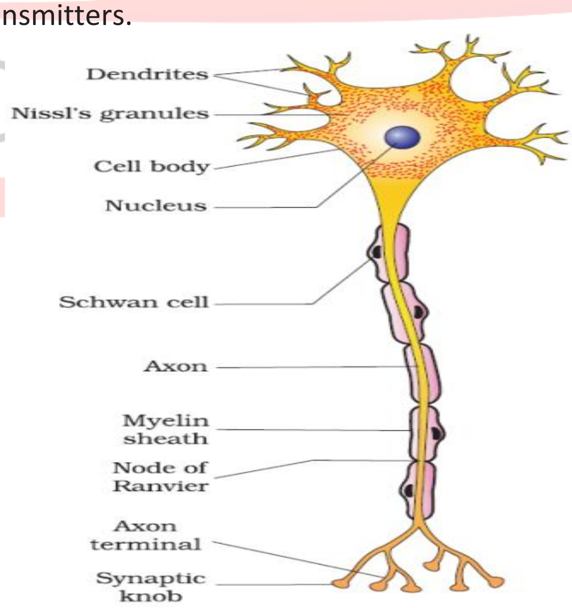

Figure Structure of a neuron

- The axons transmit nerve impulses away from the cell body to a synapse or a neuromuscular junction.

- Types of neurons- Based on the number of axon and dendrites, the neurons are divided into three types

(i) **Multipolar neuron- A neuron** with one axon and two or more dendrites. These are found in the cerebral cortex.

(ii) **Bipolar neuron- A neuron with** one axon and one dendrite. These are found in the retina of the eye.

(iii) **Unipolar neuron- A neuron with** one axon only. It is found usually in the embryonic stage.

- Axon is a long fiber-like structure. The nerve transmission occurs through it. It may or may not be surrounded with myelin sheath accordingly nerve fibers may be of two types

(i) **Myelinated-** The myelinated nerve fibers are enveloped with Schwann cells, which form a myelin sheath around the axon. The gaps between two adjacent myelin sheaths are called nodes of Ranvier. Myelinated nerve fibers are found in spinal and cranial nerves.

(ii) **Non-myelinated**- Non-myelinated nerve fiber is enclosed by a Schwann cell that does not form a myelin sheath around the axon and is commonly found in autonomous and the somatic neural systems.

Generation and conduction of nerve impulse

Neurons are excitable cells because their membranes are in a polarized State. Different types of ion channels are present on the neural membrane. These ion channels are selectively permeable to different ions.

(i) **Resting potential**-When a neuron is not conducting any impulse, i.e., resting, the axonal membrane is comparatively more permeable to potassium ions (K+) and nearly impermeable to sodium ions (Na+). Similarly, the membrane is impermeable to negatively charged proteins present in the axoplasm. Consequently, the axoplasm inside the axon contains a high concentration of K+ and negatively charged proteins and a low concentration of Na+. In contrast, the fluid outside the axon contains a low concentration of K+, a high concentration of Na+, and thus forms a concentration gradient. These ionic gradients across the resting membrane are maintained by the active transport of ions by the sodium-potassium pump which transports 3 Na+ outwards for 2 K+ into the cell. As a result, the outer surface of the axonal membrane possesses a positive charge while its inner surface becomes negatively charged and therefore is polarized. The electrical potential difference across the resting plasma membrane is called the resting potential.

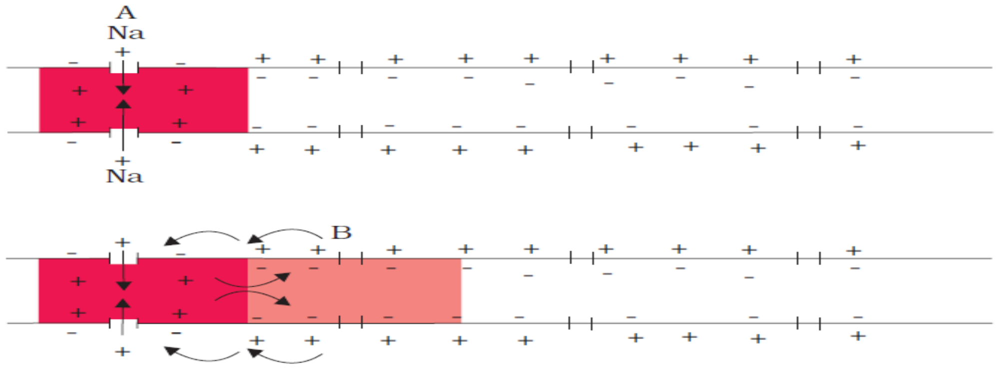

Figure Diagrammatic representation of impulse conduction through an axon (at points A and B)

(ii) Action potential- When a stimulus is applied at a site on the polarized membrane, the membrane at the site A becomes freely permeable to Na+. This leads to a rapid influx of Na+ followed by the reversal of the polarity at that site, i.e., the outer surface of the membrane becomes negatively charged and the inner side becomes positively charged. The polarity of the membrane at the site of the arrival of stimulus is thus reversed and hence depolarized. The electrical potential difference across the plasma membrane at the site A is called the action potential, which is termed as a nerve impulse.
At sites immediately ahead, the axon membrane has a positive charge on the outer surface and a negative charge on its inner surface. As a result, current flows on the inner surface from the site of action potential to site resting potential. On the outer surface, the current flows in just the opposite direction, to complete the circuit of current flow. It results in the generation of an action potential at the site where previously the resting potential was. Thus, the impulse generated at the site arrives at the next site. The sequence is repeated along the length of the axon and consequently, the impulse is conducted in point to point manner. The rise in the stimulus-induced permeability to Na+ is extremely short-lived. It is quickly followed by a rise in permeability to K+. Within a fraction of a second, K+ diffuses outside the membrane and restores the resting potential of the membrane at the site of excitation and the fiber becomes once more responsive to further stimulation.

Transmission of impulse

A nerve impulse is transmitted from one neuron to another through junctions called synapses. A synapse is formed by the membranes of a pre-synaptic neuron and a post-synaptic neuron, which may or may not be separated by a gap called the synaptic cleft.
There are two types of synapses
(i) **Electrical synapses**- At electrical synapses, the membranes of pre- and post-synaptic neurons are in very close proximity. Electrical current can flow directly from one neuron into the other across these synapses. Transmission of an impulse across electrical synapses is very similar to impulse conduction along a single axon. Impulse transmission across an electrical synapse is always faster than that across a chemical synapse. Electrical synapses are rare in our system.

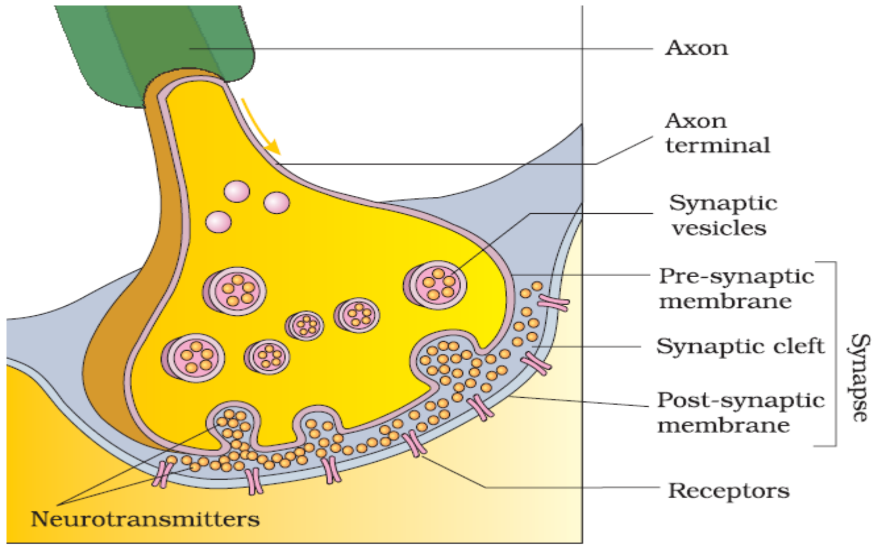

Figure Diagram showing axon terminal and synapse

(ii) **Chemical synapse-**At a chemical synapse, the membranes of the pre- and post-synaptic neurons is separated by a fluid-filled space called synaptic cleft. Chemicals called neurotransmitters are involved in the transmission of impulses at these synapses. The axon terminals contain vesicles filled with these neurotransmitters. When an impulse arrives at the axon terminal, it stimulates the movement of the synaptic vesicles towards the membrane where they fuse with the plasma membrane and release their neurotransmitters in the synaptic cleft. The released neurotransmitters bind to their specific receptors, present on the post-synaptic membrane. This binding opens ion channels allowing the entry of ions which can generate a new potential in the post-synaptic neuron. The new potential developed may be either excitatory or inhibitory.

Central neural system

The central nervous system is consisted of Brian and Spinal cord. Brain is located in cranium of skull. The brain is the central information processing organ of our body, and acts as the 'command and control system'. It controls the voluntary movements, balance of the body, functioning of vital involuntary organs e.g., lungs, heart, kidneys, etc, thermoregulation, hunger and thirst, circadian or 24-hour rhythms of our body, activities of several endocrine glands and human behaviour. It is also the site for processing of vision, hearing, speech, memory, intelligence, emotions and thoughts.

Meninges- The human brain is well protected by the skull. Inside the skull, the brain is covered by cranial meninges consisting of an outer layer called dura mater, a very thin middle layer called arachnoid and an inner layer called pia mater. Pia mater is in contact with brain tissue. The brain can be divided into three major parts: (i) forebrain, (ii) midbrain, and (iii) hindbrain

(i) **Fore brain-** The forebrain consists of cerebrum, thalamus and hypothalamus.

(a) **Cerebrum-** Cerebrum forms the major part of the human brain. A deep cleft divides the cerebrum longitudinally into two halves, which are termed as the left and right cerebral hemispheres. The hemispheres are connected by a tract of nerve fibres called corpus callosum. The layer of cells which covers the cerebral hemisphere is called cerebral cortex and is thrown into prominent folds. The cerebral cortex is referred to as the grey matter due to its greyish appearance. The neuron cell bodies are concentrated here giving the colour.

The cerebral cortex contains motor areas, sensory areas and large regions that are neither clearly sensory nor motor in function, which is known as association areas and it is responsible for complex functions like inter sensory associations, memory and communication.
Fibres of the tracts are covered with the myelin sheath, which constitute the inner part of cerebral hemisphere. They give an opaque white appearance to the layer and, hence, is called the white matter.

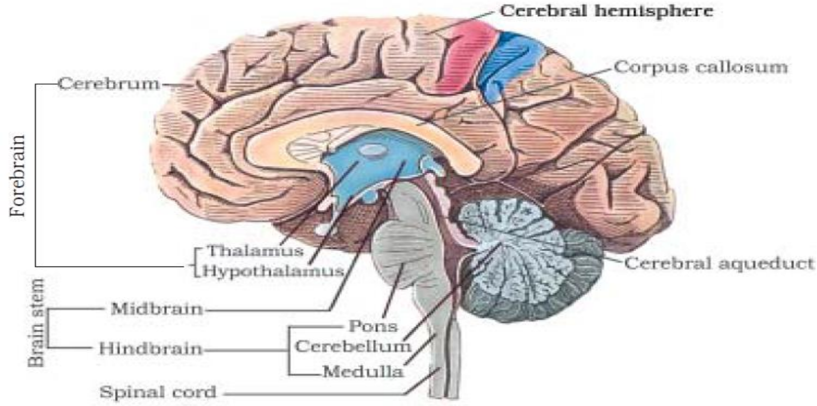

Figure Diagram showing sagital section of the human brain

(b) **Thalamus**- The cerebrum wraps around a structure called thalamus, which is a major coordinating centre for sensory and motor signaling.
(c) **Hypothalamus**-It lies at the base of the thalamus. The hypothalamus contains a number of centres which control body temperature, urge for eating and drinking. It also contains several groups of neuro secretory cells, which secrete hormones called hypothalamic hormones.

Limbic system-The inner parts of cerebral hemispheres and a group of associated deep structures like amygdala, hippocampus, etc., form a complex structure called the limbic lobe or limbic system. Along with the hypothalamus, it is involved in the regulation of sexual behaviour, expression of emotional reactions e.g., excitement, pleasure, rage and motivation.

(ii) Mid brain- The midbrain is located between the thalamus/hypothalamus of the forebrain and pons of the hindbrain. A canal called the cerebral aqueduct passes through the midbrain. The dorsal portion of the midbrain consists mainly of four round swellings or lobes called corpora quadrigemina. Midbrain and hindbrain form the brain stem.

(iii) Hind brain- The hindbrain comprises pons, cerebellum and medulla or medulla oblongata. Pons consists of fibre tracts that interconnect different regions of the brain. Cerebellum has very convoluted surface in order to provide the additional space for many more neurons. The medulla of the brain is connected to the spinal cord. The medulla contains centres which control respiration, cardiovascular reflexes and gastric secretions.

Reflex action

In our body we can found a sudden withdrawal of a body part which comes in contact with objects that are extremely hot, cold pointed or animals that are scary or poisonous.
The entire process of response to a peripheral nervous stimulation, that occurs involuntarily, i.e., without conscious effort or thought and requires the involvement of a part of the central nervous system is called a reflex action.

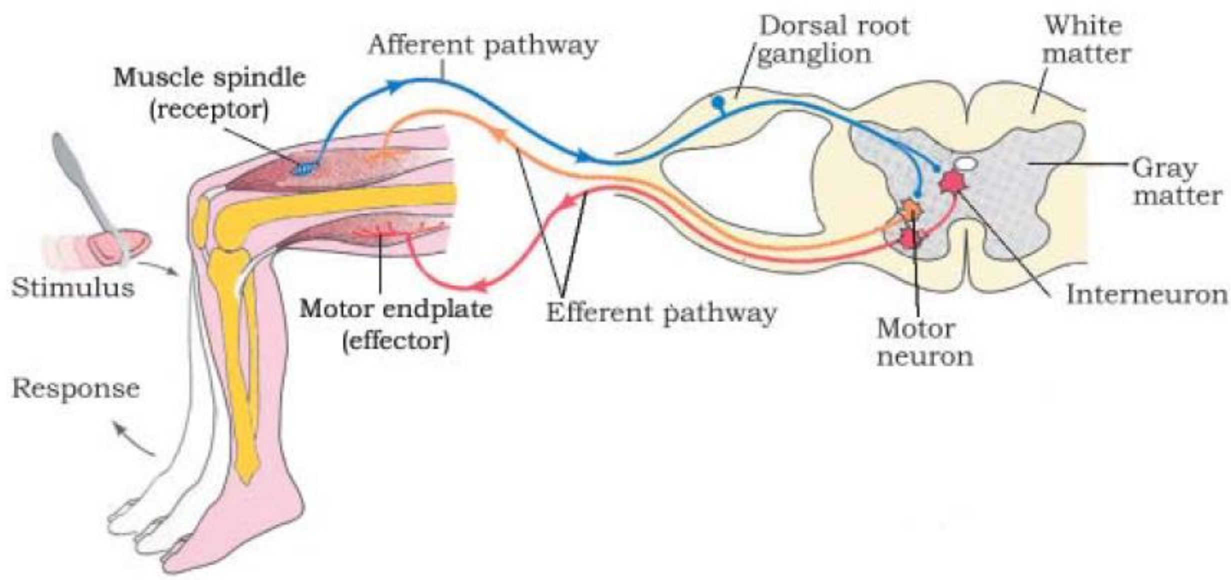

Figure Diagrammatic presentation of reflex action (showing knee jerk reflex)

The reflex pathway comprises at least one afferent neuron or receptor and one efferent effector or excitor neuron appropriately arranged in a series. The afferent neuron receives signal from a sensory organ and transmits the impulse via a dorsal nerve root into the CNS i.e. at the level of spinal cord. The efferent nueuron then carries signals from CNS to the effector. The stimulus and response thus forms a reflex arc.

Sensory reception and processing

The sensory organs detect all types of changes in the environment and send appropriate signals to the CNS, where all the inputs are processed and analyzed. Signals are then sent to different parts or centres of the brain. Thus we can sense changes in the environment.

Eye- Structure and function

In human body we have a pair of eyes which are located in sockets of the skull called orbits. The adult human eye ball is nearly a spherical structure. The wall of the eye ball is composed of three layers.

(i) **Sclera**-The external layer is composed of a dense connective tissue and is called the sclera. The anterior portion of this layer is called the cornea.

(ii) **Choroid**- The middle layer is known as choroid. It contains many blood vessels and looks bluish in colour. The choroid layer is thin over the posterior two-thirds of the eye ball, but it becomes thick in the anterior part to form the ciliary body. The ciliary body itself continues forward to form a pigmented and opaque structure called the iris which is the visible colored portion of the eye. The eye ball contains a transparent crystalline lens which is held in place by ligaments attached to the ciliary body. In front of the lens, the aperture surrounded by the iris is called the pupil. The diameter of the pupil is regulated by the muscle fibres of iris.

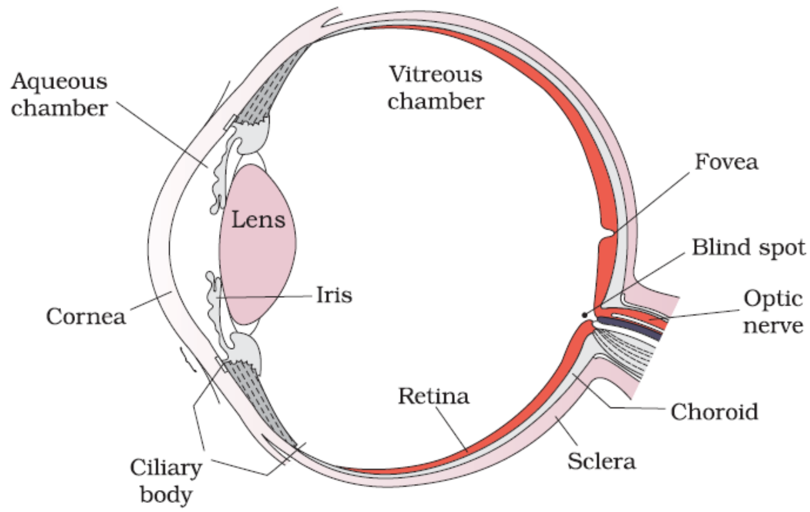

Figure Diagram showing parts of an eye

(iii) **Retina**-The inner layer is the retina and it contains three layers of cells – from inside to outside – ganglion cells, bipolar cells and photoreceptor cells.

Photo receptor cells-In human retina there are two types of photoreceptor cells- rods cells and cones cells. These cells contain the light-sensitive proteins called the photo pigments. The daylight or photopic vision and colour vision are functions of cones and the twilight or scotopic vision is the function of the rods. The rods contain a purplish-red protein called the rhodopsin or visual purple, which contains a derivative of Vitamin A. In the human eye, there are three types of cones which possess their own characteristic photo pigments that respond to red, green and blue lights. The sensations of different colors are produced by various combinations of these cones and their photo pigments. When these cones are stimulated equally, a sensation of white light is produced.

Optic nerve-The **optic nerves** leave the eye and the retinal blood vessels enter it at a point medial to and slightly above the posterior pole of the eye ball. Photoreceptor cells are not present in that region and hence it is called the blind spot. At the posterior pole of the eye lateral to the blind spot, there is a yellowish pigmented spot called macula lutea with a central pit called the fovea. The fovea is a thinned-out portion of the retina where only the cones are densely packed. It is the point where the visual acuity or resolution is the greatest. Aqueous and Vitreous chamber- The space between the cornea and the lens is called the aqueous chamber and contains a thin watery fluid called aqueous humor. The space between the lens and the retina is called the vitreous chamber, which is filled with vitreous humor.

Mechanism of vision

The light rays in visible wavelength focused on the retina through the cornea and lens generate potentials or impulses in rods and cones. The photosensitive compounds or photo pigments in the human eyes is composed of opsin (a protein) and retinal (an Aldehyde of vitamin A).

Light induces dissociation of the retinal from opsin resulting in changes in the structure of the opsin. This causes membrane permeability changes. As a result, potential differences are generated in the photoreceptor cells. This produces a signal that generates action potentials in the ganglion cells through the bipolar cells. These action potentials are transmitted by the optic nerves to the visual cortex area of the brain, where the neural impulses are analyzed and the image formed on the retina is recognized based on earlier memory and experience.

Ear

In human body there are two ears. The ears perform two sensory functions, hearing and maintenance of body balance. Anatomically, the ear can be divided into three major sections called the outer ear, the middle ear and the inner ear. The

(i) **External ear-** It consists of the pinna and external auditory meatus or canal. The pinna collects the vibrations in the air which produce sound. The external auditory meatus leads inwards and extends up to the tympanic membrane or ear drum. There are very fine hairs and wax-secreting sebaceous glands in the skin of the pinna and the meatus. The tympanic membrane is composed of connective tissues covered with skin outside and with mucus membrane inside.

(ii) **Middle ear**- It contains three ossicles called malleus, incus and stapes which are attached to one another in a chain-like fashion. The malleus is attached to the tympanic membrane and the stapes is attached to the oval window of the cochlea. The ear ossicles increase the efficiency of transmission of sound waves to the inner ear.

An Eustachian tube connects the middle ear cavity with the pharynx. The Eustachian tube helps in equalizing the pressures on either sides of the ear drum.

(iii) **Inner ear-** The fluid-filled inner ear is called as labyrinth. Labyrinth consists of two parts, the bony and the membranous labyrinths. The bony labyrinth is a series of channels. Inside these channels lies the membranous labyrinth, which is surrounded by a fluid called perilymph. The membranous labyrinth is filled with a fluid called endolymph. The coiled portion of the labyrinth is called cochlea.

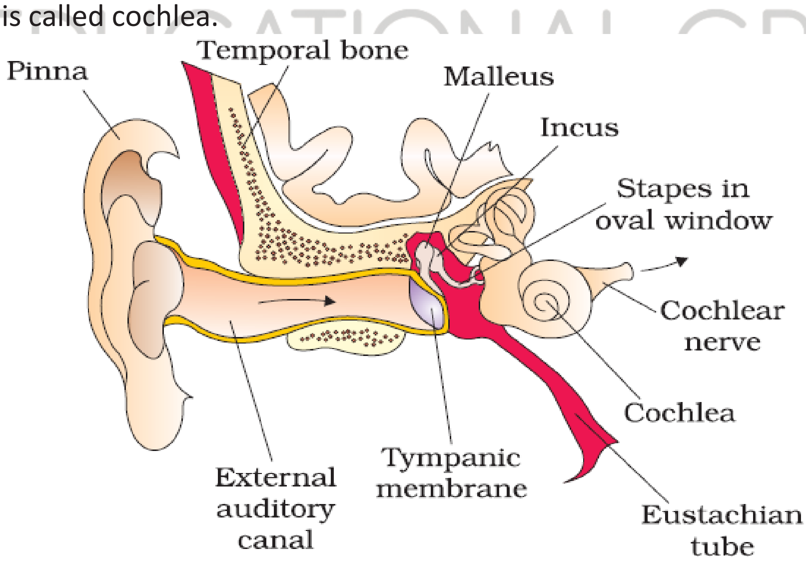

Figure Diagrammatic view of ear

The membranes constituting cochlea, the reissner's and basilar, divide the surounding perilymph filled bony labyrinth into an upper scala vestibuli and a lower scala tympani. The space within cochlea called scala media is filled with endolymph. At the base of the cochlea, the scala vestibuli ends at the oval window, while the scala tympani terminate at the round window which opens to the middle ear.

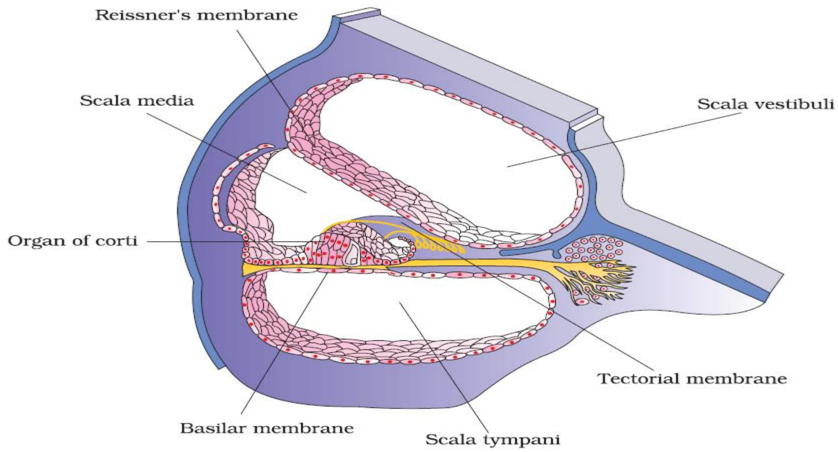

Figure Diagrammatic representation of the sectional view of cochlea

Organ of corti- It is a structure located on the basilar membrane which contains hair cells that act as auditory receptors. The hair cells are present in rows on the internal side of the organ of corti. The basal end of the hair cell is in close contact with the afferent nerve fibres. A large number of processes called stereo cilia are projected from the apical part of each hair cell. Above the rows of the hair cells is a thin elastic membrane called tectorial membrane.

Vestibular apparatus-The inner ear also contains a complex system called vestibular apparatus, located above the cochlea. The vestibular apparatus is composed of three semi-circular canals and the otolith organ consisting of the saccule and utricle. Each semi-circular canal lies in a different plane at right angles to each other. The membranous canals are suspended in the perilymph of the bony canals. The base of canals is swollen and is called ampulla, which contains a projecting ridge called crista ampullaris which has hair cells. The saccule and utricle contain a projecting ridge called macula. The crista and macula are the specific receptors of the vestibular apparatus responsible for maintenance of balance of the body and posture.

Mechanism of hearing

The external ear receives sound waves and directs them to the ear drum. The ear drum vibrates in response to the sound waves and these vibrations are transmitted through the ear ossicles to the oval window. The vibrations are passed through the oval window on to the fluid of the cochlea, where they generate waves in the lymphs. The waves in the lymphs induce a ripple in the basilar membrane. These movements of the basilar membrane bend the hair cells, pressing them against the tectorial membrane. As a result, nerve impulses are generated in the associated afferent neurons. These impulses are transmitted by the afferent fibres via auditory nerves to the auditory cortex of the brain, where information is analyzed and sound is recognized.

IMPORTANT TERMS

Sl No.	Terms	Explanation
1	**Action potential**	Potential at a point on nerve fibre which is generated at site of arrival of stimulus. Usually it varies from + 30to +35 mv.
2	**ANS**	Autonomic nervous system. It controls the involuntary activities of our body.
3	**Aqueduct of Silvis**	The brain ventricle passes through mid brain.
4	**Brain ventricle**	Brain is hollow structure. The cavity in side of brain is brain ventricle. CSF is flowing through it
5	**Cerebral cortex**	Outer grey matter of brain. It is mainly consisted of cell body of neurons. It is highly folded.
6	**CSF**	Cerebrospinal fluid. It flows through brain ventricle and carries respiratory gases and food material to different part of brain and transport away the CO2 and other excretory material from different part of brain.
7	**Cerebrum**	The fore brain is consisted of three parts. The largest part is known as cerebrum.
8	**Cerebral hemisphere**	Cerebrum is divided in two longitudinal half. Each half is known as cerebral hemisphere.
9	**Corpus callosum**	A fibrous tract which connects two cerebral hemisphere
10	**Diencephalon**	The third part of for brain is diencephalon. Its ventricle is IIIrd ventricle, which consists of epithalamus (Roof), Thalamus (Lateral Wall) and Hypothalamus (Floor).
11	**Electrical synapse**	Synapse between neuron in which pre and post synaptic membranes are in physical contact with each other. It is most commonly found in invertebrates however in human being it is rare and found in heart.
12	**Resting potential**	Potential developed on axolemma at time when there is no nerve transmission through it.
13	**Stimulus**	Any change in environment is stimulus.
14	**Medulated fibre**	The axon which is surrounded with myelin sheath.