CHAPTER 2

Nervous Coordination

In multicellular animals, the millions of cells, the different tissues, organs and systems that make up the body do not work independently of one another. Their activities are co-ordinated by the nervous system. The nervous system provides the fastest means of communication within the body.

The nervous system of vertebrates consists of the brain and the spinal cord which together form the **central nervous system (CNS)** and the **peripheral nervous system (PNS)** comprising the nerves from the brain and the spinal cord (see Fig. 2.10). The nervous system is connected to all parts of the body by **nerves** which are composed of thousands of long, thin, nerve fibres. Fig. 2.1 shows a simplified arrangement of the nervous system in the human body.

Structure and function of a neurone

The nervous system is composed of millions of **nerve cells** (neurones) together with the different types of supporting tissues in which they are embedded. The function of a nerve cell is to transmit messages (impulses). Hence, it is the basic functional unit of the nervous system.

Let us now examine the structure and function of a neurone.

Each neurone has three main parts: a **cell body (soma),** the **dendrites,** and the **axon** or **nerve fibre.** Some neurones have a **dendron** (Fig. 2.2B).

1. The **cell body** consists of the nucleus and cytoplasm.
2. The dendrites are short cytoplasmic filaments which conduct impulses towards the cell body.
3. The **axon** is a single, long fibre which transmits impulses away from the cell body. Each axon is enclosed within a fatty **myelin sheath,** which acts as an insulator, and an outer layer of **neurilemma.** The myelin sheath is interrupted at intervals by constrictions called **nodes of Ranvier.** The myelin sheath not only insulates the axon but also speeds up the transmission of impulses.
4. A **dendron** is a long fibre which transmits impulses towards the

cell body.

5. A **synapse** is the point where one nerve cell joins another. A typical **motor neurone** in the spinal cord of vertebrates is covered with hundreds of synaptic knobs derived from numerous adjacent cells (see Fig. 2.3). It is commonly believed that the transmission of impulses across most synapses occurs by a chemical process. The **grey matter** of the brain and spinal cord consists of cell bodies and their synapses.

Classification of neurones

Neurones are usually classified into three:

1. *Sensory or afferent neurones:* These transmit impulses from the **receptors** (e.g. sense organs and organs like the liver and heart) to the central nervous system (CNS).
2. *Motor or efferent neurones:* These transmit impulses from the CNS to the effectors (e.g. muscles and glands).
3. *Association or connector neurones:* These join sensory neurones with motor neurones.

The central nervous system

In vertebrates, the central nervous system (CNS) is made up of the brain and the spinal cord (see Fig. 2.5). The system is hollow and is filled with **cerebrospinal fluid.** This fluid nourishes the brain and serves as a shock absorber, so that the brain is cushioned from damage when a person jumps around or bangs his head against an object. The brain is protected by the **cranium** or brain case, while the spinal cord runs down the center of the backbone. Hence, the entire CNS is protected by a covering of bones.

The CNS has millions of interconnected nerves which are of two types. Some of them come out of the brain and enter mainly structures in the head (e.g the eyes, ears). These are the **cranial nerves.** Others come out of the spinal cord and go into the arms, legs and various structures in the trunk. These are the **spinal nerves** (see Fig. 2.1).

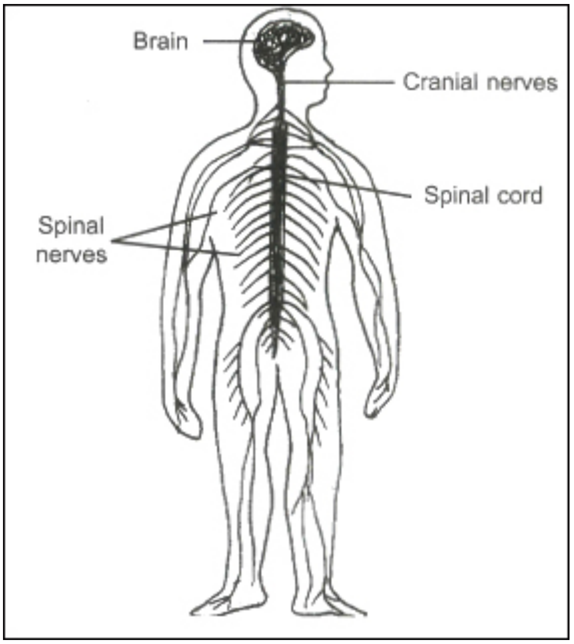

Fig. 2.1   Central Nervous System

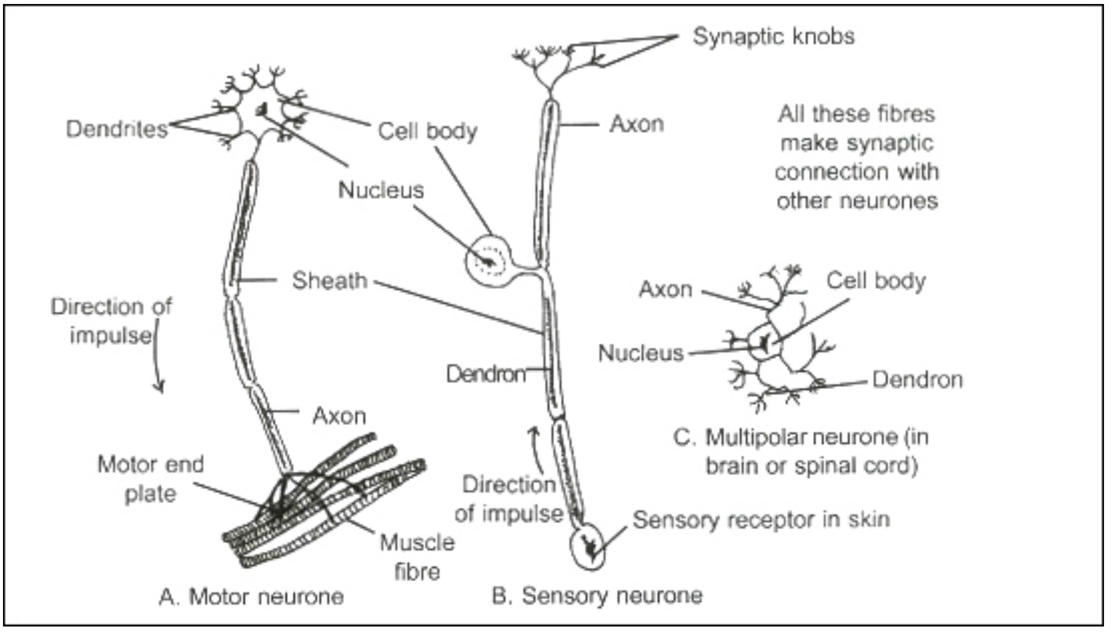

Fig. 2.2   Different nerve cells.

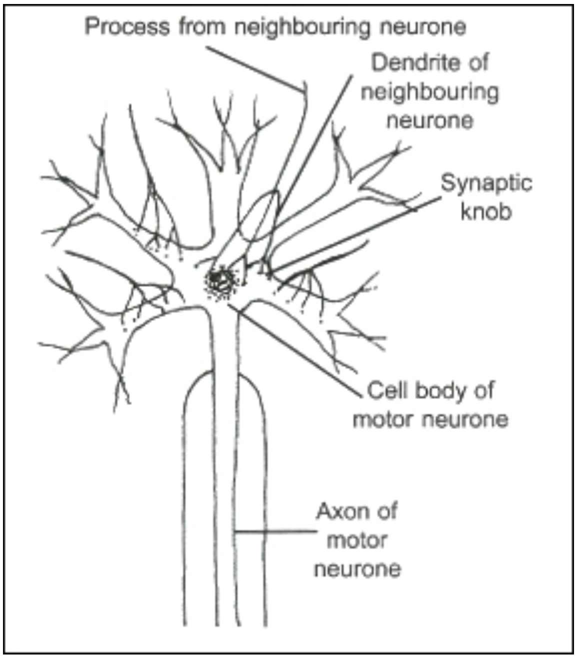

Fig. 2.3 Nerve cells join one another via synapses.

Activity 2.1

Observe a dissected rabbit make a full labelled diagram of the central nervous system.

Components and functions of the brain

Introduction

The brain forms the centre of the central nervous system, which enables organisms (mammals) achieve an equilibrium between their eternal and internal environments at all times. The adult human brain weighs about 1.2 to 1.4 kg. and forms only 2 percent of the bodyâ€™s mass. The brain cells are the first to react to low oxygen supply and low glucose level. The human brain is made up of millions of nerve cells which are connected with one another in very complex ways. The vertebrate brain (including human brain) consists of three main parts: the fore-brain, mid-brain and hind-brain (see Fig. 2.6)

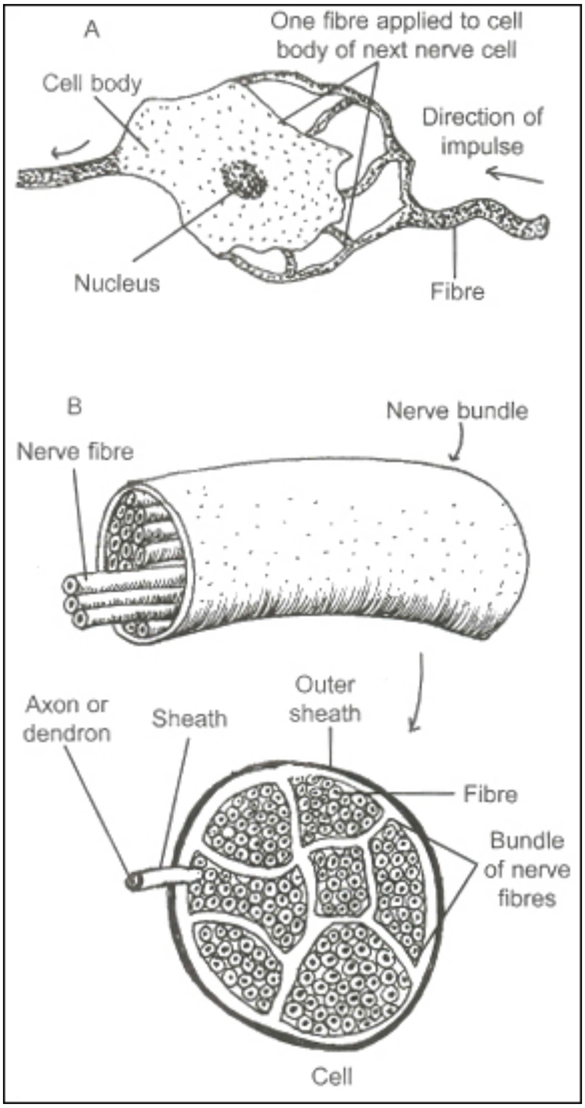

Fig. 2.4 A Diagram of a synapse
B Nerve fibres grouped into a nerve

The fore-brain

The fore-brain is made up of the cerebrum and the olfactory lobes. The olfactory lobes receive sensory impulses of smell from the nasal organs. In mammals, the cerebrum consists of an outer layer of grey matter composed of neuronal cell bodies called the **cerebral cortex** in humans. Beneath it is a thick mass of white matter (nerve fibres). The cerebral cortex is the seat of intelligence and higher activities of the brain such as speech, memory and learning.

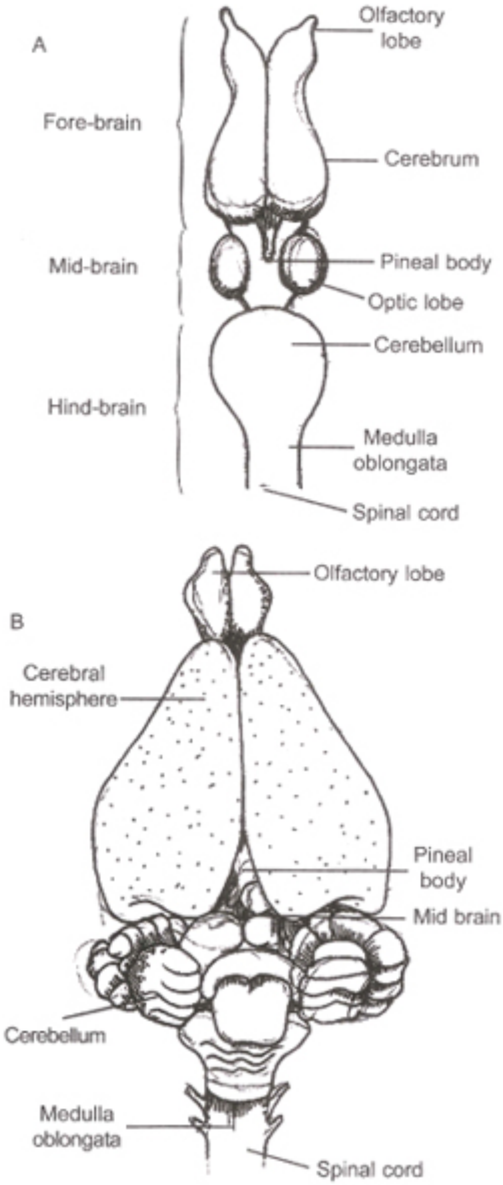

Fig. 2.5 The brain and spinal cord of A. toad and B mammal.

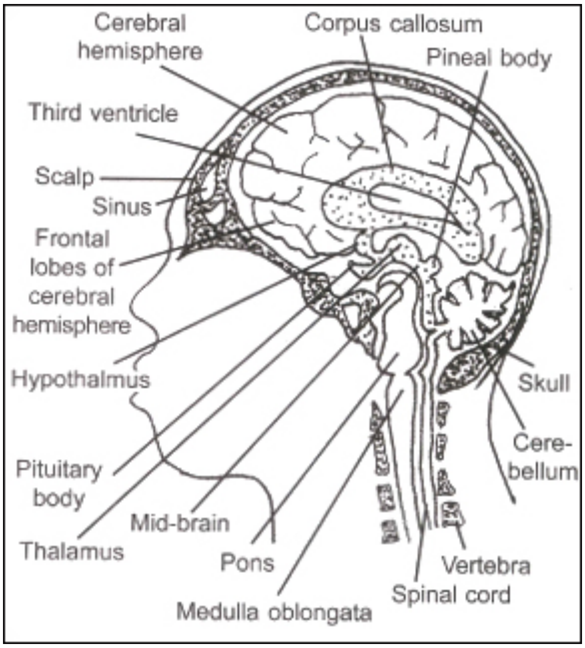

Fig. 2.6 Section through the human brain

The cortex can be divided into the sensory, motor and association areas. The sensory area receives impulses from the sense organs (receptors). The motor areas send out impulses to the voluntary muscles and glands (i.e. effectors). The association areas sort out, integrate and store information before it is sent out to the appropriate motor areas.

The mid-brain

This consists of the optic lobes which receive impulses from the eyes. Thus, the mid-brain controls the sense of sight and hearing which includes movement of the head to focus the eyes on an object as well as detect sound and locate its source. The large optic lobes of the frogs, fishes, reptiles etc are part of the mid brain.

The hind-brain

This consists of the cerebellum pons varolli and the medulla oblongata. The cerebellum is responsible for the maintenance of posture, balance, and muscular co-ordination in activities like walking and running. Pons varolli is a band of broad fibres that connect the lateral cerebella hemisphere.

The medulla oblongata controls many reflex (unconscious) processes such as the regulation of body temperature, blood pressure, rate of heart beat and breathing.

The hypothallamus controls such functions as sleep and wakefulness, feeding and drinking, body temperature and osmoregulation.

Functions of the Brain

The cerebrum co-ordinates all voluntary activities as well as being the site of higher mental activities, e.g. learning, reasoning, speech and creativity.

The thallamus acts as the relay centre for incoming sensory impulses and outgoing motor impulses

The hypothallamus is the coordinating and controlling centre for autonomic nervous system as well as the maintenance of homeostasis, regulation of body temperature etc.

The cerebellum coordinates muscular movement and maintenance of body balance.

The pons varolli connects the cerebella hemispheres – while the medulla oblongata co-ordinates and controls many involuntary activities, e.g heart rate, blood pressure and ventilation rate.

Structure of the spinal cord

The spinal cord (see Fig. 2.7) is composed of a white soft tissue running from the medulla oblongata to the tail region. It is protected by the bones of the vertebral column and passes through the neural canal.

Between the vertebrae, the spinal nerves come out and run to all parts of the body. The fibres of these nerves may be concerned with spinal reflexes or may carry sensory impulses to the brain or motor impulses from the brain to the muscles and other organs of the body.

The inner part of the spinal cord contains an H-shaped grey matter filled with cerebrospinal fluid. The grey matter consists of nerve cell bodies. On the outside of the spinal cord is the white matter consisting of nerve fibres running up and down the cord or passing out to the spinal nerves.

Some reflex actions occur in the spinal cord which also transmits nervous impulses to and from the brain. An example of a reflex action that occurs in the spinal cord is the quick withdrawal of oneâ€™s hand on touching a hot object unconsciously.

The two main functions of the spinal cord are:

(1) the coordination of simple reflex actions such as knee jerk, automatic reflexes such as sweating,

(2) connecting all peripheral pathways to the brain.

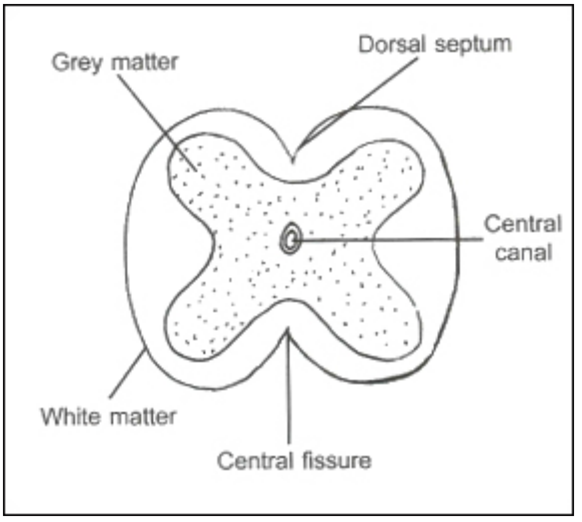

Fig. 2.7 Transverse section of the vertebrate spinal cord.

The functions of the central nervous system

The main functions of the central nervous system include the following:

1. It receives impulses from the sense organs (receptors).
2. It sends impulses to the effectors (muscles and glands) which respond accordingly.
3. The brain integrates the impulses from all the receptors and effectors so that the body can function as a unit.
4. It stores impulses as information, which is the basis of future learning and behaviour.

Peripheral nervous system

The peripheral nervous system (PNS) joins the CNS with the bodyâ€™s receptors and effectors in mammals. The PNS signals changes in the environment, registered by the receptors, to the CNS which integrates the information it receives and sends appropriate messages to the effectors accordingly.

The peripheral nerves are of two types: the spinal nerves, connected to the spinal cord and the cranial nerves, connected to the brain. The cranial nerves are associated chiefly with the receptors and effectors in the head, while the spinal nerves serve the receptors and effectors in other body parts.

The PNS consists of the somatic nervous system (SNS) and the autonomic nervous system (ANS)

Somatic nervous system

In the somatic nervous system (SNS), nerve fibres without synapses extend from the brain through the spinal cord to the skeletal muscles. The motor neurones of the SNS stimulate the effectors (i.e muscles and glands). It also controls the emptying of the bladder and the opening of the anal sphincters.

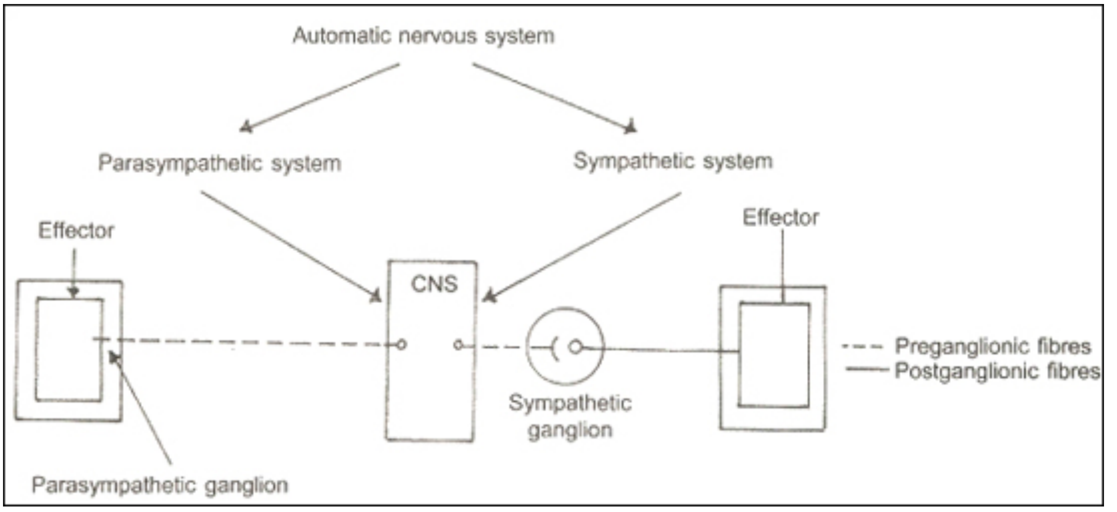

Fig. 2.8 General organization of the vertebrate autonomic nervous system.

Autonomic nervous system

The autonomic nervous system (ANS) is concerned with the control of the bodyâ€™s involuntary activities, e.g. heartbeat, movements of the gut, and secretion of sweat. The ANS consists of two parts: the sympathetic and parasympathetic systems. Both contain nerve fibres serving structures over which the body has little or no voluntary control. In both cases, nerve fibres come out from the brain or spinal cord and pass to the organs concerned. Along the course of each pathway, there is a complex set of synapses forming a **ganglion.**

The main structural difference between the sympathetic and parasympathetic systems relate to the position of the ganglia (see Fig.2.8)

In the sympathetic system, the ganglia lie alongside the vertebrae close to the spinal cord. In the parasympathetic system, the ganglia are embedded in the wall of the effector itself. The effects produced by these two systems generally oppose one another (antagonistic). Thus, if the sympathetic system causes a certain muscle to contract, the parasympathetic system relaxes it.

The functions of the sympathetic and parasympathetic systems are summarized in Table 2.1 below, while Fig. 2.9 summarizes the main features of the mammalian autonomic nervous system. Fig. 2.10 shows the sub-divisions of the vertebrate nervous system.

Table 2.1 Functions of sympathetic and parasympathetic systems

Sympathetic system	**Parasympathetic system**
Accelerates heart beat	Slows down heart beat
Constricts arteries	Dilates arteries
Dilates bronchioles	Constricts bronchioles
Dilates iris (pupil)	Constricts iris

Sympathetic system	Parasympathetic system
Slows gut movements	Speeds up gut movement
Contracts bladder and anal sphincters	Relaxes bladder and anal sphincters

Transmission of nervous impulses

Nervous impulses are transmitted along a neurone in two main ways: electrical and ionic (chemical) means.

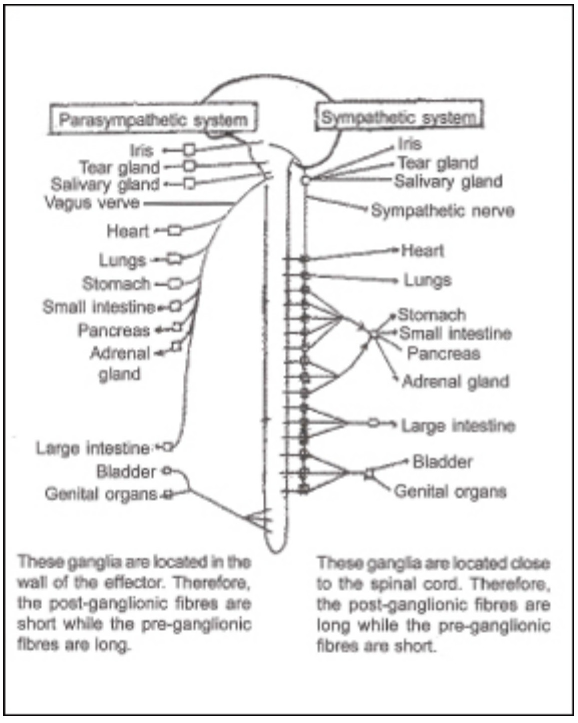

Fig. 2.9 Diagram summarizing the major features of the mammalian autonomic nervous system

Electrical transmission

It has been observed that when an axon is in the resting state, its inside is negatively charged and its outside is positively charged. This is called **resting potential.** This shows that the membrane surrounding the axon is polarized, i.e. can maintain a different electrical charge on its two sides.

When an impulse passes through the axon, its inside suddenly becomes positively charged and its outside becomes negatively charged. This sudden reversal of the resting potential, which accompanies the impulse, is called the **action potential** and thus, the nerve membrane is depolarized for a short time, after which the original resting potential is restored. It is by this means that impulses pass along the axon as a wave of depolarization.

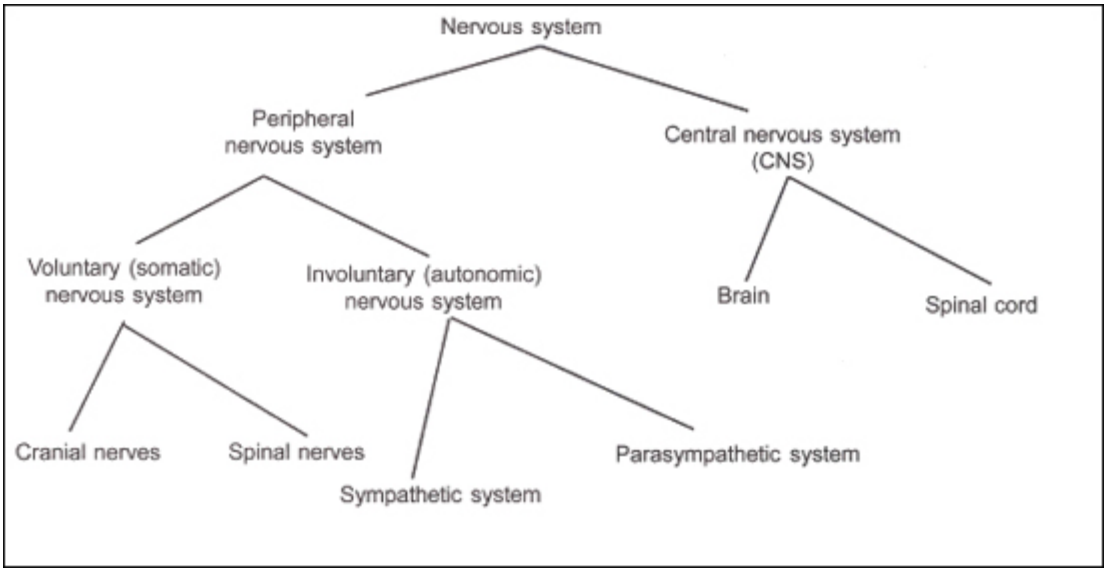

Fig. 2.10 Subdivisions of the nervous system of a vertebrate

Ionic transmission

When an axon is at rest, the membrane becomes polarized: that is, its outside becomes positive and its inside negative. When more potassium ions are inside and excess sodium is actively pumped across the membrane, the sodium ions will be prevented from entering the axon.

When an impulse passes along the axon, the membrane suddenly becomes depolarized. It then becomes permeable to sodium ions. This reverses the resting potential i.e., the inside of the axon becomes positively charged compared with the negatively charged outside. This results in an action potential. Small local currents on both sides of the membrane (at the leading end of the region of depolarization), excite the next part of the axon, so that action potential is propagated along it as shown in Fig. 2.12. The whole process is completed in about two milliseconds.

In normal circumstances, impulses are set up in nerve cells as a result of excitation of the receptors. An axon can also be excited by direct application of any appropriate stimulus that causes local depolarization of the membrane. Generally, nerves are stimulated by mechanical, osmotic, chemical, thermal and electrical stimuli.

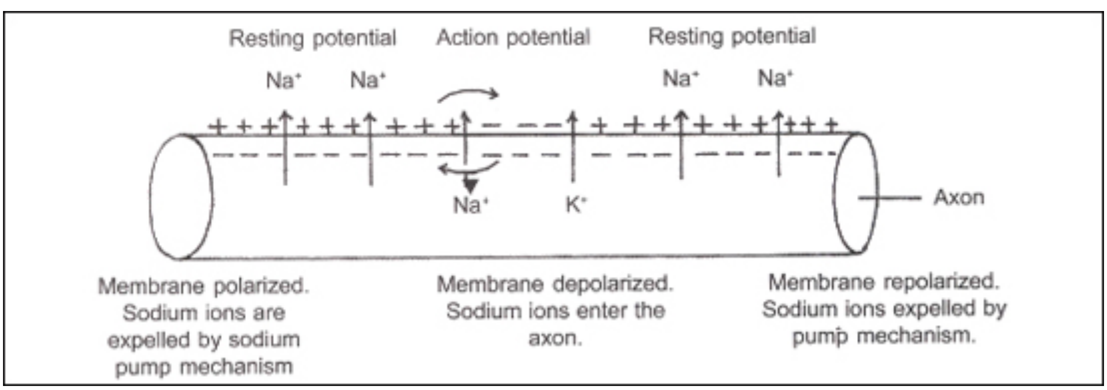

Fig. 2.11 The nature of a nerve impulse

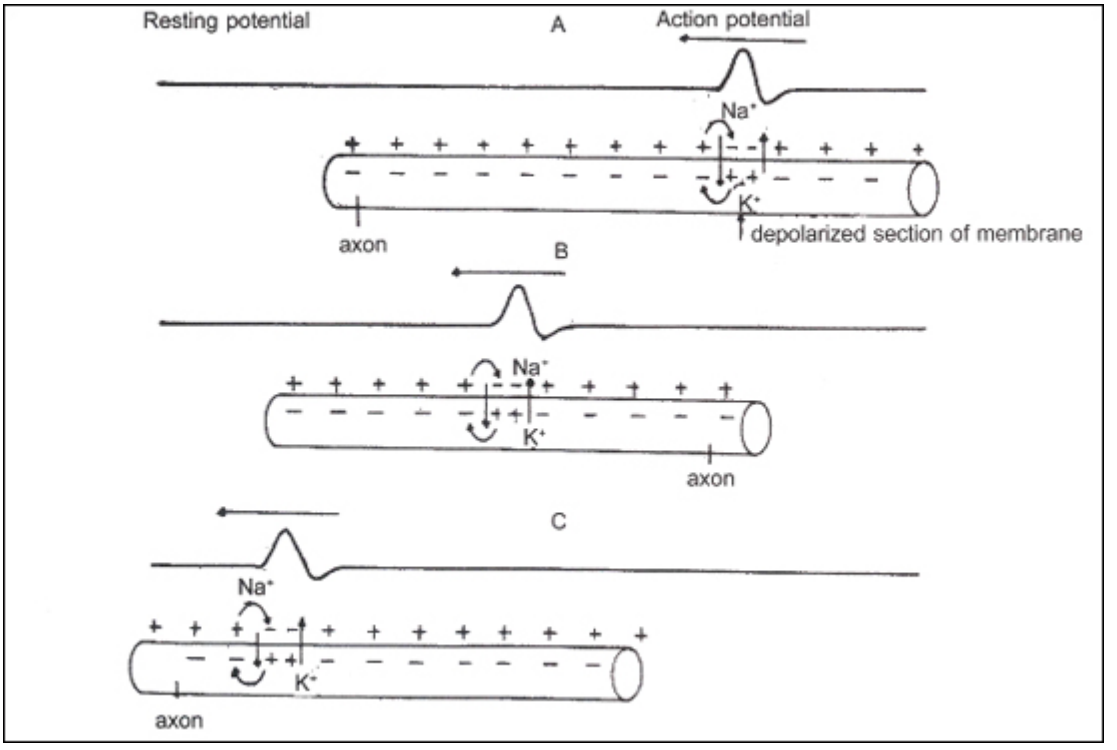

Fig. 2.12 Diagram showing three stages in the transmission of an impulse along an axon. Notice that the action potential moves from the right to the left

If the strength of a stimulus is below a certain threshold intensity or certain level, no action potential (or transmission of impulse) is evoked. If however, the stimulus is above the threshold, a full action potential is evoked. Further increase in the intensity of the stimulus, however great, does not give a larger potential (transmission). This is called the **all-or-nothing law** which states that the response of an excitable unit (e.g. an axon) is independent of the intensity of the stimulus. In other words, the size of the impulse is independent of the size of the stimulus. Hence, all that is required for an impulse to be transmitted is that the stimulus must be above the threshold required to excite the axon.

The spread of transmitted impulses varies greatly, depending on the type of neurone and the animal in question. In certain mammalian axons, transmission speeds of over 100m/s are found. On the other hand, neurones of many invertebrates transmit impulses at speeds of 0.5m/s or less. Generally, myelinated axons transmit impulses faster than non-myelinated axons. Again, the thicker the axons, the faster it will transmit impulses.

Transmission of impulses across the synapse (see Fig. 2.3) occurs by chemical means. When an impulse arrives at a synapse, a chemical substance, **acetylcholine,** is released. This diffuses across the gap and causes the excitation of the post-synaptic nerve cell. The synapse also prevents impulses from going in the wrong direction. An impulse can pass along an axon in either direction but it can cross a synapse in only one direction.

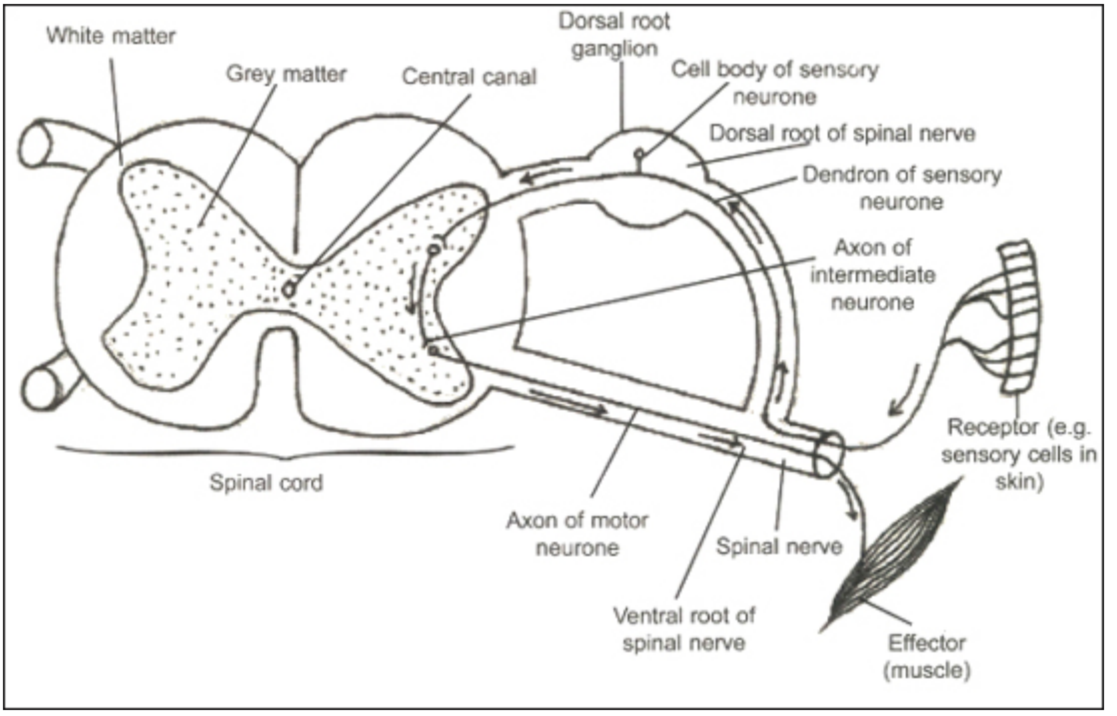

Fig. 2.13 A reflex arc.

Reflex action

A reflex or involuntary action is a fast, automatic response to a stimulus by an organ or system of organs, the initiation of which does not involve the brain. Pulling your leg away from a hot or sharp object is an example of a reflex action. Commonly, we are aware of reflex actions taking place but we cannot control them. For example, blinking when a foreign body touches the cornea, sneezing, beating of the heart, and movement of the gut are reflex actions which we cannot control. The knee jerk, is also an example of a reflex action or reflex. In this case, if the left leg is crossed over the right and struck sharply just above or below the knee cap, the lower leg jerks outwards by reflex.

The reflex arc represents the series of units (neurones) through which impulses have to pass in order to bring about a reflex response. The events that occur during a reflex action, for example, when a person suddenly and unknowingly touches a hot object, can be outlined as follows (see Fig. 2.13)

1. On touching the hot object, the nerve endings of a sense organ (e.g the skin) are stimulated.
2. The impulses are transmitted through the sensory neurone (afferent nerve) passing through the dorsal root into the spinal cord.
3. From here, the impulses are relayed via synapses, into the intermediate neurone through another synapse to the motor efferent nerve.
4. This passes through the ventral root to the motor (effector) organ

which brings about a response.

In the case above, the impulse causes the muscle of the hand to contract, thereby removing the hand from the painful stimulus, and preventing injury to the tissue. The whole response occurs within a fraction of a second. This shows how quickly impulses travel through the nervous system.

Activity 2.2

Perform experiments on examples of reflex actions, e.g. banging the fist on the table, knee jerk, and record your observations

Reflex actions are not as simple as described above. Several receptors of different types might be stimulated at once. Besides, many groups of muscles or glands might be brought into action thereby involving many more than the three nerve cells mentioned in the reflex arc described above. Since we are usually aware that a reflex is occurring, nerve fibres must transmit the impulses passing through the reflex arc up the spinal cord. A few reflexes (e.g. the knee jerk) do not involve the brain and can occur in an animal whose brain has been totally destroyed.

The term spinal reflex refers to reflex actions in areas below the head, while cranial reflex refers to reflex actions occurring in the brain.

Activity 2.3

Identify the main parts of the brain and spinal cord from the specimen provided.

Voluntary action

A voluntary action involves the brain for its initiation. Voluntary actions are the various activities which we usually think about before we do them. Examples are singing, dancing, walking, running, reading and typing.

In a voluntary action, a nerve impulse is transmitted from the sensory neurones to the spinal cord and then to the brain for interpretation. The brain then sends a message back through the motor neurones to the effector organ.

The emptying of the bladder and the bowels are examples of some actions which we cannot control early in life but we gradually learn to control as we grow older. Again, some activities such as breathing, are partly voluntary and partly involuntary. For example, we breathe automatically without thinking about it. Yet, we can change the rate of our breathing if we wish to.

Table 2.2 displays some of the main differ ences between reflex (involuntary) and voluntary actions.

Table 2.2 Differences between reflex and voluntary actions

Reflex action	Voluntary action
1. Action is initiated by muscle receptor cells	Action is initiated in the brain
2. It occurs unconsciously	It occurs consciously
3. It is automatic and fast	It is neither automatic nor fast
4. It is inborn	It can be learnt
5. Nerve impulses do not reach the brain	Nerve impulses always reach the brain

Conditioned reflex

A conditioned reflex is a behaviour which is acquired through learning. As a result, it can be repeated without thinking about it. Most of our behaviours are conditioned reflexes. Examples are walking, driving, reading, writing, typing, cycling and swimming. It takes a fairly long time to learn each of these skills. But once we have mastered them, we perform them very fast and efficiently without thinking about them.

Behaviour conditioning was first described by a Russian scientist, Ivan Pavlov, in 1902 from his experiments on dogs. Usually, a dogâ€™s mouth waters when it is given food due to reflex action. In one experiment, Pavlov rang a bell, just before giving the dog its food. After repeating this several times, the dog learnt to associate the bell with food. Hence, it salivated as soon as it heard the bell, even before the food appeared. Pavlov called this response a **conditioned reflex.** Many examples of this kind of behaviour are shown by humans and other animals.

In general, conditioning allows animals to modify their behaviour so as to obtain maximum rewards and avoid punishment. The principle of conditioning is used in training dogs and other animals.

Suggested practicals

1. *Studying the brain and spinal cord of a toad*
   (a) Examine the brain of a toad dissected by your teacher.
   (b) Identify the main parts of the brain and spinal cord. Use Fig. 2.5 as guide.

2. Microscopic examination of the spinal cord
   (a) Examine the slide of the transverse section of the spinal cord under the low power of a microscope. Identify the grey and white matter.
   (b) Can you see the nerve cells in the grey matter?
   (c) Use the high power to focus on a single nerve cell. Draw the nerve cell to show its shape.
   (d) What part of the nerve cell shown in Fig. 2.2A does your drawing cor respond to?

Summary

1. The vertebrate nervous system consists of the brain, the spinal cord and related nerves (forming the central nervous system) and the peripheral nervous system.
2. The nervous system is connected to all parts of the body by nerves made up of thousands of long, thin, nerve fibres.
3. The basic functional unit of the nervous system, a neurone, has three main parts – a cell body (soma), dendrites and the axon or nerve fibre. Some neurones have dendron.
4. A synapse is the point where one neurone joins another.
5. Motor neurones transmit impulses from the central nervous system (CNS) to the effectors (muscles and glands).
6. Sensory neurones transmit impulses from the receptors (sense organs, liver, heart etc.) to the central nervous system (CNS).
7. Association or connector neurones join sensory neurones with motor neurones.
8. The mammalian brain consists of three main parts – the fore-brain (the seat of intelligence), the mid-brain (controlling the sense of sight), and the hind-brain made up of cerebellum and the medulla oblongata. The cerebellum is responsible for muscular coordination, while the medulla oblongata controls many reflex actions.
9. The peripheral nervous system (PNS) joins the central nervous system (CNS) with the bodyâ€™s receptors and effectors in mammals.
10. Impulses can be transmitted along a neurone by chemical, electrical, mechanical, thermal and osmotic stimuli.
11. For an impulse to be transmitted across a neurone, the stimulus must be above the threshold required to excite the axon.
12. Transmission of impulses across synapses is effected by a chemical called acetylcholine.
13. Nervous impulses in mammals are very fast and are transmitted in either direction along an axon but can cross a synapse in only one direction.
14. Reflex actions (e.g. sneezing, yawning, knee jerk, and breathing) are actions that are not initiated by the brain but by the muscle receptor cells. Most reflex actions involve the brain, while a few do not reach the brain but end in the spinal cord.
15. Voluntary actions are the actions initiated by the brain and which we can control consciously (e.g. walking and running).
16. Conditioned reflexes are behaviours that are learnt. Once they are mastered, we can perform them without thinking about them (e.g. swimming, running and cycling).

Objective Questions

1. The basic functional unit of the nervous system is the
   A. dendrite
   B. dendron
   C. neurone
   D. nerve fibre
   E. soma
2. All the following structures are parts of a neurone except the
   A. soma
   B. grey matter
   C. axon
   D. dendrite
   E. dendron
3. The main function of myelin sheath in a neurone is to
   A. slow down the speed of transmission of impulses.
   B. retard the speed of transmission of impulses
   C. accelerate the speed of transmission of impulses
   D. depolarize the axon
   E. polarize the axon
4. The part of the mammalian brain that controls body posture is the
   A. medulla oblongata
   B. cerebellum
   C. cerebrum
   D. cerebral cortex
   E. hypothallamus
5. Which of the following is an example of a reflex action?
   A. walking
   B. running
   C. sneezing
   D. reading
   E. cycling

Essay Questions

1. (a) With the aid of well-labelled diagrams, describe the structure and functions of a neurone.
   (b) Name the various types of neurones and the function of each.
2. (a) With the aid of a well-labelled dia-gram, explain the structure and functions of the brain of a vertebrate.
   (b) Describe the structure of the spinal cord.

(c) What are the main functions of the central nervous system?

3. (a) By means of a table, show the functions of the sympathetic and parasympathetic systems.

(b) Briefly describe how nervous impulses are transmitted across a nerve cell.

4. (a) With the aid of a well-labelled diagram, explain what happens when a girl suddenly carries a hot plate and drops it immediately.

(b) In a tabular form, list five differences between a reflex action and a voluntary action.