CO-ORDINATION
(Irritability/sensitivity)

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

Terms used in coordination

Define the following terms as applied to coordination in organisms. Give examples where applicable.

(i) Stimulus
(ii) External environment
(iii) Internal environment
(iv) Response
(v) Receptors
(vi) Effectors

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 ductless glands which pour their secretions directly into the blood stream.

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.

CHARACTERISTICS OF HORMONES:

Give five characteristics of hormones

Position of the major endocrine organs.

(leave 10 lines)

Classification of hormones

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:

- 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.
- 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.
- 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.

MECHANISMS OF HORMONAL ACTION

Describe the mechanism of hormonal for;

(a) Steroid hormone
(b) Non steroid hormone.

Ways in which hormones affect cell function

- Some hormones affect the permeability of membrane to particular substances eg. Insulin stimulates glucose uptake.
- Some hormones release a ' second messenger' inside the cell. They bind to a receptor on the membrane, which then activates an enzyme in the membrane, which catalyses the production of a chemical in the cytoplasm, which affects various aspects of the cell.
  For example adrenaline stimulates glycogen breakdown.

- Some hormones activate proteins synthesis
- Some hormones stimulate the release of particular substances such as mucus.

THE ENDOCRINE GLANDS

HYPOTHALAMUS

It lies at the base of the brain to which it is attached by numerous nerves.

Functions of the hypothalamus

- It regulates activities such as thirst, sleep and temperature control
- It monitors level of hormones and other chemicals in the blood passing through it.
- It controls the functioning of the anterior pituitary gland.
- It produces ADH and oxytocin which are stored in the posterior pituitary gland.

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 and its relationship with the hypothalamus *(U.B page 515 fig.26.2)*

(leave 15 lines)

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 (Thyrotrophic 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 ***gigantism***.

If over secretion occurs at adulthood, it results into formation of more bones tissues which is then 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. ***Triiodothyronin***, ***thyroxin*** and ***calcitonin*** hormone.

Triiodothyronin(T_3) and thyroxin (tetraiodothynine T_4) hormones

These are chemically and functionally similar (both contain iodine), however thyroxin contain 4 iodine molecules while triiodothyroxin contain 3 iodine molecules.

They both regulate the growth and development of cells, and the metabolic rate. They also assist 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, triiodothyronin 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 triiodothyronin and thyroxin.

Control of thyroxin production

The secretion of thyroxin is kept to the requirement of the body by the ***negative feedback process***.

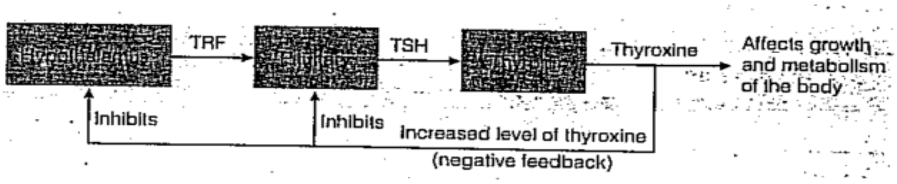
The shedding of thyroxin into the blood stream is triggered by ***thyroid stimulating hormone*** or ***thyrotrophic hormone*** produced by the anterior pituitary gland.

The production of thyrotrophic hormone is regulated by thyroxin itself.

A slight excess of thyroxin inhibits the anterior lobe of the pituitary which responds by secreting less thyrotrophic hormone. This in turn reduces the activity of the thyroid gland, leading to a drop in the amount of thyroxin produced. This then removes the inhibitory influence on the pituitary so that more thyrotrophic hormone will be produced again, and so on.

Summary

- The hypothalamus produces ***thyrotrophin releasing factor (TRF)*** which passes to the pituitary along blood vessels
- TRF stimulates the anterior pituitary to produce ***thyroid stimulating hormone (TSH)***
- **TSH** stimulates the thyroid gland to produce ***thyroxin***
- As the level of thyroxin builds up in blood it suppresses **TRF** production from the hypothalamus and **TSH** production by the anterior pituitary gland. By this form of negative feedback, the level of ***thyroxin*** in blood is maintained at a constant level.



Calcitonin

It is concerned with calcium metabolism in conjunction 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 muscle 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

High level of Ca^+ in blood
↓
Thyroid stimulated to release calcitonin
↓
Calcitonin stimulates greater Ca^+ loss by the kidney, reduced Ca^+ absorption by the gut, excess Ca^+ store in the bones
↘ Ca^+ levels fall in blood

Low level of Ca^+ in blood
↓
Parathyroid gland stimulated to produce parathormone
↓
Parathormone causes reduced Ca^+ loss by the kidney, greater Ca^+ absorption from the gut, Ca^+ stored is released from the bone.
↙ Ca^+ levels in blood rises

Normal levels of Ca^+

Over production of parathormone leads to excess removal of calcium ions from bones making them brittle and prone 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 the amount of 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 in the body

Effect	Function
Bronchioles dilate	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 pumped per beat increase.	Increases the rate which glucose and oxygen are 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.
Muscles of the alimentary canal relax to reduce peristalsis and digestion.	More energy is made available for action.
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.
Arterioles of the skin constrict	To divert more blood to muscles
Fats in fat depots are converted to fatty acids.	Fatty acids are made available in blood for muscle action
Depth and rate of breathing increase.	Increased the oxygenation of blood and rapid removal of carbon dioxide.

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
(leave two pages)

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

Summary (Advance biology by campbel page 985)

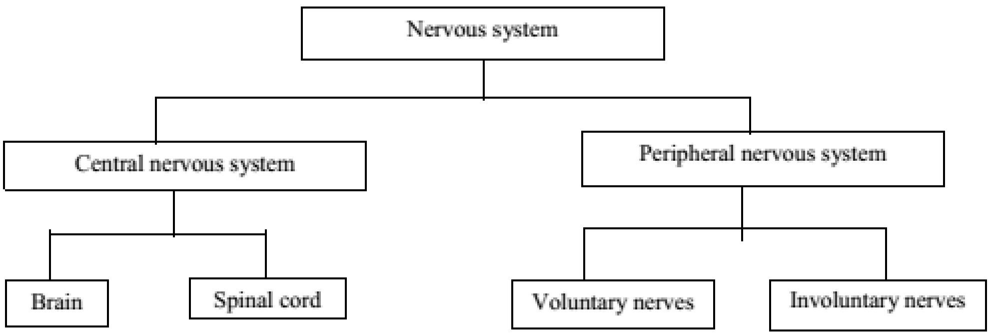
Other hormone-like substances

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.

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.

Read and make short notes about neurons.

THE IMPULSE

An impulse is an electrical message that propagates along a nerve fibre.

During the transmission of an impulse, both **resting** and **action potentials** exist along the length of a neuron but at different sections

Resting potential

A resting potential is so called because it does not convey a nerve impulse, not because it is inactive. On contrary, a resting neuron expends much energy in maintaining a potential difference across its membrane. This is called a ***resting potential.***

During the resting potential, the inside of the neuron is negative relative to the outside due to unequal distribution of charge ions.

On the outside, Na^+, Cl^-, and Ca^{2+} are present in higher concentration than inside the cell. By contrast, the inside of the cell has a higher concentration of K^+ and organic ions (COO^-).

This unequal distribution of ions resulting from a combination of ***active transport*** and ***diffusion*** of Na^+ and K^+ across the cell membrane, and the inability of the large organic anions to pass out of the cell.

The membrane, however, is more permeable to K^+ than any of the others. Thus K^+ diffuse out the neuron more rapidly along the concentration gradient while Na^+ diffuse into the neuron very slowly. This creates a negative electrical charge inside compared with the outside. In this state, the membrane is said to be ***polarized***.

How is the resting potential maintained?

It is maintained by the active transport of the ions against the concentration gradients. The mechanisms by which these ions are transported are called **pumps.**

A sodium – potassium pump actively transports Na^+ ions out of the membrane and K^+ ions in. For every three Na^+ ions pumped out, two K^+ ions are pumped inwards.

Action potential.

A nerve impulse occurs when the resting potential across the membrane of the neuron has a sufficiently high ***stimulus***.

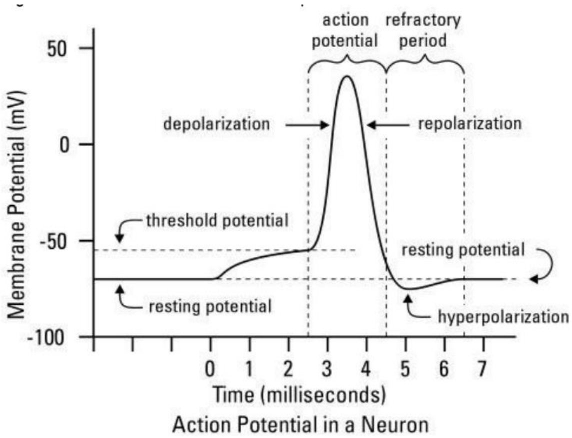
By appropriate stimulation, the charge on the membrane can be reversed. As a result the inside of the membrane becomes positively charged relative to the outside. In this condition, the membrane is said to be ***depolarized***.

During the action potential, special ion channels control ion movement across the membrane. These channels are believed to have voltage – sensitive gates that open and close in response to voltage changes and are therefore called ***voltage – gated ion channels.***

During the resting potential, the voltage gated sodium and potassium ion channels are closed. When a stimulus is applied, sodium ion channels open rapidly, sodium ions move in and the inside becomes more positive. If the stimulus reaches the ***threshold*** level an action potential occurs.

TRANSMISSION OF A NERVE IMPULSE

An individual action potential is short lived, localized event but it leads to the transmission of a nerve impulse which travels rapidly along the nerve fibre.



1. **At the resting potential**, most voltage – gated sodium channels are closed. Some potassium channels are closed, but most voltage – gated potassium channels are closed.
2. When a stimulus depolarizes the membrane, some gated sodium channels open, allowing more Na^+ to diffuse into the cell.
3. The Na^+ inflow causes further depolarization, which opens still more gated sodium channels (positive feedback), allowing even more Na^+ to diffuse into the cell causing rapid increase in membrane potential.
4. **Repolarisation**. Sodium ion channels close, potassium channels open, causing potassium ions to diffuse out down their concentration gradient, making the inside more negative again.
5. **Undershoot/hyperpolarization:** Potassium channels delay to close, more K^+ ions diffuse out of the membrane causing the membrane to become more negative.

FACTORS AFFECTING THE SPEED OF IMPULSE TRANSMISSION

(i) **Diameter of the axon/cross section area of the axon.**
The greater the axon diameter, the faster the speed transmission speed.
This because a wider diameter provides a greater area of the membrane for the exchange of ions.

(ii) Temperature.
Increase in temperature increases the speed of an impulse by increasing the kinetic energy of sodium and potassium ions leading to their fast movement across the membrane.

(iii) Myelin sheath
Myelinated neurons conduct impulses faster than non – myelinated ones.
The myelin sheath insulates the axon except at the node of ranvier. This leads to formation of action potentials at the node of ranvier only. Thus action potentials leap from one node of ranvier to another i.e. ***saltatory conduction***.

The table below shows the speeds of impulse conduction in nerves of various animals.

Animal (nerve)	*Temperature (^0C)*	*Fibre diameter (μm)*	*Impulse velocity (ms^{-1})*
Crab nerve	*20*	*30*	*5*
Squid giant axon	*20*	*500*	*25*
Cat nerve (unmyelinated)	*38*	*0.3 – 1.5*	*0.7 – 2.5*
Cat nerve (myelinated)	*38*	*2 – 20*	*10 – 100*
Prawn nerve (myelinated)	*20*	*35*	*20*
Frog nerve (myelinated)	*24*	*3 - 16*	*6 - 32*

Explain the above results *(12mks)*

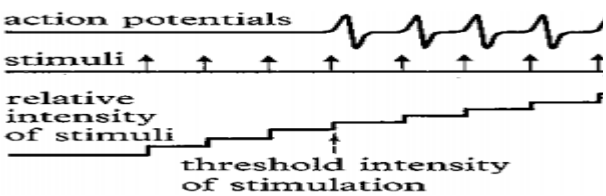
PROPERTIES OF NERVES AND NERVE IMPULSES

These properties are based on the following:

(i) Stimulation
(ii) The all or nothing law
(iii) Refractory period
(iv) Transmission speed

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:
They obey 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.



One end of the axon is stimulated with eight electrical shocks of gradually increasing intensity and action potentials are recorded from the other end. The results indicate that a stimulus either evokes a full or no response at all

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:
Absolute refractory period: where the axon is completely incapable of transmitting an impulse.
Relative refractory period: where it is possible to generate an impulse provided that the stimulus is longer than normal.
Illustration (F.A page 268, fig 18.7,) (leave 15 lines)

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.

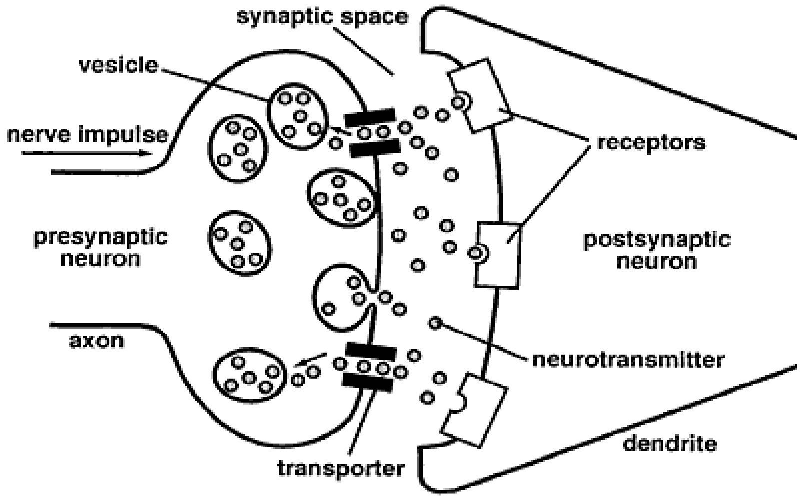
Transmission speed:
This depends on the type of the neuron of the animal in question. This variation in speed depends on the diameter, body temperature and whether the axon is myelinated or not.

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 diffuse into the presynaptic knob and cause the vesicles to move close to the presynaptic membrane and fuse with it to release the transmitter substance, ***acetylcholine*** by ***exocytosis***

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.

Name four neurotransmitter substances apart from acetylcholine and noradrenaline (4marks)

How the transmission of the impulse across the synapse is controlled?

- Presence of the synaptic resided on one side of the pre-synaptic membrane
- Destruction of acetylcholine after transmission ensures at depolarization of the post synaptic membrane
- The rate of receptor e.g. sites on the post synaptic membrane only.
- The rate of formation of acetyl chorine.

Types of Synapse.

The human nervous system uses a number of different neurotransmitters and neuroreceptors, and they don't all work in the same way. We can group synapses into 5 types:

(i) Excitatory Ion-channel Synapses.

These synapses have neuroreceptors that are sodium (Na^+) channels. When the channels open, positive ions diffuse in, causing a local depolarization called an ***excitatory postsynaptic potential*** **(EPSP)** and making an action potential more likely.

Typical neurotransmitters in these synapses are acetylcholine, glutamate or aspartate.

(ii) Inhibitory Ion-channel Synapses.

These synapses have neuroreceptors that are chloride (Cl^-) channels. When the channels open, negative ions diffuse in causing a local hyperpolarization called an ***inhibitory postsynaptic potential* (IPSP)** and making an action potential less likely. So with these synapses an impulse in one neuron can inhibit an impulse in the next. *Typical neurotransmitters in these synapses are glycine or GABA.*

(iii) Non-channel Synapses.

These synapses have neuroreceptors that are not channels at all, but instead are membrane-bound enzymes. When activated by the neurotransmitter, they catalyse the production of a "messenger chemical" (e.g. Ca^{2+}) inside the cell, which in turn can affect many aspects of the cell's metabolism. In particular they can alter the number and sensitivity of the ion channel receptors in the same cell.

Typical neurotransmitters are adrenaline, noradrenaline (NB adrenaline is called epinephrine in America), dopamine, serotonin, endorphin, angiotensin, and acetylcholine.

(iv) Neuromuscular Junctions.

These are the synapses formed between effector neurones and muscle cells. They always use the neurotransmitter acetylcholine, and are always excitatory.

(v) Electrical Synapses.

In these synapses the membranes of the two cells actually touch, and they share proteins. This allows the action potential to pass directly from one membrane to the next without using a neurotransmitter. They are very fast, but are quite rare, found only in the heart and the eye.

Structure of the neuromuscular junction

Read and make brief notes about a neuromuscular junction (leave one page)

Action of drugs and poison

Summary of the effect of drugs on synapses.

Drug action	Effect	Examples
Mimic a neurotransmitter	Stimulate a synapse	Levodopa
Stimulate the release of a neurotransmitter	Stimulate a synapse	Cocaine, caffeine
Open a neuroreceptor channel	Stimulate a synapse	alcohol, marijuana, salbutamol
Block neuroreceptor channel	Inhibit a synapse	Atropine, curare, apioids
Inhibit the breakdown enzyme	Stimulate a synapse	DDT

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 ACTIONS AND THE REFLEX ARC

Write short notes about the reflex arc and reflex action (leave one page)

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.

Functions of the brain

- Stores information so that behavior can be modified according to past experience.
- It receives impulses from all the sensory organs of the body.
- As a result of these impulses, it sends off motor impulses to the glands and muscles, causing them to function accordingly.
- In its association centers it correlates the various stimuli from different sense organs and the memory
- The association centers and motor areas co – ordinate bodily activities so that the mechanisms and chemical reactions of the body work efficiently together.

Structure of the human brain
F.A page 286, fig 18.20 (leave 20 lines)

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
(F.A page 283, fig 18.9)
Leave ¾ of a page

SENSORY RECEPTORS

These contain cells that detect and transduce stimuli.
Transduction is the process by which a stimulus is converted into a form which can be transmitted within the body of an organism

TYPES OF RECEPTORS

(a) Mechanoreceptors
These sense physical deformation caused by forms of mechanical energy such as pressure, touch, stretch, motion and sound.
Such receptors include; the skin, ear, hairs etc.

(b) Chemoreceptors
These are stimulated by chemicals, eg. Receptors mediating the senses of smell and taste, and receptors that detect changes in levels of respiratory gases in the body.

(c) Photoreceptors
These are stimulated by light, for example eyes and scattered light sensitive cells

(d) Thermoreceptors
These are stimulated by temperature, for example receptors located in the skin, sensitive to warmth and cold.

(e) Pain receptors
These detect extreme pressure or temperature, as well as certain chemicals which can damage animal tissues.

THE HUMAN EYE

Structure of the human eye

Relate the structure of the eye to its function ***(15mks)***
Make short notes about the following
- ***Formation of an image by a mammalian eye***
- ***Control of the amount of light entering the eye***
- ***Accommodation of the eye***

THE RETINA

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

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

(Leave half a page)

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.

(leave 10 lines go to function Approach)

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.

Compare rods and cones

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 up to 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. For example, 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 discrimination 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

A complete 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 compensated 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 inthe environment that bees and other insects detect.

Structure of the compound eye

Longitudinal section through an ommatidium

(leave 15 lines)

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.

Read and make short notes about the comparison between a compound eye and mammalian eye

Question:

Why do insects generally have very low visual acuity compared with the vertebrates?

How have insects overcome the above problem?

THE MAMMALIAN EAR

Function.

- It functions as an organ for hearing and balance. It contains mechanoreceptors sensitive to gravity, displacement and sound.

Structure and function of the ear.

It is composed of three main regions;

- An air filled outer ear
- An air filled middle ear
- A fluid filled inner ear

(a) **The outer ear:** consists of the
Pinna (ear flap) strengthened by an elastic cartilage.
It traps and directs (focuses) sound waves to the auditory canal.
Auditory canal: It is an ear tube lined with wax that traps dust. It links the pinna and the ear drum.
It directs sound waves to the ear drum.
In some animals, the pinna can be rotated without movement of the head to located direction of sound in order to avoid predators or locate prey without movement of the body that would alert them.
The end of the outer ear is demarcated by the ear drum (tympanic membrane), which separates the outer ear from the middle ear.

(b) **Middle ear.** This consists of;
The three interconnected bones called the ear ***ossicles;*** **malleus**, **incus** and **stapes** (**M.I.S**) or (Hammer, anvil and stirrup (**H.A.S**))
The air pressure in the middle ear is has to be equal to the external one in order to avoid tension on the tympanic membrane. This pressure is balanced by allowing in air through the **Eustachian** tube when the pressure in the middle ear is low, and allowing it out when the pressure is high. This is done through swallowing and yawning.
The middle ear is separated from the inner ear by the oval window and the round window.
A diver at lower depths in water (beyond 5m), experiences a lot of pain in the ear due to the fact that the pressure applied to the ear drum by the water exceeds that in the middle ear which exerts a lot of tension to the ear drum.

(c) The inner ear.
It is embedded in the inside of the cranium and is made up of two main parts.
The cochlea, concerned with hearing
Semicircular canals (vestibular apparatus), concerned with balancing.
Diagram of the mammalian ear.
(leave 15 lines)

Detailed structure of the cochlea.

The cochlea is made up of a coiled tube that is longitudinally divided into three parallel canals

(i) **The vestibular canal** (scalar vestibule), connecting with the oval window. It contains **perilymph**
(ii) **The tympanic canal** (scalar tympani.), which is the lower canal connecting with the round window. Also contains **perilymph.**
(iii) **The middle canal** (scalar media), found between the scalar vestibule and scalar tympani. It contains **endolymph.**

The three canals are separated from each other by membranes; **reissner's membrane**, between the vestibular and middle canals, and the **basilar membrane**, between the middle and tympanic canals.

In the middle canal lies the **tectorial membrane**, running parallel to the basilar membrane. Sensory cells fill the gap between the basilar membrane and the tectorial membrane. Their bases rest on the basilar membrane and connected to nerve fibres that connect them to the auditory nerve. At their top, they bear fine sensory hairs whose ends touch the tectorial membrane.

The sensory cells collectively form the **organ of corti**, which responds to sound waves.

Section through the cochlea (10 lines)

MECHANISM OF HEARING

Sound waves are trapped by the pinna and directed to the auditory canal, which also directs them to the ear drum.

The sound waves strike the ear drum causing it to vibrate and transmit the sound vibrations to the three ear ossicles (i.e. malleus, incus and stapes) which in turn vibrate and amplify sound vibrations and transmit them to the oval window.

The oval window vibrates and sets up vibration pressure waves in the perilymph of the scalar vestibule and scalar tympani, which cause the movement of the reissner's membrane.

The vibrations from the perilymph are then transmitted to the endolymph causing the movement of the basilar membrane which distorts the sensory hair cells of the organ of corti putting pressure on them resulting into impulses being fired in the auditory nerves to the brain.

On reaching the brain, sound impulses are interpreted and a sensation of sound is produced.

How sound of various intensities is perceived by the ear?

The intensity i.e. loudness of sound is related to the amplitude of sound waves impinging (striking) up on the tympanic membrane. This in turn determines the amplitude with which the basilar membrane vibrates. Loud sound that is, sound waves of larger amplitude bring about greater displacement of the basilar membrane. The result is that the receptor cells are stimulated more strongly and numerous impulses are discharged in a larger number of auditory nerve.

Faint sound i.e. sound waves of smaller amplitude bring about lesser displacement of the basilar membrane, which results in low stimulation of the receptor cells that brings about fewer impulses being discharged in fewer auditory nerves.

The human ear can only detect sounds within a certain range of intensities. Sounds above 120dB can be painful and may cause immediate damage to the cochlea receptors. Long term exposure to sounds over 85dB can also damage the receptors leading to partial loss of hearing.

Perception of pitch of sound by the ear.

Pitch refers to the degree of highness or lowness of a tone. A **tone** depends on the number of different frequencies making up the sound.

The human ear can detect a wide range of sound waves which vary in pitch (frequency) because of the different responsiveness of the hair cells along the length of the cochlea.

The pitch of sound determines the frequency at which the basilar membrane vibrates, this leads to stimulation of the sensory hair cells along the basilar membrane.

At the base of the cochlea, the basilar membrane is narrow, thin and rigid. Its hair cells respond readily to high frequencies which are interpreted by the brain (cerebral cortex) as high pitched sound. In the apex of the cochlea, the basilar membrane is wider and less rigid. It contains hair cells which are more sensitive to low – frequency pressure waves; movement of these is interpreted as low pitched sounds. Responsiveness to high pitched sound decreases with age.

N.B: *High frequency sound waves travel as short distance of the basilar membrane and die out while low frequency ones travel a longer distance and are detected towards the end of the cochlea.*

The human ear can detect sounds ranging from 20 to 20,000Hz. Pitch discrimination is best between 1000 and 3000 Hz, which corresponds to a range encompassed by a normal human speech.

THE VESTIBULAR APPARATUS AND BALANCE.

The vestibular part of the inner ear consists of an assemblage of interconnected sacs and canals continuous with those of the cochlea. Like the cochlea, they are filled with fluid and contain receptor cells. However, the receptor cells in the vestibular part are ***proprioceptors*** which give us a sense of balance.

The vestibular apparatus consists of lymph filled sacs called the ***saccule*** and the ***utricle.*** Projecting from the top of the utricle are three **semicircular canals** in planes at right angles to each other.

Semicircular canals

There are three semicircular canals which are in planes at right angles to each other. They contain a fluid called **endolymph,** that communicates with the middle chamber of the cochlea.

Each of the three semicircular canals has a swollen portion called the **ampulla,** which contains a cone (dome) shaped gelatinous **cupula (**that contains a sense organ, **crista)** and **receptors.** The ampulla receptors consist of a group of cells with hairs, rather like those in the cochlea. However in this case the hairs are embedded in the cupula.

The ampula receptors are sensitive to movements of the head, and the fact that the semicircular canals are in different planes ensures sensitivity to movement in any plane. Thus if you shake your head the horizontal canal is activated; if you nod your head, one of the vertical canals is brought into play.

Diagram (15 lines)

The utricle and saccule.

These give information on the position of the head in relation to the force of gravity as well as changes in the position of the head due to acceleration and deceleration.

The receptors called **maculae** found in these organs consist of sensory cells whose free ends are embedded on a mass of ***calcium carbonate*** called the ***otolith***. The utricle responds to vertical movement of the head. The saccule responds to lateral (sideways) movements.

Mechanism of balance.

Balance is the ability of the body to remain stable when subjected to different forces of destabilization.

Body balance is brought about by information from the position of the body and movement of the head. When the head changes position, movements are produced in the endolymph in the semicircular canals, in a direction opposite to that in which the head is displaced, which also displaces the cupula.

For instance, if the head is displaced to the left, due to inertia of the endolymph in the semicircular canals, the cupula gets deflected to the right. This puts a mechanical tension on the receptor cells, causing them to fire impulses in the sensory(vestibular) nerve fibres that lead to the brain.

Response to gravity

Gravity causes the otaliths to distort the sensory hairs in a direction detected by the position of the head, leads to firing of impulses in the vestibular nerves to the brain. If the head is moved to a different position, the otoliths distort the sensory hairs in an opposite direction.

Information about the direction of movement and new position of the head is interpreted by the brain while visual information from the eye contributes to the body awareness of spatial position. This information is used by the brain to co – ordinate movement and posture of the body to ensure balance.

N.B.

- Read about the defects of the ear

- Adaptations of the ear to its functions.

CO-ORDINATION IN PLANTS

Plants often respond to an external stimulus acting from a particular direction by a bending movement of differential growth - that is, more growth in one region than another. Such growth movements are called **tropisms**

TROPISM

This is the growth movement of a plant part in response a unidirectional source of stimulus. Plants can either grow towards the stimulus (positive) of away from the stimulus (negative) tropic response.

Characteristics of tropic responses

- Involve growth
- Are slow responses
- Mainly occur at root and shoot tip (apical meristems)
- Often related to the direction of stimulus
- Are induced by directional stimulus.

Types of tropic response

Tropic response	stimulus
- Phototropism	light
- Geotropism	gravity
- Hydrotropism	water
- Chemotropism	chemical substance
- Aero tropism	air
- Thigmotropism	touch
- Etc.	

How do plant cells receive and transduce external stimulus/signal?

***Transduction** refers to the process by which a stimulus/signal is changed to an intercellular form which can cause a response in a cell or tissue.*

There are two basic types of signal transduction pathways i.e. **phosphorylation cascades** and **second messengers.** Both begin with a protein receptor in the cell membrane.

Phosphorylation cascades and second messenger mechanisms

- The phosphorylated protein triggers the phosphorylation cascade
- The phosphorylated protein initiates the response by

<table>
<tr><th>Phosphorylation cascades</th><th>Second messenger</th></tr>
<tr><td colspan="2">- A stimulus binds at the protein receptor in the cell membrane.
- The receptor protein changes in response to the stimulus
- The receptor or associated protein catalyzes the phosphorylation reaction</td></tr>
<tr><td>- The phosphorylated protein triggers the phosphorylation cascade</td><td>- The phosphorylated protein triggers the release of a second messenger</td></tr>
<tr><td>- The phosphorylated protein initiates a response either by</td><td>- Second messenger initiates the response either by</td></tr>
<tr><td colspan="2">- Activating or repressing transcription in the nucleus
- Activate or repress translation in the cytoplasm or
- Change ion flow through the channels or pump in the cell membrane.</td></tr>
</table>

How do plants detect stimuli?

(a) Gravity detection

The statolith hypothesis.

Certain cells in shoots and roots contain special starch grains (amyloplasts) called **starch statoliths,** which give plants a gravitational sense.

When a seedling is laid down, the statoliths fall under gravity to the lower side of cells where they exert pressure on the plasma membranes which activates a sensory protein that initiates a geotropic response.

Evidence to support this theory

- If a vertically growing seedling is placed in a horizontal position for enough long time and then returned to vertical position, a bending response can only occur if the presentation time is reached.
- If the statoliths are destroyed by keeping the seedling at 35^{0}C, for 2 days, the root does not respond to gravity.
- Removal of the root cap in which the statoliths are found, leads to loss of gravitational response.

Limitations

Some roots respond too quickly to gravity to be explained by this mechanism.

Roots of certain mutant species lack statoliths but respond to gravity.

Auxin hypothesis

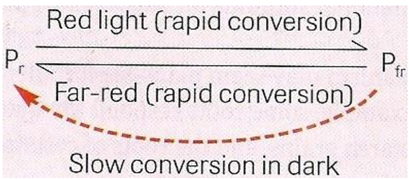
According to this hypothesis, root cap cells that sense the change in the direction of gravitational pull respond by changing the distribution of auxins in the root tip.

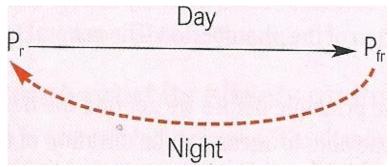
Under normal conditions (vertical position), auxins flow down in the middle of the root and towards the perimeter and away from the root cap. But if the root is tipped (horizontal position), auxins are redistributed, with the lower portion of the root having a higher concentration than the upper one. In response to the differences in auxin concentration, cells in the upper portion of the root elongate and grow faster than those in the lower portion causing the root to curl downwards.

(b) Light detection

Light is detected by a photoreceptor substance called **phytochrome,** which exists in two interconvertible forms, i.e. Phytochrome 660 (P_{660}/ P_r) and Phytochrome 730 (P_{730}/P_{fr}) which absorb red light (light of a wave length of 660nm) and far red light (light of a wave length of 730nm). It is synthesized in leaves and some seeds such as tobacco seeds.

When P_r absorbs red light, it is rapidly converted into P_{fr} and when P_{fr} absorbs far red light, it is rapidly converted into P_r . in the dark, P_{fr} is slowly converted into P_r





In natural sunlight, P_r is converted into P_{fr} and P_{fr} into P_r. However, the former reaction predominates because sunlight contains more red than far- red light and in any case less energy is needed to covert P_r into P_{fr} than viceversa. So Pf_r tends to accumulate during day hours, whilst at night it is slowly converted back into P_r.

Responses associated with phytochrome

Light is known to be involved in many plant responses and developmental processes including germination, straightening of the plumule, stem elongation, leaf expansion, leaf fall, chlorophyll formation and flowering.

The control of flowering by light.

Flowering in plants is regulated by day length i.e. duration of photoperiod, a phenomenon called **photoperiodism**..

Photoperidism refers to the response of an organism to the changing lengths of day and night. The length of day or night to which an organism responds is termed as **photoperiod.**

Flowering plants are classified into three groups basing on their response to photoperiod. These are;

- Short – day plants
- Long – day plants
- Day – neutral plants

Short – day plants (SDP) /long – night plants: e.g. tobacco, strawberry, soya bean, cocklebur and chrysanthemum only flower if the period of uninterrupted darkness is ***more*** than a certain critical length of each day.

Characteristics of SDP

- Require short days and long nights to flower
- Only flower when days become shorter than critical length of day
- Need uninterrupted night (darkness) to flower
- Do not flower if given short days and long nights are interrupted by flashes of light.
- On the contrary, if short days are interrupted by intervals of darkness but left with uninterrupted long nights, they flower.
- Flower in autumn and winter when the nights become longer than the critical period.

Long – day plants (LDP)/ short – night plants, such as cabbage, spring wheat, spring barley, henbane, petunia and snapdragon only flower if the period of uninterrupted darkness is ***less*** than a certain critical length of day.

Characteristics of LDP

- Require long days and short nights to flower
- Only flower when light period becomes longer than critical length of day (12 hours)
- Can flower even when the short nights are interrupted by flashes of light so do not need uninterrupted dark periods to flower.
- Also show flowering even when a long day is interrupted by short dark periods
- Long day plants flower during summer when days are longer than nights.

Day – neutral plants. E.g. cucumber, tomato, garden pea, maize, cotton, geranium, flower irrespective of the relative durations light and dark which they receive each day. They mainly grow in regions near the equator.

The role of phytochrome in flowering.

Phytochrome absorbs both red and far red light. In short – day plants, far red light stimulates flowering by promoting the conversion of P_{fr} into P_r which leads to the production of **florigen,** a hormone that induces formation of buds. If red light is absorbed, a short – day plant will not flower since it inhibits the conversion of P_{fr} into $P_{r.}$

In long – day plants, red light promotes the conversion of P_r to P_{fr} which leads to production of florigen which induces flowering.

(*read about vernalization*)

PLANT HORMONES

Five major types of hormones regulate plant growth and development.

1. **AUXINS/Indole – 3 – acetic acid (IAA).** It is the main auxin made in plants. It is produced in the meristems of apical buds, young leaves, and embryos within seeds, from the amino acid ***tryptophan***. From the apical buds, auxin is transported backwards to the zones of elongation in roots and shoots, where it regulates cell elongation and differentiation of vascular tissues. In coleoptiles, IAA is carried in parenchyma tissue in mature roots and shoots, the main transporting tissue is probably the phloem.

Effects of IAA

- It induces apical dominance whereby the terminal bud suppresses the development of lateral buds.
- Stimulates stem elongation by softening the primary cell walls of newly formed cells thus allowing cells to stretch when turgor pressure builds up.
- Stimulates fruit growth by stimulating the cell walls to stretch in more than one direction. It also induces pathenocarpy e.g. in pineapples
- Stimulates translocation of organic substances in the phloem
- Induces phototrophic and geotropic responses
- It also induces the suppression of lateral root growth by the growth of the main root.
- It delays senescence by inhibiting protein and chlorophyll breakdown and control of mobilization of resources.
- Promotes root initiation

- Promotes femaleness in flowers
- It delays flower, leaf and fruit abscission.

Abscission refers to an organized shedding of parts of a plant usually leaves, fertilized flowers or fruits.

At the base of abscission zone, is a layer of cells separated by the breakdown of their middle lamellae or breakdown of their cell walls. This forms the abscission layer. Final shedding of the organs occurs when the vascular strands are broken down by the action of wind.

A protective layer is formed beneath the abscission layer to prevent infection by germs. This layer thus seals off the scar and vascular strands. In woody plants, the protective layer is a corky, being part of the tissue produced by the cork cambium (periderm)

Effect of auxin concentration on shoot and root growth.

(Leave 15 lines)

From the graph, a positive result means relative stimulation while a negative result means relative inhibition. At low auxin concentration ($< 10^{-3}$ ppm) auxins cause no effect on the growth of the shoot, auxin concentration greater than 10^{-3} ppm stimulates rapid growth in the shoot. In the root, auxin concentration less 10^{-4} ppm, causes a gradual increase stimulation of growth while auxin concentration causes a rapid increase in the inhibition of growth. Thus relatively lower auxin concentrations stimulate growth in the root but have little or no observable effect on the shoot while higher auxin concentrations stimulate rapid growth in the shoot but inhibit growth in the root.

Auxin stimulate growth by causing cell elongation and cell division.

How do auxins cause cell elongation?
Auxin initiate cell elongation by weakening cell walls**.** Auxin stimulates a protein in a plant's cell membrane to pump H^+ into the cell wall. H^+ ions then activate enzymes that break some hydrogen bonds cross – linking cellulose molecules (cellulose myofibrils) in the cell wall allowing them to slide past each other. On taking in water, the cell swells and elongates. After this initial elongation caused by the uptake of water, the cell sustains the growth by synthesizing more wall material and cytoplasm.

Auxin also induces cell division in the vascular cambium, thus promoting growth in stem diameter. However, very high concentrations of auxin usually inhibit growth in shoot and root. This is because at very high concentration, a plant is stimulated to synthesize another hormone ethylene, which generally counters the effect of auxins.

2. **Gibberellins. eg. Gibberelic Acid (GA)**
   It is produced in roots and young leaves of plants. They mainly stimulate cell division and cell elongation
   Effects

- *Break seed dormancy*. Eg in barley seeds gibberellins stimulate the synthesis of alpha amylase which breaks down starch to sugars for germination. As a seed absorbs water, the embryo secretes G.A which diffuses to the aleurone layer in a seed which produces alpha amylase.
- *Cause internode elongation* by stimulating cell division and cell elongation in stems.
- In combination with auxins*, gibberellins cause fruit development and parthenocapy*, a phenomenon called **synergism**
- *Break bud dormancy*
- *Promote increase in girth in ferns* by promoting cell division and cell elongation.

- *Promote bolting of some rosette flowers* such as cabbages.
- Inhibits root initiation
- Promote maleness in flowers
- Promotes flowering in long – day plants and inhibits flowering in short – day plants. Sometimes, they substitutes for red light.
- Increases fruit cluster in grapes.

3. **Cytokinins.**

   They are synthesized in the roots and transported to other parts of the plant. They are growth regulators that mainly promote cell division, or **cytokinesis,** and differentiation in developing roots, stems, leaves and flowers. *They do this only in presence of auxins*.

   Other effects

- Delay senescence by controlling protein synthesis and mobilization of resources.
- Break bud durance i.e. inhibits apical dominance
- Promote stomatal opening.
- Induce parthenocapy in fruits
- Promote tuber formation in potatoes.

4. **Abscisic acid (ABA)**

   Made is leaves, stems, fruits and seeds. It is a major inhibitor of growth in plants and is **antagonistic** to all the three classes of growth promoters discussed above. Its classical effects are on bud dormancy (including apical dormancy), seed dormancy and abscission.

   Other effects

- Promotes closing of stomata under conditions of water stress (wilting)
- Promotes flowering in short day plants and inhibits it in long day plants.
- Sometimes promotes senescence
- Inhibits root growth.

  Mechanism of stomatal closure in response to ABA

- ABA binds to receptors in guard cells
- Pumping by H^+ - ATPases stops and outwardly directed Cl^- channels open causing Cl^- to move out of guard cells (Cl^- exit along the electrochemical gradient.)
- Changes in membrane potential opens the out wardly directed K^+ channels, causing the outward movement of K^+ from the guards which increases the water potential of the guard cells
- Water moves from the guard cells to epidermal cells by osmosis, causing them to shrink thus closing the stomatal pore.

5. **Ethylene (Ethene)**

   Produced by ripening fruits, nodes of stems, ageing leaves and flowers. It is involved in seed dormancy, fruit ripening and leaf abscission.

   Effects

- Induces ripening of fruits by promoting the conversion of starch to soluble sugars and triggering a sudden and dramatic increasing in respiration rate which leads to ripening.
- Promotes wound healing. When a plant is damaged, ethene is at the wounded site which stimulates the formation of a callus tissue which plugs up the damaged area
- Promotes leaf and fruit fall
- Breaks seed dormancy
- Inhibits root growth
- Breaks bud dormancy

COMMERCIAL USES OF PLANT GROWTH SUBSTANCES.(applications in agriculture)

Auxins are used as;

- Selective herbicides (selective weed killers). They are taken up by leaves and translocated to all parts of the plant, so they kill the roots as well as leaves of dicotylenous (broad leafed) plants by interfering with their growth and metabolism. E.g. MCPA (4 – chloro – 2- methylphenoxyacetic acid), 2,4 – D (2,4,- dichlorophenoxyacetic acid), used to kill weeds from cereals, while 2,4,5-T(2,4,5,-trichlorophenoxyacetic acid) used to kill weeds in woody plants.
- Growth promoters. E.g. NAA (1-naphthylacetic acid), induces root formation in cutting
- Growth retardants. When applied to a cereal crop such as wheat and barley, some auxins stops the stalks growing too long. This prevents lodging (plants falling over), making them easier and cheaper to harvest.
- Flower inducers, when applied to perennials such as apple and pear trees, some auxins induce flowering.
- Fruit inducers. When NAA, is applied to unpollinated flowers of say tomato plant or pear tree, fruits are formed without prior fertilization (parthenocarpy)
- Fruit fall controllers, auxins are applied to orange and grape plants by farmers to control when to plants will drop their fruits.

Gibberellins

- Fruit inducers, GA**,** promotes fruit setting and are used for growing seedless grapes
- GA is used in brewing industry to stimulate alpha amylase production in barley, and hence promote malting.
- Used to overcome losses of apple yield due to frost damage
- Applied to induce flowering in perennial and biennial plants such as cabbage and sugar – beet.

Ethylene (ethene)

- Applied to fruits such as banana, mangoes to promote their ripening.
- Used to thin peaches and prunes
- It is sometimes sprayed on berries, grapes and cherries to loosen their fruits so they can be picked by machines.
- It is applied to pineapples to induce flowering

ABA

- Can be sprayed on tree crops to regulate fruit drop at the end of the season. This removes the need for picking over a long time – span

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

END