CO-ORDINATION

Irritability is a characteristic feature of all living organisms and involves their ability to respond to stimulus. In all organisms, some degree of internal coordination and control is necessary in order to ensure that all events of the stimulus and response bear some natural relationship associated with the maintenance of a steady and survival of the organism.

Terms used in coordination

Irritability:
This is the ability of an organism to detect and respond to stimuli in a required period of time.

Stimulus:
This is the change in the environment of an organism that can cause a response e.g. touching a hot object, change in blood pH, change in level of metabolites, etc.

Response:
This is the change in the activity of part or the whole organism in reaction to stimulus.

Receptors:
These are organs or structures of an organism that detect changes in the environment.

Effectors:
These are parts of the body that carry out the response. E.g. glands and muscles.

COORDINATION AND CONTROL IN ANIMALS

Animals unlike plants have two different but related systems of coordination; the nervous and endocrine system. The nervous system is fast acting, its effects are localized and it involves electrical and chemical transmission whereas the endocrine system is slower in acting, its effects are adverse and it relies on chemical transmission through the circulatory system.

THE ENDOCRINE SYSTEM

A gland is a structure which produces a specific chemical substance. The substance released by glands is called secretions which affect the physiological activities of organisms. There are two types of glands in the body, i.e. exocrine and endocrine glands.
Exocrine glands are those that release their secretions through ducts or tubes like pancreas, tear glands, sweat glands, etc.
Endocrine glands are those which pour their secretions directly into the blood stream because they don't have ducts. They are also called ductless glands.
The pancreas is both endocrine and exocrine. It's endocrine because it produces pancreatic juice through the pancreatic duct and is exocrine because it produces insulin and glucagon directly into the blood stream.
Endocrine system is the system consisting of endocrine glands. Their secretions are hormones. ***A hormone is a specific chemical substance produced by one part of the body that enters the blood stream and is transported to the target organ where it exerts a specific regulatory effect.*** A hormone may be effective in minute quantities.
Together with nervous system, the endocrine system plays a principle role in the integration, coordination and control of physiological activities of organisms. When hormones pass through the liver, they are converted to relatively inactive substance which are excreted by the kidneys.
Endocrine glands are stimulated to secrete hormones either by impulses from motor nerves or by hormones from other glands. The endocrine system is linked to the nervous system by the hypothalamus which exerts a major control over the pituitary gland of the endocrine system.

Mechanism of hormone action

Chemically hormones belong to one of the four groups;

- Amines like adrenaline
- Proteins like growth hormone
- Steroids like testosterone
- Fatty acids like prostaglandins

Mechanisms controlling the release of hormones is as follows:

1) The presence of a specific metabolite in the blood for example glucose in the blood causes the release of insulin from the islets of the Langerhans of the pancreas which lowers the glucose level.
2) The presence of another hormone in blood. Such hormones are called stimulating hormones and most of them are produced by the anterior pituitary gland like thyroid stimulating hormone.
3) Stimulation by neurons from the autonomic nervous system like adrenaline and noradrenaline are released from the cells of the adrenal medulla by the arrival of the nerve impulse in situations of anxiety and danger.

THE ENDOCRINE GLANDS

HYPOTHALAMUS

PITUITARY GLAND

The pituitary gland is called a Master gland because it produces a number of hormones many of which influence the activity of other endocrine glands.
It's connected to the brain by the pituitary stalk. The two lobes of the pituitary gland are the anterior and posterior pituitary lobes.

Structure of the pituitary gland ***(****B.S page 602 fig. 17.48****)***

Anterior pituitary:

This lobe is derived from an up-growth of the glandular roof of the mouth. It produces and secretes six hormones and controls the release of other endocrine glands. The secretion of the six hormones is triggered off by specific chemical substances from the hypothalamus called releasing factors. The process by which some neurons secrete hormones is called neuro-secretion and the secretions are called neuro-hormones.
The hormones secreted include;

Hypothalamus hormone	Anterior pituitary hormones	Function
Growth hormone releasing factor	Growth hormones	❖ Promotes growth of skeletal muscles. ❖ Control protein synthesis and general body metabolism.
Thyrotrophin releasing factors	Thyroid stimulating hormones (Thyrophic hormones)	Stimulates growth of thyroid glands. Stimulates the Thyroid gland to secrete thyroxine hormone
Adrenocorticotrophic releasing factor (C.R.F)	Adrenocorticotrophic hormone	Regulates growth of adrenal cortex
Prolactin releasing factor (P.R.F)	Prolactin hormones (Luteotrophin)	Induces milk production in pregnant women. Maintains progesterone production in corpus luteum.
Luteinizing hormone releasing factor	Luteinizing hormone	Causes the release of ovum from the ovary. Stimulates ovary to produce progesterone or corpus luteum.
Follicle stimulating factors	Follicle stimulating hormones	Initiates cyclic changes in ovary causing development of the graafian follicle.

		Stimulates the secretion of oestrogen in the ovary. Initiates sperm formation in the testis.

Posterior pituitary lobe:
The posterior lobe communicates to the hypothalamus by means of nerve fibres. It does not synthesize any hormone but stores and releases two (2) hormones i.e. antidiuretic hormone (ADH) and oxytocin.
Antidiuretic hormone is released in response to fall in the water content of the plasma and leads to an increase in the permeability to water of the distal convoluted tubule and collecting ducts of the nephron so that water is retained in the blood plasma. It also rises the blood pressure by constricting arterioles.
Oxytocin causes the contraction of uterine walls during birth. It also causes the release of milk from the nipples.
The ADH and oxytocin are produced by neural secretory cells in the nucleus of hypothalamus and passed down to the nerve fibres attached to the carrier protein molecule called neuro-physiness.
Question: Discuss the pituitary gland as master gland.

GROWTH HORMONES

These are hormones that have a general effect of increasing the metabolic energy and extra energy being diverted to cell division and protein synthesis.
When the pituitary gland cell secrets the excess of these hormones at adolescence. It results in the increase of the growth of the body which can result in a condition called giantism.
If over secretion occurs at adulthood, it results into formation of more bones tissues being laid down in hands and feet which become greatly enlarged leading to the condition known as Acromegany.
If the pituitary gland produces little growth hormones this results into a condition known as dwarfism. It results when growth takes place slowly leading to a short and stunt individuals but having normal intelligence and reproductive functions.

Thyroid glands

It produces 3 hormones i.e. Tri-iodothyroxine, thyroxin and calcitonin hormone.

Tri-iodothyroxin and thyroxin hormones

These are chemically and functionally similar (both contain iodine), however thyroxin contain 4 iodine molecules while tri-iodothyroxine contain 3 iodine molecules.
They both regulate the growth and development of cells and regulate the metabolic rate. They also help in the oxidation of glucose by the cells. This has an effect of increasing the heat production thus these hormones are produced when an animal is exposed to extreme coldness, emotional stress and hunger.
The overall function is to increase the rate of metabolism thus thyroxin work in conjunction with adrenaline and insulin.
In conditions of low iodine levels, tri-iodothyroxin is produced instead of thyroxin in order to maximize the use of limited iodine. If the thyroid gland is unable to make adequate supply of this hormone and results into under activity of the gland.

Abnormalities of thyroid gland

i) Under activity (hypothyroidism)
ii) Over activity (hyperthyroidism)

Hypothyroidism:
In young ones, it brings about sluggishness, physical and mental retardation. In adults, it results in mental and physical sluggishness, reduced metabolic rates, reduced heart beat rates, lowered body temperature and obesity (over weight). Such a condition is called myxedema. This results into the swelling of the neck called Goitre. Hypothyroidism is caused by insufficient supply of thyroid stimulating hormones and can be cured by taking in thyroxin orally.
Hyperthyroidism:

It leads to increased metabolic rates, increased heart beat rate and ventilation rate, raised body temperature, nervousness i.e. restless. It brings about wasting of muscles where one fails to grow fat.
Extreme cases of hypothyroidism results into heart failure. The main cause of over activity is a blood protein that stimulates thyroid gland to produce tri-iodothyroxin and thyroxin.

Calcitonin

It is concerned with calcium metabolism in conjuction with parathormone from the parathyroid glands. Calcitonin control the level of calcium ions in blood. It is produced to respond to high levels of calcium ion concentration.

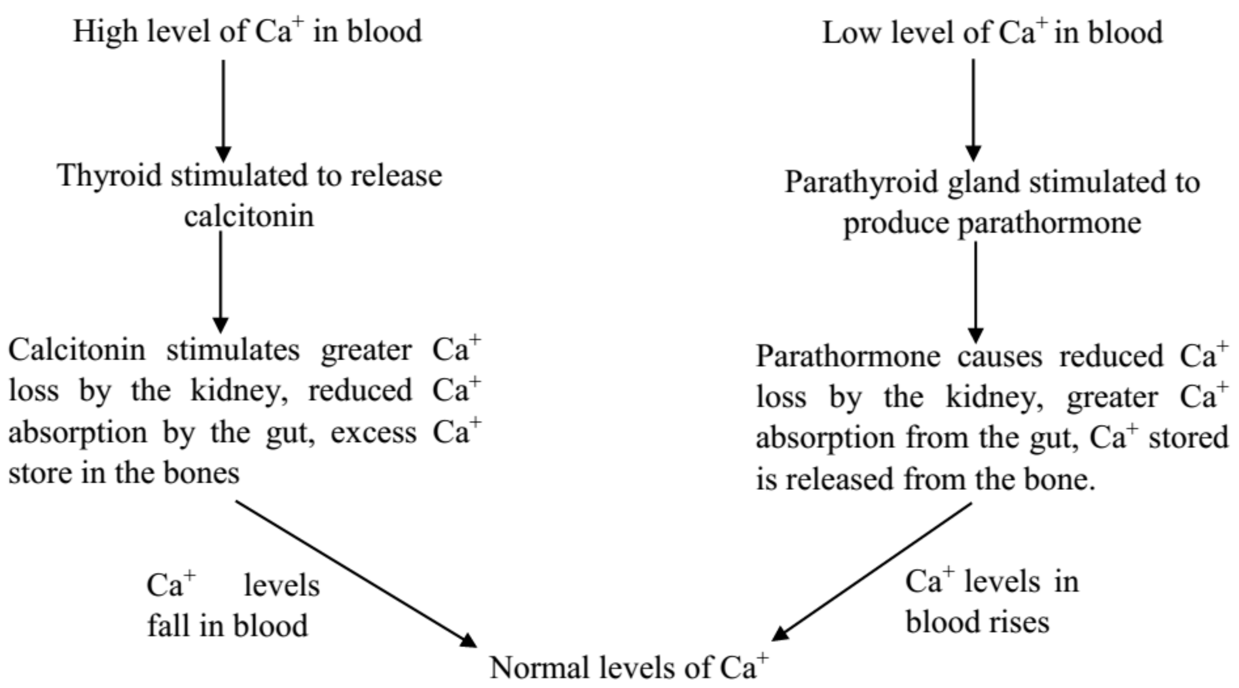
Parathyroid

They produce parathormone which maintain the level of Ca^+ in blood at a higher concentration in order to allow normal muscles and nervous activity.
The hormones rise the level of Ca^+ in 3 ways;

i) Increases the level of Ca^+ absorption from the gut
ii) Increases the rates of Ca^+ reabsorption by the kidney at the expense of phosphate ions
iii) Causes the release of Ca^+ from the bones into the blood stream.

Note: it works antagonistically with calcitonin

Summary of calcium control



Over production of parathormone leads to excess removal of calcium ions from bones making them brittle and reliable to fracture. This over production also causes excess calcium ions to be removed from the kidney causing kidney stones.
Under production of those hormones results into low levels of calcium ions in blood leading to nervous disorder and uncontrolled contraction of muscles.

ADRENAL GLANDS

They are of two parts, i.e.

i) Adrenal cortex: consisting of the outer region of the gland.
ii) Adrenal medulla: consisting of the inner region of the gland.

ADRENAL CORTEX

All the hormones produced by the cortex are steroid hormones formed from cholesterol. Hormones from this cortex are collectively called corticoids and are of two types:
i) Gluco-corticoids which is concerned with glucose metabolism.

ii) Mineral corticoid that is concerned with mineral metabolism.

Gluco-corticoids

Such hormones include cortisol hormone which is produced in response to stressful situation like pain, stroke, emotion and extreme cold infection.

The hypothalamus stimulates the anterior pituitary gland to produce the adrenal corticotrophine hormone which causes the adrenal cortex to increase the rate of Gluco corticoid release including the cortisol. When stress is prolonged, the size of adrenal glands increases. Gluco-corticoid fight stress in the following ways:

- Rise the blood sugar level by inhibiting insulin and leads to the formation of glucose (glucogenesis)
- Increases the rate of glycogen formation in the liver.
- Increases the uptake of amino acids by the liver. These are deaminated to form more glucose.

Deficiency of Gluco-corticoids leads to the Addison disease. There is also high blood pressure and a symptom of diabetes mellitus.

Mineral corticoids

This is a group of hormones including Aldosterone which regulate water retained in the body. It does this by controlling the distribution of Na^+ and other minerals in the tissues. This increases the re-absorption of Na^+ and Cl^- ions by the kidney and K^+ lost in urine.

The reduction of Na^+ concentration in the total blood volume causes special kidney cells to produce renin which activates the plasma proteins and angiotensin that stimulates the release of aldosterone form adrenal cortex. This causes the kidney to conserve both water and sodium ions.

Angiotensin also affects the centre of the brain creating a sensation of thirst that drives the organism to drink water thus helping to restore the blood volume.

Over production of aldosterone often results into excessive Na^+ retention by tissues, high blood pressure and headache.

Retention of sodium ions in the body leads to a fall in potassium ions level in the blood leading to muscle weakness.

Under production of aldosterone leads to the fall in the amount of sodium ions.

ADRENAL MEDULLA

It produces two hormones;

i) Adrenalin
ii) Noradrenalin

Both are important in preparing organisms for emergence or action. The cells producing them are modified neurons of sympathetic nerve system. Therefore, they act as a link between the nervous and endocrine system. They are sometimes known as 'fight or flight' hormones as they prepare an organism for either flight or face the enemy.

The effect of both hormones is to prepare a body for danger and to tighten its response to stimulus. In some cases, adrenaline and noradrenalin differs e.g. adrenaline dilates blood vessels while noradrenaline constricts them. This explains why blood vessels around the gut constrict while those supplying the muscles, lungs and liver dilates.

Effects of adrenalin and noradrenalin in the body

Effect	Function
Bronchioles dilates	Air is more easily inhaled and more oxygen is made available for the production of energy by glucose oxidation.
Glycogen in the liver is converted to glucose	Increases blood sugar level making glucose available for oxidation.
Heart beat rate increases and the volume of blood	Increases the rate which glucose and oxygen are

pumped per beat increase.	distributed to tissues.
Blood is diverted from digestive and reproductive system to vital organs e.g. liver, lungs and muscles.	Blood rich in oxygen and glucose is diverted from tissues with low energy need to those with high energy need.
Peristalysis and digestion inhibited.	Inhibition of the process diverts them to muscles, liver and lungs that need more energy.
Sensory perception increases.	It produces rapid reaction to stimulus.
Mental awareness.	To allow big response to stimuli.
Pupil of the eye dilates.	Increases the range of vision and perception of visual stimulus.
Erector muscles of hair contract.	Gives an impression of increased size of fighting the enemy.

PANCREAS

It is an exocrine as well as endocrine gland with special cells called islets of Langerhans. Within them are the beta cells which produce insulin and alpha cells which secret glucagon hormones.

Glucagon increases blood sugar levels by stimulating the breakdown of glycogen to glucose reducing the metabolic rates by stimulating glucogenesis while insulin reduces the blood sugar levels by stimulating conversion of glucose to glycogen in the process called glycogenesis.

Increase in the rate of protein and fat synthesis

Increase in the formation of ATP, DNA and RNA.

Insufficient levels of insulin in blood leads to disorders called diabetes mellitus. As a result, the blood sugar levels rises to dangerous levels causing blindness and kidney failure.

In case the kidney is unable to reabsorb all glucose passing through it, it results into the symptom of the presence of glucose in urine. Treatment involves administering insulin.

Summary of endocrine glands and their functions

Gland	Hormone	Function
Pituitary gland		
Thyroid gland	Tri-iodothyroxine Iodine Calcitonin	Regulates growth and development by affecting metabolism.
Parathyroid	Parathormone	Raise calcium levels as it lowers phosphate levels
Adrenal gland i) Adrenal cortex ii) Adrenal medulla	Cortisol hormone	Helps in combating stress by rising blood sugar levels and pressure.
	Aldosterone	Increases reabsorption of Na^+ by kidney tubules.
	Adrenaline and noradrenaline	They prepare the body for fright or fight/emergency or stressful situations.
Pancreas	Insulin	Lowers blood sugar levels
	Glucagon	Increases blood sugar levels
Duodenum	Secretin	Stimulates secretion of minerals and pancreatic juice by pancreas. Stimulates the secretion of bile by the kidney.
	Cholecystokinin	Causes contraction of gall bladder to release bile. Stimulates the pancreas to release its enzymes.
Ovary	Oestrogen	Stimulates the pituitary gland to produce luteinizing hormone. Causes repair of uterine lining after menstruation.
	Progesterone	Causes the uterus lining to be maintained in readiness for the embryo to be implanted.

		Inhibits production of FSH and luteinizing hormone thus inhibiting ovulation and maintaining pregnancy.
Testis	Testosterone	Produces male sex secondary characteristics.
Placenta	Progesterone	Maintains pregnancy after corpus luteum has degenerated.
	Chorionic gonadotrophin hormone	Maintains the presence of corpus luteum in the ovary.
Kidney	Renin	Activates plasma proteins and angiotensin.
Stomach walls	Gastrin	Initiates secretion of gastric juice.

INSECT HORMONES

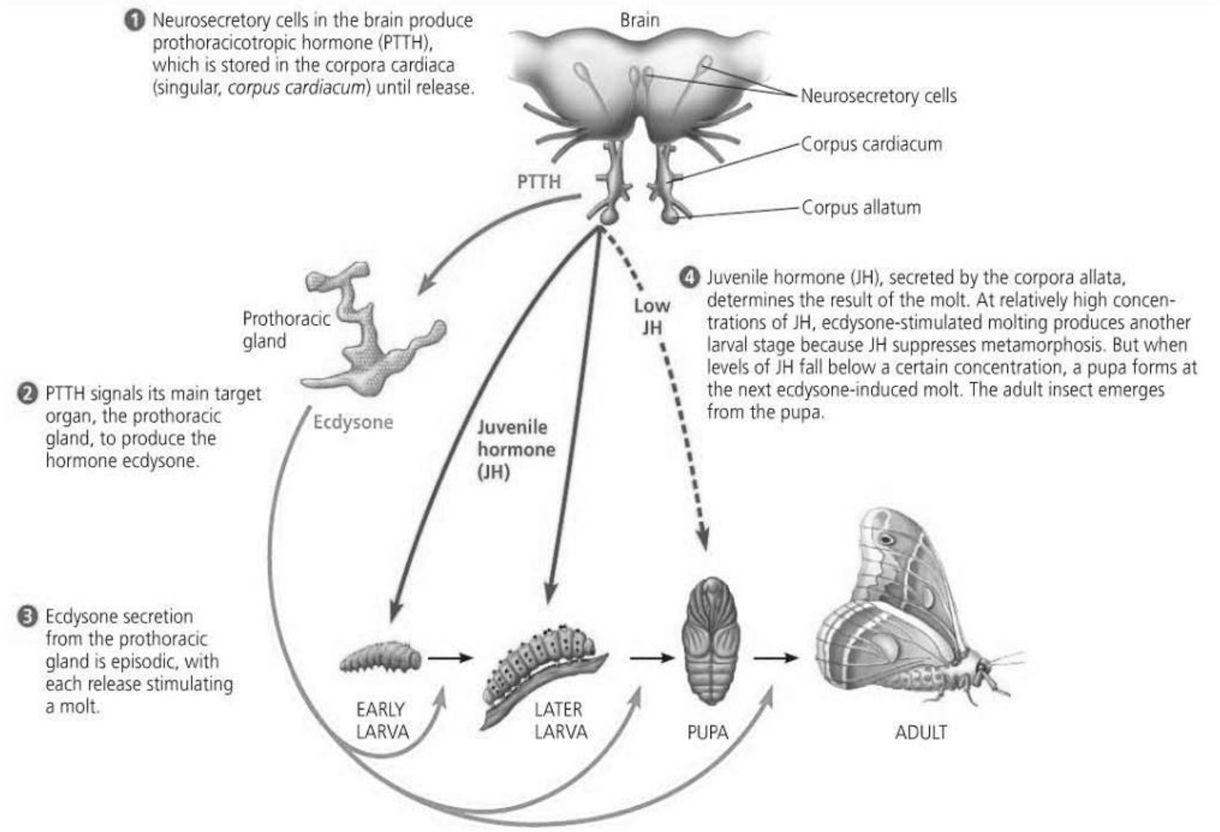
Most invertebrate hormones are nerve secretory hormones. In insects their important in controlling ecdysis/moulting. The process involves two hormones; ecdysin and juvenile/neunitin hormones.

In holometabolous (complete metamorphosis), all moults require ecdysin hormones. If however a high concentration of juvenile hormone is present the larva moults to another larva stage. As growth proceeds, the level of juvenile decreases. At less levels of juvenile, the larva moults to give rise to pupa. In absence of juvenile hormone, ecdysin causes the pupa to moult to an adult.

Production of two hormones is controlled by the insect brain as follows:

The brain produces a hormone prothoracic-trophic hormone which passes to a pair of bodies called corpora cardiata which lies next to the brain where it's stored. In response to external stimulus like day length, temperature and food supply, the brain sends impulses to corpora cardiata to release the formed prothoracic trophic hormones.

Juvenile/neunitin is produced by the region behind the brain called corpus collatum. The production of neunitin decreases as the insect develops and resumes in adults.



Other hormone-like substances

Pheromones:
These are also part of the chemical coordinating systems of some organisms. Unlike hormones they don't operate within an individual but between members of the same species thus they are referred to as social hormones. Some species like female silk moth produce sweet smell that attract male sex moth.
Pheromones attract individuals from far distance thus these pheromones are used to control population of the same species. Ants, termites and bees all produce chemicals which aid others in their social groups to go for food resource.
Worker bees lack a hormone produced by mandibular glands of the queen spread all over the body. They transfer chemicals among themselves to prevent maturation of the ovaries thus maintaining their sterility and controls the size of the colon.

Prostaglandins:
They are produced throughout the body and are found in the semen. They bring about contraction of the uterus to push the sperm up to the oviduct.

Endorphins:
They act in such a way that they reduce pain, induce thyroxin activities, influence hibernation, lower ventilation and cardiac rate. They act by attaching on the receptor sites on the cells of the human brain.

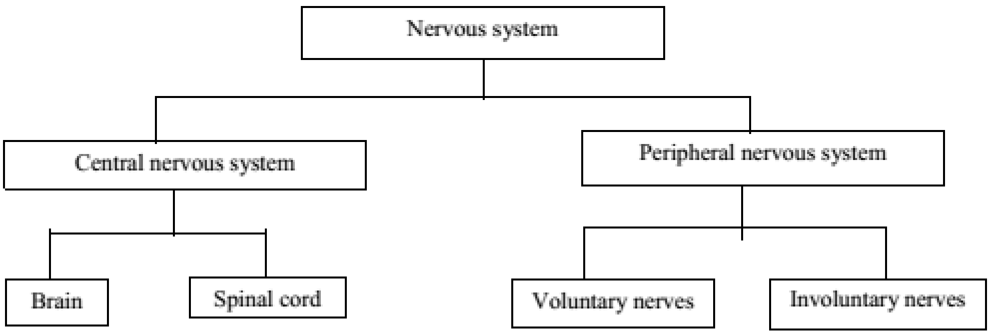
CO-ORDINATION IN ANIMALS

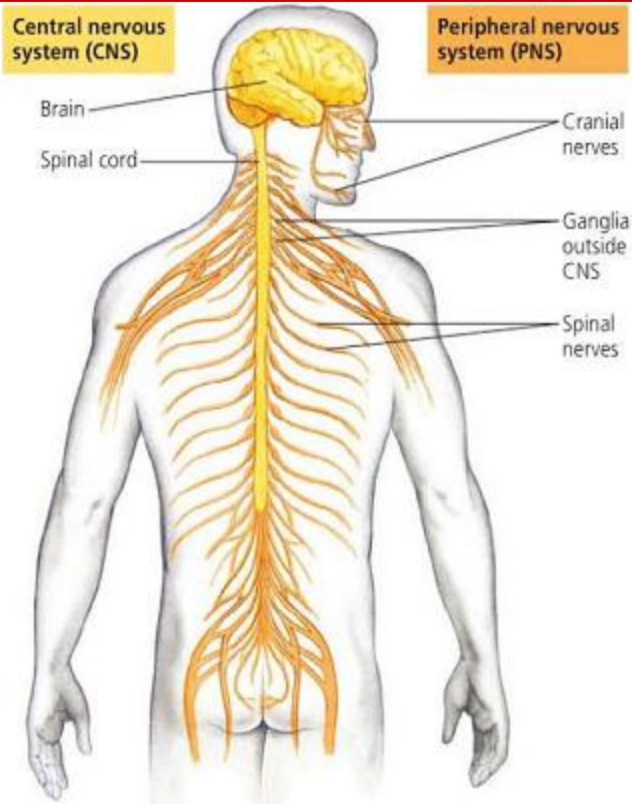
All living organisms are sensitive to changes taking place within their surroundings. They detect the changes (stimuli) and respond to them appropriately. The ability of an animal's body to detect and respond appropriately to stimuli depends on the nervous system and endocrine system.
The stimuli may be within an animal's body or in its surrounding. Different parts of the body of an animal do not work independently of each other.
They depend upon one another performing various functions as a single unit.
The nervous system controls all the organs and makes them to work together.

THE NERVOUS SYSTEM

This is a system of nerve cells and sensory organs that carry out co-ordination by transfer of impulses.

COMPONENTS OF THE NERVOUS SYSTEM





The nervous system consists of;

i) Receptors:

These detect the stimuli e.g. sensory endings in the skin, eye and ear.

ii) The central nervous system (CNS)

This interprets and determines the nature of the response. The CNS consists of the brain and spinal cord.

iii) Peripheral nervous system

This consists of voluntary and involuntary nerves.

iv) Effectors

These are organs that carry out the response.

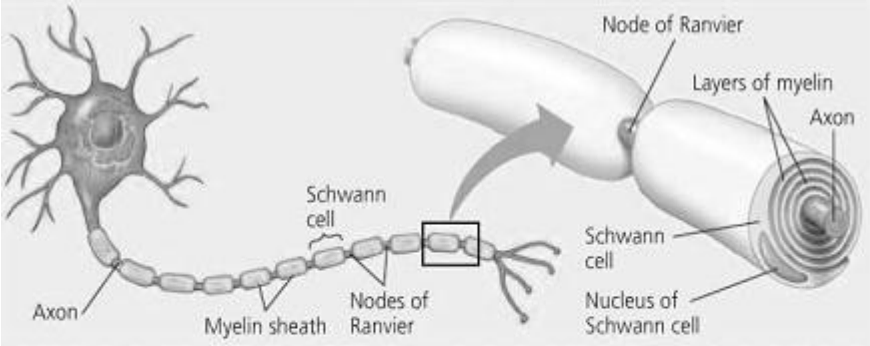
Functions of the nervous system

1. It receives impulses from all sensory organs of the body.
2. It stores information
3. It correlates various stimuli from different sensory organs
4. It sends messages to all parts of the body making them function accordingly.
5. It's involved in temperature regulation.

The nervous system is made up of cells called neurons. A neuron is a functional unit cell of the nervous system that transmits an impulse or an electrical message.

STRUCTURE OF THE NEURONE

A neuron is made up of a small mass of cytoplasm, a nucleus in a structure called the cell body, branching cytoplasmic filaments called dendrites and a single long fiber called axon.



General functions of the parts of a neuron

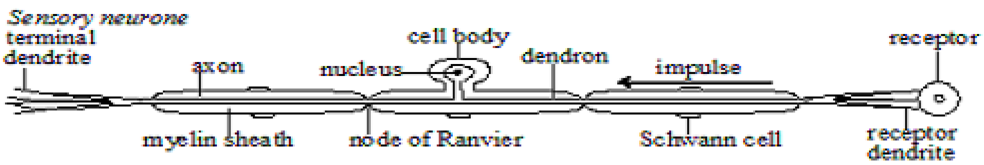
1. **Cell body**; this consists of a nucleus surrounded by a mass of cytoplasm. The nucleus controls all activities of the neuron.
2. **Axon**; this is one or more long cytoplasmic extensions running from the cell body. Axons carry impulses over long distances in the body. Each axon is filled with cytoplasm called **axoplasm**.
3. **Myelin sheath**; this is a fatty material that covers the axon. The myelin sheath is secreted by cells called **Schwann cells**. The myelin sheath insulates the axon and speeds up transmission of impulses. It also protects the axon from any injuries especially which may be as a result of contraction from muscles.
4. **Dendrites**; these are fine structures on the neuron that link up nerve cells to form a complex network of communication.
5. **Schwann cell**; this is a cell which secretes the myelin sheath.
6. **Nissl's granules**; these are groups of ribosomes responsible for protein synthesis.
7. **Node of Ranvier**; this is the space on the axon between two adjacent myelin sheaths. It speeds up nervous transmission.
8. **Cytoplasm**; this is a site for chemical reactions in the neuron.
9. **Dendrone**; it is a branch through which impulses are transmitted to the body.

There are three types of neurons.

1. Sensory neuron
2. Motor neuron
3. Interneuron (relay neuron)

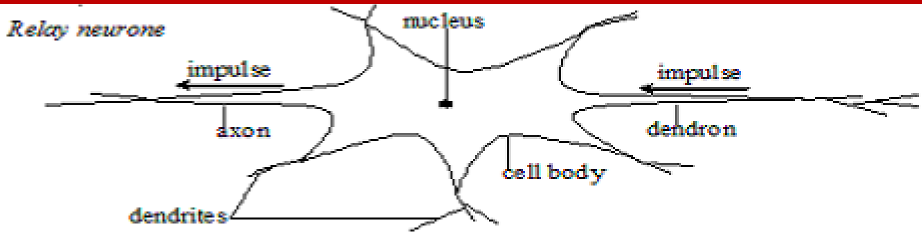
SENSORY NEURON

These are neurons that transport impulses from the receptors to the central nervous system. A sensory neuron has a single elongated dendrite called a dendron consisting of a fluid filled cytoplasmic tube. It has a cell body in the middle of a short axon and dendron. It is sometimes surrounded with myelin sheath. The myelin sheath increases the speed of the impulse in the neuron.



THE INTERNEURONE (RELAY NEURON)

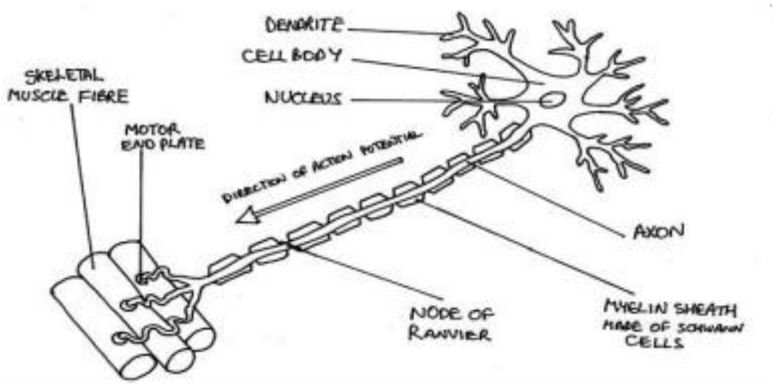
This is a neuron found in the central nervous system and carries impulses from the sensory neuron to the motor neuron.



THE MOTOR NEURONE

This is a neuron that carries impulses from the central nervous system to the effectors. Motor neurons consist of short dendrites with a cell body at one end of a long axon. It is also sometimes surrounded by the myelin sheath.

Structure of the motor neuron



Transmission of nerve impulses

1. **Polarization of the neuron's membrane:**

Sodium is on the outside, and potassium is on the inside.

Cell membranes surround neurons just as any other cell in the body has a membrane. When a neuron is not stimulated — it's just sitting with no impulse to carry or transmit — its membrane is **polarized**. Being polarized means that the electrical charge on the outside of the membrane is positive while the electrical charge on the inside of the membrane is negative. The outside of the cell contains excess sodium ions (Na+); the inside of the cell contains excess potassium ions (K+).

You're probably wondering: How can the charge inside the cell be negative if the cell contains positive ions? Good question. The answer is that in addition to the K+, negatively charged protein and nucleic acid molecules also inhabit the cell; therefore, the inside is negative as compared to the outside.

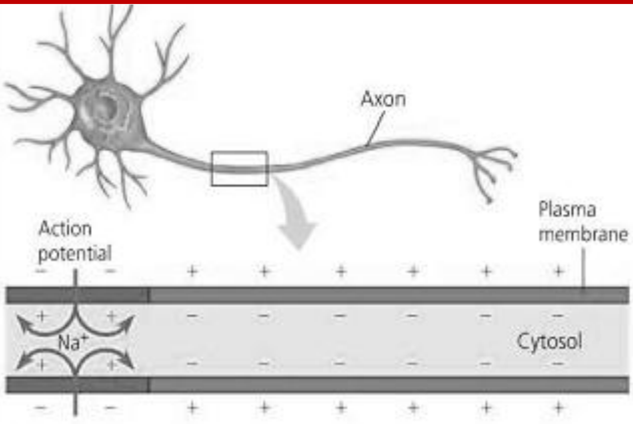
Then, if cell membranes allow ions to cross, how does the Na+ stay outside and the K+ stay inside? If this thought crossed your mind, you deserve a huge gold star! The answer is that the Na+ and K+ do, in fact, move back and forth across the membrane. However, Mother Nature thought of everything. There are Na+/K+ pumps on the membrane that pump the Na+ back outside and the K+ back inside. The charge of an ion inhibits membrane permeability (that is, makes it difficult for other things to cross the membrane).

2. **Resting potential** *gives the neuron a break.*

When the neuron is inactive and polarized, it's said to be at its resting potential. It remains this way until a stimulus comes along.

3. Action potential: Sodium ions move inside the membrane.

When a stimulus reaches a resting neuron, the gated ion channels on the resting neuron's membrane open suddenly and allow the Na+ that was on the outside of the membrane to go rushing into the cell. As this happens, the neuron goes from being polarized to being depolarized.



❶ An action potential is generated as Na^+ flows inward across the membrane at one location.

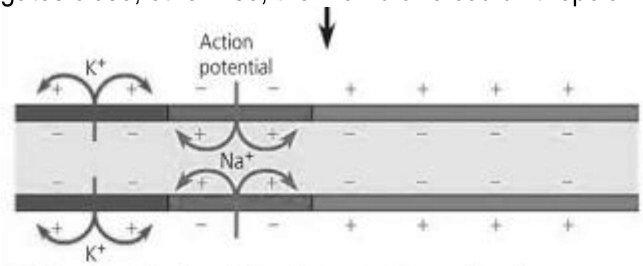
Remember that when the neuron was polarized, the outside of the membrane was positive, and the inside of the membrane was negative. Well, after more positive ions go charging inside the membrane, the inside becomes positive, as well; polarization is removed and the threshold is reached.

Each neuron has a threshold level — the point at which there's no holding back. After the stimulus goes above the threshold level, more gated ion channels open and allow more Na+ inside the cell. This causes complete depolarization of the neuron and an action potential is created. In this state, the neuron continues to open Na+ channels all along the membrane. When this occurs, it's an all-or-none phenomenon. "All-or-none" means that if a stimulus doesn't exceed the threshold level and cause all the gates to open, no action potential results; however, after the threshold is crossed, there's no turning back: Complete depolarization occurs and the stimulus will be transmitted.

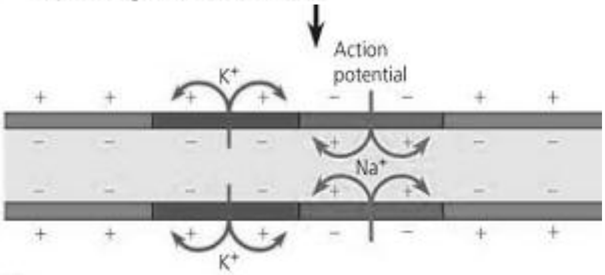
When an impulse travels down an axon covered by a myelin sheath, the impulse must move between the uninsulated gaps called nodes of Ranvier that exist between each Schwann cell.

4. Repolarization: Potassium ions move outside, and sodium ions stay inside the membrane.

After the inside of the cell becomes flooded with Na+, the gated ion channels on the inside of the membrane open to allow the K+ to move to the outside of the membrane. With K+ moving to the outside, the membrane's repolarization restores electrical balance, although it's opposite of the initial polarized membrane that had Na+ on the outside and K+ on the inside. Just after the K+ gates open, the Na+ gates close; otherwise, the membrane couldn't repolarize.



❷ The depolarization of the action potential spreads to the neighboring region of the membrane, reinitiating the action potential there. To the left of this region, the membrane is repolarizing as K^+ flows outward.



❸ The depolarization-repolarization process is repeated in the next region of the membrane. In this way, local currents of ions *across* the plasma membrane cause the action potential to be propagated *along* the length of the axon.

5. Hyperpolarization: More potassium ions are on the outside than there are sodium ions on the inside.

When the K+ gates finally close, the neuron has slightly more K+ on the outside than it has Na+ on the inside. This causes the membrane potential to drop slightly lower than the resting potential, and the membrane is said to be hyperpolarized because it has a greater potential. (Because the membrane's potential is lower, it has more room to "grow."). This period doesn't last long, though (well, none of these steps take long!). After the impulse has traveled through the neuron, the action potential is over, and the cell membrane returns to normal (that is, the resting potential).

6. Refractory period puts everything back to normal: Potassium returns inside, sodium returns outside.

The refractory period is when the Na+ and K+ are returned to their original sides: Na+ on the outside and K+ on the inside. While the neuron is busy returning everything to normal, it doesn't respond to any incoming stimuli. *It's kind of like letting your answering machine pick up the phone call that makes your phone ring just as you walk in the door with your hands full.* After the Na+/K+ pumps return the ions to their rightful side of the neuron's cell membrane, the neuron is back to its normal polarized state and stays in the resting potential until another impulse comes along.

Figure shows the transmission of an impulse.

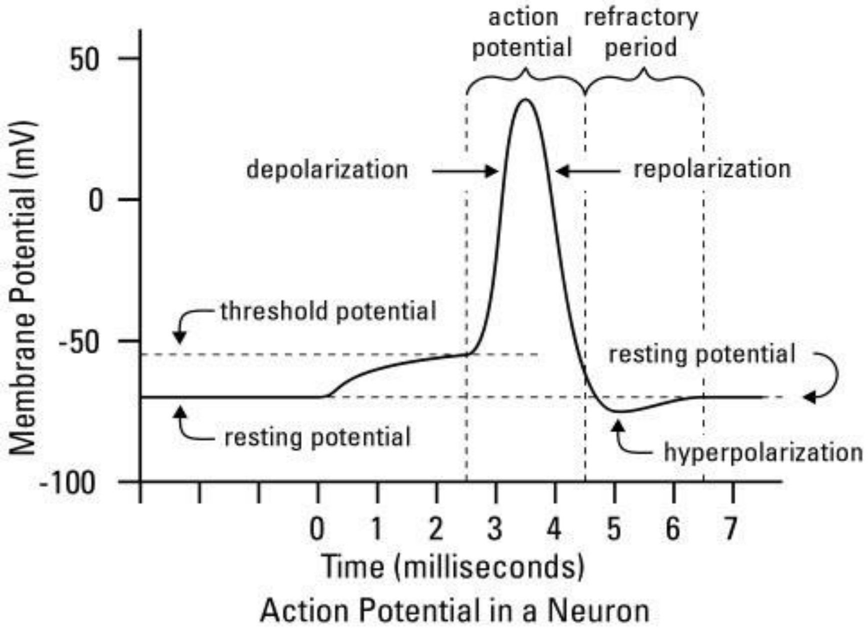


Figure: Transmission of a nerve impulse: Resting potential and action potential.

Note:

The membrane is more permeable to outward diffusion of K^+ than inward diffusion of Na^+. This will leave a surplus negative charges inside and positive charges outside hence resting potential.

When an impulse is passing, the membrane suddenly become permeable to Na^+ and they diffuse into the axon rapidly and reverse the resting potential by making the inside positive and leaving the outside negative hence an action potential which is propagated along the axon as a current of propagation.

As sodium ions enter the axon, potassium ions leave to the outside and this restores the negative charges inside. The sodium ions are later expelled from the inside by Na-K pump and return potassium hence restoring the distribution of ions as normally exist when an axon is at rest.

Properties of nerves and nerve impulses

These properties are based on the following:

i) Stimulation
ii) The all or nothing law
iii) Transmission speed

iv) Myelin sheath
v) Axon diameter

Stimulation:

Most of the time impulses are as a result of excitation of receptors. However the axon can be excited by exact direct application of appropriate stimulus that cause local depolarization of the axon membrane. Usually nerves are stimulated by mechanical, osmotic, chemical, thermal and electric stimuli.

The all or nothing law:

It states that if the strength of the stimulus is below certain threshold intensity, no action potential is evoked. If however the stimulus is above the threshold, a full sized potential is evoked and remain the same however-much intensity the stimulus becomes.

Refractory period:

It's the period of in excitability that accompanies the recovery phase of the axon and it lasts for 0.3s. It is categorized into:

i) Absolute refractory period: where the axon is completely incapable of transmitting an impulse.
ii) Relative refractory period: where it is possible to generate an impulse provided that the stimulus is longer than normal.

Importance of refractory period

Determines the maximum frequency at which an axon can transmit an impulse.

Ensures separation of action potential and specify the stimulus causing the excitation.

Prevents spreading of action potential and makes it flow in one direction.

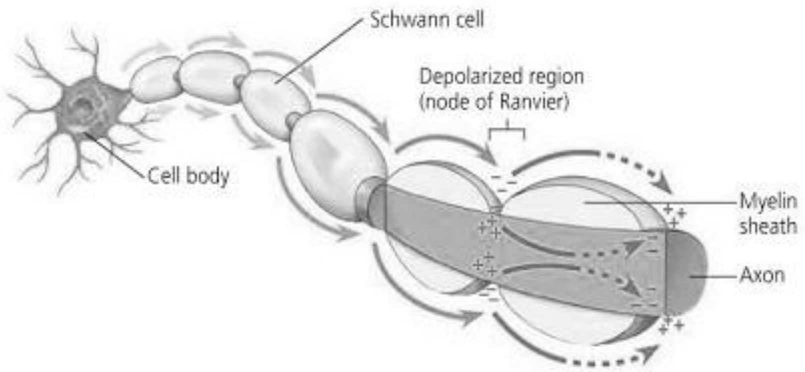
Transmission speed:

This depends on the type of the neuron of the animal in question. This variation in speed depends on the diameter and whether the axon is myelinated or not.

Myelin sheaths:

This allows depolarization of the nodes of Ranvier which bring about exchange there. This causes the action potential to leap form node to another.

Transmission of an impulse along a myelinated neuron



The insulating myelin causes ions to occur at the nodes of Ranvier and impulses jump from one node to another. This is known as **salutatory** impulse transmission.

Axon diameter:

The thicker the axons, the faster it will transmit impulses. This is because there is a greater surface area over which ionic exchange will occur. This is a major adaptation for invertebrates' axon e.g. annelids, clay fish and other crustaceans.

Temperature:

Organisms with high body temperature have high impulse speed transmission than those with low temperature.

SYNAPSE

This is the point where the axon of one neuron meets and joins with the dendrite or cell body of another neuron. This allows information to cross from one neuron to another neuron.

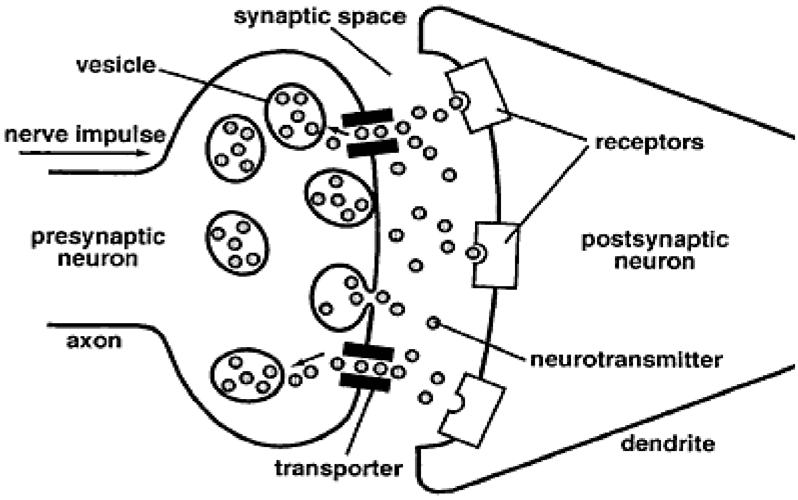
Structure of the synapse

It consists of swelling at the end of the nerve fibre called the synaptic knob. The cytoplasm of the synaptic knob consists of numerous mitochondria for provision of energy and small synaptic vesicles. Each synaptic vessel consist of molecules of transmitter substance called neurotransmitter substance which are responsible for transmission of nerve impulse across the synapse.

The membrane of synaptic knob near to the synapse is called a presynaptic membrane whereas the membrane of the dendrites is called postsynaptic membrane.

These two membranes are separated by a gap of about 20nm called the synaptic cleft.

The post synaptic knob contains large protein molecules which act as receptor sites for transmitter substances and numerous channels and pores that are normally closed and they are for the purpose of movement of ions.



Transmission of the impulse across a synapse

When an impulse arrives on the presynaptic knob, the calcium ion channels in the presynaptic membrane are opened. Calcium ions from the synaptic cleft enter the knob and cause the vesicles to move close to the presynaptic membrane.

When these vesicles reach the membrane, they discharge/release the transmitter substances through the membrane to the cleft.

The released neurotransmitter substances then diffuse across the synaptic cleft attaches to specific receptor sites on the postsynaptic membrane.

What follows depends on whether the synapse is either excitatory or inhibitory.

At excitatory synapse, the reception of neurotransmitter substance (acetyl choline) on the receptor sites changes their configuration such that the membrane channels in them are opened up thus allowing sodium ions to diffuse into the postsynaptic membrane.

The potential difference of the membrane therefore changes and an excitatory postsynaptic potential (epsp) results. This fills up until the threshold is reached which results into an action potential being fired in the post synaptic neuron. At that point the impulse has crossed the synapse.

At an inhibitory synapse, release of transmitter substances (noradrenaline) into the synaptic cleft leads to the opening up of chloride ion channels in the post synaptic membrane resulting into chloride ions entering and potassium ions leaving.

As a result, the interior of the post synaptic membrane becomes more negative. This increases the threshold making the post synaptic membrane harder to be excited.

Note:

After neurotransmitter substance has performed its function, it does not stay because if it was to stay it would continue to stimulate the post synaptic neuron.

Acetyl choline is normally hydrolyzed by an enzyme, acetyl cholinesterase to choline and acetyl. These two products then diffuse back and re-enter the presynaptic knob and combine back to form the transmitter substance which is packed into vesicles ready for reuse.

Because this process is energy demanding, it explains why the synaptic knob has many mitochondria.

Action of drugs and poison

The fact that transmission of impulse is as a result of chemicals, it provides explanations that drugs and poisons have an effect on the synapse which may be as a result of:

- ❖ Destruction of acetyl choline
- ❖ Inhibition of acetyl choline production
- ❖ Prevention of acetyl action

Poisons such as tropine and curare stop acetyl choline from depolarizing the post synaptic membrane but curare does it on the fibre end plate.

Strychnine enhances synaptic transmission causing compulsive condition upon slight stimulation.

Some of the poisonous nerve gases militarily use it also work in the same way.

Other terms used in impulse transmission

1. Summation:

This is a phenomena used to describe how the depolarizing effect of several excitatory post synaptic potential is additive. There are two types i.e.

i) Spatial summation:

This is the addition of transmitter substances from two synaptic knobs so that it can be enough to exact the post synaptic membrane.

ii) Temporal summation:

This involves the facilitation process i.e. the first impulse transmission is insufficient to trigger off an impulse in the post synaptic membrane but cause an effect therefore the second faster stimulation will add to the former and generate an impulse at the post synaptic membrane. The rapid repeated release of transmitter substance from several synaptic vesicles by the same synaptic knob as a result of an intense stimulus produces individual excitatory post synaptic potentials (epsp) which are so close together that they summate and give rise to an action potential in the post synaptic membrane.

2. Accommodation:

If a synapse has had a persistent high frequency impulse for a long time than usual, the post synaptic nerve cell may fail to respond and impulses are no longer generated. This means supply of transmitter substance is exhausted and its re-synthesis can't keep pace with the rate at which the impulse are reaching the synapse therefore the synapse is said to be fatigue or accommodate.

Functions of the synapse

i) Transmit information within neurons.

ii) Direct impulses into one direction only. This is because neural transmitter substance can only come from side of synapse where there is synaptic vesicles.

iii) Act as junctions. A number of neurons may converge at the synapse to bring together their carried impulse that can generate an impulse across the cleft as a result of releasing sufficient neurotransmitter substance.

iv) Filter out low levels of stimulus e.g. back ground stimuli at a constantly low level are filtered out, such impulse may be low which the body may not need to respond to.

v) Allow adaptation to intense stimulation as a result of being fatigued e.g. if there is a persistent pain inflicted on the body the intensity of the pain goes on reducing.

Disadvantages of synapse

- ❖ Slows down the speed of transmission
- ❖ Are highly prone to drugs and fatigue which may inhibit impulse transmission.

REFLEX ARC

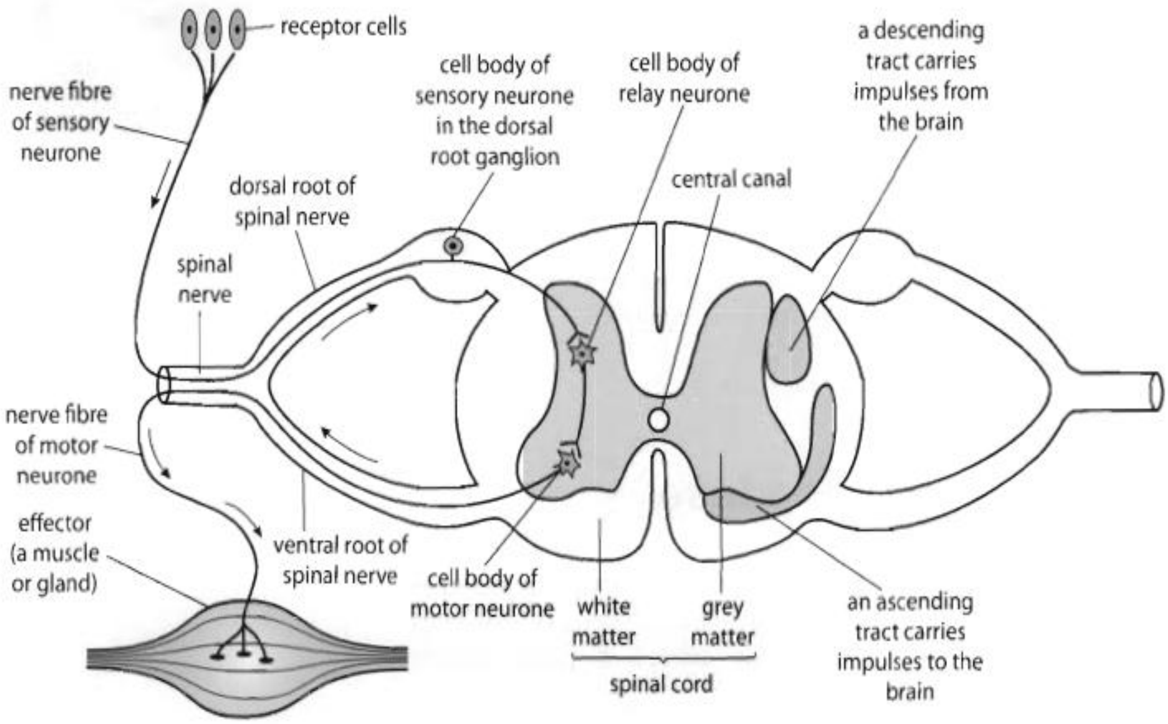
This explains the pathway taken by the impulse from the receptor to the effector. This mainly applies to the reflex action i.e. rapid automatic response to stimulus which is not under voluntary control of the brain e.g. withdraw of the hand from a hot object.

Structure of the generalized reflex arc

This is a series of units through which impulses have to pass in order to bring about reflex responses. The receptors may be scattered sensory cells in the skin or an organ in the sensory cells like the eye. Here the stimulation is mainly from the sensory (efferent) neuron.

Impulses from the efferent neuron are conveyed to the central nervous system by the efferent neurons where they make synaptic connections with the intermediate neuron. The feedback from the central nervous is conveyed to the effectors by motor neuron.

Diagrammatic cross section of the spinal cord illustrating a typical vertebrate reflex arc



Grey matter:

It contains the intermediate nerve cells together with cell bodies. Each spinal nerve cell is connected to the spinal cord by separate roots i.e. dorsal roots for sensory neuron and ventral roots for motor neuron fibres.

Considering the spinal reflex, if its pain, the pain receptors in the skin trigger off the impulse in sensory neurons contained in the nerve supplying a particular part e.g. the hand.

The impulse enters the spinal cord via the dorsal root to the intermediate neurone in the grey matter and finally leaves the spinal cord via the appropriate motor neuron in the ventral root to the right effectors for response to occur.

Note:

The nervous reflex arcs in the nervous system are interconnected by the longitudinal neurons located in the white matter of the spinal cord. These neurons can also connect the arcs to the higher centre of the brain in case the impulse needs to reach the brain.

Differences between the grey matter and white matter

Grey matter	White matter
It's grey in colour due to high concentration of neurons.	It's white in colour due to concentration of axon.
Consists of cell body, dendrites and synapses of	Consists of nerve fibres arising from or to the

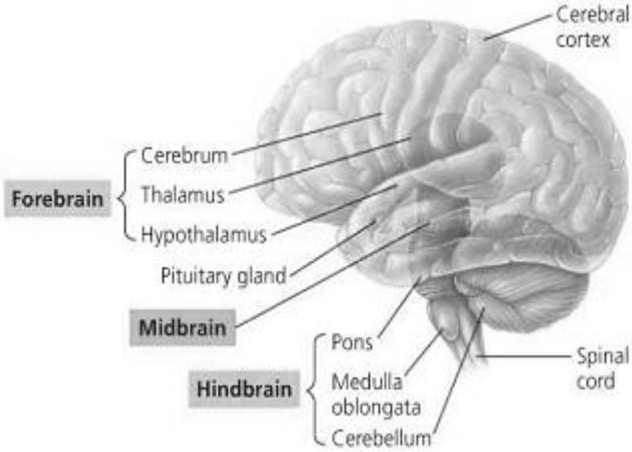
the brain.	nerve cells present in grey matter.
Contains numerous intermediate neurons.	Mainly consists of neurons connecting various parts of the body with the brain and links the brain to the spinal cord.

Conditioned reflexes

These are coordinated specifically by the brain. Learning forms the basis of all conditioned reflexes e.g. toilet training, salivation on the sight and smell of food, awareness of danger, etc. conditioned reflexes were first demonstrated by Pavlov's bell experiment.

THE HUMAN BRAIN

It is protected by the cranium and consists of mainly nervous tissues. On the surface, the brain appears grey because of the cell body's dendrites and the synapse of the neurons in it. Inside however, it is white in colour because of the axons in their myelin sheath.



It is divided into 3 regions i.e.

1) Fore brain: this is divided into
   i) Thalamus;
      - ❖ It perceives pain and pressure.
      - ❖ Processes and integrates sensory information.
   ii) Hypothalamus;
      - ❖ Controls the autonomic nervous system
      - ❖ Controls sleeping, feeding and aggression
      - ❖ Acts as an endocrine gland
      - ❖ Monitors the composition of blood.
   iii) Cerebrum;
      - ❖ Coordinates the body's voluntary activities
      - ❖ Controls learning, reasoning and memory
   iv) Corpus collasum;

❖ This connects the left and right cerebral hemispheres

2) Mid brain;
   This consists of corposa quadrigemina which controls the ordinary and usual reflexes.
3) The hind brain:
   This is divided into
   i) Medulla oblongata;
      This controls the activities of the autonomic nervous system e.g. ventilation rates, heartbeat, blood pressure, peristalysis, swallowing, etc.
   ii) Cerebellum;
      Controls muscular movement and body postures
      Coordinates movements to ensure it is carried out smoothly

The primitive nervous system

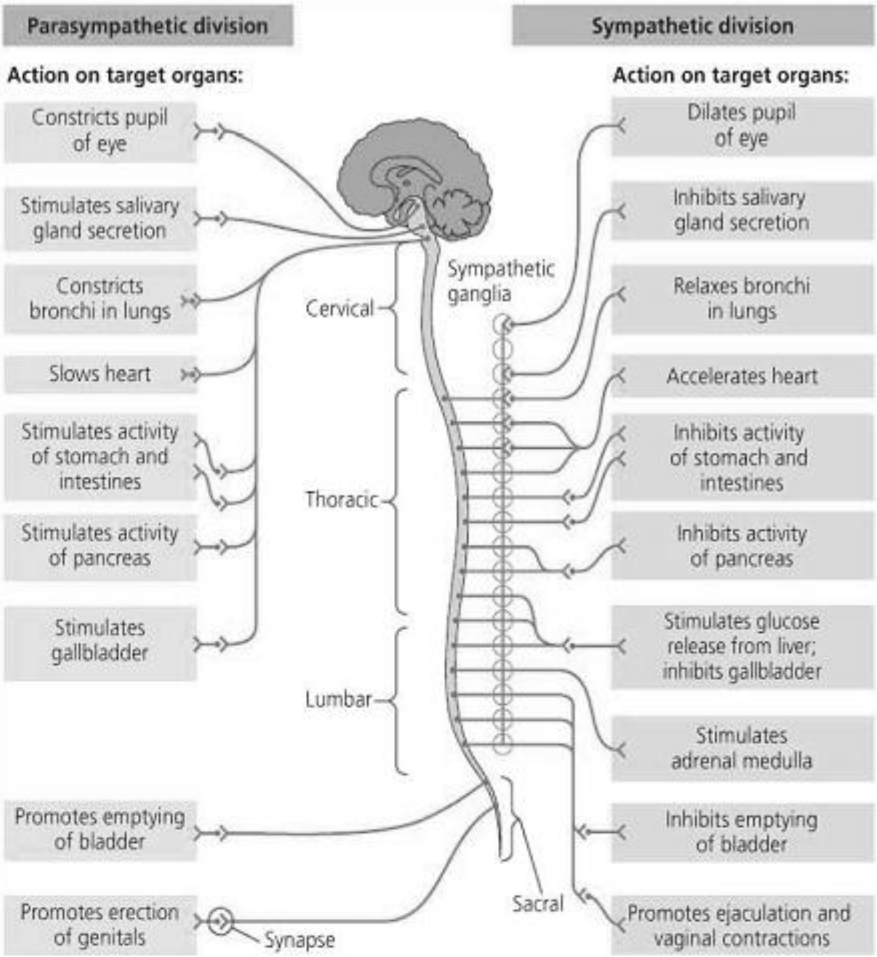
Such type of nervous system is found in coelenterates like hydra and sea anemones. They have a nerve network that spreads throughout the body. Sea anemones have got cambium tracts to move the stimuli faster than in other lower vertebrates. There is interneuron facilitation kind of condition i.e. from neuron to neuron.

AUTONOMIC NERVOUS SYSTEM

This is subdivided into two parts all controlling involuntary activities. These are the sympathetic nervous system and parasympathetic nervous system.
Most pathways in each division consist of preganglionic neurons (having cell bodies in the CNS) and postganglionic neurons (having cell bodies in ganglia in the PNS).

Action point: most tissues regulated by the autonomic nervous system receive both sympathetic and parasympathetic input from postganglionic neurons. Responses are typically local. In contrast, the adrenal medulla receives input only from the sympathetic division and only from preganglionic neurons, yet responses are observed throughout the body. Explain.

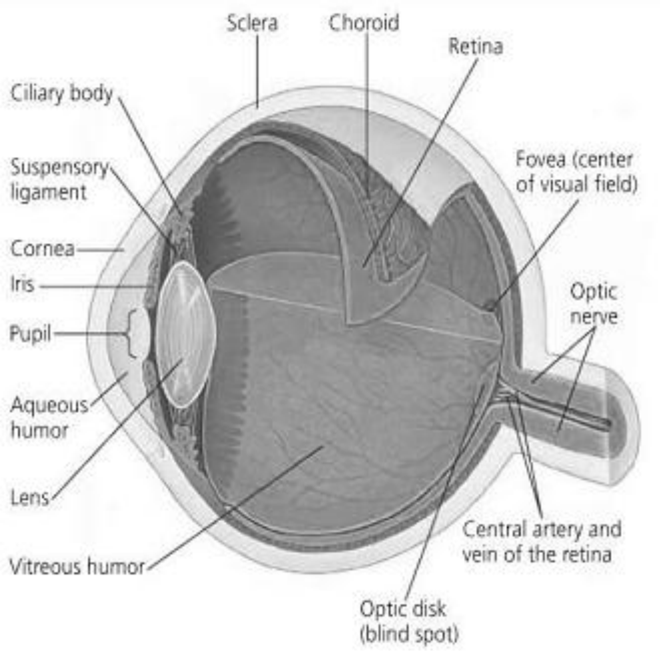
The parasympathetic and sympathetic divisions of the autonomic nervous system



SENSE ORGANS (RECEPTOR ORGANS)

THE HUMAN EYE

Structure of the human eye



The globe of the human eye, or eyeball, consists of the **sclera**, a tough white outer layer of connective tissue, and a thin, pigmented inner layer called the **choroid**. At the front of the eye, the sclera becomes the transparent **cornea** which lets light into the eye and acts as a fixed lens. Also at the front of the eye, the choroid forms the doughnut-shaped iris, which gives the eye it colour.
By changing size, the **iris** regulates the amount of light entering the pupil, the hole in the center of the iris. Just inside the choroid, the **retina** forms the innermost layer of the eyeball and contains layers of neurons and photoreceptors.

Functions of different parts

Sclera:
It maintains the shape of the eyeball and protects the inner layer of the eye.
Conjunctiva:
It is a thin and transparent layer over the cornea and is continuous with skin over the eye. It protects the cornea.
Choroid layer:
It's a pigment layer present beneath the sclera and contains numerous blood vessels that nourish the retina. The pigmentation prevents unnecessary reflection within the eye.
Ciliary muscle:
They are collected in the ciliary body and they are set of smooth muscles controlled by the autonomic nervous system.
They alter the shape of the lens. Their contraction results into the spherical shape of the lens and the relaxation results in the flattening of the lens.
Suspensory ligaments:
These are thread-like ligaments that attach the ciliary body to lens hence holding the lens in position.
The aqueous humour:
It is a solution of sugar, salts and proteins.
The aqueous humor is a watery fluid which maintains the shape of the eye.
It also refracts light into the pupil and the lens.
The vitreous humour:
It is a jelly-like substance that fills the inner cavity of the eye.

It is transparent and maintains the shape of the eye.
It refracts light to the retina.

The ciliary body:
This contains ciliary muscles, which control the size of the lens during viewing nearby or distant objects.

The lens.
It is transparent and held by suspensory ligaments.
It refracts light to make an image on the retina.

The iris
This is made up of an opaque tissue the center of which is a hole called pupil that allows in light to form an image on the retina.
The contraction of the muscles of the iris increases the size of the pupil and relaxation decreases the size of the pupil.
It is therefore responsible for controlling the amount of light entering the eye.

The retina
This is a layer containing photoreceptor cells (light sensitive cells). It is where the image is formed in the eye.

The blind spot:
This is a region where the nerve fibers leave the eye to enter the optic nerve. It has no light sensitive cells. When an image falls on this point, it is not taken to the brain thus blind spot.

The fovea
This is a small depression in the center of the retina. It has only cones in a high concentration. It is therefore a region on the retina that contains the largest number of sensory cells. Due to this, it produces the most accurate images in the eye.

Eye lids
These protect the eye and remove any foreign bodies that enter it. Regular blinking enables the spread of the fluid all over the exposed surface of the eye.

Eye lashes
They prevent dust particles and other objects from entering the eye.

Working of the eye

The camera and the eye work on the basic principles which include;

i) Control the amount of light entering the structure.
ii) Focuses the images of the external world by the lens system
iii) Registering images on sensitive surface
iv) Processing a captured image to produce a pattern which can be seen.

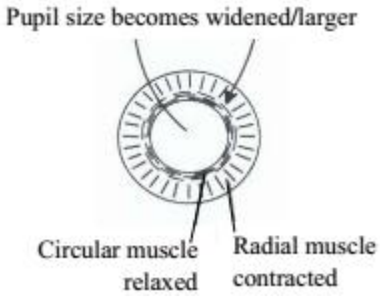
All the working principles of the eye and the camera are the same only that the lens of the human eye does not move forward or backward like that of the camera but it adjusts the distance of focus by undergoing changing of its shape.

CONTROL OF LIGHT AMOUNT ENTERING THE EYE

The iris controls the amount of light entering the eye. It is made up of circular and radial muscles.
When the circular muscles of the iris contract, the size of the pupil is reduced and less light is allowed in.
Contraction of the radial muscles widens the pupil so allowing more light to enter the eye.
In light of low intensity, the pupil widens and in bright light, the pupil reduces in size. This is done to protect the retina from damage by bright light and the wide size of the pupil during dim light allows in enough light of low intensity.

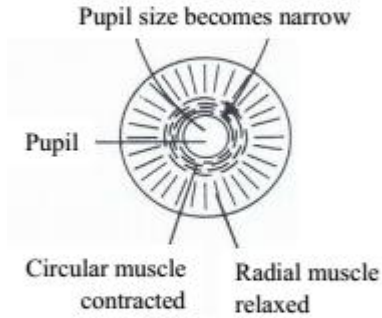
Control of the amount of light rays entering the eye when in dim light:

In dim light, radial muscles contract,
Circular muscles relax,
Pupil widens and more light is admitted into the eye.



Control of amount of light rays entering the eye in bright light:

Circular muscles of the iris contract,
Radial muscles relax,
Pupil becomes smaller and narrower,
Less light is admitted into the eye.

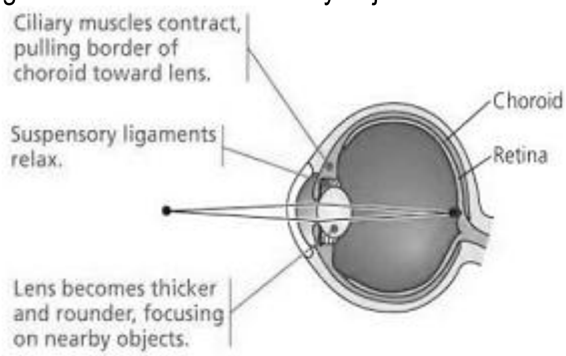


ACCOMMODATION OF THE EYE

This is the ability of the eye to change the focal length of the lens when viewing distant or nearby objects.

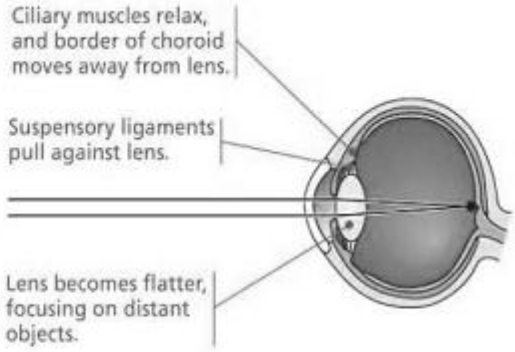
Accommodation for a nearby object:

When looking at a nearby object, the ciliary muscles in the ciliary body contract, the suspensory ligaments slacken. This makes the lens short and thick. This increases the ability of the lens to refract light and reduces the focal length of the lens for the nearby object to be seen clearly.



Accommodation for a distant object:

When viewing a distant object, the ciliary muscles in the ciliary body relax. This causes tension in the suspensory ligaments. The suspensory ligaments pull the lens apart making the lens thin and long. This makes the lens to refract less and increase the focal length of the lens.



THE RETINA

The human retina contains **rods** and **cones,** two types of photoreceptors that differ in shape and in function.

Rods are more sensitive to light but do not distinguish colours; they enable us to see at night, but only in black and white.

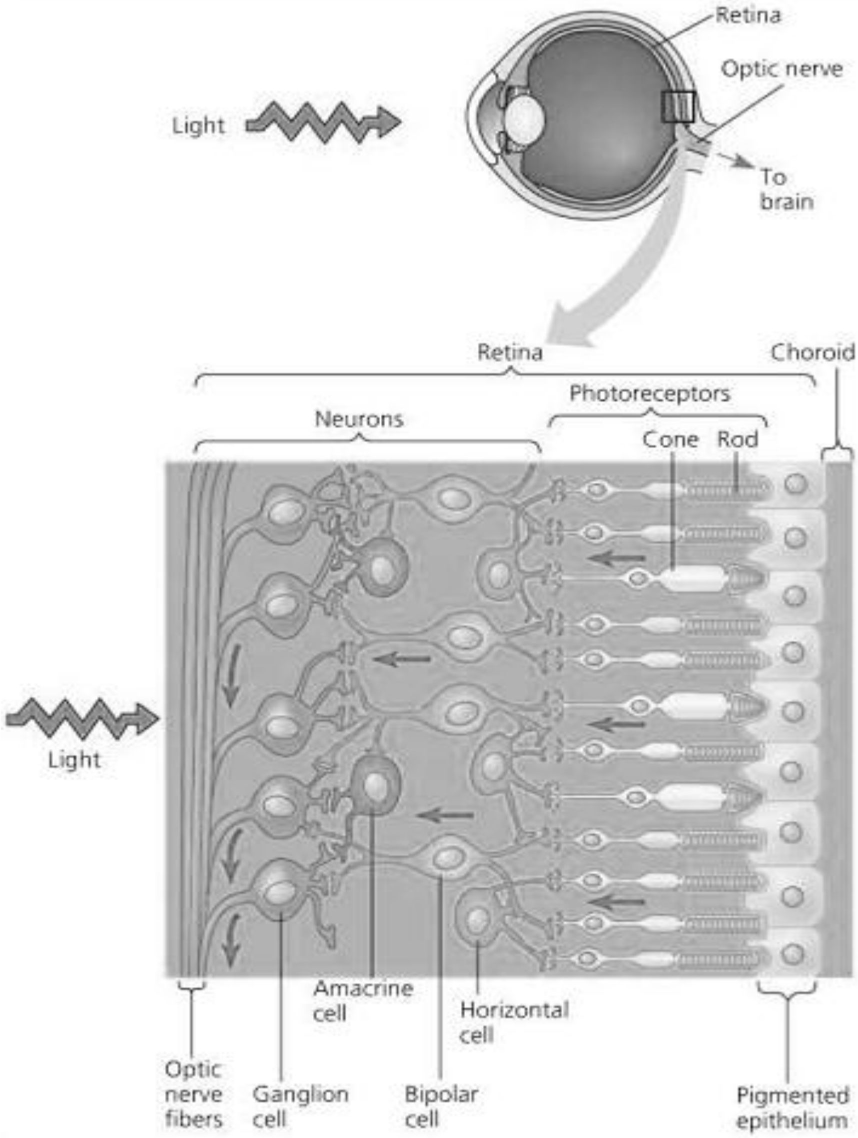
Cones provide colour vision, but, being less sensitive, contribute very little to night vision. There are 3 types of cones. Each has a different sensitivity across the visible spectrum, proving an optimal response to red, green, or blue light.

The relative numbers of rods and cones in the retina varies among different animals, correlating to some degree with the extent to which an animal is active at night.

The distribution of rods and cones varies across the human retina. Overall, the human retina contains about 125 million rods and about 6 million cones.

The fovea, the centre of the visual field, has no rods, but has a very high density of cones – about 150,000 cones per square millimeter. The ratio of rods to cones increases with distance from the fovea, with the peripheral regions having only rods. In day light, you achieve your sharpest vision by looking directly at an object, such night light shines on the tightly packed cones in your fovea. At night, looking directly at a dimly lit object is ineffective, since the rods-the more sensitive light receptors – are found outside the fovea. Thus, for example, you see a dim star best by focusing on a point just to one side of it.

Structure of the human retina



The retina is composed of 3 layers of cells containing a characteristic type of cells, i.e.

i) Photoreceptor layer (outermost layer):

This contains the photosensitive cells, the rods and cones partially embedded in the microvilli of pigment epithelium cells of the choroid.

ii) Intermediate layer:

This contains bipolar neuron with synapses connecting the photoreceptor layer to the third layer. Horizontal and Amacrine cells are found in this layer and enable lateral inhibition to occur.

iii) Inter surface layer:

This contains ganglion cells with dendrites in contact with bipolar neuron and axons of the optic nerves.

The structure and composition of cones and rods

Rods and cones have an essentially similar structure and their photosensitive pigments are attached to the outer surface of the membrane in the outer segment. They have four similar regions where structure and function are shown below;

i) Outer segment:

This is the photosensitive region where light energy is converted into a generator potential. The entire outer segment is composed of flattened membranous vesicles containing the photosensitive pigments.

ii) Constriction:

The outer segment is almost separated from the inner segment by an in folding of the outer membrane. The two regions remain in contact by cytoplasm and pair of cilia which pass between the two.

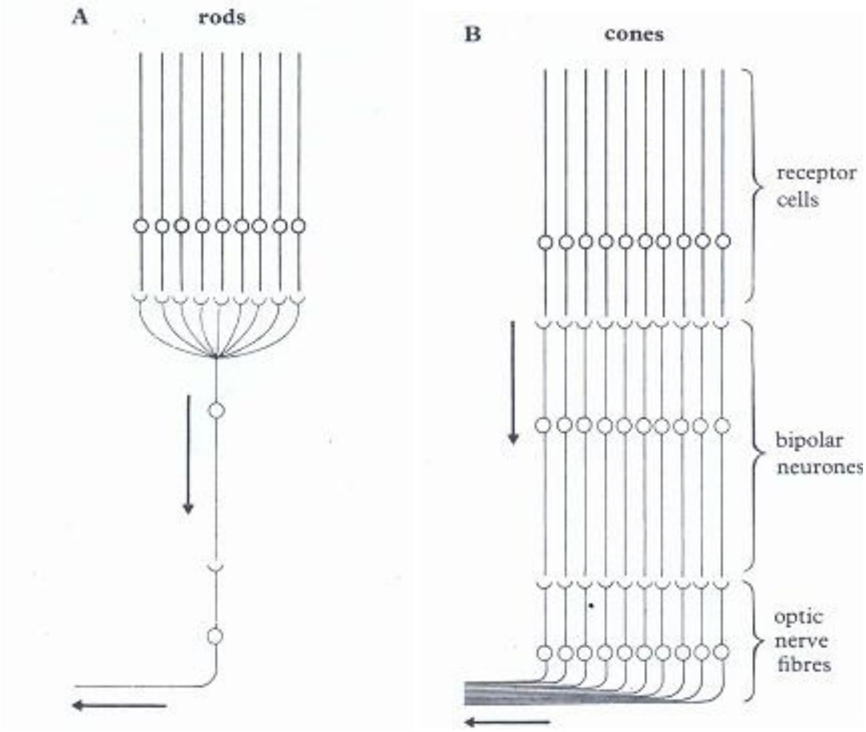
iii) Internal/inner segment:

This is an actively metabolic region. It's packed with mitochondria producing energy for visual processes and polysomes for synthesis of proteins involved in the production of membranous vesicles and visual pigments. The nucleus is located in this region

iv) Synaptic region:

Here the cells form synapses with bipolar cells. Different bipolar cells may have synapses with several rods; this is called synaptic convergence and it increases visual sensitivity. (This is illustrated in figure A below).

Mono synaptic bipolar cells link one cone to one ganglion cell and this gives the cone greater visual acuity than the rods. (Illustrated in figure B below). The high visual acuity in the cones is also because they are highly packed at fovea with direct connection to the optical nerves.



Horizontal cells and amacrine cells function in neural pathways that integrate visual information before it is sent to the brain.

Signals from rods and cones can follow several different pathways in the retina. Some information passes directly from photoreceptors to bipolar cells to ganglion cells. In other cases, horizontal cells carry signals from one rod or cone to other photoreceptors and to several bipolar cells. When an illuminated rod or cone stimulates a horizontal cell, the horizontal cell inhibits more distant photoreceptors and bipolar cells that are not illuminated. The result is that the light spot appears lighter and the dark surroundings even darker. This form of integration, called lateral inhibition, sharpens edges and enhances contrast in the image. Amacrine cells distribute some information from one bipolar cell to several ganglion cells. Lateral inhibition is repeated by the interactions of the amacrine cells with the ganglion cells and occurs at all levels of visual processing in the brain.

A single ganglion cell receives information from an array of rods and cones, each of which responds to light coming from a particular location. Together, the rods or cones that feed information to one ganglion cell define a receptive field-the part of the visual field to which the ganglion can respond. The fewer rods or cones that supply a single ganglion cell, the smaller the receptive field. A smaller receptive field results in a sharper image, because the information as to where light struck the retina is more precise. The ganglion cells of the fovea have very small receptive fields, so visual acuity (sharpness) in the fovea is high.

Differences between rods and cones

Rods	Cones
Photochemical pigment is readily regenerated when bleached.	Pigment take long to be regenerated once bleached.
Poor colour vision and visual acuity	High ability of recognizing colours and high visual acuity.
Have retinal convergence.	Lack retinal convergence.
The photosensitive pigment is rhodopsin.	The photosensitive pigment is iodopsin.

MECHANISM OF PHOTORECEPTION

Light reception in the rods

Each rod or cone in the vertebrate retina contains visual pigments that consist of a light absorbing molecule called **retinal** (a derivative of vitamin A) bound to a membrane protein called an **opsin.** The opsin present in rods, when combined with retinal, makes up the visual pigment **rhodopsin.**

Absorption of light by rhodopsin shifts one bond in a retinal from a *cis* to a *trans* arrangement, converting the molecule from an angled shape to a straight shape. This change in configuration destabilizes and activates rhodopsin. Because it changes the color of rhodopsin from purple to yellow, light activation of rhodopsin is called “bleaching.”

When this potential difference is large enough, it results into an impulse being generated into an optic nerve leading to the brain.

Rhodopsin returns to its inactive state when enzymes convert retinal back to the *cis* form for it to be stimulated again (dark adaptation). In very bright light, however, rhodopsin remains bleached, and the response in the rods becomes saturated. If the amount of light entering eyes decreases abruptly, the bleached rods do not regain full responsiveness for some time. This is why you are temporarily blinded if you pass abruptly from the bright sunshine into a dark place.

Rods are more sensitive than the cones because:

i) Their pigment is readily broken down and regenerate faster than that of the cones. That’s why they are mostly used for vision during conditions of low illumination or darkness.
ii) They show retinal convergence where separate rods add up or summate to build a generator potential upto a threshold.

Colour perception in the cones

The perception of colour in humans is based on three types of cones, each with a different visual pigment i.e. red, green, or blue. Their absorption spectra overlap depending on differential stimulation of two or more classes of cones. Forexample, when both red and green cones are stimulated, we may see yellow or orange, depending on which class is more strongly stimulated. Equal stimulation of all cones produces the colour sensation of white. The initial descrimination of the colour occurs in the retina but the final colour received involves the intergrative properties of the brain.

Colour vision is explained in terms of trichromatic theory which states that “different colour and shades are produced by the degree of simulation of each type of cone produced by light reflected from an object.”

Colour blindness

Acomplete absence of a particular cone or shortage of one type of cone leads to colour blindness or a degree of colour weakness. E.g. a person lacking red and green cones suffers from red-green colour blindness whereas a person with reduced number of red and green cones will have a difficult of distinguishing a range of red-green shades.

Colour blindness is a sex-linked recessive character resulting in the absence of appropriate colour genes in the X chromosome.

Binocular vision

Binocular vision occurs when the visual fields of both eyes overlap so that the fovea of both eyes are focused on the same object. It has several advantages over monocular vision and these include;

- Larger visual fields.
- Damage to one eye is copesated for by the other e.g. it cancels the effect of the blind spot and provides the basis of stereoscopic vision.

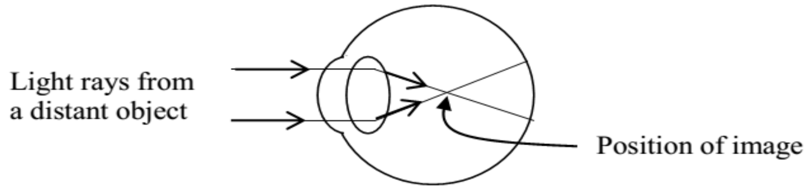
Stereosccopic vision depends upon the eyes simultaneously producing slight different retinal images which the brain resolve as one image.

Eye defects

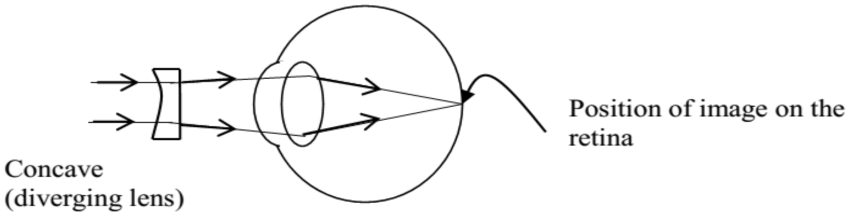
An eye defect is a condition where the eye fails to focus an object well unless aided by external lenses. The common eye defects include:

1. Short sightedness (myopia):

This is usually caused by a large eyeball or a very strong lens. Light from a distant object is focused in front of the retina. The individual can only see nearby object but not distant ones.

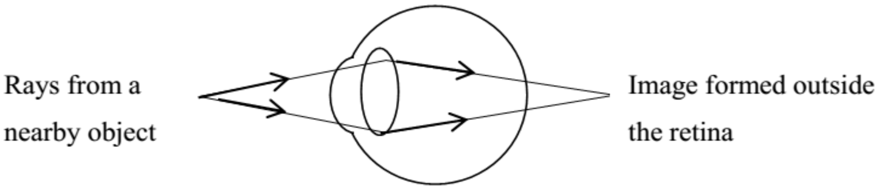


This can be corrected by putting on diverging (concave) lenses.

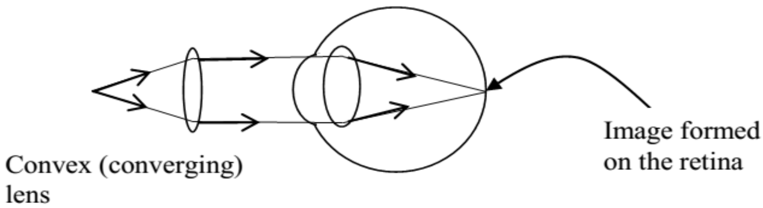


2. Long sightedness (hypermetropia):

This is caused by a small or short eyeball or a very weak lens such that a close object is focused far behind the retina. The individual can see distant objects but cannot see nearby objects.



Long sightedness can be corrected by wearing converging (convex) lenses.



3. Astigmatism

This is caused by unequal refraction of the cornea and lens due to uneven curving in them. It results into some parts of the object being well focused on the retina and some not to be focused. It is normally due to old age. This can be solved by wearing cylindrical lenses.

4. Presbyopia

This condition occurs when the lens hardens due to old age and does not focus. It can be corrected by wearing spectacles with convex lenses or often 2 pairs of spots may be necessary i.e. a pair with convex lenses for close vision and a pair of concave lenses for distant vision or the 2 types of lenses can be combined into one pair known as bi-focal spectacles.

5. Cataract

It is a condition which occurs when an individual is aging. It is caused by the eye lens becoming opaque due to a thin covering formed on it. It is corrected by surgical removal of the thin opaque layer of the lens.

COMPOUND EYE

Arthropods have compound eyes and some have simple eyes.

Simple eyes consist of a single lens able to distinguish between light and dark, unable to produce an image.

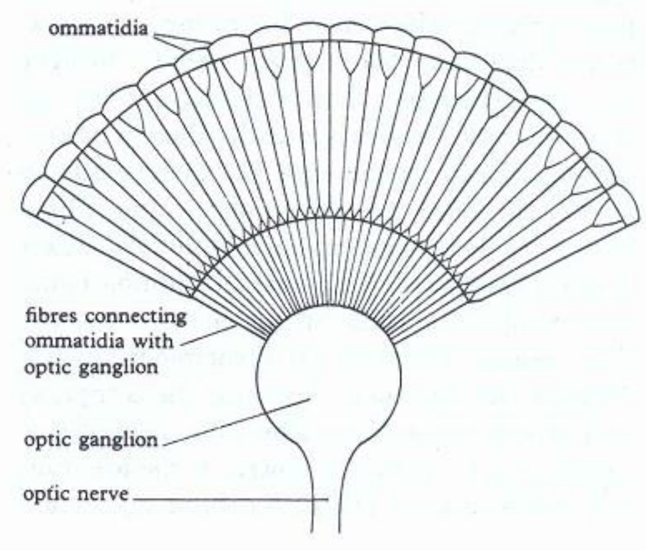
A compound eye consists of up to thousand light detectors called ommatidia, each with its own light focusing lens. Each ommatidium detects light from a tiny portion of the visual field.

A compound eye is very effective at detecting movement, an important adaptation for flying insects and small animals constantly threatened with predation.

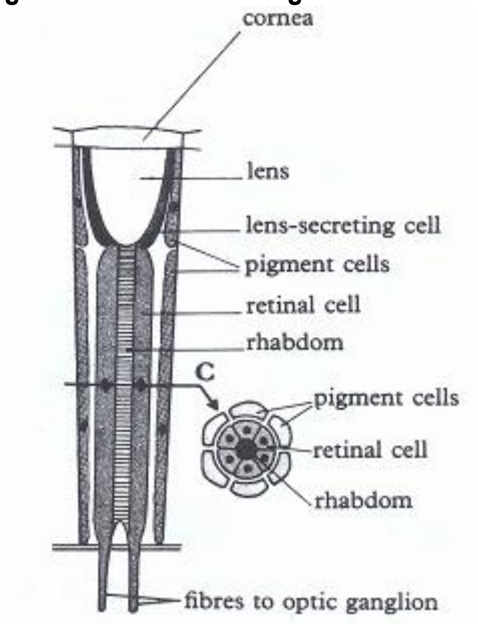
Whereas the human eye can only distinguish about 50 flashes of light per second, the compound eyes of some insects can detect flickering at a rate six times faster. If they slipped into a movie theatre, these insects could easily resolve each frame of the film being projected as a separate still image- this is termed as flicker fusion.

Insects have an excellent colour vision, and some (including bees) can see into the ultra-violet (UV) range of the electromagnetic spectrum. Because UV light is invisible to us, we miss seeing differences in the environment that bees and other insects detect.

Structure of the compound eye



Longitudinal section through an ommatidium



N.B: *C shows the cross section through ommatidium*

Functions of the parts

- The ***lens*** converges light rays onto the tip of the rhabdom.
- The ***pigment cells*** regulates the amount of light reaching the retinal cells. They also separate the ommatidium from its neighbor.

- The ***rhabdom*** is the light sensitive part of the ommatidium where photochemical stimulation occurs leading to depolarization of the membrane of the retinal cells.

The ommatidia would serve the same function as the rods and cones of the vertebrate eye but they are much larger and this brings about the reduced visual acuity in arthropods.

Differences between compound eye and mammalian eye

Compound eye	Mammalian eye
No rods and cones.	Rods and cones are present.
Consists of many repeated units able to function on their own - ommatidia.	The whole eye functions as a single unit.
Lens is crystalline and very elastic.	Lens is membranous and elastic.
Has a rhabdom.	No rhabdom.
No muscles attached to it i.e. it's immovable.	Has muscles attached to it and is very movable.
Has no eye lids and isn't protected at all.	Has eyelids for external protection.
Has a fixed focus (no accommodation).	Has adjustable focus (accommodation is possible).
Overlap image is greater.	Overlap image is small.
Detect light parallel to its longitudinal access.	Detects light reaching it at all angles.
Has poor resolving ability and poor visual acuity.	Good resolving ability and greater visual acuity.
Shows near sightedness.	Can see both near and far objects.

Similarities

- Both contain pigmented cells.
- Both have the cornea.
- Both possess convex lens.
- Both have nerve fibres to the brain.
- There is overlap of image in both.

Question:

Why do insects generally have very low visual acuity compared with the vertebrates?
How have insects overcome the above problem?

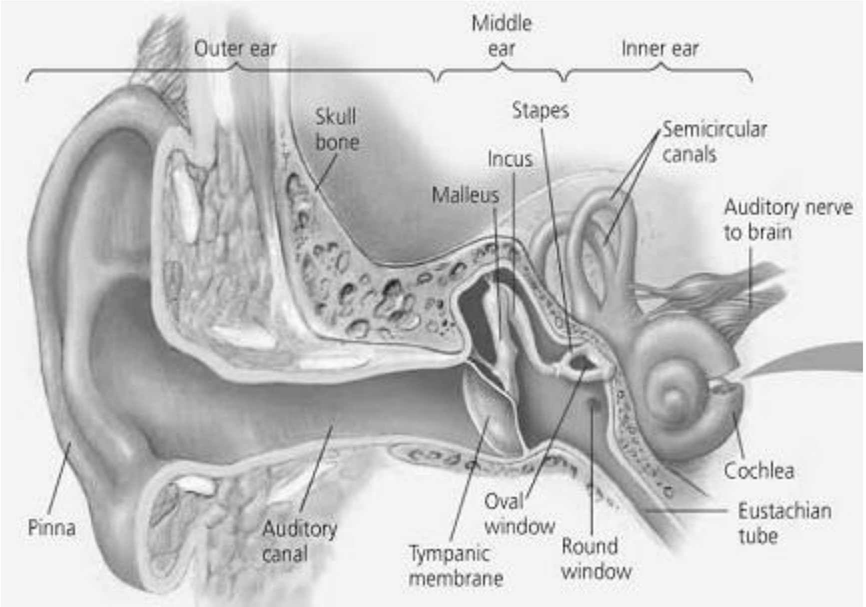
THE MAMMALIAN EAR

The ear has **mechanoreceptors** (receptors that detect physical transformation) associated with sound, gravity and displacement.

The ear performs three basic functions i.e. detection of:

- Sound (hearing)
- Head movements
- Changes in gravity (balance or posture)

Structure of the ear



The ear is made up of three areas i.e. the outer ear, middle ear and inner ear.

1. **The outer ear:**

This is the tube opening to the side of the head and inwards stopping at the eardrum. It consists of the pinna, auditory canal and the ear drum.

The outer projecting portion of the outer ear is known as the ***pinna (auricle).*** Its function is to receive and concentrate sound waves.

The ***auditory canal*** has hairs and wax that trap foreign bodies. It transmits sound waves to the eardrum (tympanum).

The ***ear drum*** is a thin membrane. The eardrum transmits sound waves to the middle ear.

2. **The middle ear:**

This is a cavity in the skull filled with air. It is comprised of three small bones called ***ossicles***, *i.e.* ***hammer*** *(**malleus**),* ***anvil*** *(**incus**) and* ***stapes*** *(**stirrup**).* They transmit sound vibrations from the eardrum to the ***oval window*** *(**fenestra ovalis**) that* transmits sound vibrations to the inner ear.

It communicates with the mouth cavity through the ***Eustachian tube*** (a slender canal that connects the middle ear to the pharynx). It equalizes the air pressure on the two sides of the eardrum.

3. **The inner ear:**

The inner ear is filled with a fluid and consists of mainly a coiled tube known as the cochlea. The cochlea has sensory ***auditory nerve*** that transmits impulses to the brain.

The ***semi-circular canals***, ***utriculus*** and ***sacculus*** form the ***vestibular apparatus***, which controls body balance and orientation.

The ***round window (fenestra rotunda)*** equalizes pressure in the cochlea.

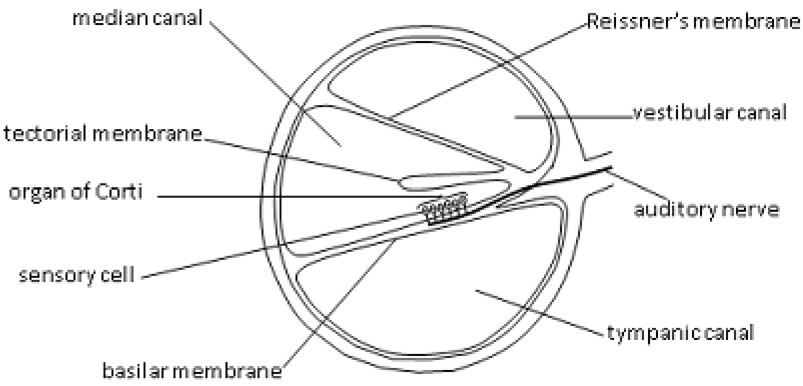
Hearing

The pinna receives and concentrates the sound waves.

They are transmitted to the eardrum, which vibrates.

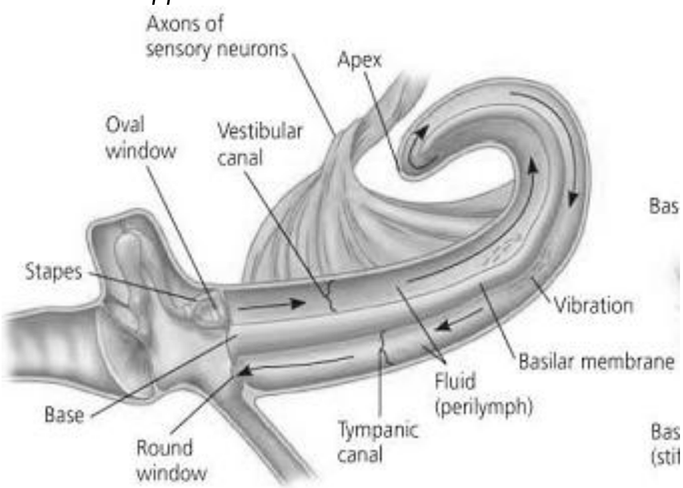
The vibrations of the eardrum are transmitted to the ossicles that vibrate and transmit the vibrations to the oval window at the entrance of the **vestibular canal** of the cochlea.

Transverse section of the cochlea



The **perilymph** (fluid) in the vestibular canal vibrates and causes **Reissner's membrane** to vibrate.
The displacement of Reissner's membrane causes the **endolymph** in the **median canal** to vibrate, which in turn causes the **basilar membrane** to vibrate.
The vibration of the basilar membrane stimulates sensory cells (in the **organ of Corti**), which generate impulses.
The impulses are transmitted by the auditory nerve to the brain, which interprets them into sounds.
The vibrations of the basilar membrane disturb the perilymph in the **tympanic canal**. The round window takes up these vibrations.

Questions: What prevents pressure waves from reverberating within the ear and causing prolonged sensation?
Once pressure waves travel through the vestibular canal, they pass around the apex (tip) of the cochlea. The waves then continue through the tympanic canal, dissipating as they strike the round window. This damping of sound waves resets the apparatus for the next vibrations that arrive.



Discrimination of sound intensity

The human brain is able to discriminate the sound quality in terms of pitch and intensity.
The pitch of sound (frequency) depends on its wave length.
High tones are as a result of sound of high frequency (short wave length) while low tones are as a result of sound of low frequency (long wave length).
The basilar membrane is about 2-5 times wider at the apex than at its base between the oval and round window. Sound of short wave length (high frequency) vibrates relatively a short portion of basilar membrane. Only the hair cells nearest the oval window will be stimulated. The impulses fired from these few cells and arriving at the brain are interpreted as a high pitched sound.

On the other hand, sound of a longer wave length (low frequency) causes a larger portion of the basilar membrane to vibrate, therefore the sensory hair cells that are stimulated further along this membrane are stimulated. The impulses fired from these cells when they reach the brain are interpreted as sound of low pitch.

In this way, the brain is therefore able to determine the pitch of each sound according to the source of impulse from the cochlea.

The role of the semi-circular canals and utriculus and sacculus in maintaining body balance

i) Semi-circular canals:

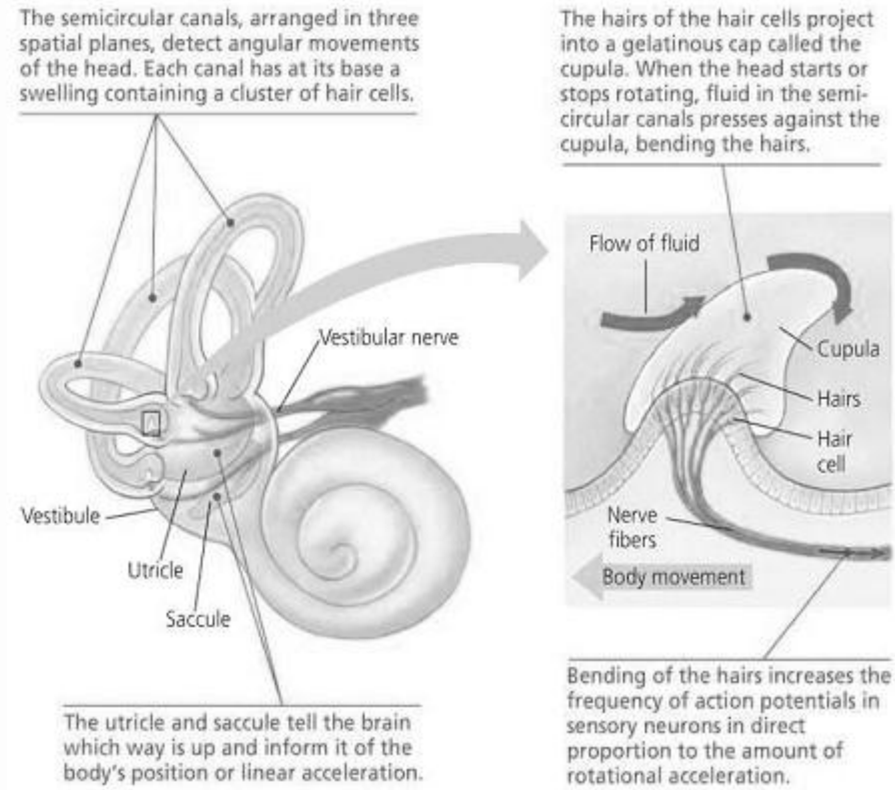
The semi-circular canals are important in in dynamic equilibrium.

Each semi-circular canal terminates in a swelling known as the **ampulla**, which contains the **cupula** (dome-shaped, gelatinous structure). The cupula is in contact with sensory hairs.

The canals are filled with fluid and are three in number, arranged in three planes; vertical canals detect movement in upward direction, horizontal canals detect backward and forward motion while lateral canals detect sidewise movements of the head.

When the head moves, the endolymph in the ampulla of one of the canals moves in the opposite direction and deflects the cupula. This stimulates the **cristae** (sensory cells), which generate impulses. The impulses are transmitted by the **vestibular neurones** to the brain.

The pattern of impulses is interpreted by the brain which detects the direction and speed of movement and sends instructions to relevant organs that maintain dynamic balance.



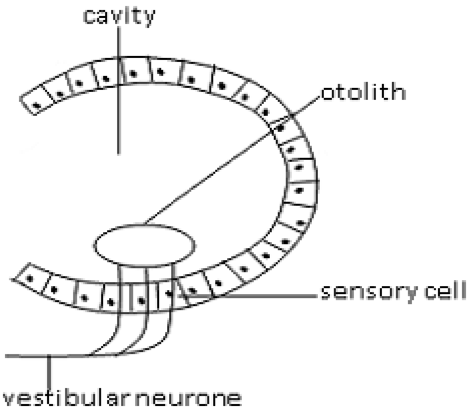
ii) Utriculus and sacculus:

The utriculus and sacculus contain structures called **maculae** which maintain body posture (static equilibrium).

Each macula consists of a patch of sensory cells with the free ends embedded in the **otolith** (gelatinous granule of calcium carbonate). The otolith detects the position of the head with respect to the force of gravity. By varying the position of the head, the pull of gravity over the hairs on the otolith tilts them accordingly.

The different influences of the pull of gravity result in a pattern of impulses to the brain.

The impulses are interpreted thus providing information about the position of the head and accordingly sends instructions to relevant muscles to restore balance. When the head is upright, the otolith is positioned on top of the sensory cells and no stimulation occurs.



Echolocation in bats

Bats fly so swiftly at night without seeing but do not collide with obstacles on their way. This is done because they use sound orientation in the environment.

They are able to use echoes of the sound they produce to detect on their way, a phenomenon known as echolocation.

Bats produce sound of high frequency (short wave length) which are far beyond which man can perceive and use thus can't hear sounds used in echolocation.

Major advantages of sound of echolocation

These sounds do not spread so wide and their echoes are so refined that they pin point the obstacle on which they are correctly reflected.

These sounds having short wave length, they allow location of even small objects.

Differences between hearing in bats and man

Bat	Man
Depend on sound produced and deflected by object.	Depend mainly on sound produced by vibrating objects in the environment.
Have the ability to eliminate noise in their echoes.	Have the ability to discriminate between sounds.
Able to detect sounds of very high frequency.	Can perceive sounds of low frequency.

COORDINATION AND IRRITABILITY IN PLANTS

Coordination and control in plants is carried out by hormones. Plants lack the nervous system and information is carried by hormones especially ***auxins.***

Plants do not move from one place to another. Their response involves growth movements of part of the plant and turgor changes within cells. Parts of the plant move towards or away from a stimulus due to changes in auxins concentration in the parts concerned.

Plant responses are divided into three categories.

1. **Nastic responses.**
   This is the movement of part of the plant in response to a non-directional stimulus. This can be observed in the closing of the leaves of *mimosa pudica* when touched (thigmonasty)
2. **Tactic responses**
   This is a type of response where the whole organism moves towards or away from a unidirectional stimulus. This response is common in lower plants such as chlamydomonas and chlorella.
3. **Tropisms**

This is a growth movement of part of the plant towards or away in response to a unidirectional stimulus.

Note;

Tactic responses and tropisms can be described as negative if movement is away from the stimulus or positive if the movement is towards the stimulus.

The responses are of different types depending on the nature of the stimulus.

TACTIC RESPONSE (TAXIS)

This is the movement of whole organism or cell from one place to another in response to a directional stimulus.

It is a positive tactic response when the whole organism moves towards the stimulus and negative tactic when the organism moves away from the stimulus.

Types of taxis

i) Phototaxis in response to light
ii) Chemotaxis in response to chemicals
iii) Thigmotaxis in response to touch
iv) Geotaxis in response to gravity

Examples of taxis

i) Unicellular organisms e.g. Euglena swim towards light hence positively tactic (phototactic)
ii) Earth worms, wood lice and cockroaches move away from light hence negative phototactic.
iii) Sperms swim towards the chemical produced by the ovum hence positively chemotactic.
iv) White blood cell moves towards harmful bacteria in the body hence positively chemotactic.

NASTIC RESPONSE (NASTIC)

This is the movement of a plant part in response to a non-directional stimulus or it is a response in which plant movements are not related to the direction of stimulus but to its intensity.

Nastic response are named depending on the type of stimulus i.e. Photo nastic if the stimulus is light.

Hydronasty if the stimulus is water

Thigmonastic if the stimulus is touch

Nastic movements do not involve growth.

Characteristics of nastic

1) It involves changes of turgidity of plant cells.
2) It is a rapid response.
3) It occurs in any part of a plant
4) The response is not related to the direction of the stimulus
5) It is induced by non-directional stimulus.

Examples of nastic response

1) Opening and closing of flowers in response to light e.g. morning glory.
2) Sudden closer of leaf lets of mimosa pudica in response to touch.
3) Closures of leaves of insectivorous plants e.g. butter Walt and pitcher plant where the insect lands on the leaf. Such plants are found in nitrogen deficient soil.

Similarities between nastic and tropic movement

- ✓ Both are brought about by external stimulus.
- ✓ Both occur in plants
- ✓ Both involve movement of plant parts.

Differences between tropisms and nastic responses

	Nastic response	Tropism
i)	Does not depend on the direction of the stimulus.	It depends on the direction of the stimulus
ii)	It occurs in any part of the plant.	It occurs in growing tips of plants
iii)	It does not involve auxins	It involves auxins
iv)	Are usually faster	Are usually slower
v)	It involve growth and turgor changes	It involves growth only.

TROPISMS

This is the growth movement of the plant part in response to the direction of stimulus. The direction of response is related to stimulus and the plants move towards or away from it.

Characteristics of tropisms

1. It involves growth
2. It is a slow response
3. It occurs at the shoots and root tips
4. It is related to the direction of stimulus
5. It is induced by directional stimulus

Importance of tropisms to plants

1. It enables plants leaves to trap maximum sunlight by enabling plant shoots to grow upright.
2. It enables plants to become firmly anchored in the soil by the roots growing towards the ground.
3. It enables plant roots to absorb or obtain water which is necessary for plant growth.
4. It enhances fertilization in plants since the pollen tubes grow towards the chemicals of the embryo sac.
5. It enables climbing plants to gain support by twinning around the support.
6. Tropisms allow plant parts to alter direction in response to changing conditions in the environment.

TYPES OF TROPISMS

Tropisms are divided into different types depending on the nature of the stimulus.

Phototropism:

This is the growth movement of part of the plant in response to unidirectional light. Plant shoots are positively phototropic that is, they grow towards the direction of light while the roots are negatively phototropic (they grow away from the direction of light).

Hydrotropism; this is the growth movement of a plant and part in response to a unilateral source of water. The roots grow towards the source of water hence show positive hydrotropism. The shoots grow away from the source hence negatively hydrotropic.

Thigmotropism; this is the growth movement of part of a plant in response to touch.

Chemotropism; this is the growth movement of part of the plant towards or away from a particular chemical e.g. pollen tube grows towards the embryo sac through the style during fertilization by responding to the source of chemicals produced by the embryo sac.

Geotropism:

This is the growth movement of the plant part in response to the direction of the force of gravity. Roots grow towards the direction of force of gravity hence positive geotropism.

Aerotropism; this is the growth movement of part of the plant towards or away from air.

The table below shows some of the tropic movements shown by plants

Type of tropism	Stimulus	Positive response	Negative response
Phototropism	Light	Shoot	Root
Geotropism	Gravity	Root	Shoot
Hydrotropism	Water	Roots	Shoots
Chemotropism	Chemicals	Pollen tube	-

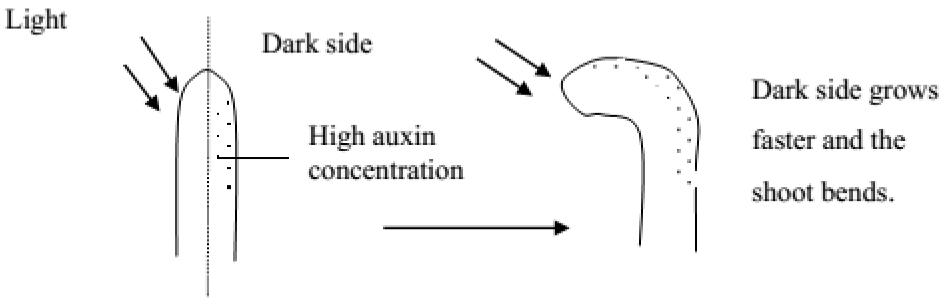
Thigmotropism	Touch	Tendrils of passion fruits	Root tips when in contact with an obstacle

AUXINS AND PHOTOTROPISM

Light from one direction of the shoot causes auxins on that side to escape to the opposite side without light. The side without light receives more auxins than one receiving more light.

A high concentration of auxins on the side with little or no light increases the rate of cell division and elongation on that side.

This causes the shoot to bend towards the direction of light (positive phototropism)



However, high auxins concentration limits growth in plant roots

Control of responses in plants

Responses in plants are controlled by a group of plant hormones especially auxins. These auxins are produced at the root and shoot tip and are transported in the phloem together with manufactured food.

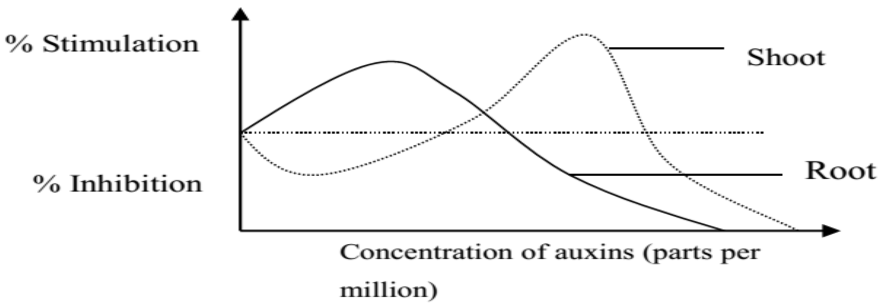
Auxins control responses by controlling growth through stimulation of cell elongation. High auxins concentration stimulates faster growth in shoots and inhibits growth in roots.

Light affects the distribution of auxins. When the shoot tip is illuminated from one side, auxins diffuse to the dark side there by causing faster growth on the dark side which then becomes longer than the illuminated side. This causes the shoot to bend towards light.

Gravity also affects the distribution of auxins. If a seedling is lying horizontally, more auxins will diffuse on the lower side of the root and shoot due to gravity.

In roots, the high concentration of auxins inhibits growth causing the lower side to grow slowly, while the upper side grows faster. This results in the roots bending towards gravity.

Graph showing the effect of auxins concentration on the growth of roots and shoots.



When the concentration of auxins increases, growth in the shoot also increases to a maximum beyond which further increase in auxins concentration inhibit growth in shoots. Growth response in the root decreases with increase in auxin concentration.

Importance of auxins

- ✓ Causes apical dominancy where by the terminal bud inhibits development of lateral buds.
- ✓ Leads to parthenocarpy
- ✓ Causes tropism

- ✓ Causes rooting of the stem cutting.
- ✓ They delay flowering, leaf and fruit abscission (premature fall of flowers, leaves and fruits).
- ✓ Promotes fruit ripening.

Commercial application of auxins

i) They promote rooting of stem cuttings.
ii) Inhibits sprouting of potatoes.
iii) Prevent premature fruit drop.
iv) Used as a selective weed killer.
v) Auxins e.g. Indole acetic acid (IAA) and naphthyls are used for fruit setting, sometimes cause setting in absence of pollination (parthenocarpy).

Other plant growth substances

1. Indole acetic acid

Produced in the apical meristems and have the following effects;

i) Promotes growth by increasing the rate of cell elongation in shoots.
ii) Inhibits cell elongation in roots.
iii) Promotes apical dominancy by inhabiting growth lateral roots.
iv) Stimulates growth of adventitious roots.
v) Stimulates flower development.
vi) Stimulates fruit growth and ripening.
vii) Stimulates termination of bud dormancy.
viii) Inhibits fruit and leaf fall.

2. Gibberellic acid

Produced in buds, seeds and root tips. They have the following effects:

i) They promote stem growth of normal plants by affecting cell elongation.
ii) They break seed dormancy of certain seeds, notably of cereals. Germination is triggered by soaking the seed in water. After imbibing water the embryo secretes gibberellins which diffuses to the aleuronic layer, stimulating synthesis of several enzymes including α-amylase. These enzymes catalyse the breakdown of food reserve in the endosperm and the products of digestion diffuse to the embryo, where they are used in growth.
iii) They promote cell division, cell elongation, fruiting and parthenocarpy.
iv) Promote rapid shoot and root growth.
v) Promote flowering in long day plants.
vi) Promote production of auxins
vii) Inhibits root initiation.

3. Abscisc acid (ABA)

It's made in leaves, stems, fruits and seeds. It has the following effects:

i) Inhibits growth.
ii) Promotes bud and seed dormancy.
iii) Promotes abscission and leaf senescence.

ABA is sprayed on tree crops to regulate fruit drop at the end of the season.

4. Cytokinins

Cytokinins are most abundant where rapid cell division is occurring, particularly in fruits and seeds where they are associated with embryo growth. They have the following effects:

i) They promote cell division only in the presence of auxins.
ii) Delays leaf senescence.
iii) Sometimes inhibit cell expansion.

iv) Promote leaf growth and fruit growth.
v) Promote apical dominancy.
vi) Promote stomatal opening.

Commercially they prolong the life of fresh leaf crops such as cabbages by delaying leaf senescence as well as keeping flowers fresh.

5. Ethene (ethylene)

It's made by almost all plant organs. It has the following effects:

i) Inhibits stem growth and root growth.
ii) Breaks bud dormancy.
iii) Promotes flowering in pine apple.
iv) Promotes fruit ripening.

Commercially it induces flowering in pine apple and stimulates ripening of tomatoes and citrus fruits.

Synergism is where the combined effect of growth substances is much greater than the sum of their separate effects.

Antagonism is where the two substances have opposite effects on the same process, one promoting and the other inhibiting.

Examples

i) The effect of gibberellins on elongation of stems, petioles, leaves is dependent on the presence of auxins.
ii) Cytokinins promote cell division only in presence of auxins.

PHOTOPERIODISM

This is the response of an organism to changing length of days and nights. One of the important ways in which light exerts its influence on living organisms is through variations in day length (photoperiod).

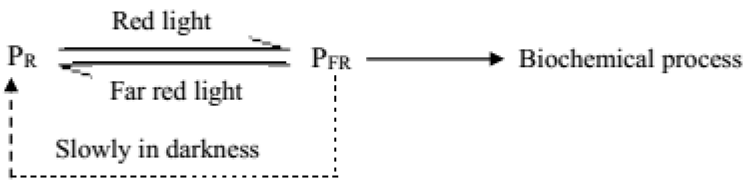
Photoperiodism helps organisms to time their activities to coincide with favourable conditions e.g. matching of flowering with presence of pollinators and breeding matched with availability of food by the time young ones are born.

During Photoperiodism responses are triggered off by changes in the day length i.e. photoperiod in 24 hours cycle.

In many plants, flowering is a photoperiodic response. The pigment that is responsible for this is ***Phytochrome.*** Phytochrome is a blue-green pigment which exists in two inter-convertible forms i.e.

i) Phytochrome 660/P_R which absorbs red light.
ii) Phytochrome 730/P_{FR} which absorbs far red light.

Absorption of light by one form converts it rapidly and reversibly to another form within a second.



Normal sun light contains more red than far red light, so the P_{FR} form predominates during the day. This is the physiologically active form, but reverts slowly to the more stable, but inactive, P_R form at night.

One major influence on the timing of flowering is the length of the day or photoperiod. The effects of the photoperiod on flowering differ from species to species but plants fall into 3 basic categories, i.e. long day plants, short day plants and day neutral plants.

Long day plants

These only flower when the period of day light exceeds a critical minimum length, e.g. clover, barley and wheat.

Characteristics of long day plants

- They require long days and short nights to flower.
- They flower only when the light period exceeds the critical length of the day (12 hours).
- Short nights are more essential than the length of the day. Thus they are commonly known as short night plants.
- They flower even when the short night is interrupted by flashes of light and do not need an interrupted short night. They also show flowering even when the long day is interrupted by short dark periods.
- They flower during summer when the days are longer than the night, like wheat.

Short day plants

These only flower when the period of day light is shorter than a critical maximum length, e.g. tobacco.

Characteristics of short day plants

- They require short days and long nights for them to flower.
- They flower only when day length become shorter than the critical day length.
- They need an uninterrupted period of darkness.
- They do not flower if given short days and long nights interrupted by flashes of light. On the contrary, if the short days are interrupted by intervals of darkness but left with an interrupted long night they flower.
- Such plants flower during autumn and winter.

Day neutral plants

These flower regardless of the length of day light. E.g. cucumber, carrot, tomato, garden peas, etc.

Characteristics of day neutral plants

- They are independent of day length.
- They flower after a period of vegetative growth regardless of the photoperiod.

Control of flowering

Where flowering is controlled by Photoperiodism, light has to be trapped and converted into unstable energy using light trapping pigment known as Phytochrome.

The relative amounts of red and far red lights determine the amount of Phytochrome activated and thus the response of plants. On absorbing light of a particular wave length the Phytochrome is converted is converted into another form rapidly. The physiological processes affected by light through the Photochromic effects include;

i) Germination of small seeds
ii) Growth of internodes
iii) Chlorophyll development
iv) Leaf expansion
v) Flowering in long day and short day plants.
vi) Leaf fall.

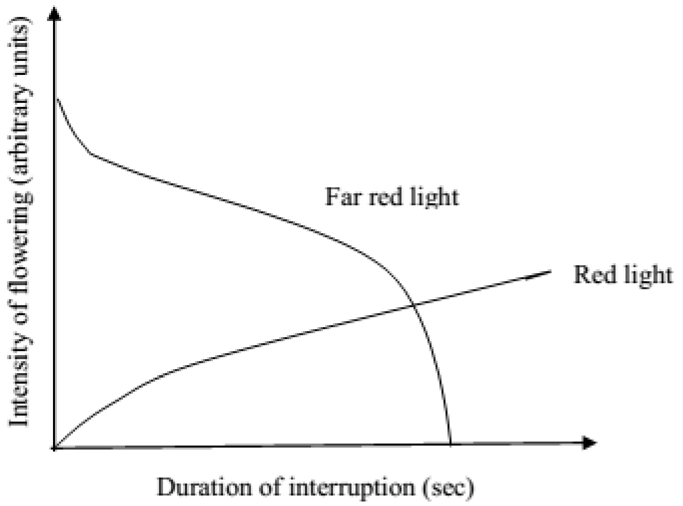
Role of florigen hormone

These are hormones that control flowering in long day plants. A high concentration of Phytochrome far red is required for inducing the leaves to produce florigen that travels to the buds to cause flowering.

Vernalisation

This is the exposure of seeds/plant to low temperature requirements for the initiation of germination/flowering. In some plants like perennials the treatment to cool temperature between 0-4^{0}C from 4 days to 3 months induce flowering depending on a plant.

Question: *figure below shows the effect of red light and far red light interruption of the night period on flowering of a plant.*



a) What is the effect of interruption of light period by each type of light?
   i) Red light
   ii) Far red light
b) Suggest the type of plant that would exhibit responses to light treatment as shown in figure above.
c) How can the knowledge of the effect of red light and far red light and far red light on flowering be utilized in the commercial growing of flowers?

NOTE:

If the whole plant is covered with light proof material except the leaves, flowering occurs proving that the point of perception is in the leaves. Flowering has been induced to occur in short day plants kept in long days by keeping one of the leaves in short days i.e. covering it with light proof material for a period longer than critical point of light.

Solution:

a) i) The interruption of red light lowers the intensity of flowering. The longer the duration of interruption, the lower the intensity of flowering up to duration of 30s when no flowering occurs because it leads to accumulation of P_{FR}, this inhibits flowering.
   ii) The interruption of far red light increases the intensity of flowering. The longer the duration of interruption, the higher the intensity of flowering up to a maximum of 50s when no further increase in the intensity of flowering is achieved and this is because of accumulation of P_{FR} that induces flowering.
b) Short day plant.
c) Plants can be induced to flower at the required time. By interruption of dark period by far red or red light at the right time and duration.

*****

"Iron rusts from disuse; water loses its purity from stagnation…even so does inaction sap the vigour of the mind".