The nervous system performs 3 functions:

1.

2.

3.

Stimulus \rightarrow \text{receptors} \rightarrow \text{CO-ORDINATING SYSTEM} \rightarrow \text{effectors} \rightarrow \text{Response}

In mammals, there are many sense organs (receptors) to receive stimuli. In order to react to external and internal stimuli, responses are made through effectors. The receptors have to be co-ordinated with the effectors so that appropriate responses can be made. Thus co-ordination is necessary to link many activities together. There are two co-ordinating systems:

1. Nervous co-ordination by transmission of nervous impulses
2. Chemical co-ordination by chemicals from endocrine glands

In contrast to the endocrine system, the nervous system responds virtually instantaneously to a stimulus.

- In lower animals, the nervous system simply consists of a nerve net
- In higher animals like mammals, the nervous system consists of:
  1. The Central Nervous System which includes the brain and the spinal cord
  2. The Peripheral Nervous System which includes the cranial nerves and the spinal nerves

The portion which activates involuntary responses is known as the Autonomic Nervous System whereas that activating voluntary responses is called the Somatic System. The collection of information from the internal and external environment is carried out by the receptors. Along with the neurons (nerve cells) which transmit this information, the receptors form the sensory system. The processing and integration of this information is performed by the CNS. The final function whereby information is transmitted to effectors, which act upon it, is carried out by the effector (motor) system.
27.1 The Nervous Tissue & the Nerve Impulse
- Neuron (nerve cell) consists of a cell body and nerve fibres
- All living cells maintain a potential difference (membrane potential) across their membranes
- Ganglion: group of cell bodies together

Dendron: part of nerve fibre transmitting impulses towards the cell body
Axon: part of the nerve fibre transmitting impulses away from the cell body

Myelin sheath: a fatty layer outside the nerve fibre, functions:

**Types of Neurons**

There are three types of neurons:

1. The motor neuron transmits nerve impulses from the CNS to the effectors
2. The sensory neuron transmits nerve impulses from the receptors to the CNS
3. The associate neuron connects the sensory neuron to the motor neuron and also neurons in the CNS

![Schwann cell and axon](image)

**Fig. 1 Schwann cell and axon**

![Healthy nerve cell](image)

**Fig. 2(a) Healthy nerve cell**

![Damaged nerve cell in multiple sclerosis](image)

**Fig. 2(b) Damaged nerve cell in multiple sclerosis**
27.1.1 Resting Potential
- membrane of a neuron is negatively charged internally with respect to outside
- potential difference: around 50 - 90 mV (resting potential)
- membrane is said to be polarized with the distribution of 4 ions:
  \( K^+ \), \( Na^+ \), \( Cl^- \) and \( COO^- \) ions
- **Cation pumps** (Na pumps) maintain active transport of \( K^+ \) ions in and \( Na^+ \) out but with permeability of \( K^+ \) ions 20 times higher than \( Na^+ \) ions, therefore \( K^+ \) ion loss from inside is greater than \( Na^+ \) gain → a net loss of \( K^+ \) from inside → -ve charge inside

27.1.2 Action Potential
- an **action potential** is produced when membrane of neuron is stimulated, the change is reversed:
  inside was -70 mV changes to +40 mV and membrane is said to be **depolarized**
- within about 2 milliseconds, the same portion of the membrane returns to resting potential of -70 mV inside → **repolarization**
- provided the stimulus exceeds a certain value (the **threshold value**), an action potential results
- **All or none response**: above the threshold value, the size of the AP remains constant, regardless of the size of the stimulus
- The size of the AP does not decrease as it is transmitted along the neuron but always remains the same

27.1.3 Ion Movement
- A P is produced due to a **sudden increase in the permeability of the membrane to \( Na^+ \)**:
  \( Na^+ \) ions rush into neuron to depolarize the membrane, then further increases its permeability to \( Na^+ \), leading to greater influx & further depolarization → positive feedback
  When inside becomes sufficiently positively charged, permeability to \( Na^+ \) ions start to decrease.
  At the same time as \( Na^+ \) begins to move inward, \( K^+ \) begins to move in the opposite direction along a diffusion gradient slowly until the membrane is **repolarized**

** Proteins of the neurone membrane possess channels which allow \( Na^+ \) ions to pass through while others permit the movement of \( K^+ \) ions. In the resting state, these channels are closed, but become depolarized and open when stimulated. The gates of the sodium channel open more quickly than those of the potassium channel. This explains why sodium ions entering the neurone cause depolarization followed by the potassium ions leaving which cause repolarization.
27.1.4 Refractory Period

The refractory period is about 1 msec after the influx of Na⁺ ions, the membrane cannot be stimulated to generate another AP.

Importance of refractory period:
1. The AP can only be propagated in one direction.
2. Set an upper limit to the frequency of impulses along a neuron.

Absolute refractory period:
lasts for about 1 msec during which no impulses can be propagated however intense the stimulus.

Relative refractory period:
lasts for about 5 msec during which new impulses can only be generated if the stimulus is more intense than the normal threshold.

Determination of impulse frequency
Where the stimulus is at the threshold value the excitability of the nerve must return to normal before a new action potential can be formed. In the time interval shown, this allows just 2 action potentials to pass i.e. a low frequency of impulses. Where the stimulus exceeds the threshold value a new action potential can be created before neurone excitability returns to normal. In the time interval shown this allows six action potentials to pass, i.e. a high frequency of impulses.

27.1.5 Transmission of The Nervous Impulse
- greater diameter, faster transmission; myelinated faster than non-myelinated.
Transmission of an impulse along an unmyelinated neuron

1. At resting potential there is a high concentration of sodium ions outside and a high concentration of potassium ions inside.

2. When the neuron is stimulated sodium ions rush into the axon along a concentration gradient. This causes depolarization of the membrane.

3. Localized electrical circuits are established which cause further influx of sodium ions and no progression of the impulse. Behind the impulse, potassium ions begin to leave the axon along a concentration gradient.

4. As the impulse progresses, the influx of potassium ions causes the neurone to become repolarized behind the impulse.

5. After the impulse has passed and the neurone is repolarized sodium ions are once again actively expelled in order to increase the external concentration and so allow the passage of another impulse.

27.2 The Synapse: a small gap between 2 neurons

27.2.1 Structure of the Synapse

- synaptic knob contains many metacentre, microfilaments & synaptic vesicle containing a transmitter substance (acetylcholine or noradrenaline);
- presynaptic neuron: before the synapse
- postsynaptic neuron: behind the synapse with receptor molecules
- synaptic cleft: a narrow gap about 20 nm wide

27.2.2 Synaptic Transmission

When a nerve impulse arrives at the synaptic knob it alters the permeability of the presynaptic membrane to Ca, which therefore enters

- synaptic vesicle fuse with membrane & discharge its transmitter substance
- transmitter diffuses across synaptic cleft & fuses with receptor molecules
- alters permeability of postsynaptic membrane to Na+

- excitatory postsynaptic potential (EPSP)
- EPSP by summation exceeds threshold
- Action potential

OR in inhibitory synapses: membrane more -ve, therefore more difficult to generate an action potential
Transmitter substance (acetylcholine) is hydrolysed by the enzyme acetylcholinesterase on the postsynaptic membrane. Its breakdown can be reused to synthesize acetylcholine again at the synaptic knob, with energy from mitochondria.

Sequence of diagrams to illustrate synaptic transmission (only relevant detail is included in each drawing)

1. The arrival of the impulses at the synaptic knob alters its permeability allowing calcium ions to enter.

2. The influx of calcium ions causes the synaptic vesicle to fuse with the presynaptic membrane so releasing acetylcholine into the synaptic cleft.

3. Acetylcholine fuses with receptor molecules on the postsynaptic membrane. This alters its permeability allowing sodium ions to rush in.

4. The influx of sodium ions generates a new impulse in the postsynaptic neurone.

5. Acetylcholinesterase on the postsynaptic membrane hydrolyses acetylcholine into choline and ethanoic acid (acetyl). These two components then diffuse back across the synaptic cleft into the presynaptic neurone.

6. ATP released by the mitochondria is used to recombine choline and ethanoic acid (acetyl) molecules to form acetylcholine. This is stored in synaptic vesicles for future use.

27.2.3 Functions of Synapses
1. Transmit information between neurons
2. Pass impulses in one direction only
3. Act as junctions
4. Filter out low level stimuli
5. Allow adaptation to intense stimulation
F 6 Biology - Ch 27: The Nervous System

Name: ____________________________

Effects of Drugs on Synaptic Transmission

Excitatory drugs: These amplify the process of synaptic transmission by
1. mimicking the transmitter substance
2. stimulating the release of more of the natural transmitter
3. slowing or preventing the breakdown of the transmitter examples: amphetamines, caffeine, nicotine

Inhibitory drugs: These decrease the process of synaptic transmission by
1. preventing the release of the synaptic transmitter
2. blocking the action of the transmitter at the receptor molecules on the postsynaptic neuron
   example: atropine

27.3 The Reflex Arc

Reflex arc involved in withdrawal from an unpleasant stimulus

- A simple reflex action is a quick, inborn & automatic response of an animal to a stimulus. It does not involve thinking (the brain) but inform the brain (cerebrum) later.

The simple reflex actions are protective in function & need not be learnt.

The same stimulus initiates the same response at different times.

- withdrawal reflex protects the hand from being hurt, e.g. burnt
- blinking reflex protects the eyes from being damaged by closing the eyelids
- coughing reflex forces food out from the trachea
- sneezing reflex forces secretions from blocking the nose

REFLEX ARC

- THE NEURAL PATHWAY between the receptor and the effector involved in a reflex action
- spinal reflex: only the spinal cord is involved, e.g. knee jerk reflex, withdrawal reflex
- cranial reflex: involves the medulla oblongata, e.g. blinking, sneezing

monosynaptic: the reflex arc has only 1 synapse between the sensory & motor neurons in the spinal cord
polysynaptic: reflexes involving two or more synapses

These simple reflexes are important in making involuntary responses to various changes in both the internal & external environment. In this way homeostatic control of things like body posture may be maintained. Control of breathing, blood pressure and other systems are likewise effected through a series of reflex responses, e.g. constriction of pupil to strong light intensity

CONDITIONED REFLEX

- requires a period of learning or training
- same response can be evoked to unrelated stimuli, e.g. typing

- Pavlov found that the association of the brain, impulses initiated by the bell and food were correlated; thus the sound of the bell alone could cause salivation of the dog.
27.4 The Autonomic Nervous System

IN VOLUNTARY RESPONSES
- responses that do not involve the brain (cerebrum):
  unconscious, independent of external stimuli,
- controlled by the ANS (autonomic nervous system) which consists of two branches:
  1. sympathetic nervous system
  2. parasympathetic nervous system
- examples: heart beat, peristalsis, prepare for emergencies

Effects of the sympathetic & parasympathetic nervous systems are **antagonistic**.
The balance between the two systems accurately regulates the involuntary activities of glands and organs.
Training is possible to control consciously certain activities, e.g. urination & defaecation

| TABLE 27.1 Comparison of some effects of sympathetic & parasympathetic branches |
|---------------------------------|---------------------------------|
| **Sympathetic nervous system**  | **Parasympathetic nervous system** |
| increases cardiac output       | increases secretions of tears   |
| increases blood pressure       |                                |
| dilates bronchioles            |                                |
| increases ventilation rate     |                                |
| dilates pupils                 |                                |
| contracts anal & bladder sphincters |                           |
| contracts erector pili muscles |                                |
| increases sweat production     |                                |

27.5 The Central Nervous System
- consists of the brain and the spinal cord

**How the CNS is protected and nourished**
- the brain is protected by the **cranium**, while the spinal cord is protected by the **vertebral column**;
  both are bony tissues
- **meninges** covering the whole CNS
- cavities between meninges, ventricle of brain, central canal of spinal cord are filled with **cerebrospinal fluid** for ____________________________
  ____________________________
27.5.1 The Spinal Cord
- a reflex centre for controlling involuntary actions such as knee jerk;
- transmits impulses to and from the brain

PERIPHERAL NERVOUS SYSTEM
- consists of the cranial nerves and spinal nerves

Cranial Nerves
- 12 pairs from medulla oblongata to sense organs in the head & neck

Spinal Nerves
- 31 pairs in man, running from spinal cord to body trunk & limbs
- all are mixed nerves
- dorsal root for sensory nerve fibres; with a dorsal root ganglion of cell bodies
  ventral root for motor nerve fibres; cell bodies in grey matter of spinal cord

27.5.2 Structure of The Brain & 27.5.3 Functions of The Brain

Regions and Functions of the Brain
- The brain is divided into 3 regions: the forebrain, midbrain & the hindbrain

1. The Forebrain
- cerebrum is divided into two cerebral hemispheres connected by nerve fibres
- surface is folded to increase the surface area for increased co-ordination
- centre for thinking, memory, reasoning, imagination, learning & voluntary actions
- sensory areas receive impulses from the receptors; removal of these areas results in loss of the senses
- motor areas send impulses to the effectors; if these areas are damaged, no responses will be evoked;
- association areas correlate impulses from different receptors and assist in producing the appropriate responses
F 6 Biology - Ch 27: The Nervous System

Name: ____________________________ ( )

2. The Midbrain
- includes the optic lobes for vision
- floor is the hypothalamus for homeostasis:
  main controlling region for the autonomic nervous system;
  two centres (sympathetic & parasympathetic);
  controls complex patterns of behaviour such as feeding, sleeping;
  monitor composition of blood;
  acts as an endocrine gland

3. The Hindbrain
- cerebellum: a centre for muscular co-ordination and body balance
- medullar oblongata: the reflex centre for controlling involuntary actions such as breathing,
  heartbeat, swallowing, coughing, sneezing, and salivation;
  damage of the medulla oblongata may lead to death

Internal Structure of the Brain
- grey matter: outside the brain; consists of nerve cell bodies only
- white matter: inside the brain; consists of nerve fibres only
* In medulla oblongata & spinal cord, the distribution of grey and white matters is the reverse

27.5.4 Comparison of Endocrine and Nervous Systems

TABLE 27.2 Comparison of endocrine and nervous systems

<table>
<thead>
<tr>
<th>Endocrine system</th>
<th>Nervous system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication: chemical messengers or hormones</td>
<td></td>
</tr>
<tr>
<td>Transmission: by blood stream</td>
<td></td>
</tr>
<tr>
<td>Target organ receives message</td>
<td></td>
</tr>
<tr>
<td>Transmission: relatively slow</td>
<td></td>
</tr>
<tr>
<td>Effect: widespread</td>
<td></td>
</tr>
<tr>
<td>Response: slow</td>
<td></td>
</tr>
<tr>
<td>Response is often long-term</td>
<td></td>
</tr>
<tr>
<td>Effect: permanent &amp; irreversible</td>
<td></td>
</tr>
</tbody>
</table>

27.6 Sensory Perception
Receptors are sensitive to stimuli, some have become highly specialized to detect a particular form of energy and give out response into a nervous impulse, they act as biological transducers.
Primary sense cells is a simple receptor with dendrite receives the stimulus & creates an action potential to the remainder of the nervous system, e.g. cones
Secondary sense cells outside the nervous system pass chemical or electrical messages to a neuron to create an action potential, e.g. taste cells of tongue
Exteroceptors collect information from the external environment
Interoceptors collect information from the internal environment
Proprioceptors provide information on the relative position & movements of muscles
F 6 Biology - Ch 27: The Nervous System

Name: ____________________________ 

Classification according to the form of energy:
1. Mechanoreceptors - detect movements, pressures and tensions, e.g. sound
2. Chemoreceptors - detect chemical stimuli, e.g. taste & smell
3. Thermoreceptors - detect temperature changes
4. Electromagnetic fields (mainly fish)
5. Photoreceptors - detect light & some other forms of electromagnetic radiation

Mechanoreception
- respond to mechanical stimuli: gravity, vibration & pressure
- examples: touch, pressure receptors, ear

Chemoreception
- respond to taste & smell
- taste buds for sweet, sour, bitter & salt

Functions in mammals:
1. Locating food & its acceptance or rejection
2. Locating a mate
3. Detecting its predators
4. Detecting dangers, e.g. fire
5. Locating & marking territories

27.6.1 The Mammalian Eye
- surface of eyeball is kept moist & clean by blinking;
tear gland produces a fluid containing NaCl, HCO₃⁻ and an enzyme (lysozyme) to kill bacteria
- excess fluid drains away into the nasal cavity through the tear duct
- eyelashes: stop dirt & sweat from running into the eye
- sclera: white, tough & opaque coat;
functions -

- cornea: front of sclera, transparent to allow light to pass through;
  refracts light into the eye;
  covered by transparent conjunctiva

- choroid: middle layer;
  deeply pigmented for absorbing light and preventing light from being reflected out of the eye;
  richly supplied with blood vessels which provides nutrients and oxygen for the eye

- ciliary body: contains ciliary muscles which hold the lens in position through the suspensory ligaments;
  Function - for accommodation (looking viewing distant & near objects)

- aqueous humour in anterior chamber & vitreous humour in posterior chamber for refracting light & maintaining the shape of the eyeball;
aqueous humour helps diffusion of food & oxygen from choroid to lens and cornea
F 6 Biology - Ch 27: The Nervous System

Name:
- iris is continuous with choroid; it is pigmented & forms the colour of the eye, with a pupil at centre & consists of radial & circular muscles to control the size of pupil
- retina: innermost layer with light sensitive cells and nerve fibres
- cones: sensitive to light of high intensity & colour
- rods: sensitive to dim light (night vision)
- yellow spot: in centre of retina with only cones for clear vision
- blind spot: nerve fibres from cones & rods join at retina and leave the eyeball as the optic nerve going to the brain, no photoreceptors, therefore forms no images

<table>
<thead>
<tr>
<th>TABLE 27.3 Difference between rods and cones</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rods</strong></td>
</tr>
<tr>
<td>Outer segment is rod-shaped</td>
</tr>
<tr>
<td>More numerous than cones</td>
</tr>
<tr>
<td>Distributed more or less even over the retina</td>
</tr>
<tr>
<td>None found at the yellow spot</td>
</tr>
<tr>
<td>Give poor visual acuity because many rods share a single neuron to brain</td>
</tr>
<tr>
<td>Sensitive to low light intensity; therefore for night vision</td>
</tr>
<tr>
<td>Not sensitive to colour vision</td>
</tr>
<tr>
<td>Contains visual pigment rhodopsin</td>
</tr>
</tbody>
</table>

Each rod possesses up to a thousand vesicles in its outer segment containing rhodopsin. Rhodopsin is made up of the protein opsin and retinal (a derivative of vitamin A). Retinal normally exists in its cis isomer form, but light causes it to become converted to its trans isomer form. This change initiates reactions which lead to the splitting of rhodopsin into opsin and retinal - bleaching.

This splitting leads to the creation of a generator potential in the rod cell, if sufficiently large, generates an action potential along the neurones leading from the cell to the brain. Before the rods can be activated again in the same way, opsin & retinal must be resynthesized into rhodopsin with energy supplied by mitochondria. Resynthesis takes time and is possible in low light intensity.

A similar process occurs in cone cells except that the pigment is iodopsin. It is less sensitive to light and so a greater intensity is required to cause its breakdown and so initiate a nerve impulse.
**Colour Vision**

- Colour vision is due to the presence of 3 kinds of cone cells detecting 3 kinds of primary colours (*trichromatic theory*):
  - Other colours are determined by the relative number of each kind of colour cone cells stimulated.
  - Colour blindness is a hereditary defect and cannot be corrected by wearing glasses, e.g. a colour-blind man cannot distinguish red from green because of defects in the red and green cone cells.

**Changing The Size Of The Pupil**

- **Pupil**: allows light to pass through; its size limits the amount of light entering the eye.
- **Circular iris muscles**: contract to constrict pupil; **radial iris muscles**: contract to dilate pupil.
- Changing size of the pupil is automatic (a reflex action):
  - Bright light $\rightarrow$ pupil constricts by parasympathetic nerve (circular muscles constrict; radial muscles relax)
  - Dim light $\rightarrow$ pupil dilates by sympathetic nerve (radial muscles contract; circular muscles relax)

**Mechanism of control of light entering the eye**
F 6 Biology - Ch 27: The Nervous System

Name: ________________________

Accommodation - the ability of the eye to adjust the thickness of lens for viewing near and distant objects
- thick lens has a shorter focal length;
  - thin lens has a longer focal length

Summary of events during accommodation

<table>
<thead>
<tr>
<th>Looking at near object</th>
<th>Looking at distant object</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Iris circular muscles contract to constrict pupil &amp; let less light in</td>
<td></td>
</tr>
<tr>
<td>2. Suspensory ligaments loosen</td>
<td></td>
</tr>
<tr>
<td>3. Lens becomes thicker</td>
<td></td>
</tr>
<tr>
<td>4. Near object is focused on the retina</td>
<td></td>
</tr>
</tbody>
</table>

The Mammalian Ear - FOR HEARING AND BALANCING

The ear is divided into 3 parts:
- outer ear, middle ear & inner ear

1. Outer Ear
- **pinna**: to collect sound waves & detect the direction of the sound
- **external auditory canal**: covered with hair & wax to prevent entry of dust or small insects
- **ear drum**: change sound waves into mechanical vibrations

2. Middle Ear
- an air-filled cavity
- 3 ear bones (ossicles): malleus, incus & stapes; they transmit and magnify vibrations from the eardrum to the oval window
- **round window**: to dissipate vibrations from the inner window
- **Eustachian tube**: joining middle ear & pharynx, equalizing pressure on both sides of the eardrum

3. Inner ear
- consists of **membranous labyrinth** (filled with **endolymph**)
  - inside a **bony labyrinth** (filled with **perilymph**)
- **cochlea**: detects sound;
  - contains sensory hair cells which forms **organ of Corti**
- **semi-circular canals, utriculus, and sacculus**: organs for balancing

Hearing

1. Transmission of sound waves

sound waves in air → pinnae → auditory canal → eardrum → ear ossicles → oval window
* sound waves are magnified by the lever system of the ear ossicles and the eardrum is much larger than the oval window
2. Initiating nerve impulses

vibrations of oval window → perilymph → middle canal → sensory hair cells → impulses to brain via auditory nerve

* sound waves dissipate their vibrations at the round window

Balancing

1. Utriculus and Sacculus
- Both are fluid-filled containing sensory hair cells called otoliths
- Detect **static position** of the head relative to gravity

2. Semicircular Canal
- The 3 semi-circular canals are situated at 90° to each other for detecting movements in 3 different planes
- **ampulla**
  - For detecting movements of the head (helps to keep dynamic balance)
  - Contains sensory hair cells with protruding hairs in a jelly **cupula**
  - Changes in direction and speed of movement of the head will trigger impulses (information) from the sensory hair cells to the brain
* In addition, the **eyes** also supply information about the movement and position of the body; the **pressure receptors** in feet and **stretch receptors** in tendons also provide messages to the brain for static and dynamic balances

27.7 **Behaviour** - not required in syllabus