FORM 2 BIOLOGY

1 TRANSPORT IN PLANTS & ANIMALS

Meaning of Transport

Transport is the movement of materials into and out tissues of various parts of the body. Such materials transported into various parts of the body include Oxygen, nutrients and secretions such as hormones and enzymes. Metabolic wastes such as Carbon(IV) oxide (CO_2) and nitrogenous wastes like urea are transported out of the body tissues.

Importance of transport/Necessity of transport in organisms.

1. Supply of nutrients to tissues
2. Supply of oxygen to tissues
3. Removal of waste products of Metabolism from tissues.
4. Movement of Secretions such as hormones and enzymes to sites of their function.
5. Distribution of heat.

Transport in Micro-organisms

- Micro-organisms such as amoeba and lower organisms such as spirogyra and hydra have a large surface area to volume ratio hence materials are transported across their CellMembranes and within their cells by diffusion alone.

Transport system in higher organisms

- Higher organisms have a small surface

area to volume ratio due to their large body sizes hence diffusion alone can not accomplish their transport needs. Hence they have a circulatory system to transport materials within and out of their bodies.
- The circulatory system consists of the following in animals
  - i, The heart - Means of pumping
  - ii, Blood - Transporting fluid
  - iii, Blood vessels - for conveying blood.
- In higher plants the transport system comprises the vascular bundles - xylem and phloem.

TRANSPORT IN PLANTS

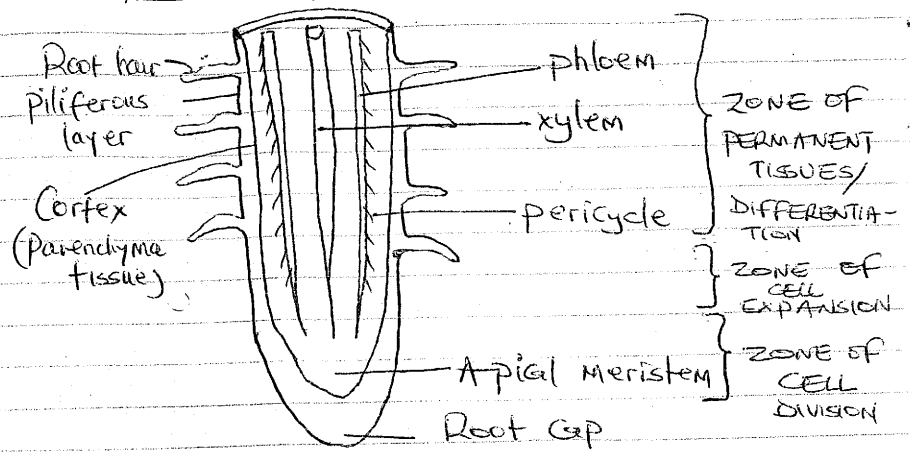
- simple plants meet their transport needs by mere diffusion. Such include Mosses and liverworts
- Higher plants have vascular bundles for transport of water, Mineral salts and soluble Manufactured food. Vascular bundles comprise xylem and phloem tissues.
- The vascular bundles spread through leaves, stems and roots.

Internal structure of Roots and Root Hairs

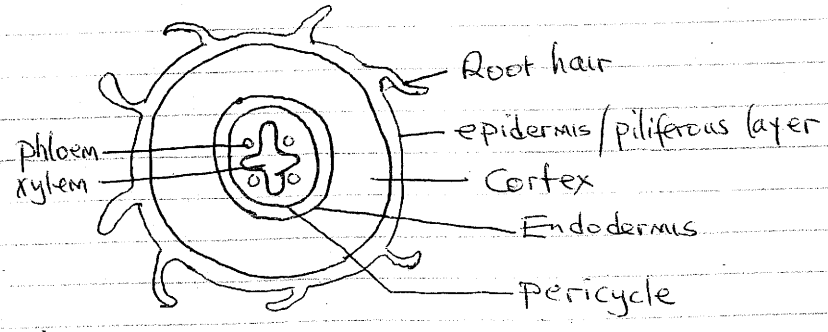
- The primary functions of roots include;-
  1. Anchorage
  2. Absorption of water and mineral salts
  3. specialised functions including storage, gaseous exchange and perennation.
- The diagrams below illustrate internal

structures of roots.

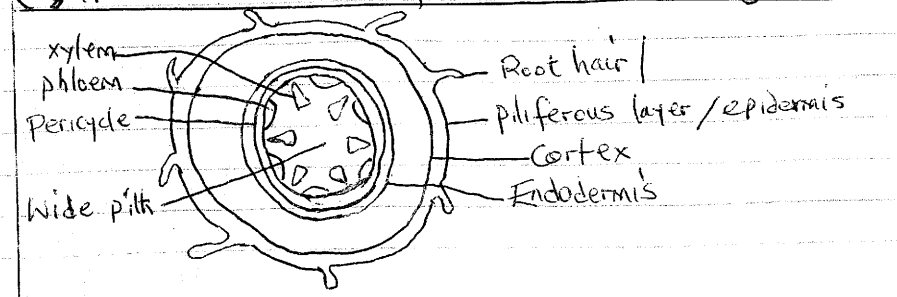
(a) Longitudinal structure (L/s) of a root of a dicotyledonous plant



(b) Transverse section of a dicot root (eg Sunflower)



(c) Transverse section of a Monocot root eg Maize



Functions of various Root parts

① **Root cap** – Is the terminal position of the root tip.

Adaptation – Consists of simple parenchyma cells that protect the apical Meristem as the root tip is pushed past soil particles. The cells are also impervious / impermeable to water and solutes thus offer protection to the apical Meristem.

– As the root tip wears out and tears, it is replaced with new cells from apical Meristem.

② **Apical Meristem / Zone of Cell Division / Zone of Cell Multiplication**

– Consists of actively dividing cells which give rise to new cells.

③ **Zone of cell elongation / cell expansion**

– Found 2–3 cm from the root tip.

– Cells lengthen and increase in size here pushing the root tip through the soil causing overal growth of the root).

④ **Zone of permanent tissues**

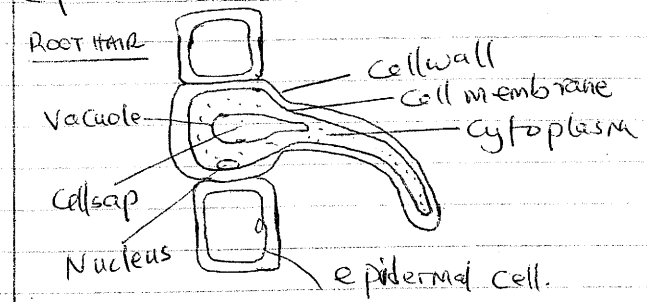
– characterised by presence of root hairs, Other tissues present include phloem, xylem, pericycle, Cortex, endodermis and pith.

(a) **Root hairs**

– Are microscopic outgrowths of epidermal cells. Have the following adaptations :-

- Are numerous, narrow and long to provide a large surface area for diffusing for absorption of water and Mineral salts.
- Are thin-walled for faster diffusion of water and mineral salts
- Have a large vacuole with Cell sap

to exert the necessary osmotic pressure for absorption of water.
• Numerous mitochondria in cytoplasm for active transport.
— Root hair cells wear out and are replaced from the piliferous layer/young epidermis.



(b) piliferous layer

— Is a special, young epidermis which gives rise to root hair cells/root hairs.
— Later it gets suberised to form the epidermis. Epidermis performs the following functions given that the cells are closely packed & suberised;
• Protects inner tissues from mechanical injury, water loss and invasion by bacteria/micro-organisms.

(c) Cortex

— Comprises loosely packed, thin-walled parenchyma cells for packing/storage. May also contain collenchyma or sclerenchyma tissues for support/strengthening.
— Water from root hairs passes through the cortex before reaching xylem tissue.

(d) Endodermis

— Is a single layer of cells surrounding the vascular bundles. It is characterised

by :-
• starch grains. (These stain blue-black with iodine).
• Casparian strip which has impervious deposit on the radial and crosswalls.
— Endodermis controls amount of water and mineral salts entering into vascular bundles. Also called starch sheath.

(e) pericycle

— A single layer of cells immediately below the endodermis. Gives rise to lateral roots.

(f) vascular bundles

— Occupy central position both in dicotyledonous and monocotyledonous roots.
— Vascular bundles consists of xylem and phloem.
— In dicotyledonous roots xylem occupies the centre and is star-shaped with phloem alternating at the arms.
— In monocotyledonous roots, xylem and phloem alternate around the pith.
• xylem — found slightly to the inside. Functions include ① transport of water and mineral salts to the leaves
② support.
• phloem — slightly to the outside. Transport manufactured food from the leaves to other parts of the plant ie translocation.

(g) Cambium

— Found between phloem and xylem

Function - Divide to give rise to new cells for secondary thickening. The new cells form secondary phloem and secondary xylem.

Differences between Dicot and Monocot Roots

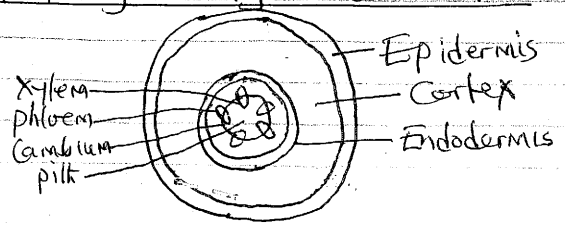
Monocot Root	Dicot root
① xylem in a ring alternating with phloem	xylem at the centre and star-shaped with phloem at the arms
② Centre occupied by a pith.	Centre occupied by xylem. pith is absent.

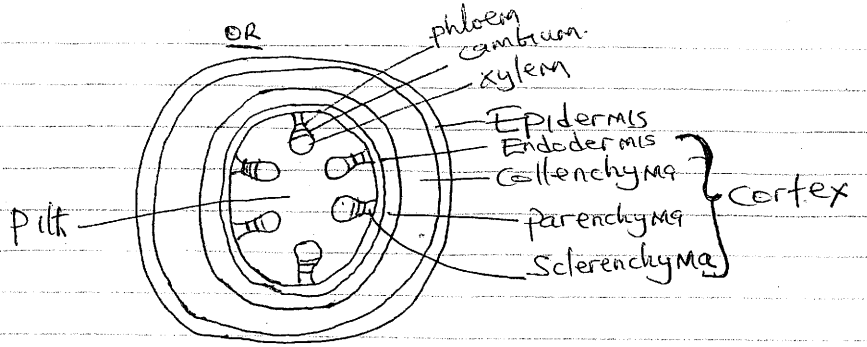
Internal structure of stems

The primary functions of the stem include
① To provide support and expose leaves and flowers to the environment
② To conduct water and mineral salts from roots to leaves.
③ To conduct manufactured food from leaves to other parts of the plant and for storage
④ Specialised functions eg gaseous exchange, storage, perennation etc.

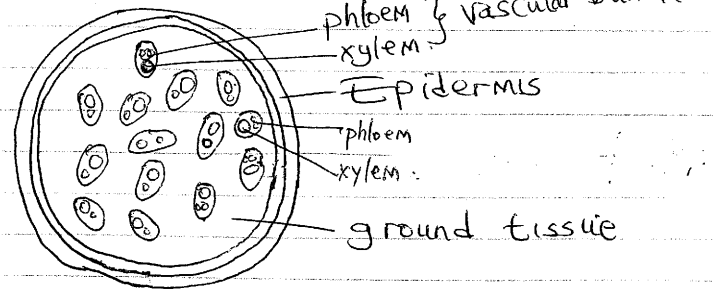
Internal structure of a stem

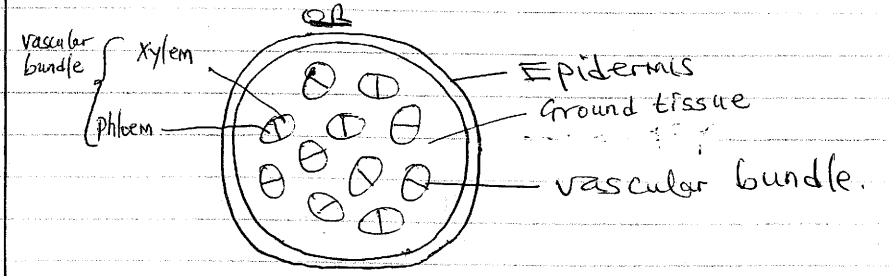
(a) A young dicotyledonous stem





(b) Monocotyledonous stem.





Functions of the stem parts

① Epidermis
- Has closely packed cells which are suberised and thickened with cuticle, for protection against water loss, invasion by Microbes and for protection against Mechanical injury.

- Epidermis also secretes cuticle from its cuticle secreting cells; for protection.
- Young green epidermis has stomata for gaseous exchange.

② Cortex

- Section of the stem beneath epidermis extending inwards to vascular bundles. May comprise:-

(a) Collenchyma

- Cortex collenchyma lie just beneath epidermis.
- The collenchyma cells have elongated and pointed oblique ends when viewed longitudinally.
- The cells also have walls thickened at the corners with cellulose and pectin deposits for strengthening.
- Collenchyma therefore is a strengthening tissue.

(b) Parenchyma

- Parenchyma constitutes the greater part of the cortex.
- Parenchyma cells are irregular in shape, thin-walled and loosely packed together creating intercellular spaces with air; for gaseous exchange
- Some parenchyma cells contain chloroplasts for photosynthesis. These cells are known as chlorenchyma; and make some stems green.
- Function of parenchyma — storage of water and food; a packing tissue;

(c) Sclerenchyma

- The cortex sclerenchyma is found in close association with vascular bundles.
- Sclerenchyma have walls thickened with lignin for support or strengthening. Deposition of lignin is known as lignification.

(d) Endodermis

- Innermost layer of cortex. Less visible in stem than in roots. The cells of endodermis contain starch grains.

③ The pith / Parenchymatous pith.

- Is the central region of the stem. Consists of parenchyma cells that store water and food substances. In some stems eg sunflower the pith may be hollow.

④ Vascular bundles

- Consists of highly specialised cells continuous in tubes from roots to leaves, through the stem. Consists of xylem — for transport of water and mineral salts and for support; phloem for translocation of manufactured food.

Differences between Dicot and Monocot stem sections

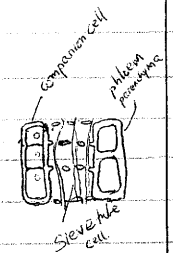
Dicotyledonous stem	Monocotyledonous stem
① Has pith	- Lacks pith.
② Vascular bundles arranged in a ring	- Vascular bundles are scattered.
③ Vascular bundles fewer	- Vascular bundles many.
④ Has cambium	- Lacks cambium.
⑤ Has pronounced cortex	- Cortex absent

Differences between Root & stem sections

(a) Dicotyledonous stem	Dicotyledonous root
① Lacks root hairs	Has root hairs
② Has pith	Lacks pith
③ Xylem in a ring around the pith	Xylem at centre and star-shaped
④ phloem in a ring alternating with xylem.	phloem at arms of xylem.

(b) Monocotyledonous stem	Monocotyledonous root
① Root hairs absent	Root hairs present
② Vascular bundles are scattered	Vascular bundles arranged around pith
③ Pith absent	Pith present.

Structure of vascular bundles



(1) phloem tissue

- Is a living tissue made of sieve tubes, companion cells and phloem parenchyma cells.
- The function of phloem is translocation of manufactured food from leaves to other parts of the plant.
- The following are adaptations of phloem:-

(a) Sieve tubes / sieve elements

- Are elongated; arranged end-to-end along a vertical axis; with cross walls perforated to form sieve plates and protoplasmic strands passing through the pores into adjacent cells. Thus allowing movement of food down the tubes.

(b) Companion cells

- Are small with large nuclei, dense cytoplasm and many Mitochondria to generate energy for the translocation process.

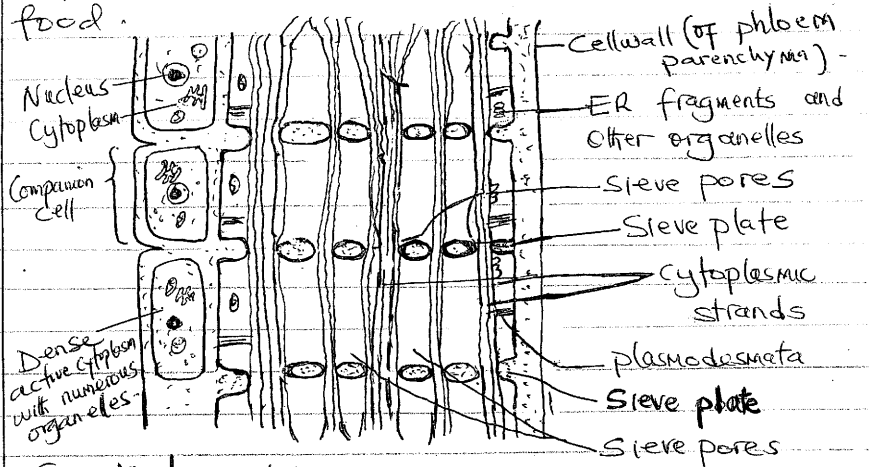
- They are connected by plasmodesmata to sieve tubes.

(c) phloem parenchyma.

- Are found between sieve elements / sieve tubes.
- Act as packing, storage and strengthening tissue for phloem.

(d) Cytoplasmic strands:

- Protoplasmic strands running through the sieve pores of the sieve tubes.
- Function → translocation of manufactured food.



(2) Xylem tissue

- Function → Transport of water and mineral salts from roots to leaves; Also lignified for support. It is therefore a mechanical tissue.
- Xylem is a dead tissue consisting of:-

1. xylem vessels

- Have the following adaptations:-

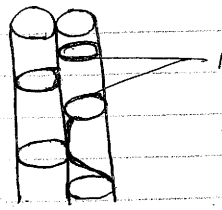
i) Narrow continuous tubes to allow capillarity
ii) Arranged end-to-end along vertical axis and lacking cross-walls to allow passage of water and mineral salts from

one cell to another. (The protoplasm disintegrate leaving only cellwall).

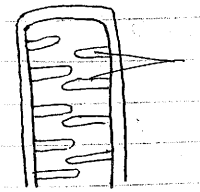
iii. Their walls are lignified for support.

- The lignification results in the following patterns :-

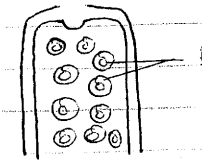
- Annular thickening



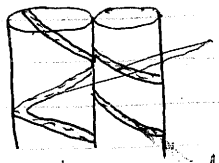
- Reticulate thickening



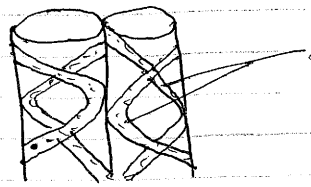
- Pitted vessel



- Spiral



- Double spiral



(iv) Have pits to allow passage of water to adjacent cells.

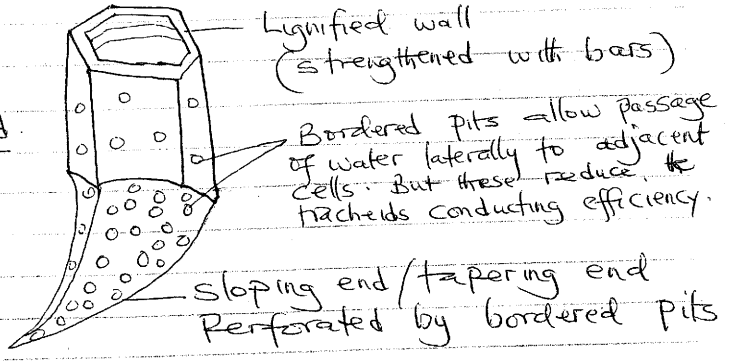
2. Tracheids.

- Formed and adapted to their functions in the same way as xylem vessels.
- Have the following structural differences compared to xylem vessels

(i) Tracheid cross-walls are more perforated whereas the xylem vessels are less perforated.

(ii) Tracheids are longer whereas xylem vessels are shorter

(iii) Tracheids have tapering ends whereas xylem vessels have straight ends



3. Xylem fibres

- Are cells elongated and lignified.
- Are impermeable, dead without lumen.
- Form wood; hence offer support.

4. Xylem parenchyma

- Are living cells between the xylem vessels.
- Function → Packing tissue.

Absorption & Conduction of Water and Mineral salts

(a) Uptake of Mineral salts from the soil

- Mineral salts are absorbed by root hairs from the soil by active transport. This involves Carrier molecules which combine with mineral ions from soil water and move them across the cell Membrane of root hair cells into the Cytoplasm.
- The dissolved mineral salts / ions diffuse into xylem of the root, then to stem xylem and finally to leaves together with water by processes of capillarity, cohesion & adhesion, root pressure and transpiration pull. Other forces include diffusion and osmosis.

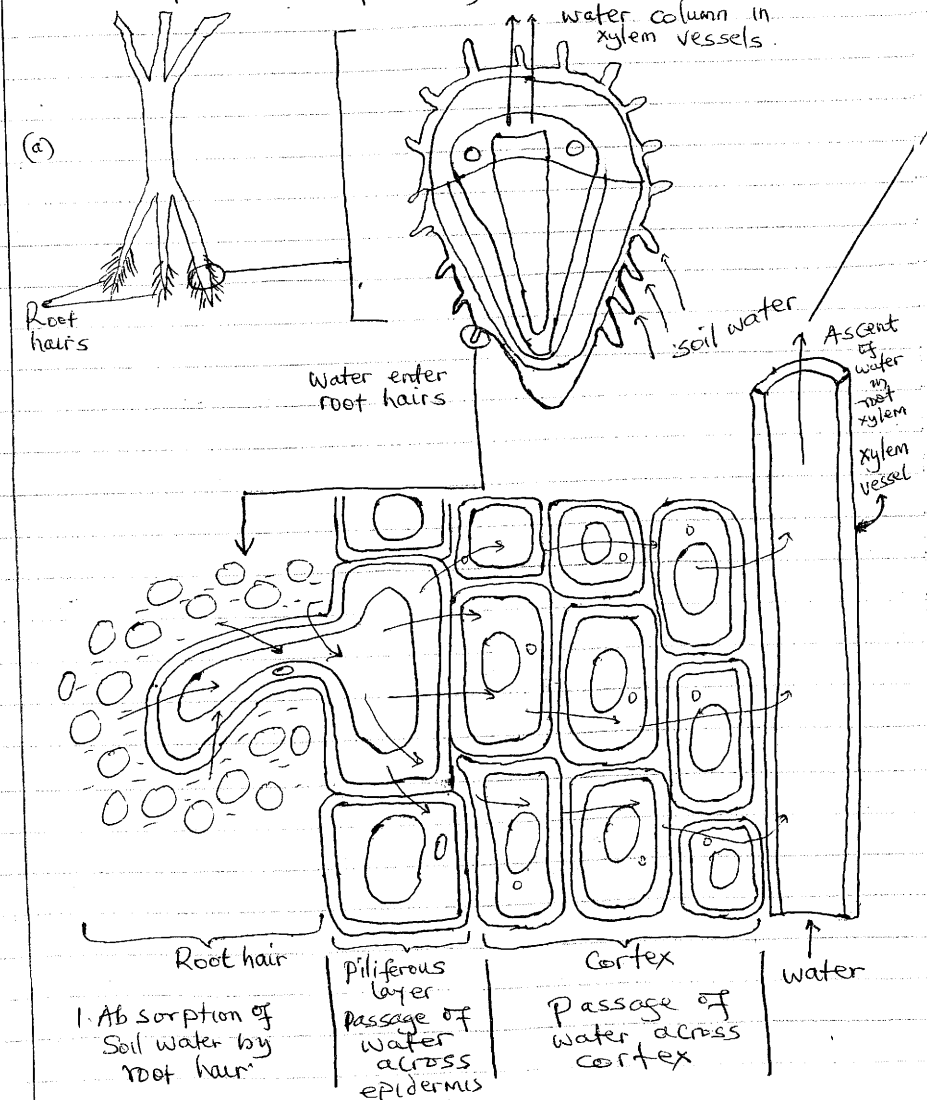
(b) Absorption of water and Conduction of the water to leaves of a plant and eventually to the atmosphere.

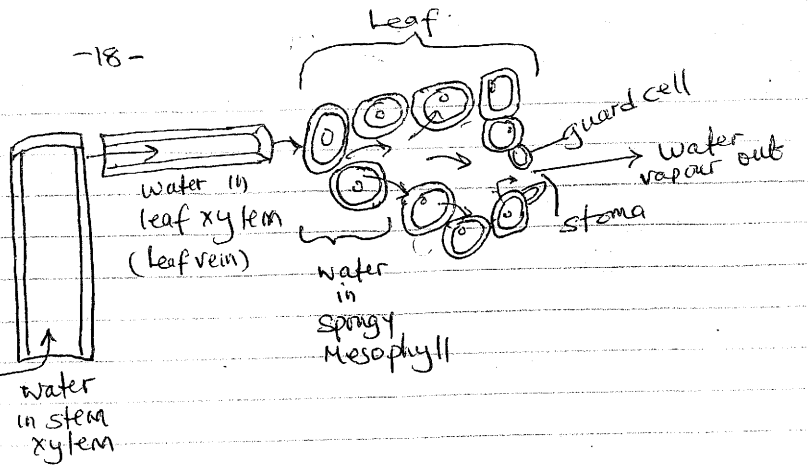
- Soil particles are surrounded by a film of water.
- The cellsap of root hair cells is more concentrated than / is hypertonic to soil water.
- Due to the concentration difference or concentration gradient between the cellsap and water in the soil, an osmotic pressure is exerted which draws water by osmosis from the spaces between the soil particles; through the cellwall and cellmembrane (which acts as the semi-permeable membrane),

through the cytoplasm and into the cellsap of the vacuole of a root hair cell.
- As a result concentration in the cellsap of root hair reduces / dilution occurs and root hair cell becomes less concentrated than the neighbouring cells of the cortex. Hence water moves by osmosis to the cells of the cortex of the root. As dilution occurs, water moves from cell to cell in the cortex by osmosis, and then across endodermis by active transport, into xylem vessels of the root;
- The water is then conducted up xylem vessels of the stem; into xylem vessels of the leaves.
- Water is pushed / rises up the stem by **root pressure**. In the xylem vessels water rises by **capillarity & cohesive and adhesive** forces.
- Water moves as a **continuous uninterrupted water column** in the xylem vessels up the tree to the leaves;
- As water vaporises from the **spongy mesophyll cells** their cellsap becomes more concentrated than adjacent cells. This increases the osmotic pressure of the spongy mesophyll cells. As a result, water flows into the cells from other surrounding cells; which in turn take in water from xylem vessels within the leaf veins. This creates a **transpiration pull** / suction force, that pulls a stream of water from xylem vessels in the stem and roots called **transpiration stream**.
- The transpiration stream maintains a

a continuous column of water from the roots to the leaves.

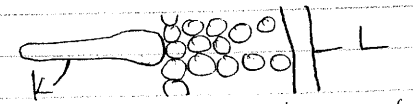
- As water moves along the intercellular spaces of the leaves, it finally reaches the sub-stomatal chambers where it evaporates into the air by transpiration, creating a transpiration pull;





Rev. Questions

1. Describe the movement of water from the soil to the leaves of a tall plant (20 MKS) (KCSE 1997)
2. Describe the path taken by water from the soil to the leaves of a tall plant and eventually to the atmosphere (20 MKS) (KCSE 1998)
3. Explain how water in the soil enters root hairs (5MKS) (KCSE 1989 No 3(c)).
4. study the figure below



(a) Name the structures labelled K and L (2MKS)
(b) Explain how water from the soil reaches the structure labelled L (5MKS).
5. Explain how water moves from the soil to the leaves of a tree (20MKS) (KCSE 2006).

Forces involved in transportation of water and Mineral salts

- As water evaporates from the plant more is absorbed forming a continuous flow of water from the roots, up the stem to evaporating surfaces of leaves. This forms a continuous flow of water known as transpiration stream.
- The forces behind this include

i) Transpiration pull.

- As water vaporises from the spongy mesophyll cells into the substomatal air spaces, their Cellsaps become more concentrated than the adjacent cells. This creates an increase in osmotic pressure which draws water, from neighbouring cells and eventually from the xylem vessels, within the leafveins. This developments create a pull or suction force that pulls a stream of water from xylem vessels in stem and roots, known as transpiration pull. This force is important in replacement of water lost from the plant through transpiration.

ii) Cohesion and Adhesion forces.

- Cohesion force is one that keeps and attracts water molecules to each other.
- Adhesive force is one that attracts water molecules to the walls of a Container such as xylem vessels.
- These forces maintain a continuous and uninterrupted water column in the thin xylem vessels up the trees.

iii) Capillarity

- A force that makes water to rise up in narrow tubes such as are xylem vessels. The force is more effective if there is no air bubble and the tubes are narrow eg a tube of a diameter of 0.01mm will have water rising to a height of 3M.

iv) Root Pressure

- A force that involves active pumping of water across endodermis to xylem vessels of roots. Evident when a plant is cut above the soil level. Involves use of energy (hence active transport). Hence inhibited by respiratory inhibitors such as poisons eg Cyanides.

Transpiration.

- Transpiration is the process by which plants lose water in form of water vapour to the atmosphere through stomata or lenticels or the cuticle.

Types of Transpiration

i) stomatal Transpiration

- Loss of water vapour through the Stomata.
- Accounts for 80-90% of total transpiration in plants.
- Most stomata occur in leaves. Some may occur in young epidermis of herbaceous stems.

ii) Cuticular Transpiration

- Is the loss of water in form of water vapour through the cuticle. Accounts for 20% of total transpiration. In plants with thick cuticles cuticular transpiration is negligible.

iii, Lenticular Transpiration

- Loss of water in form of water vapour through Lenticels. It is negligible.

The internal structure of a leaf shows that each stoma opens into sub-stomatal air spaces that are lined with spongy mesophyll cells.

As water vaporises from spongy mesophyll cells into the sub-stomatal air spaces their cellsaps become concentrated than the adjacent cells. This increases osmotic pressure of the spongy mesophyll cells. As a result, water flows into the cells from the surrounding cells which in turn take in water from xylem vessels within the leaf veins.

Hence as water vapour escapes through the stomata, more is replaced from xylem in which there is a continuous flow of water known as transpiration stream.

Transpiration stream

- Is a continuous stream/film of water from root xylem and ~~up~~ the stem xylem and finally into evaporating surfaces of leaves; due to transpiration pull.

Factors Affecting Rate of Transpiration.

(A) structural factors of the leaf

i, Cuticle

- Thick, waxy and shiny cuticle reduces rate of transpiration as in arid plants. The cuticle is absent in hydrophytes; or is very thin since cuticle is a waterproof material. This encourages water loss.

ii, Leaf size and shape.

- Rate of transpiration is high in plants with broad leaves as this expzses more surface area for water loss.
- plants growing in dry areas/arid areas/deserts have leaves with reduced surface/leaves reduced to scales/leaves needle-like to minimise transpiration.

iii, stomata :-

(a) Number of stomata.

- plants which grow in dry areas have few or no stomata on the upper surface of leaves. Stomata are mainly located on the lower side of leaves. The number of stomata in such desert plants is greatly reduced; to reduce rate of transpiration.

(b) Sunken stomata into epidermis.

- plants which grow in dry places have stomata sunken into epidermis forming pits. Water vapour tends to accumulate in the pits thus reducing rate of transpiration.

(c) Reversed stomatal rythm.
- Plants that grow in dry places open their stomata at night and close them during the day to reduce the rate of transpiration.
- Other plants tend to close their stomata at midday when it is hot to reduce the rate of transpiration. This phenomenon is called Mid-day closure.

(d) Small stomatal aperture to reduce transpiration

(iv) Hairy leaves.
In some plants, leaves are covered with hairs. These trap a layer of moist air on the surface of leaves thus reducing transpiration.

(vi) Leaf-fall
- During periods of drought, some plants such as broad-leaved deciduous trees shed their leaves to reduce the surface area over which transpiration occurs. eg Nandi flame.
- In some species of grass, the aerial shoot drys up to the ground level.

(vii) Succulent/fleshy leaves.
- Store water for use during drought.
- The succulent tissues trap water reducing rate of transpiration.

(B) Environmental factors.

① Temperature
- High temperature increases the capacity of the atmospheric air to hold more water vapour.
- High temperature increases the internal temperature of the leaf which in turn increases latent heat of vaporisation and therefore enhances evaporation from the leaf cells. The rate of transpiration increases. The reverse takes place when temperature is low.

② Humidity
- The rate of transpiration is generally high in dry atmosphere due to high concentration of water vapour in the intercellular air spaces than in the dry atmosphere. This causes water vapour to diffuse out of the leaf into the dry atmosphere. The humidity difference between the inside and outside of the leaf is known as **saturation deficit** and it determines the rate of water loss from the leaf. In dry atmosphere, saturation deficit is high and this increases rate of transpiration compared to the low rate of transpiration when humidity is high and saturation deficit is low.
- Under conditions of high humidity and hence low saturation deficit, some plants secrete water droplets through specialised pores called **hydathodes**. This process of water loss in form of water droplets through hydathodes is called **guttation** and is common in hydrophytes.

③ Wind

- In windy conditions, moist air around the leaf is blown away, increasing diffusion gradient and hence higher rate of transpiration.
- When the air is still the region around the leaf becomes saturated with water vapour. Diffusion of water from leaf surface reduces leading to low transpiration rate.

④ Light intensity

- High light intensity increases the rate of photosynthesis in guard cells resulting in opening of stomata. Thus more water is lost to the surrounding since substomatal air is brought into direct contact with the external environment.
- High light intensity from the sun also increases internal temperature of the leaf, thus increasing evaporation rate in the intercellular spaces hence higher rate of transpiration.

⑤ Water availability

- With more water available in the soil, the plant absorbs this to saturate the spongy mesophyll cells of the leaf giving more water to the intercellular spaces. This increases the diffusion gradient hence higher rate of transpiration.
- At the same time, guardcells become turgid and stomata remains open hence more water is lost to the atmosphere.

⑥ Atmospheric pressure

- At higher atmospheric pressure, evaporation of water from intercellular spaces is reduced therefore rate of transpiration is low.
- At lower atmospheric pressure, there is high evaporation rate and water loss to the atmosphere is equally high.

Revision Ques

1. KNEC 1990 No. 16 - Explain how environmental factors affect the rate of transpiration in flowering plants. (20 mks).
2. KNEC 1991 No. 10.
   (a) With reference to leaf structure only, state five ways by which plants are adapted to living in arid areas (5mks)
   (b) State two aspects of light that affect the rate of photosynthesis (2mks)

Adaptations of plants to deal with problems of Transpiration / excessive water loss

(i) Thick waxy cuticle
(ii) Sunken stomata / stomata sunken into epidermis.
(iii) Hairy leaves
(iv) Scaly / thin / tiny / needle-like leaves / leaves with reduced surface area.
(v) Reversed stomatal rythm.
(vi) Leaf folding
(vii) shedding of leaves during drought
(viii) Extensive superficial roots
(ix) Deep roots to reach underground H_2O
(x) Succulent leaves / stems.

Importance of Transpiration

(i) Creates transpiration pull, which facilitates absorption of water and mineral salts from the soil and also their distribution in the plant
(ii) Confers cooling effect on the plant, when hot due to latent heat of vaporisation.
(iii) Responsible for turgor in plants.
(iv) Removal of excretory products from the plant.
(v) Removal of excess water especially in aquatic habitats.

Disadvantage of transpiration

— Causes wilting in plants in dry weather.

Translocation of organic compounds

— Translocation is the transport of soluble organic products of photosynthesis from the leaves to other parts of the plant through phloem tissue.
— The organic materials translocated are mainly food materials and include sugars, glucose, vitamins, amino-acids, fatty acids and glycerol.
— The materials are translocated to various regions where they are required for various purposes. These include
① Growing and developing parts eg buds, young shoots, leaves, flowers fruits and roots.
② The storage organs such as

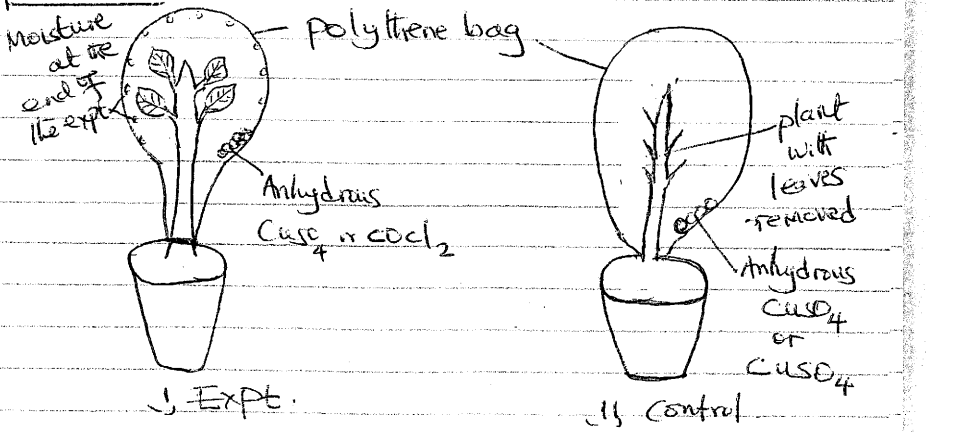
bulbs, tubers, corms, rhizomes and seeds.
③ Secretory organs such as nectar glands of some insect-pollinated flowers such as bananas (*Musa* spp).
— The mechanisms involved in translocation include :-
① Cytoplasmic streaming
② Diffusion / Mass flow
③ Active transport.

Practical Activities

1 Demonstration of Transpiration

(a) Using a polythene bag

Procedure:



— The two potted plants are treated as shown in the diagrams and left in the sun for 1 — 2 hours.
— Observation :-
i) Moisture collects in the polythene bag.
ii) Cobalt(II) chloride turns from blue to pink

or

EXPT

Copper (II) Sulphate changes from white to blue.

Expt 2. Control expt – No observable colour change. No Collection of Moisture in the polythene bag and no colour change for $CuSO_4$ or $CoCl_2$.

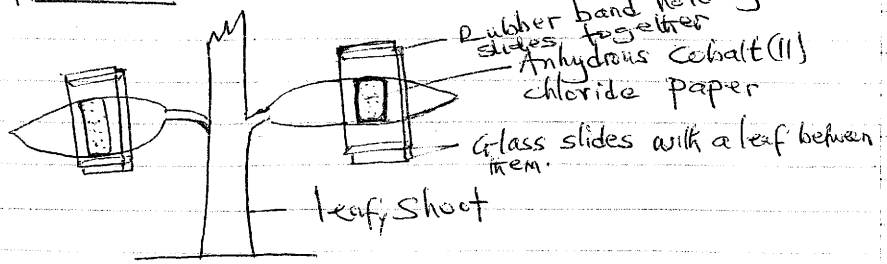
Explanation

Expt 1 - The plant lost water vapour by transpiration which then collects as Moisture in the polythene bag; and the water reacts with anhydrous $CuSO_4$ turning it blue / anhydrous $CoCl_2$ turning it pink. The loss of water occurs through the stomata of the intact leaves.

Expt 2 – Removal of leaves removes the surface area over which transpiration occurs. Hence no water loss from the plant occured. Set up (ii) acted as a Control experiment.

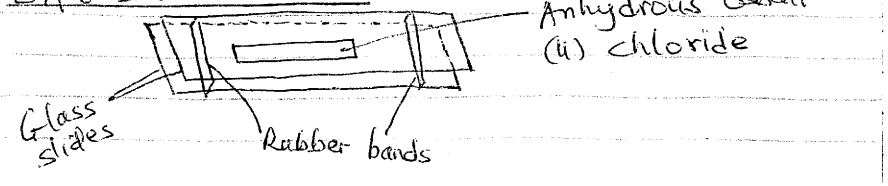
(b) Using Cobalt chloride paper

Procedure



Expt A. ↗

Expt. B : Control expt ↘



- Anhydrous $CoCl_2$ paper is placed on a leaf and the two are held between two Microscope or glass slides, one on each surface. The two slides are then bound together using rubber bands.
- The time taken for a colour change to occur on the $CoCl_2$ paper is noted.
- In the Control experiment only $CoCl_2$ paper is held between two dry glass slides as shown.

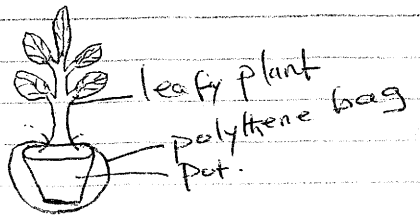
Results

- After sometime, the $CoCl_2$ paper on the leaves turns from blue to pink. Moisture is also observed on the inner walls of the glass slides. This is due to water vapour lost from the leaves through the process of transpiration.
- No colour change occurs on the $CoCl_2$ Paper in expt B. Thus acted as a Control experiment.

2. Measurement of Transpiration Rate

(a) Weighing Method

- A potted plant is well watered.
- The Pot is then Covered with polythene bag up to the upper end of the Stem as shown below:



-The set up is weighed and its initial mass is recorded.
-It is then left in the sun for 2-3 hours and then weighed again and ~~initial~~ Final mass recorded.

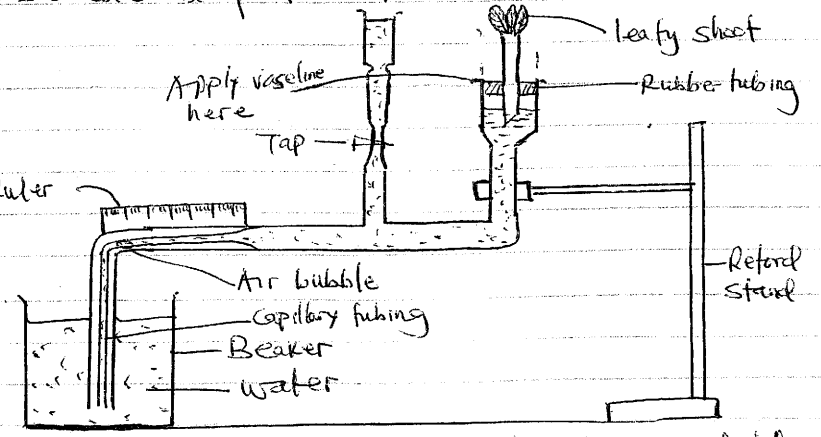
$$\text{Rate of transpiration} = \frac{\text{Initial wt(g)} - \text{final wt(g)}}{\text{Duration of expt.}}$$
$$= X_g T^{-1}$$

(b) Potometer Method.

-A potometer is the instrument used in measuring rate of transpiration.

Procedure

i, Obtain a leafy shoot from herbaceous plant and keep the stem under water in a basin.
ii, Assemble a potometer as shown below.



iii, The stem of the leafy shoot should immediately be immersed into water to avoid blockage of water channels with air. Fix a rubber

bung over the cut end while it is still in water.
iv, Connect the end of the shoot in the bung to the potometer already filled with water. Apply petroleum jelly around the rubber bung to render the system air tight.
v, Transfer the set up to a bench near the window in the lab. The end of the capillary tubing should rest in a beaker of water as shown.

NB
For commercially prepared potometer that is already mounted, dipping the capillary in water is not required. Open up the reservoir tap and run water to expel any air in the capillary tube. Then introduce an air bubble by lifting the capillary tube from the beaker for a few seconds. Adjust the position of the air bubble using the reservoir tap.

Place a plastic ruler behind the capillary tube to measure the rate of movement of the air bubble as shown in the diagram. Allow the set up to stand for some time and work out the rate of transpiration as shown below.

$$\text{Rate of transpiration} = \frac{\text{Distance moved by air bubble}}{\text{Time taken}}$$
$$= Y_{mm}\, T^{-1}$$

- The set up can be transferred next to a fan, near a bright bulb of light or a shedded area to investigate the rate of transpiration.

Precautions to take during the experiment include :-

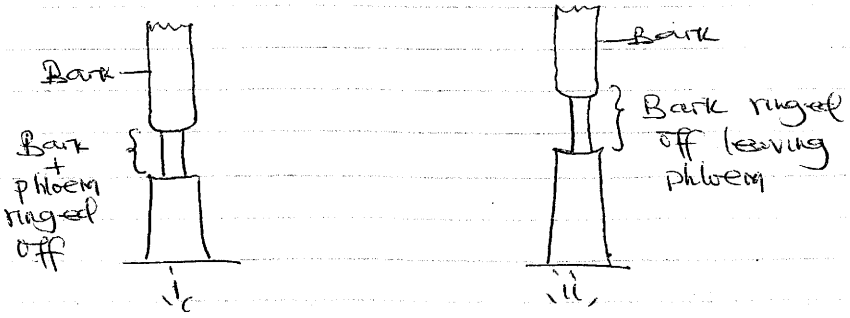
(i) Cut the shoot under water - to ensure no air bubbles enter the xylem.

(ii) Apply petroleum jelly to cork-glass/rubber bung connection to ensure the apparatus are air tight.

(iii) Open reservoir tap; to remove air bubbles from tubes.

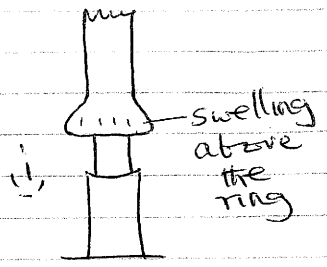
3. To investigate translocation in plants.

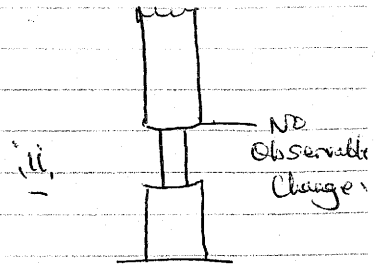
- A bark of a stem is ringed off in one plant including the phloem tissue. phloem tissue is found close to the bark.
- A similar stem is also ringed off of its bark carefully leaving the phloem intact; as shown below :-



- The set ups are left for 2-3 weeks.

Results -





Explanation

(i) - During translocation, photosynthetic products moving down the phloem accumulate in the part above the ring due to removal of ~~xylem~~ phloem (in expt 1)

(ii) phloem was intact hence the manufactured ~~food~~ did not accumulate in the part above the ring. Expt (ii) acted as a control experiment.

Revision Questions

1. KNEC 1989 No. 11. In an experiment, a leafy shoot was set up in a potometer and left in a dark room for 2 hours. The set up was then transferred to a well lit room for 2 hours.
   (a) What was the aim of the experiment? (1mk)
   (b) Explain the results which would be expected in ~~each~~ of the two experimental set ups. (3mks)
2. KNEC 1989 No. 18.
   (a) Name the tissues in flowering plants that are responsible for transport of
   (i) water
   (ii) Manufactured food. (2mks)
   (b) Describe an experiment you would carry out to demonstrate that the tissues you have

named above transport
(i), water
(ii), manufactured food (1½ MKS)
(c) Explain how water from the soil enters root hairs of a plant (4 MKS)

3. KNEC 1990 NO. 16.
Explain how environmental factors affect the rate of transpiration. (20 MKS).

4. KNEC 2005 NO. 14. Refer set up in Expt 2(b) above.
A set up that was used to investigate a certain process in plants is shown in the diagram below (Refer expt 2(b) above).
(a) What process was being investigated? (1MK)
(b) (i), state two precautions that should be taken when setting up the experiment (2MKS)
(ii), Give a reason for each precaution in (b)(i), above (2MKS).
(c) state three environmental factors that influence the process under investigation (3MKS)

5. The rate of transpiration of maize plants was measured over a 24-hour period and the following were the results

Time of the day	7am	9am	11am	1pm	3pm	5pm	7pm	9pm	11pm
Water loss per hour cm^3	90	160	218	248	195	179	124	8	18

1am	3 am	5 am
18	13	23

TRANSPORT IN ANIMALS

The circulatory system

- Large and complex animals have a circulatory system consisting of
  (i), Means of pumping (heart)
  (ii), transporting fluid (blood)
  (iii), Means of conveying the transporting fluid.
- The circulatory system transports the the substances and maintains a steep concentration gradient at the surfaces where diffusion occurs such as lungs & gills.
- There are two types of circulatory systems.
  (a) Open circulatory system — here the transporting fluid is contained in general body cavities or coelom. The transporting fluid in the cavities also known as haemocoel is common in invertebrates.
  (b) Closed Circulatory system — here transporting fluid (blood) flows in special tubes called blood vessels. Common in vertebrates and annelids.

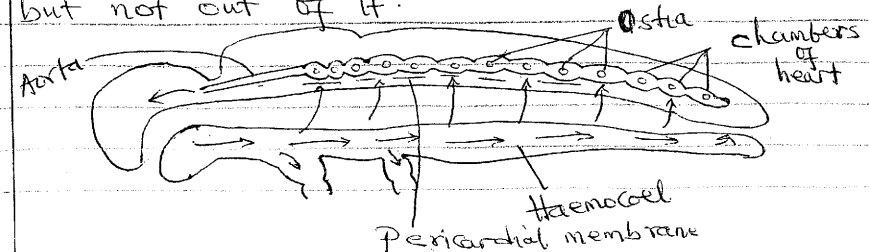
Comparison between closed & Open circulatory systems

closed circulatory system	Open circulatory system
1. Blood pumped into closed blood vessels	Blood pumped into open cavities/haemocoel
2. There is generation of high pressure causing blood to flow faster.	Generation of low pressure / Loss of pressure as blood flows in the cavities.
3. Tissues receive their requirements at a faster rate and removal of wastes is faster, hence the animal is always active.	Tissues receive their requirements at slower rate. So is removal of Metabolic wastes Hence animal is generally less active.

closed circulatory system	Open circulatory system
4. Blood is in indirect contact with tissues.	Blood is in direct contact with tissues.

Transport in insects

- Insects have an open circulatory system where blood flows and is contained in the haemocoel and within a **tubular dorsal heart**.
- The blood contains suspended leucocytes (white blood cells) and some other pigments.
- The insect blood does not largely transport respiratory gases (CO_2 and O_2). The gases diffuse into and out of the tissues through the tracheal system. Thus explains why insect blood is, not coloured.
- In a Cockroach (a typical insect) there is a tubular heart just above the alimentary canal. The heart has 13 chambers (three in thorax and 10 in abdominal segments). The anterior segment is joined to the **aorta** which empties the blood to the sinuses of the head.
- Each chamber contains a pair of valves which prevents backward flow of blood.
- Each chamber also has a pair of openings called **ostia** which are closed by valves. The valves allow blood to flow into the heart through the ostia but not out of it.



Differences between transport of gases in insects and Mammals

Insects	Mammals
① By tracheal system	By blood.
② Gases diffuse to and from tissues directly via the tracheoles.	Gases carried by blood before diffusing into tissues or after diffusing out of tissues.
③ Respiratory Pigments eg haemoglobin are not involved.	Respiratory pigment. ie haemoglobin is involved

The Mammalian Circulatory system

- Mammals have a closed type of circulatory system.
- It consists of a 4-chambered heart which pumps blood to arteries. Arteries convey blood to their narrower branches called arterioles. Arterioles subdivide into capillaries to which arterioles convey blood.
- From capillaries, blood filters into the intercellular spaces forming tissue fluid. The process of filtration through the capillary walls is called ultrafiltration. Ultrafiltration occurs due to narrowing of blood vessels and increased resistance to blood flow. Cells get nutrients by active transport, water by osmosis and oxygen by diffusion and pass out their wastes by the same physiological processes.
- Capillaries re-unite / coalesce to form venules which collect tissue fluid with

waste products from intercellular spaces. This is because in the venules the blood flows under low pressure. ①

— Venules re-unite to form veins. Blood from venules flows into veins and from veins back to the heart.

— In mammals blood flows twice into the heart for every complete circulation. ② This is called **double circulation**. This involves:

(a) Pulmonary Circulation

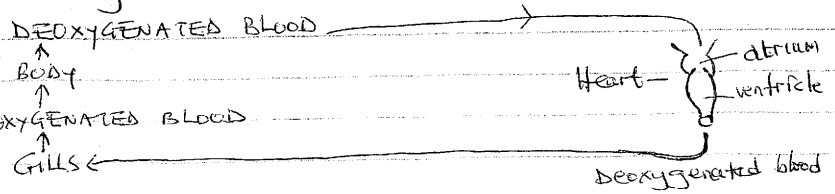
— Blood from the body tissues is pumped to the lungs and then back to the heart.
ie Blood from body → Right atrium → Right ventricle → pulmonary artery → lungs → pulmonary vein → heart.

(b) Systemic circulation

— Blood from the heart which is now oxygenated is pumped to the rest of the body organs ie oxygenated blood from the left atrium → left ventricle → Aorta → arteries → body organs → veins → venacava → heart (Right atrium).

— Double circulation is also found in birds which also have a four-chambered heart.

— In some other animals eg fish, blood flows only once through the heart for every one complete circuit. This is called **single circulation**. Here the heart has only one atrium and one ventricle.



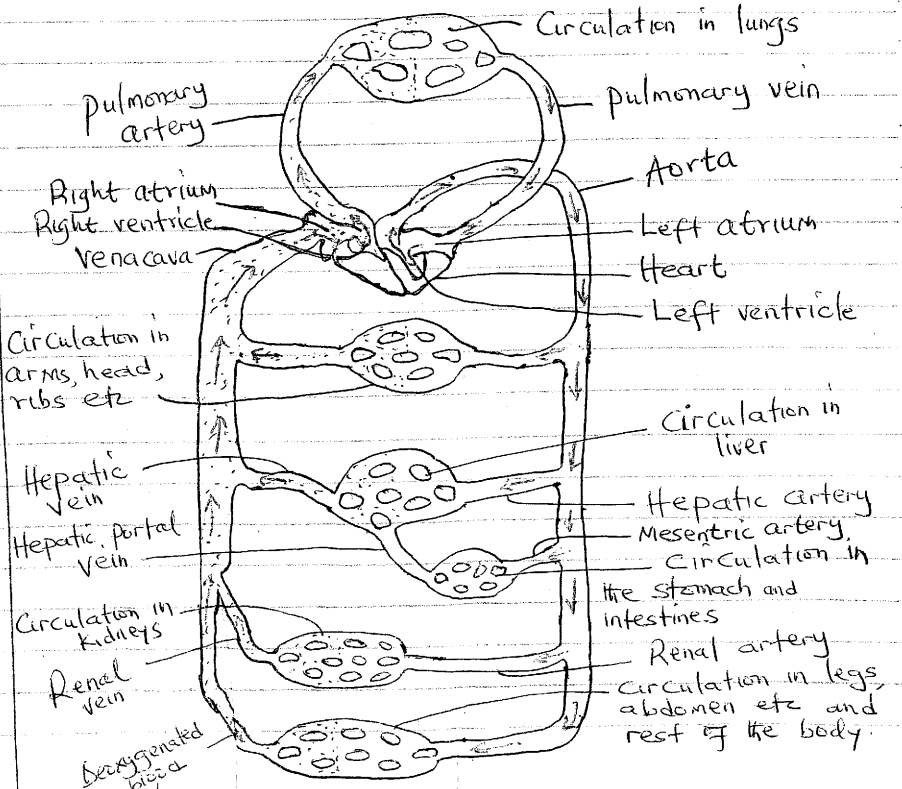
Advantages of double circulation over single circulation.

The right two chambers, right atrium and right ventricle deal with deoxygenated blood whereas the left atrium and ventricle deal with oxygenated blood hence no mixing of the two bloods.

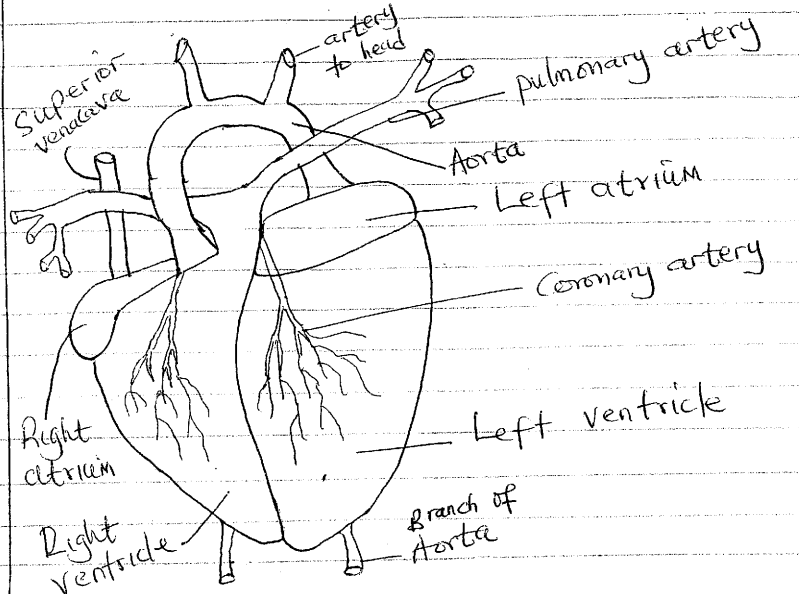
High blood pressure is generated and maintained supplying tissues with oxygen and nutrients and removing waste products at a faster rate, hence the organism is active throughout.

NB. In single circulation there is loss of pressure in gill capillaries.

— Below is a generalised diagram of the Mammalian circulatory system.

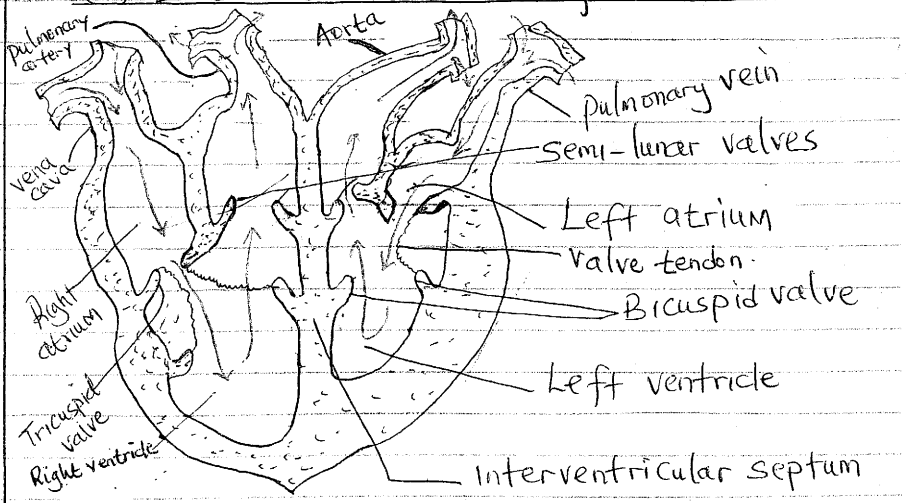


The structure and functions of the Heart
(Adaptations of Mammalian heart to its functions)
(a) External structure of the heart



- The heart is located in the thoracic cavity between lungs. It is enclosed by the pericardium membrane which :-
  i. secretes a fluid, pericardial membrane, which lubricates the heart;
  ii. has a fat which acts as a shock-absorber;
  iii. holds the heart in position checking it from over dilation;
- On the right atrium / auricle is found the sino atrial node (SAN) which initiates the contractions of the heart muscles hence acts as a pacemaker. Impulses then travel rapidly through atrial muscles to the atrioventricular node and to the purkinje fibres.
- The heart is made up of cardiac muscles which do not fatigue. The muscles initiate their own contractions hence are myogenic.
- The heart is supplied with blood rich in nutrients and oxygen by the coronary artery and waste products of metabolism are removed by coronary vein, which drains blood into right atrium;
- It is supplied by vagus and sympathetic nerves. Vagus nerve decreases heartbeat whereas sympathetic nerve accelerates heartbeat according to physiological demand. In this way the vagus and sympathetic nerves (which comprise the autonomic nervous system) control the heartbeat;

(b) Internal structure of the heart



- Internally the mammalian heart is made up of four chambers ie right atrium and left atrium or auricles and right and left ventricles.
- ventricles are larger in volume and pump blood from the heart;
- Auricles/atria are smaller in volume and receive blood from body tissues and from the lungs.
- On the septum seperating the ventricles is the atrioventricular node and purkinje fibres through which contraction waves spread to the ventricles so as they contract at the same time.
- Has atrioventricular valves ie bicuspid valve and tricuspid valve prevent backward flow of blood to auricles/atria;
- Semi-lunar valves (pocket valves) prevent backward flow of blood from the pulmonary artery and aorta to the ventricles when the two arteries relax.
- Heart has inter-ventricular septum that prevents mixing of oxygenated with deoxygenated blood;
- presence of valvular tendons prevent valves from turning inside out due to changes in pressure in the ventricles;
- Left ventricle is more muscular to pump blood to farthest tissue; right ventricle is less muscular to pump blood to lungs only;

(c) Circulation in the heart

- Deoxygenated blood from tissues except the lungs enter right atrium through the vena cava; to right ventricle, through the tricuspid valve, when the heart relaxes.
- At the same time, oxygenated blood from lungs enter left atrium from pulmonary vein; to the left ventricle, through bicuspid valve when the heart muscles relax.
- When ventricles contract, deoxygenated blood leaves the heart through pulmonary artery to the lungs. Oxygenated blood leaves the heart through aorta to all parts of the body. Blood from the ventricles to aorta and pulmonary artery is prevented from flowing backwards by the semi-lunar valves.

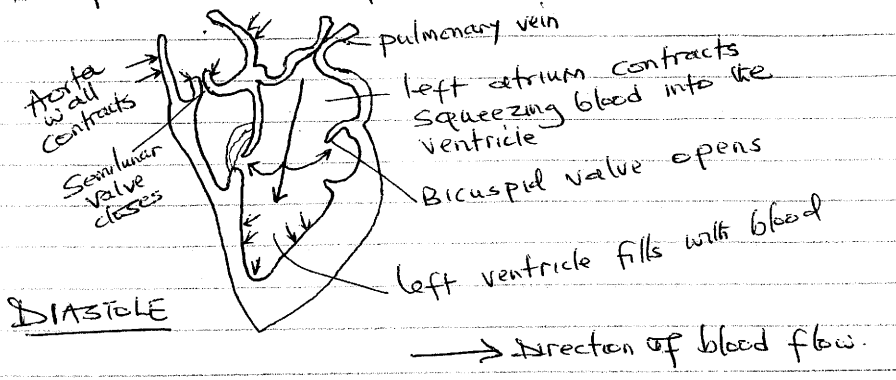
The pumping mechanism of the Heart.

- The heart undergoes contractions (systole) and relaxation (diastole) rythmically throughout the animal's life.

(a) Diastole (Relaxation)

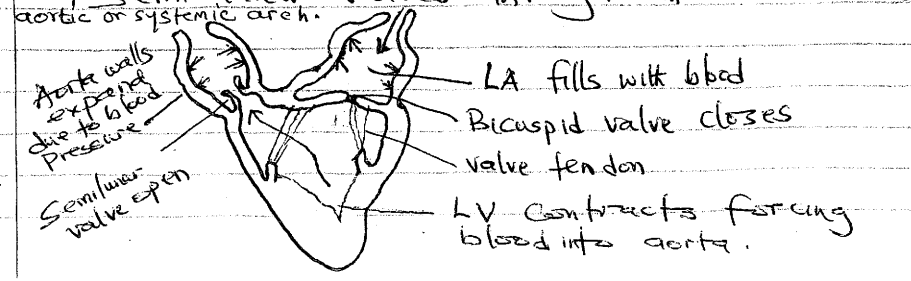
- occurs when ventricular muscles relax causing the volume of the ventricles to increase while the pressure decreases (both the right and left ventricles).
- The atrio-ventricular valves (Tricuspid and bicuspid valves) open allowing :-
  i, deoxygenated blood to flow from the body tissues to right ventricle via right auricle / atrium;
  ii, Oxygenated blood to flow from the

lungs to left ventricle via the left atrium
- The semi-lunar valves close to prevent backward flow of blood to the ventricles.
- The auricles / atria contract slightly to force blood flow to the ventricles.



(b) Systole (Contraction)

- occurs when ventricular muscles contract, the atrio-ventricular or cuspid valves close preventing backward flow of blood to the auricles. The semi-lunar valves open.
- The volume of the Ventricles decreases while the pressure increases, forcing blood out of the heart to the :-
  i, lungs via the semi-lunar valves through pulmonary artery
  ii, body tissues except lungs via the Semi-lunar valves through the aorta hence aortic or systemic arch.

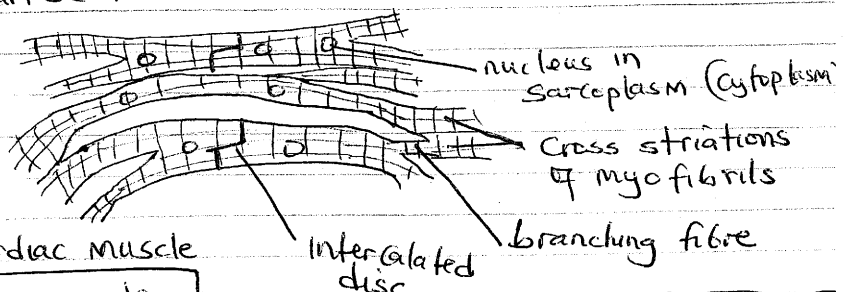


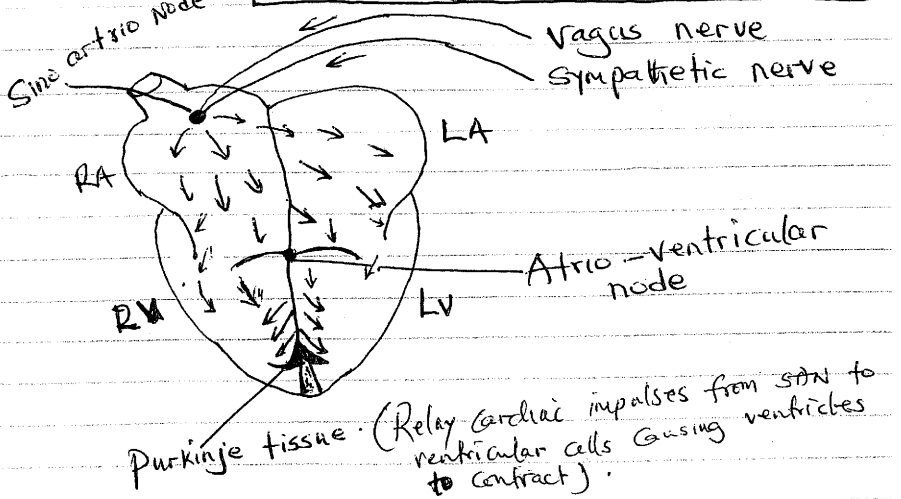
- The thick cardiac muscles of the left ventricle generate high pressure which forces the blood to the furthest tissue.
- A systole is always followed by a diastole and the two make a complete heart beat. A complete diastole and systole constitutes a **Cardiac cycle**.
- The heart contracts at an average of 60-70 times per minute. But the heart beats may increase due to high temperature, emotions and the age of a human being (heartbeats are faster in children than adults).
- A heartbeat can be felt as a pulse by placing a finger on a large artery, such as at the wrist, against a bone.

Heartbeat

- Is the rythmic contractions (systole) and relaxations (diastole) of the heart.
- Those rythmic contractions and relaxations of the heart is due to its special muscles called Cardiac Muscles which do not fatigue The Cardiac Muscles are interconnected so that the waves of contractions can travel through the Mass of the muscle.
- The rythmic contractions of the heart arises from within the heart muscles without nervous stimulation. The contraction is therefore said to be **myogenic**; ie from within the muscles.
- The heartbeat is however initiated by the pacemaker or sino atrio node (SAN) — a small area of specialised cardiac muscles in the wall of the right auricle. The

spontaneous rythmical electrical activity of the SAN initiates and maintains a heartbeat.
- However heart beat rate is under nervous control:- the vagus nerve slows down heart beat whereas sympathetic nerve accelerates heartbeat.





The electrical excitations that follows the contraction of the heart.

Structure and function of Arteries Veins and Capillaries.

- Arteries, veins and capillaries are the main blood vessels.

Arteries

-Are blood vessels which originate from the heart and carry blood away from the heart eg aorta carries blood from heart to all parts of the body except lungs, pulmonary artery which carries deoxygenated blood to the lungs.

-Arteries have the following adaptations to their functions :-

i, Have thick muscular elastic walls to resist the pressure of blood inside them since they carry blood under high pressure from the heart.

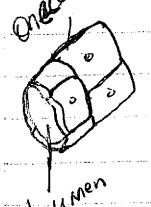
ii, Have a smooth endothelium (single layer of cells of the innermost layer) to reduce frictional resistance to blood flow.

iii, Have narrow lumen to maintain the high pressure of blood inside them

iv, Are invervated with nerves and are under control of hormones which alter the diameter of arteries regulating the flow of blood to body organs.

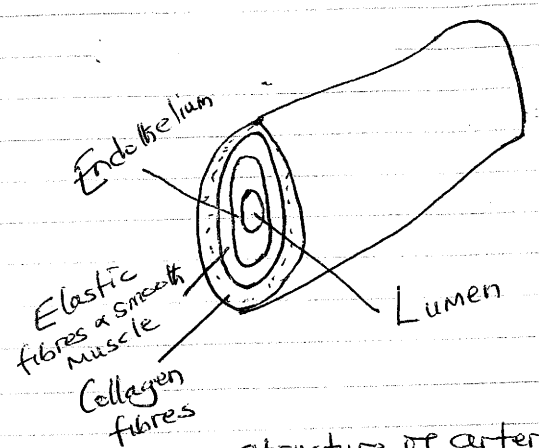
NB:- The outermost layer of arteries is composed of elastic muscular fibres (collagen fibres); the middle layer is composed of elastic fibres and smooth muscles.

— When ventricles contract (systole), the muscular layer of arteries relaxes stretching outwards to allow blood into arteries. When ventricles relax (diastole) the muscular layer contracts, pressing inwards forcing blood flow forwards.



This produces the pulsating action in arteries.

-Aorta branches into arteries which supply blood to major organs. Those branches divide to smaller vessels called arterioles. The arterioles further divide into capillaries.



structure of artery

Capillaries

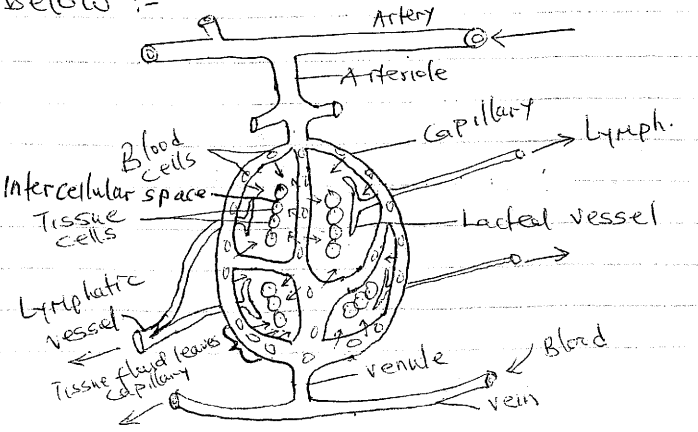
-Are branches of arterioles which are in close contact with cells. They have the following adaptations :-

i, Are numerous and very close to tissues in such a way that each cell is near a blood capillary to provide huge surface area for exchange of materials.

ii, They are thin-walled / consists of a single layer of cells endothelial cells to allow diffusion of materials

iii, They are small & narrow to increase pressure or resistance for materials to diffuse out to intercellular spaces to form tissue fluid.

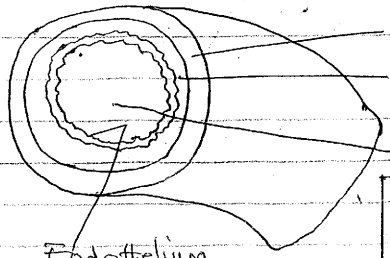
- Branching of arterioles to capillaries increases the surface area of the capillaries and pressure of blood in them. Thus forces small molecules out of blood within the capillaries into the intercellular spaces to form **tissue fluid**.
The forcing out of these small molecules of blood from capillaries to intercellular spaces through capillary walls is called **ultrafiltration**.
- Tissue fluid formed is plasma lacking proteins, red blood cells and some leucocytes. But phagocytic leucocytes squeeze out through capillary walls into tissue fluid.
- From tissue fluid, cells extract glucose, amino acids, vitamins, hormones and mineral ions by active transport or diffusion. water by osmosis and oxygen by diffusion.
- Ultrafiltration results in drop of pressure in venules and in the capillary bed. Hence waste products of metabolism such as CO_2 diffuse back into venules (by diffusion); water passes back by osmosis and nitrogenous wastes by active transport.
- Excess tissue fluid passes into lacteal vessels of the lymphatic system as shown below:-

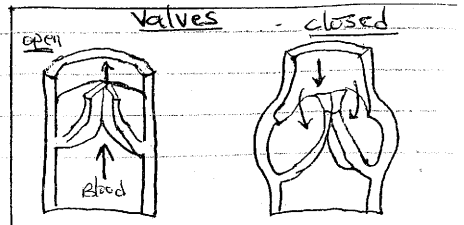


- Venules join up to form veins.

Veins

- Veins carry blood from all parts of the body to the heart.
- Due to loss of pressure in capillaries, blood pressure in veins is low hence blood flows in them smoothly.
- Veins have the following adaptations to their function:-
  (i) Have relatively larger lumen compared to arteries to offer minimum resistance to blood flow;
  (ii) Have valves along their lengths which prevent backward flow of blood thus ensuring blood flows only towards the heart.
  (iii) Have thin walls to minimise resistance to blood flow;
  (iv) Have a smooth endothelium to minimise resistance to blood flow.
  (v) Large veins are placed between skeletal muscles which upon contraction force blood in veins forward to the heart. (Hence importance of physical exercises).





- Veins carry deoxygenated blood and blood rich in nitrogenous wastes and fewer nutrients except:-

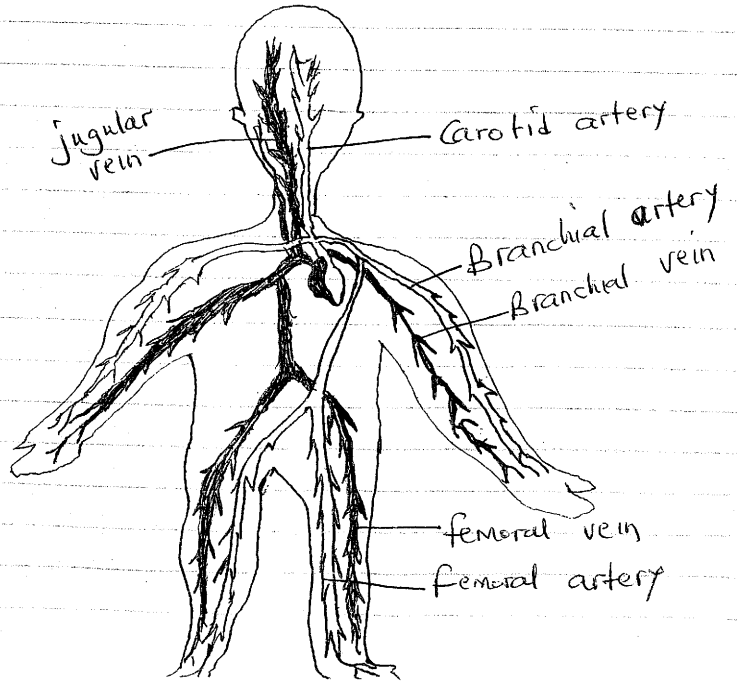
i) Renal vein which carries blood from kidney where nitrogenous wastes, some water and salts have been removed.

ii) Hepatic Portal vein that carries blood rich in dissolved food substances from the gut to the liver.

iii) pulmonary vein that carries oxygenated blood from lungs to the left auricle of the heart.

Major Blood Vessels of the Body

The figure below illustrates the major arteries which supply blood to the various body organs and the major veins which collect blood from the organs.



Organ	vein	artery
Head/Neck	Jugular	Carotid
Arms	Branchial	Branchial
Legs	Femoral	Femoral
Kidney	Renal	Renal
Liver	Hepatic Hepatic portal	Hepatic
Intestines	Hepatic portal	Messenteric
Lungs	pulmonary	pulmonary
Ovaries	Ovarian	Ovarian
Umblical cord	Umblical	Umblical

Differences between arteries & veins

(a) Structural differences

Arteries	veins
1. walls are thick ^More Muscular and ^more elastic	walls are thin, less Muscular and less elastic
2. Lack valves except at base of large arteries leaving the heart	Have valves at intervals throughout their lengths.
3 Narrow lumen	wide lumen.

(b) Functional differences

Arteries	veins
1. Transport oxygenated blood except pulmonary artery.	Transport deoxygenated blood except Pulmonary vein.
2. Transports blood under high pressure / Blood flows rapidly under pressure	Transports blood under low pressure/ blood flows slowly under low pressure.

(c) Other differences

Arteries	veins

Arteries	veins
1. Blood flows rapidly in pulses	Blood flows smoothly
2. Tend to lie deeper in the body	Tend to lie near the body surface.

Diseases & Defects of Circulatory system

① Thrombosis

- Refers to the formation of a clot in vessels.
- Coronary thrombosis is the common type which leads to blockage of Coronary artery which supplies blood to heart muscles.
- The causes of coronary thrombosis include:-
  - i) Arteries becoming increasingly fibrous
  - ii) Heavy intake of fat which results in high amount of cholesterol in blood, and accumulation of the fatty material in the artery walls
  - iii) Heavy intake of alcoholic drinks
  - iv) Smoking
  - v) overweight
  - vi) physiological and emotional stress.
- The subsequent narrowing of the arteries reduces supply of oxygen to the oxygen dependent heart muscles causing fatal heart attack / Cardiac arrest hence death.
- Control → practising healthy lifestyles eg diet less in fat; regular exercises etc

② Arteriosclerosis

- Refers to deposition of Calicium in the walls of blood vessels. This leads to hardening of the arteries / loss of elasticity hence a permanent change in arterial wall; ie loss of elasticity and thickening of the walls.
- possible causes:-
  - i) overweight
  - ii) Lack of exercise
  - iii) Emotional stress.
- Control
  - i. Taking drugs that reduce cholesterol level in blood
  - ii) Regular exercises to break down excessive fats in the body.

③ Varicose veins

- Condition in which superficial veins especially those at the back of legs become swollen and flabby due to failure of some valves to function properly This results in retention of some tissue fluid
- Control → Regular physical exercises

④ Hypertension / High blood pressure

- Is a blood disorder associated with high blood pressure above the normal which is 90/60 to 140/90 mm Hg The numerator refers to systolic pressure and denominator refers to diastolic pressure of the heart.

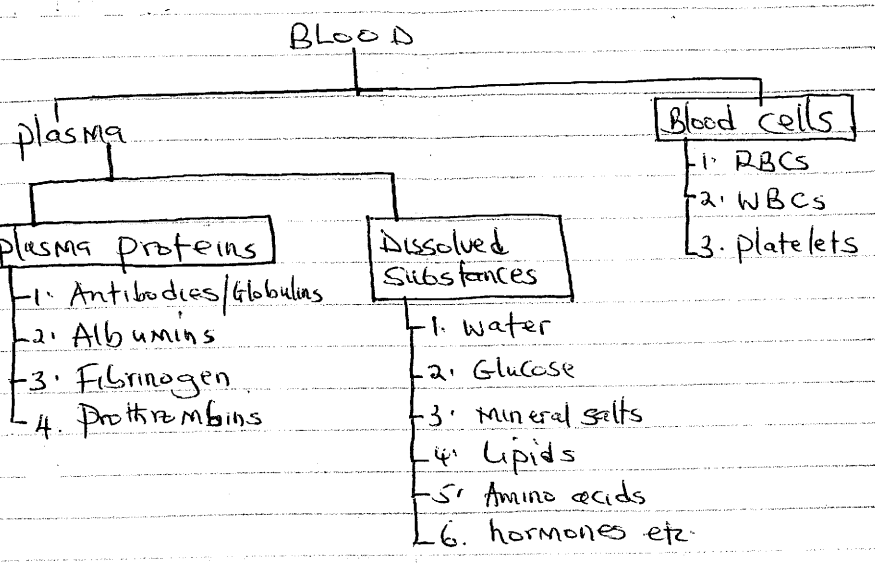
- The Causes include :-
  i. Heavy drinking of alcoholic drinks
  ii. Smoking
  iii. Diet rich in salts
  iv. General body stress.
  v. Arteriosclerosis
- Hypertension causes the heart to overwork in pushing blood through the narrow blood vessels and can lead to heart failure.
- It may also lead to bursting of capillaries - when this happens in the brain it results in a stroke. A stroke causes death of some brain cells and subsequent paralysis or death.
- Control
  i. Regular physical exercises
  ii. Intake of less salt in diet
  iii. Avoid excessive alcohol consumption
  iv. Avoid smoking of cigarettes and related drugs
  v. Avoid general body stress by practising healthy lifestyles.

Structure and Functions of blood

Composition of blood

- Mammalian blood consists of a fluid medium called plasma with cellular components suspended in it.
- The cells include :-
  i. Red blood cells / Erythrocytes / RBCs
  ii. White blood cells / Leucocytes / WBCs
  iii. Platelets / Thrombocytes which are non-

nucleated.



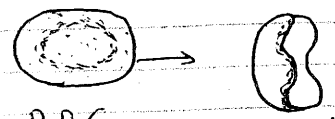
Plasma

- Is a yellow fluid consisting mainly of plasma proteins (globulins/antibodies, albumins, fibrinogen, prothrombins) and dissolved substances such as hormones, mineral salts glucose, lipids, waste products of metabolism such as carbon(IV) oxide and urea, plasma is 90% water, with dissolved or suspended materials.
- Blood plasma from which ~~plasma~~ fibrinogen has been removed is called serum (plural = sera).
- Functions of plasma include :-
  i. Transports red blood cells that contain oxyhaemoglobin to tissues hence facilitating transport of oxygen

(ii) forms the medium in which dissolved substances are transported to the liver and then to other tissues.
(iii) Transports metabolic wastes such as carbon(IV) oxide and other nitrogenous wastes to excretory organs for elimination
(iv) Transportation of hormones
(v) Transport of carbon(IV) oxide and oxygen since the gases partly dissolve in plasma.
(vi) Regulation of pH of body fluids
(vii) Distributes heat around the body hence regulate body temperature
(viii) Bathes tissues allowing exchange of materials between cells.

Red Blood cells / Erythrocytes

- Manufactured in bone marrow of short bones such as sternum, ribs, vertebrae in adults and Liver and spleen in embryo.



RBC Side view of RBC

- The red blood cells
(i) transport oxygen from lungs to tissues
(ii) transport carbon(IV) oxide from tissues to lungs.
- They have the following adaptations to their functions:-
(i) Are biconcave-shaped to increase surface area over which gaseous exchange occurs

(vi) Have thin membrane for faster diffusion of oxygen.
(vii) Have enzyme carbonic anhydrase for faster conversion of CO_2 to H_2CO_3.

Transport of oxygen

(ii) Mature RBCs lack nucleus (hence have a sunken centre) to allow room for packing of more haemoglobin molecule
(iii) Have haemoglobin which has high affinity for oxygen to be transported.
(iv) Are small to be many per unit volume for efficient oxygen transport (≈ 5 million/mm³)
(v) Have ability to change their shapes/ are flexible / are pliable hence can squeeze through narrow capillaries.
- Haemoglobin is a protein which contains iron and readily combines with oxygen to form an unstable compound oxyhaemoglobin RBCs carry oxygen to tissues in form of oxyhaemoglobin from lungs to tissues. In tissues oxhaemoglobin dissociates to haemoglobin and oxygen which then diffuses through capillary walls to tissues.

Oxygen + Haemoglobin $\underset{\text{In tissues}}{\overset{\text{In lungs}}{\rightleftharpoons}}$ Oxyhaemoglobin
(In lungs with high oxygen concentration) (In tissues with low oxygen concentration)

$O_2 + Hb \rightleftharpoons HbO_2$

- Haemoglobin is then free to pick up more oxygen in lungs.

NB - Besides oxygen, haemoglobin can also combine readily with carbon (II) oxide [CO] to form carboxyhaemoglobin which is a very stable compound. This does not dissociate in tissues to release oxygen. As a result the capacity of RBCs to transport

oxygen is reduced causing death if the CO inhaled for a long time. Hence CO is a a respiratory poison. Carbon (II) oxide is formed when carbon such as charcoal burns in limited oxygen supply such as burning charcoal stoves / jikos in poorly ventilated rooms and also from exhaust fumes of vehicles.

Transport of Carbon (IV) oxide

- RBCs transport 95% of carbon (IV) oxide from tissues to lungs ① An enzyme **Carbonic anhydrase** speeds up the conversion of Carbon(IV) oxide to weak Carbonic acid, H_2CO_3. Carbonic acid dissociates to hydrogen carbonates and hydrogen ions. The HCO_3^- ions diffuse out of RBCs into the plasma in which it is transported to lungs (ie in form of hydrogen carbonates). This accounts for 80% of CO_2 transport.

$$CO_2 + H_2O \xrightarrow{\text{carbonic anhydrase}} H_2CO_3$$

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- In the lungs the reverse process occurs releasing CO_2 for exhalation.
- The H^+ ions formed during dissociation of H_2CO_3 combine with oxyhaemoglobin forming haemoglobinic acid releasing oxygen.

$$HbO_2 + H^+ \longrightarrow HHb + O_2$$

Oxyhaemoglobin — Haemoglobinic acid

② About 15% of carbon (IV) oxide combines loosely with haemoglobin to form

carbamino haemoglobin. In the lungs carbamino haemoglobin dissociates into haemoglobin and CO_2 releasing the CO_2 for exhalation.

③ About 5% of Carbon(IV) oxide is transported in solution in plasma to the lungs.

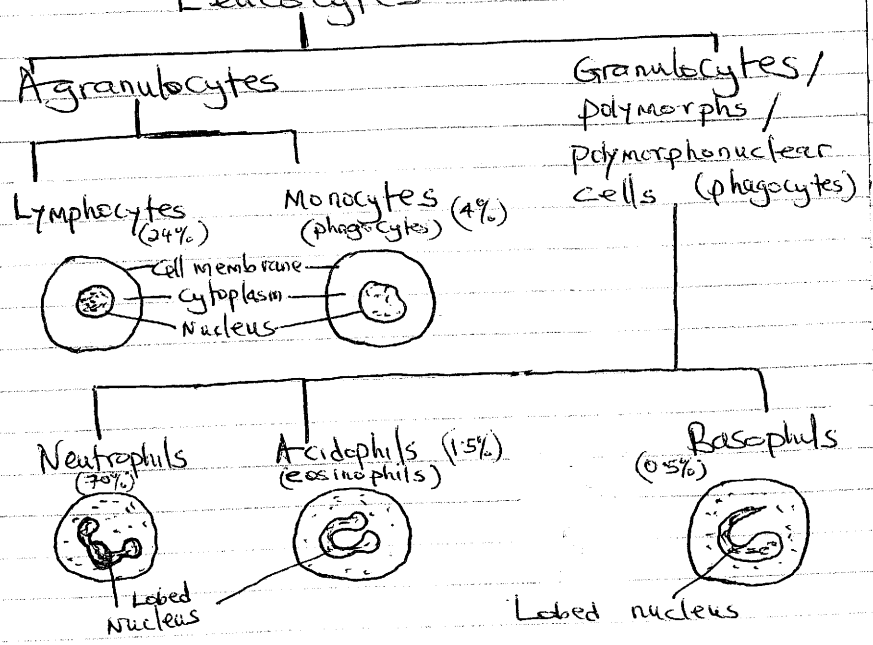
Adjustment to high Altitudes.

- In case of people living in high altitudes or those climbing mountains (Mountaineering), the body responds to the low oxygen concentration by increasing the total number of red blood cells and the haemoglobin content in them. This increases the oxygen carrying capacity of RBCs.

White blood cells / Leucocytes

- The white blood cells are so called because their cytoplasm is colourless / contain no haemoglobin. They are also nucleated unlike RBCs, and contain other organelles.
- Their functions include:-
  - (i) Ingestion and destruction of pathogens by phagocytosis ie by the phagocytes
  - (ii) Secretion of antibodies to destroy foreign antigens ie by the lymphocytes / immunocytes.
- WBCs are fewer in number compared to RBCs ie about 7000 leucocytes / mm^3 (between 6000 – 9000 / mm^3). However their numbers increase during infection (even up to 200,000 per mm^3 of blood).
- WBCs are formed in the Marrow of long bones and in lymph nodes.

Types of Leucocytes



- Granulocytes / polymorphs phagocytes with a granulated cytoplasm and lobed nucleus. They use amoeboid movement to pass through walls of capillaries into infected areas / tissues where they engulf pathogenic micro-organisms by phagocytosis. Once ingested the micro-organisms are digested. The WBCs which die in the process, the dead micro-organisms and dead tissues form pus. Monocytes also function as polymorphs
- Agranulocytes have rounded or bean-shaped nucleus and lack granules in their cytoplasm / cytoplast. They consist of Monocytes and lymphocytes.
- Lymphocytes are formed in lymph nodes. They produce antibodies that

protect the body against infections in the following ways:-

i. By antitoxins – antibodies which neutralise antigens / toxins produced by microbes
ii. By agglutinins – antibodies which cause clumping of micro-organisms inhibiting their multiplication. Such micro-organisms clumped together die or are ingested by phagocytes. The whole process is agglutination
iii. By lysins – antibodies which cause digestion and destruction of cellwalls or cell membranes of micro-organisms causing bursting. The process is lysis.
iv. By opsonins – antibodies which adhere to micro-organisms on their outer surfaces making it easier for phagocytes to ingest them.

Platelets / Thrombocytes

- Are fragments from large cells in bone marrow. They are discoid in shape and assume a star-shaped appearance in extracted blood.
- They are approximately 215 million / mm^3 of blood.
- Function → Contain enzyme thrombokinase / Thromboplastin which initiates blood clotting.

Blood clotting process

- This is a series of complex reactions where soluble blood protein fibrinogen is converted into an insoluble meshwork fibrin clot in an injured blood vessel.

—When a blood vessel is injured, exposed platelets rapture releasing enzyme **thrombokinase/ Thromboplastin**.

—Thrombokinase :-

i, neutralises **heparin** which is an anti-clotting factor in blood. In uninjured blood vessel heparin prevents conversion of **prothrombin** to **thrombin** thus preventing blood from clotting in blood vessels which can be fatal.

ii, activates prothrombin to thrombin. (prothrombin is an inactive enzyme or protein found in blood. Synthesis of prothrombin requires vitamin K). The activation of prothrombin to thrombin requires calcium ions.

—Thrombin enzyme activates conversion of **fibrinogen** (a soluble plasma protein) to **fibrin** which forms a meshwork of fibres on the cut surface to trap red blood cells to form a clot. The clot dries up to form a scab that stops bleeding and **protects** the damaged tissue from infection.

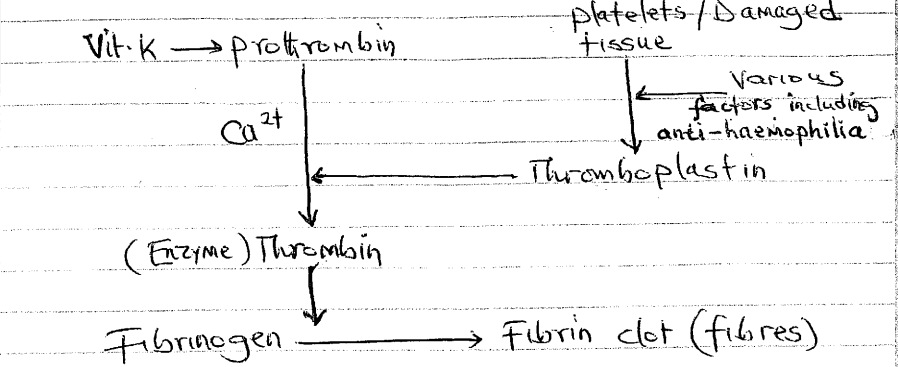
—Thus blood clotting reduces loss of blood which may lead to severe anaemia and subsequent death (if not corrected immediately by blood transfusion).

NB → loss of blood leads to dehydration, loss of nutrients, anaemia etc causing death.

② Losing more than 2L of blood causes

severe anaemia.

Summary of blood clotting



NB - In undamaged tissues any thrombin formed accidentally is neutralised by heparin.

Blood Groups

- Red blood cells have certain proteins called **antigens** on their plasma membrane. There are two of these antigens designated antigen A and antigen B.

—Antigens A and B determine blood groups.

—Individuals whose RBCs have antigen A have blood group A. Those whose RBCs have antgen B have blood group B. Those whose RBCs have both antigens A and B have blood group AB. Those without antigens A and B ie zero antigen have blood group O.

—The plasma too has proteins called **antibodies** namely and designated as antibody 'a' or antibody 'b'. An individual who is blood group A (ie with antigen 'A') has antibodies 'b' in plasma;

An individual who is blood group B (ie with antigen 'B') has antibodies 'a' in plasma. An individual who is blood group AB (ie with both antigens 'A' and 'B' on RBCs) lacks antibodies 'a' and 'b' in plasma. An individual who is blood group 'O' (ie lacks antigen A and B on RBCs) has both antibodies 'a' and 'b' in plasma.

- If an antigen comes into contact with a corresponding antibody, an antigen-antibody reaction occurs causing clumping together of RBCs, a reaction known as **agglutination**. This can cause death due to blockage of capilleries.

Summary table

Blood group	Antigen on RBCs	Antibody in plasma
A	A	'b'
B	B	'a'
AB	A and B	None
O	None (Neither A or B)	Both 'a' and 'b'

Blood Transfusion

- Is the transfer of blood from a donor to the circulatory system of the recepient.
- A recepient can only recewe blood from a donor if they are compatible ie if the recepient's blood can not produce antibodies against the donor's blood to cause agglutination.
- Below is a summary table of the blood types and their reactions:-

RECEPIENT \ DONOR	A b	B a	AB	O ab
A b	✓	X	X	✓
B a	X	✓	X	✓
AB	✓	✓	✓	✓
O ab	X	X	X	✓

Key = Capital letter → Antigen on RBC.
= small letter → antibody in plasma
= The sign ✓ = Compatible (no agglutination)
= The sign X = Not Compatible (agglutination)

- From the table we note that:-

(a) Blood group AB is a universal recepient because the blood plasma lacks antibodies a and b in plasma hence does not agglutinate with any blood group.

(b) Blood group O is a universal donor because the blood group lacks antigens A and B on RBCs hence does not agglutinate with any other blood group.

- Healthy donors aged between 18-65 years are encouraged to donate blood to save lives. Half a litre of blood from such a donor is drained from a vein in the arm into a clean plastic container containing an **anti-coagulant**. The blood may then be kept in a blood bank at a temperature just above freezing point for a months if not immediately transfused. Beyond one month many RBCs would have died.
- After donating blood, the donors are given a drink to top up the blood volume

and advised to take a balanced diet there after.
- Before blood is transfused it has to be screened for pathogens such as HIV/AIDS and also to ensure compatibility between donor and recepient.

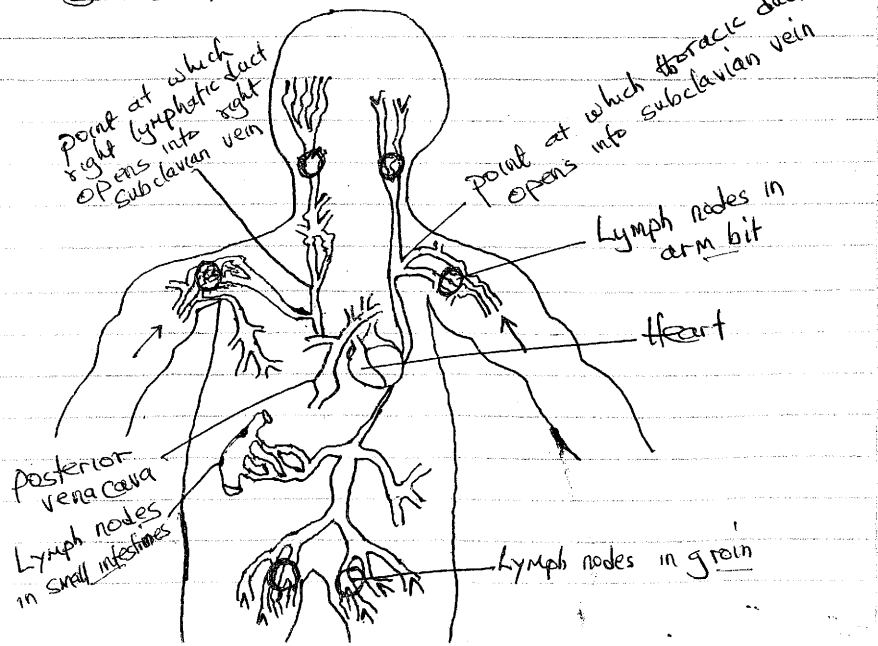
The Rhesus Antigens

- Other than A and B antigens, RBCs also have another antigen known as Rhesus factor or antigen D.
- People whose RBCs contain the Rhesus antigen are described as Rhesus positive (Rh+ve) whereas those who lack the antigen are described as Rhesus negative.
- If a Rh-ve person is transfused with Rh+ve blood, the former responds by producing rhesus antibodies and nothing further happens. But if the same is repeated in a period of less than two weeks, agglutination of RBCs occurs due to large scale production of rhesus antibodies and subsequent Ag-ab reaction.
- In a case where a Rh-ve mother bears a Rh+ve baby, fragments of RBCs from the foetus's blood cross the placenta into the mother's blood stream. The blood of the mother reacts by producing anti-rhesus antibodies. Hence an ag-ab reaction occurs on the RBCs of the foetus. In the first pregnancy the reaction is in small scale and does not affect the foetus. But in subsequent pregnancies

the primed mother's blood produces alot of the antibodies and the ag-ab reaction causes large scale agglutination of the foetus RBCs causing haemolytic disease of the Newborn/ Erythroblastosis foetalis which can lead to still births.
- The condition can be managed by transfusing the foetus with Rh-ve blood and/or treating the mother with anti-rhesus globulins which coats the surface of RBCs of the foetus preventing the antigen-antibody reactions.

Lymphatic System

- In vertebrates, besides the blood circulatory system, there is a lymphatic system consisting of lymph vessels (thin-walled tubes) which branch to lymph capillaries in which a fluid known as lymph flows.



Lymph is a fluid similar to blood plasma except it contains **less proteins**. It is formed as a result of ultrafiltration of blood from the narrow blood capillaries. The ultrafiltration is caused by the narrowness of the capillaries' lumens which increases resistance to blood flow and the pumping force of the heart. This forces the fluid part of blood out to the intercellular spaces forming tissue fluid or intercellular fluid
- Tissue fluid bathes tissues supplying them with oxygen, nutrients, water and other useful materials. Cells pass out metabolic wastes such as carbon (iv) oxide to the tissue fluid.
- NB - Tissue fluid lacks proteins and blood cells because they are too large to filter out through the capillary pores/wall.
- Most of the tissue fluid then returns into the blood system through the venule end of capillaries. This is due to the lower hydrostatic pressure of blood at the venule end compared to that of the arteriole end of capillary.
- The excess tissue fluid drains into lymph vessels where it forms **lymph**. (NB - The tissue fluid first drains to lacteals, then lymphatic capillaries and finally lymph vessel(s).
- Lymphatic system as swollen ends at armpits, groin, neck and intestines called lymph nodes / lymph glands.

- Lymph glands produce antibodies and lymphocytes.
- Lymph finally joins blood at the subclavian veins in the neck via the **right lymphatic duct** and **thoracic duct**.

Immune Responses

- **Immune responses** are reactions of the body as a result of introduction of antigens which involves production of antibodies or leucocytes to combine with them (antigens).
- An **antibody** is a chemical substance, usually protein, formed in blood when an antigen is introduced into a tissue of an animal.
- Antibodies have a chemical composition which is complimentary to the antigen against which it reacts. Hence a particular antibody combines with or responds to a particular antigen to make it harmless.
- Antibodies are produced by **Lymphocytes** when harmful organisms or proteins invade the body.
- Whenever a foreign protein or organism invades the body some lymphocytes begin to produce antibodies complimentary to them. At the same time the **bone marrow** and **thymus gland** begin to produce more polymorphs/phagocytes and lymphocytes respectively.
- The ability of an organism to identify foreign substances and develop mechanisms that remove or destroy foreign substances from the body is called **immunity**

Types of Immunity

- There are two types of immunity namely, Natural immunity and acquired immunity.

(a) Natural immunity / Inherited immunity

- Natural immunity is the type of immunity which is inherited from parent to offspring through genes; eg blacks are generally less susceptible to malaria than whites.

(b) Acquired immunity - Immunity developed after suffering from a disease or through vaccination.

- Acquired immunity may be classified into the following :-

1, Naturally acquired immunity - develops when an animal forms antibodies upon natural exposure to an antigen / disease causing micro-organism under natural conditions. This type is inborn and lasts for long. Naturally acquired immunity can be further classified into :-

• Acquired Natural active immunity

- produced in response to natural infection by a pathogen / disease causing organism.

• Acquired Natural passive immunity

- produced when antibodies are passed from mother to developing foetus via placenta or to baby through Colostrum. These antibodies protect the foetus / baby against diseases the mother has been exposed to or has been immunised against. It lasts as long as the antibodies are being supplied ie foetus / baby does is not

stimulated to produce own antibodies.

II, Artificially Acquired immunity

- Develops when an animal forms antibodies upon artificial contact with an antigen or receives antibodies artificially through vaccination. Can be divided into

• Artificial active immunity

- Develops when antibodies are formed in response to artificial administration of dead or weakened (attenuated) pathogens or chemically treated toxins (toxoids). These may or may not cause mild disease but stimulate production of antibodies which prevent the animal from infection by the normal pathogens. This is the basis of vaccination or immunization. Humans are vaccinated this way against diseases like poliomyelitis, Diphtheria tetanus among others.

• Artificial Passive immunity

- Develops when serum containing antibodies is transferred from one animal to another. The antibodies last for a few weeks since, like other proteins, they are continually destroyed in the body. Examples of such this type of immunity includes vaccines against rabies and tetanus. Antibodies against tetanus are made by injecting chemically treated toxin into a horse. The horse responds by making antibodies / anti-toxins against the toxin. Blood is then

withdrawn from the horse and antitoxin containing the serum is made. This is the antiserum which is administered to people with deep wounds to protect them from tetanus and also for treatment of tetanus.

In like manner anti-rabies antiserum is made by injecting horses with life attenuated (weakened virus. The resulting anti-serum is used in treating dog-bite victims. Anti-sera for snake bites are also made by injecting chemically treated snake venom into horses.

The Role of Vaccination

① Vaccination protects individuals from infections of many diseases such as smallpox, tuberculosis, poliomyelitis etc.

② Vaccination prevents spread of certain diseases. Through vaccination diseases such as smallpox have been eliminated (since 1977).

The table below shows the immunization schedule for children.

Name of disease	Causative Agent	Age for Administration	Method of Vaccination
Tuberculosis	Bacterium (Mycobacterium tuberculosis)	At birth	injection
Poliomyelitis (Polio)	poliomyelitis virus	At birth 6 weeks 10 weeks 14 weeks	Oral inoculation
Hepatitis B	Virus	14 weeks	injection
Haemophilus influenza type B (Hi B)	Haemophilus influenzae	14 weeks	"

Name of disease	causative agent	Age for Administration	Method of Vaccination
Diphtheria	Bacterium (Corynebacterium diphtheriae)	6 weeks 10 weeks 14 weeks	injection with vaccine
Whooping cough	Bacterium (Bordetella pertusis)	6 weeks 14 weeks	injection with vaccine
Measles	Measles virus	9 months	injection with weakened (attenuated) virus

- Vaccinations are done at regular intervals as shown above. Some Vaccinations / immunizations against certain diseases eg poliomyelitis require regular boosting.
- Apart from vaccinations, another method of preventing spread of diseases is through quarantine imposition.

NB ① A vaccine is a weakened or dead form of a disease causing micro-organism administered to prevent infections by stimulating an immune response.

② In recent years a vaccine has been developed which is a combined vaccine against five diseases - diphtheria, whooping cough, tetanus (DPT), hepatitis B (HB) and haemophilus influenza B (HiB) known as **Pentavalent vaccine** given to babies between 1½ months and 1 year.

③ People of different ages are also

vaccinated against cholera, yellow fever, typhoid hepatitis B, Meningitis (caused by Neisseria meningitidis), pneumonia (caused by streptococcus pneumoniae), tetanus among other diseases.

④ People travelling to other countries also are vaccinated against such diseases as yellow fever and cholera.

Allergic Reactions

- An **allergy** is a **hypersensitive reaction** to an antigen by the body. This occurs when the combination of antibody with an antigen produces a violent reaction or severe damage to the body.
- Allergic people are hypersensitive to materials like dust, pollen grains, some foods, some drugs eg penicillin, chloroquin, aspirin etc. These substances are called **allergens**.
- The allergy manifests itself in form of itching, body rashes, sneezing, vomiting and even difficulties in breathing.
- The allergic conditions are brought about by the body overproducing ~~too~~ antibodies to harmless antigens. The antigen-antibody reactions take place on surfaces of cells which burst open releasing chemical substance known as **histamines**. Histamines make epithelial cells permeable to fluids which take them up and swell. The fluids also flood intercellular spaces. This results in **inflammation** and **pain**.

- A severe condition called **anaphylaxis** sometimes occur in which blood vessels get dilated and permeable, to an extent of lowering blood pressure which may cause death. This is how bee sting can cause death. This is **anaphylactic shock**.
- Avoiding the allergens or administration of **anti-histamines** can control allergies.

Organ Transplants

- Involves the transfer of a tissue or organ from a donor to a recepient. The parts of organs so transplanted are known as **grafts**. The grafts can be obtained from other people or other animals eg pig. Organs or parts of organs or tissues that have been transplanted include kidneys, liver, spleen, reproductive organs, parts of skin and limbs.
- There are two types of grafts namely **homografts** (from members of same species) or **heterografts** (from a member of different species).
- The grafts "take" or are easily **accepted** between identical twins. In most cases grafts from a donor, other than in cases of identical twins, may fail to be accepted by the recepient's body because the immune system of the host recognises the graft as foreign and produces antibodies to destroy it. This is called **rejection**. The cells of one individual have specific protein receptors unique to that individual only.
- To overcome rejection drugs called

immunosuppressors eg interferon are administered to suppress the immune system and thus allow the graft to be accepted. But this may also pave way to opportunistic diseases. Some transplants however such as of cornea of eye, lungs, heart, kidneys and bone marrow have been successfully done using these immuno-suppressors.

- During organ transplant operations some sophisticated machines are used to keep the organs to be transplanted and the patient alive.

Other important notes in Immune Responses

① Depending on mechanism of action antibodies can be classified into :- Agglutinins ; Lysins ; Opsonins and anti-toxins.

② Primary mechanisms that prevent entry of micro-organisms into the body include :-

(i) Skin barriers - Cornified layer, sebaceous and sweat glands whose secretions have anti-microbial effects

(ii) Mucous secretions to remove inhaled microbes

(iii) Reflex actions - coughing, sneezing, vomiting

(iv) Lysozyme enzyme in saliva, tears and nasal secretions kill bacteria

(v) Gastric secretions with HCl to kill bacteria

(vi) Blood clotting

③ In acquired immunity (both artificial and natural acquired immunity) when the body comes into contact with the antigens, a group

of B lymphocytes called "committed" cells in the lymph nodes undergo cell division to produce large plasma cells. plasma cells synthesize antibodies which are released into the lymph and eventually reach blood. A small number of these plasma cells remain in the lymph nodes for years to respond rapidly to subsequent infections.

④ The first person to carry out vaccinations is Dr. Edward Jenner against smallpox (using pus from cowpox infections).

2. GASEOUS EXCHANGE.

Introduction

Gaseous exchange is the process by which respiratory gases (Carbon(IV) oxide and oxygen) are passed across respiratory surfaces along a concentration gradient.

Importance of Gaseous Exchange

1. Promotes intake of oxygen for respiration.
2. Enhances removal of Carbon (IV) oxide from tissues as a waste product of Metabolism.
3. Promotes intake of Carbon (IV) oxide for photosynthesis.

Gaseous Exchange in plants

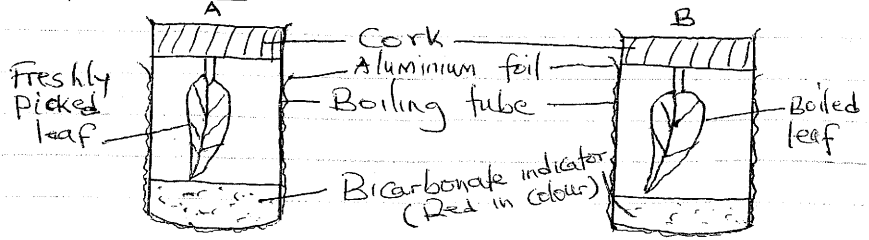
- Gaseous exchange takes place in the spongy mesophyll;
- During the day air diffuses into large air spaces in the spongy mesophyll; through the stomata.
- The carbon(IV) oxide in air diffuses into photosynthetic cells; in solution form;
- During photosynthesis Carbon(IV) oxide is used while oxygen is produced; some of the oxygen is used in respiration while the rest diffuses out of the leaf through the stomata since the rate of photosynthesis exceeds that of respiration.
- During the night air diffuses into the air spaces of the spongy mesophyll. The air dissolves into a film

of moisture; The oxygen in the air diffuses into cells; and is used in respiration. During respiration CO_2 is produced. The CO_2 diffuses out of the leaf through the stomata due to diffusion gradient; At night CO_2 accumulates in the leaf since photosynthesis does not take place.

- Some gaseous exchange also takes place through the cuticle. Gaseous exchange occurs through the epidermis of young leaves and stems. Epidermis of the root carries out gaseous exchange with air in the soil.
- Some plants have breathing roots through which gaseous exchange occurs called pneumatophores.
- Gaseous exchange also occurs through Lenticels found on older stems. The cork cells at a lenticel are loosely packed and gaseous exchange takes place between cork and the atmosphere within the loosely packed cells with moist surfaces;

Practical Activity 1: To investigate Release of Carbon (IV) oxide by plants

Procedure



The set up is left to stand for one hour.

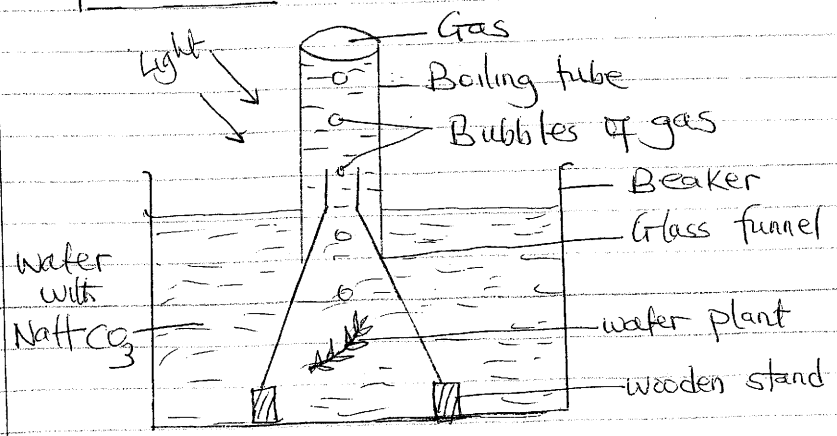
Results - The bicarbonate indicater changed from red to orange/yellow in A. No colour change in B.

Accounting for the Results

- Respiration takes place in the leaf in A producing Carbon(IV) oxide which reacts with the indicator turning it to orange/yellow.
- The aluminium foil prevents penetration of light into the boiling tubes to prevent photosynthesis from taking place in the leaf so as to utilize CO_2 produced during respiration.
- In set up B, there is no colour change since the leaf was boiled killing the protoplasm and deaturing enzymes. This was a control experiment.

Practical Activity 2:- To investigate the Release of Oxygen by plants

Procedure



- The set up is left in the sunlight for 2-3 hours

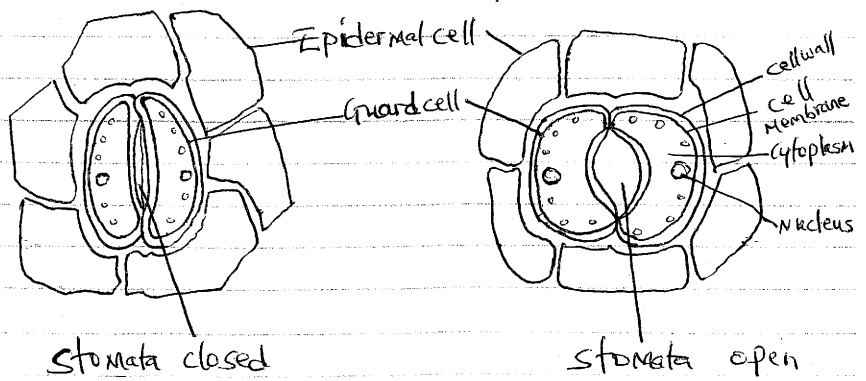
Results

- Bubbles of a gas are formed which collect on the upper part of the inverted testtube.

Accounting for Results

- The aquatic/water plant carries out photosynthesis utilizing dissolved CO_2 from $NaHCO_3$ and water in the presence of sunlight and produced starch/carbohydrates/glucose and oxygen as a by-product. Oxygen is evolved as bubbles of the gas which collects above the water. If the gas is tested with a glowing splint, the splint is rekindled/re-lit.

Structure and function of Stomata



- stomata are tiny openings on the leaf surface bordered by sausage/bean-shaped cells called guard cells. Guard cells are the only green cells in the epidermis since they have chloroplasts. The inner sides of

guard cells are not attached to the adjacent epidermal cells. Stomata are frequently more on the lower leaf surface compared to upper leaf surface, to be hidden from direct sunlight to reduce rate of transpiration.

- The functions of stomata include;-
  i, Gaseous exchange
  ii, Transpiration
- Guard cells control opening and closing of stomata and are adapted to their functions by:-
  i, Having chloroplasts for photosynthesis
  ii, Having differentially thicker inner cells and thinner outer cellwalls to control opening and closing of stomata.

Mechanism of opening and closing of stomata

- Explained by three theories

① The photosynthetic Theory

Opening

- Guard cells have chloroplasts.
- Hence in the presence of light, photosynthesis occurs in the guardcells of stomata, producing sugar in guardcells; Osmotic pressure increases / osmotic potential decreases in guard cells. Hence water from neighbouring epidermal cells enter the guardcells by osmosis causing turgidity.

The inner walls of guardcells are thicker than the outer walls, so during turgidity the inner walls stretch more causing guardcells to bulge outwards hence stomata opens.

closing

- In the absence of light, no photosynthesis occurs in guardcells. Sugar in guardcells is converted into starch. Osmotic pressure in guard cells lowers / osmotic potential increases and guardcells therefore loose water by osmosis to the neighbouring epidermal cells and become flaccid. The thinner outer walls of guardcells shrink more and thicker inner cellwalls reduce curvature hence stomata closes.

② Starch-sugar interconversion / pH Theory

Opening

- Guardcells have chloroplasts. Hence in the presence of light photosynthesis occurs in the guard cells of the leaves. This lowers the carbon(IV) oxide concentration hence reducing acidity / increasing pH in the guard cells. The increased pH triggers off enzymatic conversion of starch to glucose / sugar; by enzyme **starch phosphorylase**. This leads to high osmotic pressure / low osmotic potential in guardcells. Guard cells thus draw water by osmosis from neighbouring epidermal cells, becoming turgid. The inner cellwalls of guardcells are thicker than the outer cellwalls. Hence during turgidity, the

outer walls stretch out more causing the stomata to bulge outwards and stomata opens.

Closing

- In the absence of light/at night, no photosynthesis occurs in the guardcells. Therefore CO_2 concentration increases due to respiration. Hence the pH is lowered / acidity increases in the guardcells. This leads to enzymatic conversion of glucose to starch. Osmotic pressure thus decreases / osmotic potential increases causing guardcells to loose water to the neighbouring epidermal cells by osmosis; becoming flaccid. The thinner outer walls of guard cells shrink and the thicker inner walls loose curvature and the stomata close.

(3) Mineral ion Concentration Theory

Opening

- Guard cells have chloroplasts. Hence in the presence of light ATP is produced. The energy drives potassium, K^+ ions from the adjacent epidermal cells into guardcells. The accumulation of K^+ ions raises osmotic pressure of guardcells. Guardcells thus draw water from neighbouring epidermal cells by osmosis becoming turgid. The inner cellwalls of guard cells are thicker than the outer walls. Hence outer walls stretch more causing guardcells to bulge outwards

and stomata open.

Closing

- In the absence of light, ATP rapidly decreases. Hence there is no energy for the potassium ion pump.
- The K^+ ions thus migrate by diffusion from guardcells to the adjacent epidermal cells, lowering osmotic pressure / increasing osmotic potential in the guard cells. Guardcells hence loose water by osmosis to the neighbouring epidermal cells and become flaccid. The thinner outer walls shrink more and the inner thicker walls loose curvature and stomata close.

Stomata and Habitats of plants

(a) Arid plants - xerophytes.

- These plants grow in dry places hence they have; i, few stomata / reduced number of stomata
  ii, sunken stomata into epidermis to saturate moisture in the substomatal spaces to reduce diffusion gradient
  iii, reversed stomatal rythm and mid-day closure of stomata
  iv, stomatal aperture/opening is small
  v, hairs covering stomatal pores which trap escaping water vapour to reduce rate of transpiration.

(b) Aquatic / fresh water plants - Hydrophytes.

- Plants which grow in fresh water areas

-Submerged hydrophytes have :-

i, numerous stomata on the upper leaf surface only to facilitate gaseous exchange and allow loss of excess water by transpiration.

ii, The stomata are large in size - to encourage loss of excess water and also facilitate transpiration.

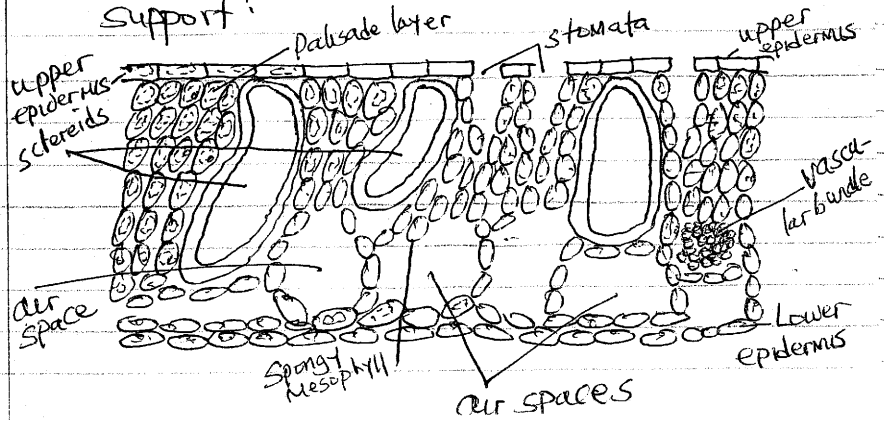
iii, The stomata are more exposed on the epidermis for gaseous exchange.

iv, aerenchyma tissue which store air for gaseous exchange and for buoyancy. The aerenchyma tissue are thin-walled and have large air spaces between them/ in the spongy mesophyll to allow maximum circulation of air.

v, Cuticle is absent to encourage loss of excess water by transpiration.

vi, sclereids are present which also contribute to buoyancy

vii, Vascular bundles are poorly developed ie xylem because the plants obtain water by diffusion and water provides support.

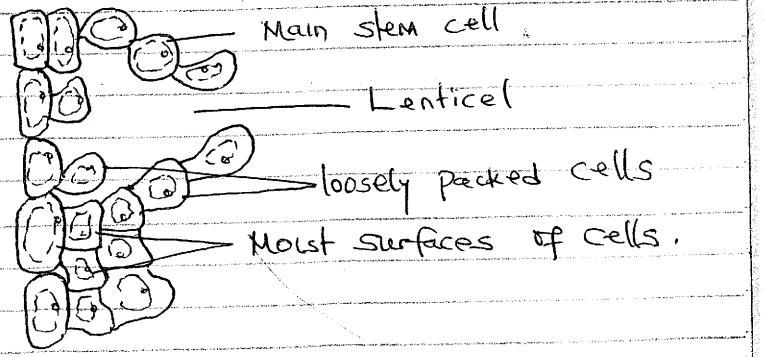


(c) Mesophytes

- Are plants which grow in forests or grasslands with ordinary wet soils.
- stomata are fairly numerous/many on both sides of the leaf but upper surface has less compared to the lower surface of the leaf.

Structure & function of Lenticel

- Lenticels are openings on woody stems formed due to loosely packed cork cells. They allow gaseous exchange between the interior of the plant and the outside by diffusion. The actual gaseous exchange occurs in the moist surfaces of cells under lenticels.
- In halophytes which grow in muddy salty areas eg Mangroves, lenticels are found in specialised breathing roots called Pneumatophores.



GASEOUS EXCHANGE IN ANIMALS

-Depending on the size of the animal, the type of the animal and the activity and the environment in which the animal operates the following are the respiratory surfaces in animals :-

Type of Respiratory surface	Environment or Medium of operation	Examples of organisms
i, cell membrane	Water	Amoeba
ii, Gill filaments	Water	Fish
iii, Tracheoles	Air	Insects
iv, Alveoli / lungs	Air	-Mammals -Birds -Amphibians -Reptiles
v, Skin	-Water -Air	-Frog -Earthworm
vi, Buccal Cavity	-Air	-Frog -Toad

Characteristics of Respiratory Surfaces

i, have large surface area ; for maximum and efficient diffusion of gases / gaseous exchange

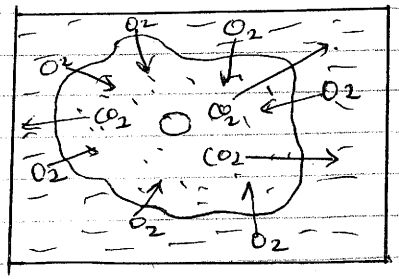
ii, Moist surface to dissolve the respiratory gases.

iii, Thin walls / thin epithelium / Are thin for faster diffusion of gases by reducing diffusing distance

iv, Highly vascularised / have numerous blood capillaries to facilitate / maintain / increase / enhance diffusion gradient for the respiratory gases.

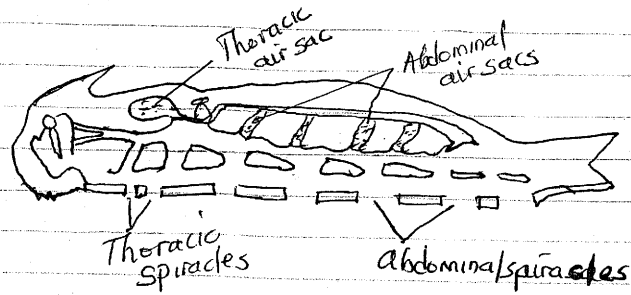
Gaseous Exchange in protozoa eg Amoeba

- The unicellular organisms like protozoans (belonging to kingdom protoctista) live in aquatic medium.
- Gaseous exchange occurs across the cell membrane by diffusion because they have a large surface area to volume ratio hence a large surface area is exposed to the environment.
- oxygen diffuses from the surrounding aquatic medium along a concentration gradient across the cell membrane into the cytoplasm where it is used in respiration in the mitochondria. Carbon (IV) oxide liberated also diffuses out through the cell membrane into the water medium.
- other unicellular organisms such as the paramecium, plasmodium, bacteria also undergo gaseous exchange in the same way.

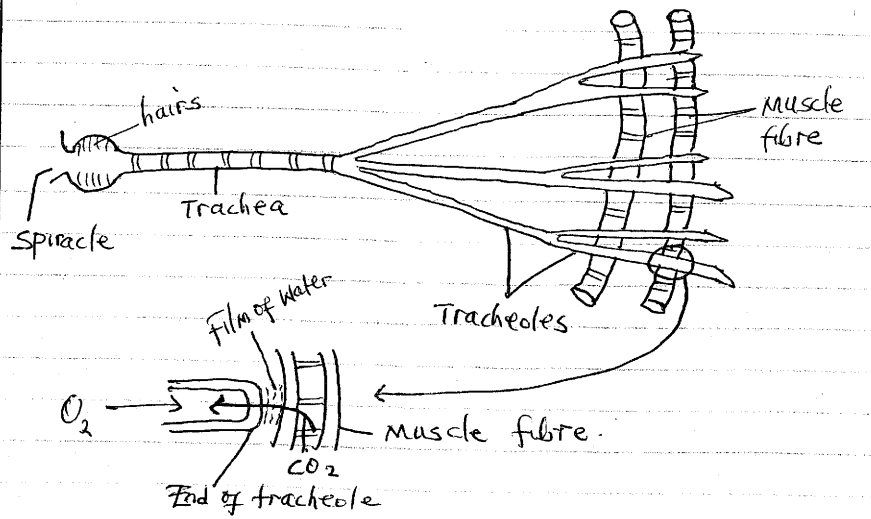


Gaseous Exchange in Insects eg Grasshoppers

- Insects use the tracheal system for gaseous exchange.
- The tracheal system consists of i, spiracles ii, trachea iii, tracheoles. as shown below :-



- The trachea opens externally by spiracles. Each spiracle is surrounded by a Muscular valve and hairs. The Muscular valves control opening/closing of the spiracle and the hairs prevent water loss.
- The spiracles open into tubes called tracheae which are kept open by chitinous rings.
- Trachea subdivides into tracheoles. The tracheoles are not reinforced by chitinous rings. They are moist, thin-walled and have a large surface area for gaseous exchange, because they are branched and numerous;

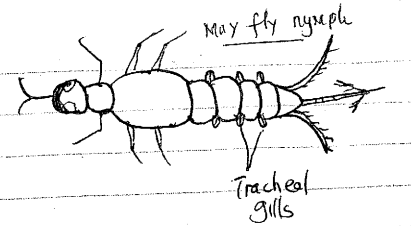


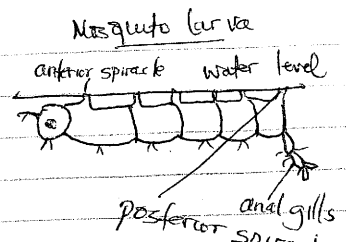
Mechanism of gaseous Exchange in insects

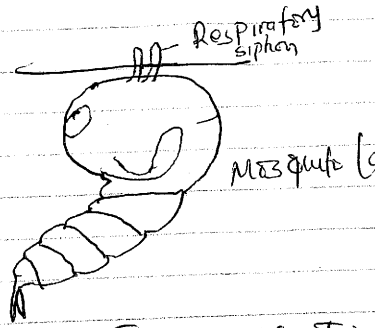
- Muscular movements of the segments open the spiracles.
- Oxygen from the atmosphere diffuses through the spiracles to the trachea, then to the tracheoles and finally to muscle tissues across the thin-walled moist tracheoles along a concentration gradient.
- Carbon (IV) oxide produced from tissues during respiration diffuses out from the tissues, to tracheoles, to trachea and finally out to the atmosphere through spiracles. The film of water dissolves the respiratory gases. The tracheoles are thin for faster diffusion of the gases.
- In most insects oxygen diffuses into the tracheal system through thoracic segments and CO_2 diffuses out through abdominal segments when the thoracic segments close.

Modifications of the tracheal system in some insects.

i) As tracheal gills eg in dragonfly and mayfly
ii) As respiratory siphons as in mosquito larvae and pupa.
iii) As anal gills eg mosquito larvae. The larvae occasionally come to the surface for air replenishment.
iv) Some use plastrons/hairs to trap air as air bubbles in water eg water beetles.



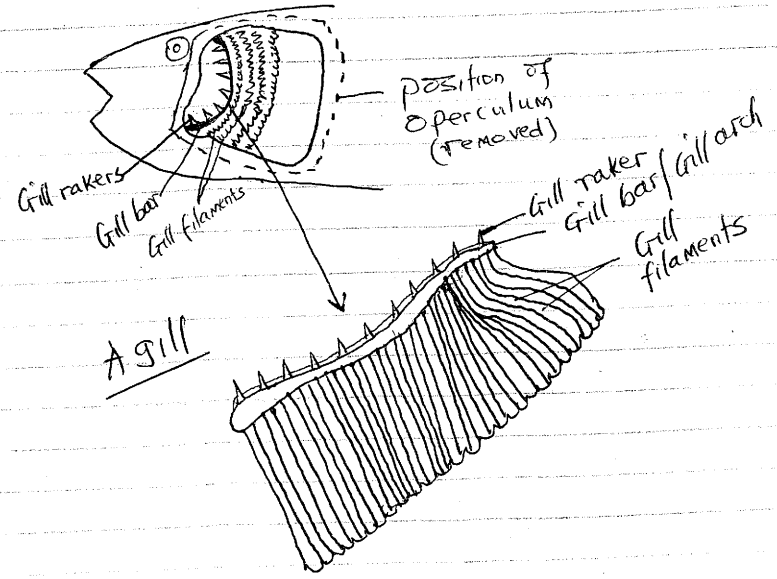




Mosquito larva.

Gaseous Exchange in fish eg Tilapia

- Fish use gill filaments for gaseous exchange.
- The breathing System of fish consists of Buccal Cavity, gills, opercular cavity (covered with operculum), and operculum.



A gill

Adaptations of a gill to its functions.

- Has a rigid, curved and long gill bar / gill arch to support the gill filaments and gill rakers
- Has projected / pointed gill rakers or rake-like gill rakers which trap solids excluding them from damaging the delicate gill filaments.
- The gill filaments are numerous / many to increase surface area for gaseous exchange.
- The gill filaments are thin for faster diffusion of the respiratory gases by reducing diffusing distance.
- The gill filaments are long to increase surface area for gaseous exchange.
- The gill filaments are highly vascularised / supplied with numerous capillaries / blood vessels to enhance diffusion gradient for the respiratory gases.

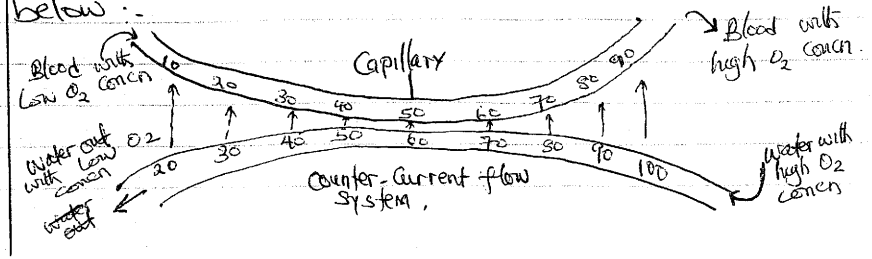
NB ① Gills trail in water and open up to increase surface area for gaseous exchange. When removed from water, they clump together hence reducing surface area for gaseous exchange and fish therefore dies.

② Operculum is a bony plate which protects gill filaments and also participates in gaseous exchange.

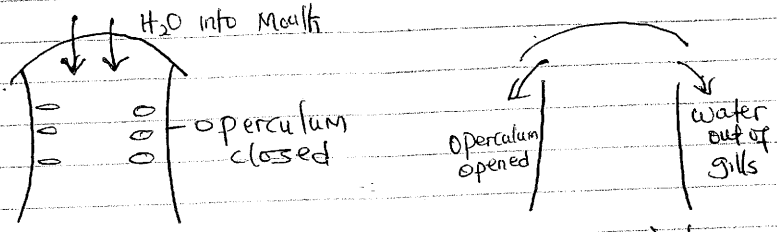
Mechanism of Gaseous Exchange in fish.

- During inhalation, the floor of the mouth is lowered by muscular contraction, thus increasing the volume of the mouth / buccal cavity and reducing the pressure;

as the mouth opens. Hence water containing dissolved oxygen flows into the mouth.
- As this is happening, higher external pressure of water pushes the free edge of the operculum against the mouth hence ensuring water enters in only through the mouth.
- The mouth is then closed by raising the floor of the mouth by relaxation of the muscles. This forces the water in the mouth into the gill cavity. This is because operculum opens, volume in opercular cavity increases and pressure decreases. Water then flows over the gill lamellae / filaments.
- Oxygen being in higher concentration diffuses across the thin walls of the gill filaments into blood capillaries where the oxygen is picked by haemoglobin on the RBCs and transported to body tissues.
- Carbon (IV) oxide from tissues diffuses into the flowing water and then to the outside.
- To enhance faster diffusion of the respiratory gases, water flowing over the gills and blood flowing in the gill capillaries flow in opposite directions to maintain a steeper concentration gradient as shown below:-



- Therefore as water flows out it has less oxygen and more CO_2 whereas blood from the gill capillaries has more O_2 and less CO_2.



Gaseous Exchange in Amphibians

- Amphibians live both in water and on land.
- Gaseous exchange structures include
  i) Lining of buccal cavity / Mouth
  ii) Lungs
  iii) Skin

Lining of buccal cavity / Mouth

- Air is taken in and out by raising or lowering of the floor of the mouth due to contraction and relaxation of muscles respectively.
- Oxygen being in higher concentration dissolves in the moist lining of buccal cavity and diffuses along a concentration gradient across the thin lining of the buccal cavity into the capillaries. Oxygen is then carried by haemoglobin on RBCs to tissues. CO_2 from tissues diffuses out in the reverse direction. The lining of buccal cavity is highly vascularised.

The Lungs

- The pumping action of the mouth forces air into the lungs. Oxygen dissolves in the moist lining of alveoli which are also highly vascularised, and diffuses into capillaries

where it combines with haemoglobin on RBCs and transported to tissues. CO_2 diffuses out into the alveoli and is exhaled.

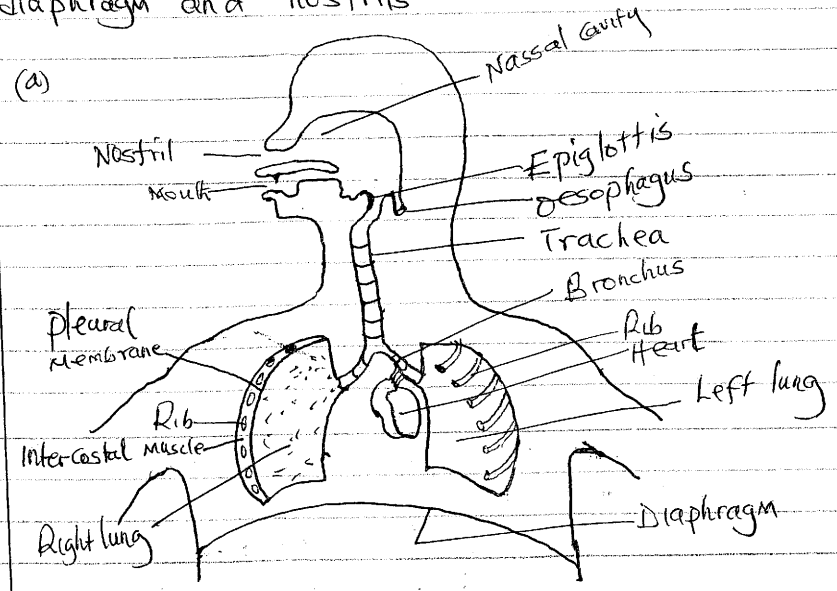
The Skin

- Oxygen from the atmosphere diffuses through the moist skin into blood stream in the capillaries. CO_2 diffuses out from blood. The skin is thin and highly vascularised.

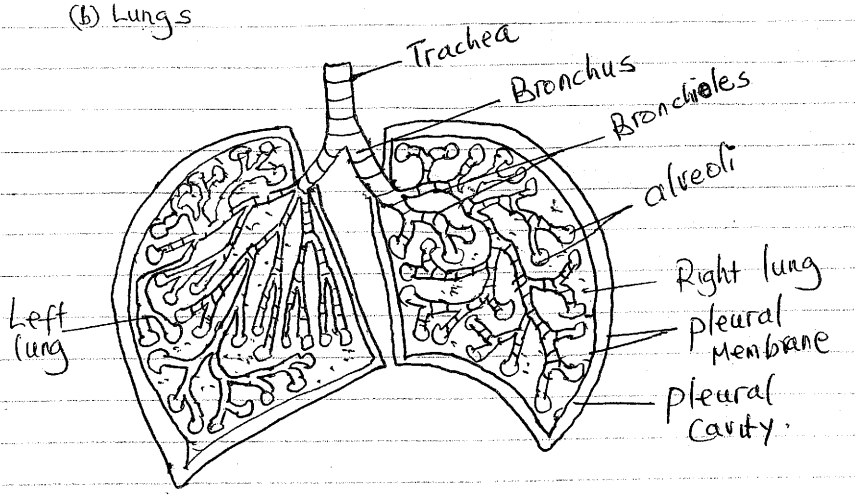
Gaseous Exchange in Mammals eg Human beings.

- Breathing system in mammals consists of the following structures :- Lungs, trachea, chest cavity made of ribs and intercostal muscles, diaphragm and nostrils.

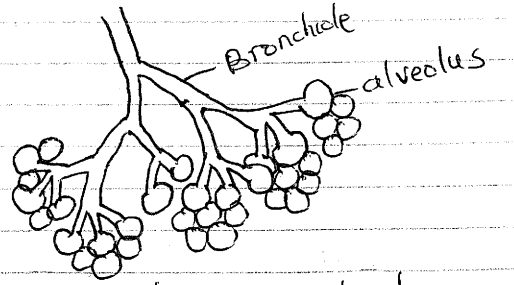
(a)



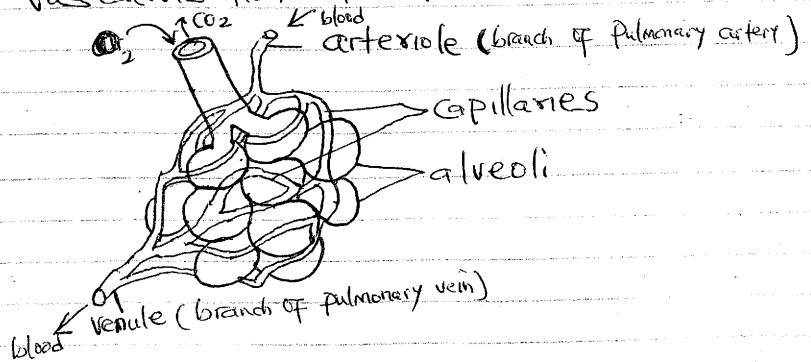
(b) Lungs



(c) Alveoli



(c) vascularisation at alveolus



Nose

- The nose has two openings called nostrils which let in air into the air passages. As air moves in the passages it is warmed and moistened. The nasal lining has chemoreceptor cells sensitive to smell; for survival.

The Larynx

- Also called the voicebox. Located above the trachea. Its muscle fibres and vocal chords control the pitch of the voice.

Trachea.

- Is a tube made up of rings of cartilage which keep it open and prevent it from collapsing during breathing.
- The lumens of trachea are lined with ciliated epithelium which beat in waves and move mucus and foreign particles towards pharynx away from lungs.
- Trachea divides into two bronchi (sing. bronchus) as it enters the lungs.

Lungs

- Lungs are located in chest cavity. They are enclosed in a double membrane called pleural membrane. One part of the membrane adheres tightly to lungs and another covers the inside of the thoracic cavity. The spaces between the membranes are called pleural cavity. The cavity is filled with pleural fluid which reduces friction as lungs move in the chest cavity; during breathing.
- Within lungs, each bronchus divides into small tubes called bronchioles (for passage of air into alveoli). The bronchioles terminate in groups of tiny air-sacs called

alveoli (sing. alveolus). This makes the lungs spongy. The alveoli are covered by a fine network of of capillaries to enhance diffusion gradient. The inner lining of alveoli is moist to dissolve respiratory gases. The spongy nature of the lungs gives them a large surface area for maximum gaseous exchange. The walls of the alveoli are also thin / made of thin epithelium for faster diffusion of the respiratory gases by reducing diffusing distance.

The Mechanism of Breathing

- Involves two processes, inhalation / inspiration and exhalation / expiration.

Inspiration / inhalation

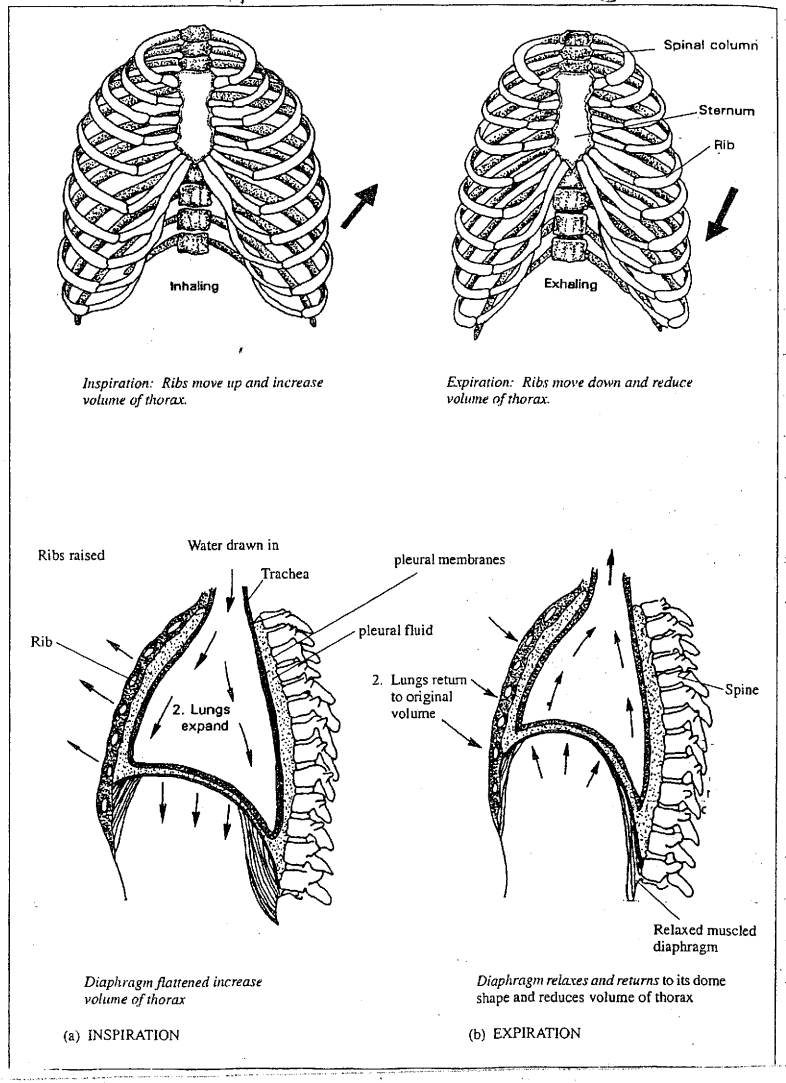
- During inhalation / inspiration :-
- External intercostal muscles contract; internal intercostal muscles relax, hence the rib-cage is pulled upward and outwards. The diaphragm which is normally dome-shaped flattens due to contraction of its muscles; hence the volume of the chest cavity increases while pressure decreases. As a result higher atmospheric pressure forces air through the nostrils, trachea, bronchi, bronchioles and finally alveoli thus inflating the lungs.

Expiration / Exhalation

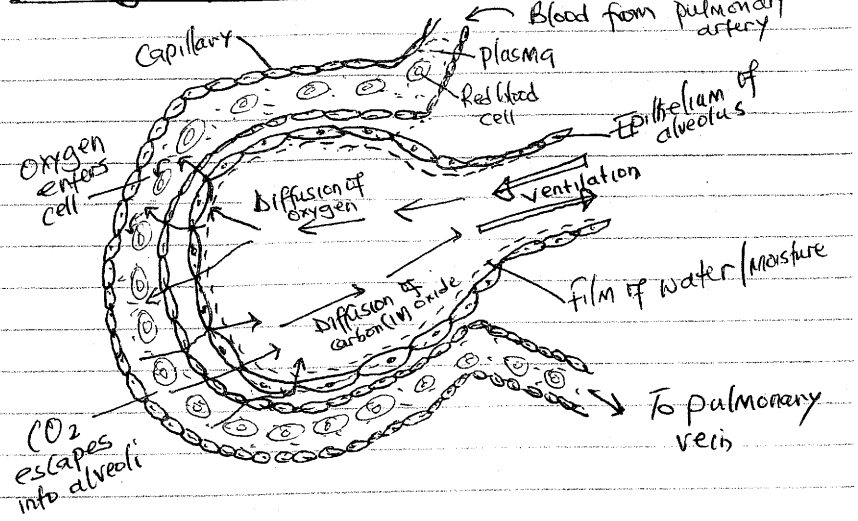
- During expiration / exhalation :-
- External intercostal muscles relax; internal intercostal muscles contract; hence the ribcage is pulled downwards and inwards; The diaphragm muscles relax and the diaphragm becomes dome-shaped. Hence the volume of the chest cavity decreases while the pressure

increases. As a result air is forced out of the lungs to the atmosphere ie from the alveoli, to bronchioles to bronchi, to trachea and out through nostrils.

Movement of ribs during breathing



Exchange of Gases in the Alveolus



- Oxygen from the atmosphere, where it is in high concentration, enters alveolus and dissolves in the film of water/moisture (which makes alveolus moist); and diffuses through the thin epithelium of alveolus into plasma in blood capillary. The epithelium is thin for faster diffusion. From plasma oxygen diffuses into the RBCs where it combines with haemoglobin and transported to tissues.
- Carbon(IV) oxide in the capillaries and water vapour diffuse from the blood in capillaries into the alveoli along a concentration gradient from where it is exhaled.
- Below is a table showing the composition by percentage of exhaled and inhaled air

GAS	% IN INHALED AIR	% IN EXHALED AIR
OXYGEN	20.0	16.9
CARBON(IV) OXIDE	0.03	0.4
NITROGEN & OTHER GASES	79.97	79.97

Factors Affecting Breathing Rate in Human beings

① Exercise – During vigorous exercise the rate of breathing increases to supply more oxygen to meet the demand and also remove the extra CO_2 produced during respiration.

② Age – Young people breath faster than the old because they have a higher demand for O_2.

③ Emotions – When emotions are high, production of adrenaline hormone increases general metabolism and demand for oxygen, hence breathing rate increases.

④ Temperature – In high temperature, breathing rate increases. But in too high temperature the rate reduces.

⑤ Health – In cases of fever, there is increased metabolism hence high breathing rate. Some diseases make breathing to be difficult.

Lung Volumes.

① Lung capacity – Is the volume of air lungs can hold when completely filled. About $5500cm^3$.

② Tidal volume – Volume of air taken in and out of lungs. About $500\,cm^3$.

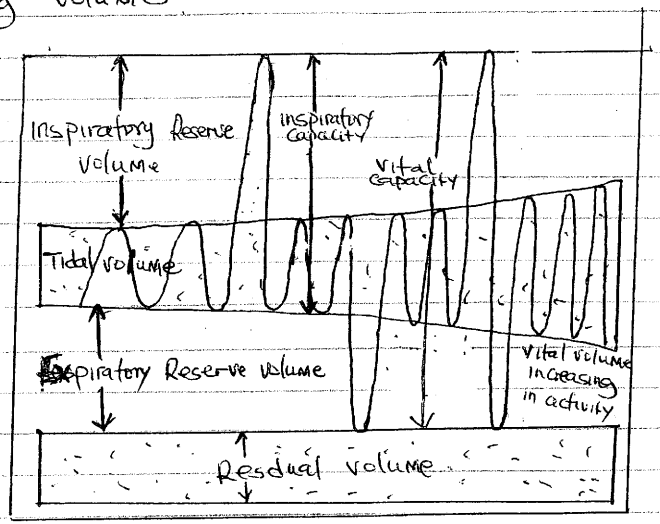
③ Inspiratory Reserve volume – Additional volume of air forcefully inhaled on top of the tidal volume. Maximum of $2000\,cm^3$.

④ Inspiratory Capacity – Is the tidal volume plus inspiratory Reserve volume.

⑤ Expiratory Reserve Volume – Extra volume of air forcefully exhaled after normal exhalation, up to $1300cm^3$.

⑥ Vital Capacity – The volume of air due to the deepest exhalation.

⑦ Residual volume – Volume of air remaining in the lungs even after the deepest exhalation. Up to $1500\,cm^3$. The figure below illustrates lung volumes.



Regulation of Breathing

– Breathing is controlled by the Medulla Oblongata of the brain. As CO_2 reaches the region in blood, the Medulla Oblangata sends impulses to the intercostal muscles and diaphragm to contract and relax to expel CO_2 and take O_2 hence breathing continues unconsciously.

– During vigorous activity more CO_2 is produced from tissues stimulating Medulla oblangata to trigger increased breathing rate to expel CO_2 and meet the increased demand for tissue respiration.

Diseases Of The Respiratory system

① Asthma

- A common respiratory disease caused by :-
  - i, Allergens eg pollen grains, smoke, dust, animal fur, scents from certain drugs, foods and flowers
  - ii, Lung or bronchial infections by bacteria or viruses.
- The attack by asthma is more severe when it is cloudy or chilly. Upon exposure to the causative agent the patient develops breathing difficulties caused by muscular contractions of air channels. The patient produces a characteristic "wheezing" sound accompanied by the feeling of suffocation.

Treatment & Control

i, spraying muscle relaxants directly on the bronchial tubes
ii, Injection of drugs or oral administration of pills prescribed by doctors
iii, Avoiding causative agents.

② Bronchitis

- This is an inflammation of the bronchial tubes. There are two types of bronchitis :-

(a) Acute bronchitis

- widespread in children and frail adults.
- Caused by :-
  - i, Complication of common cold when one is exposed to low temperature especially in high altitudes. The body chills giving way to bacterial infections.
  - ii, A Complication from previous disease

attack eg measles, dengue, whooping cough and influenza.

- Symptoms include :- headache, mild fever and coughing accompanied by uncomfortable feelings behind the sternum. The illness may clear or persist for several months.

(b) chronic bronchitis

- Develops after repeated several attacks of acute bronchitis. It is a fatal condition which makes the sufferer unable to walk or work.
- Symptoms include
  - i, production of phlegm (thick sputum) that is greenish yellow due to pus from respiratory tracts.
  - ii, Difficulties in breathing, walking or sleeping requiring being propped in bed.

Treatment & control

- Seek medical assistance in early stages of infection.

③ Whooping Cough

- Caused by a bacterium Bordetella pertussis

The disease is endemic in Kenya.

- Symptoms include :-
  - i, prolonged coughing and vomiting
  - ii, conjuctival haemorrhage accompanied by peri-orbital oedema.
  - iii, severe bronchopneumonia.
  - iv, convulsions and coma.
  - v, Ulcers and cardiac failure or complications.
  - vi, Malnutrition signs for proteins and energy foods due to repeated vomiting.

Treatment

i, Complicated cases to be hospitalised

and treated with appropriate antibiotics.
ii, Patients to feed on balanced diet.
NB - children to be immunised at an early age.

④ Pneumonia

- Inflammation of lungs due to infection by micro organisms. There are several types of pneumonia caused by different micro organisms. Common ones include
(a) Lobar pneumonia caused by streptococcus pneumoniae
(b) Bronchopneumonia caused by multiple bacteria such as Mycoplasma pneumonia

Symptoms

i, coughing ii, fevers iii, chest pains iv, deposits of fluids in lungs.
- The infection proceeds to throat to other parts of the body completely weakening the patient.

Treatment

- Use of antibiotics such as penicillin and sulphonamides.

Control

i, Avoid overcrowded places
ii, provide good ventilation in living premises

⑤ Pulmonary Tuberculosis

- A respiratory disease caused by bacterium Mycobacterium tuberculosis. It is airborne but occasionally it is spread in infected cow's milk or other fluids taken as meal.

- Symptoms

i, General weight loss
ii, Coughing, sometimes with sputum containing blood.
iii, Slight afternoon fever.
- The bacteria destroy lung tissues causing breathing difficulties and death.

Treatment

- Using prescribed antibiotics especially streptomycins.

Control

i, Detection of the disease in its early stage by radiographical method.
ii, Pasteurisation of milk
iii, Vaccination of the population using BCG (Bacille Calmette Guerin).

⑥ Lung Cancer

- Cancer is an uncontrolled cell growth in the body resulting into tissue tumour or enlargement. The tumour can be benign (which affects cells at a single point) or Malignant (when affected parts break away and spread to other parts of the body).
- There are no specific causes of lung cancer but it may result from:-
i, smoking cigarettes. The tar in cigarette smoke contains carcinogenic (cancer-causing) substances.
ii, Inhalation of carcinogenic substances such as asbestos dusts
iii, Exposure to radiations (x-rays, gamma rays, cosmic rays); radioactive

substances eg uranium and substances that alter genetic composition (Mutagens) eg Mastard gas, sulphur(IV) oxide used as a food preservative.
— Lung cancer destroys lung cells and tissues resulting in death.

Treatment

(i) Surgery to remove tumour
(ii) Radiotherapy to destroy cancerous cells
(iii) Chemotherapy to relieve the patient of pain and destroy cancer cells
(iv) Combination of several drugs to treat the patient
(v) Avoid smoking (both active & passive)
(vi) Avoid using SO_2 as food preservative.

⑦ Influenza

— Caused by a virus, Haemophilus influenzae
— Mode of transmission - carborne through droplet infection.
— Symptoms include :- headaches, chills, fever, sore throat, sneezing, running nose, muscular aches, abdominal pains, nausea and vomiting.
— Treatment :- Use of antibiotics and antihistamines
— Control - Avoid overcrowded places.

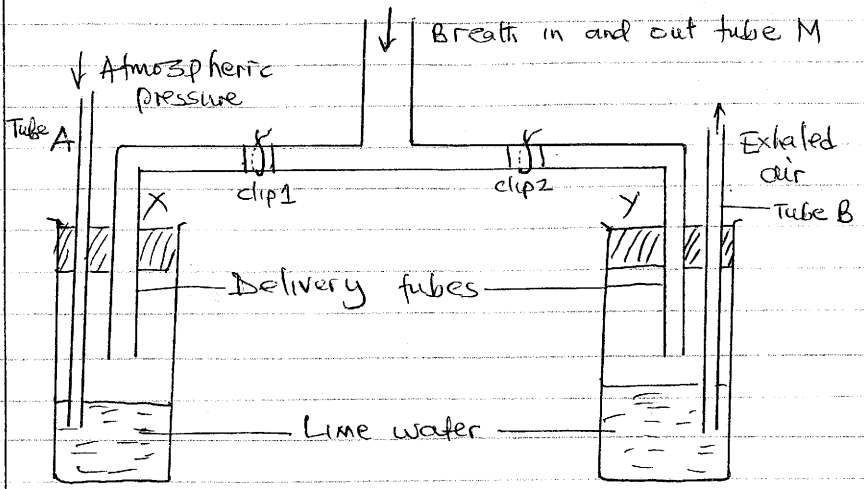
⑧ Emphysema

— Distention of alveolus leading to loss of elasticity causing prolonged and difficult breathing.
— Caused by bacterial infection of lungs.
— Symptoms include :- breathing difficulties,

wheezing sound when breathing, Severe Cough.
Treatment — Use of antibiotics.

Other Practical Activities

1. A set up as one shown below was used by students to investigate an aspect of gaseous exchange



(a) What was the aim of the experiment?
— To compare the amount of CO_2 in exhaled and inhaled air
(b) What observations were made in test tubes X and Y when the student :-
(i) Slowly breathes through the mouth into the mouth piece several times while blocking tube A / pressing clip 1 ?
— Many gas bubbles are produced ; and a white precipitate forms in the lime water in test tube Y.
(ii) Slowly breathes in through the mouth by sucking in from test tube X and Y while blocking tube B / closing clip 2 ?
— Few bubbles are produced and the

lime water remains clear / white suspension is not formed / A small amount of white precipitate.

(c) Account for the observations made in (b)(i) and (ii) above.

— Exhaled air contains more CO_2 which reacts with lime water forming a white suspension. Atmospheric air contains less CO_2 which is not enough to react with lime water to form much suspension / white precipitate

(d) State the purpose of clips 1 and 2 in this experiment.

— clip 1 - closed to prevent exhaled air reaching lime water in tube X

— clip 2 - closed to prevent lime water from being sucked into the mouth and opened to allow exhaled air to bubble through lime water.

(e) What is the significance of the aspect being investigated in this experiment to mammals?

— Allows CO_2 to diffuse from the body and oxygen to diffuse into the body / Gaseous exchange.

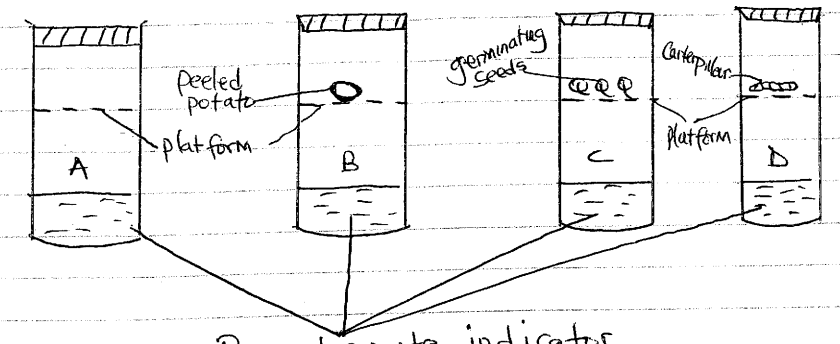
(f) State two advantages of breathing through the nose than breathing through the mouth.

— The nose has hairs to filter solids/particles in air/mucus lining to trap dust particles

— The nose has cells sensitive to smell for survival of man.

— The nose warms the air before reaching lungs.

2. The diagram below is an experimental set up to investigate gaseous exchange in living organisms. After every 10 minutes each test tube was gently shaken.



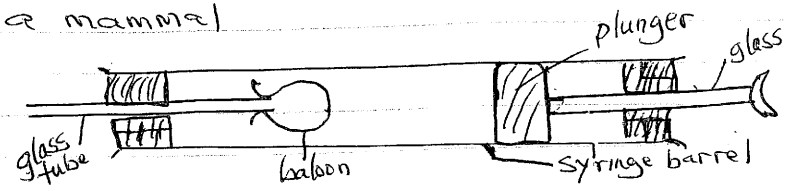
(a) Name the tubes in which there would be a change in the indicator.

— C and D

(b) Suggest the test-tube in which the indicator would change fastest. Give reasons.

— D; The caterpiller is an animal and is in the active phase of growth and development hence has a higher rate of respiration than the germinating seeds which are plants and which respire at a slower rate. Hence gaseous exchange and CO_2 production is faster in D.

3. The apparatus below can be used to demonstrate the mechanism of breathing in a mammal



(a) What structures in a mammal are represented by the following structures?

(i) Rubber baloon – lungs

(ii) Syringe barrel – Ribcage

(iii) plunger – Diaphragm.

(b) If the plunger is pulled away from the baloon, what will happen to the rubber baloon?

– Expands / inflates ;

7. Samples of atmospheric and exhaled air were analysed by 4 groups of students for oxygen and carbon(IV) oxide. The following are results expressed in volumes per thousand.

(i) Amount of O_2 in the atmosphere – 200

(ii) " " " " exhaled air – 160

(iii) " " CO_2 " atmosphere – 300

(iv) " " " " exhaled air – 410

Explain the difference in volume in each gas between the atmosphere and exhaled air.

– There is more O_2 in the atmospheric air than exhaled air because some O_2 ($10cm^3$) was used in the body tissues during respiration.

– There is more CO_2 in exhaled air than atmospheric air per volume because during tissue respiration more CO_2 is produced which is added to the exhaled air.

8. A student divided a small airtight box into 2 chambers with a wire mesh. In one chamber he kept a number of rats and in the other chamber a number of potted plants. What was likely to happen if the box was placed in the dark for two hours? Explain your answer.

– In the dark, plants carry out respiration and in the absence of photosynthesis CO_2 accumulates. Oxygen is thus used up and CO_2 given as a waste product in both the plants and the rats. The rats suffocate and die due to lack of oxygen.

9. In an expt. the rate of gaseous exchange was determined and recorded as shown in the table below. Suggest which plant gaseous exchange structures were responsible for the figures observed:-

Structure	Gaseous exchange in % (approx)
A	97.0
B	2.5
C	0.5

A – stomata B – Lenticel C – cuticle

10. In an experiment to analyse a sample of air, a J-tube was used to find out the amount of CO_2 and O_2 in air sample. The length of the air sample in the J-tube was 8cm. After mixing with some NaOH solution for some minutes, the length reduced to 7.6cm. When pyrogallic acid was also made to mix with the remaining air sample, the remaining air sample reduced to 6.6cm.

(a) Calculate the percentage of

i) Oxygen

$$\%ge\ of\ O_2 = \frac{7.6\,cm - 6.6\,cm}{8\,cm} \times 100\% = 12.5\%$$

ii) CO_2 in the air sample. Show your working.

$$\%ge\ of\ CO_2 = \frac{8.0\,cm - 7.6\,cm}{8\,cm} \times 100\% = 5\%.$$

(b) What was the role of NaOH and pyrogallic acid in this experiment?

i) NaOH – To absorb Carbon (IV) oxide

ii) Pyrogallic acid – To absorb oxygen.

3. RESPIRATION

Introduction

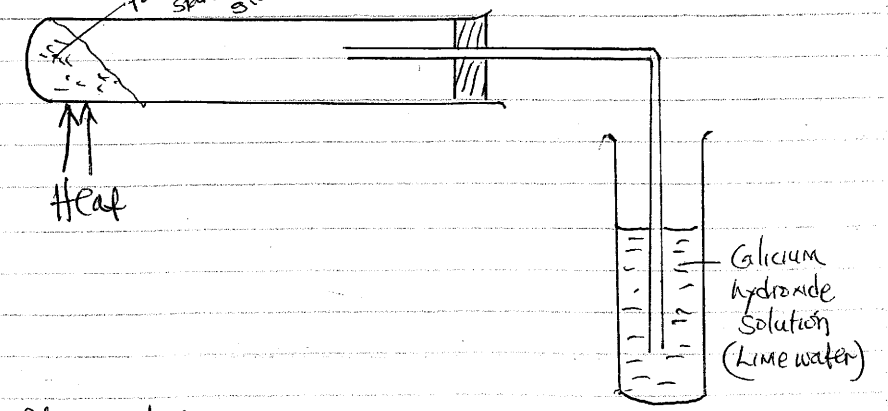
- Is the process by which food substances are chemically broken down in all living cells to release energy, Carbon (IV) oxide, water or alcohol or lactic acid.
- It occurs slowly and continuously in cells releasing small amounts of energy. It is also called tissue respiration or internal respiration

Differences between Respiration and Gaseous exchange

- Gaseous exchange is a physical process taking process across respiratory surfaces by diffusion whereas respiration is a chemical process controlled by enzymes and taking place in cells (Cytoplasm / mitochondria.

Practical Activity 1: To investigate the gas given off during respiration / when food is burnt.

PROCEDURE



Observation

i) steam condenses on the cooler parts of the test-tube.

↓ Lime water forms a white suspension (ppt)

Accounting for Results

- When the food sample is burnt steam and CO_2 are produced. Steam cools on the cooler parts of the test tube whereas CO_2 liberated reacts with $Ca(OH)_2$ (aq) forming a white suspension ($CaCO_3$).
- The equation for the final reaction is

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Heat}$$

- This reaction is equivallent to what happens in living cells during respiration (aerobic respiration).

Significance of Respiration.

- Produces energy in cells due to breakdown of food substances. The energy is used in muscular contraction, conduction of nerve impulses, secretion of enzymes, hormones, growth, repair of worn out tissues and functioning of body organs such as brain, kidney, lungs, heart and brain.
- Tissue respiration occurs mainly in cell organelles called Mitochondria.

Types of Respiration

- Include aerobic and anaerobic respiration

(a) Aerobic Respiration.

- A process in which oxygen is used in breakdown of food substrates, mainly glucose in tissue cells to Carbon (IV) oxide, and water releasing energy.

OMIT

Glucose + ATP
↓ hexokinase
Glucose phosphate 6c
↓ glucose phosphate isomerase
Fructose phosphate 6c + ATP
↓
Fructose diphosphate 6c
↓
pyruvate 3c
(1 ATP → 2 ATP = 3 ATP)

- It is enzyme controlled and occurs in stages to prevent overproduction of heat.
- In each enzyme-controlled stage, the energy released is stored in a compound known as Adenosine Triphosphate (ATP). The reactions take place in a series of enzyme controlled stages summarised in the Kreb cycle or Citric acid cycle.
- The conditions necessary for aerobic respiration include :-
  - Food substrate - glucose
  - Oxygen - for oxidation / combustion
  - Respiratory enzymes - catalysts
  - Optimum temperature - to activate enzymes
  - Mechanism of removal of end products of respiration - H_2O, CO_2 and energy.

Phase 1 - Glycolysis.

- Takes place in the cytoplasm.
- It does not require oxygen.
- Glucose is broken down by enzymes to produce 3-Carbon compounds known as pyruvic acid. This phase releases 7% of the total energy in the glucose molecule.

$$\text{GLUCOSE} \xrightarrow{\text{Enzymes}} \text{PYRUVIC ACID} + \text{ENERGY}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2CH_3CH_2COOH + 2ATP \text{ (Net gain)}$$

- The total energy produced at the end of this process is used to combine a compound known as adenosine diphosphate (ADP) with an inorganic phosphate to form Adenosine Triphosphate, ATP.

$$ADP + (PO_4)^{3-} + \text{Energy} \longrightarrow ATP + H_2O$$

(high energy molecule)

$$ADP + P \longrightarrow ATP + H_2O$$

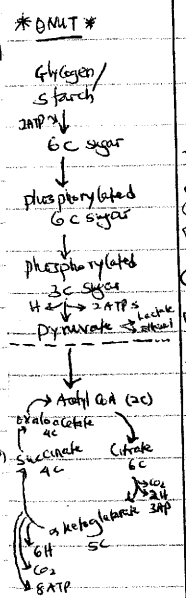
- This breakdown of glucose to pyruvate is known as glycolysis
- If oxygen is not available in the cell the pyruvic acid is partially broken down to ethyl alcohol (ethanol), in plants, and carbon(IV) oxide; or to lactic acid in animals; liberating a small amount of energy.
- In plant tissues alcohol production during fermentation by yeast or bacteria progresses like this and keeps on accumulating as long as O_2 is excluded.

Plants

Glucose —Glycolysis (Enzyme controlled)→ Pyruvic acid —Enzymes→ Ethanol + Carbon(IV) oxide + Energy

Animals

Glucose —Glycolysis (Enzyme controlled)→ pyruvic acid —Enzymes (in Cytoplasm)→ lactic acid + Energy



Phase 2 - Kreb's cycle

- Also referred to as Tricarboxylic acid cycle or Citric acid cycle.
- Takes place in the Mitochondrion Matrix
- Pyruvic acid is fed into the mitochondrion and broken down in a series of enzyme-controlled reactions that require oxygen.
- Pyruvic acid is converted into a 2-carbon compound of acetic acid called acetyl Co-enzyme A (Acetyl-CoA). During the conversion carbon(IV) oxide is given off and two hydrogen atoms are also lost and 3 ATPs are produced.

- Acetyl CoA enters a series of enzyme-controlled reactions and at the end of the aerobic respiration, glucose is thus completely broken down to water, carbon(IV) oxide and 38 ATP molecules.
- The equation below summarises the oxidation of pyruvic acid:-

$$2CH_3CH_2COOH + 7O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + \text{Energy}$$

- The general equation for aerobic respiration therefore is

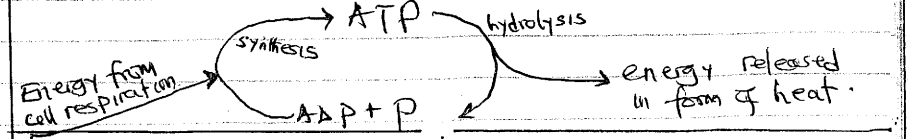
$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + 38ATP$$

- The energy liberated from breakdown of glucose is used to bring about a chemical reaction in which a compound in the cell called adenosine diphosphate (ADP) combines with an inorganic phosphate to form Adenosine Triphosphate, ATP.

Adenosine diphosphate + Inorganic phosphate + Energy ⇌ Adenosine Triphosphate + Water + Heat

$$ADP + (PO_4)^{3-} + \text{Energy} \rightleftharpoons ATP + H_2O + \text{Heat}$$

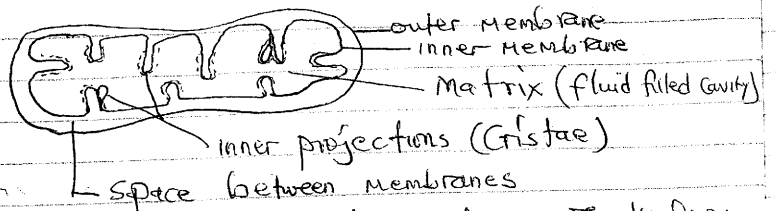
- ATP stores the energy and upon demand it is broken down to ADP + inorganic phosphate + Energy used in cellular activities



NB* During aerobic respiration some H_2O_2 may be produced. Being toxic, it is rapidly broken down to H_2O and O_2 by enzyme catalase.

The structure and function of a Mitochondrion.

- Mitochondria are small, round or rod-shaped cell organelles found in cells and provide sites for respiration.



- Actively respiring cells such as of kidney, flight muscles, liver, muscles, sperm cells have a high density of mitochondria to meet their energy requirements.
- Adaptations of Mitochondrion to its functions:-
  i, Inner membrane forms projections called Cristae to increase surface area for respiratory activities.
  ii, Cristae provide a large surface area for attachment of enzymes.
  iii, The matrix is fluid-filled to provide medium for enzyme activities.

(b) Anaerobic Respiration

- Is a process by which food substrates such as glucose are broken down to ethanol and Carbon (IV) oxide (in plants) or lactic acid (in animals) producing energy, in the absence of oxygen.
- The glucose is partially broken down into intermediate compounds ethanol in plants, producing little energy.

In plants

Glucose $\xrightarrow{\text{Enzymes}}$ Ethanol + Carbon (IV) oxide + Energy

$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2C_2H_5OH + 2CO_2 + \text{Energy}$.

In Animals

Glucose $\xrightarrow{\text{Enzymes}}$ Lactic acid + Energy

$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} C_3H_6O_3 + \text{Energy}$

- In the absence of oxygen most plant and animal tissues respire anaerobically for a limited period. But it is essential that the end products (CO_2 and ethanol in plants and lactic acid in animals) be removed immediately to avoid accumulation because they are toxic to cells.
- Anaerobic respiration that results in accumulation of alcohol is known as fermentation.
- Fermentation occurs when bacteria or yeast breaks down simple sugars into energy, Carbon (IV) oxide and alcohol.
- Some bacteria breakdown alcohol into ethanoic acid through anaerobic respiration. Similarly the breakdown of sugar in milk (lactose) to lactic acid by lactobacilli bacteria results in production of energy and sourness (due to lactic acid).

"Oxygen Debt"

- This is the oxygen required to get rid of lactic acid that accumulates in body tissues when supply of oxygen is less than the demand.

- Under these conditions the animal tissues respire anaerobically causing accumulation of lactic acid in muscles.
- The lactic acid causes fatigue and muscle cramps.
- An example of anaerobic respiration which leads to oxygen debt is when a short distance runner holds his breath while running or during diving. The oxygen "debt" incurred is paid back by the person breathing more quickly and deeply after the strenuous activity.
- During the recovery period lactic acid is broken to carbon (IV) oxide, water and energy or taken to the liver and converted to glycogen for storage. Other examples of anaerobic respiration include:- Denitrification, putrefaction/decay and fermentation.

Application of Anaerobic respiration in Industries and at home.

i, Fossil fuel formation - organic matter from dead plants and animals deeply burried decays anaerobically producing natural gas, oil, coal and peat.

ii, Biogas and gasohol formation - Anaerobes breakdown organic matter to produce biogas and gasohol eg Saccharomyces cerevisiae (yeast) breaks down Cane sugar to gasohol. Gasohol is used to run engines or is mixed with other fuels to run machinery. Biogas

- a mixture of methane and carbon (IV) oxide is produced from anaerobic decomposition of organic matter (NB Gasohol = power alcohol).

iii, Brewing - Beer, wines and spirits are produced by fermentation process using yeast.

iv, Bread production for domestic and commercial use: During fermentation production of CO_2 by yeast makes the dough to rise making bread porous.

v, Commercial production of oxalic acid citric acid and vinegar. These products from anaerobic respiration of anaerobes are used in food processing.

vi, Silage - formed from fermentation of vegetation by bacteria giving it a good flavour and scent.

vii, Sewage and industrial effluent treatment - Anaerobic bacteria break down organic matter in sewage thus reducing its harmful effects.

viii, Manufacture of dairy products. Anaerobic respiration is important in production of cheese, ~~[illegible]~~ and yoghurt.

ix, Making of composit manure

x, production of organic solvents such as butanol, ethanol, pentanol and methanol.

xi, Reting of flax, curing of tobacco and fermentation of tea & silage.

Comparison Between Aerobic & Anaerobic Respiration.

Aerobic Respiration	Anaerobic Respiration
1. Oxygen is needed	Oxygen is not needed.
2. The substrate is broken down completely to water Carbon(IV)oxide & energy	Substrate is partially broken down to lactic acid or ethanol and CO_2 and energy
3. High amounts of energy released ie 2880 KJ or 38 ATP Molecules per Molecule of glucose. Efficient Method.	Low amounts of energy released ie 210 KJ or 2 ATP molecules per molecule of glucose. Inefficient.
4. End products are water, Carbon(IV) oxide and energy. The waste products diffuse out of cells and are excreted.	End products are lactic acid in animals and ethanol in plants. These accumulate in the body.
5. Water molecules are produced	Water molecules not produced.
6. Over a short period, energy is not released faster.	Over a short period, energy is released faster.
7. Occurs in cytoplasm and Mitochondria	Occurs in cytoplasm only.

Respiratory Substrates

- Are energy-rich foods which when oxidised release energy in cells. Include:-

1. Carbohydrates – Mainly glucose, galactose and fructose. Before oxidised, galactose and fructose are first converted to glucose. Carbohydrates are the main respiratory substrates because they are soluble and easily

transported to respiratory sites. They require less oxygen for oxidation also compared to lipids. A molecule of glucose produces 2881 KJ/mol or 17 KJg^{-1} when completely oxidised. Sources of carbohydrates include maize, Cassava, yams potatoes, sugar cane, Sorghum etc.

2. Lipids / fats & oils – Are used when carbohydrates are not readily available. A molecule of a lipid produces 38 KJg However they are not the main respiratory substrates because they are not easily soluble and hence not readily transported to respiratory sites. A molecule of a lipid also requires more oxygen molecules for oxidation compared to carbohydrates.
- Sources of lipids include sesame, groundnuts, Coconuts, Cashew nuts, Meat, butter, milk, cheese etc.

3. Proteins – Used only during starvation. During these times they are first broken down to amino acids The amino acids are de-aminated before oxidised to water, Carbon(IV) oxide and energy.

Respiratory Quotient (RQ)

- Is the ratio showing the relationship between amount of Carbon(IV) oxide produced and the amount of oxygen consumed during respiration.

RQ = $\frac{\text{Volume of } CO_2 \text{ produced}}{\text{Volume of } O_2 \text{ Consumed}}$.

- RQ has no units because it is a ratio.

Significance of RQ

i, It gives an indication of the type of substrate oxidised. eg when carbohydrates are oxidised eg sucrose or glucose, RQ = 1, due to complete oxidation of substrate. RQ of lipids is 0.7 and RQ of proteins is about 0.9.

ii, It gives an indication of the nature/type of respiration/conditions under which respiration took place.

- RQ can range from less than 1 to greater than 1.
- RQ of less than 1.0 indicates more consumption of oxygen and less production of CO_2 implying aerobic respiration.
- RQ of greater than 1.0 indicates more production of CO_2 and less consumption of O_2 implying anaerobic respiration; where alcohol and CO_2 are produced.

- Factors affecting RQ include:-

i, Age
ii, Temperature
iii, Health status
iv, Type of substrate
v, Presence or absence of oxygen
vi, Activity
vii, The metabolic process
viii, Type of respiration

- For example in germinating seeds, RQ is initially greater than 1.0 because of anaerobic respiration due to presence of testa. Later it is less than 1.0 as aerobic respiration sets in during breakdown of lipids and carbohydrates.

NB. when working out RQ of green plants, this should be done in the dark since in light, some of the CO_2 produced is used in photosynthesis.

Role of Enzymes in Respiration

- Enzymes are biocatalysts that alter rate of reaction but are not consumed.
- Every stage in respiratory pathway is controlled by an enzyme. A defect in any one enzyme would lead to accumulation of one substance to toxic levels. Killing the cell.
- Examples of enzymes include:-

i, Carboxylases - remove carbon atoms from substrate
ii, Isomerases - formation of isomers eg glucose phosphate to fructose phosphate
iii, Polymerases - Synthesis of polymers
iv, Hydroses - add water molecules to substrate
v, Oxidases - add oxygen molecules to substrate causing combustion.
vi, Reductases - add hydrogen atoms to substrates / remove oxygen atoms from substrate
vii, Mutases - alter structure of a substrate permanently.

(viii) Lyases — eg decarboxylases which remove CO_2 from substrate

(ix) Cofactors and co-enzymes — accelerate rate of enzyme activities.

Metabolism, Anabolism & Catabolism

- Catabolism — stages leading to breakdown of complex organic molecules to simple ones releasing energy.
- Anabolism — stages leading to synthesis of complex organic molecules from simple ones requiring energy.
- Metabolism — Catabolic and anabolic reactions in the body involving use of food in cells.

Micro-organisms which Respire Anaerobically

① Obligate anaerobes — respire only in the absence of oxygen. presence of oxygen poisons them eg Escherichie coli in colon. It breaks down glucose to formic acid; Bacillus subtilis in marshy areas. It breaks down proteins to H_2S and CH_4 (Methane); syphylis spirochaeta (Treponeme palladium); Lactobacillus bacteria; and clostridium tetani.

② Ficultative anaerobes — Respire anaerobically only when oxygen is in limited supply eg soil bacteria; plant seeds with impermeable seed coats; Roots in waterlogged soils; plant and animal fungal parasites;

Factors Affecting Rate of Respiration

① Oxygen concentration.

- When amount of oxygen in tissues increase rate of respiration also increases and vice versa.
- In diving animals when oxygen concentration reduces, cardiac frequency drastically reduces (bradycardia) and arterides of all the vital body organs constrict so that oxygen can be delivered to vital organs which can not endure oxygen deprivation eg brain & heart. Respiration thus reduces in these other organs.

② Substrate concentration

- When substrate concentration, mainly sugar increases, rate of respiration also increases.

④ Hormones

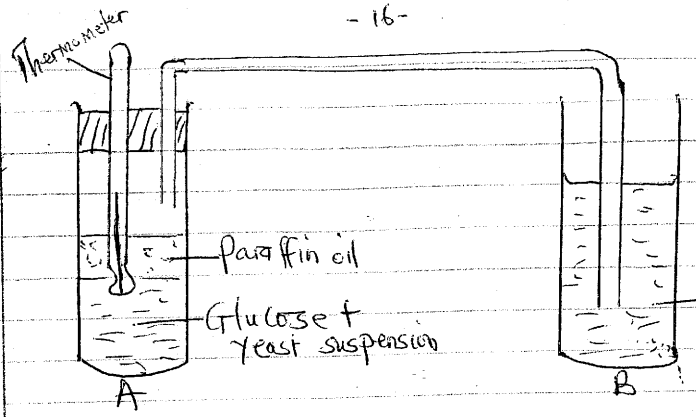
- Hormones such as adrenaline and thyroxine increase rate of respiration.

⑤ Surface area to volume ratio (Body size)

- Animals with larger surface area to volume ratio loose heat faster to the environment, hence respiration rate is higher in them to produce more heat to maintain body temperature.

Other Practical Activities

1. To investigate the gas produced during fermentation.



- The glucose is boiled and then cooled to 40°c before yeast is added. Kerosine is added on top of the mixture. The set up is left for one hour.
- Gas bubbles are produced in tube A after about 30 minutes. Temperature in A also rises.
- In tube B a white suspension is formed on lime water.

Accounting for Results

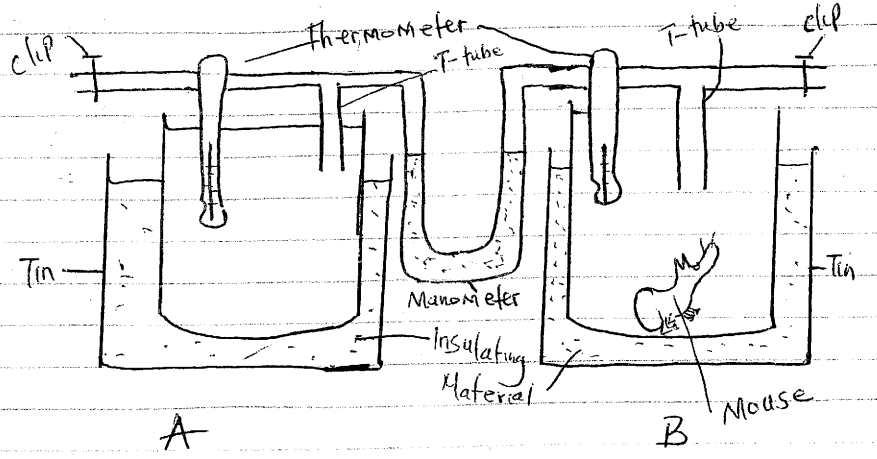
Yeast respires anaerobically in the absence of oxygen. Yeast enzyme (Zymase) breaks down glucose to Carbon (IV) oxide and ethanol thus liberating energy. Carbon (IV) oxide evolved reacts with lime-water forming a white suspension. Some of the energy is lost in form of heat hence rise in the temperature as recorded by thermometer.

$$C_6H_{12}O_6 \xrightarrow{\text{Yeast}} 2C_2H_5OH + 2CO_2 + \text{Energy}$$

- Paraffin prevents entry of air with oxygen.
- A Control expt can be a set up without

yeast or paraffin.

2. To Investigate oxygen consumption and CO_2 production by a small Mammal.



- The set up is left for about 60 minutes.

Observations

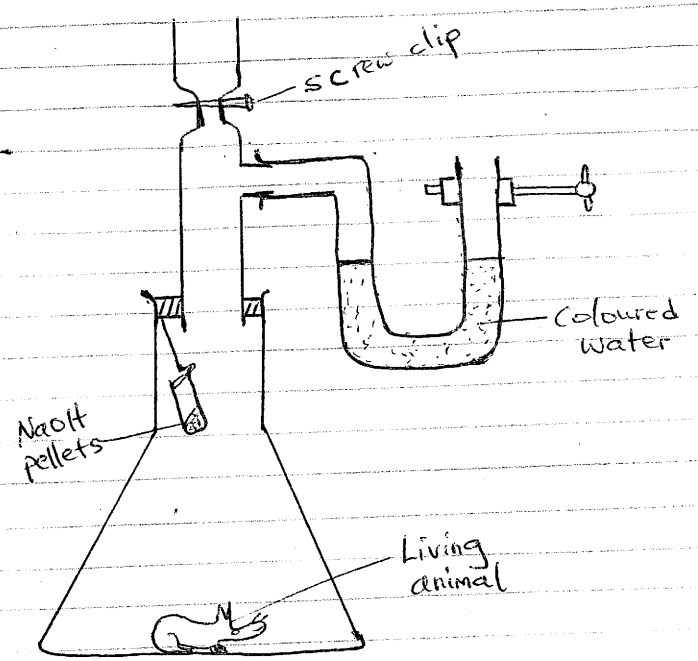
(a) Thermometer readings
   i) A - No change
   ii) B - Rise in temperature

(b) Level of liquid in Manometer
- There is a rise in level of liquid in arm adjacent to B and a fall in the arm adjacent to A.

Explanation

- The animal consumes oxygen for respiration producing CO_2. More oxygen is consumed than CO_2 produced hence the liquid in arm of Manometer adjacent to B rises to occupy space left ~~fo~~ by oxygen. Heat produced causes temp. rise.
- Set up A is a control experiment.

3. To investigate whether animals consume Oxygen from air.



Results

- Liquid in manometer rises in the arm adjacent to the animal / set up with an animal.

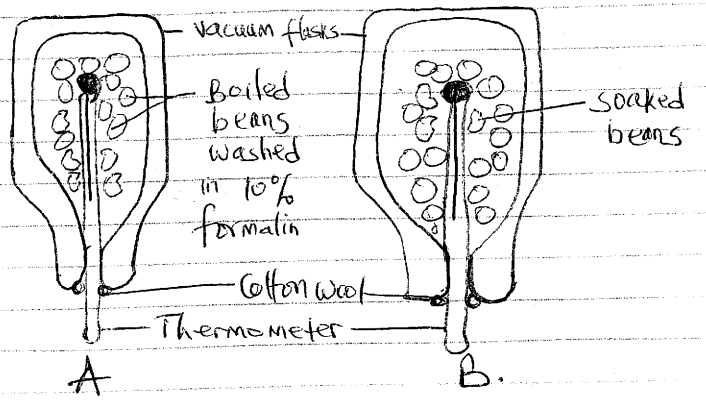
Explanation

- During gaseous exchange, the animal consumed oxygen from the air in the flask causing coloured water to rise up to occupy the space left by oxygen. More oxygen is consumed for respiration than CO_2 produced.
- NaOH pellets were included to remove CO_2 from the air in the flask.
- A control experiment would involve the

same set up but without an animal.

5. To investigate the production of heat by germinating seeds.

Procedure



Results

A - No observable change in thermometer reading

B - Rise in temperature recorded in thermometer.

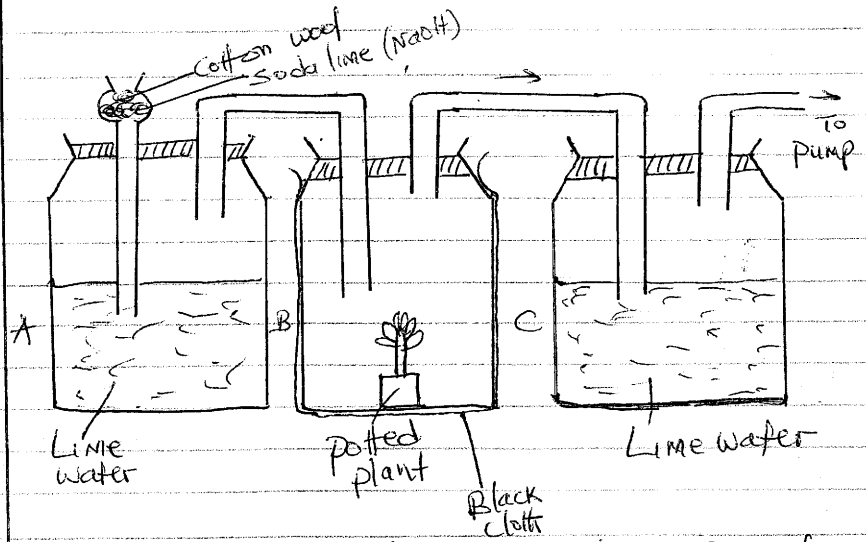
Accounting for Results

- In set up A, boiling killed the protoplasm of the seeds and denatured enzymes hence no germination took place and there was no heat production since no respiration took place.
- In set up B respiratory enzymes hydrolysed the stored food in the seeds and oxidised it producing energy for germination. Some of the energy was lost in form of heat hence causing temperature rise.
- Washing the seeds in formalin was

Meant to prevent decomposition by bacteria which could have brought about temperature changes; hence unreliable results.
To have more reliable results, the thermometer bulb must touch the seeds.
Set up A was included to act as a control experiment.

7. To Investigate release of CO_2 by green plants during respiration.

Procedure



- The set up is left to stand for 12 hours

Results

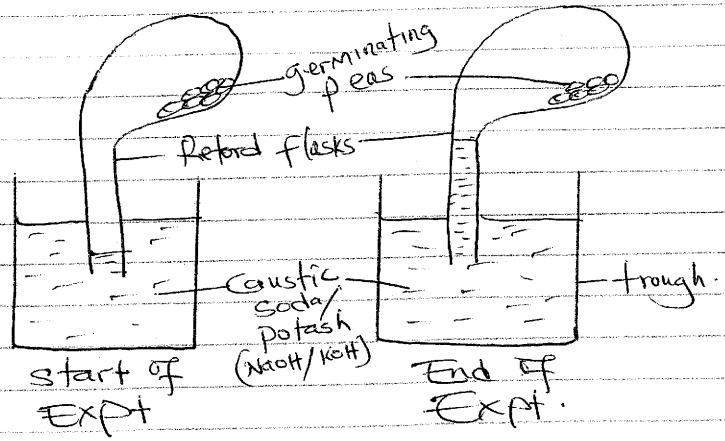
- Lime water in A remains clear
- Lime water in C forms a white suspension

Accounting for Results

- The role of NaOH is to absorb CO_2 from air entering lime water in A.

- The black cloth prevents penetration of light hence the plant in B does not carry out photosynthesis. The air it is receiving also lacks CO_2 since it was absorbed by NaOH at set up A. Hence only respiration occurs in the green plant in B producing CO_2 which reacts with lime water in C producing a white suspension.
- A control to this experiment can be a set up lacking a green plant.

8. To investigate oxygen consumption during germination of seeds.



- The set up is left to stand for 12 hours

Results - Level of NaOH or KOH rises in the retord flask, and falls in the trough

Explanation - Germinating peas respired using oxygen from the retord flask. Hence level of NaOH/KOH rises to occupy space left by oxygen.

4. EXCRETION & HOMEOSTASIS

Introduction

- Excretion is the process by which living things seperate and eliminate waste products of Metabolism from cells eg Carbon (IV) oxide, excess water, excess salts, oxalates, purine, tannins, etc.

Importance of Excretion

1. Removal of waste products of Metabolism from cells whose accumulation can be toxic to cells
2. Creates a steady internal environment for cells to function normally. The maintenance of a steady internal environment of cells within narrow limits is called **homeostasis**. Such factors include temperature, pH, osmotic pressure, blood-sugar level etc.

Distinguishing between Excretion, egestion and Secretion.

(a) **Egestion** — Is the process that results in the removal of undigested and indigestible materials from vacuoles or alimentary canal eg faeces.

(b) **Secretion** — Is the release of useful chemical substances from cells eg enzymes, hormones, oxalates, sebum, mucus etc.

EXCRETION IN PLANTS

- Plants do not have elaborate excretory organs like those of animals and do experience fewer excretory problems.

This is because :-

i, plants manufacture their **own organic compounds** according to their requirements hence do not have excessive accumulation.

ii, plants are able to **recycle** most of their Metabolic by- and waste products eg oxygen from photosynthesis is reused in respiration and CO_2 from respiration is reused in photosynthesis.

iii, some **excretions serve as secretions** with some functions eg protection against damage / browsing grazing; attracting insects for pollination etc.

iv, plants are not as active as animals hence their **rate of excretion** of waste products is lower.

Mechanisms of Excretion in plants

i, **Diffusion** — for gaseous metabolic wastes eg CO_2 from respiration and oxygen from photosynthesis. The gases diffuse out through stomata.

ii, **Transpiration** — Water vapour from inter-Cellular spaces and substomatal spaces diffuse out to the atmosphere through the stomata. This creates a transpiration pull along the transpiration stream.

iii, **Guttation** — Some plant seedlings such as maize, tomatoes and cabbage force out/exude excess water out of their leaf Margins. This is guttation.

iv, Other waste products are stored as insoluble non-toxic forms in ageing structures such leaves. This is non-toxic storage

v, Leaf fall etc - old plant structures eg leafs, flowers and fruits contain stored waste products. Upon falling off the plant eg leaf fall, the waste products are thus removed from the plant. Such wastes include resins, tanins, Calicium oxalates, Calcium carbonates and alkaloids :-

(a) Tanins - stored in barks of many trees and get rid off through bark fall.

(b) Alkaloids - nitrogenous wastes in various organs and are either used in protein synthesis or get rid off when these parts fall.

(c) Anthocyanins - Give red, purple and blue colours to petals and drying leaves and get rid off when these parts fall off the plant.

(d) Non-gaseous wastes - are converted into insoluble non-toxic compounds and often remain in cells in form of granules or oil droplets.

v, Exuding through the bark of the stem eg resins, tanins, gums / gum arabica.

Economic importance of plant Excretory products.

(a) Alkaloids

	Alkaloids	source	Uses / characteristics
i,	Ephedrine	Ephedra spp	- As a decongestant / bronchodilator in cough syrups - CNS stimulant
ii,	Arecoline	Areca spp.	- CNS stimulant.
iii,	Cocaine	Leaves of Coca plant	- Local anaesthesia in minor surgery - Induces euphoria / false sense of well being and is addicting - An illegal drug
iv,	Khat	Khat edulis (Miraa)	- Mild CNS stimulant - Medicinal
vi,	Cannabis	Flowers / leaves of Cannabis sativa	- Narcotic drugs and insecticide manufacture
vii,	Quinine	- Cinchona tree - Aloe leaves	Anti-malarial drug.
viii,	Caffein	Tea, cocoa, coffee	- Mild stimulant of CNS - Reduces fatigue
ix,	Nicotine	Tobacco leaves	- Heart & CNS stimulant - Carcinogenic
x,	Morphine	Opium poppy plant	- Induces sleep and hallucinations
xi,	Strychnine	Seeds of strychenes nuxvomica	- Powerful CNS stimulant. Induces convulsions.
xii,	Colchicine	plants	- Cancer therapy - In plant & animal breeding

(b) Non-Alkaloids

i, Rubber - Made from latex of Rubber tree (Havea brasiliensis). Used in shoe and tyre industry. Sapodilla tree also produces rubber used in manufacture of chewing gums.

ii, Tanins - Obtained from the bark of Acacia mearnsii (black wattle) and Rhizophora spp. Combines with animal proteins producing a tough indigestible complex which proteases can not digest. Used in ~~leather tanning~~ and in making patterns on pots.

iii, Papain - Obtained from skin of paw-paw which is unripe. Contains enzyme papain, a protease used as ~~Meat tenderizer~~.

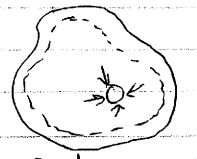
iv, Gum arabica - Is an exude from some varieties of Acacia trees. Used in ~~food processing~~ and ~~printing~~ industry.

NB → Indiscriminate use of some of these products like nicotine, cocaine etc constitutes drug abuse

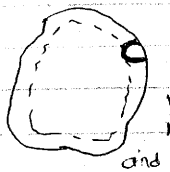
EXCRETION & HOMEOSTASIS IN UNICELLULAR ORGANISMS.

- Uncellular organisms such as paramecium, Amoeba and plasmodium meet their excretory requirements by simple diffusion because they have a large surface area to volume ratio.
- The organisms inhabit aquatic habitats.
- Gaseous waste products of metabolism ie CO_2 diffuse into the surrounding aquatic medium along a concentration-gradient

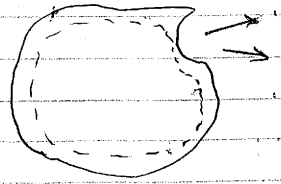
through the cell membrane.
- Nitrogenous wastes (waste-products of Metabolism mainly ammonia rapidly diffuse out or dissolve in water with excess salts and other soluble wastes and collect in the contractile vacuole. When contractile vacuole reaches maximum size it moves and fuses with cell membrane and bursts to release its contents into the aquatic medium. The contractile vacuole is the organelle for excretion & osmoregulation in such uncellular organisms.



i, Wastes accumulating in contractile vacuole



ii, Contractile vacuole at maximum size and fuses with cell membrane.



Contractile vacuole bursts to release the wastes.

NB → i, An organism with an active contractile vacuole lives in fresh water habitat which is hypotonic to its cytoplasm.

ii, During formation of a new vacuole many mitochondria, surround it to supply energy for this active process of excretion (which involves active transport)

EXCRETION IN HIGHER ANIMALS

- Higher animals have elaborate and specialised organs for excretion, viz :-

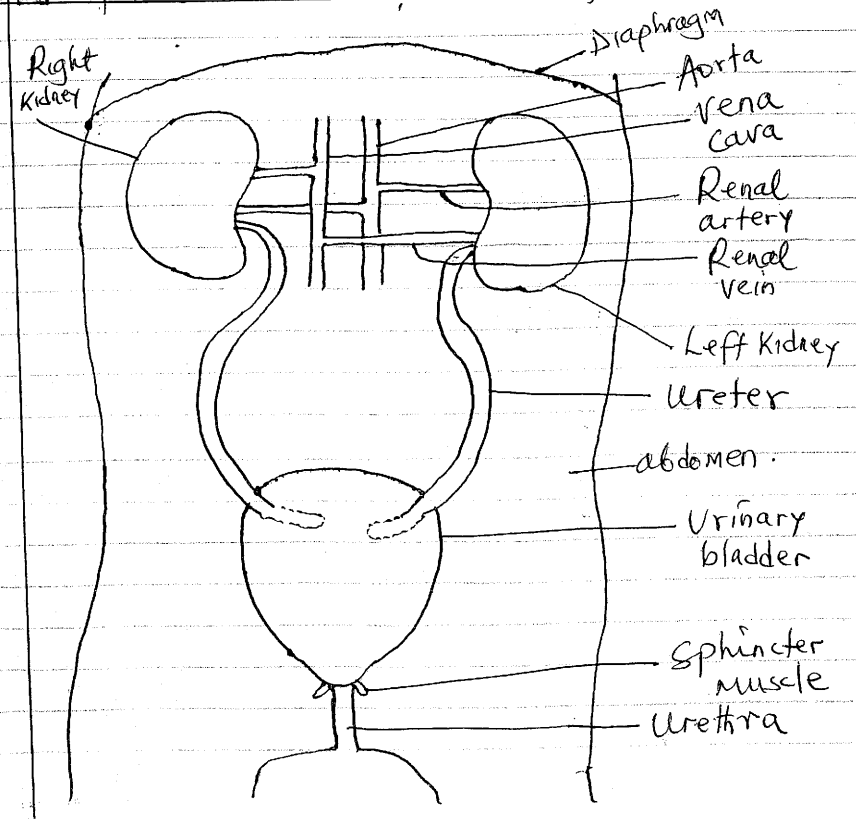
① Platyhelminthes eg Tapeworms — flame cells
② Annelids eg earthworm — nephridia
③ Insects — Malpighian tubules
④ Mammals — Lungs, Kidneys, Liver, skin
⑤ Birds — Lungs, Kidneys, Liver, skin
⑥ Reptiles — Lungs, Kidneys, Liver, skin
⑦ Amphibians — Lungs, Kidneys, Liver, skin.
⑧ Fishes and tadpoles — gills.

EXCRETION IN MAMMALS, eg human beings

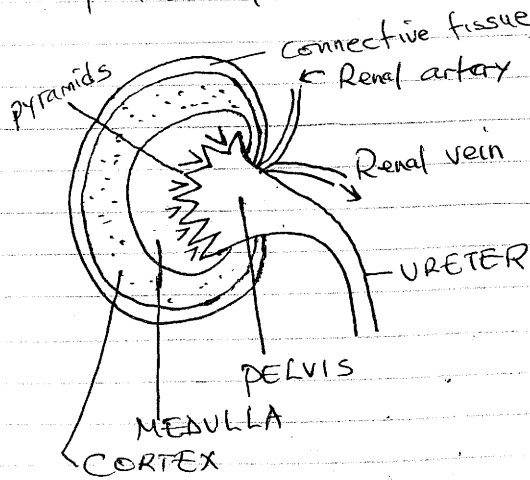
- The main excretory organs in mammals are lungs, kidneys, liver and skin.

① The Kidneys

A — position and structure of kidneys



- Kidneys are a pair of bean-shaped dark-red organs in the lumbar region of the body on the dorsal part of the abdominal cavity.
- On the concave side of each kidney is a depression known as hilum, through which the renal artery enters the kidney and renal vein and ureter leave the kidney.
- Ureter conducts urine to the urinary bladder which upon relaxation of its sphincter muscles releases the urine out of the body through the urethra.
- A longitudinal section through the kidneys shows three main parts :-
  i) Cortex — the outer part
  ii) Medulla — the middle part
  iii) Pelvis — the part which has conical projections known as pyramids. The pelvis opens to the ureter.



- The inside of the kidney contains numerous (about 1 million) functional units called nephrons / Malpighian Corpuscles

[B] The Nephron

- The nephron is the functional unit of the kidney. It is made up of two main parts:-

(a) Glomerulus

- Is a ball of blood capillaries from the afferent arteriole of renal artery.

(b) Renal tubule

- It is subdivided into the following parts

(i) Bowman's capsule – a funnel-shaped structure into which the glomerulus fits.

(ii) Proximal convoluted tubule – The first coiled tubule projecting from the Bowman's capsule.

(iii) Descending loop of Henle

(iv) Loop of Henle

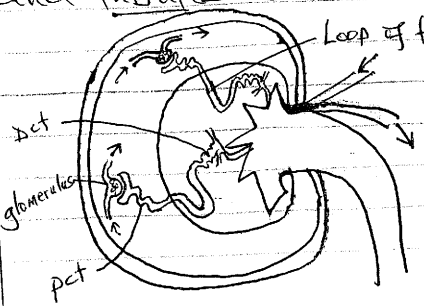
(v) Ascending loop of Henle

(vi) Distal convoluted tubule – The second coiled tubule of renal tubule

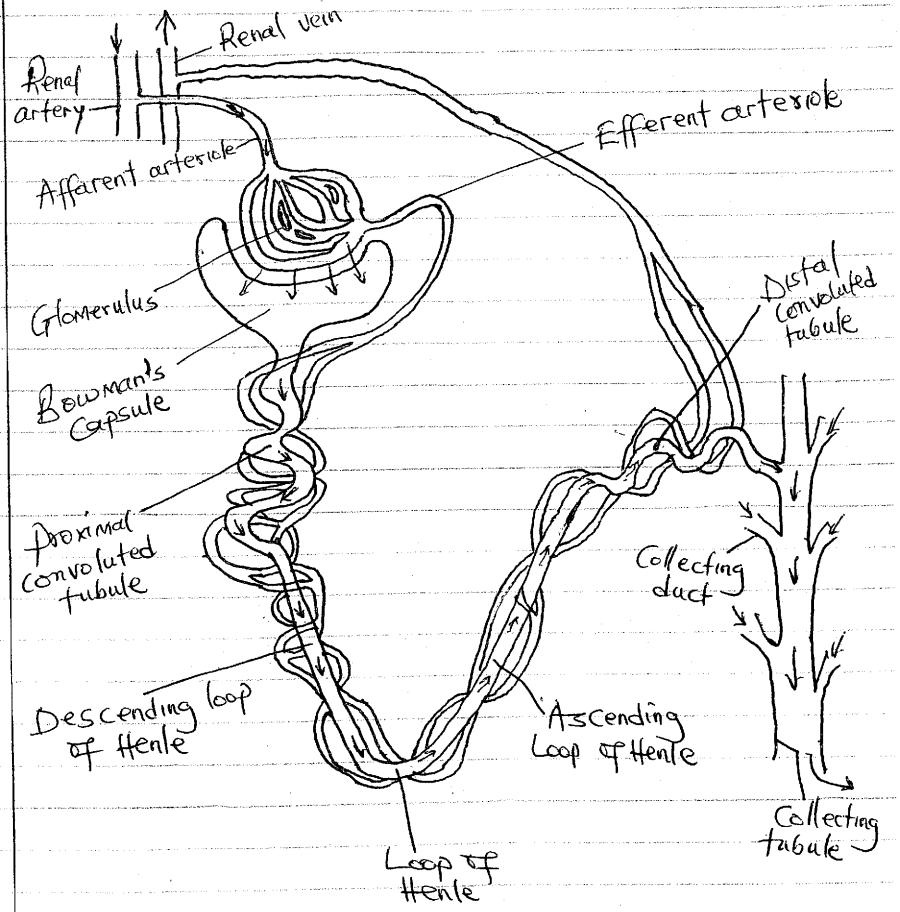
(vii) Collecting ducts and tubules.

- The efferent arteriole collects blood from glomerulus and extends to and ramifys the renal tubule before coalescing to venules which in turn coalesce to form the renal vein.

- Bowman's capsule, glomerulus, proximal convoluted tubules occur in the cortex whereas loops of Henle, collecting ducts and tubules occur in the medulla.



- Below is an isolated nephron.



[C] Functions of the Kidney

1. Excretion
2. Osmoregulation and water balance
3. Ionic balance.
4. Regulation of pH /acid-base balance.

[D] Role of Nephron in Excretion

i) Ultrafiltration

- Renal artery, a branch of dorsal aorta, supplies blood rich in nitrogenous wastes

eg urea, uric acid, ammonia and other dissolved substances (amino acids, vitamins, mineral salts, glucose) to the kidney.

- Renal artery branches into afferent arteriole which subdivides into a fine capillary network called glomerulus.
- An extension from the glomerulus known as efferent arteriole also branches into capillaries which ramify the renal tubule. The capillaries coalesce to form renal vein
- The efferent arteriole is narrower than afferent arteriole. This coupled with the high pressure from the heart (since renal artery receives blood from dorsal aorta), creates high resistance/back pressure within the glomerus. The high back pressure and increased resistance in glomerular capillaries forces out molecules of blood of smaller molecular weight ie nitrogenous wastes (urea, ammonia, uric acid), glucose, amino acids, dissolved mineral salts/ions, water, hormones etc into the Bowman's capsule. The filtrate so formed is called glomerular filtrate or renal fluid and this process is known as ultrafiltration.
- Larger components of blood ie blood cells (RBCs, WBCs, platelets) and plasma proteins do not filter out of the capillary walls because they are too large. They pass on to the efferent arteriole.

ii, selective reabsorption:

- As the glomerular filtrate flows down the renal tubule, useful substances there in are reabsorbed back into the blood capillaries ramifying the renal tubule. This process is known as selective reabsorption and occurs by active transport, diffusion and osmosis.

- Selective reabsorption at proximal convoluted tubule (pct)

- At the pct all glucose, all amino-acids, some salts (80% of the salts mainly NaCl, $NaHCO_3$ and others), some water, are reabsorbed by active transport and osmosis (ie water).
- The pct has the following adaptations to its functions:
  1. Cells lining the tubule have numerous mitochondria to provide ATP for active transport.
  2. The cells of the tubule have microvilli to increase surface area for selective reabsorption.
  3. The proximal convoluted tubule is long and coiled to provide large surface area and allow more time for selective reabsorption.
  4. The proximal convoluted tubule is supplied with dense capillary network/is highly vascularised to increase diffusion gradient for the reabsorption and also to supply oxygen and remove reabsorbed materials.

• **Selective reabsorption of salts and water at the loop of Henle**

- 5% of water and most salts, mainly Na^+ salts are reabsorbed here selectively depending on their concentration in blood.
- The Loop of Henle has the following adaptations :-
  1. Supplied with dense capillary network to increase diffusion gradient and supply oxygen for active transport
  2. Long and looped / U-shaped to increase surface area and allow more time for selective reabsorption.
  3. Blood in the surrounding capillaries and the renal fluid flow in a counter-current flow system to increase diffusion gradient.
  4. Lining of tubule has cells with many mitochondria to provide ATP for active transport.
  5. A hormone known as aldosterone produced by adrenal glands regulates intake of Na^+ and Cl^- ions. Low salt content in blood stimulates the adrenal glands to secrete more aldosterone hence more Na^+ salts are reabsorbed.

• **Selective Reabsorption of water at distal convoluted tubule and collecting ducts.**

- The adaptations of the distal convoluted tubule and proximal convoluted tubule are the same.
- Mainly at the ~~Dct~~ is where water reabsorption takes place. The process is enhanced in two ways :-
  1. Due to active intake of sodium salts at Loop of Henle which increases osmotic pressure of body fluids/ blood.
  2. A hormone known as Antidiuretic hormone (ADH) or vasopressin secreted by pituitary gland. This hormone controls water reabsorption eg if osmotic ~~pressure~~ of blood is high due to excessive water loss through sweating, more ADH is secreted making the pct and collecting tubules more permeable and hence more water is reabsorbed back to blood stream resulting in small quantities of concentrated urine.

• **Formation and Removal of Urine**

- The renal filtrate reaching the collecting ducts is now urine.
- Urine of a healthy person consists of :-
  1. 95% excess water
  2. 2% urea
  3. 0.03% uric acid
  4. 0.1% Creatinine
  5. Excess salts of Na^+, K^+, Cl^-, $(PO_4)^{3-}$
  6. 0.04% Ammonia
- NB → Urine of a healthy person lacks proteins (ie 0% proteins) and glucose

(ie 0% glucose) since all are reabsorbed. However the composition of urine by percentage depends on environmental factors and the habitat.

- The quantity and concentration of urine is also affected by the physiological and structural adaptations of the animal eg desert rat has a long loop of Henle to maximise water reabsorption.
- The urine so formed drains from the collecting ducts, to pelvis, to ureter and urinary bladder. About 1 to 2 litres of urine collects in the urinary bladder per day. Whenever the volume is about 250 ml, the sphincter muscles of the urinary bladder relax and urine passes out through the urethra.

Kidney Diseases & Disorders.

1. Nephritis

- Inflammation of kidney caused by bacteria or associated infections; Such as Smallpox, Measles, typhoid fever and Sorethroat.

Symptoms & Signs

- Headaches, fever, vomiting, oedema, general weakness, passing out highly coloured and turbid urine due to presence of proteins.

Treatment & control

i, Dietary restrictions especially salts & proteins
ii, Administration of drugs (eg morphines, atropines, codeine etc)

2. Kidney stones / Renal Calculi

- Caused by:-

(a) Improper balance of diet lacking certain vitamins and inadequate intake of water.
(b) chemical salts in urine eg oxalates, phosphates, urates and uric acid. These may precipitate forming hard deposits or stones in pelvis, ureter hence causing blockage of urine.

Symptoms

(i) Increased frequency in passing out urine
(ii) Pain and Soreness in upper back side.
(iii) Pain, chills, fever.

Control & Treatment

i, Consult a physician.
ii, Balanced diet with plenty of water.
iii, Take hot baths and massage the back with hot soft material.
iv, Surgical treatment which may involve kidney transplant.
v, Dialysis or artificial washing of kidneys to remove wastes from kidneys.
vi, Use of laser beams to disintegrate the stones.

3. Albuminuria (Protens in urine)

- This is a disorder also known as proteinuria
- Is a condition in which proteins, mainly, albumen, is found in urine. This is due to increased permeability of glomerular Capillaries caused by bacterial infections.

Symptoms & Signs.

- Fluid accumulation in tissues / oedema. It

is fatal if not treated.

4. Kidney failure

- Situation where kidney fails to function.
- A person may still lead a normal life using one kidney if one fails. However if both kidneys fail or malfunction, the person can survive if treated promptly through:-
  i) Kidney dialysis
  ii) Kidney transplant.

5. Uraemia

- Condition of high concentration of urea in blood due to
  i) formation of cysts in kidney tubules
  ii) constriction of renal artery/arterioles impairing flow and leading to retention of organic acids / acidosis.
- The symptoms include:- jaundice, itching, pruities, smell of urine in breath, nausea and vomiting.
- Treatment includes:-
  i) Diet low in salts especially Nat salts
  ii) Artificial salt-electrolyte balance to allow kidney tissues to regenerate,
  iii) Dialysis.

Role of skin in Excretion

- The skin is the largest organ in the body.
- Its functions include:-
  i) Protection of underlying tissues from entry of micro-organisms, physical damage and ultra-violet rays from the sun.

ii) Regulation of body temperature / Thermoregulation.
iii) Excretion of excess salts, excess water and traces of urea. Hence excretory organ.
iv) Reception of stimuli of heat, cold, pain, touch and pressure. Hence a sensory organ.
v) Synthesis of vitamins D / Calciferol.
vi) Storage of fats.

Adaptations of the skin to its functions (Structure & functions of the skin)

- The mammalian skin consists of two layers
  1. Epidermis — outer layer
  2. Dermis — inner layer.

Epidermis

- Epidermis consists of the following parts:-
  i) Cornified layer - Is the outermost layer. Consists of dead cells. Keratin is filled between intercellular spaces. Cornified layer protects the skin against mechanical damage, loss of water (dessication) and invasion by bacteria. It wears and is replaced by granular layer. It is thickest in the palms and thinnest in the eyeballs.
  ii) Granular layer - Is the middle layer consisting of living cells which are granular. The granular layer replaces worn out cells of cornified layer.
  iii) Malpighian layer. - Is the innermost epidermal layer. It is made of cells which actively divide to give rise to

new epidermal cells which contain Melanin. Melanin screens against harmful ultra-violet rays from the sun which can cause cancer. Melanin also gives the skin its colour.

Dermis

- The dermis is the inner layer of the skin and is thicker than the epidermis.
- It contains the following structures:-

i) Blood capillaries and arterioles/ Blood vessels and lymphatic vessels.

- Blood vessels supply nutrients and oxygen and remove excretory products.
- The arterioles also vasodilate when temperatures are high to encourage heat loss. They also vasoconstrict when temperatures are low to conserve heat. In this way the skin is acting as a thermoregulatory organ.
- Lymphatic vessels drain excess tissue fluid

ii) Sweat glands

- produce sweat which consists of excess water, excess salts (mainly NaCl), urea, uric acid, lactic acid and Carbon (IV) oxide. Secretory cells in the tubules of the sweat glands absorb these products from surrounding blood capillaries and pass them out in sweat. In this way the skin is acting as an excretory organ.
- As sweat evaporates, latent heat of vaporisation is taken from the body lowering body temperature when it is hot. Under cold conditions, little or no sweat is produced thus heat is conserved in the body.

This is also thermoregulation.

iii) Hairs and hair follicles

- Hair originates from a deep infolding of the epidermis called hair follicle. The hair follicle is lined with granular and Malpighian layers of the skin and at its base is the dermal papilla from which root hairs develop.
- Hair insulates against heat loss when temperature is ~~high~~ low as the hairs stand erect to trap air within the hair follicles. Air being a poor conductor of heat insulates against heat loss. During this time erector or pili muscles contract.
- When temperature is high, the erector/ pili muscles relax and hairs lie flat on the skin surface to allow heat loss. In this way the skin is acting as a thermoregulator.

NB:- "Growth" of hair involves addition of new dead cells at the base of dermal papilla.

iv) Sebaceous glands

- produces secretions containing oily substances called sebum. Sebum is water repellant, prevents drying and cracking of the skin (keeps the skin supple and kills bacteria on the skin ie it's antiseptic

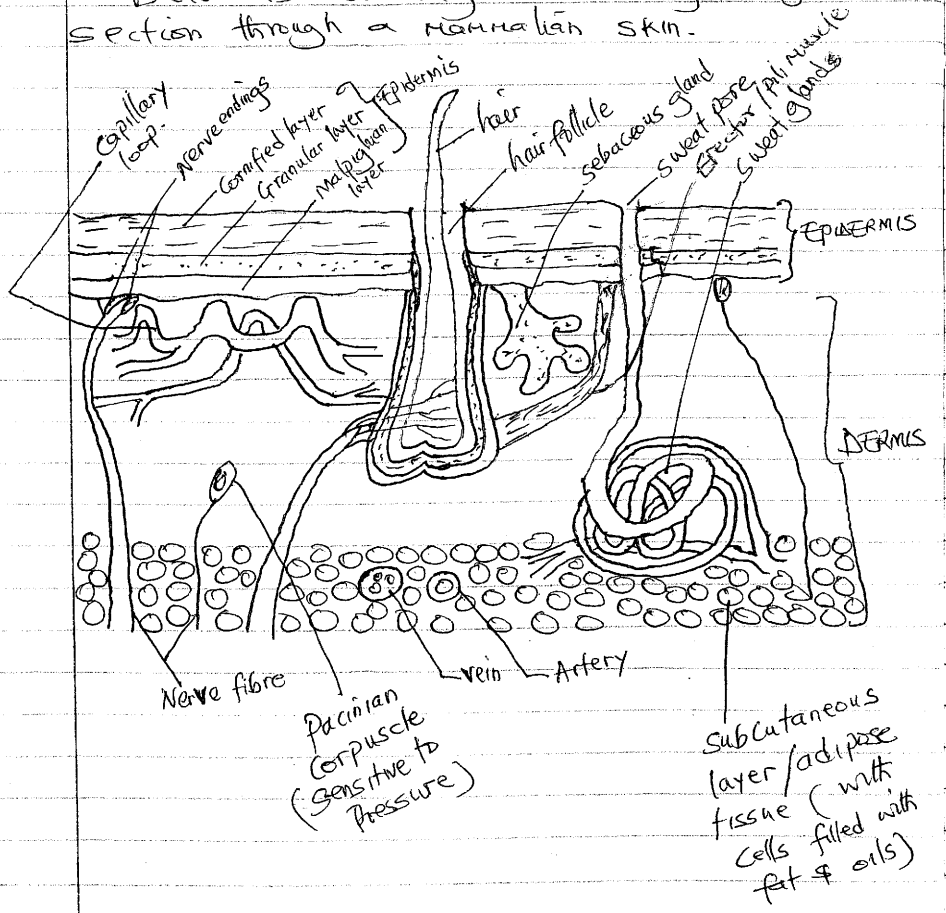
v) Nerve-endings - are sensitive to changes in various stimuli - heat, pain, cold, pressure and touch. In this way the skin is acting as a sensory organ.

vi) Sub-cutaneous layer/Adipose tissue

- Is the layer of fat beneath the dermis.

It binds the skin and other organs deep in the body. It acts as a storage region for fats and as an insulation layer against heat loss. Synthesis of vitamin D also occurs here.

– Below is a diagram showing longitudinal section through a mammalian skin.



③ Role of Lungs in Excretion

– In mammals, birds, reptiles and amphibians, CO_2 formed during tissue respiration is removed from the body by lungs.

– Water vapour is also removed by lungs from the body.

– Alveoli of lungs are surrounded by a dense capillary network. Blood in the surrounding capillaries has higher CO_2 concentration than the alveolar space hence CO_2 diffuses out along a concentration gradient into the alveolar space from which it is exhaled. Water vapour also diffuses out in the same way.

④ Roles of Liver in General

(a) Structure of the Liver

– The liver is the second largest organ in the body after the skin. It is immediately below the diaphragm and is made up of several lobes ie it is lobular. It receives more blood per unit volume per time than any other organ other than the heart.

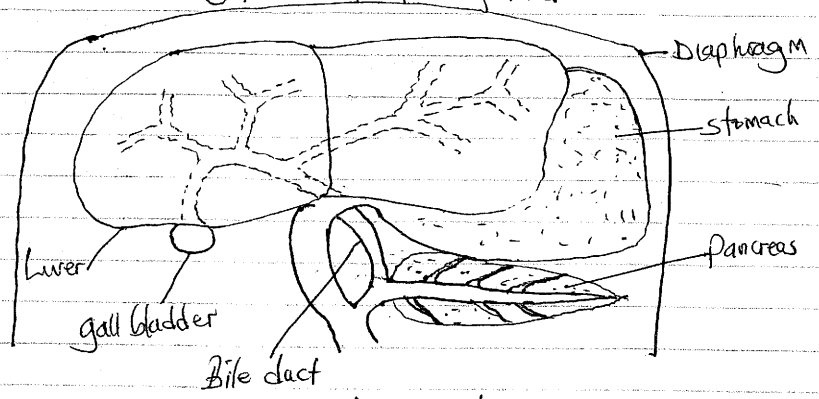
– It receives blood from the hepatic portal vein (rich in digested food from the gut) and hepatic artery (rich in oxygen). Blood flows out via hepatic vein.

– The liver consists of large lobules. Each lobule is made of mainly liver cells. The cells are arranged radially around a central blood vessel which is a branch of hepatic vein. The blood supply to each lobule is from two sources – hepatic artery and hepatic portal vein. The vessels branch between the liver lobules.

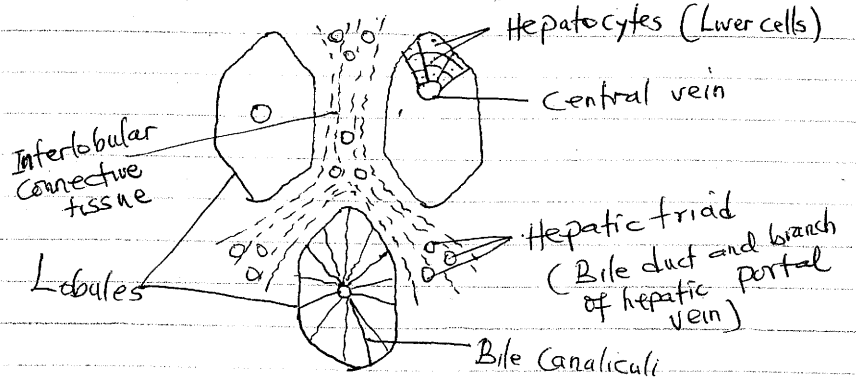
– Between the plates of liver cells are channels called canaliculi which receive

bile. Bile moves outwards to the periphery of lobules where it collects into bile duct.

External structure of Liver



Internal structure of Liver



(b) Functions of the Liver

—The liver performs over 500 functions some of which are discussed hereunder:-

i. Deamination of excess amino acids

—Excess amino acids, from breakdown of protoplasm and digestion of proteins, can not be stored in the human body.

—Hence excess amino acids are broken down in a process known as deamination

in the liver in which the amino-group ($-NH_2$) of the amino acid is removed and used to form ammonia. Ammonia is taken to the ornithine cycle in which it is combined with CO_2 to form less toxic urea in a series of enzyme-controlled reactions.

$$2NH_3 + CO_2 \xrightarrow[\text{enzyme arginase}]{\text{ornithine cycle}} CO(NH_2)_2 + H_2O$$

(Ammonia) (Carbon (IV) oxide) (urea) (water)

—Urea formed is released into blood stream and eventually passed out in urine through the kidneys.

(ii) Detoxification.

—Some metabolic activities in the liver produce harmful substances which if left to accumulate can destroy body tissues.

—The liver also receives harmful substances by way of drugs, food or drinks. It therefore makes these substances less harmful or harmless in a process called detoxification.

—Liver cells achieve this process by oxidation, combination or reduction eg hydrogen peroxide produced by actively respiring cells is broken down by enzyme catalase to form water and oxygen.

—Enzyme catalase is found in tissues of animals and plants where active respiration

occurs leading to accidental production of H_2O_2. Enzyme catalase in the tissues thus breaks it down as shown below:-

Hydrogen peroxide $\xrightarrow[\text{Catalase}]{\text{Enzyme}}$ water + oxygen

$$2H_2O_2 \xrightarrow[\text{Catalase}]{\text{Enzyme}} 2H_2O + O_2.$$

(iii) Thermoregulation

- Under conditions of low temperature, the liver carries out exothermic metabolic reactions producing more heat that is distributed to all parts of the body by blood. The liver carries out these activities upon receiving impulses from the hypothalamus.

(iv) Haemoglobin elimination.

- Kupffer cells in the liver break down old and worn out RBCs. Haemoglobin from RBCs is broken down into biliverdin and Bilirubin residual pigments which are excreted in bile into alimentary canal. The pigments give faeces its characteristic yellow-green colour. Some residual pigments are excreted in urine as urochromes; giving urine the yellow tinge.

(v) Formation and Regulation of plasma proteins

- plasma proteins - albumins, fibrinogen, prothrombin and Globulins are manufactured in the liver from amino-acids. Many of these proteins are involved in regulatory mechanisms of homeostasis eg blood clotting by fibrinogen which prevents loss of salts and water hence maintaining steady osmotic pressure.
- Serum albumen also contributes to maintenance of colloidal osmotic pressure. They also act as buffers.

- Globulins also play role in formation of antibodies.
- The quantities of these plasma proteins are regulated through the process of deamination of excess amino-acids.

(vi) Regulation of blood sugar level
(vii) Regulation of fat metabolism
(viii) Regulation of amino-acid and protein synthesis
(ix) Production of bile. Bile is manufactured by liver cells and is stored in the gall bladder.
(x) Storage of blood in cold conditions
(xi) Formation of RBCs in foetal stages
(xii) Storage of vitamins A, D, E and K (fat soluble) and C and B_{12} (water soluble) and minerals - copper, cobalt, potassium and zinc; calcium and molybdenum.
(xiii) Inactivates hormones whose functions are over as well as drugs.
(xiv) Formation and elimination of excess cholesterol which is an important component of the cell membrane.

Liver Diseases and Disorders

(i) Liver cirrhosis / rotting

- It is the degeneration of liver tissue due to :-

(i) viral infections
(ii) Excessive intake of alcohol
(iii) Nutritional deficiencies
(iv) Protozoan infections
(v) Infections by schistosomes.

Symptoms

(i) General body weakness, indigestion, poor appetite.

(ii) Loss of weight
(iii) Abdominal pain on upper right
(iv) Jaundice
(v) Vomiting of blood tissue
NB - These symptoms are slow in developing and appear at advanced stages.

Treatment

(i) Chemotherapy to alleviate causal micro-organisms
(ii) Adequate digestible diet.
(iii) Enough rest for patients
(iv) Avoid excessive alcohol intake
(v) Diet low in salt.

(2) Hepatitis

- There are two types of hepatitis, namely
(a) Hepatitis A / Infectious hepatitis - caused by Hepatitis A virus
(b) Hepatitis B / Serum hepatitis - caused by hepatitis B virus.
- Hepatitis A is common among children. Its mode of transmission is through :-
  - contaminated food / water
  - contaminated medical impliments eg syringes and needles
  - Contact with body fluids eg blood.
- Symptoms appear between 2 - 6 weeks; including :- nausea, fatigue, jaundice / yellowing of skin and abdominal pains.
- Hepatitis B is common in adults. It is transmitted through contaminated injections and other medical impliments, exchange of body fluids eg saliva, blood and semen.

- Symptoms appear 3-4 months after infection.
- The symptoms are like those of Hepatitis A. Hepatitis B is more serious and more difficult to treat.

Control

- Proper disposal of sewage ; vaccination ; bed-rest and prescribed diet.

(3) Diabetes

(a) Diabetes Mellitus (sugar disease).
- caused by deficiency of insulin. This can be hereditary or disease-caused.
- It is characterised by excretion of glucose in urine (glucosuria).
- Symptoms include :-
  (i) Glucose in urine
  (ii) copious / large quantities of urine
  (iii) Loss of weight due to breakdown of fats, proteins and glycogen.
  (iv) Chronic starvation of cells.
  (v) Thirstness.
- Excessive oxidation of fatty acids leads to formation of ketones (acid-compounds) which lower the body pH leading to acidosis (pH < 6.8) and hence death.
- Excessive deamination also increases urea in blood and in urine.
- Treatment involves :-
  (i) Regular administration of insulin
  (ii) Dietary restrictions eg foods rich in sugars.

(b) Diabetes insipidus.
- caused by deficiency of antidiuretic hormone (ADH) or vasopressin. This leads to excessive

loss of water in urine causing dehydration. This is compensated by drinking large amounts of water regularly.

Ⓐ Jaundice / Liver Jaundice

- Yellowish colouration of eyes / skin due to presence of bile pigments in blood; due to blockage of bile duct by cholesterol.
- Symptoms include :- vomiting, loss of appetite, itching of skin, Low pulse rate,
- Treatment and control includes :-
  (i) Removal of stones from gall bladder or bile duct
  (ii) Administration of antihistamines to reduce itching
  (iii) Dietary restrictions eg fat-free, low-protein diet.

HOMEOSTASIS

- Homeostasis is the maintenance of a constant steady internal environment of cells within narrow limits.
- Internal environment of cells refers to the tiny fluid-filled spaces that surround the cells known as intercellular or interstitial or tissue fluid,
- In contrast, external environment refers to immediate surrounding of an organism - aquatic or terrestrial.
- Tissue fluid is formed when blood in the capillaries undergoes ultrafiltration due to the beating action of the heart and the narrowing of capillaries, which results in increased resistance to blood flow hence forcing out components of blood of smaller molecular weight out of capillaries into intercellular spaces.

- cells get nourished from this bathing fluid and pass out waste products into it (at the venule side). This is achieved by diffusion, active transport and osmosis.
- factors such as osmotic pressure of body fluids, temperature, ionic concentration, pH of body fluids and blood-sugar level have to be kept constant for normal functioning of cells.

Principles of Homeostasis

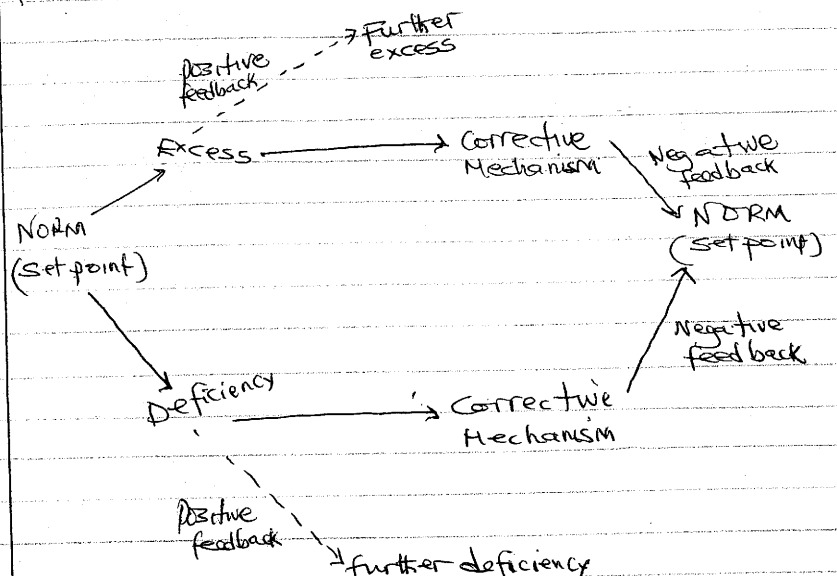
- Various body systems such as excretory, circulatory, excretory, endocrine / hormonal and nervous work in a cordinated way to bring homeostasis. In order to maintain a state of balance in the internal environment, these systems work on a feedback Mechanism.
- There are two types of feedback mechanisms :-

Ⓐ Negative feedback Mechanism

- When a factor in the body eg temperature or blood sugar level drops below the normal or shoots above the normal it is detected and corrective action taken to restore the condition to normal.
- Such an action is either :-
  (i) an increase in level if it was dropping,
  (ii) a decrease in level if it was increasing.
- Such a response bringing about a corrective measure is called negative feedback
- **Negative feedback** is a mechanism / process in which the products of a process inhibit the source such that the production of the same product is stopped thereby bringing about a corrective response.

(b) Positive feedback

- In positive feedback, a change below or above the normal is not corrected and instead what is meant to be a corrective action leads to further undesirable change from the normal as shown below:-



- Homeostasis is normally based on the negative feedback mechanism.
- The components involved in homeostasis are related as follows:-
  (i) Change in internal environment is detected by receptors eg skin.
  (ii) Impulse is conveyed to CNS / Control centre.
  (iii) Control centre sends appropriate impulses to effectors such as muscle or glands.
  (iv) Effectors carry out corrective responses eg sweating.

THERMOREGULATION

Role of Hypothalamus in Thermoregulation

- Thermoregulation is the regulation of body temperature within narrow limits.
- Thermoregulation is controlled by hypothalamus which is a small region of the brain between the cerebrum and cerebellum.
- External temperature changes are perceived by thermoreceptors in the skin and conveyed through sensory neurones to the hypothalamus.
- Internal temperature changes are perceived by thermoreceptor cells in the hypothalamus as blood passes through it.
- When hypothalamus detects a drop or rise in temperature, it initiates mechanisms which correct the situation by stimulation of skin, liver, and other appropriate effectors.
- Hypothalamus also controls other homeostatic processes eg osmoregulation and blood-sugar levels in mammals.

(a) The Skin and Thermoregulation

- The following parts of the skin are involved in thermoregulation:-

(i) Sweat glands — When temperature increases sweat glands are stimulated to increase sweat production. Sweat evaporates from the skin surface taking away excess heat in form of latent heat of vaporisation resulting in cooling. When environmental temperature is low sweat glands are inactivated, no or little sweat is produced and hence heat is conserved in the body.

ii) Hairs and erector/pili muscles

- When temperature lowers, erector/pili muscles are stimulated to contract, making the hairs to stand erect thus trapping air with the hair follicles. Air being a poor conductor of heat, insulates against heat loss.
- When environmental or body temperature is higher than normal, erector pili muscles are stimulated to relax, thus hairs lie flat on skin surface. Hence little or no air is trapped within the hair follicles encouraging heat loss by radiation and convection. The body temp. thus reduces to the norm.

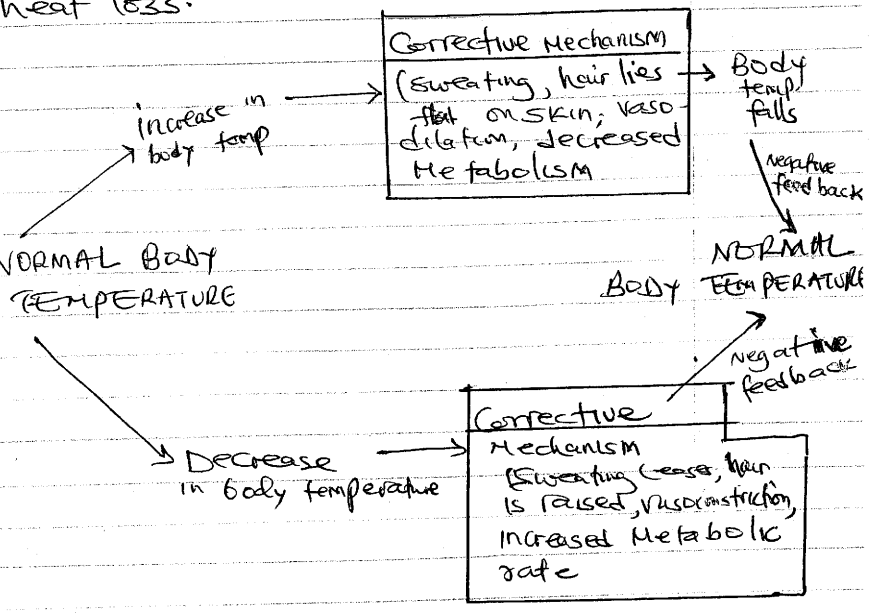
iii) Blood vessels/arterioles

- When body temperature lowers blood vessels in the skin vasoconstrict (shrink and tend to lie deeper in the skin and their diameter reduces. Thus is vasoconstriction. Blood is also directed to a shunt system. Thus reduces blood flow to the skin and more blood is stored in liver and spleen thus conserving heat in the body.
- When body temperature is high blood vessels enlarge in diameter and tend to lie close to the skin surface. This is vasodilation. Thus more blood flows along the skin encouraging heat loss by radiation, convection hence reducing body temp. to the norm.

iv) Sub-cutaneous fat

- Thick sub-cutaneous fat is a good insulator against heat loss. Animals in

cold places have thick subcutaneous fatty layers whereas those in warm areas have the fatty layers thin to encourage heat loss.



(b) Metabolic Activities of the liver and Thermoregulation.

- When temperature is low, the hypothalamus sends impulses to the liver to increase exothermic Metabolic activities to produce more heat, a process called thermogenesis. The heat is distributed in blood to all body parts.
- When temperature is high, hypothalamus stimulates the liver to decrease Metabolic activities hence reducing heat production.

(c) Other factors involved in thermoregulation

i) Muscles

- When temperature is low, involuntary

contraction and relaxation of muscles takes place. This is shivering which generates heat to maintain body temperature. There is no shivering when body temperature is high.

iii, Behavioural responses/activities

- Hypothalamus stimulates the following responses:-

1. coiling, clustering, putting on of heavy clothing, burrowing which leads to decreased surface area to decrease heat loss/ conserve heat.
2. Basking, warming around fire - to help raise body temperature.
3. Hibernation - going to prolonged sleep or becoming inactive in cold conditions. This leads to low Metabolic activities.
4. Aestivation - going to prolonged sleep or becoming inactive when it is hot.
5. Migrations from adverse environmental conditions of temperature - too cold or too hot.

Classification on Basis of Thermoregulation

① Homoiotherms / endotherms.

- Animals which regulate their body temperatures eg mammals and birds.

② Poikilotherms / exotherms / ectotherms

- Animals which do not regulate their body temperatures ie temperature depends on that of the surrounding eg amphibians, fishes and reptiles.

Advantages of Homoiotherms over exotherms

① Homoiotherms maintain a constant body temp. optimum for enzyme activities. This also prevents overheating / heat stroke.

② Homoiotherms are active throughout.

③ Homoiotherms can inhabit many habitats both cold and hot.

④ Able to escape from predators, search for food, water and mates;

Osmoregulation

(a) Role of the skin in Osmoregulation. (Salt and water balance).

- Although the skin is not the main organ for Osmoregulation, it excretes sweat which is 99% water, and 1% salts, urea, uric acid and lactic acid. This causes osmotic pressure changes in body fluids. For example when it is hot alot of sweating causes dehydration. This results in the sensation of thirst followed by urge for intake of alot of water and salt containing fluids to restore lost water and Mineral salts.

(b) Role of Kidneys in Osmoregulation.

- The relative amounts of salts / solutes and water in blood, tissue fluids and protoplasm determine their osmotic pressure.
- changes in osmotic pressure can affect Metabolic activities of cells eg if osmotic pressure of body fluids falls below that of the cells (ie is hypotonic) cells would get haemolysed; if it becomes hypertonic, cells would be crenated.
- Osmoregulation attempts to maintain

an optimum osmotic pressure in body tissues and fluids that is favourable to normal functioning of cells.

- The body gains water through drinking water/fluids, in food taken and metabolic water.
- The body looses water through sweating, faeces, urine and exhaled air.
- These changes produce corresponding changes in salt and water. Balance of salts and water is carried out by kidneys and the neuro-endocrine system (hypothalamus and pituitary gland).
- When osmotic pressure of body fluids rises due to dehydration, the hypothalamus is stimulated and sends impulses to the pituitary gland to secrete Antidiuretic hormone (ADH) or Vasopressin into blood. On reaching the kidneys, ADH makes the kidney's Distal convoluted tubules (DCT) and collecting ducts and tubules more permeable to water which is then reabsorbed into blood stream. Consequently osmotic pressure of body fluids is lowered to the normal; and urine produced is concentrated and little.
- When osmotic pressure of body fluids falls due to large intake of water, the pituitary gland is less stimulated. Therefore little or no ADH is secreted into the blood stream. The kidney tubules become less permeable ~~to~~ and therefore less water reabsorption takes place. Osmotic pressure of blood rises and large quantities/copious

quantities of dilute urine is produced.

Regulation of Ionic Content :- Role of Kidneys, Gut and bones

- Salts dissolve in water and dissociate into ions eg $NaCl \longrightarrow Na^+ + Cl^-$
- These ions and many others eg K^+, Ca^{2+}, Mg^{2+}, PO_4^{3-} are important in body processes such as protein synthesis, nervous transmission of impulses and muscle contraction.
- The balance of these ions is regulated within narrow ranges of their optimum concentrations for efficient functioning of these processes.
- A hormone called aldosterone produced by adrenal glands regulates levels of Na^+ salts/ions in blood. When level of Na^+ salts is low in blood, adrenal glands are stimulated to release aldosterone into blood which then stimulates the loop of Henle of kidneys of the mammal to reabsorb more Na^+ salts and the gut to absorb the Na^+ salts into blood stream. This is automatically followed by reabsorption and absorption of Cl^- ions to balance the charge.
- When the level of Na^+ salts rises in blood adrenal glands are less stimulated and little or no aldosterone is secreted into blood hence less reabsorption of Na^+ salts by loop of Henle and less absorption of the Na^+ salts by the gut; hence

osmotic pressure drops to the normal.
—The concentration of other ions eg K^+, Ca^{2+}, PO_4^{3-} is regulated by the kidneys, gut and bones. For example, a hormone known as parathormone secreted by the parathyroid gland regulates the levels of Ca^{2+} ions in blood. When the level of Ca^{2+} ions falls in blood, parathyroid gland is stimulated to secrete parathormone hormone which stimulates :-
(i) kidneys to conserve / reabsorb Ca^{2+} from glomerular filtrate
(ii) intestines to absorb Ca^{2+} from food
(iii) bones to release Ca^{2+} into blood.

Regulation of pH - acid-base balance :- Role of kidneys

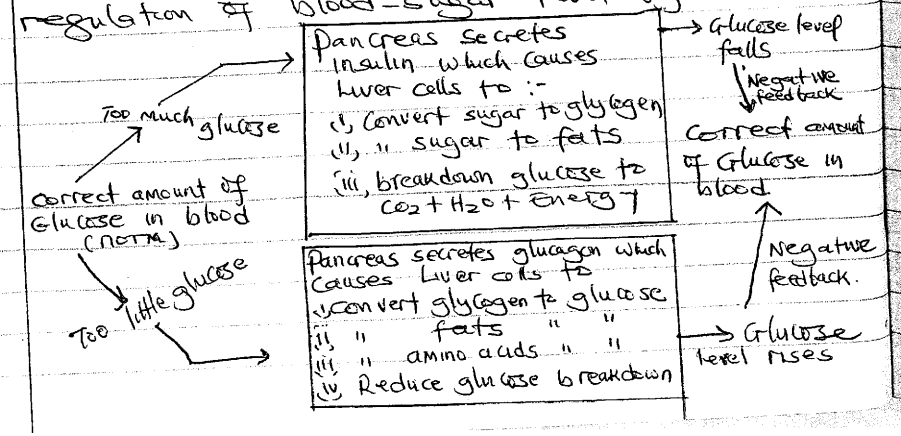
—pH of body fluids is maintained between 7.2 — 7.4.
— However chemical reactions in cells alter this pH. Intake of substances eg food and drugs also alter pH.
—Increase in pH (alkalosis) is mainly due to deamination of excess amino acids which releases NH_4^+ ions into blood. This is counteracted by retention of H^+ or reduction of H^+ excreted by kidneys.
—Decrease in pH (acidosis) is mainly due to respiration which produces CO_2 leading to formation of H_2CO_3 and dissociation into H^+ ions. This is counteracted by active excretion of H^+ by kidneys in urine.

Role of Liver in Homeostasis

① Regulation of blood-sugar level.

—All sugars, galactose and fructose taken to the liver from alimentary canal by hepatic portal vein are converted to glucose. Glucose is then broken down to yield energy and excess glucose is converted to glycogen for storage in the liver, or converted to fats and stored as adipose tissue.
—Some glucose flows in general circulation and its concentration is maintained within narrow ranges of 90mg — 100mg / 100ml of blood.
— However fluctuations do occur due to large supplies of glucose or increased utilisation of glucose in cells.
—A steady concentration of glucose in blood is maintained by the liver under influence of two hormones — insulin and glucagon from the pancreas. The two hormones work antagonistically.
— When glucose level increases in blood above the normal ie hyperglycaemia, the pancreas is stimulated to secrete insulin. Insulin is carried in blood to the liver and stimulates liver cells to
(i) convert excess glucose to glycogen
(ii) convert excess glucose to fats
(iii) oxidise excess glucose to CO_2, H_2O and energy / increase glucose respiration / Metabolism.
—Glucose level thus falls to the normal. During this time the pancreas

secretes less glucagon.
- When glucose level in blood decreases below the norm, the pancreas is stimulated to secrete more glucagon (and less insulin). Glucagon is carried in blood to the liver cells and stimulate liver cells to :-
  (i) break down glycogen to glucose
  (ii) break down fats to glucose
  (iii) breakdown amino acids to glucose.
  (iv) decrease rate of glucose metabolism.
- Thus glucose level is raised to the normal.
- Insulin and glucagon hormones are secreted from interstitial cells of the pancreas in the islets of Langerhans.
- Another hormone adrenaline produced by adrenal glands also has homeostatic effect on glucose. Thus hormone is secreted during emergency to increase availability of glucose for respiration. In high concentrations, it causes hydrolysis of glycogen to glucose.
- Below is a homeostatic scheme showing regulation of blood-sugar level by hormones:



(2) Deamination :
- Excess amino acids are deaminated by removal of the amino-group.
- The amino group is converted to ammonia.
- Ammonia being highly toxic can not be retained in cells, hence is combined with carbon(IV) oxide to form urea in the ornithine cycle under a series of enzymatic reactions.
- Urea is then excreted in urine through the kidneys. Some urea is also eliminated in sweat by the skin.

$$2NH_3 + CO_2 \longrightarrow CO(NH_2)_2 + H_2O.$$

(3) Detoxification :
- Some metabolic activities in the liver produce poisonous substances such as ammonia and hydrogen peroxide.
- The liver also receives some poisonous substances by way of drugs, food or drinks
- Liver cells convert these harmful or poisonous substances to less harmful substances by either oxidation combination or reduction eg

① $2H_2O_2 \xrightarrow[\text{Catalase}]{\text{Enzyme}} 2H_2O + O_2$

② $2NH_3 + CO_2 \xrightarrow[\text{Enzyme arginase}]{\text{ornithine cycle}} CO(NH_2)_2 + H_2O$

④ Thermoregulation (Maintenance of body temperature;

- Heat is generated in the liver by exothermic metabolic chemical activities. The heat is then distributed by blood to all body parts hence maintaining body temperature;

THE ROLE OF THE LIVER IN EXCRETION.

① Formation and elimination of urea

- Excess amino acids from breakdown of protoplasm and digestion of proteins are deaminated by removal of the amino-group. The amino group is converted to ammonia. Ammonia is combined with CO_2 to form urea in the ornithine cycle in a series of enzyme-controlled reactions.

$$2NH_3 + CO_2 \longrightarrow CO(NH_2)_2 + H_2O$$

- Urea so formed is passed to plasma bloodstream and eventually out of the body through the kidneys.

② Breakdown of haemoglobin from old and worn out RBCs

- Old and worn-out RBCs are broken down by kupffer cells in the liver. The haem-group is then broken down to bilverdin and bilirubin pigments which are excreted in bile into the alimentary canal and out in faeces.

Some residual pigments are excreted as urochromes in urine.

③ Excretion of excess cholesterol through bile.

- Excess cholesterol ingested in food is collected in the liver and eliminated through bile. Cholesterol is an important component of the cell membrane. Excess cholesterol especially by way of food into the body is excreted by the liver in bile.

④ Inactivation of drugs and hormones and their excretion.

- The liver inactivates hormones whose functions are over and eliminates them through bile or the kidneys. In like manner drugs are metabolised in the liver and excreted through bile or into blood stream to be excreted in urine

⑤ Detoxification of poisonous substances and their elimination

- Poisonous substances which get into the body by way of food such as alcohol and drugs are broken down or converted to less toxic substances which are then eliminated in bile or passed into blood stream and eliminated via kidneys, lungs or skin.