Chapter 18: Neural Control and Coordination

Exercises — Exercises

Q1 Briefly describe the structure of the Brain.

SOLUTION

The human brain is enclosed within the skull and covered by three cranial meninges: the outer dura mater, the middle arachnoid, and the inner pia mater (in contact with brain tissue).

The brain is divided into three major regions:

1. Forebrain — consists of cerebrum, thalamus, and hypothalamus.
   - Cerebrum: the largest part; divided longitudinally into left and right cerebral hemispheres connected by the corpus callosum. The surface (cerebral cortex / grey matter) contains motor areas, sensory areas, and association areas (responsible for memory, communication, intersensory associations). The inner white matter is myelinated fibre tracts.
   - Thalamus: a major relay/coordinating centre for sensory and motor signals.
   - Hypothalamus: lies at the base of the thalamus; controls body temperature, hunger, thirst, and circadian rhythms; contains neurosecretory cells that secrete hypothalamic hormones.
   - Limbic system: inner parts of cerebral hemispheres together with amygdala, hippocampus, etc.; involved in emotional responses, sexual behaviour, and motivation.

2. Midbrain — located between the forebrain (thalamus/hypothalamus) and hindbrain (pons). A cerebral aqueduct passes through it. Its dorsal surface has four round lobes called corpora quadrigemina.

3. Hindbrain — comprises pons, cerebellum, and medulla oblongata.
   - Pons: fibre tracts that interconnect different brain regions.
   - Cerebellum: highly folded (convoluted) surface; integrates information from the semicircular canals (ear) and auditory system for balance and coordination.
   - Medulla oblongata: connected to the spinal cord; controls vital centres for respiration, cardiovascular reflexes, and gastric secretions.

The midbrain, pons, and medulla together form the brain stem, which connects the brain to the spinal cord.

Answer: The brain has three regions — forebrain (cerebrum, thalamus, hypothalamus + limbic system), midbrain (corpora quadrigemina), and hindbrain (pons, cerebellum, medulla oblongata) — enclosed by three meninges (dura mater, arachnoid, pia mater) inside the skull.

Q2 Compare the following:
(a) Central neural system (CNS) and Peripheral neural system (PNS)
(b) Resting potential and action potential

SOLUTION

(a) Central Neural System (CNS) vs Peripheral Neural System (PNS):

CNS:
- Consists of the brain and spinal cord.
- Acts as the site of information processing and control.
- Integrates all incoming sensory information and generates coordinated responses.
- Protected by skull (brain) and vertebral column (spinal cord) and by meninges.

PNS:
- Comprises all the nerves of the body that connect the CNS to the rest of the body.
- Divided into somatic neural system (relays impulses to skeletal muscles) and autonomic neural system (controls involuntary organs and smooth muscles).
- Autonomic system is further divided into sympathetic and parasympathetic divisions.
- Has two types of fibres: afferent (transmit impulses from tissues to CNS) and efferent (transmit regulatory impulses from CNS to tissues).

(b) Resting Potential vs Action Potential:

Resting Potential:
- The electrical potential difference across the neural membrane when the neuron is NOT conducting an impulse.
- The outer surface is positively charged and the inner surface is negatively charged — the membrane is polarised.
- Maintained by selective permeability: the axonal membrane is permeable to K+ and impermeable to Na+ and negatively charged proteins.
- The sodium-potassium pump (3 Na+ out, 2 K+ in) maintains the ionic gradients.

Action Potential:

- The reversal of electrical charge across the membrane at a specific site when a stimulus is applied — also called a nerve impulse.
- The membrane at the stimulated site becomes freely permeable to Na+; rapid influx of Na+ causes the outer surface to become negative and the inner surface to become positive (depolarisation).
- It is a brief, all-or-nothing electrical event that propagates along the axon.
- After depolarisation, K+ diffuses outward to restore the resting potential (repolarisation).

Answer: (a) CNS = brain + spinal cord (processing/control centre); PNS = all body nerves (afferent/efferent; somatic + autonomic). (b) Resting potential = polarised state at rest (outer +, inner -); action potential = reversed polarity (depolarisation) during a nerve impulse when Na+ rushes in.

Q3 Explain the following processes:
(a) Polarisation of the membrane of a nerve fibre
(b) Depolarisation of the membrane of a nerve fibre
(c) Transmission of a nerve impulse across a chemical synapse

SOLUTION

(a) Polarisation of the membrane of a nerve fibre:

When a nerve fibre is at rest (not conducting an impulse), the axonal membrane is in a polarised state:

- The membrane is more permeable to K+ and nearly impermeable to Na+.
- It is also impermeable to negatively charged proteins in the axoplasm.
- As a result, the axoplasm inside has high K+ and low Na+ concentrations; outside has high Na+ and low K+.
- The sodium-potassium pump actively transports 3 Na+ outward and 2 K+ inward, maintaining these concentration gradients.
- Consequently, the outer surface of the axonal membrane is positively charged and the inner surface is negatively charged.
- This charge difference across the resting membrane is called the resting potential, and the membrane in this state is said to be polarised.

(b) Depolarisation of the membrane of a nerve fibre:

When a stimulus of adequate strength is applied to the polarised membrane:

- The membrane at the stimulated site (e.g., point A) becomes freely permeable to Na+.
- There is a rapid influx of Na+ into the axoplasm at that site.
- This influx reverses the polarity: the outer surface becomes negatively charged and the inner surface becomes positively charged.
- This reversal of polarity is called depolarisation.
- The electrical potential difference at this site during depolarisation is called the action potential (nerve impulse).
- The action potential then moves along the axon: local current flows inward at the depolarised site and outward at adjacent resting sites, depolarising them in sequence, thus conducting the impulse.
- Depolarisation is short-lived: it is quickly followed by increased K+ permeability, K+ diffuses out, and the resting potential is restored (repolarisation).

(c) Transmission of a nerve impulse across a chemical synapse:

- A chemical synapse consists of a pre-synaptic neuron and a post-synaptic neuron separated by a fluid-filled gap called the synaptic cleft.
- The axon terminal of the pre-synaptic neuron contains synaptic vesicles filled with neurotransmitters.
- When an action potential (impulse) arrives at the axon terminal, it stimulates the synaptic vesicles to move towards and fuse with the pre-synaptic membrane.
- The neurotransmitters are released (by exocytosis) into the synaptic cleft.
- The neurotransmitters diffuse across the synaptic cleft and bind to specific receptors on the post-synaptic membrane.
- This binding opens specific ion channels in the post-synaptic membrane, allowing ions to enter.
- The influx of ions generates a new electrical potential (excitatory or inhibitory) in the post-synaptic neuron.
- If the new potential is excitatory and of sufficient magnitude, a new action potential is generated in the post-synaptic neuron, thus transmitting the impulse.

Answer: (a) Polarisation: resting membrane is negative inside, positive outside due to low Na+ permeability and Na+-K+ pump activity. (b) Depolarisation: stimulus causes Na+ influx, reversing polarity (outer negative, inner positive) — this is the action potential. (c) Chemical synapse: action potential triggers neurotransmitter release from vesicles into synaptic cleft; neurotransmitters bind post-synaptic receptors, opening ion channels and generating a new potential.

Q4 Draw labelled diagrams of the following:
(a) Neuron
(b) Brain

SOLUTION

(a) Labelled Diagram of a Neuron:

A neuron has three main structural parts. The labels to include are:

- Dendrites: short, branched fibres projecting from the cell body; contain Nissl's granules; receive impulses and transmit them towards the cell body.
- Cell body (Soma / Cyton): contains the nucleus, cytoplasm with typical organelles, and Nissl's granules.
- Nissl's granules: granular bodies in the cytoplasm and dendrites (characteristic of neurons).
- Nucleus: present in the cell body.
- Axon: the single long fibre arising from the cell body; transmits impulses away from the cell body.
- Schwann cells: surround the axon and form the myelin sheath.
- Myelin sheath: insulating lipid-rich covering formed by Schwann cells around a myelinated axon.
- Node of Ranvier: gap between two adjacent myelin sheaths along the axon.
- Axon terminal / Synaptic knob: bulb-like endings at the branched distal end of the axon; contain synaptic vesicles filled with neurotransmitters.
- Synaptic vesicles: present in the synaptic knob; contain neurotransmitters.

Description of the figure: Draw an elongated cell body with multiple short branching dendrites at one end. A single long axon extends from the other end, wrapped in Schwann cells forming a segmented myelin sheath with visible gaps (nodes of Ranvier). The axon ends in branched terminals with enlarged synaptic knobs.

(b) Labelled Diagram of the Human Brain (sagittal section):

The labels to include are:

Forebrain:
- Cerebrum: the large dome-shaped folded (convoluted) structure; the most prominent part.
- Cerebral hemisphere: left and right halves of the cerebrum.
- Corpus callosum: the band of nerve fibres connecting the two cerebral

hemispheres.
- Thalamus: oval mass below the cerebrum, acting as a relay centre.
- Hypothalamus: below the thalamus; controls homeostatic functions.

Midbrain:
- Cerebral aqueduct: the canal passing through the midbrain.
- Corpora quadrigemina: four round lobes on the dorsal surface of the midbrain.

Hindbrain:
- Pons: the part of the brain stem connecting different brain regions.
- Cerebellum: the cauliflower-like structure with convoluted surface at the back; controls coordination and balance.
- Medulla oblongata (Medulla): lowest part of the brain, continuous with the spinal cord; controls vital involuntary functions.

Other labels:
- Spinal cord: shown extending below the medulla.
- Dura mater / Arachnoid / Pia mater: the three meningeal layers covering the brain.

Answer: (a) Neuron labels: dendrites, cell body, Nissl's granules, nucleus, axon, Schwann cell, myelin sheath, node of Ranvier, synaptic knob, synaptic vesicles. (b) Brain labels: cerebrum, corpus callosum, thalamus, hypothalamus (forebrain); cerebral aqueduct, corpora quadrigemina (midbrain); pons, cerebellum, medulla oblongata, spinal cord (hindbrain).

Q5 Write short notes on the following:
(a) Neural coordination
(b) Forebrain
(c) Midbrain
(d) Hindbrain
(e) Synapse

SOLUTION

(a) Neural Coordination:

Neural coordination refers to the rapid, point-to-point communication system by which the neural system integrates and coordinates the activities of all organs and organ systems in the body. It is achieved through a network of specialised cells called neurons. The neural system, together with the endocrine system, maintains

homeostasis and ensures synchronised functioning of the body. Neural coordination is fast and uses electrical impulses (action potentials) transmitted along neurons and across synapses. It enables voluntary movements, reflexes, sensory perception, and regulation of involuntary functions.

(b) Forebrain:

The forebrain consists of three parts:
- Cerebrum: the largest part of the brain; divided into left and right hemispheres connected by the corpus callosum. The grey matter (cerebral cortex) contains motor areas, sensory areas, and association areas (for memory, communication, intersensory associations). The white matter (inner layer) is composed of myelinated fibres.
- Thalamus: a major coordinating centre for sensory and motor signalling; relays information between the cerebral cortex and other brain areas.
- Hypothalamus: lies at the base of the thalamus; controls body temperature, hunger, thirst, and circadian rhythms; contains neurosecretory cells secreting hypothalamic hormones.
The inner parts of the cerebral hemispheres together with the amygdala, hippocampus, etc. form the limbic system, which regulates emotional responses, sexual behaviour, and motivation.

(c) Midbrain:

The midbrain is located between the forebrain (thalamus/hypothalamus) and the hindbrain (pons). It has a canal called the cerebral aqueduct passing through it. The dorsal portion consists of four round lobes (swellings) called corpora quadrigemina. The midbrain receives and integrates visual, tactile, and auditory inputs and is part of the brain stem.

(d) Hindbrain:

The hindbrain comprises three parts:
- Pons: fibre tracts that interconnect different regions of the brain; part of the brain stem.
- Cerebellum: has a highly convoluted surface (providing space for many neurons); integrates information from the semicircular canals and auditory system; controls balance, posture, and coordination of voluntary movements.
- Medulla oblongata: the lowest part of the brain; connects to the spinal cord; contains vital centres controlling respiration, cardiovascular reflexes, and gastric secretions.

Together, midbrain, pons, and medulla form the brain stem.

(e) Synapse:

A synapse is a junction between two neurons (or between a neuron and an effector cell) through which nerve impulses are transmitted. There are two types:
- Electrical synapse: the membranes of pre- and post-synaptic neurons are in very close proximity; electrical current flows directly from one neuron to the next. Transmission is fast; rare in humans.
- Chemical synapse: the pre- and post-synaptic membranes are separated by a fluid-filled synaptic cleft. When an impulse arrives at the pre-synaptic terminal, synaptic vesicles fuse with the membrane and release neurotransmitters into the cleft. These bind to receptors on the post-synaptic membrane, opening ion channels and generating a new potential (excitatory or inhibitory) in the post-synaptic neuron. Chemical synapses are the most common type in the human nervous system.

Answer: (a) Neural coordination: rapid point-to-point communication via neurons maintaining homeostasis. (b) Forebrain: cerebrum (cortex, motor/sensory/association areas), thalamus (relay centre), hypothalamus (homeostasis), limbic system (emotions). (c) Midbrain: corpora quadrigemina, cerebral aqueduct; integrates sensory inputs. (d) Hindbrain: pons (fibre tracts), cerebellum (balance/coordination), medulla (vital centres). (e) Synapse: junction between neurons; electrical (direct current) or chemical (neurotransmitter-mediated).

Q6 Give a brief account of Mechanism of synaptic transmission.

SOLUTION

Synaptic transmission is the process by which a nerve impulse is passed from one neuron (pre-synaptic) to another (post-synaptic) across a synapse.

At a chemical synapse (the most common type), the mechanism is as follows:

1. Arrival of impulse: An action potential travels along the axon and reaches the axon terminal (synaptic knob) of the pre-synaptic neuron.

2. Release of neurotransmitters: The action potential stimulates the synaptic vesicles in the axon terminal to move toward and fuse with the pre-synaptic membrane. The neurotransmitters stored in the vesicles are released by exocytosis into the synaptic cleft.

3. Diffusion across the synaptic cleft: The neurotransmitters diffuse across the fluid-filled synaptic cleft.

4. Binding to receptors: The neurotransmitters bind to specific receptor proteins on the post-synaptic membrane.

5. Generation of a new potential: The binding of neurotransmitters opens specific ion channels in the post-synaptic membrane, allowing ions to flow in or out. This generates a new electrical potential in the post-synaptic neuron. The potential can be:

- Excitatory: if it depolarises the post-synaptic membrane and triggers a new action potential.
- Inhibitory: if it hyperpolarises the post-synaptic membrane and prevents action potential generation.

At electrical synapses, the membranes are so close that electrical current flows directly from the pre-synaptic to the post-synaptic neuron without any chemical intermediary. This makes electrical synaptic transmission faster than chemical synaptic transmission.

Answer: At a chemical synapse: action potential arrives at pre-synaptic terminal → synaptic vesicles fuse with membrane and release neurotransmitters into the synaptic cleft → neurotransmitters bind to post-synaptic receptors → ion channels open → new excitatory or inhibitory potential generated in post-synaptic neuron. Electrical synapses allow direct current flow (faster, rarer).

Q7 Explain the role of Na+ in the generation of action potential.

SOLUTION

Sodium ions (Na+) play a central and decisive role in the generation of an action potential:

Resting state (before stimulus):
- In the resting neuron, the axonal membrane is nearly impermeable to Na+.
- The sodium-potassium pump actively transports 3 Na+ out of the cell for every 2 K+ pumped in.
- As a result, Na+ concentration is high outside the axon and low inside, creating a concentration gradient.
- The outer surface is positively charged and the inner surface is negatively charged (resting potential = polarised state).

Upon stimulation (generation of action potential):
- When an adequate stimulus is applied at a site on the axonal membrane, the membrane at that site suddenly becomes freely permeable to Na+.
- Na+ rushes rapidly into the axoplasm down its concentration gradient (Na+ influx).
- This rapid influx of positive charges (Na+) into the interior of the axon reverses the polarity of the membrane at that site:
  - The outer surface becomes negatively charged.
  - The inner surface becomes positively charged.
- This reversal of polarity (depolarisation) constitutes the action potential (nerve impulse).

Propagation:
- The depolarised site now has a charge difference with the adjacent resting membrane, causing local currents to flow.
- These local currents depolarise the adjacent site, triggering Na+ influx there, and thus the action potential propagates along the axon.

Repolarisation:
- The increased Na+ permeability is extremely short-lived.
- It is quickly followed by increased K+ permeability: K+ diffuses outward, restoring the original resting potential.

In summary, the sudden surge of Na+ into the axon is the direct ionic event that generates the action potential.

Answer: Na+ generates action potential by sudden influx: stimulus makes membrane permeable to Na+, which rushes inward, reversing polarity (outer surface becomes negative, inner becomes positive) — this depolarisation IS the action potential. Na+ influx is short-lived; subsequent K+ efflux restores resting potential.

Q8 Differentiate between:
(a) Myelinated and non-myelinated axons
(b) Dendrites and axons
(c) Thalamus and Hypothalamus
(d) Cerebrum and Cerebellum

SOLUTION

(a) Myelinated vs Non-myelinated Axons:

Myelinated axons:
- Enveloped by Schwann cells that wrap around the axon to form a multi-layered myelin sheath.
- Gaps between adjacent myelin sheaths are called nodes of Ranvier.
- Impulse conduction is faster (saltatory conduction — the impulse jumps from one node to the next).
- Found in spinal and cranial nerves.

Non-myelinated axons:
- Enclosed by a Schwann cell that does NOT form a myelin sheath around the axon.
- No nodes of Ranvier.
- Impulse conduction is slower (continuous conduction along the entire membrane).
- Commonly found in the autonomic and somatic neural systems.

(b) Dendrites vs Axons:

Dendrites:
- Short, highly branched fibres projecting from the cell body.
- Contain Nissl's granules.
- Transmit impulses TOWARDS the cell body.
- A neuron typically has multiple dendrites.

Axons:
- A single, long fibre arising from the cell body.
- The distal end is branched, ending in synaptic knobs (containing synaptic vesicles with neurotransmitters).
- Transmit impulses AWAY from the cell body to a synapse or neuro-muscular junction.
- May be myelinated or non-myelinated.

(c) Thalamus vs Hypothalamus:

Thalamus:
- Located in the forebrain; the cerebrum wraps around it.
- Acts as a major coordinating/relay centre for sensory and motor signalling.
- Does not directly secrete hormones.

Hypothalamus:

- Lies at the base of the thalamus.
- Controls body temperature, hunger, thirst, and circadian rhythms.
- Contains neurosecretory cells that secrete hypothalamic hormones (acts as a neuroendocrine structure).
- Along with the limbic system, regulates sexual behaviour and emotional reactions.

(d) Cerebrum vs Cerebellum:

Cerebrum:
- The largest part of the brain; part of the forebrain.
- Divided into left and right cerebral hemispheres connected by the corpus callosum.
- Cerebral cortex (grey matter) has motor areas, sensory areas, and association areas.
- Controls voluntary movements, intelligence, memory, speech, vision, hearing, and behaviour.

Cerebellum:
- Part of the hindbrain.
- Has a highly convoluted surface to accommodate more neurons.
- Integrates inputs from the semicircular canals (vestibular system) and auditory system.
- Controls coordination of voluntary movements, posture, and balance; does NOT initiate movement.

Answer: (a) Myelinated: Schwann cells form myelin sheath, nodes of Ranvier, fast saltatory conduction (cranial/spinal nerves); non-myelinated: no myelin, slower conduction (autonomic/somatic). (b) Dendrites: short, branched, carry impulses TO cell body; axons: long, single, carry impulses AWAY from cell body. (c) Thalamus: sensory/motor relay; hypothalamus: controls temperature/hunger/thirst, secretes hormones. (d) Cerebrum: largest forebrain structure, cognition/voluntary control; cerebellum: hindbrain, coordination/balance.

Q9 Answer the following:
(a) Which part of the human brain is the most developed?
(b) Which part of our central neural system acts as a master clock?

SOLUTION

(a) The most developed part of the human brain is the Cerebrum.

The cerebrum forms the major part of the human brain and is the site for higher mental functions. Its cerebral cortex (grey matter) is highly folded (convoluted) and contains motor areas, sensory areas, and large association areas responsible for complex functions like memory, intelligence, communication, intersensory associations, and conscious thought. The human cerebrum is proportionally the largest and most elaborately developed among all animals.

(b) The Hypothalamus acts as the master clock (biological clock) of our central neural system.

The hypothalamus contains a group of neurosecretory cells that control circadian (24-hour) rhythms of the body. It regulates the body's biological clock by controlling sleep-wake cycles, body temperature fluctuations, hormone release patterns, and other time-dependent physiological processes. The suprachiasmatic nucleus (SCN) within the hypothalamus is the primary circadian pacemaker.

Answer: (a) Cerebrum — the largest, most complex part; site of consciousness, memory, intelligence, and voluntary control. (b) Hypothalamus — contains the master circadian clock (suprachiasmatic nucleus) that controls 24-hour biological rhythms.

Q10 Distinguish between:
(a) afferent neurons and efferent neurons
(b) impulse conduction in a myelinated nerve fibre and unmyelinated nerve fibre
(c) cranial nerves and spinal nerves

SOLUTION

(a) Afferent Neurons vs Efferent Neurons:

Afferent neurons:
- Also called sensory neurons.
- Transmit nerve impulses FROM tissues/organs/sense organs (periphery) TO the CNS (brain and spinal cord).
- Carry sensory information (pain, temperature, pressure, etc.) to the central

processing centre.

Efferent neurons:
- Also called motor neurons.
- Transmit regulatory impulses FROM the CNS TO peripheral tissues and organs (muscles, glands, etc.).
- Carry motor commands from the CNS to effectors, producing a response.

(b) Impulse conduction in myelinated vs unmyelinated nerve fibre:

Myelinated nerve fibre:
- The axon is wrapped in a myelin sheath (formed by Schwann cells), with exposed nodes of Ranvier between successive sheaths.
- Impulse conduction occurs by saltatory conduction: the action potential 'jumps' from one node of Ranvier to the next, skipping the myelinated internodal regions.
- This is considerably faster than continuous conduction.
- Less energy is expended per unit length since depolarisation occurs only at the nodes.
- Found in spinal and cranial nerves.

Unmyelinated nerve fibre:
- The axon is enclosed by a Schwann cell that does not form a myelin sheath; no nodes of Ranvier.
- Impulse conduction is continuous (wave-by-wave depolarisation along the entire membrane surface).
- Conduction is slower and requires more energy.
- Commonly found in the autonomic and somatic neural systems.

(c) Cranial Nerves vs Spinal Nerves:

Cranial nerves:
- Arise from the brain (arise directly from various parts of the brain — forebrain, midbrain, hindbrain).
- In humans, there are 12 pairs of cranial nerves.
- They carry sensory, motor, or mixed (both) impulses to/from the head, face, neck, and some thoracic and abdominal organs.
- The nerve fibres are myelinated.
- Examples: olfactory (I), optic (II), oculomotor (III), vagus (X) nerves.

Spinal nerves:
- Arise from the spinal cord.

- In humans, there are 31 pairs of spinal nerves.
- All spinal nerves are mixed nerves (both sensory/afferent and motor/efferent fibres).
- Carry impulses between the spinal cord and the trunk and limbs.
- Each spinal nerve has a dorsal root (sensory fibres) and a ventral root (motor fibres).

Answer: (a) Afferent (sensory): periphery to CNS; efferent (motor): CNS to periphery. (b) Myelinated: saltatory conduction at nodes of Ranvier — fast, energy-efficient; unmyelinated: continuous conduction along the entire membrane — slower. (c) Cranial: 12 pairs from brain, sensory/motor/mixed; spinal: 31 pairs from spinal cord, all mixed (dorsal root = sensory, ventral root = motor).