5 COORDINATION

Students Learning Outcomes

After studying this chapter, students will be able to:

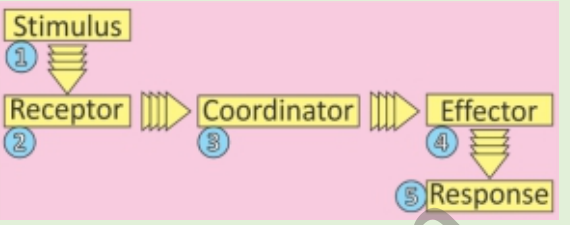
- Describe the nervous system and its role.
- Discuss the central nervous system and peripheral nervous system.
- Outline the types of neurons with diagrams.
- Define a stimulus with examples.
- State that nerve impulses are electrical signals that travel across neuron.
- Define and sketch synapses.
- Introduce neurotransmitters.
- Explain through sketching a diagram the involvement of the nervous system when a person accidentally touches something painfully hot and withdraws their hands as a reflex.
- Explain the endocrine system.
- Identify the major endocrine glands and hormones with their functions.

BACKGROUND INFORMATION

Coordinated Action: A coordinated action has five components;

1. Stimulus

Any change in external or internal environment, which can initiate a response in the body, is called a stimulus. For example, touch, light, sound, heat, cold, pressure, infection etc. are the stimuli.



2. Receptor

The organ, tissue or cell which receives stimuli is called the receptor. For example, ears are the receptors for the stimulus of sound. Receptors send the messages of stimulus to coordinators.

The junction between two neurons and between a neuron and another cell is called **synapse**.

3. Coordinator

A coordinator receives information from receptors and sends impulses to particular organs for proper action. In nervous coordination, **brain** and **spinal cord** are coordinators. In chemical coordination, **endocrine glands** are the coordinators.

4. Effector

These are the parts of the body which receive coordinator's message and perform specific actions. In nervous coordination, **muscles** and **glands** are the effectors. While in chemical coordination, different tissues of the body act as effectors.

5. Response

A response is the action performed by effectors, on receiving the message from coordinator. For example, pulling our hand away from something very hot.

Coordination means integration among different parts of the body and their response to stimuli in order to keep harmony with the environment. Coordination occurs in all living organisms. Animals possess two systems for this function i.e., nervous system and endocrine system.

5.1 NEURONS – THE UNITS OF NERVOUS SYSTEM

Neurons or nerve cells are the cells that transmit impulses in the body in the form of nerve impulses.

Nerve Impulse: It is a wave of electrochemical change that travels across the membrane of a neuron.

Structure of Neuron

A neuron consists of three major parts i.e., cell body, dendrites and axon. The **cell body** contains the nucleus, other organelles and most of the cytoplasm. Small branches which project from the cell body are called **dendrites**. They transmit nerve impulses towards cell body. **Axon** is a long branch from cell body. Its terminal end is further branched. Axon transmits nerve impulses from cell body to other neurons, muscles, or glands.

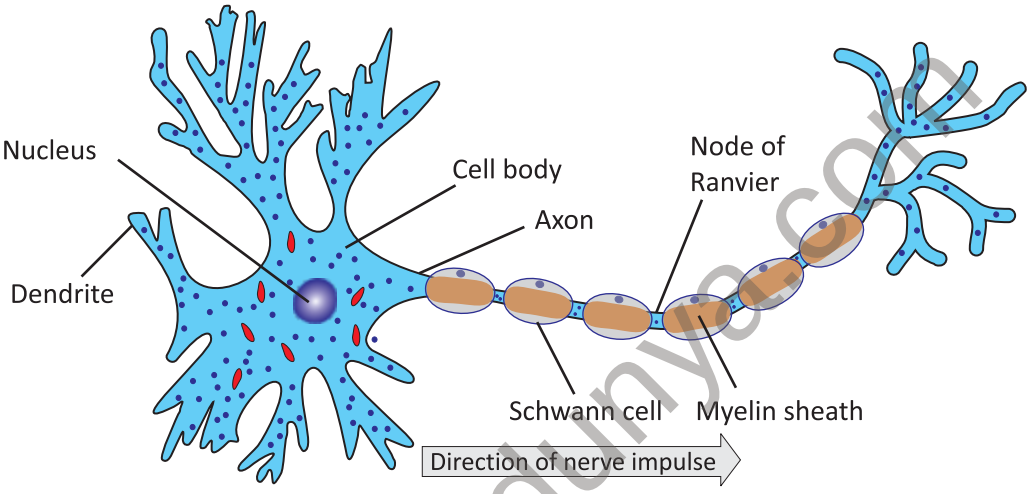


FIGURE 5.1: A Model Neuron (Motor Neuron)

Neurons are supported by specialized cells, called **neuroglia. Schwann cells** are a type of neuroglia. In many neurons, Schwann cells produce insulating covering called **myelin sheath** over the membrane of axon. Axons which are covered by myelin sheath are called myelinated. The axons which are not covered with myelin sheath are called non-myelinated. The myelin sheath is interrupted at intervals by small gaps called **nodes of Ranvier**. In myelinated neurons, nerve impulses 'jump' from node to node. This increases the speed of nerve impulse.

In the Central Nervous System (CNS), myelinated axons form the **white matter**, and the non-myelinated axons, dendrites and cell bodies form the **grey matter**

Synapse and Neurotransmitters

A synapse is a small gap between two neurons or between a neuron and an effector cell. When nerve impulse reaches the end of a neuron, it cannot jump directly to the next neuron or effector. Neurotransmitters are special chemicals that help to carry messages across a synapse.

When a nerve impulse reaches the end of a neuron, it releases

neurotransmitters. They travel across the synapse and attached to the dendrite next neuron or effector cell. It helps the nerve impulse to continue its journey. Examples of neurotransmitters include dopamine, serotonin and acetylcholine.

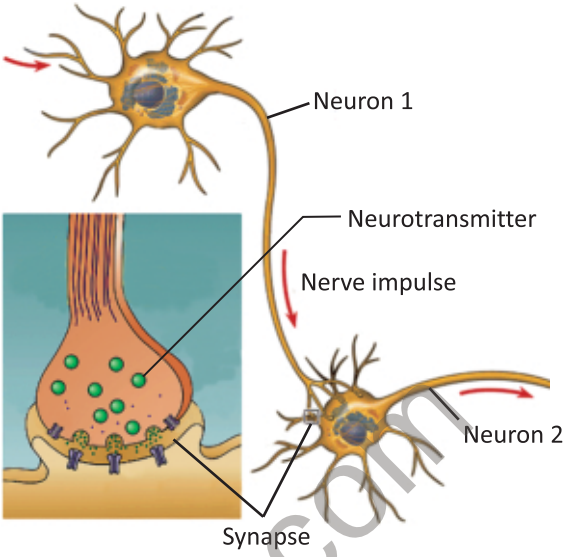


FIGURE 5.2: Synapse

Types of Neurons

1. **Sensory neurons** transmit nerve impulses from receptors to the CNS.
2. **Inter-neurons** are present in brain and spinal cord. They receive impulses from sensory neurons and transmit them to motor neurons.
3. **Motor neurons** transmit nerve impulses from inter-neurons to effectors (muscle or glands).

In certain parts of body, the cell bodies of neurons form groups enveloped by membranes. The groups of cell bodies are called **ganglia** (*Singular:* **ganglion**).

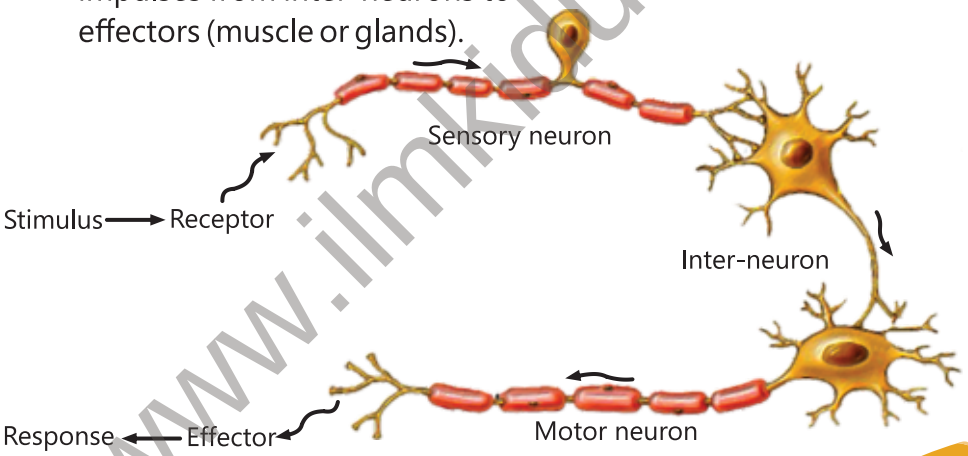


FIGURE 5.3: Types of Neuron

Nerve

A nerve is collection of axons that are enveloped by a covering of connective tissue. Nerves arise from brain and spinal cord and make the **Peripheral Nervous System (PNS)**. There are three types of nerves, on the basis of axons present in them. **Sensory nerves** contain the axons of

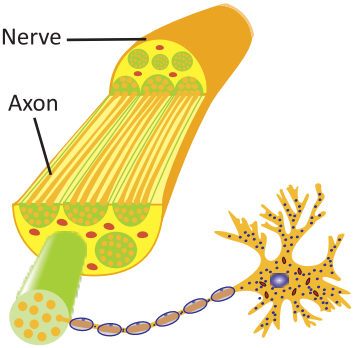


FIGURE 5.4: Nerve

sensory neurons only. **Motor nerves** contain the axons of motor neurons only. **Mixed nerves** contain the axons of sensory and motor neurons.

5.2 DIVISIONS OF THE NERVOUS SYSTEM

There are two major components of nervous system i.e., **central nervous system (CNS)** and **peripheral nervous system (PNS)**. The CNS comprises of brain and spinal cord. The PNS consists of nerves that arise from brain and spinal cord and spread in different parts of body.

All these components are made of neurons and supporting (neuroglial) cells.

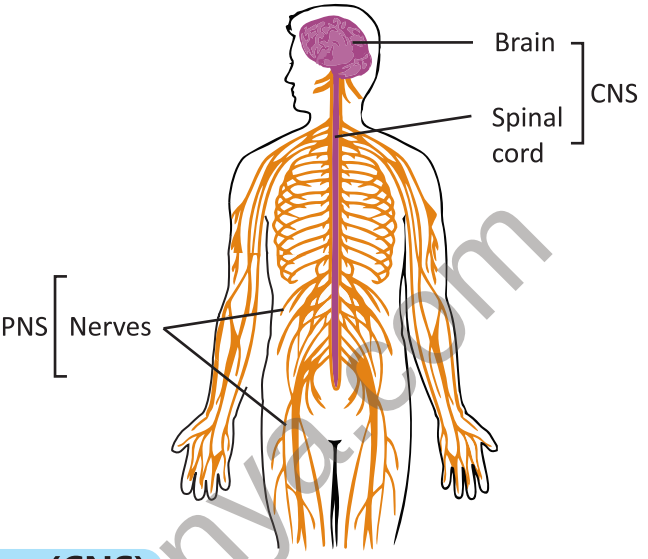


FIGURE 5.5: CNS and PNS

1. Central Nervous System (CNS)

The central nervous system consists of brain and spinal cord.

A. Brain

All life activities are under the control of brain. Brain is present inside **cranium** (part of skull). Inside cranium, brain is covered by three layers of membranes, collectively called **meninges**. Meninges protect the brain from harmful substances. Brain contains fluid-filled cavities called **ventricles**. The ventricles of brain are continuous with the central canal of spinal cord. Fluid within ventricles and central canal is called **cerebrospinal fluid** (CSF). The brain can be divided into three major parts: forebrain, midbrain and hindbrain.

The average adult human brain weighs 1.4 kg, or about 2% of total body weight. It contains about 100 billion neurons.

1. Forebrain

It is the largest area of brain. Following are the major parts of this region.

(i)- Cerebrum is the largest part of forebrain. A deep groove (longitudinal fissure) divides the cerebrum into right and left **cerebral hemispheres**.

The upper layer of both hemispheres is highly folded and is called cerebral cortex. It is made of

Each hemisphere receives information from the opposite side of the body and sends message to that side. For example, the sensation of a touch on the right hand is received by the left hemisphere.

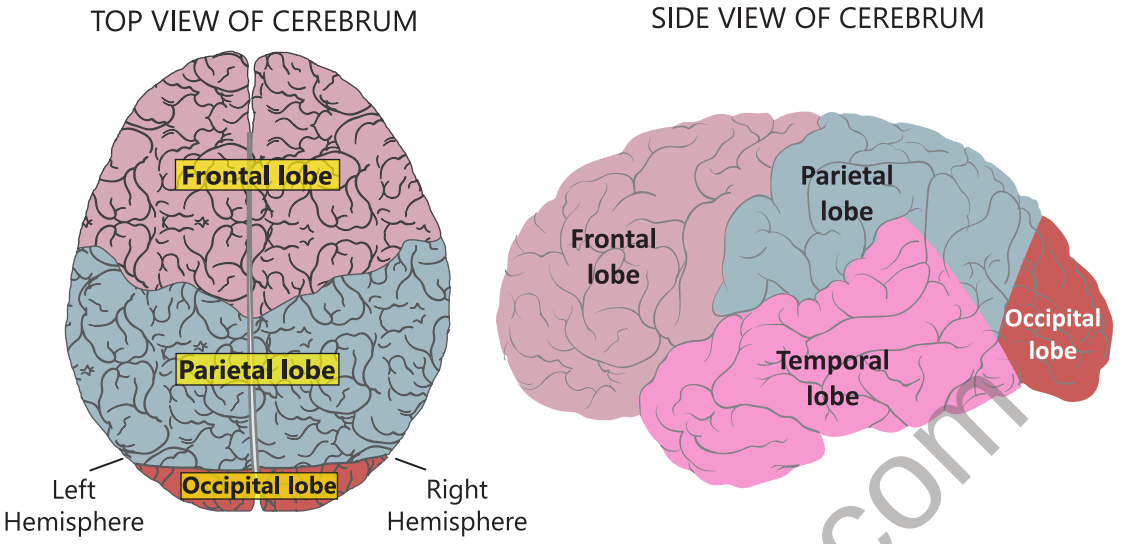


FIGURE 5.6: Cerebral hemispheres and the 4 lobes

grey matter (containing cell bodies and non-myelinated axons). The material beneath cortex is **white matter** (containing myelinated axons).

Each hemisphere is further divided into four lobes. The **frontal lobe** contains regions for problem solving, judgment, speaking, and movements. The **parietal lobe** has regions for language and touch. The **temporal lobe** contains regions which deal with memory, learning, feelings, and hearing. The **occipital lobe** has regions for vision and color perception.

(ii)- Thalamus is a structure wrapped by the cerebrum. It conveys information coming from receptors to the cerebrum. Thalamus is also involved in pain perception and consciousness.

(iii)- Hypothalamus lies above midbrain and just below thalamus. In humans, it is about the size of an almond. It regulates body temperature, hunger, thirst, sleep, and emotional states. It also controls the secretions of the major endocrine gland i.e., **pituitary gland**.

2. Midbrain

The midbrain is located between forebrain and hindbrain. So, it is a bridge between these two parts. It conveys information between them. It also enables the body to make adjustments to movements. It is also responsible for sleep/wake, alertness and temperature regulation.

Medulla oblongata, pons, and midbrain connect the rest of brain to spinal cord. They are collectively called **brain stem**.

3. Hindbrain

Hindbrain controls all automatic body functions. It consists of three parts.

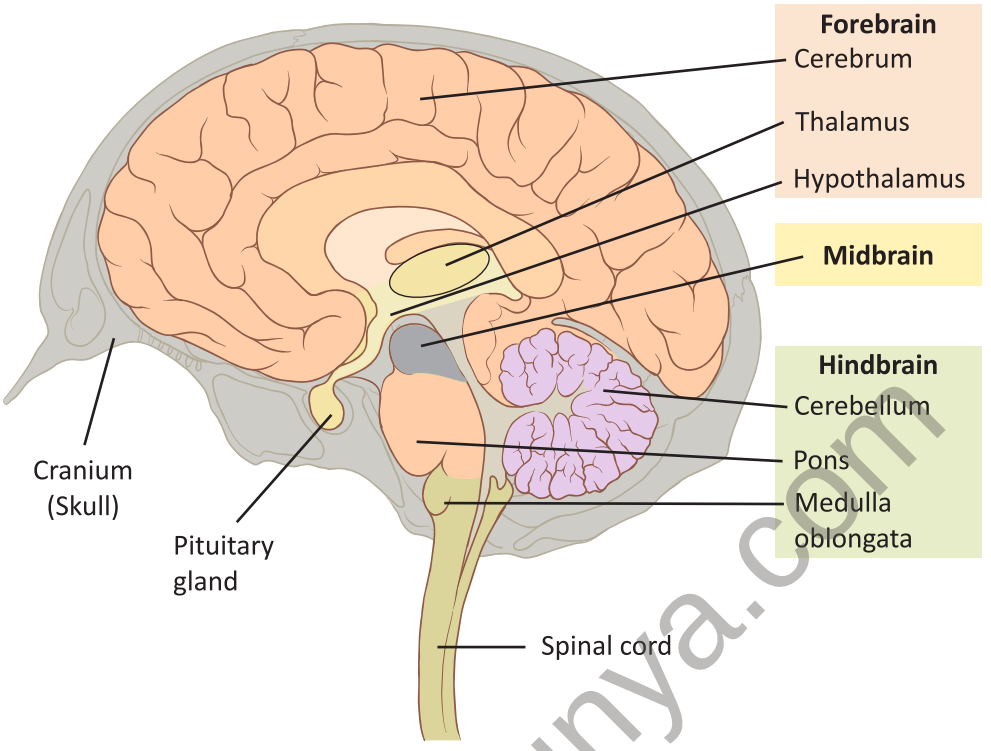


FIGURE 5.7: Structure of brain

(i)- Medulla oblongata is on the top of the spinal cord. It transmits impulses between spinal cord and the higher parts of brain. It controls autonomic functions such as heartbeat, heart rate, breathing and blood pressure. It also controls reflexes such as vomiting, coughing, sneezing.

(ii)- Cerebellum is behind medulla oblongata. It is the second largest part. Its surface is highly folded. It coordinates balance and muscle movements.

(iii)- Pons is present on top of the medulla. It makes connections between the spinal cord and cerebellum, and between cerebrum and cerebellum. It also regulates alertness, sleep, and wakefulness.

B. Spinal Cord

It is a tubular bundle of nerves that starts from brain and extends to lower back. It is located in vertebral column. It is also covered by **meninges**. Spinal cord transmits impulses between brain and body parts. It also acts as a coordinating centre for some simple reflexes.

The outer region of spinal cord is made of **white matter**. The central region is made of **grey matter**. It is butterfly shaped and surrounds the central canal. Thirty-one pairs of spinal nerves arise from spinal cord. All the spinal nerves are **"mixed"** nerves because each contains axons of both sensory and

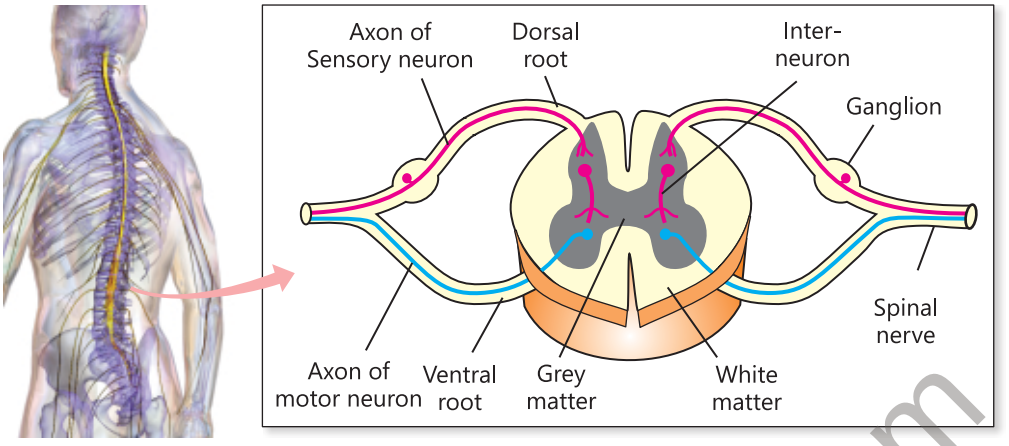


FIGURE 5.8: Spinal Cord and Spinal Nerves

motor neurons. The **dorsal root** contains sensory axons and a ganglion where cell bodies are located. The **ventral root** contains axons of motor neurons.

2. Peripheral Nervous System (PNS)

It is composed of nerves and their ganglia. Humans have 12 pairs of **cranial nerves** and 31 pairs of **spinal nerves**. Some cranial nerves are sensory,

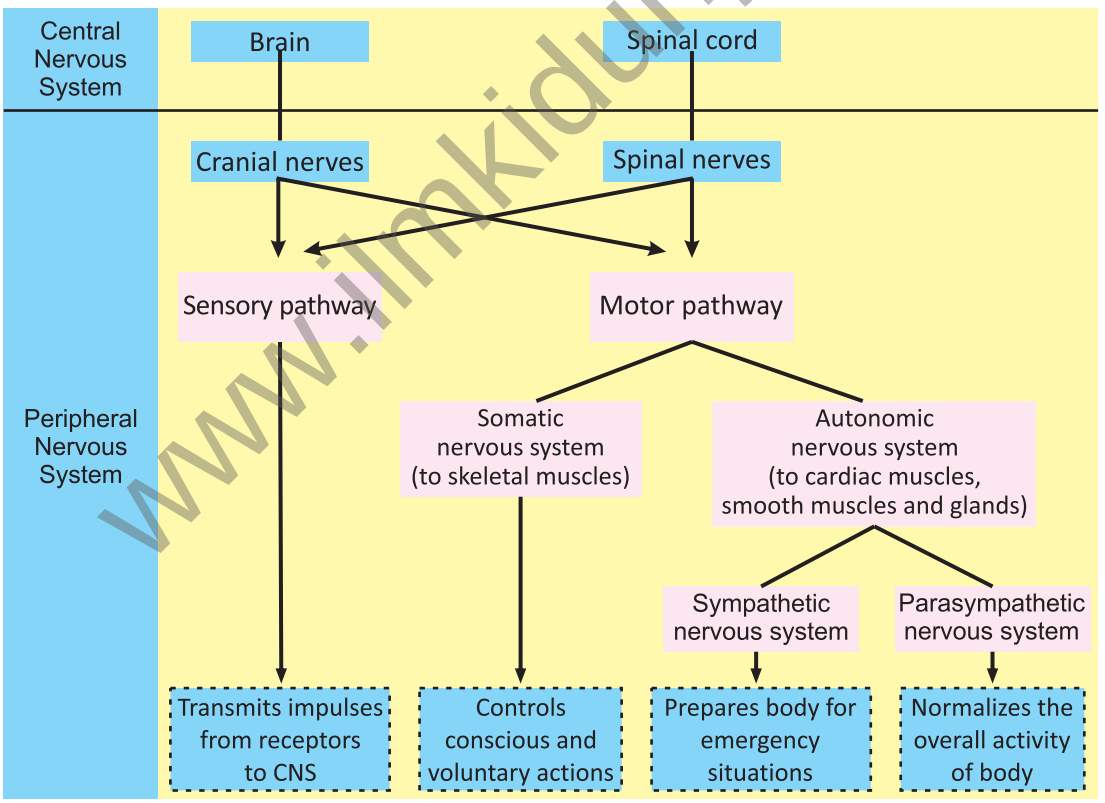


FIGURE 5.9: The Divisions of Nervous System

some are motor and some are mixed. On the other hand, all spinal nerves are mixed. The cranial and spinal nerves make two pathways i.e. sensory pathway (conducting impulses from receptors to CNS) and motor pathway (conducting impulses from CNS to effectors). Motor pathway makes two systems.

Somatic Nervous System: It controls conscious and voluntary actions. It includes all of the motor neurons that are connected to skeletal muscles.

Autonomic Nervous System: It consists of motor neurons that are connected to cardiac muscles, smooth muscle and glands. It is generally without conscious control. Autonomic nervous system consists of sympathetic and parasympathetic systems. **Sympathetic** nervous system prepares body in emergency situations. This is often called the **"fight or flight"** response. This system dilates pupils, speeds up heartbeat, increases breathing rate and inhibits digestion. When there is no stress, **parasympathetic** nervous system normalizes the activity of body. It is called **"rest and digest"** response. It causes pupils to contract, promotes digestion, and normalizes the rate of heartbeat.

Reflex Action

Reflex actions are the **quick involuntary response** in which brain is not involved. Reflex actions are controlled by a reflex

When a receptor is stimulated, it sends information to the brain. The higher centres of brain (regions of cerebrum) analyse the information and send messages for appropriate actions. Such actions are under our conscious control and are called **voluntary actions**. Some regions of brain control actions without any conscious control. Such actions are called **involuntary actions**

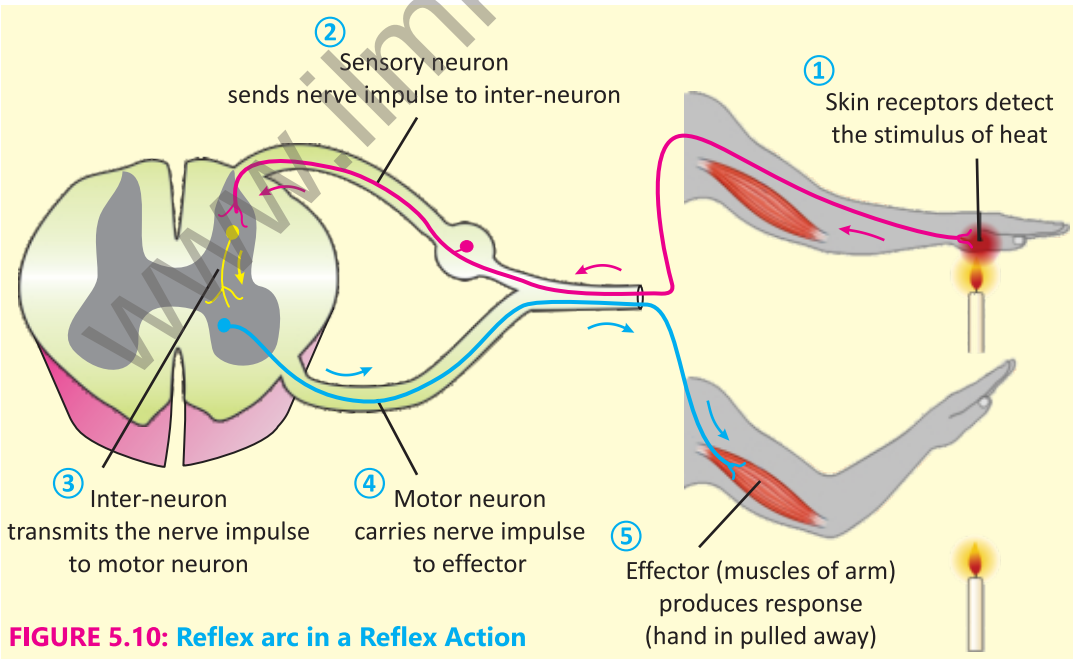


FIGURE 5.10: Reflex arc in a Reflex Action

arc. A **reflex arc** is the pathway of neurons over which the nerve impulses travel during a reflex action.

Example:

We pull our hand away from a hot flame without thinking about it. It is a reflex action and happens in the following way;

1. Skin receptors detect the stimulus of heat.
2. Sensory neuron sends nerve impulse to inter-neuron of spinal cord.
3. The inter-neuron transmits the nerve impulse to motor neuron.
4. The motor neuron carries the nerve impulse to effector (muscles of arm).
5. The effector produces a response by contracting. So, our hand is pulled away.

5.3 ENDOCRINE SYSTEM

It is another system responsible for coordination in animals. The **endocrine system** consists of special endocrine glands which produce and secrete hormones. **Hormones** are the chemicals, released from endocrine gland, which regulate different body functions like growth, reproduction, and glucose level in blood etc.

The secretion of saliva from salivary glands is an involuntary action. When we start chewing food in mouth, brain sends message to salivary glands to secrete saliva. It can also happen when we smell, see or even imagine food.

The endocrine glands do not have ducts to pour their hormones. That is why; they are also called **ductless glands**. They secrete hormones into blood which carries them to different parts of the body. The following are the major endocrine glands and their important hormones.

1. Pituitary Gland

It is a small gland present in the brain. It is suspended from the hypothalamus by a short stalk. There are two lobes of pituitary gland i.e., anterior lobe and posterior lobe.

a. Hormones of Anterior Lobe of Pituitary

1. Growth hormone (GH) stimulates the growth of muscle, bone, and other tissues. If growth hormone is produced more than normal, it results in extra growth in body. This condition is called **gigantism**. On the

Naseer Soomro was once the tallest man in Pakistan. He was born normal size, but developed pituitary gland problem at the age of 10. His pituitary gland produced excess amounts of the **Growth Hormone**.

other hand, if growth hormone is produced less than normal, it results in less growth in the body. This condition is known as **dwarfism**.

2. **Adreno-cortico-tropic hormone (ACTH)** stimulates the adrenal cortex gland to produce its hormones which control stress.

3. **Thyroid-stimulating hormone (TSH)** stimulates the thyroid gland to produce its hormone (thyroxine) which controls metabolism.

4. **Luteinizing hormone (LH)** is needed for the release of egg cells from ovary (ovulation) in females. In males, it stimulates the testes to produce sex hormones. Anterior lobe also produces **follicle stimulating hormone (FSH)** that is involved in the reproductive system.

b. Hormones of Posterior Lobe of Pituitary

The hypothalamus produces two hormones that are stored in the posterior lobe of pituitary gland.

1. **Antidiuretic hormone (ADH)**, also called **vasopressin**, increases the reabsorption of water from nephrons in kidneys. Hence, control blood volume and blood pressure

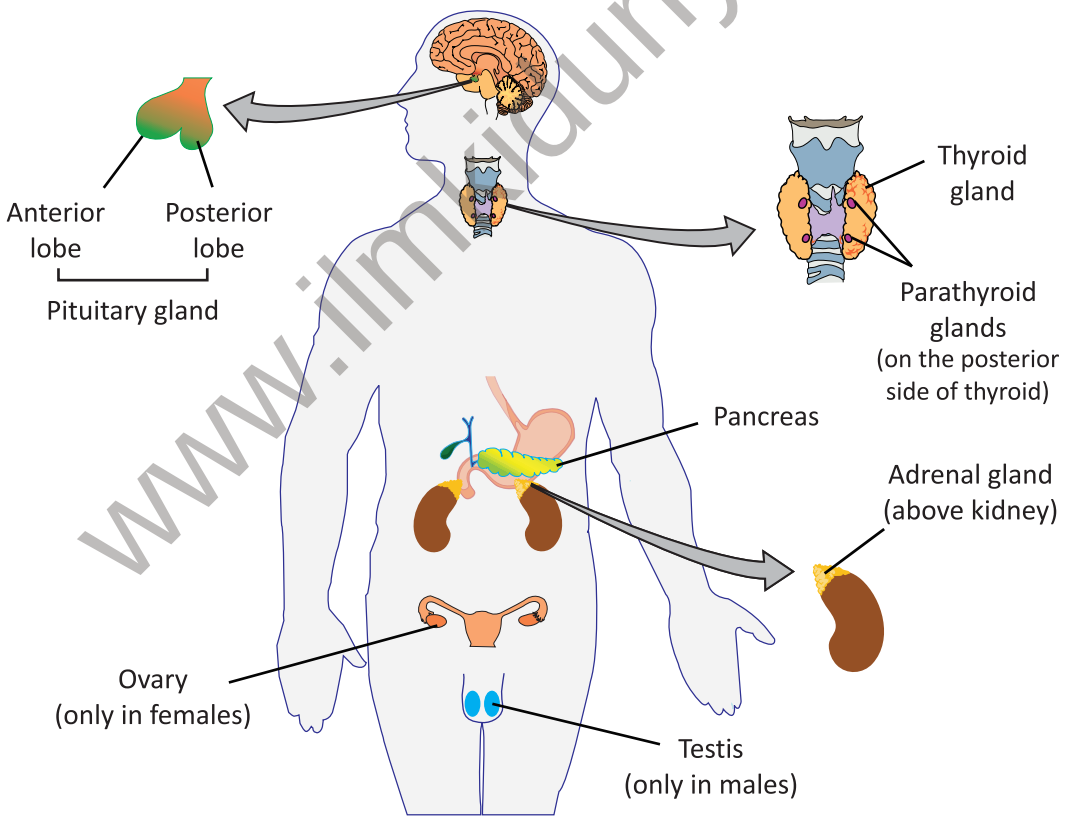


FIGURE 5.11: Important endocrine glands in human body

2. Oxytocin initiates contractions in uterus during childbirth. It also stimulates the flow of milk during breastfeeding.

2. Thyroid gland

It is located near the lower part of the larynx. It secretes two hormones.

i. Thyroxin stimulates enzymes of cellular metabolism (glucose oxidation) for energy production. It increases basal metabolic rate and produces heat.

If thyroxine is produced less than the required amount, cellular metabolism slows down. It results in lethargy, weight gain, low heart rate and low body temperature.

If thyroxine is produced more than required, cellular metabolism becomes faster. It results in weight loss, high blood pressure, high heart rate, and high body temperature.

Iodine is required for the production of thyroxine. If a person lacks iodine in diet, thyroid gland cannot make hormone. In this condition, thyroid gland enlarges. This disorder is called **goitre**. Goiter is now rare in Pakistan because iodine is added to commercially available table salt.

ii. Calcitonin stimulates the transfer of calcium ions from blood to bone, where the calcium ions can be used to generate bone tissue. In this way, calcitonin acts to decrease blood calcium levels.

When there is more parathormone, more calcium is transferred from bones to blood. So, the bones become weak. The deficiency of parathormone results in decreased blood calcium level. It leads to tetany (muscle twitching, cramps and convulsions).

3 Parathyroid glands

The four parathyroid glands are embedded in the back of the thyroid gland. They secrete a hormone called **parathormone**. It stimulates the transfer of calcium ions from the bones to the blood. Thus, it has the opposite effect of calcitonin.

4. Adrenal glands

An adrenal gland is located above each kidney. Each adrenal gland has an inner core, the **medulla**, and an outer layer, the **cortex**.

The **adrenal medulla** produces two hormones: **epinephrine** (adrenaline) and **nor-epinephrine** (nor-adrenaline). These hormones take part in the emergency response of the sympathetic nervous system. When a person is in emergency, the medulla releases its hormones to prepare the body for **"fight or flight"** response. These hormones increase heart rate, blood

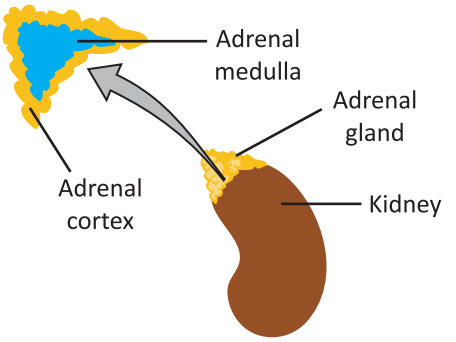


FIGURE 5.12: Parts of adrenal gland

pressure, blood glucose level, and blood flow to the heart and lungs. They also stimulate enlargement of the bronchioles and dilation of the pupils.

The **adrenal cortex** secretes hormones cortisol and aldosterone. **Cortisol** promotes the production of glucose from proteins. **Aldosterone** raises blood pressure and volume by stimulating salt absorption and water retention by the kidneys.

v. Pancreas

Pancreas has two functions. It is a part of digestive system, where it plays the role of a ducted (exocrine) gland and secretes digestive enzymes. It also has special cells called the **islets of Langerhans** (discovered in 1869 by a German student, Paul Langerhans). These cells function as an endocrine gland. They secrete two hormones i.e., **insulin** and **glucagon**. They regulate the level of glucose in the blood. **Insulin** lowers the blood glucose level by stimulating body cells to store glucose or use it for energy. In contrast, **glucagon** stimulates release of glucose from liver into the bloodstream.

In **diabetes mellitus**, the cells are unable to obtain glucose resulting in high blood glucose concentrations. In type-1 diabetes mellitus, the pancreas does not produce required insulin. Such patients are treated with daily injections of insulin. In type-2 diabetes, insulin is produced but the target cells do not respond to it. This type of diabetes can be controlled through exercise and diet.

In diabetes excess glucose inhibits water reabsorption by the kidneys, producing large amounts of urine. It results in dehydration and can cause kidney damage. Excess glucose may also lead to imbalance in water and salt concentration in body. The patients also experience loss of body weight, weakening of muscles and tiredness.

Blood Glucose Concentration (BGC) Test: The amount of glucose in blood is measured by this test. It is used to diagnose diabetes. Blood glucose may be measured on a fasting basis (collected after an 8 to 10 hour fasting), randomly (anytime) and after a meal. The results of some BGC tests are given here.

Table 5.1: Different Blood Glucose Concentrations according to WHO

Blood Glucose After 8 – 10 hours Fast		Blood Glucose 2 hours after a 75-gram Glucose intake	
BGC	**Diagnosis**	**BGC**	**Diagnosis**
From 70 to 99 mg/100mL	Normal	Less than 140 mg/100mL	Normal
From 100 to 125 mg/100mL	Pre-diabetes	From 140 to 200 mg/100mL	Pre-diabetes
126 mg/100mL and above	Diabetes	Over 200 mg/100mL	Diabetes

Table 5.2: Major Endocrine Glands and Their Functions		
Gland	**Hormone**	**Functions**
Anterior lobe of Pituitary	Growth hormone	Regulates development of muscles and bones
	Adrenocorticotropic hormone	Stimulates secretion of cortisol and aldosterone by the adrenal cortex
	Thyroid stimulating hormone	Stimulates the thyroid gland to produce its hormone
	Luteinizing hormone	Stimulates the ovary to release egg Stimulates the testes to produce sex hormones
Posterior lobe of Pituitary	Antidiuretic hormone	Increases the reabsorption of water from nephrons
	Oxytocin	Initiates contractions in uterus during childbirth Stimulates flow of milk from breasts
Thyroid	Thyroxine	Stimulates enzymes of cellular metabolism
	Calcitonin	Decreases blood calcium concentration
Parathyroid	Parathormone	Increases blood calcium concentration
Adrenal medulla	Epinephrine, Norepinephrine	Initiate body's response to stress and the "fight-or-flight" response to danger
Adrenal cortex	Cortisol	Promotes production of glucose from proteins
	Aldosterone	Promotes salt and water retention by the kidneys
Pancreas	Insulin	Lowers the blood glucose level by stimulating body cells to store glucose or use it
	Glucagon	Stimulates release of glucose from liver into blood
Ovaries	Oestrogen and Progesterone	Cause the release of egg from the ovary and regulate female secondary sex characteristics
Testes	Androgens (Testosterone)	Regulate male secondary sex characteristics

6. Gonads

Gonads (ovaries in females and testes in males) are gamete-producing organs. They also produce sex hormones.

In females, the ovaries secrete hormones called **estrogen** and **progesterone**. These hormones cause the release of egg from the ovary and regulate female secondary sex characteristics (e.g., development of breast).

In males, the testes secrete a group of sex hormones called **androgens (e.g., testosterone)**. It regulates male secondary sex characteristics (e.g., growth of hair on face and coarseness of voice etc.)

EXERCISE

A. Select the correct answers for the following questions.

1. Schwann cells are the supporting cells for neurons. They make:
   a) Cell body b) Axon c) Myelin sheath d) Dendrites
2. Which part of the brain controls balance while riding a bicycle?
   a) Cerebrum b) Medulla c) Cerebellum d) Spinal cord
3. Which part is responsible for sensations of temperature, hunger, thirst, and sleep?
   a) Hypothalamus b) Thalamus c) Pons d) Cerebellum
4. If a patient cannot remember things, which part of their brain may be affected?
   a) Cerebrum b) Cerebellum c) Medulla d) Spinal cord
5. During danger, which system activates quickly?
   a) Parasympathetic b) Skeletal c) Endocrine d) Sympathetic
6. Why are reflex actions faster than normal actions?
   a) Brain processes them quickly b) Brain is not involved
   c) Signals move slower d) They need thinking
7. Which of these acts as exocrine as well as endocrine gland?
   a) Pituitary b) Thyroid c) Adrenal d) Pancreas
8. The chemical messengers of the endocrine system are called;
   a) Neurotransmitters b) Hormones c) Neurons d) Enzymes
9. What could happen if hormone of parathyroid gland were missing?
   a) Low calcium levels b) High blood sugar
   c) Weak muscles d) Poor digestion
10. Which endocrine gland prepares the body for "fight or flight" response?
    a) Thyroid b) Pituitary c) Adrenal d) Pancreas

B. Write short answers.

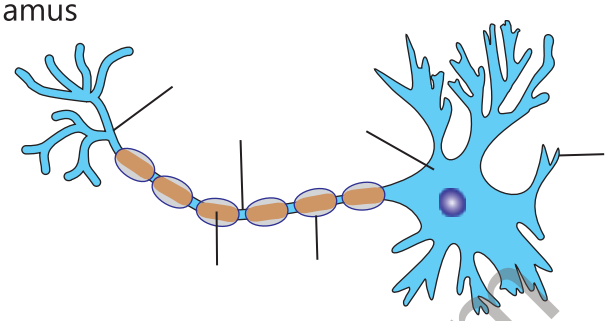
1. Define stimulus with examples.
2. Differentiate between sensory, motor, and inter-neurons.
3. Define reflex action and the reflex arc.
4. Differentiate between the following:

(a) Dendrite and axon

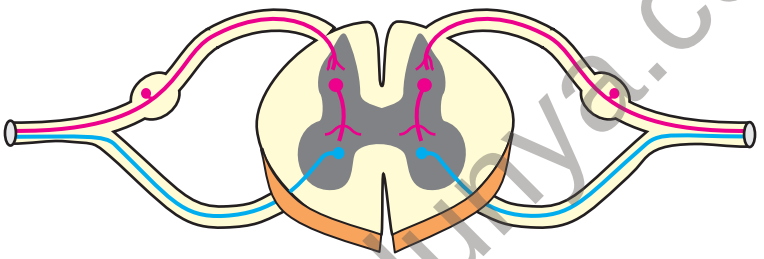
(b) Cerebrum and Cerebellum

(c) Thalamus and Hypothalamus

5. Identify the diagram and label the different parts.



6. Identify the following diagram, and locate the white matter, grey matter, three types of neuron, and ganglia.



C. Write answers in detail.

1. Describe the structure of a neuron and support your answer with a labelled diagram.
2. What are the differences and similarities among the three types of neurons?
3. Write the major functions of the forebrain, midbrain, and hindbrain.
4. What is meant by reflex action? Describe an example of reflex action and identify the reflex arc in this example.
5. State the hormones of the pituitary gland and write their functions.
6. Write notes on adrenal glands, pancreas, ovaries and testes.

D. Inquisitive questions

1. Why is the spinal cord important in reflex actions?
2. Why is adrenaline called an "emergency hormone"?
3. If pancreas releases too much insulin, what happens to blood sugar?
4. If the medulla of a patient is injured, which function is most at risk?