TRANSPORT

Definition: Transport is the movement of materials from one part of an organism to another part

MOVEMENT OF MATERIALS IN AND OUT OF CELLS

This is vital for all living organisms.

Unicellular organisms like amoeba and multicellular organisms have simple methods of transporting materials in and out of the cells to sites where they are needed or removed as waste products.

There are several functions of transport systems of organisms which include;

(i) To transport materials from one part of the body to another in order for an organism to obtain its body requirements.
(ii) To transport wastes out of the body in order to minimize toxicity. Incase toxins accumulate in the body like carbon dioxide which is a product of respiration is toxic to parts of body, therefore it is transported to the gaseous exchange system where it is expelled out of the body.
(iii) Transport enables movement of important substances such as hormones, enzymes, water.
(iv) It enables movement of respiratory gases i.e. oxygen is transported away from alveoli after diffusion into the transport system.

In higher organisms/multicellular organisms, both plants and animal tissues are bulky therefore the body is complex. Diffusion alone can’t efficiently supply the body requirements such organisms involve; a highly vascularized tissue to enable them conduct materials throughout the body.

Question: Explain the significance of transport system in multicellular organisms.

Transport system in animals consists of the following;

(i) Tubular tissues of transportation channels called **blood vessels** and **lymphatic vessels**.
(ii) Transportation medium of a fluid called **blood** or **lymph** that dissolves substances
(iii) A pumping organ called the **heart** for circulating materials around the body of an organism.

Plants don’t have a pumping organ but have vascular tissues of **xylem tissue** which transports water and mineral salts and **phloem tissue** that translocates manufactured food.

There are 5 processes by which materials move in and out of cells namely;

1. Diffusion
2. Osmosis
3. Active transport
4. Phagocytosis
5. Pinocytosis

Question: State the processes by which materials move in and out of cells.

DIFFUSION

This is the net movement of molecules or ions from a region of high concentration to a region of low concentration across a fully permeable membrane.

- Diffusion is a passive process because it doesn't require energy and oxygen.
- The difference in concentration of molecules/ions between the 2 regions is called a **concentration gradient.**
- Diffusion of materials occurs along/down a concentration gradient i.e. from a region of high concentration to a region of low concentration.
- Diffusion continues to occur until a uniform concentration gradient is reached i.e. when the system reaches a dynamic equilibrium like movement of air molecules (oxygenated) from the lungs where they are in high concentration into red blood cells via the alveolar lining (membrane) where oxygen concentration is low.
- Diffusion occurs in living and non-living structures like across alveoli and non-living structures such as movement of gases in the atmosphere.
- Diffusing molecules can be solids, liquids or gases.

Examples of diffusion

1. When a drop of ink is placed into a glass of water, the colour of ink spreads in the water until all the water is equally coloured by the ink particles.
2. We are able to smell perfume that other people have applied because the particles of perfume diffuse from them through the air to our noses.

Question: Explain why diffusion is a passive process.

Types of diffusion

1. **Simple diffusion**
   This is where molecules or ions move freely across the cell membrane without being aided.
2. **Facilitated diffusion**
   This is the type of diffusion where molecules or ions move across the cell membrane by being aided with a protein carrier.

AN EXPERIMENT TO DEMONSTRATE DIFFUSION OF A SOLID/SOLUTE IN A LIQUID/SOLVENT

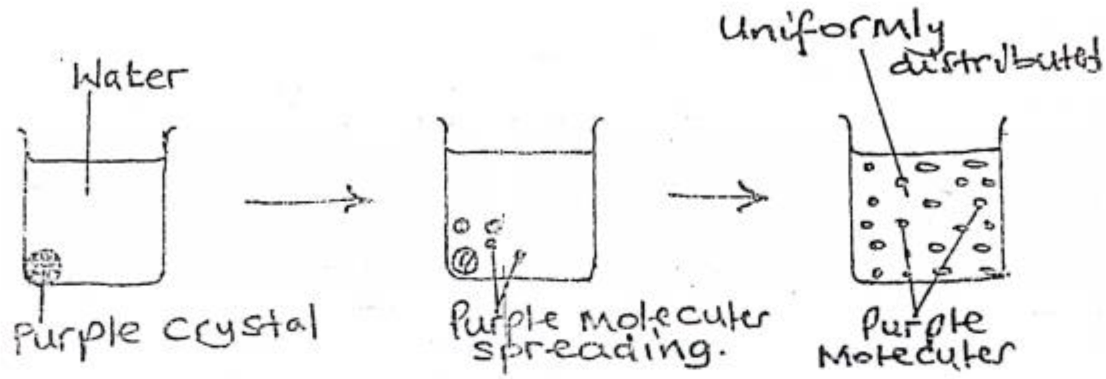
REQUIREMENTS

- Potassium permanganate crystals/ copper (II) sulphate crystals.
- Water
- Beaker
- Glass tube
- Measuring cylinder
- Stop clock

PROCEDURE

- Fill the beaker with about $250cm^3$ of water.
- Drop a few crystals (4) of purple potassium permanganate at the bottom of water in the beaker through the glass tube.
- Note the time on the stop clock.
- Leave the set up to stand undisturbed for 30 minutes
- Observe and note the changes every after 5 minutes
- Note the time when the water will be uniformly coloured.

EXPERIMENTAL SET UP



OBSERVATION

- The potassium permanganate crystals dissolve in water, forming a purple coloured solution that slowly spreads from the origin (bottom of the beaker) through the water until the purple colour is equally/uniformly distributed in water.
- Parts far from the origin of the purple colour take longer to be coloured.

CONCLUSION

- Diffusion of potassium permanganate ions from a region of their higher concentration to their regions of lower concentration in water occurred.

NB:

- ✓ Blue copper(II) sulphate crystals can be used instead of the purple potassium permanganate.
- ✓ Solution of potassium permanganate/ copper (II) sulphate can be used instead of the crystals to demonstrate diffusion of a dissolved solute in water.

Question: Describe an experiment to demonstrate diffusion in a liquid.

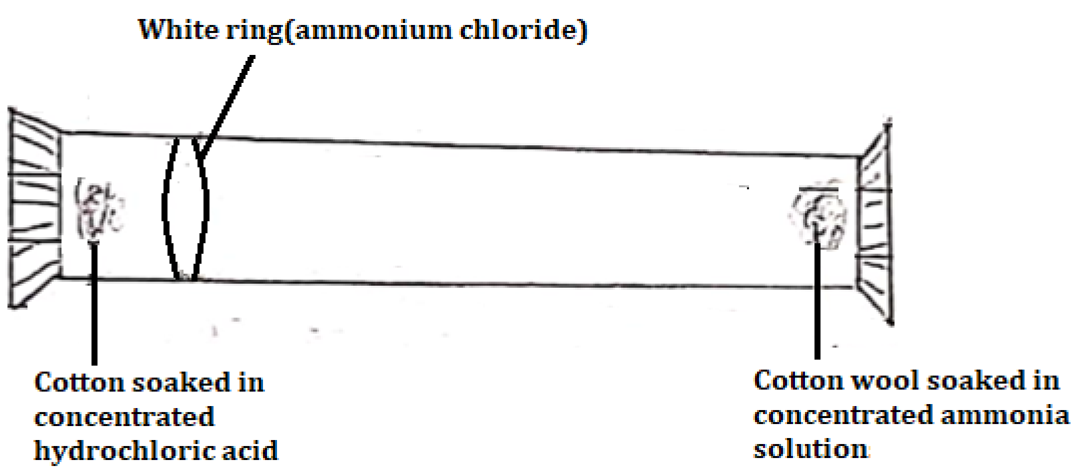
AN EXPERIMENT TO DEMONSTRATE DIFFUSION IN GASES

REQUIREMENTS

- Cotton wool
- Concentrated ammonia solution
- Concentrated hydrochloric acid
- Glass tube
- Rubber band

PROCEDURE

- A piece of cotton wool is soaked in concentrated ammonia solution and another piece is soaked in concentrated hydrochloric acid.
- The two pieces are then placed at the opposite end of a glass tube as shown in diagram below.



- A cotton wool soaked in ammonia solution is placed on side while that soaked in hydrochloric acid is placed on the other side.

OBSERVATION

- A white ring is formed towards the cotton wool soaked in hydrochloric acid.

CONCLUSION

- Ammonia gas molecules from concentrated ammonia solution and hydrogen chloride gas molecules from concentrated hydrochloric acid diffuse towards each other.
- Ammonia gas molecules diffuse faster than hydrogen chloride gas because its lighter/less dense.

Question: Describe an experiment to demonstrate diffusion in gaseous.

Question: Explain why a white ring is formed on the side of the cotton wool soaked in concentrated hydrochloric acid.

ALTERNATIVELY

AN EXPERIMENT TO DEMONSTRATE DIFFUSION OF A GAS

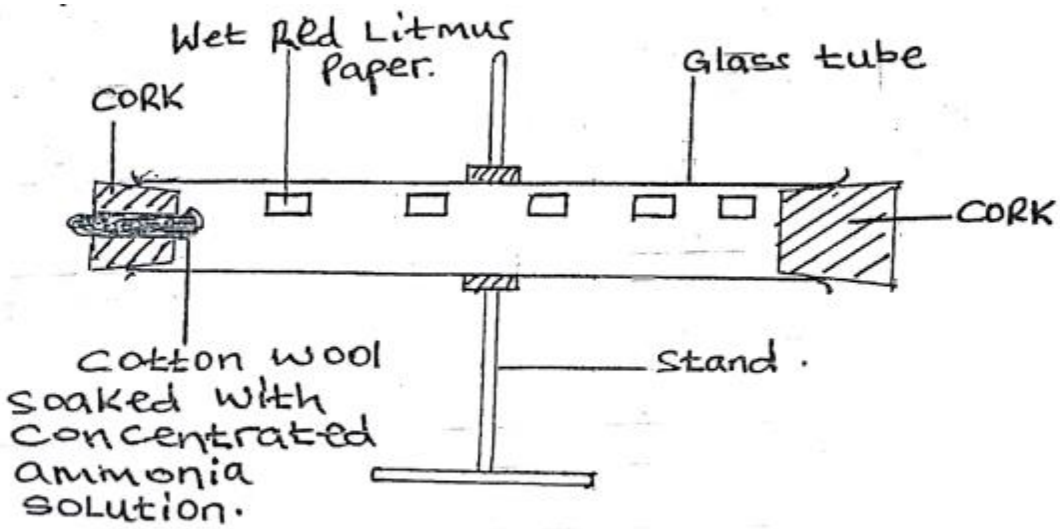
REQUIREMENTS

- Red litmus paper
- Water
- Wide glass tube
- Cork
- Concentrated ammonia solution
- Cotton wool
- Glass rod/wire
- Stand and clamp

PROCEDURE

- Cork one end of the glass tube.
- Wet the red litmus papers.
- Push squares of the wet red litmus papers using a glass rod/wire at even intervals sticking them to the inside wall of the glass tube.
- Soak cotton wool in concentrated ammonia solution and use it to close the open end of the glass tube.
- Support up the glass tube using a stand and a clamp.
- Note the time taken for each litmus paper to change colour from red to blue.

EXPERIMENTAL SET UP



OBSERVATION

- The red litmus papers turn blue at time intervals starting one nearest the cotton wool up to the last one.

CONCLUSION

- The alkaline ammonia gas has diffused along the inside of the glass tube.

FACTORS AFFECTING THE RATE OF DIFFUSION

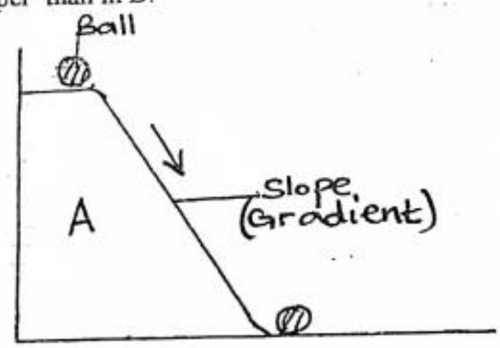
1. Concentration gradient/diffusion gradient
2. Temperature
3. Diffusion distance (thickness/size of material across which diffusion occurs)
4. Size and density of diffusing molecules/particles
5. Surface area
6. Permeability of the membrane(number & size of pores in the material across which diffusion occurs)

1. **CONCENTRATION GRADIENT/DIFFUSION GRADIENT**
   This is the difference in concentration of particles between the two regions where diffusion occurs.
   The greater the difference in concentration between two regions of a diffusing substance, the faster the rate of diffusion due to a steeper the concentration gradient, and the smaller the difference in concentration between the two regions, the slower the rate of diffusion due to a less steep the concentration gradient.

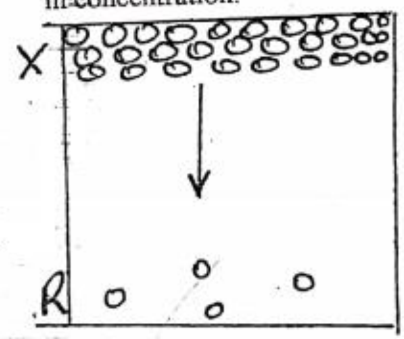
   ILLUSTRATION

   Consider a ball released from 2 hills with different slopes/gradients down the slope to represent diffusion of particles between regions with different concentration gradients.

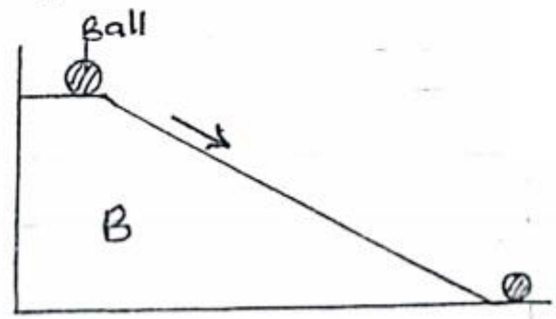
A. The ball is faster because the gradient/slope is steeper than in B:



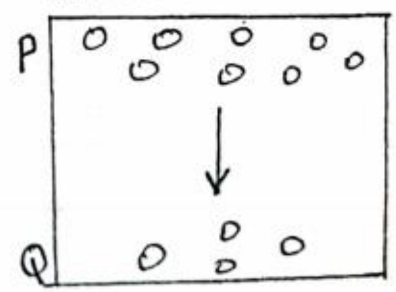
Diffusion is faster between region X and R due to greater difference in concentration:



B. The ball is slower because the gradient/slope is less steep than in A:



Diffusion is slower between region P and Q because there is little difference in concentration.



HINT: Steep concentration gradient can be maintained by not allowing the particle that has diffused to accumulate but must be kept low by being carried away like blood that carries away absorbed food from the ileum and oxygen from the alveoli to maintain a steep diffusion gradient.

2. **TEMPERATURE**
The higher the temperature, the faster the rate of diffusion and the lower the temperature, the slower the rate of diffusion. This is because, increase in temperature increases the kinetic energy gained by the diffusing molecules, thus move at higher velocities/speed leading to increase in rate of diffusion. Decrease in temperature; decrease the kinetic energy gained by diffusing molecules/ions thus move at low velocities/speed thus low rate of diffusion.
E.g. tea molecules diffuse faster when placed in a beaker containing hot water than another containing cold water.
3. **DIFFUSION DISTANCE(Thickness of material through which diffusion occurs)**
    - This is the distance over which diffusion occurs.
    - The shorter the distance between two regions of the diffusing substance, the faster the rate of diffusion and the longer the diffusion distance, the slower the rate of diffusion. This is because molecules/ions take long time to diffuse across the longer distance thus slow rate of diffusion but

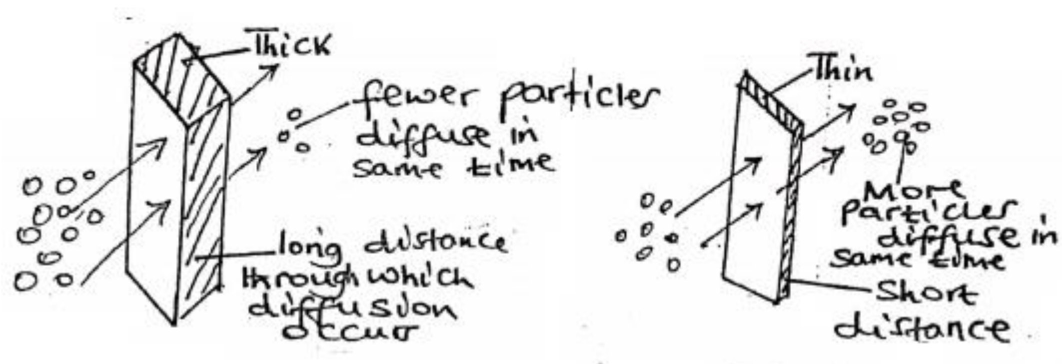
molecules/ions take short time to diffuse across a short distance thus faster rate of diffusion.

i.e.

- ✓ The thinner, the shorter the distance across which diffusion occurs, thus faster rate of diffusion.
- ✓ The thicker, the longer the distance across which diffusion occurs thus slower rate of diffusion.

Hint: This explains why body structures where diffusion often occurs like cell membranes, alveolar membranes(alveoli) in lungs, villi, and capillary walls have a thin epithelium; leaves are thin/flattened and flatworms like tapeworms are flattened (reduced distance between the surfaces) to provide a short distance for diffusion therefore increasing the rate of diffusion.

Illustration



4. **SIZE AND DENSITY OF DIFFUSING MOLECULES/PARTICLES**

   Small molecules diffuse faster than big (large) ones. The denser the molecule, the lower the rate of diffusion. This is because small particles have less inertia than heavy, big ones.

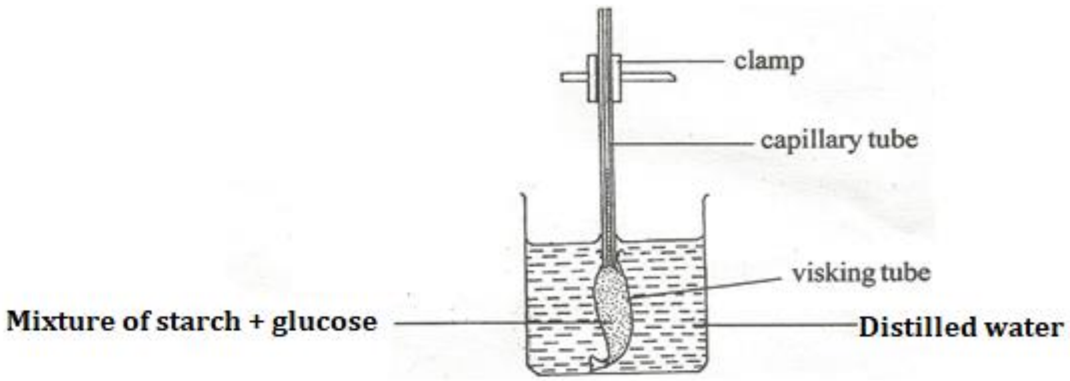
   HINT: Certain structures like cell membranes, visking tubes etc, are semi-permeable/partially permeable/selectively permeable because they have pores that allow only substances with smaller size to diffuse through and prevent those with larger size.

   E.g.

   (i) Starch and protein molecules are too large to diffuse through the small pores in cell membranes and visking tubes.

   (ii) Glucose, water and salt molecules are small enough to diffuse through the small pores in the cell membranes and visking tubes.

Question: An experiment was arranged as below & left to stand for 40mins.



(a) State what was observed after the 40mins when the contents of the beaker were tested for;
   (i) Starch **[Absent]**
   (ii) Glucose **[Present]**

(b) Explain the observations made.

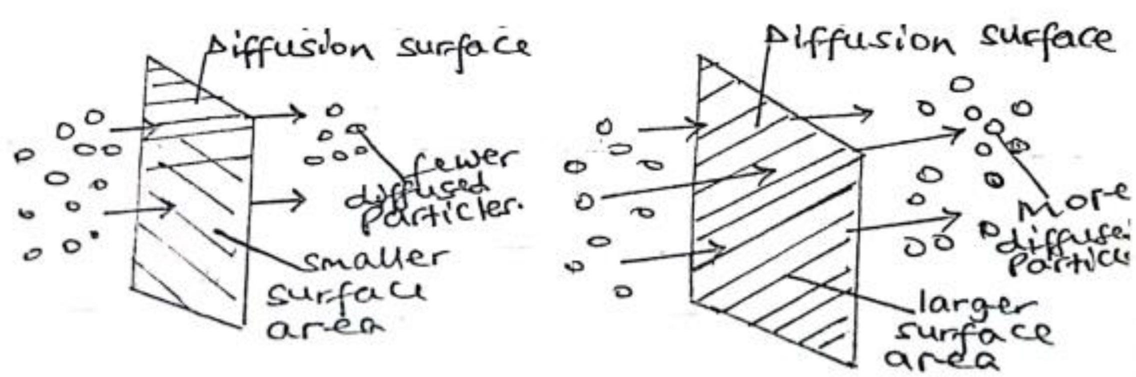
5. SURFACE AREA

This is the area over which diffusion occurs. The larger the surface area; the greater the rate of diffusion and the smaller the surface area ; the slower the rate of diffusion. This is because the larger the surface area, the more avenue for diffusion of molecules thus faster diffusion rate and the smaller the surface area, the less avenue for diffusion of molecules thus the slower the rate of diffusion. Keeping other factors like temperature, concentration etc constant.

Examples

- Diffusion surfaces like;
  - ✓ .Gill filaments, alveoli, blood capillaries and villi are numerous to provide large surface area for diffusion.
  - ✓ Dicot leaves are broad to provide large surface area for diffusion of a lot of gases.
  - ✓ Ileum has numerous villi to increase the rate of diffusion.

Illustration



6. **PERMEABILITY OF THE MEMBRANE**(number & size of pores in the material across which diffusion occurs)
   The more porous (permeable) the membrane is, the faster the rate of diffusion and the less porous the membrane is, the slower the diffusion rate. This is because, the more porous the membrane is, the higher the number of particles that diffuse through it and hence the higher the diffusion rate and vice versa.
   i.e.
   - The larger the pores the faster the rate of diffusion.
   - The more numerous the pores the faster the rate of diffusion.

   Examples
   - The larger the stomata of a leaf, the faster the diffusion of gases for photosynthesis and respiration.
   - The more the number of stomata of a leaf the more gases that diffuse.

Question: Explain factors affecting the rate of diffusion.

SIGNIFICANCE/IMPORTANCE OF DIFFUSION

1. Allows exchange of gases at alveoli in lungs within mammals, and through stomata of leaves thus, it plays a role in photosynthesis because it allows the entry of carbon dioxide.
2. Facilitates absorption of digested food materials in the ileums e.g. glucose.
3. Enhances movement of hormones from endocrine glands into blood to target cells/organs.
4. Facilitates absorption of some mineral salts by plant roots.
5. Enables movement of mineral salts across the cortex of roots.
6. Enhances exchange of materials at capillary bed between blood capillaries and respiring tissues (exchange of materials between tissue fluid and cells).
7. Enhances excretion of metabolic waste products like ammonia in fresh water fishes (enables removal of excretory waste products from plants and animals).
8. Facilitates selective reabsorption of materials in the kidney.
9. Enables formation of the glomerular filtrate in the kidney.
10. Facilitates respiration, constant use of oxygen and release of carbon dioxide in the tissues lead to low concentration as a result of oxygen diffuses into cells while carbon dioxide diffuses out.
11. It is a major process of exchange of materials in unicellular organisms like amoeba.
12. Harnesses transportation of materials within cellular cytoplasm.
13. Facilitates nerve impulse generation and transmission/propagation.
    - Movement of sodium ions when sodium ion gates open during transmission of nerve impulses.
    - Diffusion of neurotransmitter substances at synapse; thus, enhancing synaptic transmission.

OSMOSIS

Definition: Is the net movement of solvent molecules from a region of their higher concentration to a region of their lower concentration across a semipermeable.

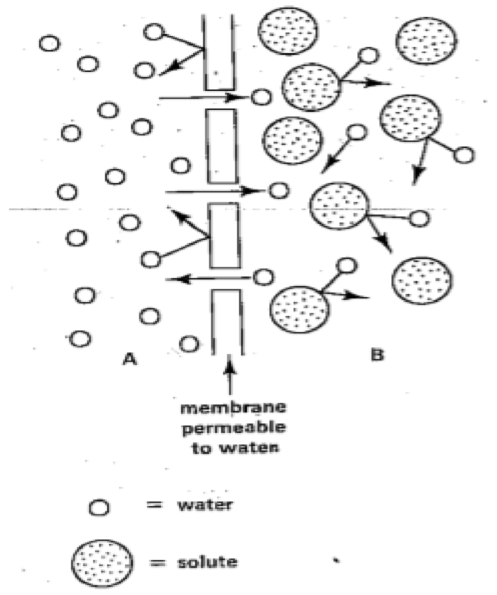
OR

Is the movement of solvent molecules from a region of low solute concentration (dilute solution) to a region of high solute concentration (concentrated solution) across a semi-permeable membrane.

In other words, is special form of diffusion/ is the diffusion of solvent molecules across a semi (selectively) permeable membrane.

A semipermeable/selectively/partially permeable membrane is the one that permits the passage of some substances but not of others i.e. it restricts passage of certain molecules (permits passage of solvent molecules but not of solutes).

Consider as system of less concentrated solution A and more concentrated solution B separated by a semi-permeable below as shown below.



In the above system, water moves from solution A to solution B through the semi-permeable membrane by **osmosis**.

NB: In biotic/biological systems, water is the commonest solvent.

Types of osmosis

(i) **Endosmosis**; Is the osmotic flow of water into the cell.
(ii) **Exosmosis**; Is the osmotic flow of water out of the cell

TERMS USED IN OSMOSIS

1. Hypotonic solution
2. Isotonic solution
3. Hypertonic solution
4. Crenation
5. Haemolysis
6. Osmotic potential
7. Solute potential
8. Osmotic pressure
9. Water potential
10. Pressure potential

1. **Hypotonic solution**; is a solution that has higher concentration of solvent molecules i.e. is more dilute solution.
2. **Isotonic solution**; is a solution that has the same concentration of solute molecules as that of cell sap/adjacent solution
3. **Hypertonic solution**; is a solution that has a lower concentration of solvent molecules/a higher concentration of solute molecules i.e. is a more concentrated solution
4. **Crenation**; is the shrinkage of animal cells due to osmotic loss of water when placed in a hypertonic solution.
5. **Haemolysis**; is the bursting of red blood cells due to excessive osmotic intake of water when placed in hypotonic solution.
6. **Osmotic potential**; is the capacity of a solution to allow water molecules to enter the solution/cell by osmosis.
7. **Solute potential**; it is the measure of amount of solute in a solution.
8. **Osmotic pressure**; is the force built up to stop the flow of pure water molecules into the solution.
9. **Water potential**; is the ability of water molecules to move out of the cell/solution by osmosis.
10. **Pressure potential**; this is a force extended into the cell contents by the cell wall as a result of reaching the cell wall, after water absorption.

OSMOSIS AND DIFFUSION COMPARED

(i) **Similarities**

- Both are passive; don’t require energy (ATP) to occur.
- Both occur along the concentration gradient.
- Both occur in living and non-living systems.

(ii) **Differences**

Osmosis	Diffusion
• Involves movement of solvent molecules. • Occurs across a semipermeable membrane. • Doesn't require channel proteins. • Solvent molecules flow from dilute to concentrated solution.	• Involves movement of molecules or ions. • Occurs across a fully permeable membrane. • Facilitated diffusion requires channel proteins. • Molecules/ions flow from concentrated solution to dilute solution.

NB: A fully permeable membrane; is the one that allows the passage of all materials through it.

EXPERIMENT TO DEMONSTRATE OSMOSIS IN A NON-LIVING TISSUE

REQUIREMENTS

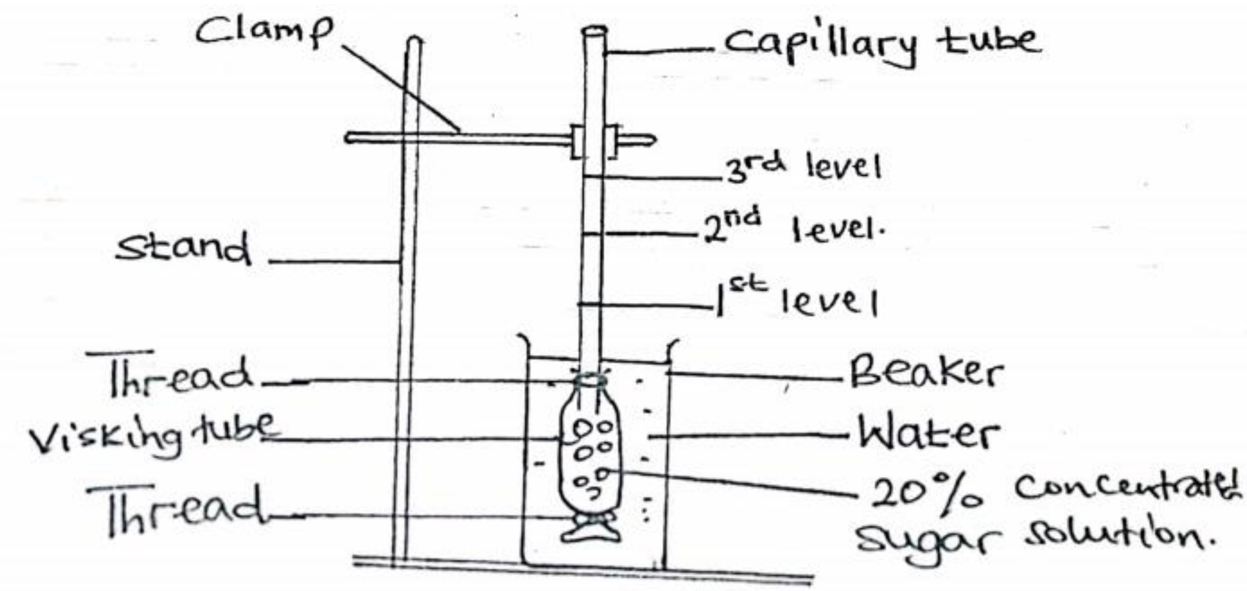
- Distilled water
- Beaker
- Thistle funnel/capillary tube
- Visking tube/dialyzing tube/cellophane tube
- 20% sugar solution
- Restort stand
- Thread/rubber bands
- Ruler

PROCEDURE

- Put $10cm^3$ of distilled water in a beaker.
- Measure and cut an 8cm length of a visking tube.
- Tie tightly one side of visking tube using a strong thread, 1cm from the end.
- Wet your fingers and open the opposite end of the visking tube
- Fill the visking tube about ¾ full, with a strong. 20% concentrated sucrose (sugar) solution.
- Cover the mouth of the thistle funnel/capillary tube tightly using a thread visking tube.
- Ensure that the solution rises to a small extent in the capillary tube.
- Clamp the capillary tube/thistle funnel and lower the visking tube into a beaker containing distilled water, to completely cover the visking tube.
- Mark the level of sucrose solution in the capillary tube using ink pen/a strip paper.
- Mark also the original level of water in the beaker.

- Set up a control in the same way but with water substituted for the sucrose solution in the visking tube **OR** substitute the water in the beaker with sugar solution of the same concentration (20%) as for the one in the visking tube.
- The setup is left to stand, while the levels of sucrose solution and water in capillary tube and beaker are marked in a 10 minute interval for 2 hours.[OR: 5 minute interval for 20 minutes]

EXPERIMENTAL SET UP



OBSERVATION

- After 2 hours, the sucrose solution is found to have risen upwards in the thistle funnel/capillary tube, while the water level in the beaker decreases slightly.
- The longer the time left for the experiment, the higher the rise of sucrose solution in the capillary tube and the more the decrease in water level in the beaker.
- The level of water in the capillary of the control experiment remains unchanged.

CONCLUSION

- Osmosis occurs in a non-living material; the visking tube.

EXPLANATION

- The visking tube acts as a semi-permeable ; allowing water to flow from water in the beaker to hypertonic sucrose solution by osmosis leading to rise in the level of solution in the capillary tube.

EXPERIMENT TO DEMONSTRATE OSMOSIS IN A LIVING TISSUE

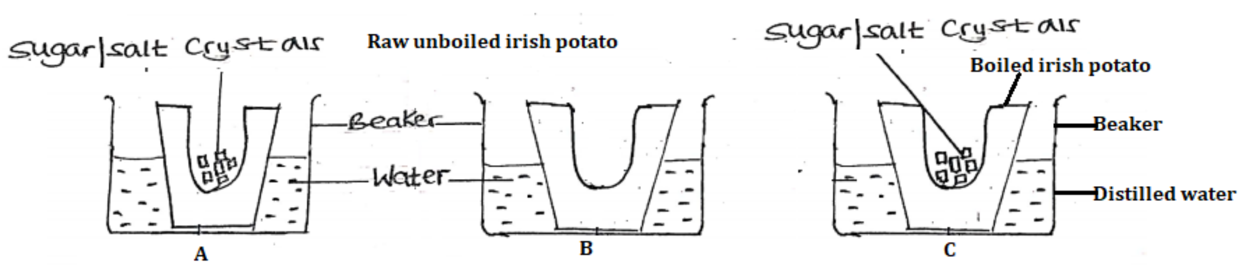
REQUIREMENTS

- 3 Petri dishes/beaker
- 3 Irish potatoes/raw pawpaw/yam
- Knife/scalpel/razor
- Distilled water
- Source to heat
- 2 spoon endfuls of sugar/salt crystals
- Blotting paper

PROCEDURE

- Peel off the epidermis of 3 irish potatoes using a knife and cut them into 2 equal halves/cubes.
- Scoop out the middle cavity of each half/cube of the irish potato using a knife.
- Pick one half/cube of irish potato and boil it in boiling water for 5 minutes to kill the living protoplasm.
- Dry the cubes between blotting paper
- Put 3 irish potato halves/cubes with their flat bases on a petridish and pour some distilled water on the petri dish.
- Put a spoonful of salt in the cavity of the boiled potato half/cube and another spoonful in one of the raw potato halves/cubes.
- The set up with boiled potato tissue acts as the control.
- The setup is left to stand for 3 hours.

EXPERIMENTAL SET UP



OBSERVATION

- In the cavity of the raw potato A, the salt/sugar dissolved to form as solution whose level rose.
- In the cavity of raw potato B, there was no observable change, no solution formed .
- In the cavity of the boiled potato C, there was no observable change, no solution formed. i.e. sugar didn't dissolve, water level in beaker remained the same.
- The water level in petri dish A decreased slightly..

CONCLUSION

- Osmosis occurs in a living tissue but not dead one.

EXPLANATION

- In set up A, osmosis occurred because there was a difference in water potential between the solute molecules in the cavity of the cube and distilled water in beaker.
- In set up B, osmosis didn't occur because; there was no solute molecule in the cavity of the potato tissue to enable a concentration gradient of osmotic flow of water molecules from the petri dish to potato cavity.
- Osmosis didn't occur in set up C, because the semi-permeable membrane of the tissue was destroyed by boiling, therefore doesn't allow movement of water molecules by osmosis across the semi-permeable membrane into the solid.

NB:

- ✓ The plasma membrane is functional in A therefore causes osmotic flow of water molecules from the petri dish to the potato cavity.
- ✓ When water moves across a semi-permeable membrane by osmosis into the solution, a pressure is built up to stop the flow of pure water molecules into the solution. This pressure is called osmotic pressure.
- ✓ **Water molecules** tend to move from a region of high osmotic pressure to a region of low osmotic pressure.

EFFECTS OF WATER STRESS IN PLANTS

1. Excessive water loss causes wilting.
2. Stomata rapidly close due to secretion of abscisic acid by the cells in the wilted leaf.
3. Stomata closure reduces photosynthesis due to lack of carbon dioxide.
4. Reduced photosynthesis reduces growth rate causing stunting.
5. Reduced growth rate causes economic losses in commercial agriculture due to reduction in agricultural yield.
6. Excessive water loss may lead to desiccation and drying up of plant which may lead to death.
7. Loss of crops due to wilting leads to food insecurity

IMPORTANCE OF TURGIDITY

1. Turgor pressure maintains the shape and form of the plant.
2. Stems of herbaceous plants and non-woody plants are maintained in an erect position by full turgidity of the parenchyma cells.
3. Turgor pressure holds the leaf lamina in a flat and horizontal position to receive adequate sunlight.
4. Turgidity enhances cell enlargement and stretches the stem leading to increase in stem girth (width).

5. The opening and closing of the stomata is controlled by the turgidity of guard cells.
6. The quick nastic responses *Mimosa pudica* (don't touch me) is controlled by turgor movements.

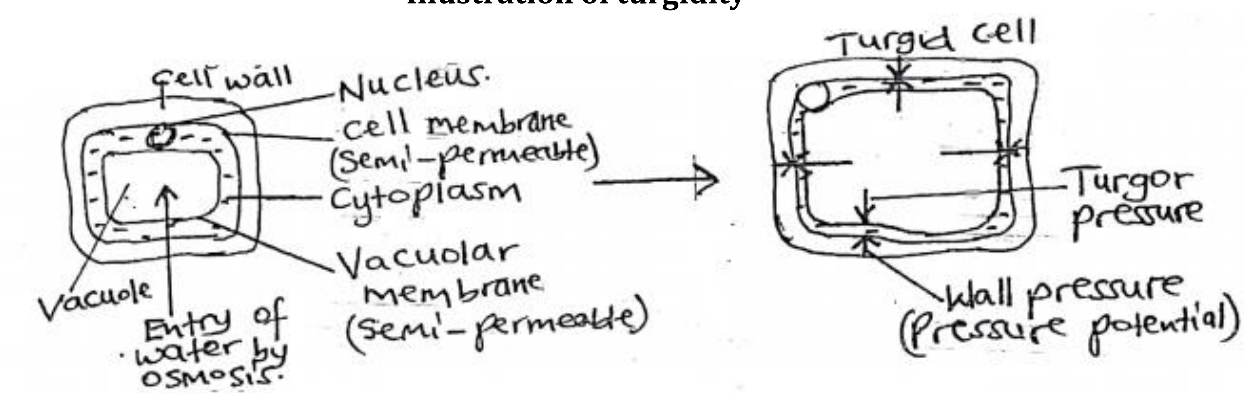
GUTTATION

- This is the loss of water from the tip of leaves in form of water droplets.
- Guttation occurs through specialized cells called hydathodes.

OSMOSIS AND THE CELLS

1. When a plant cell is placed in a hypotonic solution like distilled water, it swells therefore increasing in size because water enters by osmosis as it gains water osmotically, it reaches an extent when no more water molecules can enter it. This is because the cell wall of the plant cell resists further expansion of the place cell.
   At this stage, the cell is said to be fully turgid (condition when body can no more expand when a plant cell is in a hypotonic solution).
   NB: The pressure that exerted outwards by the protoplasm against the cell wall is called turgor pressure.
   The cell wall is tough and rigid therefore when fully stretched; it resists further expansion and exerts a back pressure (opposite pressure) onto the cytoplasm that is equal and opposite to turgor pressure. This pressure is called wall pressure (force equal and opposite to turgor pressure that resists further expansion by the plant cell).

Illustration of turgidity



Question: Explain what happens to the plant cell when placed in a hypotonic solution.

Question: What is meant by ***fully turgid***?

Question: Define **turgor pressure**.

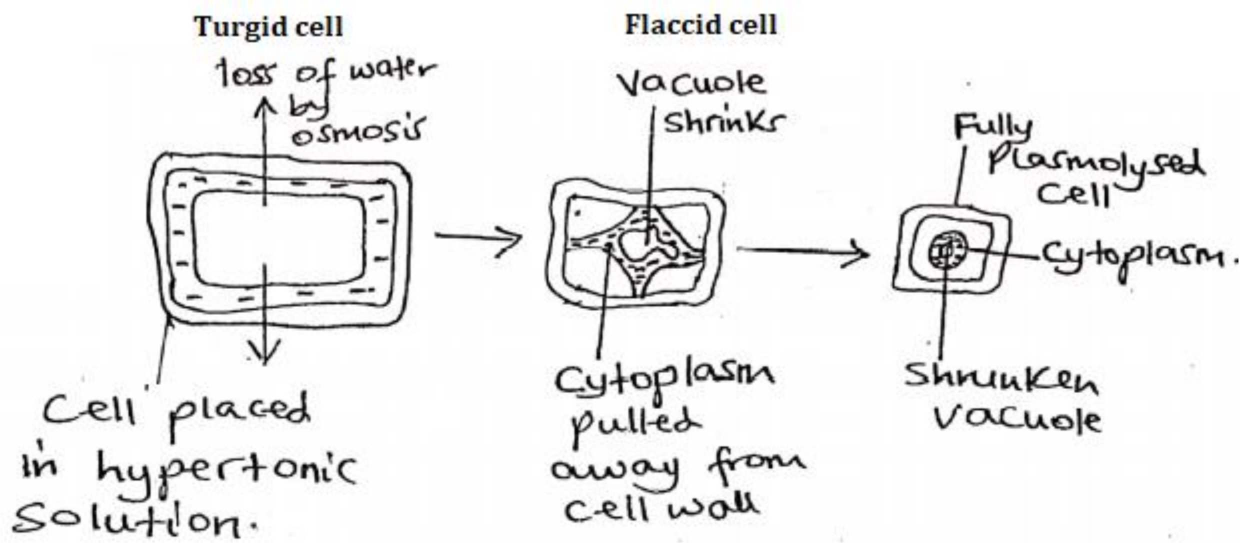
2. When a plant cell is placed in a hypertonic solution, it loses water from the sap vacuole by osmosis.
   The loss of water causes the protoplasm to shrink, thus pulling away from the cell.
   At this point, the cell is said to be flaccid.

Further loss of water, will result into plasmolysis which is a condition when the cytoplasm has completely pulled away from the cell wall and the cell is said to be fully plasmolysed.

Question: Define **flaccidity**.

Question: Describe a condition when a plant cell is said to be fully plasmolysed.

Illustration of plasmolysis



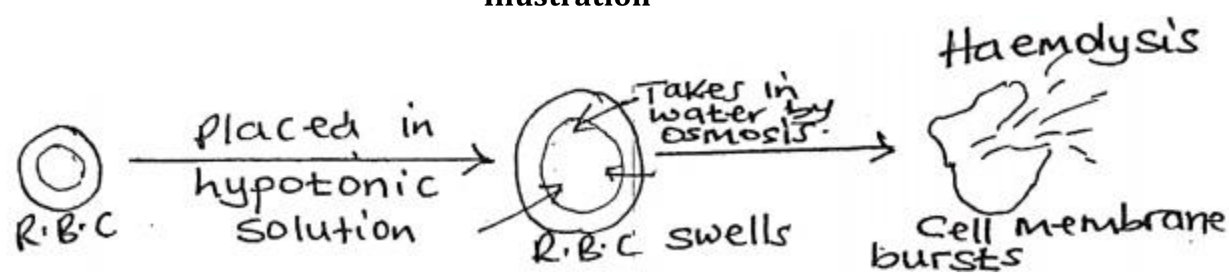
3. When a plant cell is surrounded by an isotonic solution, there is no net movement of water in and out of the cell because the cell cytoplasm and the surrounding solution have the same concentration of water molecules.

Question: Explain why there is no net movement of water molecules when a plant cell is placed in an isotonic solution.

OSMOSIS IN THE ANIMAL CELLS

1. When an animal cell is placed in a hypotonic solution, water moves from the hypotonic solution which has a high concentration of water molecules, and it enters into the cell by osmosis across a semi-permeable surface membrane.
   The cell swells as the volume of the cytoplasm increases, the cell membrane becomes weak and bursts. This process is called haemolysis.

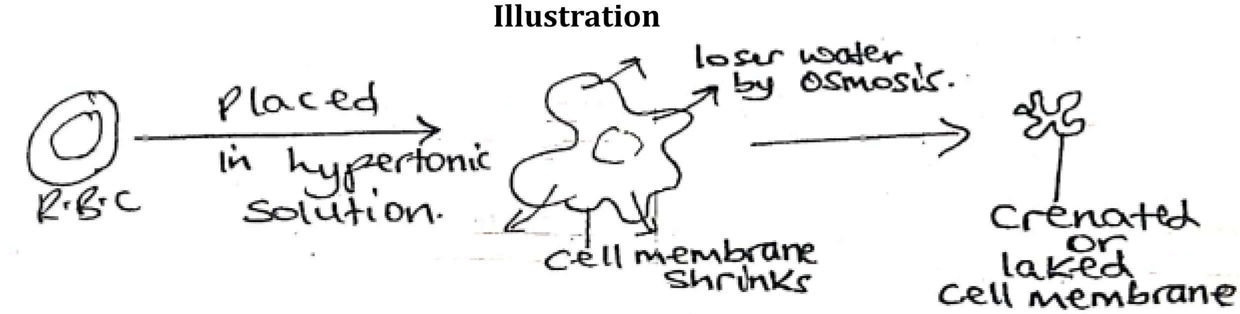
Illustration



Question: Define the term ***haemolysis***.

2. When an animal cell is placed in a hypertonic solution, water moves out of the cell by osmosis into the hypertonic solution which has a lower concentration of water molecules.
   This is occurs by osmosis through the semi-permeable membrane causing the cell to shrink and the cell membrane wrinkles and the cell contents condense. This process is known as crenation.

Illustration



Question: Define the term **crenation**.

EFFECTS OF CONCENTRATION ON PLANT TISSUES

AN EXPERIMENT TO SHOW THE EFFECT OF CONCENTRATION ON PLANT TISSUES

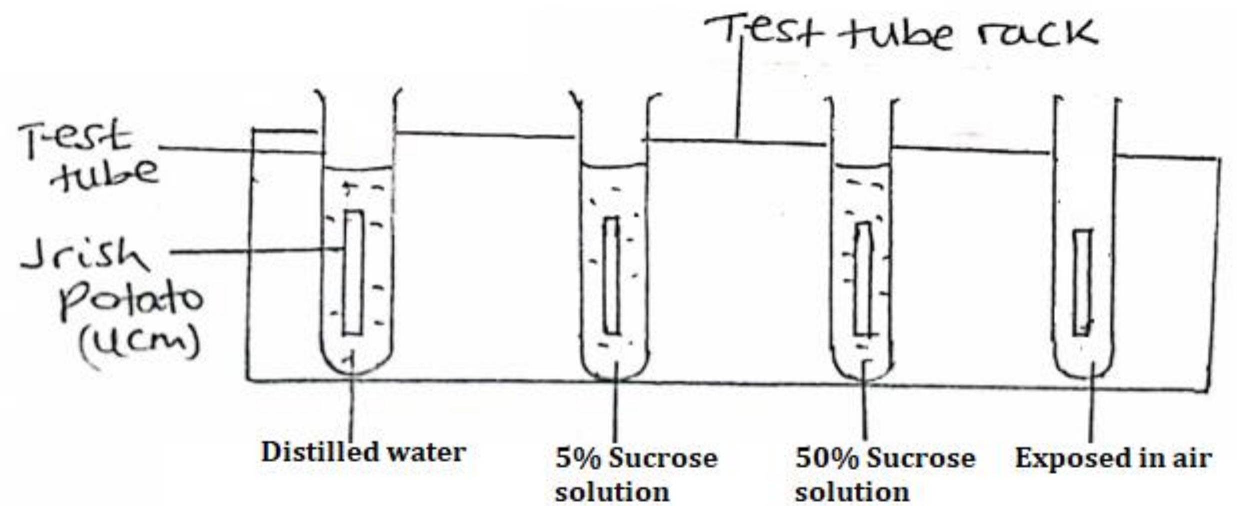
REQUIREMENTS

- Cork borer
- Fresh irish potato
- Distilled water
- 4 Beakers/test tubes/boiling tubes
- 5% of sucrose solution
- 50% of sucrose solution

PROCEDURE

- Using a cork borer, 4 uniform cylinders of fresh irish potato tissue are prepared.
- Trim the 4 cylinders to the same length (4cm) and record the original length.
- The first cylinder is immersed in distilled water in a beaker (test tube) labeled A.
- The second cylinder is immersed in 5% sucrose solution in a beaker (test tube) labeled B.
- The third cylinder is immersed in 50% sucrose solution in a beaker(test tube) labeled C.
- The fourth cylinder is exposed to air in a beaker(test tube) labeled D.
- The cylinders are left for 30 minutes after which their final length of each cylinder is measured.

EXPERIMENTAL SET UP



OBSERVATION

- Cylinder A increases in length and become hard and rough.
- Cylinder B decreases slightly in length, but no observable change.
- Cylinder C becomes soft and flabby to a greater extent and decreases in length.
- Cylinder D also decreases in length slightly, become soft and flabby to a less extent.

CONCLUSION

- Length, hardness, stiffness of the potato tissues decreases with increase in concentration of sucrose solution except the one placed in isotonic solution that doesn't change.

EXPLANATION

- Water enters tissue A by osmosis since it is placed in pure water, it becomes hard and rough and increase in length because the cells are fully turgid.
- Water leaves tissue B and C across the semi permeable membrane since they are placed in hypertonic solution.
- The decrease in length is greater in C than in B because tissue C is placed in a more concentrated solution, there C loses more water molecules faster by osmosis.
- Tissue C decreases in length and becomes soft and flabby because cells in tissue C lose water by osmosis and become flaccid.
- Tissue D decreases in length slightly because it loses water by evaporation at the surface of tissue.

Question: Describe an experiment to show the effect of concentration on plant tissues.

AN EXPERIMENT TO DEMONSTRATE TURGOR IN PLANT TISSUES

REQUIREMENTS

- Commelina strips
- Salt/Sucrose solutions of different concentrations
- Distilled water
- Petri dishes/ beakers

PROCEDURE

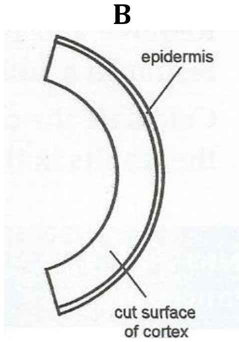
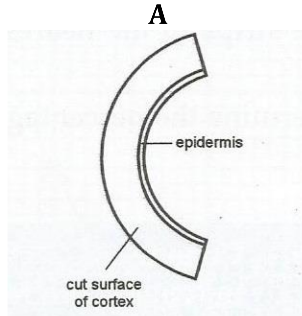
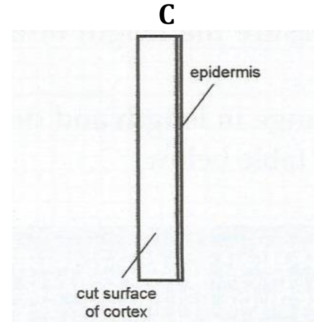
- A known length of a young soft stem of commelina or flower stalk of lily is cut into 3 longitudinal strips A, B and C.
- A is placed in pure water, B is placed in 10% sodium chloride solution and C in an isotonic solution.
- The strips are left to stand for 20 minutes.

OBSERVATION

After the 20 minutes, it is seen that the strips behaved differently.

- Strip A, which was in hypotonic solution curved outwards with the pith (cortex cells) on the outside and epidermis on the inside.
- Strip B in the hypertonic solution curved inwards with the cortex cells on the inside and the epidermis on the outside.
- Strip C remains unchanged/maintain the same curvature.

ILLUSTRATION

Hypertonic solution	Hypotonic solution	Isotonic solution
B 	**A** 	**C** 

EXPLANATION

- No curvature indicates that osmosis has not occurred and therefore the cell sap of the tissue used is at the same concentration as that of the external solution i.e. solution is isotonic to the cell sap.
- For hypotonic solution/pure water, the cortex cells in the stem expand and result in an increase in length of the cortex in relation to the epidermis.

- Since the epidermal cells are less elastic, the epidermis doesn't increase in length and this results into the strip curving with the cortex on the outside and the epidermis on the inside.
- For hypertonic solution, the strip curves inwards with the epidermis on the outside because the cortex cells have lost water to the stronger solution by osmosis and have been plasmolysed.

FACTORS AFFECTING THE RATE OF OSMOSIS

1. **Size of solute molecules**
- Osmosis only occurs when the solute molecules are too large to pass through the pores in the membrane.
2. **Osmotic pressure gradient**
- The higher the osmotic pressure gradient the higher the rate of osmosis.
3. **Temperature**
- The increase in temperature increases the rate of osmosis.

FOOD FOR THOUGHT: Differences between wilting and plasmolysis.

IMPORTANCE OF OSMOSIS IN PLANT TISSUES

1. Absorption of water by root hairs from the soil solution.
2. Movement of water molecules from the root hairs via the cortex to the xylem which transport water up the plants.
3. Enables opening and closing of stomata by guard cells.
4. Provides support to non-woody/herbaceous plants due to turgidity
5. Enables absorption of water a seed during germination
6. Enables growth at the root and shoot tips when cells absorb water by osmosis and become turgid.
7. Enables opening and closure of flowers in some species like morning glory flowers thus pollination.

IMPORTANCE OF OSMOSIS IN ANIMAL TISSUES

1. Absorption of water from gut (digestive system) into the blood stream via the gut walls.
2. Reabsorption of water into the blood stream from the kidney tubules in the nephron.
3. Intake of water by unicellular organisms.
4. Movement of tissue fluid with dissolved wastes into blood capillaries at the venous end.

APPLICATION OF OSMOSIS BY MAN

- Food preservation due to killing of bacteria by surrounding them with highly concentrated solutions or salty solutions such as sugar and honey preservatives i.e.

salted fish and salted meat. Since bacteria lose water by osmosis to surrounding concentrated solution, get dehydrated and die.

Question: Explain the Importance of osmosis in both plants and animal tissues.

OSMOSIS AND DIFFUSION COMPARED

(iii) **Similarities**

- Both are passive; don't require energy (ATP) to occur.
- Both occur along the concentration gradient.
- Both occur in living and non-living systems

(iv) **Differences**

Osmosis	Diffusion
• Involves movement of solvent molecules. • Occurs across a semipermeable membrane. • Doesn't require channel proteins. • Solvent molecules flow from dilute to concentrated solution.	• Involves movement of molecules or ions. • Occurs across a fully permeable membrane. • Facilitated diffusion requires channel proteins. • Molecules/ions flow from concentrated solution to dilute solution.

ACTIVE TRANSPORT

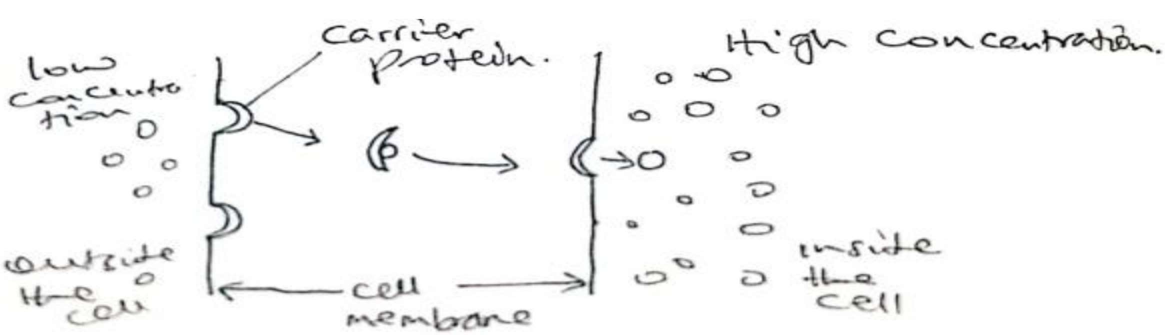
Definition: Is the movement of molecules or ions from their region of lower concentration to their region of higher concentration with expenditure of energy (ATP).

OR

Is the movement of substances against a concentration gradient with the expenditure of energy.

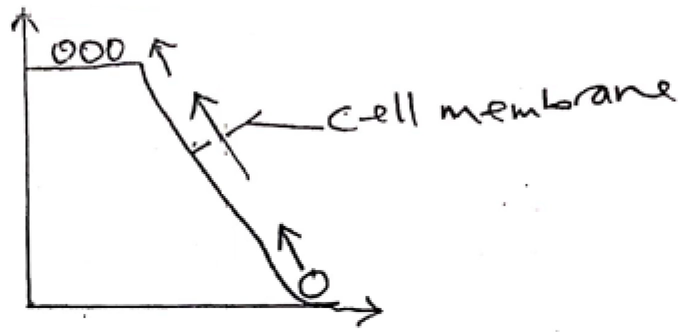
- It occurs only in living cells.
- It requires carrier proteins and occurs against the concentration gradient.

i.e.



ILLUSTRATION

- Compare active transport with moving an object up a hill



FACTORS AFFECTING ACTIVE TRANSPORT

1. **Oxygen concentration**
- At higher oxygen concentration, cells respire faster and produce more energy leading to faster active transport.
2. **Glucose concentration**
- When there is more glucose to be used in respiration, more energy is produced and increase active transport.
3. **Temperature**
- Increase in temperature, increases the rate of active transport; provided the temperature increase is not beyond optimum. An optimum temperature is required for the fastest active transport.
4. **PH**
   An optimum PH is required to prevent denaturation of protein carriers.
5. **Enzyme inhibitors or poisons**
   Presence of inhibitors lowers the rate of active transport due to inhibition of respiratory enzymes/respiration.

IMPORTANCE OF ACTIVE TRANSPORT

1. Facilitates selective reabsorption of useful substances in the kidneys.
2. It plays a role in the absorption of mineral salts by root hairs.
3. Facilitates removal of excretory wastes from the cells
4. It plays a role in the absorption of digested food from the ileum into blood stream.
5. It facilitates accumulation of solutes in animals that inhabit saline waters in order to offset osmotic balance thus osmoregulation.
6. Transmission of impulses along nerves.

DIFFUSION AND ACTIVE TRANSPORT COMPARED

Similarities

- Both occur in living organisms (involve movement of materials across the cell membrane)
- Both involve solutes (molecules or ions)
- Both facilitated diffusion and active transport involve use globular proteins to move materials.

Differences

Diffusion	Active transport
• Doesn't involve use of energy (ATP)	• Involve use of energy (ATP).
• Materials move along (down) a concentration gradient.	• Materials move against concentration gradient.
• Is non-selective process/ any state of molecules is moved	• Is a selective process (movement of solute molecules only)
• No need for carrier molecules (for simple diffusion)	• Use of carrier molecules involved.
• Is a slower process	• Is a faster process

TRANSPORT IN PLANTS

Transport system of flowering plants consists of vascular bundles (system) which include;

1. Xylem tissue
2. Phloem tissue

The major substances that are transported are;

- Water
- Mineral salts
- Manufactured food
- Hormones

SIGNIFICANCE OF TRANSPORT IN PLANTS

- Nutrients are delivered from leaves to other parts of the plant for usage.
- Enables water and mineral salts to flow from the roots to other parts of the plant for usage /storage.
- Enables movement of food substances to storage organs like fruits, roots, leaves and stem tubers.
- Delivers nutrients to growing regions like young buds & leaves as well as shoot and root tips.

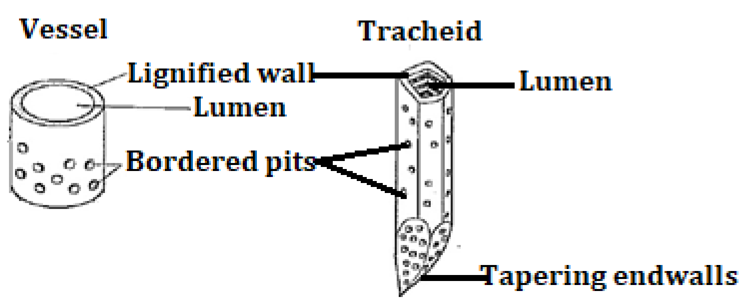
NB: Water and mineral salts are transported in the xylem while food nutrients are transported in the phloem.

THE XYLEM

The xylem is composed of two kinds of cells namely, vessels and tracheids.

These cells are dead and lignified i.e. have heavy deposits of lignin along their walls to give rigid support to the plant.

STRUCTURE



FUNCTIONS OF XYLEM

- Conducts water and mineral salts up the plant.
- Provides strength and mechanical support to the plant.

Differences between tracheids and vessels

Tracheids	Vessels
• Single elongated cells • Very short • Have tapering ends • Narrow lumen	• Several cells fused with the end walls dissolved. • Longer • Non tapering ends • Wide lumen

ADAPTATIONS OF XYLEM TO ITS FUNCTION

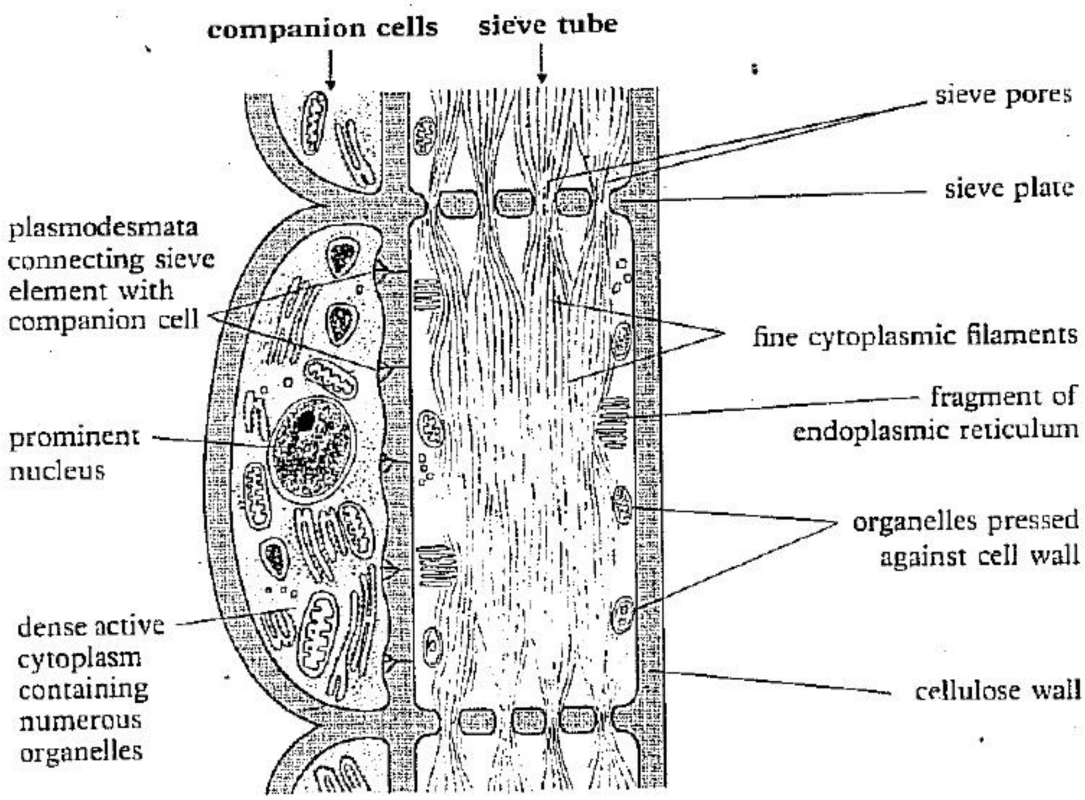
1. Vessels and tracheids are dead with empty hollow lumen to allow easy flow of water.
2. Its vessels and tracheids are dead, lignified; they don't use up water in transit.
3. Vessels long and tubular/hollow thus able to maintain a transpiration stream.
4. Vessels and tracheids have lignified walls thus impermeable to water ensuring no escape/loss of water and mineral salts.
5. Vessels and tracheids are lignified making their walls thick to provide mechanical strength thus no collapse for continuous water flow.
6. Some have bordered pits for easy communication among the cells.
7. Vessels are open ended and join end to end to enhance continuous flow of water/column.
8. Tracheids have narrow lumen to maintain (increase) water flow (rise) by capillarity.

THE PHLOEM

- The organic food compounds are transported from the photosynthetic cells to other parts of the plant by the phloem.
- The phloem is a living tissue made up of 2 kinds of cells namely;

1. <u>Companion cells</u>; which contain a dense cytoplasm, nucleus and many other organelles like mitochondria.
2. <u>Sieve tubes</u>; which lose their nuclei as they mature.

STRUCTURE OF PHLOEM TISSUE



NB: The process of transporting organic solutes like food substances in the phloem is called translocation.

ADAPTATIONS OF PHLOEM FOR TRANSLOCATION

- Mitochondria; energy provision for translocation
- Living cells that are metabolically active provide required energy for translocation
- Sieve elements have few organelles & peripheral cytoplasm; providing space for translocation of organic substances.
- Sieve pores which allow direct communication/passage between the sieve elements
- Cells are elongated & connected end to end making long tubes through which transportation occurs.
- Nucleus of companion cells controls activities of sieve elements connected to companion cells through plasmodesmata. **OR** Connection of sieve elements to companion cells through plasmodesmata to ensure effective control of activities within phloem.
- Numerous fine cytoplasmic filaments believed to take part in translocation by cytoplasmic streaming.

- Connected to specialized/modified parenchyma cells called transfer cells which load and offload sieve elements/phloem.

XYLEM	PHLOEM
• Vessels and tracheids are dead cells. • Responsible for translocation of water and mineral salts • Is lignified • Transport depends on physical means as transpiration, capillarity etc • Xylem vessels are open-ended; perforation plates	• All cells are living. • Responsible for translocation of manufactured food/organic solutes • Is not lignified • Transport depends on energy, food manufactured. • Have sieve pores; not open ended.

ASSIGNMENT

1. How is the xylem adapted to its function?
2. How is the phloem adapted to its function?
3. State differences between phloem and xylem.

TRANSPORT OF WATER & MINERAL SALTS IN PLANTS

- Plants obtain water from the soil.
- The transport of water in plants occurs in 3 stages;

(i) Absorption of water from the soil by root hairs.
(ii) Movement of water from the root hairs up to the xylem of the roots.
(iii) Conduction of water from the root up to the stem to the leaves.

ABSORPTION OF WATER FROM THE SOIL BY PLANT ROOTS

- Water is absorbed from the soil solution by <u>osmosis</u> through the <u>root hairs</u>.

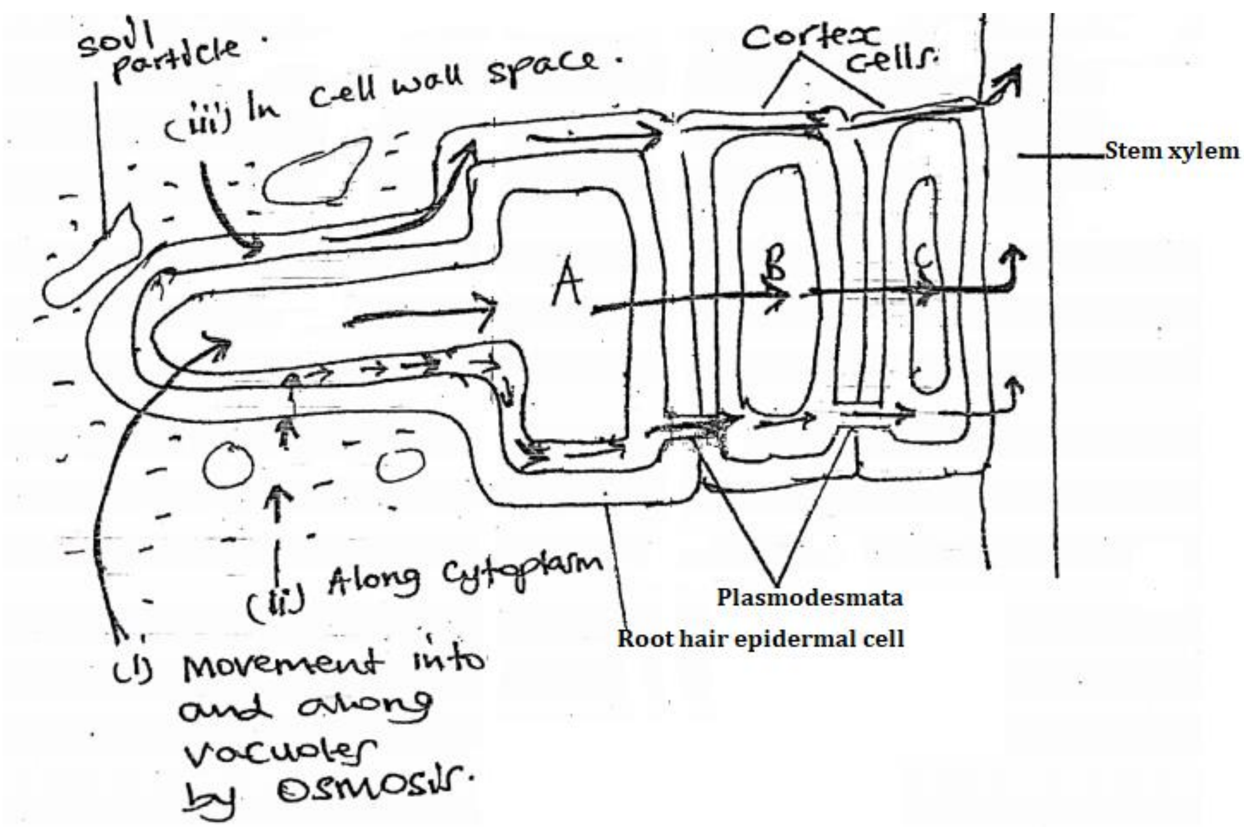
ADAPTATIONS OF ROOT HAIRS FOR WATER ABSORPTION

1. Root hairs are slender & flexible to easily penetrate between the soil particles thus accessible to water and absorb water from the soil solution.
2. Root hairs lack cuticle thus are permeable to water for easy absorption.
3. Root hairs are extremely thin to provide a short distance for rapid water absorption.
4. They are numerous to provide a large surface area for absorption of water.
5. Root hair cell sap has a higher concentration of solutes (osmotic potential) than the soil solution enhancing uptake of water by osmosis from the soil solution into the root hair.
6. The root hair cell is fully permeable but the cell membrane is semi-permeable to permit water absorption of water by osmosis.
7. Are elongated to increase surface area for water absorption.

TRANSPORT OF WATER FROM ROOT HAIRS TO THE XYLEM

- This occurs mainly by diffusion along cytoplasm & cell wall spaces and some osmosis along cell vacuoles.
- When water is absorbed by root hair, the cell sap of the root hair becomes less concentrated than that of the adjacent cortex cell causing water to move from the root hair into the adjacent cell by osmosis.
- Water moves through the cortex cells up to the endodermis by successive osmosis and diffusion via 3 routes/pathways i.e. vacuolar route (osmosis), symplast route (along cytoplasm by diffusion)and apoplast route(along cell wall by diffusion).
- The endodermal cells actively pump mineral salts into the xylem making the xylem highly concentrated. This causes rapid movement of water by osmosis from the endodermis into the xylem.
- The rapid entry of water into the xylem by osmosis from the endodermis causes pressure in the root xylem called root pressure.

An illustration of the movement of water from the root xylem via the cortex and endodermis



MOVEMENT OF WATER FROM THE ROOT XYLEM THROUGH THE STEM XYLEM UP TO THE LEAVES

It is brought about by;

(i) Root pressure
(ii) Capillarity
(iii) Tension, cohesion and adhesion forces
(iv) Transpiration pull

- The active pumping of mineral salts into the xylem of the root from the endodermis rapidly draws water into the xylem by osmosis causing a build-up of root pressure which forces water up the xylem in the stem.
- Root pressure is the pressure exerted by water in xylem due to concentration gradient of water (its accumulation)in the root which draws it up the stem against gravity
- This pressure is high enough to move water up in relatively short plats but no for water movement up long and large trees.
- Capillarity is the spontaneous upward movement of water along narrow tubes of xylem due to surface tension effects.
- Capillarity causes water movement up in the xylem vessels and tracheids. However, it is not a sufficient force to cause water to move up to leaves of a tall tree.
- Evaporative loss of water from the leaf by transpiration lowers the concentration of water (water potential) in leaf cells next to the xylem thus water enters the leaf cells from the xylem by osmosis down an osmotic gradient through cell walls of the adjacent cells.
- As water leaves the xylem vessels a tension (a pulling force) called transpiration pull is set up in the water column called transpiration stream, which is transmitted back down the stem all the way to the root. This is the greatest force responsible for the rising of water through the stem to the leaves of tall plants.
- Cohesion of water molecules to each other and adhesion of water molecules to the xylem walls aid in forming an unbroken water column. As such water moves up the xylem in the stem in a continuous stream under tension called transpiration stream by mass flow due to the transpiration pull.

NB:

- ✓ Transpiration stream is the continuous stream of flowing water in the xylem of a plant.
- ✓ Transpiration pull is the force in the xylem that is caused by successive loss of water from the leaves.

Question: Explain four (4) factors that aid in the movement of water and mineral salts up the xylem of a plant.

Question:

(a) What is the importance of water to plants?
(b) Describe how water is obtained from the soil and reaches the leaves to the atmosphere.

ABSORPTION (UPTAKE) OF MINERAL SALTS BY ROOT HAIRS

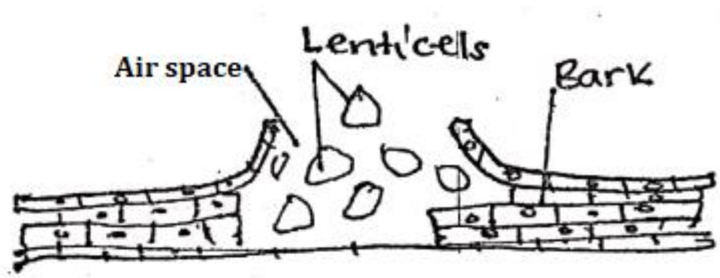
- The concentration of mineral salts in the sap vacuoles of the root hairs is higher than that of the soil solution.
- Therefore, the salts enter the root hairs by <u>active transport</u>.
- They move across the cortex cells by diffusion. When the ions reach the xylem, they are carried in solution by the transpiration pull and root pressure.

Question: How do roots take up mineral salts from the soil?

TRANSPIRATION

- Is the process by which plants lose water in form of water vapour from aerial parts of the plant to the atmosphere.

A drawing showing lenticels



TYPES OF TRANSPIRATION

1. Stomatal transpiration; water loss via stomata; 90%.
2. Cuticular transpiration; water loss via cuticle; 9%.
3. Lenticular transpiration; water loss via lenticels; 1%

FACTORS AFFECTING THE RATE OF TRANSPIRATION

These are divided into 2 categories namely;

(a) Environmental factors/external factors
(b) Non-environmental factors/internal factors/structural factors. e.g. structural features of the leaf.

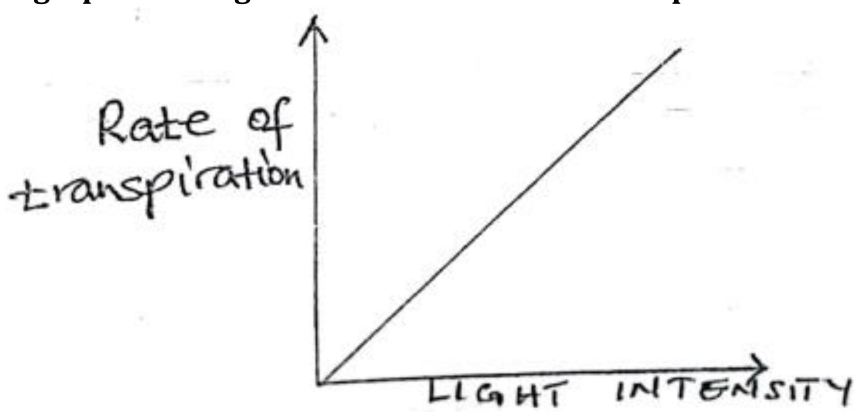
Environmental factors/external factors	Non-environmental factors/ internal factors
• Temperature	• Stomata number & distribution
• Light intensity	• Sunken or unsunken stomata
• Humidity	• Size of stomatal pore
• Wind speed	• Presence/absence of hairs on the leaf
• Water supply	• Thickness of leaf cuticle
• Atmospheric pressure	• Surface area of the leaf
	• Number of leaves

(a) EXTERNAL FACTORS

1. **LIGHT INTENSITY**

- Increase in light intensity increases the rate of transpiration and vice versa. This is because;
- Increase in light intensity, increases the opening of stomata thus more water vapour lost.
- Increases the heat energy (temperature) of leaf cells that increases the rate of evaporation.

A graph showing the variation of rate of transpiration with light intensity



Question: The table below shows the results obtained from an investigation on transpiration. Study it carefully and answer the questions that follow.

Stomatal opening(μm)	1	2	3	4	5	6	7
Light intensity (au)	4.2	8.5	13	17.2	22	25.2	30
Rate of transpiration (cm^3/s)	40	63	74	86	94	110	124

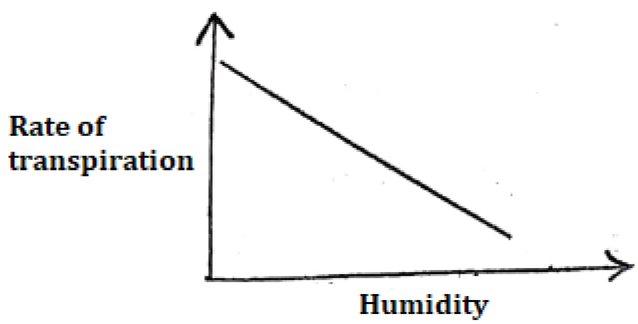
(a) Plot a graph to represent the above information on the same axes.
(b) Describe your graph made above.
(c) Explain your graph above.

2. **HUMIDITY**

- Humidity is the concentration(amount) of water vapour in the atmosphere
- Increase in humidity around the leaves decreases the rate of transpiration and decrease in humidity increases the rate of transpiration. This is because;
- Increase in humidity decreases diffusion gradient of water vapour between the inside and outside of the leaf thus decrease in the rate of transpiration.
- Increase in humidity, increases the diffusion gradient of water vapour between the inside and outside of the leaf which increases the rate of transpiration.

NB: Because of this, plants near lakes where humidity is high lose less water than those in drier areas.

A graph showing the variation of rate of transpiration with humidity



Question: The following data was obtained during an experiment on transpiration. Study it carefully and answer the questions that follow.

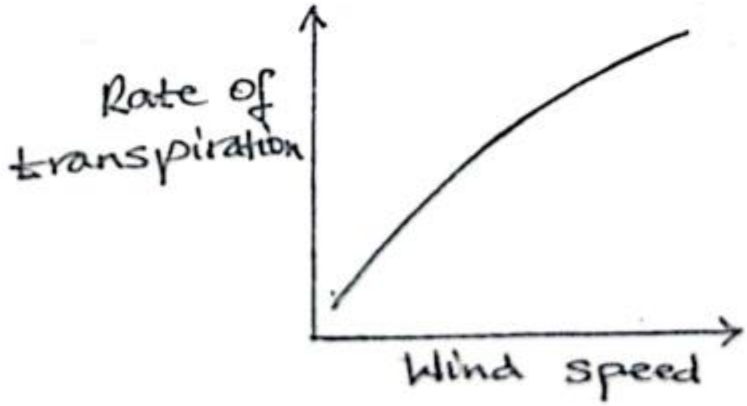
Rate of transpiration(cm^3/s)	20	30	40	50	60	70	80
Relative humidity(mm/Hg)	70	60	50	40	30	20	10

a) Represent the above information graphically.
b) Describe the relationship between the rate of transpiration and relative humidity.
c) Explain the relationship above.

3. **WIND SPEED**

- Increase in wind speed, increases the rate of transpiration and decrease in wind speed, decreases the rate of transpiration. This is because;
- Increase in wind speed, increases the speed at which water vapour is removed/disposed from the leaf surfaces; thus increasing the diffusion gradient of the vapour between the inside and outside(atmosphere) of the leaf.
- Transpiration is low in still air (stationary air) because there is a lot of water vapour around leaf surfaces which is not "swept" away; thus reducing the diffusion gradient.

A graph showing the variation of rate of transpiration with wind speed



Question: The table below shows the rate of transpiration in wind and that in still air when stomata were open to varying extents. Study it carefully and answer the questions that follow.

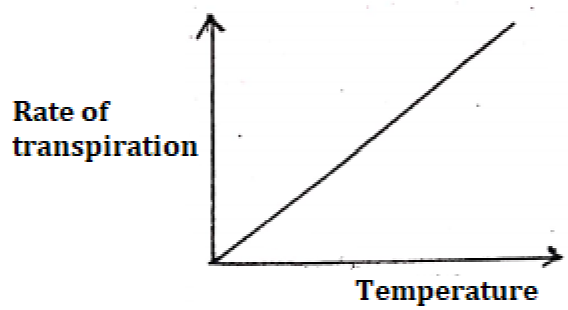
Size of stomatal opening (μm)	1	2	3	4	5	6	7
Transpiration rate in wind (mm/min)	40	63	74	86	94	110	124
Transpiration rate in still air(mm/min)	0	6	12	19	19	23	27

a) Using the same axes, represent the above information graphically.
b) What is the difference between rates of transpiration in wind and still air?
c) Explain the difference in (b) above.
d) What is the size of stomatal opening when the rate of transpiration in still air is 25mm/min?
e) How does the size of the stomatal opening affect the rate of transpiration;
   (i) In still air
   (ii) In wind?

4. **TEMPERATURE**

- The higher the temperature, the faster the rate of transpiration and the lower the temperature, the lower the rate of transpiration. This is because;
- Increase in temperature increases the kinetic energy of water in the leaf cells which increases its evaporation; thus higher transpiration rate.
- Decrease in temperature decreases the kinetic energy of water in the leaf cells that reduces its evaporation thus lower transpiration rate.
- At the same time, a rise in temperature lowers the relative humidity of the air outside the leaf. This causes a steep concentration gradient of water molecules thereby raising the rate of transpiration.

A graph showing the variation of rate of transpiration with temperature



Question: The table below shows the data from an investigation on transpiration. Use it to answer the questions that follow.

Temperature(°C)	10	20	30	40	50	60	70
Rate of transpiration(cm^3/s)	20	30	40	50	60	70	80

a) Plot a graph to represent the above information.
b) Describe the plot made above.
c) Explain your graph.

5. **ATMOSPHERIC PRESSURE**

- The higher the atmospheric pressure, the lower the transpiration rate; and the lower the atmospheric pressure, the faster the rate of transpiration.
- This is because the saturated vapour pressure needed for evaporation is decreased due to lower atmospheric pressure.

NB:

- ✓ Because of this, plants on high mountains transpire more than those lower down due to lower atmospheric pressure at higher altitude,
- ✓ The vapour pressure of water vapour in the atmosphere decreases with altitude as atmospheric pressure decreases.

6. **WATER AVAILABILITY**

- As soil dries out, there is a reduced water potential gradient between the soil and the leaf.
- This reduces the amount of water available to the plant and thus reduces the rate of transpiration; since the water lost from the plants during transpiration comes from the soil.

(b) **INTERNAL/ STRUCTURAL FACTORS**

(i) **LEAF SURFACE AREA**

- The larger the leaf surface area, the higher the rate of transpiration and the smaller the leaf surface area, the lower the rate of transpiration. i.e. broad leaves have a higher rate of transpiration than narrow(small needle-like) leaves. This is due to increased avenue (area) over which water lost occurs in broad leaves than in smaller leaves.

(ii) **THICKNESS OF THE CUTICLE**

- The cuticle is a waxy water proof covering over the leaf surface.
- The thicker the cuticle, the lower the rate of transpiration and the thinner the cuticle, the higher the rate of transpiration.
- This is because the thicker the cuticle, the longer the distance(diffusion distance) across which water vapour diffuses leading to slower rate of transpiration; and the thinner the cuticle, the short the diffusion distance across which water is lost and thus faster rate of transpiration.
- Also the more wax on the cuticle, the more water proof it is; thus the lower the rate of transpiration.
- Therefore, leaves with waxy cuticle reflect more light thus reducing the rate of transpiration.

(iii) **NUMBER AND DISTRIBUTION OF STOMATA**

- The more the number of stomata, the faster the rate of transpiration due to more openings for water loss and the reverse is true.
- Most terrestrial plants possess a higher number of stomata distributed on the lower epidermis and fewer on the upper epidermis; this reduces on the rate of transpiration. The reversible is true for aquatic plants.
- This is because very few stomata are exposed to the heat and light of the sun in the upper epidermis which lowers the rate of transpiration; the reverse is true for aquatic plants.

(iv) **HAIRINESS OF THE LEAVES**

- The more hairy the leaves are, the lower the rate of transpiration; because the hairs trap a lot of water vapour close to the leaf surface/stomata which increases the humidity and lowers the diffusion gradient of water vapour between the inside and outside of the leaf and vice versa.
- The hairs also reduce the speed of wind that passes directly over the stomata thus reducing the rate of transpiration.

(v) **SIZE OF THE STOMATAL PORE/STOMATAL APERTURE**

- The wider the stomatal pore/aperture, the higher the rate of transpiration because more space through which loss of water vapour occurs is provided.
- The narrower the stomatal pore/ aperture, the lower the rate of transpiration due to reduced space through which water vapour is lost.

(vi) **HOW DEEP THE STOMATA ARE IN THE EPIDERMIS OF THE LEAF**

- When the stomata are sunken i.e. in deep cavities, water accumulates in the cavity/depression, which lowers the concentration gradient and thus diffusion gradient leading to reduced transpiration rate. The reverse is true for unsunken stomata.

(vii) **NUMBER OF LEAVES**

- The more the leaves, the faster the rate of transpiration and the less the leaves, the slower the rate of transpiration.
- This is because increase in number of leaves increases the total surface area and number of stomata over which transpiration occurs; the reverse is true for reduced number of leaves.

NB: The first 6 are structural factors unlike the last one.

Question: Explain the environmental factors that affect the rate of transpiration.

Question: A careful study was done on the effect of temperature and relative humidity on the rate of transpiration on a bright sunny day and the following information obtained.

Temperature(°C)	10	20	30	40	50	60	70
Relative humidity(mmHg)	69	62	48	41	30	19	8
Rate of transpiration (m^3/s)	22	30	41	49	61	73	84

(a)
(i) Plot a graph to show the relationship between relative humidity, temperature and transpiration using the same axes.
(ii) Describe how the changes in temperature and relative humidity influence the rate of transpiration.

(b) Explain the effects of;
(i) Rise in temperature on the rate of transpiration
(ii) Rise in humidity on the rate of transpiration

(c) Describe any five structural adaptations of plants that reduce transpiration.

SIGNIFICANCE/IMPORTANCE/ ADVANTAGES OF TRANSPIRATION

1. Facilitates transport of absorbed water from roots to the leaves inform of a transpiration pull.
2. Aids in transport of absorbed mineral salts from roots to leaves with a plant since they are soluble in water.
3. Enables cooling of the plants since as water evaporates to the atmosphere, a lot heat is carried away from the plant which is replaced by cooling.
4. Removes excess water from the plant thereby preventing scorching.

NB: To other organisms, it is important for cloud formation thus bringing about rainfall.

DISADVANTAGES OF TRANSPIRATION

1. Excessive transpiration leads to wilting/drying and shriveling of leaves
2. Prolonged transpiration leads to dying which eventually leads to death of the plants
3. If the rate of transpiration is higher than water absorption rate, it leads to water stress thus reduced growth rate.

ADAPTATIONS OF PLANTS (XEROPHYTES) TO REDUCE EXCESSIVE TRANSPIRATION IN ARID AREAS

- Plants that are adapted to live in arid areas/ dry habitats are known as xerophytes.

Adaptations for survival

(i) Some have curled leaves to reduce the surface area over which water loss occurs by transpiration/ have rolled leaves to trap still and damp air which reduces water loss.

(ii) Some possess small needle-shaped leaves with narrow lamina which offer a small surface area for water loss thus water loss minimized.

(iii) Some shed off their leaves periodically during dry seasons to minimize water loss by transpiration via leaves like deciduous trees.

(iv) Some have few stomata to minimize water loss by stomatal transpiration

(v) Some have stomata sunken in grooves and pits to create a film of still air near them, thereby reducing water loss by transpiration due to lengthening of diffusion path.

(vi) Some have leaves with a thick, impermeable and waxy cuticle to minimize water loss by transpiration like cactus.

(vii) Some have shiny cuticle which reflects away light and heat; preventing the leaf from heating up rapidly thus reducing evaporation of water.

(viii) Some have leaves modified into thorns and spines to minimize water loss by transpiration due reduced surface area over which water loss occurs.

(ix) Reversal of stomatal rhythm; open their stomata at night and close them during day to minimize water loss by stomatal transpiration.

(x) Some have succulent tissues to store enough water for the plant to replace that water lost by transpiration like cactus.

(xi) Some have hairy leaves to trap a film of still air (air moisture) that lengthen the diffusion path thereby minimizing water loss by transpiration.

(xii) Some have long and deeply penetrating roots to penetrate deep in soil and absorb enough water.

(xiii) Some have a network of superficial fibrous roots to absorb enough water from the surface even after a brief rainfall.

Question

(a) What is transpiration?
(b) Why is transpiration a necessary evil?
(c) How are xerophytes adapted to reduce water loss?

Question: What is the significance of transpiration to plants?

EXPERIMENTS ON TRANSPIRATION

1. **EXPERIMENT TO SHOW THAT A PLANT TRANSPIRES**

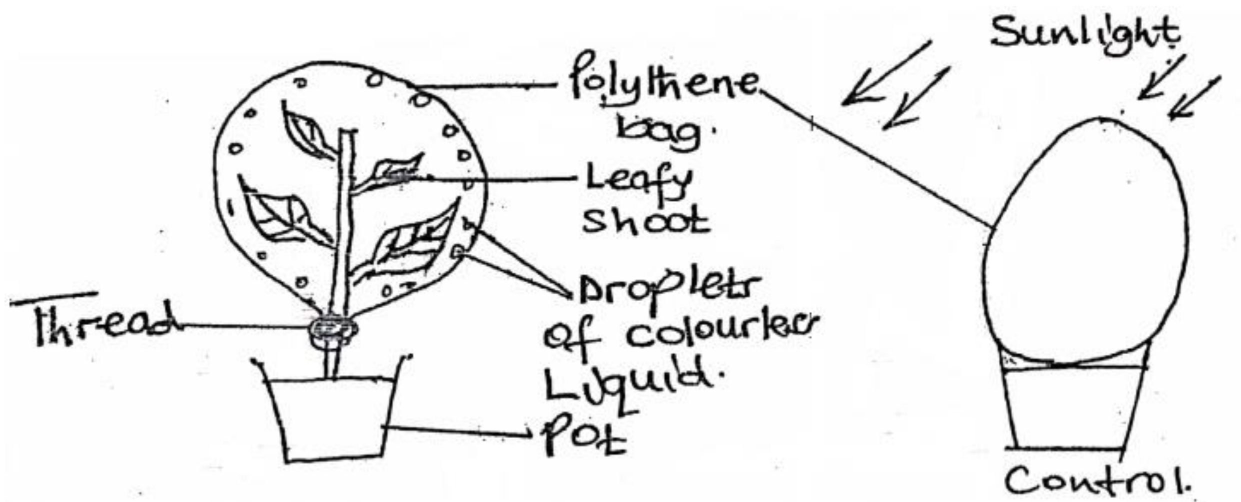
REQUIREMENTS

- A well-watered potted plants
- 2 polythene bags
- Rubber band/string
- Anhydrous copper(II) sulphate/cobalt chloride paper

Procedure

- A polythene bag is tied around a plant shoot, above the soil.
- Another polythene bag is tied above the pot without a plant. This serves as a control.
- The 2 set ups are left to stand for 6(2) hours in bright sunlight.
- After 6 hours, the polythene bags are untied and any liquid formed is tested using anhydrous copper(II) sulphate/cobalt chloride paper.

EXPERIMENTAL SET UP



OBSERVATION

- Droplets of a colourless liquid that turns white anhydrous copper (II) sulphate blue(blue cobalt chloride paper pink) are formed in set up with a leafy plant but no droplets of liquid formed in the control set up without a plant.

CONCLUSION

- Transpiration occurs in plants

EXPLANATION

- The leafy shoot transpired to give water that was collected in the polythene bag as a colourless liquid but no colourless liquid formed in polythene bag without plant thus transpiration didn't occur.

2. EXPERIMENT TO SHOW THAT TRANSPIRATION OCCURS THROUGH THE LEAVES

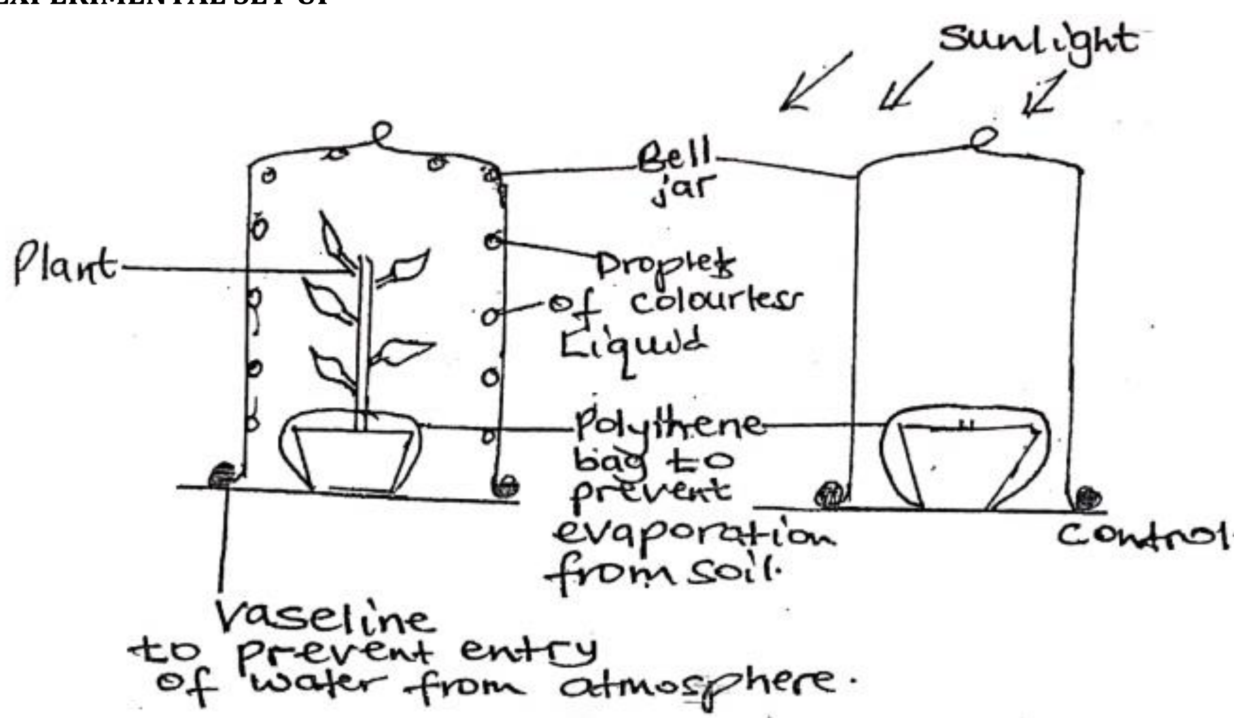
REQUIREMENTS

- 2 Well watered potted plants A and B.
- 2 Dry polythene bags
- 2 Bell jars
- Vaseline
- 2 Glass plates
- Anhydrous copper (II) sulphate (Blue cobalt chloride paper)

PROCEDURE

- The polythene bags are a tied around the pots to the stems of 2 plants to prevent evaporation of water from the watered soil in the pots.
- Leaves of the potted plant B are removed to make it a non-leafy aerial part.
- The 2 potted plants are each placed on a dry glass plate and enclosed in dry bell jars.
- Vaseline is smeared at the interface of the glass plate and enclosed in dry bell jars to prevent water vapour in the atmosphere from entering into the ball jars.
- The setup is left to stand for 6 hours in the sunshine (bright sunlight).
- After 6 hours, the polythene bags are untied and any liquid formed is tested using anhydrous copper(II) sulphate/cobalt chloride paper.

EXPERIMENTAL SET UP



OBSERVATION

- Droplets of a colourless liquid that turns white anhydrous copper (II) sulphate blue are formed in set up with a leafy plant A but no droplets of liquid formed in set up with non-leafy potted plant B.

NB: When the liquid is tested with the cobalt chloride paper, the paper turns from blue to pink showing that the liquid is water.

CONCLUSION

- The non-leafy plant B didn't form any vapour while the leafy plant A formed vapour indicating that transpiration mainly occurs through leaves.

EXPLANATION

- The leafy plant A transpired to give water that was collected in the polythene bag as a colourless liquid but no colourless liquid formed in polythene bag with non-leafy plant thus transpiration didn't occur plant B lacked leaves where transpiration would occur.

3. EXPERIMENT TO MEASURE TRANSPIRATION RATE UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

APPARATUS

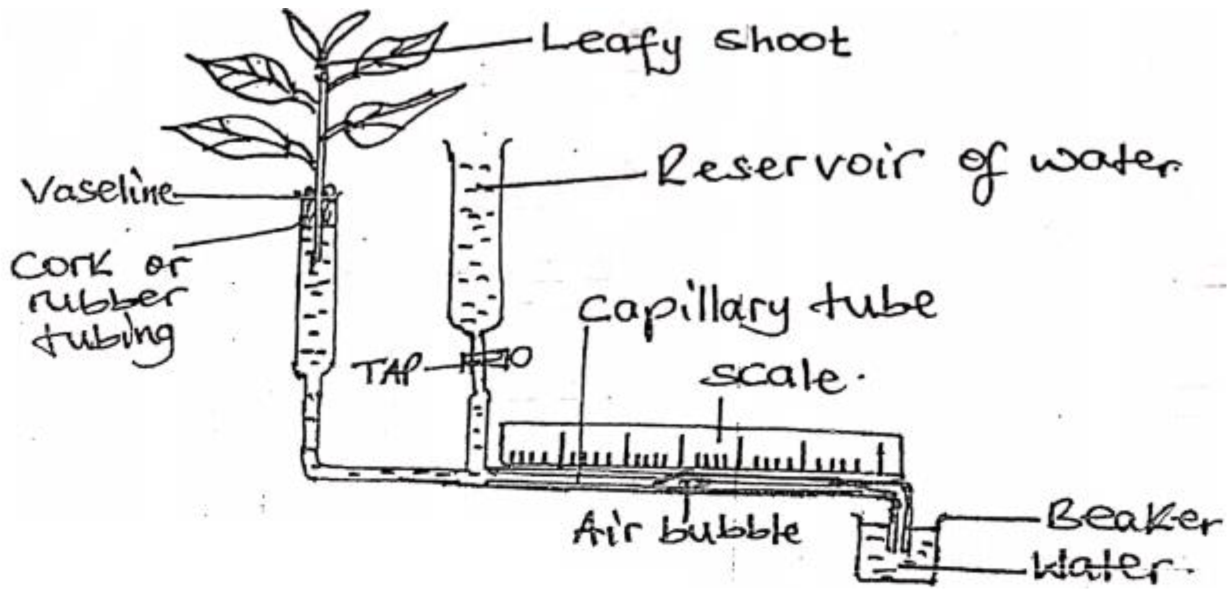
- Photometer
- A leafy short stemmed plant
- Large water trough/basin
- Beaker
- Vaseline
- Sharp knife
- Rubber stopper/cork
- Graduated scale
- Stop clock
- Polythene bag(to provide humid conditions)
- A fan
- Sunlight/a 25W bulb(to provide both heat and light)
- Refrigerator (to provide low temperature)

PROCEDURE

- The photometer is immersed totally in a basin of water until it is full.
- A shoot of a leafy plant is cut at its base underwater to prevent air bubbles from entering and blocking the xylem vessels.
- The cut leafy shoot is attached to the photometer via cork while still underwater.
- The cork is smeared with Vaseline to prevent entry of air.

- The photometer and plant are removed from water while holding the end of capillary tube closed with a finger.
- The end of the capillary tube is immersed in a beaker of water.
- The tap is opened to expel any existing air bubbles from the capillary tube.
- An air bubble is introduced at the end of the capillary tube by slightly raising it up from water in a beaker while briefly touching the tip with a finger and then back.
- The setup is put in varying environmental conditions of dim light, bright light, wind created by fan and humidity created by polythene tied around the leaves.
- The air bubble is returned to the starting mark of graduated scale by opening the tap of water reservoir.
- The time taken by the air bubble to more through a particular distance is noted.

EXPERIMENTAL SET UP



SAMPLE RESULTS

Distance moved by air bubble(cm)						
Time (minutes)	Bright light	Dim light	Strong wind	Light wind	Polythene (humid in sunshine)	Ordinary laboratory conditions
2	4.2	3.0	4.0	3.0	1.0	1.5
4	8.5	6.0	7.0	6.2	2.2	3.0
6	13.0	9.5	11.0	9.2	3.2	4.2
8	17.2	13.2	15.0	12.0	4.0	5.5
10	22.0	16.0	18.5	14.8	5.0	7.0
12	25.2	18.8	22.0	18.0	5.6	8.2

OBSERVATIONS

- The air bubble moves towards the shoot
- The air bubble moves faster in; bright light than dim light; strong wind than light wind.

- The air bubble is slowest when covered with polythene because it traps moisture lost from the plant & increases the humidity around the leaves.

  CONCLUSION
- The higher the light intensity, the faster the rate of transpiration.
- The stronger the wind, the faster the rate of transpiration
- The higher the humidity, the slower the rate of transpiration

  Treatment of results

$$Rate\ of\ transpiration = \frac{Distance\ travelled\ by\ air\ bubble(cm)}{Time\ taken\ in\ minutes}$$

ASSUMPTION

- Amount of water lost is equal to the amount of water absorbed

PRECAUTIONS TAKEN WHEN USING A PHOTOMETER

- Leafy shoot must cut under water to prevent blockage of xylem vessels by air entrance.
- A very leafy shoot must be used to count significant transpiration rate
- The instrument/water reservoir must be filled with water.
- The leafy shoot should be cut in a slanting way so that xylem can't easily be blocked.
- Air bubble must be reset at zero before any experiment by opening the tap of water reservoir.
- A well graduated scale must be used so that clear readings are taken.
- Only one air bubble should be present in the capillary tube.

ALTERNATIVELY

AN EXPERIMENT TO MEASURE THE RATE OF TRANSPIRATION USING THE WEIGHING METHOD

REQUIREMENTS

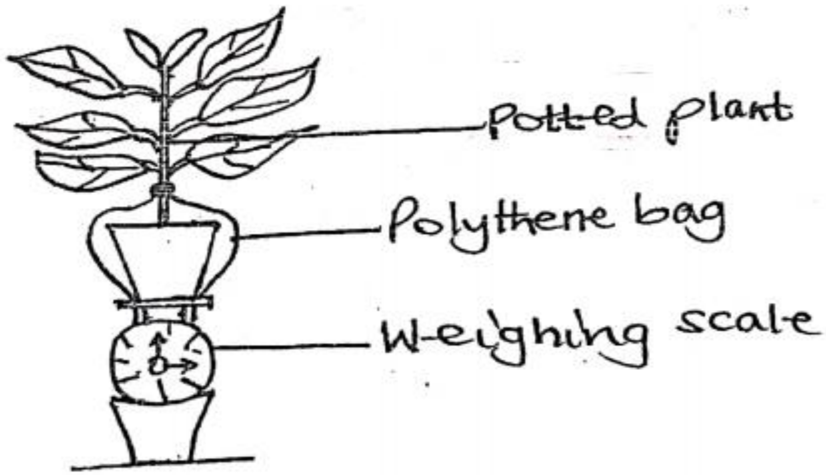
- Well water potted plant
- Dry polythene bag
- Weighing scale
- Aluminium pot cover

PROCEDURE

- A well-watered potted plant is placed in an aluminium pot cover and a polythene bag is tied around the pot (vessel) and the stem to prevent evaporation of water from the pot and soil.

- The whole potted plant and the pot are placed on a weighing scale and the total weight determined at regular intervals for several hours in a given set of environmental conditions.

EXPERIMENTAL SET UP



OBSERVATION

- The weight of the potted plant decreases with time.

CONCLUSION

- The decrease in weight is due to the amount of water lost from the uncovered parts of the stem and leaves by transpiration.

TREATMENT OF RESULTS

- The rate of transpiration is calculated by loss in mass per time intervals.

Rate of transpiration $= \frac{Loss\ in\ weight/mass}{Time}$

E.g. If it reduced from 200g to 150g in 10 minutes, then;

Rate of transpiration $= \frac{200g-150g}{10mins} = 5g\ of\ water\ per\ minute$

Question: The weight of a potted plant reduce from 400g to 350g in 10minutes. Calculate the rate of transpiration.

Solution

Rate of transpiration $= \frac{Loss\ in\ mass}{Time\ interval}$

$$= \frac{400g - 350g}{10mins}$$

$$= 5g/min$$

4. EXPERIMENT TO SHOW TRANSPIRATION PULL

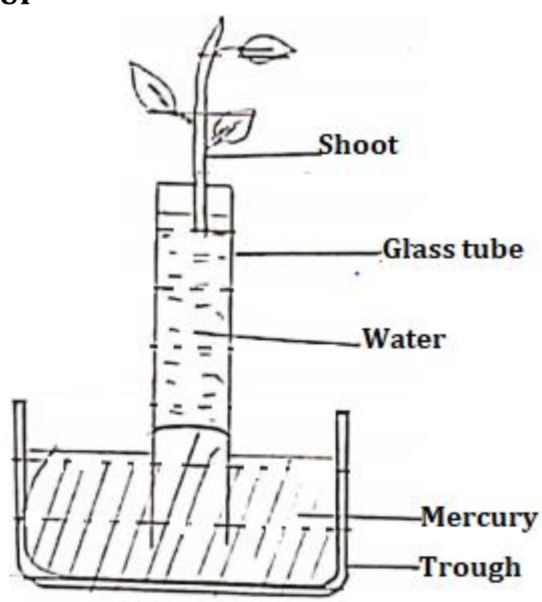
REQUIREMENTS

- Leafy shoot
- Glass tube
- Water
- Mercury
- Trough

PROCEDURE

- A leafy shoot is cut underwater.
- The cut shoot is fitted in a wide glass tube containing water.
- The glass tube is dropped in mercury in the trough.
- A control experiment with a leafless shoot is set up.
- Both shoots are left near an open window for a few hours.

EXPERIMENTAL SET UP



OBSERVATION

- Mercury rises in the first tube with a leafy shoot while there is no rise of mercury in the tube with leafless shoot.

CONCLUSION

- There is a force exerted on mercury pulling it upwards i.e. transpiration pull.

5. AN EXPERIMENT TO SHOW WHICH SURFACE OF A LEAF TRANSPIRES MORE

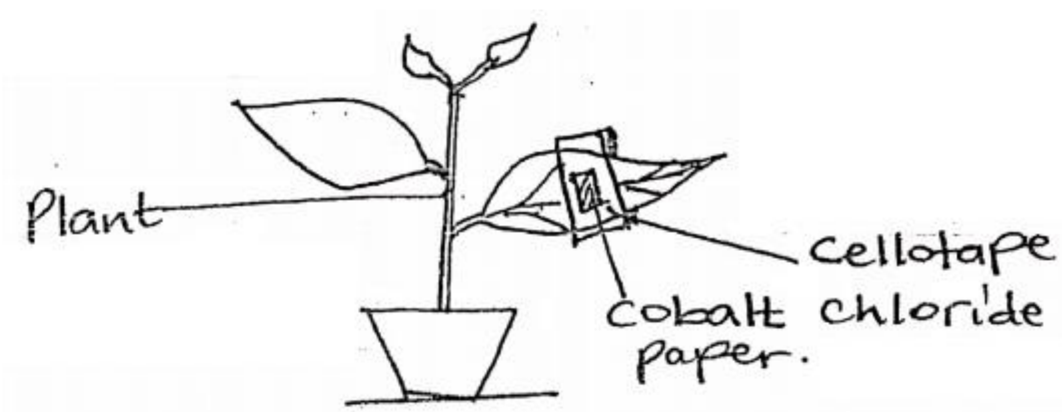
REQUIREMENTS

- Potted plant
- Anhydrous cobalt chloride paper
- 2 glass slides/microscopic slides
- Cellotape/rubber bands/paper clips
- Wooden block
- Stopclock/timer
- A pair of forceps
- Sunlight/ an electric light bulb of 60W

PROCEDURE

- 2 pieces of anhydrous cobalt chloride about $1m^2$ each are obtained
- One piece of cobalt chloride paper is put on upper surface and the other on lower surface of a leaf still attached to the shoot of plant using a pair of forceps.
- The cobalt chloride papers are completely covered using transparent cellotape/between glass slides fastened using rubber bands and supported using a stand and clamp.
- A control is set up by placing the cobalt chloride papers between glass slides attached on a wooden block, instead of a leaf.
- The setup is left to stand in bright sunlight.
- The time taken for each cobalt chloride paper to completely turn from blue to pink is noted and recorded.

EXPERIMENTAL SET UP



OBSERVATION

- The cobalt chloride paper on the lower surface (epidermis) turns pink a shorter time than the one on upper surface.

CONCLUSION

- The lower leaf surface transpires more than upper surface.

EXPLANATION

- The lower surface/epidermis has a faster transpiration rate than upper surface because it has more stomata thus loses more water than upper epidermis.

ALTERNATIVELY

AN EXPERIMENT TO SHOW WHICH LEAF SURFACE TRANSPIRES MORE (HAS MORE STOMATA)

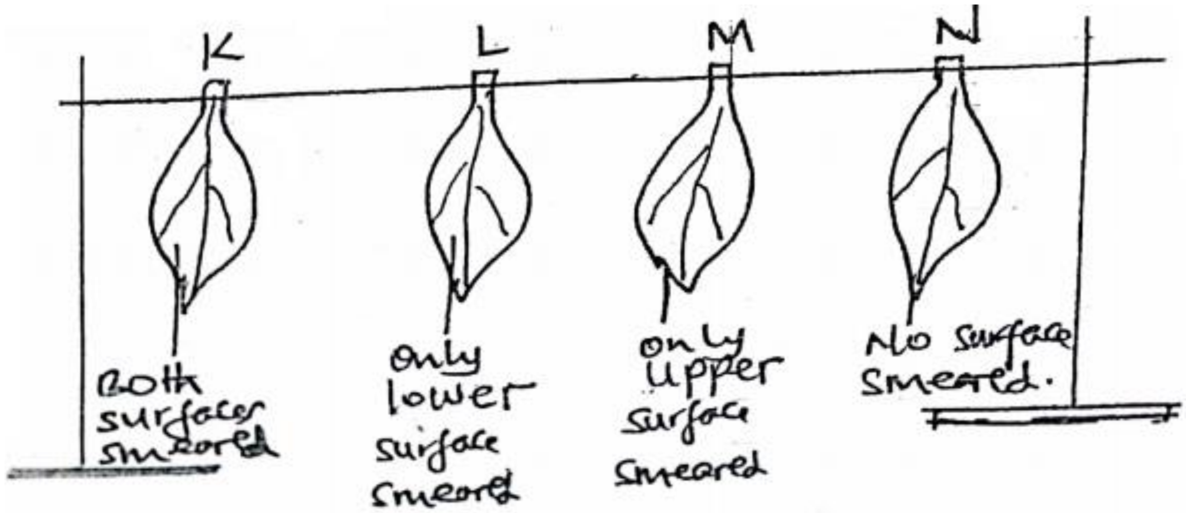
REQUIREMENTS

- 4 leaves of same size, mass and age from the same dicotyledonous plant.
- Vaseline
- Weighing scale
- Thread/string
- Retort stand
- Bright sunlight

PROCEDURE

- 4 leaves of the same size from the same plant are labeled as K, L, M and N.
- Leaves K, L and M are smeared with Vaseline as follows;
  - ✓ On both surfaces of leaf K
  - ✓ On the lower surface of leaf L
  - ✓ On the upper surface of leaf M
- Leaf N is not smeared with Vaseline.
- The leaves are weighed and the initial mass of each leaf is recorded.
- The leaves are hanged on a string by their petioles and suspended between 2 retort stand.
- Each leaf is weighed 3 more times for every after 5 minutes
- The percentage loss of weight for each leaf every after weighing is calculated in each case.

EXPERIMENTAL SET UP



OBSERVATION

- The percentage weight loss is fastest in lead N, followed by M, then L and least in least K.

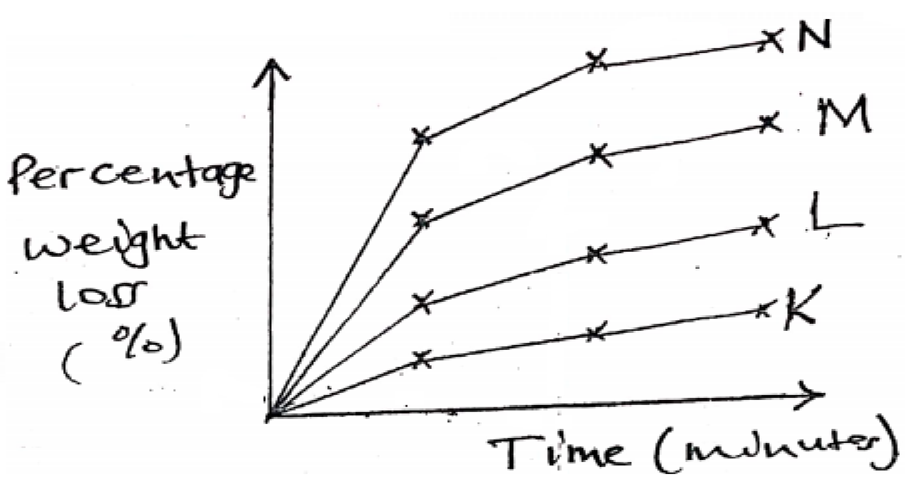
CONCLUSION

- The lower surface has more stomata thus transpires faster than the upper epidermis with fewer number of stomata.

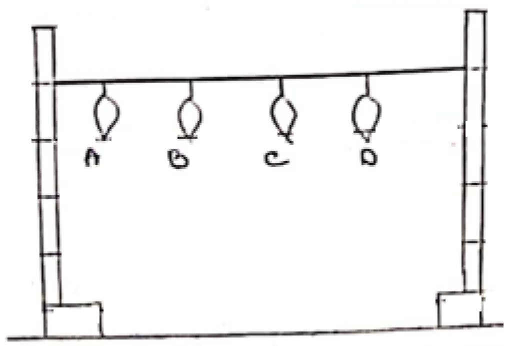
EXPLANATION

- Vaseline smeared on leaf surface(s) blocked the stomata and prevented water loss.
- Leaf N had the highest percentage of weight loss; because no stomata were blocked thus highest transpiration rate.
- Leaf M had a higher percentage of water loss than leaf L; because fewer stomata on upper epidermis of leaf M were blocked than those blocked on lower epidermis of leaf L thus higher transpiration rate in M than in L.
- Leaf K had the lowest percentage of water loss; because all its stomata were blocked thus lowest transpiration rate.

A GRAPH OF SHOWING THE VARIATION OF PERCENTAGE WEIGHT LOSS WITH TIME



Question: In an experiment to compare the rates of transpiration,4 leaves were treated with Vaseline as follows. [**NOTE**: The leaves were of the same size, age and from the same plant which is dicotyledonous]



A: Both sides of leaf are left free.

B: Vaseline is applied on upper surface only.

C: Vaseline is applied on lower surface only.

D: Vaseline applied on both surfaces.

The setup was transferred to sunlight and the time they take to dry determined using a stop clock.

(i) State what was observed.

- Leaf A dries fastest
- Leaf B dries fast
- Leaf C dries slowly
- Leaf D doesn't dry

(ii) Explain your observation

- A dicotyledonous leaf has more stomata on the lower surface than on the upper surface.
- In leaf A, both the upper & lower surface stomata are allowed to transpire, thus the rate of transpiration is very high therefore the leaf dries fastest.
- In leaf B, the upper surface stomata are covered, allowing the many lower surface stomata to transpire, thus the rate of transpiration is high so the leaf dries fast.
- In leaf C, the lower surface stomata are covered, allowing only the few upper surface stomata to transpire thus the rate of transpiration is low, so the leaf dries slowly.
- In leaf D, both the upper and lower surface stomata are covered, so transpiration doesn't take place and therefore the leaf doesn't dry.

CONCLUSION

- The rate of transpiration is higher from the lower surface of the leaf than from the upper surface.

6. **AN EXPERIMENT TO DEMONSTRATE ROOT PRESSURE**

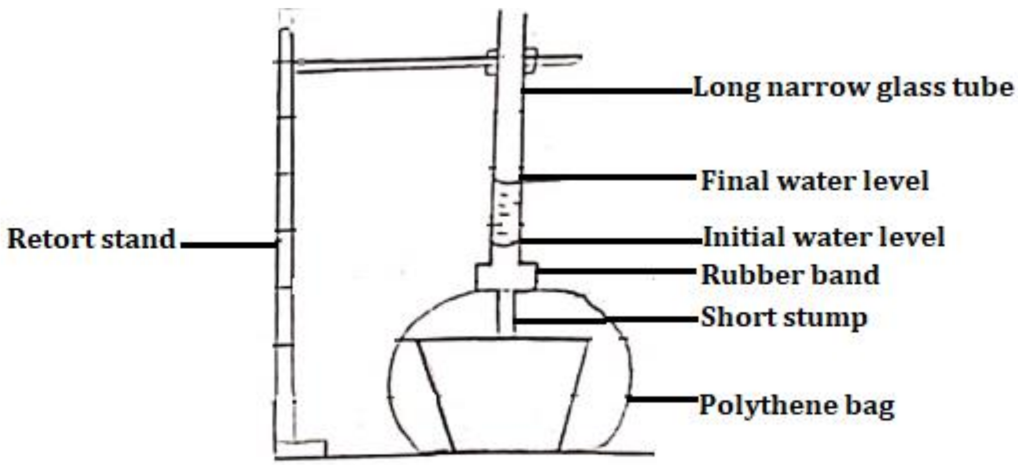
REQUIREMENTS

- Potted plant
- Rubber band
- Capillary tube
- Polythene bag
- Retort stand

PROCEDURE

- The stem of a potted plant is cut transversely & the base of the stump and the pot are enclosed in a polythene bag, to prevent evaporation of water from them.
- A monometer is then attached to the upper part of the stump or a capillary tube is attached to the cut stem using a rubber band.

EXPERIMENTAL SET UP



OBSERVATION

- Immediately a fluid is seen to exude from the surface of the stump and when a capillary tube is attached, the level of the fluid rises to a new level as shown above
- When the manometer is attached, the level of mercury rises to a new lever.

CONCLUSION

- A pressure originating from the roots called root pressure forces the fluid out of the stump. However, this root pressure is not strong enough to push the fluid to great height.

TRANSLOCATION

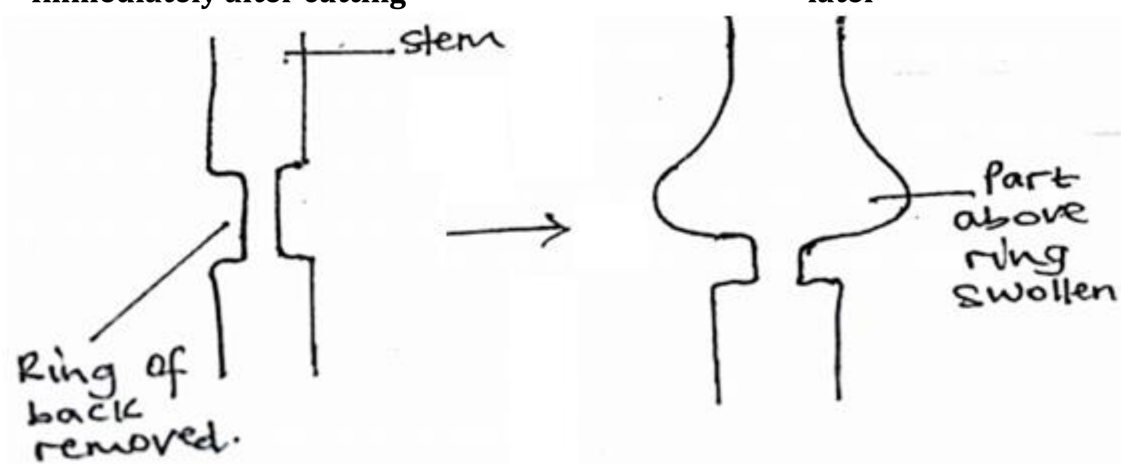
- Is the movement of dissolved food substances from where they are manufactured in the leaves to other parts where they are used or stored.
- It occurs in the phloem tissue within living sieve tubes; thus anything that kills it like poison, steam or lack of oxygen prevents translocation from taking place.

EVIDENCE TO PROVE THAT TRANSLOCATION OCCURS IN PHLOEM

1. Ringing experiment
2. Experiment with aphids
3. Use of radioactive substances.

1. **Ringing experiment**; bark of a tree stem is cut deep upto xylem and removed to form a ring; accumulation of organic solutes occurs to blockage translocation; leading to crystallization of organic solutes on the upper side of the bark ring; thus becomes swollen hence proven.

Immediately after cutting **later**



NB: The leaves of the plant in this experiment do not dry because the xylem along which water flows upwards is not cut way.

2. **Experiment with aphids**

Aphids (greenflies) are allowed to pierce the plant using their proboscis (stylets); They extract sugars via phloem and pass out lots of water. Immobilize the aphids using carbon dioxide and cut away the insect from its proboscis; The solution continues to flow out into a given container; its flow is due to hydrostatic pressure; but rather not sucking. OR The solution from the stylets is pipette by use of a micropipette. The collected substances in the solution are then tested/analyzed and found to have food substances similar to those in phloem.

3. **Use of radioactive substances**
   Using carbon dioxide with radioactive carbon-14; plant carries out photosynthesis using this carbon dioxide. Using a radioactive tracer; carbon-14 found within phloem thus the proof.
   Limitation: Xylem can also carry the radioactive substances.

MECHANISM OF TRANSLOCATION

- It occurs mainly by mass flow due to turgor pressure gradient.
- Sugars like sucrose flow from leaves with higher turgor pressure where they are made to roots and other plant plants with lower turgor pressure where they are used like in respiration or stored.
- Accumulation of sugars in leaf cells from photosynthesis attracts water from adjacent root xylem; sugars dissolve in water to form a solution, increasing the turgor pressure; sugar/sucrose solution them flows from leaves to roots and other plant parts with low turgor pressure due to its constant unloading from phloem for utilization and storage; by mass flow.

TRANSPORT IN ANIMALS

Major process involved

1. Diffusion
2. Osmosis
3. Active transport

Transport in smaller organisms/unicellular organisms

- Smaller organisms like amoeba, paramecium, coelenterates and Platyhelminthes etc lack transport systems.

Reasons for the absence of transport systems in smaller organisms (unicellular organisms)

1. Smaller animals have a larger surface area to volume ratio so simple processes like diffusion, osmosis and active transport are sufficient for exchange of materials between the organisms and surrounding medium.
2. Smaller animals have a shorter distance between the external medium and the centre of the body thus passive processes live diffusion are enough for movement of materials.
3. Smaller animals have lower metabolic rates thus have fewer metabolic requirements and fewer metabolic wastes.

Transport in larger organisms (multicellular organisms)

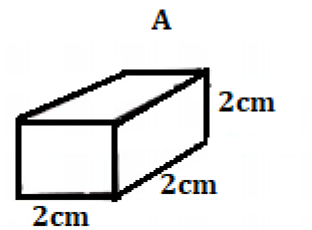
- Larger multicellular organisms have a well-developed transport system.

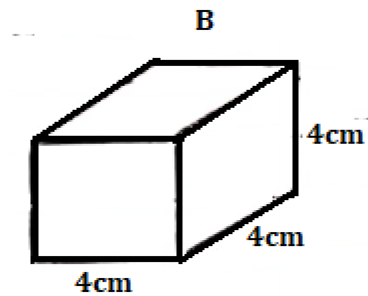
Reasons for the need of transport system in bigger multicellular organisms

1. Bigger animals have a smaller surface area to volume ratio thus passive processes like diffusion and osmosis across the external surface are insufficient for exchange/movement of materials.
2. Bigger organisms have higher metabolic rates, thus have more metabolic requirements and more metabolic wastes which need rapid supply and removal respectively.
3. Bigger organisms have distant specialized cells/organs which need to be connected for efficiency and have impermeable integuments.
4. Need to separate materials in transit.

THE CONCEPT OF THE SURFACE AREA TO VOLUME RATIO

- Consider 2 cubes A & B as model organisms of different sizes;





Cube	Surface area	Volume	Surface area: volume ratio $(\frac{Surface\ area}{Volume})$
A	=6(LXW) =6(2cmX2cm) =24cm^2	=LXWXH =2cmX2cmX2cm =8cm^3	3:1 (3cm^{-1})
B	=6(LXW) =6(4cmX4cm) =96cm^2	=LXWXH =4cmX4cmX4cm =64cm^3	1.5:1 (1.5cm^{-1})

⇒ The small cube A has a larger surface area to volume ratio than the larger cube thus small organisms have larger surface area to volume ratio than large organism therefore no need of special transport system in small organisms unlike large organisms who need well developed transport system to transport materials in and out of their bodies.

THE BASIC COMPONENTS OF A CIRCULATORY (VASCULAR) SYSTEM

1. A Pumping organ/ mechanism like the heart
2. A system of tubes/vessels like blood vessels and lymphatic vessels
3. A circulatory fluid like blood and lymph

FUNCTION OF THE CIRCULATORY SYSTEM & BLOOD

(i) Transports nutrients from absorption area like ileum to different body parts for storage, assimilation and synthesis of new compounds.

(ii) Transports excretory waste products from their sites of production to excretory organs for elimination like urea from the liver to kidneys.

(iii) Transports hormones from endocrine glands to the target organs where they exert their effect.

(iv) Distributes heat from highly metabolically active organs to less metabolically active organs like liver for temperature regulation.

(v) Transports respiratory gases like oxygen from lungs to tissue for respiration and carbon dioxide from tissues to lungs for elimination.

(vi) Transports water, inorganic ions/salts and various chemicals for uniform distribution.

(vii) Transports antibodies and white blood cells (phagocytes) which engulf and digest pathogens for defense.
(viii) Transports blood platelets for blood clotting in case of bleeding.

TYPES OF CIRCULATORY SYSTEMS IN ANIMALS

- There are 2 basic types of blood circulatory systems viz;

1. Open circulatory system
2. Closed circulatory system

1. **Open circulatory system**; is where blood is <u>not confined</u> to blood vessels throughout its course of circulation as in most arthropods like insects.
   Blood is pumped by the heart into an aorta, branching into a number of arteries opening into a series of body spaces called the <u>haemocoel</u>.
   Blood flows freely over the tissues in the haemocoel, and gradually percolates back into the heart through open ended veins.
2. **Closed circulatory system**; is where blood is confined to blood vessels throughout its circulation course in the body. Like in vertebrates and annelids.
   Types of closed circulatory system

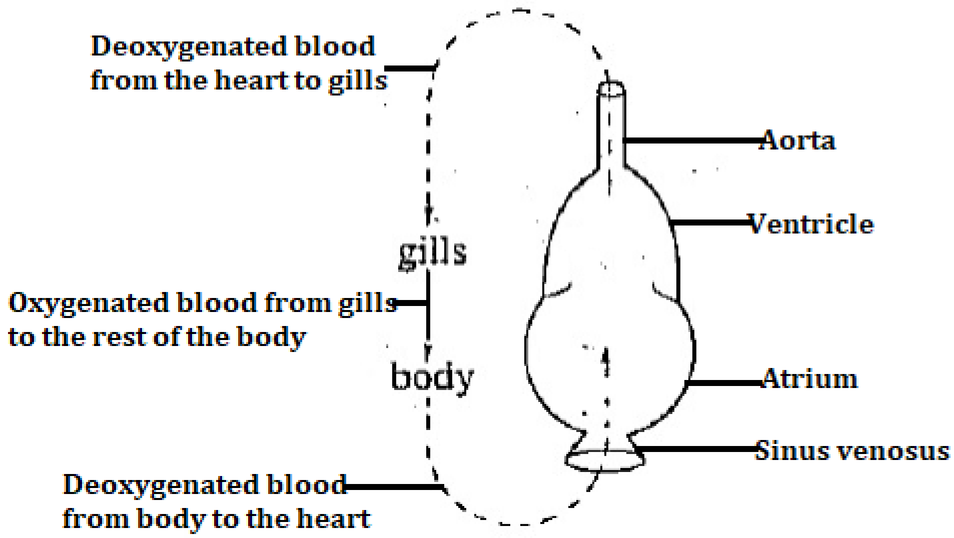
- There are 2 types of closed circulatory systems viz;

(i) Closed single circulatory system
(ii) Closed double circulatory system
(i) A **CLOSED SINGLE CIRCULATORY SYSTEM**; is where blood is confined to blood vessels and passes through the heart once for every complete circuit of the body. Like in fish and earthworms.

THE CLOSED SINGLE CIRCULATORY SYSTEM OF FISH

- Fish have a 2 chambered heart with <u>1 atrium</u> and <u>1 ventricle</u>.
- Deoxygenated blood from the body is pumped by the muscular ventricle of the heart into the aorta which takes blood to the gills.
- The blood gets oxygenated when it passes over the gills and then continues to flow to various body parts before returning slowly to the heart.
- The deoxygenated blood collects first in the sinus venosus from where it flows into the atrium.

ILLUSTRATION OF THE CLOSED SINGLE CIRCULATION IN FISH

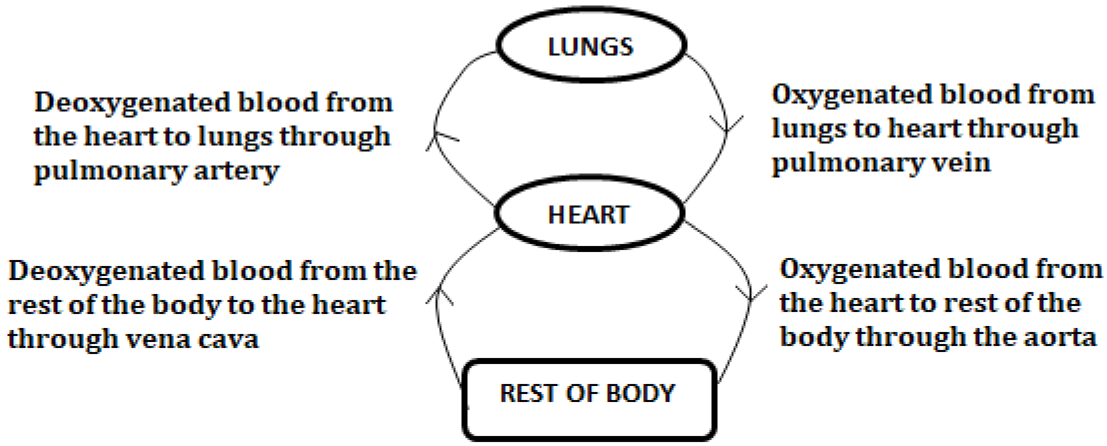


(ii) A **CLOSED DOUBLE CIRCULATORY SYSTEM**; is where blood is confined to blood vessels and passes through the heart twice for each compete circuit of the body. Like in amphibians, reptile, birds and mammals.
One circulation is between the heart and the body organs except the lungs called the systemic circulation and another circulation is between the heart and the lungs called the pulmonary circulation.

THE CLOSED DOUBLE CIRCULATORY SYSTEM

- During pulmonary circulation, deoxygenated blood from the right ventricle is pumped to the lungs through the pulmonary artery where it gets oxygenated blood.
- The oxygenated blood flows into the left atrium of the heart through the pulmonary vein.
- During systemic circulation, the oxygenated blood from the left atrium pours into the left ventricle and is pumped to the rest of the body via the aorta.
- The aorta braches into arteries, arteries into arterioles, arterioles into a network of blood capillaries in the tissues, where exchange of materials and gases occurs.
- The deoxygenated blood from the tissues flows through venules and then into veins.
- The deoxygenated blood returns into the right atrium through venacava.

ILLUSTRATION OF THE CLOSED DOUBLE CIRCULATION



DIFFERENCES BETWEEN THE OPEN AND CLOSED CIRCULATORY SYSTEM

OPEN CIRCULATORY SYSTEM	CLOSED CIRCULATORY SYSTEM
• Blood not confined to blood vessels. • Tissues in direct contact with blood. • Blood flows under lower pressure. • Arteries open into haemocoel. • Blood takes longer to circulate around the body. • Volume of blood flowing through a tissue can't be controlled. • Present in most arthropods & cephalopod molluscs.	• Blood confined to blood vessels. • Tissues not in direct contact with blood. • Blood flows under greater pressure. • Arteries open into arterioles. • Blood takes shorter time to circulate. • Volume of blood flowing through a tissue can be controlled. • Present in vertebrates, annelids, echinoderms and some mollusks

Differences between closed single circulation and closed double circulation

SINGLE CIRCULATION	DOUBLE CIRCULATION
• Blood flows once through the heart every complete circuit of the body.	• Blood passes through the heart twice for every complete circuit of the body.
• Heart pumps deoxygenated blood.	• Heart pumps deoxygenated blood to lungs and oxygenated blood to rest of the body.
• Blood is oxygenated by gills	• Blood oxygenated by lungs.
• Occurs in fish	• Occurs in amphibians, reptiles, birds and mammals.

THE COMPARATIVE ADVANTAGES OF DOUBLE CIRCULATION OVER SINGLE CIRCULATION

(i) In single circulation blood flows at lower pressure while in double circulation blood flows at a high pressure required for fast flow of blood wastes.
(ii) In single circulation blood flows slowly while in double circulation blood flows rapidly thus rapid circulation is attained.
(iii) Slow flow of blood in single circulation sustains lower metabolic activity while rapid flow of blood in double circulation sustains higher metabolic activity (metabolism).
(iv) In double circulation blood is piped directly where it's needed.
(v) In double circulation there's complete separation of oxygenated and deoxygenated bloods which improves circulation efficiency and sustains high metabolism

THE BLOOD VASCULAR SYSTEM

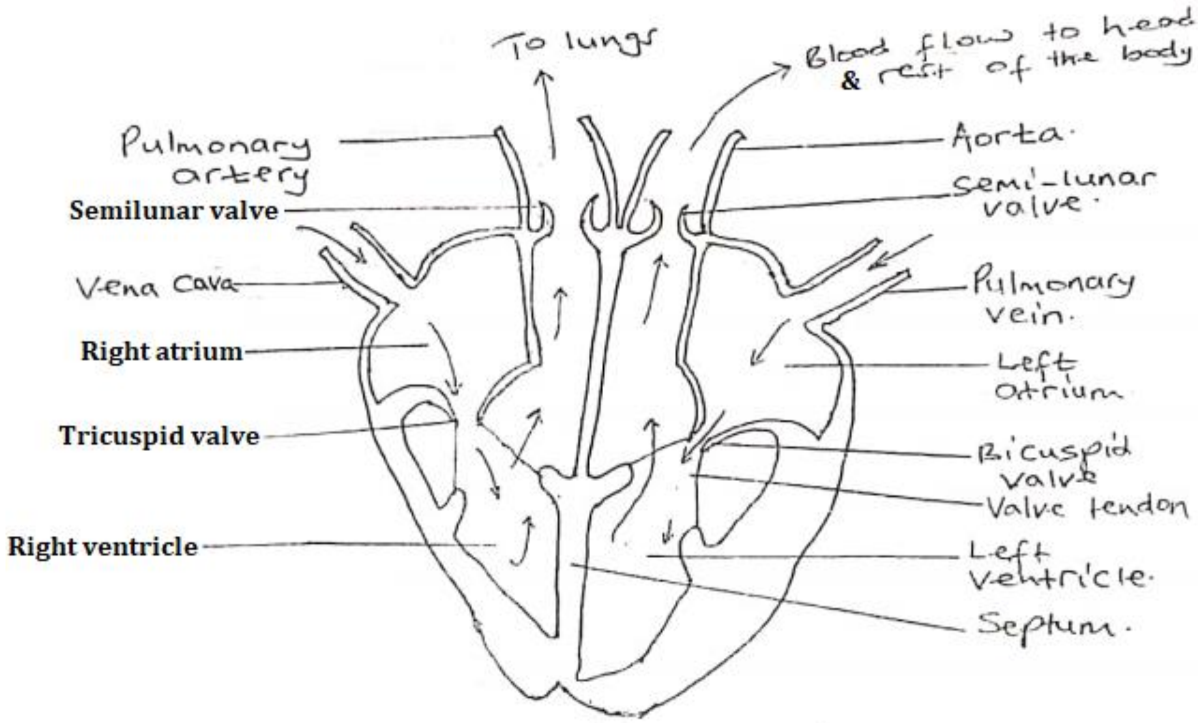
- The basic features of the blood vascular system of vertebrates are;

1. A pumping device/organ, the heart
2. A system of tubes, the blood vessels.
3. A transport medium, which is the blood.
4. One-way valves

1. THE MAMMALIAN HEART

- The heart comprises of 4 chambers, 2 thin-walled atria and 2 thick-walled ventricles.
- The heart is divided into 2 sides, the right and left; the left is thicker than the right side by septum.
- The heart contains atrio-ventricular valves between the atria and ventricles.
- The right atrium is separated from the right ventricle by the tricuspid valve, and the left atrium from left ventricle by the bicuspid valve.
- The atrio-ventricular valves are attached to the papillary muscles of the ventricular wall by fibrous cords called chordae tendinae.
- The heart has a special type of muscle called cardiac muscle which is myogenic in nature and is protected from of stretching a tough outer lining called pericardium.
- The heart is supplied with blood by coronary arteries.

THE STRUCTURE OF THE MAMMALIAN HEART



THE CARDIAC CYCLE

- Is the sequence of events that constitute one heart heart.
- It involves relaxation of heart walls called diastole and contraction of heart walls called systole.
- It occurs in 4 stages namely;
    1. **Atrial diastole**; the atrial walls relax; volume of atria increases, pressure decreases and the atria/auricles are filled with blood.
    2. **Ventricular systole**; the ventricles contract; atrio-ventricular valves close; blood is pumped out of the heart.
    3. **Atrial systole**; atria/auricles contract and blood is poured into the ventricles.
    4. **Ventricular diastole**; ventricles relax and get filled with blood.

NOTE: Two stages occur concurrently i.e. atrial diastole and ventricle systole occur at the same time as well as atrial systole and ventricular diastole.

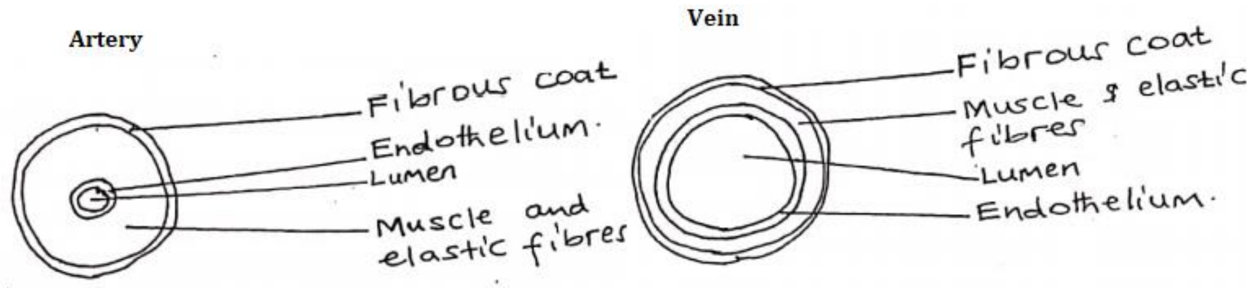
2. **THE BLOOD VESSELS**

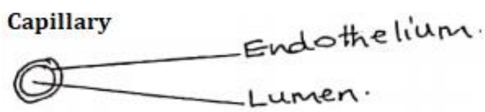
- Blood vessels are tubes through which blood is carried within the body.
- There are 3 main types of blood vessels viz;
    (a) Arteries
    (b) Veins
    (c) Blood capillaries

THE STRUCTURE OF BLOOD VESSELS

- Each artery and vein comprises of 3 layers viz;
  - (i) The tunica externa, an external layer consisting of mainly inelastic white collagen fibres.
  - (ii) The tunica media, a middle layer of smooth muscles and elastic fibres.
  - (iii) The tunica intima; inner layer of squamous endothelium.
- Blood capillaries consist of only the endothelium.
- Smaller branches of arteries are called arterioles.
- Smaller branches of veins are called venules.

Diagrammatic illustration of transverse sections of blood vessels





A comparison of arteries, veins and blood capillaries

(a) **Similarities among arteries, veins and capillaries**
- (i) All have a lumen
- (ii) All have endothelium
- (iii) All transport blood

(b) **Differences among arteries, veins and capillaries**

ARTERIES	VEINS	BLOOD CAPILLARIES
1. Thicker muscular walls.	1. Thinner muscular walls	1. Lack muscular walls.
2. More elastic fibres.	2. Less elastic fibres	2. No elastic fibres.
3. Narrower lumen relative to diameter.	3. Wider lumen relative to diameter	3. Narrow lumen relative to diameter.
4. No semilunar valves, except at the bases if the aorta and pulmonary artery.	4. Have semilunar valves throughout their length.	4. No semilunar valves.

5. Can constrict(vasoconstriction)	5. Can't constrict.	5. Can't constrict.
6. Not permeable	6. Not permeable	6. Permeable
7. Transport blood away from the heart.	7. Transport blood towards the heart.	7. Link arteries to veins.
8. Transport oxygenated blood, except the pulmonary artery.	8. Transport deoxygenated blood, except the pulmonary vein.	8. Both, blood changes from oxygenated to deoxygenated.
9. Blood flows under high pressure.	9. Blood flows under lower pressure.	9. Blood flows at moderate pressure.
10. Blood flows in pulses.	10. Blood flows with no pulse.	10. Blood flows with no pulse.
11. Blood flows rapidly.	11. Blood flows slowly	11. Blood flows slowly.
12. Carry lower blood volume.	**12.** Carry highest blood volume.	**12.** Carry higher blood volume.

(a) **ARTERIES**: Blood vessels that carry blood away from the heart to other body parts.

Function: Transport blood away from the heart.

Adaptations of arteries to their function

(i) Have thick muscular walls to produce high pressure for rapid blood flow.

(ii) Have much elastic fibres to withstand high blood pressure by stretching (dilating) and not to rupture when the heart contracts and forces blood into them at high pressure.

(iii) Have elastic tissue that causes elastic recoil which smoothens out blood flow.

(iv) Have narrow lumen to maintain high pressure for rapid blood flow.

(v) Small arteries are supplied with sympathetic neurons to control blood flow to body parts by vasodilation and vasoconstriction.

(vi) Arterioles possess sphincters whose contraction and relaxation controls blood flow to blood capillary networks.

(vii) Aorta and pulmonary artery have semilunar valves at the bases to prevent backflow of blood into the heart.

(b) **BLOOD CAPILLARIES**

- Are small blood vessels that arteries to veins(arterioles to venules).

Functions of blood capillaries

(i) Link arteries to veins

(ii) Sites for exchange of materials between blood and tissues

ADAPTATIONS OF BLOOD CAPILLARIES TO THEIR FUNCTIONS

(i) Have thin walls comprising of endothelium only, thus permeable to water and dissolved substances.
(ii) Have thin walls only one cell thick, to reduce diffusion distance for easy diffusion of substances.
(iii) Are numerous to provide a large surface area for rapid exchange of substances between blood and tissues.
(iv) Have narrow lumen that offers high resistance to blood flow thus blood flows slowly, allowing enough time for exchange of material.

(c) **VEINS**

- Are blood vessels that transport blood towards the heart.
  Function: Veins transport blood towards the heart.

ADAPTATIONS OF VEINS TO THEIR FUNCTION

(i) Have wide lumen that provides a large surface area thus reduced resistance to blood flow for mass flow of a bigger volume of blood under low pressure.
(ii) Have semilunar valves to prevent back flow of blood in the veins thus unidirectional blood flow.
(iii) Many veins are located between the large muscles of body like in the arms and legs, so that skeletal muscle contraction exerts pressure on them to cause blood flow to the heart.

MECHANISMS BY WHICH BLOOD FLOW IS MAINTAINED

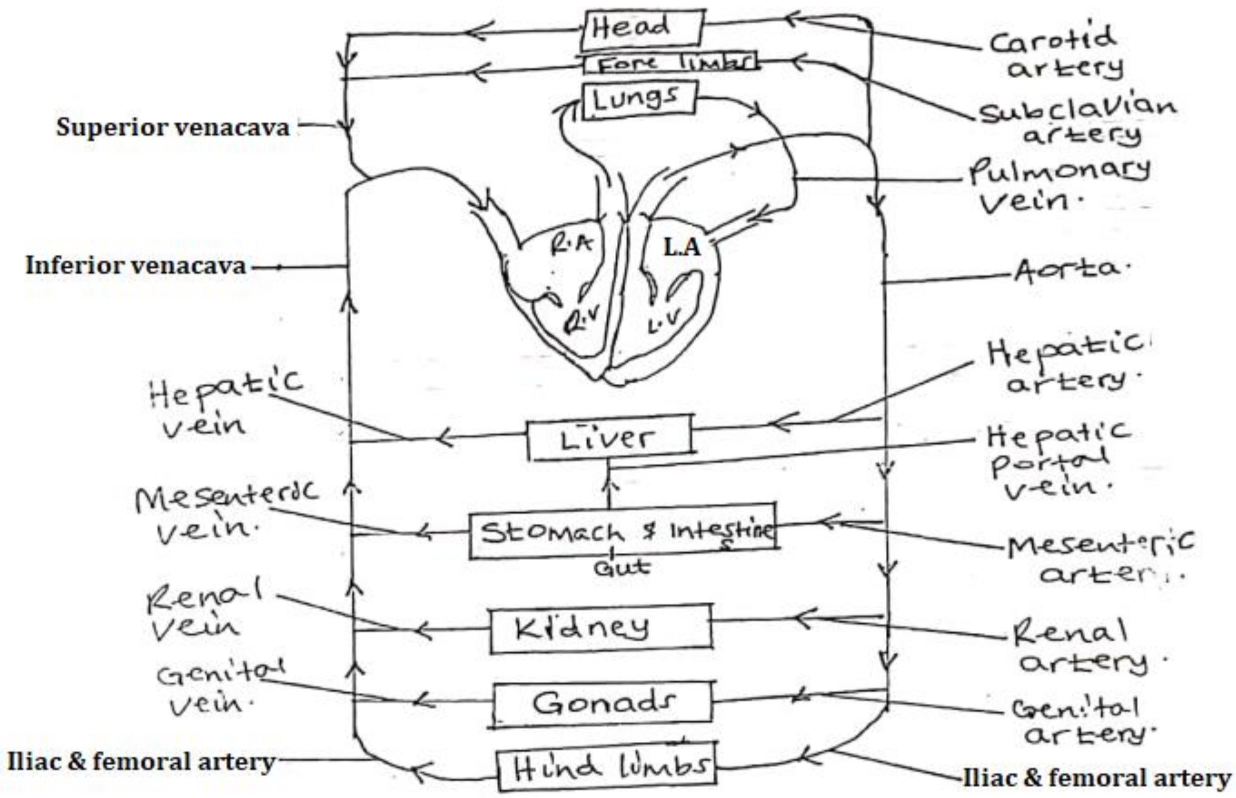
(i) The pumping action of the heart, forces blood into arteries and blood capillaries.
(ii) The contraction of skeletal muscles squeezes veins, increasing venous blood pressure.
(iii) Reduced thoracic pressure during inspiration draws blood towards the heart.
(iv) Semilunar valves prevent backflow of blood, ensuring one-way flow of blood.

NOTE: A portal vessel links two organs neither of which is the heart.

FUNCTIONS OF PORTAL VESSELS

(i) The hepatic portal vein carries nutrients from the gut to the liver.
(ii) The hypophyseal portal vessel carries hormones from the hypothalamus to the pituitary gland.

THE GENERAL PLAN OF THE MAMMALIAN CIRCULATORY SYSTEM



3. **BLOOD**

- Blood is a liquid connective tissue consisting of many cells suspended in blood plasma.

THE COMPONENTS OF BLOOD

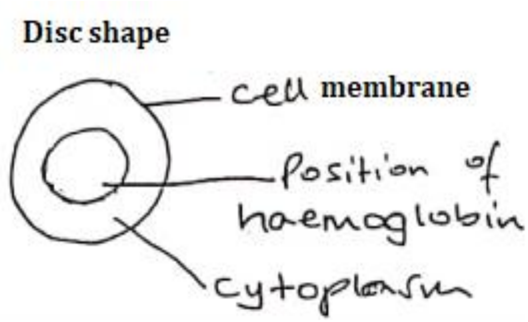
- Blood consists of blood cells (red & white cells), platelets & plasma.

(a) **BLOOD CELLS**.

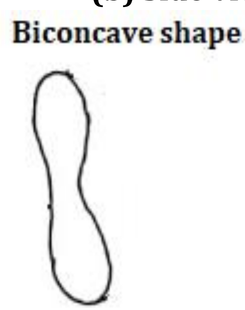
- There are 2 types of blood cells viz;
  - (i) Red blood cells
  - (ii) White blood cells
  - (i) **RED BLOOD CELLS (ERYTHROCYTES)**

STRUCTURE

(a) Front view



(b) Side view



CHARACTERISTICS OF RED BLOOD CELLS

1. Have flattened biconcave disc shape
2. Are small cells
3. Mature red blood cells lack a nucleus
4. Are very thin cells with thin membranes
5. Are numerous in blood, about 5,000,000 red blood cells permm^3 of blood.
6. They contain haemoglobin, the oxygen-carrying pigment in their cytoplasm which gives blood its red colour.
7. Mature red blood cells lack mitochondria thus respire anaerobically.
8. Have short life span of about 3 months.
9. In the foetus, red blood cells are formed in the liver, but in adults red blood cells are formed in the yellow/red bone marrow of long bones.
10. Red blood cells contain the enzymes carbonic anhydrase.

THE FUNCTIONS OF RED BLOOD CELLS

1. Carry oxygen from lungs to tissues.
   Oxygen combines with haemoglobin in the red blood cells to form oxyhaemoglobin.
2. Carry carbon dioxide from tissues to lungs.
   A little carbon dioxide combines with haemoglobin in red blood cells to form carboaminohaemoglobin, while much carbon dioxide is carried as hydrogen carbonate ions in the cytoplasm of red blood cells.

ADAPTATIONS OF RED BLOOD CELLS TO THEIR FUNCTIONS

1. Have biconcave-disc shape which provides a large surface area to volume ratio for rapid diffusion of respiratory gases like oxygen.
2. Are thin membraned (very thin cells) to provide a shorter diffusion distance of respiratory gases.
3. Have flexible membranes to easily squeeze through narrow lumens blood capillaries to exchange with tissues.
4. Are numerous for carriage of much oxygen.
5. Have haemoglobin pigment with high affinity oxygen to carry much oxygen.
6. Mature red blood cells lack nucleus & mitochondria to provide more space for haemoglobin and carriage of much oxygen.
7. Lack mitochondria so respire anaerobically and thus don’t use oxygen transported.
8. Contain carbonic anhydrase enzyme which catalyses the formation of carbonic acid for carbon dioxide transport.
9. Have permeable membranes; for easy diffusion of respiratory gases.

HINT:

- ✓ Haemoglobin combines with oxygen to form oxyhaemoglobin in areas of high oxygen tension and oxyhaemoglobin dissociates to release oxygen in areas of high carbon dioxide tension by the Bohr effect.
- ✓ The rate of destruction and development of red blood cells is determined by the oxygen tension in the atmosphere, allowing acclimatization to lower oxygen tension at higher altitudes.

NOTE:

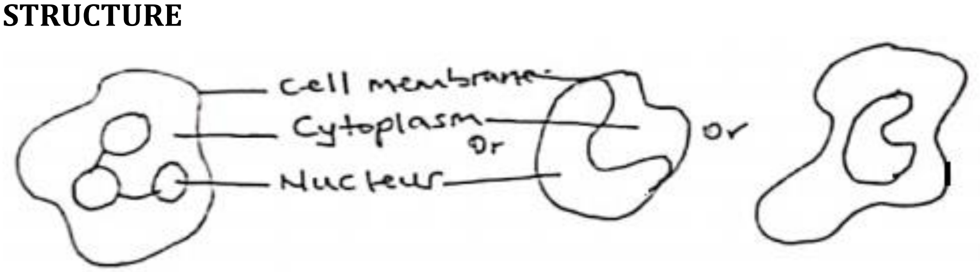
i) Diseases like malaria reduce the number of red blood cells in the blood due to destruction of RBCs by plasmodia. This causes anaemia (lack of iron).
Anaemic patients are always tired and appear pale.

ii) People living at high altitudes like mountains have more red blood cells than those at low land.
Reason: At higher altitudes, the atmospheric pressure is lower so oxygen tension/partial pressure is lower, thus more red blood cells are produced to carry sufficient oxygen for sufficient respiration to provide enough energy.
This is made use of by athletes during high altitude training.

iii) Infants have more red blood cells than adults, because infants are smaller with larger surface area to volume ratio, so lose heat rapidly thus have high metabolic rate to replace heat being lost than adults that are larger with smaller surface area to volume ratio thus lose heat slowly.

- Aged and worn out red blood cells are destroyed in the liver and spleen, resulting in the formation of the bile pigments bilirubin and biliverdin, which are excreted in bile, temporarily stored in the gall bladder.

(ii) **WHITE BLOOD CELLS (LEUCOCYTES)**
STRUCTURE



CHARACTERISTICS OF WHITE BLOOD CELLS

1. Bigger than red blood cells.
2. Have nuclei.
3. Capable of amoeboid movement.
4. There are about 7000 white blood cells per mm^3 of blood.
5. White blood cells are formed in the thymus gland, lymph nodes and white bone marrow.

6. Have amoeboid/irregular shape.
7. There are 2 types of white blood cells; granulocytes and agranulocytes.

FUNCTIONS OF WHITE BLOOD CELLS

i) Engulf and digest disease-causing bacteria and other large particles by phagocytosis.
ii) Combat allergies like hay fewer (light) & asthma, using anti-histamines.
iii) Produce histamine which causes inflammation of damaged tissues, stimulating healing and repair.
iv) Produce the anti-coagulant heparin, preventing blood clotting.
v) Involved in body immune responses.

METHODS USED BY WBCS TO DEFEND THE BODY

1. Engulfing the germs/pathogens by phagocytosis.
2. Producing antibodies to fight antigens.
   An antigen is a foreign substance stimulate immune response once enters the body.
3. Producing anti-toxins that neutralize poisonous/toxic substances.
4. Destroying pathogens by dissolving their outer coat.
5. Sticking/clumping pathogens together so that they cannot reproduce or penetrate the host cell.

Examples of white blood cells

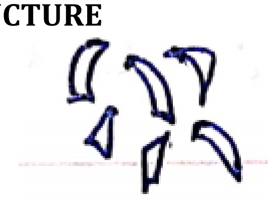
1. **Phagocytes**; these engulf germs/pathogens.
2. **Lymphocytes**; these produce antibodies.

NOTE:

- The number of white blood cells increases slightly following infection and disease i.e when one falls sick or wounded.
- However, certain diseases reduce the number of white blood cells e.g. AIDS and syphilis.

(b) **PLATELETS(THROMBOCYTES)**

STRUCTURE



CHARACTERISTICS OF PLATELETS

1. Are irregularly shaped membrane bound cell fragments.
2. Lack nuclei
3. Are formed in special red bone marrow cells.

4. Are about 250,000-400,000 platelets per mm^3 of blood.
5. Are smaller than red blood cells.

FUNCTION OF PLATELETS

- Initiate blood clotting thus their number increase when one is wounded/on cut.

(c) **BLOOD PLASMA**

- Blood plasma is a pale-yellow liquid consisting of 90% of water and 10% other substances in solution and suspension.
- Forms 55% of entire blood volume.

COMPONENTS OF BLOOD PLASMA

(i) Water
(ii) Plasma proteins; including serum albumins, serum globulins, prothrombin, fibrinogen and enzymes.
(iii) Mineral ions
(iv) Organic products of digestion like sugars, fatty acids, glucose, vitamins, amino acids glycerol
(v) Excretory waste products like urea.
(vi) Hormones like insulin sex hormones
(vii) Antibodies ; anti-toxins
(viii) Antigens

NOTE:

- ✓ The difference between blood plasma and tissue fluid is that tissue fluid lacks plasma proteins.
- ✓ Serum is blood plasma from which fibrinogen has been removed.

FUNCTIONS OF MAMMALIAN BLOOD

- The functions of mammalian blood fall into 3 categories;

(a) Transport
(b) Protection
(c) Homeostasis

(a) **THE TRANSPORT FUNCTIONS OF BLOOD**

(i) Blood transports soluble products of digestion like glucose, amino acids, fatty acids, glycerol from the ileum to various body parts for use/storage.
(ii) Blood transports food substances mobilized from storage organs to the parts of the body where they are utilized.
(iii) Blood transports soluble excretory products like urea to excretory organs for elimination.
(iv) Blood transports oxygen from lungs to the respiring body tissues for aerobiosis.
(v) It transports carbon dioxide from the respiring tissues to lungs for excretion.

(vi) It transports hormones from endocrine glands to their target organs where they exert their effects.

(b) **THE PROTECTIVE FUNCTIONS OF BLOOD**

(vii) Blood clotting prevents excessive loss of blood, prevents entry of pathogens and starts the process of wound healing.

(viii) White blood cells engulf and digest bacteria preventing infection.

(ix) Antibodies and lymphocytes build the body immunity.

(c) **THE HOMEOSTATIC FUNCTIONS OF BLOOD**

(x) Blood transports heat from the lungs and muscles to other parts of the body for temperature regulation.

(xi) Plasma proteins maintain a constant blood osmotic potential and P^H.

BLOOD CLOTTING

- Clotting is the hardening or coagulation of blood.

THE IMPORTANCE OF BLOOD CLOTTING

1. Prevents excessive loss of blood from wounds and cuts thus saves blood from wasting.
2. Prevents entry of pathogens thus prevention of secondary infections.
3. The clot is starts the process of wound healing since it's the first step towards wound healing.

THE PROCESS OF BLOOD CLOTTING

- On tissue damage, platelets breakdown and their exposure to air stimulate the exposed platelets to secrete the thromboplastin/thrombokinase enzyme.
- In presence of calcium ions and vitamin K together with other clotting factors attracted by the raptured platelets, thromboplastin/thrombokinase catalyses the conversion of inactive plasma protein prothrombin into the active plasma protein thrombin which is an enzyme.
- Thrombin catalyses the conversion of the soluble plasma protein fibrinogen into insoluble protein fibrin.
- Fibrin forms a meshwork of fibrous needle-like threads/fibres in which blood cells are trapped to form a clot.
- The clot dries to form a scab which prevents bleeding, stops entry of pathogens and starts the process of wound-healing.

SUMMARY OF BLOOD CLOTTING PROCESS

Damaged tissues

Damaged platelets exposed to air $\rightarrow$ Thrombokinase (enzyme)

Prothrombin $\xrightarrow[\text{Clotting factors}]{\text{Calcium ions, Vitamin K}}$ Thrombin (enzyme)

Fibrinogen (soluble) $\rightarrow$ Fibrin (insoluble)

$\downarrow$ Meshwork of fibres

Clot

$\downarrow$ Dries

Scab

BLOOD GROUPS AND BLOOD TRANSFUSION

BLOOD GROUPS

- Blood groups are determined by the antigen-antibody system.
- An antibody is a molecule synthesized by an animal in response to the presence of a foreign substance called an antigen.
- An antigen is a foreign substance which can cause antibody production.
- Antibodies fight antigens
- Antigens in blood are represented by capital letters
- Antibodies are represented by small letters.
- In the ABO blood group system, there are 2 antigens.
- The **A** and **B** antigens are located on the red blood cell membranes.
- Antibodies **a** and **b** complementary to these antigens and are present in the blood plasma all the time.
- The presence of an antigen and its corresponding antibody together causes an immune response which results in clumping together of red blood cells (agglutination occurs) and their breakdown (haemolysis).
- For this reason an individual doesn't produce antibodies corresponding to the antigens present, but produces other antibodies.

Therefore;

1. A person with blood group A has antigen A and antibody b.
2. A person with blood group B has antigen B and antibody a
3. A person with blood group AB has both antigens A and B, but has no antibodies.
4. A person with blood group O has no antigens but has both antibodies a and b.

A SUMMARY OF THE ABO BLOOD GROUP SYSTEM

Blood group	**Antigen(s) on red blood cell membranes**	**Antibodies in blood plasma**
A	A	b
B	B	a
AB	A and B	None
O	None	a+b

BLOOD TRANSFUSION

- Is the transfer of blood from one person called the donor to another person called the recipient.

CONSIDERATIONS BEFORE BLOOD TRANSFUSION

(i) The donor's blood should be free of diseases and pathogens like HIV and plasmodium.
(ii) The donor's blood should be immunologically compatible with that of the recipient to avoid agglutination and haemolysis, which can cause death.

A SUMMARY OF THE ABO BLOOD GROUP INTERACTION

Donor's blood group(antigens)		**Recipient's blood group (antibodies)**			
		A	B	AB	O
		b	a	None	a+b
A	A	√	X	√	X
B	B	X	√	√	X
AB	A+B	X	X	√	X
O	None	√	√	√	√

NOTE:

(i) A and B are antigens.
(ii) a and b are antibodies.
So A+a =Agglutination and B+b=Agglutination
(iii) √ donates compatible
(iv) *X* donates incompatible.

- Donors of blood group O donate to all blood groups, so are called universal donors since they lack antigens to react with antibodies.
- However, Os receive from Os only because they have both antibodies a & b.
- Recipients of blood group AB receive from all blood groups, so are universal recipients since they lack antibodies to react with antigens of the donors.
- Reciprocal transfusions may not be safe, for example a person of blood group O can safely donate blood to a person of blood group A, but that of blood group A can't donate blood to the person of blood group O.

Question: Explain why a person of blood group B cannot receive blood from a person of blood group A.

THE RHESUS FACTOR (D)

- 85% of humans possess red blood cells with an antigen called Rhesus factor (D) and are called Rhesus positive.
- The remaining humans (15%)lack the Rhesus factor, and are called Rhesus negative.
- Rhesus negative blood doesn't usually contain Rhesus antibodies in its plasma.
- Bit when Rhesus positive blood enters a Rhesus negative individual, the recipient produces the Rhesus antibodies (d) as an immune response.

IMPLICATIONS OF RHESUS FACTOR IN CHILD BEARING

- Rhesus factor is inherited; Rhesus positive dominant to Rhesus negative, and therefore a foetus can be Rhesus positive while the mother rhesus negative.
- Towards the end of pregnancy, fragments of red blood cells may cross from the foetus to the mother through the placenta.
- The mother responds by producing rhesus antibodies (d) in response to the rhesus antigen (D) on the foetal red blood cells.
- The rhesus antibodies cross the placenta into the foetal circulation, where they destroy the red blood cells of the foetus, a condition called Haemolytic disease of the newborn.
- This may cause death of the foetus before birth or death of the newborn.
- Firstborn babies are usually no severely affected, because the concentration of antibodies is not sufficiently high.
- But subsequent babies are severely affected by excessive haemolysis causing anaemia, jaundice and death of the newborn.

REMEDIES TO HAEMOLYTIC DISEASE OF THE NEWBORN

(i) The foetus can be given appropriate blood transfusions while still in the womb.

(ii) Intravenous injection of Rhesus antibodies, anti-D from the blood donors is given to the mother immediately within 72hours after the first birth.
These destroy any cell fragments with the Rhesus antigen which could have entered her blood, before the mother manufactures her own rhesus antibodies.
The injected rhesus antibodies are soon broken down by the mother, preventing sensitization of the mother's immune system.

IMMUNITY

- Is the ability of the body to resist infection and disease.
- Infection is entry of pathogen in the body.
- A disease is the poor health/ abnormal functioning of the body as a result of the activity of the pathogens overpowering immune system.

TYPES OF IMMUNITY

- There 2 broad types of immunity viz;

1. **NATURAL/INNATE/INBORN IMMUNITY**; is the type of immunity present at birth i.e. an individual is born with it.
   E.g.
   - ✓ Intact, hard skin prevents entry of pathogens.
   - ✓ Mucus and cilia in respiratory tract like nose, trap and "sweep" dust and pathogens to be digested thus preventing their entry in the body.
   - ✓ HCl in stomach kills bacteria in food.
   - ✓ Lysozymes in saliva, tear and sweet kill pathogens etc.
2. **ADAPTIVE/ACQUIRED IMMUNITY**; is the type of immunity obtained after birth. These are further divided into active and passive immunity as discussed below;
   (i) **Natural active immunity**; is the type immunity obtained as a result of suffering & recovering from an infection. i.e. the body makes its own antibodies when exposed to an infectious agent.
   (ii) **Natural passive immunity**; is the type of immunity where babies get preformed antibodies from the mother via placenta breast milk (colostrum).
   (iii) **Acquired active immunity**; is the type of immunity obtained as a result of vaccination. i.e. Body makes its own antibodies after taking a vaccine.
   NB: Vaccine is either weakened pathogen, killed pathogen or detoxified toxins of the pathogen.
   (iv) **Acquired passive immunity**; is the type of immunity where made antibodies are injected into an individual. Like anti-venoms to venoms.

Differences between active and passive immunity

Active immunity	Passive immunity
• Body makes its own antibodies. • Is long lived.	• Body acquired made antibodies from another organisms. • Is short lived.

LYMPHATIC SYSTEM

- Is a network of lymphatic vessels through which lymph fluid flows.

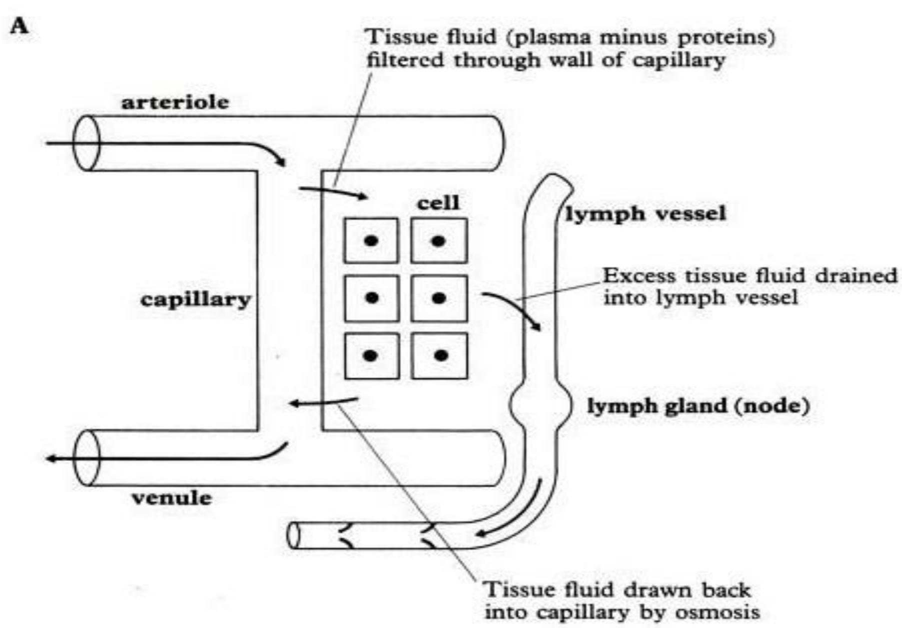
COMPONENTS OF LYMPHATIC SYSTEM

1. Lymph fluid (lymph)
2. Lymphatic vessels (lymph vessels)

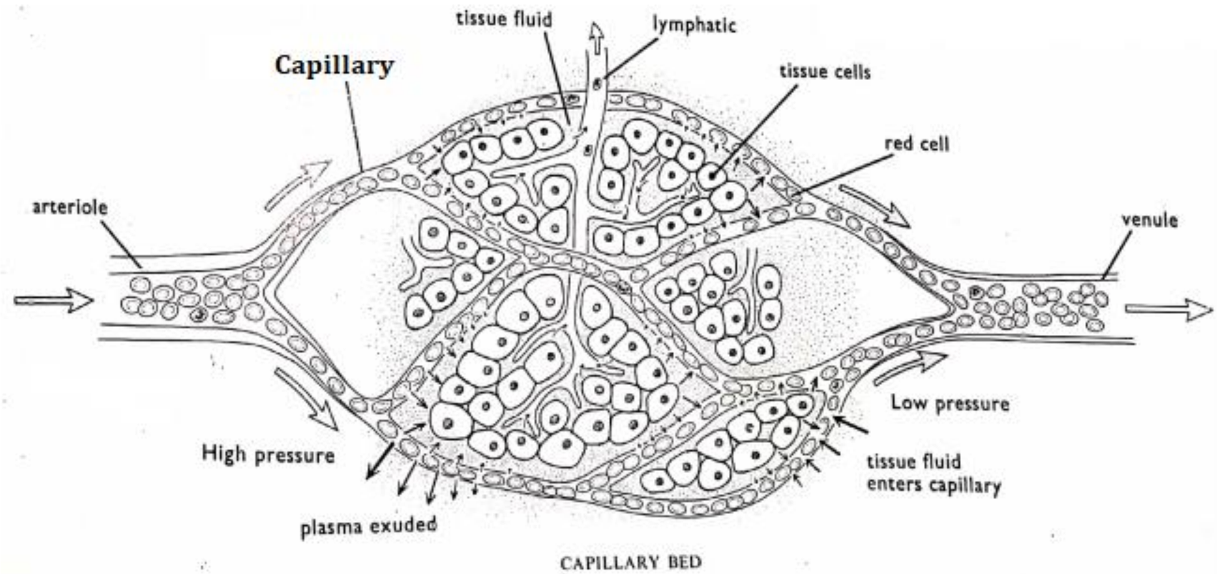
FORMATION OF LYMPH FLUID

- In order for the exchange of substances to occur blood plasma passes through the capillary walls and bathes the cells in the tissues.
- As blood flows along the arterial end of the capillary network/bed, a fluid consisting of blood components except red blood cells, platelets and plasma proteins filter through the fine pores by a process called ultra-filtration.
- This is fluid formed in the tissues by ultra-filtration is known as the tissue fluid/intercellular fluid/interstitial fluid.
- Ultra-filtration is caused by high blood pressure which develops because of the pumping action of the heart and the narrowness thus resistance of the blood capillaries.
- As tissue fluid flows through intercellular spaces, useful materials like nutrients, hormones, enzymes and oxygen enter the cells.
- The cells also shed off their excretory products into the tissue fluid. At the venous end of the capillary bed/network, blood contains more solutes than the tissue fluid i.e. the osmotic pressure of blood is higher than that of tissue fluid (hydrostatic pressure).
- Therefore, the tissue fluid flows back to the blood slowly through capillary walls by osmosis.
- The excess tissue fluid drains into narrow, blunt ended tubes known as lymph vessels (lymphatic vessels).
- The tissue fluid in lymph vessels is called lymph (lymph fluid).

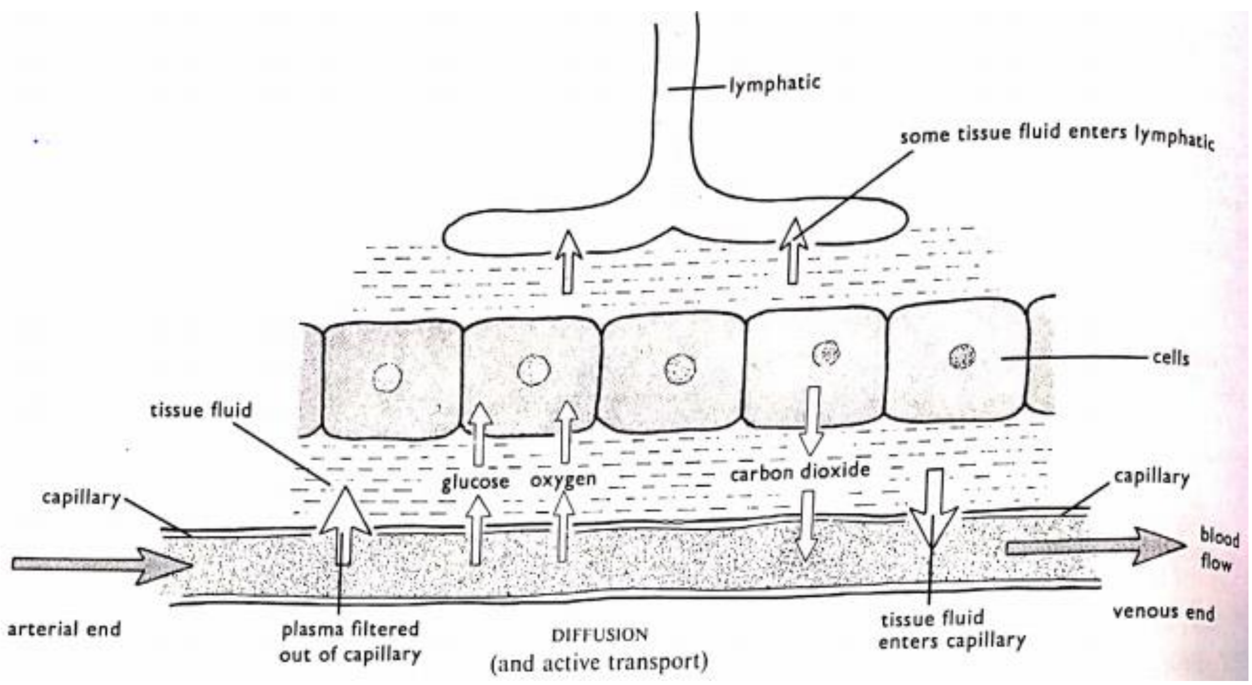
ILLUSTRATION OF LYMPH FLUID FORMATION



RELATIONSHIP BETWEEN CAPILLARIES, CELLS AND LYMPHATICS



RELATIONSHIP AMONG BLOOD, TISSUE FLUID AND LYMPH



FUNCTIONS OF LYMPH/ LYMPHATIC SYSTEM

(i) Transports wastes from tissue fluid back to the heart like carbon dioxide, urea and water.

(ii) Transports fatty acids, glycerol absorbed by the lacteals at the villi of the ileum.

(iii) Transports lymphocytes from lymph nodes to blood to fight germs.

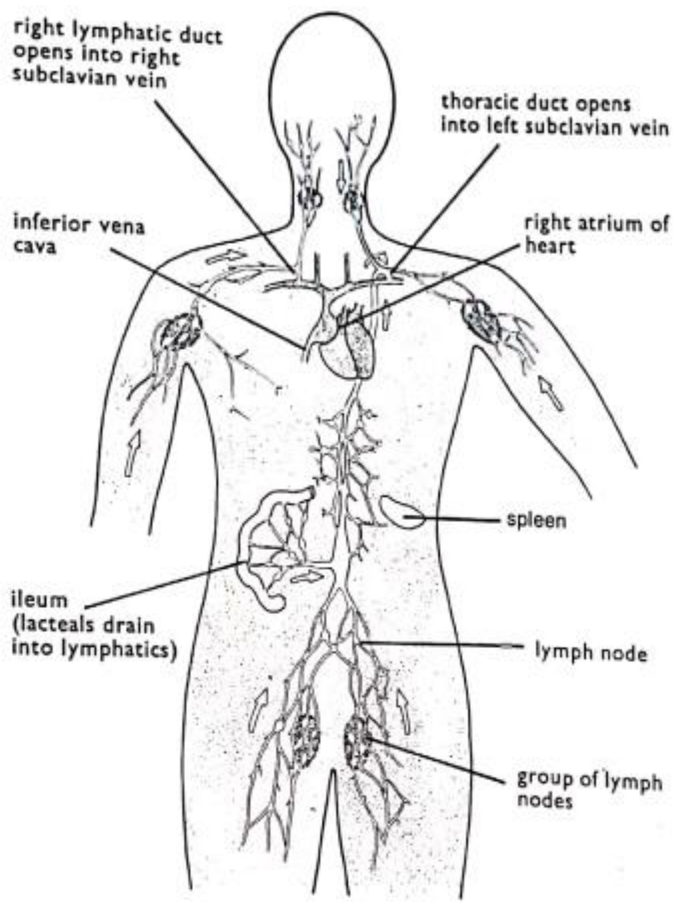
(iv) Transports hormones.

(v) It filters out poisons and bacteria.
(vi) It forms a barrier around injured tissue preventing inflammation.
(vii) It collects interstitial fluid.

NB: Blockage of the lymphatic vessels with filarial worms causes elephantiasis.

BLOOD CIRCULATORY SYSTEM	LYMPHATIC SYSTEM
• Has blood as a circulating fluid. • Has heart as a pumping organ. • Has blood vessels. • Lacks nodes. • Has valves in veins and heart only. • Blood flows rapidly except in the veins.	• Has lymph as circulating fluid. • Lacks a pumping organ, uses muscular pump of skeletal muscles. • Has lymphatic vessels. • Has lymph nodes. • All lymphatic vessels have valves. • Lymph flows slowly.

STRUCTURE OF LYMPHATIC SYSTEM



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