TRANSPORT IN PLANTS

- In plants raw materials move up the stem to the leaves where photosynthesis takes place. After, the end products are translocated to other regions usually storage organs.
- There are two organs involved in transporting of materials in plants i.e. the xylem and the phloem.

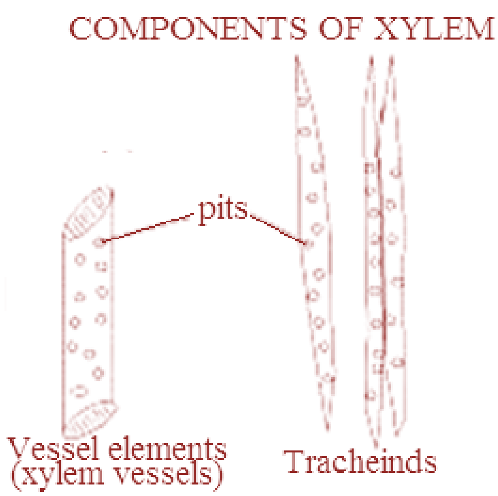
THE XYLEM

Function

- The xylem transports water and dissolved mineral salts

Structure

- Xylem is a compound tissue consisting of different types of cells. The most important ones are the xylem vessels and tracheids. These form the conducting units (transporting channels) of the xylem.
- Xylem vessels and tracheids are elongated to form tubular structures with empty lumens.
- Xylem vessels (vessel elements) are open ended cylindrical tubes while tracheids have tapering ends.
- The cells are strengthened by deposition of lignin their cell walls. Lignin makes the cell wall impermeable making the cells dead. Therefore xylem consists of dead cells.
- The cell walls are perforated with bordered pits which allow lateral movement of materials.
- The conducting cells are arranged end to end to form continous long tubes which can conduct materials from roots up to the leaves of a tall tree.



N.B: The other types of cells making up xylem tissue are;

- **Fibres:** These provide support. Their walls are thickened and strengthened with lignin (lignified) making the cells dead.
- **Parenchyma cells:** These are packing cells. They fill up spaces between the different cells. Their walls are not lignified and so are living.

Adaptation of xylem to its function

- Xylem has long cylindrical cells joined end to end, for continuous flow of water.
- End walls of xylem vessels are broken down to allow uninterrupted flow of water.
- The cells are perforated that allow water to pass from one cell to another.
- The cells have empty lumens, to allow uninterrupted flow of water.
- The cells are lignified to offer rigidity preventing collapsing when not transporting water.
- Lignin increases adhesion of water molecules allowing the rise of water by capillarity.
- The lumens of the cells are narrow to increases the rise of water by capillarity.
- Has fibres with thickened, lignified walls, to provide mechanical strength and support to the plant.

THE PHLOEM

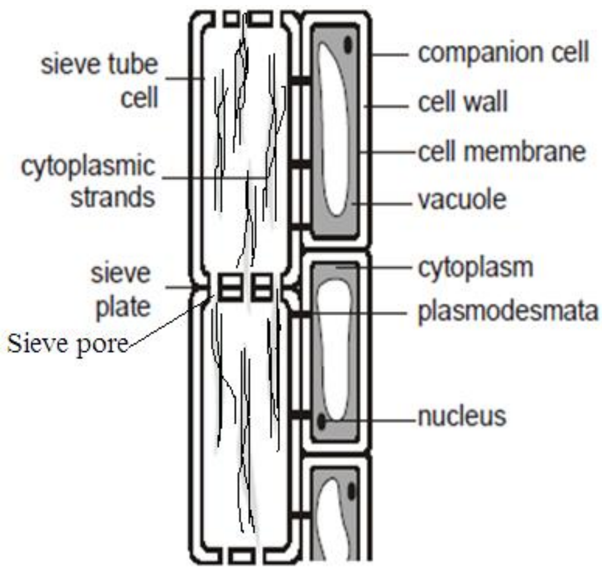
Function

- The phloem transports manufactured food throughout the plant.

Structure

- It consists of two main types of cells; sieve tubes/sieve elements and companion cells. These are all living cells.
- Sieve tubes are elongated cells with very little cytoplasmic content and lack nuclei. Their end walls are joined end-to-end forming sieve plates which are perforated with sieve pores.
- Sieve tubes have cytoplasmic strands running across the cytoplasm from one sieve plate to the other.
- Companion cells have a dense cytoplasm with numerous mitochondria therefore they are highly metabolically active.
- Companion cells are arranged alongside sieve tubes. They are connected to the sieve tubes by tinny pores called plasmodesmata.
- The sieve tubes are channels of food whereas the companion cells provide the necessary energy for transporting the food.

Structure of the phloem



N.B:
Like xylem, phloem also has other types of cells e.g **fibres** for support and **parenchyma** (packing tissue) for filling up spaces between different cells/units.

Adaptations of the phloem for its function

- Sieve tube end (sieve plate) is perforated with sieve pores allowing passage of materials from one cell to another.
- Sieve elements (sieve tube cells) lack nuclei creating room for passage of materials in solution.
- Sieve elements contain cytoplasmic strands/filaments to allow movement of materials.
- Companion cells have numerous mitochondria to provide energy in form of ATP for the active transport of materials.
- Phloem consists of living cells which are able to carry out active transport of materials.

Differences between xylem and phloem

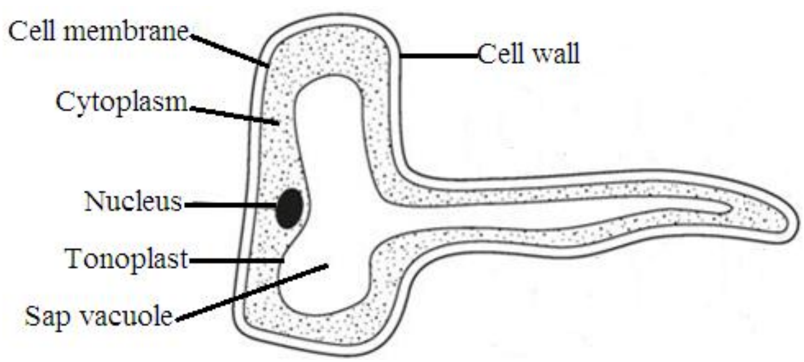
Xylem	Phloem
It consists of dead cells	It consists of living cells
The cells have lignified walls	Cell walls are not lignified
Do not have companion cells	Have companion cells
Do not have cytoplasmic filaments	Have cytoplasmic filaments
Consist of open ended vessels and tapering vessels	Consists of sieve tubes with the sieve plates perforated with sieve pores

Qn. (a) Compare the structure of xylem and phloem.
(b) Give three adaptations of each of the above tissues to function.

MOVEMENT OF MATERIALS INTO A PLANT
Water is absorbed from the soil into the plant by roots. The part of the root responsible for this function is the root hair.

Structure of the root hair
The root hair is a modified cell in the outer region (piliferous layer) of the root, with a slender and flexible extension surrounded by a thin permeable cellulose wall and the cell membrane. The membrane surrounds a concentrated cytoplasm containing a lot of mitochondria. The cell also has a large central vacuole with a concentrated cell sap. The sap vacuole also has an extension.

Diagram showing section through a root hair



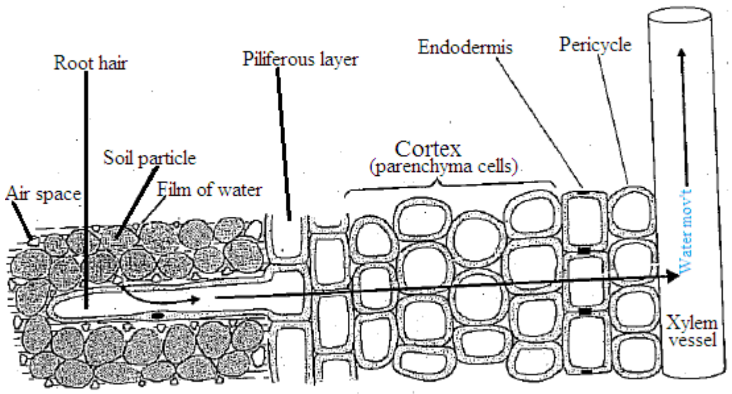
Adaptations of root hairs to their functions
1. Have very slender and flexible extension to penetrate any area in the soil so as to obtain water.
2. Have a thin cellulose wall to reduce on the **diffusion** distance of water during absorption.
3. The root hairs have a concentrated cell sap to maintain a high **osmotic** gradient/concentration gradient for uptake of water by **osmosis**.
4. They have many mitochondria in their cytoplasm which release energy in form of ATP for absorption of mineral substances by **active transport**.
5. They are very many to offer large surface area for absorption of much water.

Qn. (a) Describe the structure of a root hair.
(b) How is the root hair adapted to its function(s)?

ABSORPTION OF WATER BY PLANT ROOTS

- Root hairs are surrounded by soil particles containing a film of water. The cell sap inside the root hair cells is more concentrated (hypertonic) as compared to the solution of the soil water.
- Water from the dilute soil solution moves into the root hair cells by osmosis.
- The water entering the root hair dilutes its cell sap, making it hypotonic to that of adjacent/inner cortex cells which now have more concentrated solution/sap.
- As a result, water moves from the root hair cell into the first cortex cell, then from cell-to-cell in the cortex along the osmotic gradient until it reaches the xylem which conducts water to the stem.

Diagram showing movement of water in the roots up to the xylem



In summary;

i. Water enters the root hairs by osmosis.
ii. Water passes across the cortex cells of a root to the xylem by osmosis along the osmotic gradient.
iii. Water is drawn up in the xylem to the stem by root pressure and transpiration pull.

MOVEMENT OF WATER FROM ROOT XYLEM TO THE STEM

Once water has reached the xylem vessels, it moves up the stem by the help of the following processes;
(i) Root pressure (ii) Transpiration pull (iii) Capillarity

i. Root pressure

Water is continuously absorbed into the xylem vessels of the root. As a result more water flows into the xylem of stem. As the water accumulates at the base of the stem xylem, it builds up a pressure that pushes the water up in the stem. This pressure is referred to as root pressure.

ii. Transpiration pull

- This is a result of the loss of water vapour from the leaves (transpiration).
- The water evapourates from the surface of mesophyll cells surrounding the sub-stomatal air chamber then lost through the stoma.
- As water evaporates from the surface of these cells, more water diffuses out of the cells.
- This makes the cell sap of the mesophyll cells to be more concentrated. These cells then absorb water by osmosis from the neighbouring cells which in turn draw water from the xylem of the leaf vein.
- But the water molecules have strong forces of attraction (**cohesion forces**), thus movement of water out of leaf xylem pulls along water molecules from the lower parts of the xylem.
- This creates a continuous pull of water to the leaves, from the root and a stream is thus created.
- The forces of cohesion and adhesion enable the water to move in a continous stream without falling back or breaking. Cohesion forces (attraction between the water molecules) prevent breaking of the water column/stream, whereas the adhesion forces(attraction between water and the wall of xylem) prevent the falling back of the water stream/column.

N.B:

- Transpiration is the loss water in form of water vapour from the plant.
- The flow of water through the plant from roots to leaves is called the **transpiration stream.**

iii. Capillarity

- This is the tendency of water to rise up through very narrow tubes.
- Xylem vessels have very small diameters which enables water to rise up in vessels of the plant.
- The processes of cohesion and adhesion constitute the capillarity forces.
- Water molecules attract one another by cohesive forces.
- The attraction between water molecules and xylem walls is known as adhesion.
- The cohesive and adhesive forces ensure that the water column in the xylem vessels remains continuous and there is no air bubble.

TRANSPORT OF MINERAL SALTS

<u>Absorption of mineral salts:</u>

- The mineral salts in form of ions dissolved in water and are absorbed by root hairs.
- The ions cross the cell wall and bind to carrier proteins on the cell membrane of the root hair.
- The carrier proteins transfer the ions across the cell membrane into the root hair cell by active transport using energy from ATP. This explains why root hairs have a lot of mitochondria.

N.B:

- The mineral salts present in soil are in a low concentration compared to the concentration inside the root. Some mineral salts would diffuse out of the root hairs into the soil BUT, the cell membrane is selectively permeable and so, prevents the passive diffusion of the ions out of the cell.
- In a plant that is growing normally in its natural environment, diffusion does not participate in absorption of mineral ions. This is because the external environment naturally has a lower ion concentration than the plant cell sap.

<u>Transportation of mineral salts:</u>

- Mineral salts are dissolved in water and transported in the xylem in form of ions in solution until when they reach the leaves.

Qn: **(a) Explain why plants usually wilt in water logged soils.**

(b) Why would a plant wilt if a strong salt solution is poured around it?

TRANSPIRATION

This is process by which water is lost in form of water vapour from a plant.

Types of transpiration

a. **Stomatal transpiration:** This is the loss of water vapour through the stomata. It accounts for 90% of the water lost. The stomata occur mostly on the leaves, and on the stems of herbaceous plants.
b. **Lenticular transpiration :** This is loss of water vapour through lenticels.
   Woody trees have intervals/parts where the layer of the bark is made up of cells which are loosely packed appearing externally as raised dots. These are the **lenticels** through which water loss may occur. The amount of water lost through lenticels is very small and insignificant.
c. **Cuticular transpiration :**This loss of water vapour through the cuticle. About 10% of the water is lost through the cuticle which is not completely impermeable to gases. The thicker the cuticle, the smaller the amount of water lost.

FACTORS AFFECTING THE RATE OF TRANSPIRATION

The term **transpiration rate** refers to the amount of water lost from the shoot of a plant **per unit time**. The factors affect that affect the transpiration rate may be internal or external factors.

External/Environmental/non plant factors

1. **Temperature**
   An increase in temperature increases the rate of transpiration. This is because the increase in temperature increases the kinetic energy of water molecules. The water molecules in the air around the leaf move further apart, so their concentration reduces which increases their rate of diffusion from the leaf. An increase in temperature of the sub-stomatal air chamber also increases the rate at which water molecules vaporize, increasing the rate of transpiration.
2. **Wind velocity**
   Increasing wind velocity increases rate of transpiration. This is because the wind continuously sweeps away saturated vapour from the leaf surface, exposing the stomata to less humid air which allows more vapour to escape.
   Under still conditions, a layer of humid air surrounds the leaf. This is because the region around the leaf surface is saturated with moisture and this blocks the stomata, hence preventing water loss from the leaf. This reduces on the rate of transpiration.
3. **Light intensity**
   The rate of transpiration increases with increase in light intensity.

- Sunlight leads to opening of stomata by the plants to allow in carbon dioxide for photosynthesis. Water vapour then moves out of the leaves via the open stomata. Increasing the light intensity, leads to an increase in the size of the stomatal pore hence more water is lost from the leaves.
- An increase in light intensity also causes an increase in the internal leaf temperature, thus increasing the rate of evaporation/transpiration.

4. **Humidity**
   Humidity is the amount of water vapour in the atmosphere. The rate of transpiration decreases with increase in humidity. This is because the region around the leaf surface becomes easily saturated with moisture which prevents water vapour from escaping.
5. **Atmospheric pressure**
   The rate of transpiration increases with decrease in atmospheric pressure. This is because of a decrease in vapour pressure above the leaf surface which allows faster loss of water vapour from the leaves.
   At high altitudes, the atmospheric pressure decreases which in turn increases the rate of transpiration. High altitude plants therefore experience high rates of transpiration and show structural adaptations to reduce the transpiration rate.
6. **Water supply**
   Transpiration rate therefore increases with an increase in water supply. For transpiration to take place, the cellular walls of the spongy mesophyll cells must be fully saturated i.e. fully turgid. Fully turgid guard cells open the stomata widely hence increasing the transpiration rate.

Internal factors

1. **Leaf area;** The larger the leaf surface area, the greater the rate of transpiration. The broader the leaf the greater the rate of cuticular transpiration regardless of the number of stomata.
2. **Thickness of the Cuticle;** The cuticle is a waxy covering over the leaf surface. The thicker the waxy cuticle, the lower the rate of cuticular transpiration. This is because wax is a water proof substance which prevents water loss.
3. **Density of stomata;** The greater the number of stomata per unit area of a leaf, the higher the rate of transpiration.
4. **Distribution of stomata;** The more the stomata are exposed to environmental conditions, the faster the rate of transpiration.

   Leaves of most terrestrial plants have more stomata on the lower surface as compared to the upper surface. This is because the upper surface is more exposed and subjected to a greater temperature increase since it is facing the sunlight. Transpiration is therefore potentially greater from the upper surface. Having more stomata on the lower surface limits exposure of the stomata hence controlling the rate of transpiration.

ADAPTATIONS OF PLANTS TO CONTROL WATER LOSS (TRANSPIRATION CONTROL)

The structural modifications of certain plants which enable them to reduce water loss, particularly from their leaves and stems, are called **xeromorphic adaptations.**

Xerophytes are plants that are adapted to live in conditions in which there is either a scarcity of water in the soil, or the atmosphere is dry enough to cause excessive transpiration, or both.

Xeromorphic adaptations include;

1. **Having hairy leaves;** These trap a layer of still moist air on the leaf surface which covers the stomata thus reducing the rate of transpiration.
2. **Thick waxy cuticle;** Most plants, especially those living in arid areas, have their leaves covered a waxy substance made by the epidermal cells. The wax water-proofs the leaves and prevents excess water loss by transpiration.
3. **Rolling leaves;** Grasses roll their leaves during dry weather. This reduces on the surface area exposed to the external environment and encloses air, both of which serve to reduce the transpiration rate.
4. **Reducing the surface area of the leaves;** In some plants, the leaves are needle-like e.g. pines and cactus. This reduces on the surface area for transpiration hence conserving water in the plant.
5. **Sunken stomata;** ***Pines*** have sunken stomata. **Still** and **mois**t air is trapped around the stomata, which reduces on the rate of transpiration. The air around the stomata is as concentrated as that in the leaf's air space.

Other adaptations include;

6. **Orientation of leaves;** The ***compass plant*** has leaves which constantly change their orientation so that the sun strikes them obliquely. This reduces their temperature and hence the transpiration rate reduces.
7. **Shedding off of leaves;** Some plants shed their leaves during the dry periods to control the loss of water through the stomata, and regenerate them during the wet season.
8. **Closing of the stomata;** Some plants open their stomata during the night and close them during the day. This is common to plants that live in arid areas.

Importance of transpiration to plants (functions)

1. It serves to cool the leaves since excess heat is lost with the escaping vapor.
2. Creates a force (transpiration pull) which facilitates movement of water from roots towards leaves.
3. It provides a mechanism through which mineral elements are transported in the plant since these are dissolved in water.
4. It leads to absorption of water by the plant roots from the soil.
5. The absorption of water to replace that lost facilitates uptake of dissolved mineral nutrients from the soil.

Note.

- Although transpiration is important, excessive transpiration is dangerous to the plant especially if the water supply is limited.
- If the leaves lose more water to the atmosphere, than the roots can absorb to replace, the plant **wilts**. Temporary wilting is used in some plants as a mechanism to control transpiration.
- Under certain environmental conditions (e.g high humidity, low temperature under still air), the rate of transpiration may be too low. If the there's no loss of water by transpiration, the excess water accumulates in the leaf and ooze out of the stomata and drip from the leaf, a process called **guttation.**

EXPERIMENTS ON TRANSPIRATION

1. **<u>Experiment to show that transpiration occurs in plants</u>**

Requirements

- Polythene bag
- Potted leafy plant
- Anhydrous copper sulphate

Procedure

i. A stem of a well watered potted plant is covered with the polythene bag, leaving the soil in the pot out.
ii. The point of the stem attached between the stem and polythene bag is smeared with Vaseline to prevent the loss of water, which would have transpired by the plant, from escaping.
iii. The set-up is then placed in sun light for one hour and observations are made.

Observation

- After one hour, droplets of a colourless liquid will be seen on the sides of the polythene bag.
- If the liquid is removed from the polythene and tested with anhydrous copper (II) sulphate, the liquid changes it (copper (II) sulphate) from white to blue.

Conclusion

- The liquid is water. Therefore, plants lose water to the atmosphere through the leaves.

Note.

- A control experiment is set up using the same plant with similar conditions but without the leaves and flowers.
- No observable change on the sides of the polythene, indicating that transpiration does not occur.

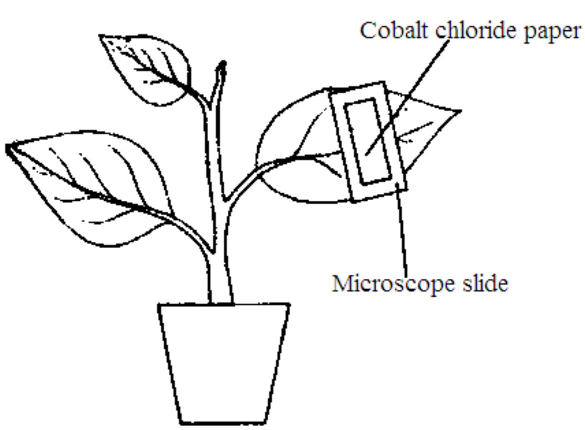
2. **<u>Experiment to show which surface of a leaf loses more water</u>**

Requirements

- Cobalt chloride paper
- Microscope slide
- Leafy plant.

Procedure

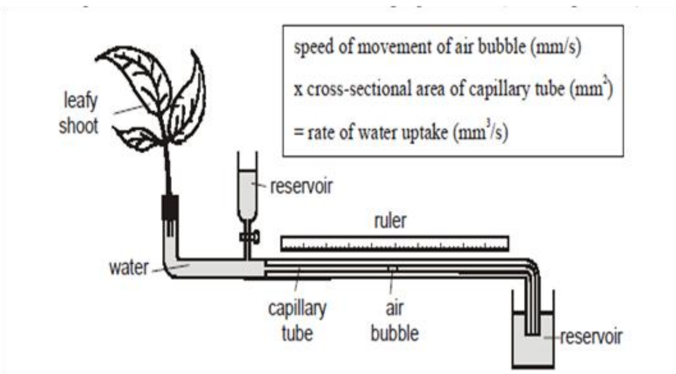
i. Pieces of cobalt chloride paper are fixed on the lower and upper surfaces of a leaf which is still attached to the stem of a plant
ii. The cobalt chloride paper is fixed on the leaf using the microscope slides
iii. The time taken for the cobalt chloride paper to turn from blue to pink is noted for both sides.



Observation
The pink colour develops faster on the lower side than the upper side.
Explanation
The lower surface has more stomata than the upper surface. This is because the upper surface receives direct sunlight which would bring about too much loss of water that would wilt (dry) the plant.
Conclusion
The lower surface loses morewater than the upper surface.

INVESTIGATING THE RATE OF TRANSPIRATION

- It is not easy to measure how much water is lost from the leaf of the plant but much easier to measure how much water the plant takes up.
- The rate at which a plant loses water to the atmosphere can be measured on a cut shoot by measuring water uptake using an instrument called a **potometer**. The potometer measures *indireclty* the rate of tranpiration but *directly* it measures water up take.
- The potometer works on the assumption that the amount of water lost equals to the amount of water taken up.



Functions of the different parts of a potometer

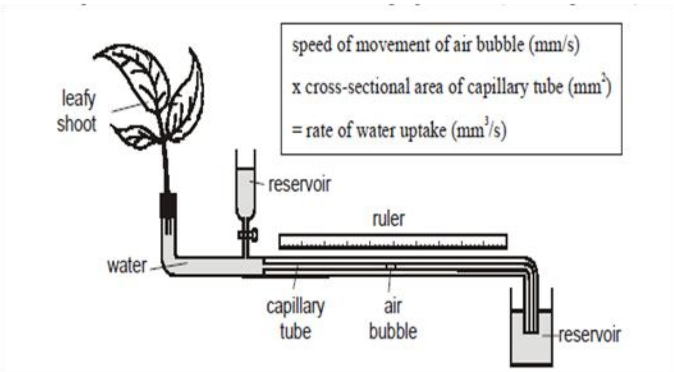
(i) Reservoir
It stores water which is used to reset the air bubble. This is done by releasing the water in reservoir by opening the tap.
(ii) Air bubble
It acts as an indicator because it is the rate of movement of the air bubble in water that shows the rate of transpiration.
(iii) Scale/ruler
It used to measure the speed at which the air bubble moves during transpiration.
(iv) Capillary tube
This is used to determine the speed of movement of the air bubble.

3. <u>Experiment to investigate the rate of transpiration in a plant (using a potometer)</u>

Requirements

- A fresh plant with leafy shoot.
- Water.
- Beaker.
- Capillary tube.
- Vaseline.
- Glass tube with reservoir and tap.

Set up of apparatus (potometer)



Procedure

i. The shoot of a leafy plant is cut under water.
ii. The whole apparatus is filled with water and then the shoot is placed in the open end of the glass tube.
iii. The shoot is tied so tightly to avoid leakage. Vaseline is smeared around the shoot to prevent air from entering.
iv. The open end of the capillary tube is allowed to draw in a bubble of air and then immediately placed in a reservoir of water in a beaker to block more air from entering the capillary tube, so that only one air bubble is seen.
v. The tap of the reservoir attached to glass tube is closed but only opened when the potometer needs refilling or to readjust the position of the air bubble to the starting point.
vi. The initial position of the air bubble in the capillary tube is recorded.
vii. The potometer is allowed to stand in various conditions e.g. light or darkness or wind or still air for four hours.

Observations

- The air bubble in the capillary tube will start moving towards the shoot indicating that water is being taken up by the shoot which is finally lost to the atmosphere.
- Mathematically, the volume of water lost from the leafy shoot in this experiment is calculated using the formula. $\boldsymbol{V = \pi r^2 h}$

r = radius of the capillary tube

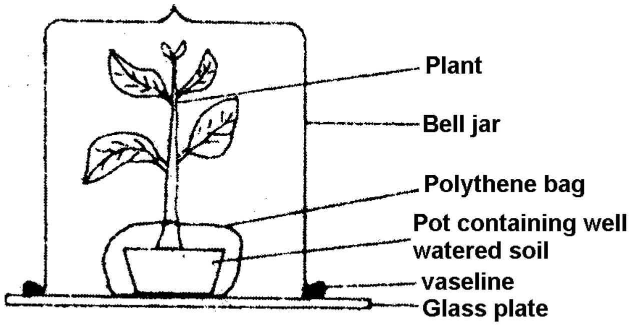
h = distance moved by the air bubble

Precautions taken when setting up a potometer

i. In setting up a potometer, the shoot of a leafy plant that to be used in the experiment is cut under water to avoid air entering the xylem because it blocks them.
ii. There must be only one air bubble in the apparatus.
iii. The whole apparatus should be full of water and air tight.
iv. The shoot used should have many leaves i.e. leafy.

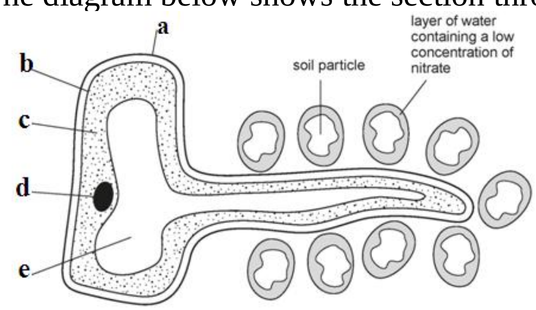
REVISION QUESTIONS

1. The figure below shows an experimental set up to demonstrate transpiration in plant



(a) Explain why:
(i) vaseline is smeared between the glass plate and the bell jar.
(ii) polythene bag is wrapped around the pot and tied at the base of the plant
(b) (i) What will be observed in this experiment?
(ii) How do you test for the identity of the substance observed in (b) (i)?
(c) Describe the set up of the control for this experiment.
(d) State two factors which affect results of this experiment.

2. The diagram below shows the section through a root hair cell in a well-watered soil.



(a) Name the parts labeled **a**-**e**.

a. ………………………………………………
b. ………………………………………………
c. ………………………………………………
d. ………………………………………………
e. ………………………………………………

(b) Explain how the root hair cell takes up water from the soil.
(c) (i) State the process used by the root hair cell to take up nitrate from soil. …………………………...
(ii) Gardeners dig soil to let more air into it. Explain how this affects the uptake of nitrate by root hair cells.
(iii) Explain how the uptake of nitrate by the root hair cell is affected by contamination of soil with metabolic poison.
(d) How is the root hair cell adapted to perform its functions?

3. a) Why are there less stomata found on the lower epidermis of a water plant than the upper epidermis?
b) Describe an experiment to show that transpiration occurs in plants.
4. With the aid of a diagram, describe the movement of water in woody plants from the time it is absorbed from the soil to the time is lost to the atmosphere.
5. a) Distinguish between transpiration and guttation.
b) How do plants lose water through the leaves?
c) Describe the features of plants which help them reduce water loss in dry condition.

6. a) Define the term transpiration.
   b) Name the various sites of transpiration in plants.
   c) Describe the environmental and non environmental factors that affect the rate of transpiration.
   d) List the forces responsible for movement of water from the roots to the top of a tall tree.
   e) How are terrestrial plants adapted to minimize water loss?
7. a) Describe the benefits of transpiration in plants.
   b) Explain how each of the following forces contribute to the movement of water and mineral salts up the xylem vessels of a plant.
      i) Transpiration pull ii) Adhesion iii) Capillarity
8. (a) What is transpiration?
   (b) State the environmental factors that affect the rate of transpiration.
   (c) Describe an experiment to show that a plant transpires.
   (d) In what ways are desert plants adapted to conserve water.

9. The data below shows the rate of transpiration of a plant at different times of the day.

TIME	TRANSPIRATION RATE(g/Hr)
8:00 A.M.	190
9:00	200
10:00	210
11:00	210
12:00 NOON	215
1:00 P.M.	220
2:00	230
3:00	230
4:00	230
5:00	220
6:00	210
7:00	210
8:00	190
9:00	120
10:00	100
11:00	100
12:00 MIDNIGHT	90

(a) Plot a graph of time against rate of transpiration.
(b) (i)What time was the rate of transpiration highest?
    (ii) Give reasons why the transpiration was highest.
(c) (i) At what time was the rate of transpiration lowest?
    (ii) Give reasons why it was lowest at that time.
(d) State three advantages and two disadvantages of transpiration.