PLANT PHYSIOLOGY

Introduction

In a flowering plant the substances that would need to be transported are water, mineral nutrients, Organic nutrients and plant growth regulators.

On the basis of distance travelled by substances, transport is of two types :

(i) Short distance transport (ii) Long distance transport

(i) Short distance transport :

- Over small distances, substances move by diffusion and by cytoplasmic streaming. Cytoplasmic streaming is supported by active transport.
- For short distance transport vascular tissues (xylem and phloem) are not required.

(ii) Long distance transport :

- Transport over long distances proceeds through the vascular system (xylem and phloem) and is called translocation.
- Over long distances substances move by bulk flow or mass flow.

Direction of transport :

- In a flowering plant there is a complex traffic of compounds (but probably very orderly) moving in different directions, each organ receiving some substances and giving out some others.
- In rooted plants, transport of water and minerals in xylem is essentially unidirectional, from roots to the stems. Organic and mineral nutrients however, undergo multidirectional transport.

Means of transport

(1) Simple diffusion:

Movement of ions (particles) and molecules of solids, liguids and gases from region of higher concentration to regions of lower concentration till equilibrium established is called diffusion.

Features of diffusion :

(i) It is a downhill process (passive process) because no energy expenditure takes place.
(ii) It is a random kinetic motion.
(iii) It is a slow process.
(iv) Driving force is concentration gradient.
(v) It is not dependent on a living system.
(vi) It is non selective process.
(vii) It is not sensitive to inhibitors.

Factors affecting rate of diffusion:

(i) Gradient of concentration : In diffusion substances move from regions of high concentration to regions of lower concentration.

(ii) Permeability of the membrane : The rate of diffusion is directly proportional to the permeability of the membrane.

(iii) Temperature : Increase in temperature, increase the kinetic energy. Thus, causes increase in rate of diffusion.

(iv) Pressure : The rate of diffusion is directly proportional to the gradient of diffusion pressure.

(v) Density : The rate of diffusion is inversely proportional to the square root of density of particles.

(Graham's diffusion law)

$$r \propto \frac{1}{\sqrt{d}}$$

Ascending order of density :
Gases < liquids < solids

Ascending order of rate of diffusion :
Solids < liquids < gases

Conclusion :

(a) Diffusion is obvious in gases and liquids.

(b) Diffusion in solids rather than of solids is more likely.

(vi) Size of particles : The rate of diffusion is inversely proportional to the size of diffusing particles.

Applications of diffusion :

- Diffusion is very important to plants since it is the only means for gaseous movement within the plant body.
- Movement of substances from one part of the cell to other part.
- Cell to cell movement.
- Movement from intercellular spaces of the leaf to outside Ooss of water vapours during transpiration).

(2) Facilitated diffusion :

The diffusion of any substance across a membrane also depends on its solubility in lipids. (Lipid is the major structural constituent of the membrane). Substance soluble in lipids diffuse through the membrane faster (simple diffusion), while substances that have a hydrophilic moiety find it difficult to pass through the membrane; their movement has to be facilitated.

In other words "this is a movement of substances with hydrophilic moiety from regions of high concentration to regions of low concentration through transmembrane proteins."

Site for facilitated diffusion :

Transmembrane proteins or tunnel proteins.

Features of facilitated diffusion :

(i) It is a downhill process (passive process) because no energy expenditure takes place.

(ii) Driving force is concentration gradient.

(iii) It is dependent on the living system (for transmembrane protein).

(iv) Facilitated diffusion can not cause net transport of molecules from a low to a high concentration.

(v) Transport rate reaches a maximum when all of the protein transporters are being used. This is called saturation.

(vi) It is sensitive to inhibitors which react with protein side chains.

(vii) It is very specific because it allows cell to select substances for uptake.

Some facts about facilitated diffusion :

- Transmembrane proteins {channel proteins) do not set up a concentration gradient: a concentration gradient must already be present for molecules to diffuse even if facilitated by the proteins.
- Some protein channels are always open while others can be controlled.
- **Porins :** They are .protein channels that form huge pores in the outer membranes of the plastids, mitochondria and some bacteria. They allow molecules upto the size of small proteins to pass through.
- In plants for the bulk movement of water, water channels are present. They made up of eight different types of aquaporins.

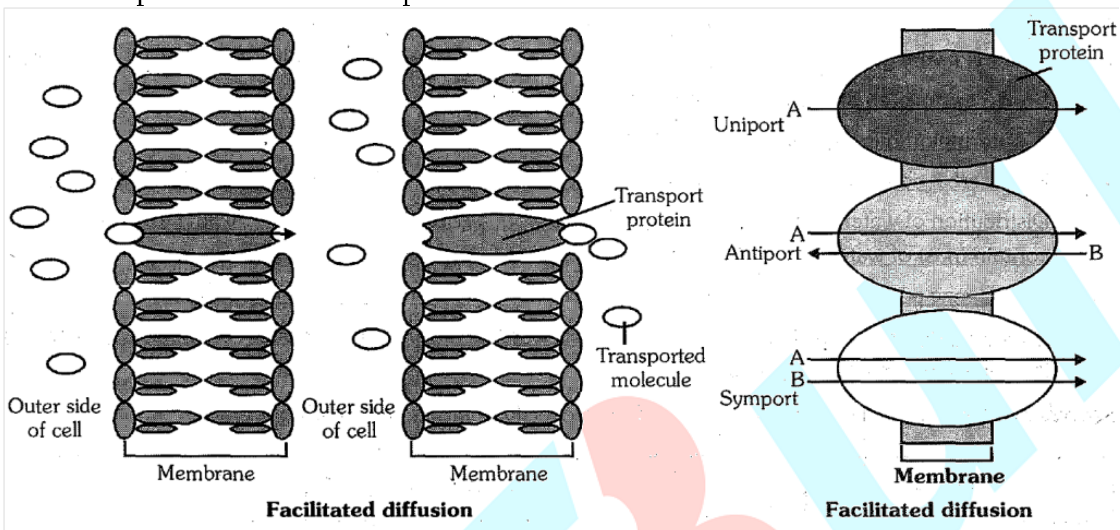
Passive symport, antiport and uniport :

Some transport proteins allow facilitated diffusion only if two types of molecules move together.

(i) **Symport :** Two molecules cross the membrane in the same direction.

(ii) **Antiport :** Two molecules cross the membrane in opposite directions.

(iii) **Uniport :** When a molecule moves across a membrane independent of other molecules, the process is called Unipart.



(3) **Active transport :**

Transport and pumping of substances from low to high concentration (against concentration gradient) by protein pumps is called active transport.

These protein pumps use energy to carry substances across the cell membrane.

Features of active transport :

(i) It is an uphill process (active process) because energy expenditure takes place.

(ii) Driving force is ATP therefore, active transport can cause net transport of molecules from a low to a high concentration.

(iii) It is dependent on the living system (for protein pumps and ATP).

(iv) Transport rate reaches a maximum when all of the protein transporters are being used. This is called saturation.

(v) It is sensitive to inhibitors which react with protein side chains.

(vi) It is very specific because it allows cell to select substances for uptake.

Comparison of different transport processes:

Comparison of Different Transport Mechanisms			
Property	**Simple Diffusion**	**Facilitated diffusion**	**Active Transport**
Requires special membrane proteins	No	Yes	Yes
Highly selective	No	Yes	Yes
Transport satuates	No	Yes	Yes
Uphill transport	No	No	Yes
Requires ATP energy	No	No	Yes
Hormonal control	No	Yes	Yes
Effect of inhibitors	No	Yes	Yes

Plant water relations

- Water is essential for all physiological activities of the plant and plays a very important role in all living organisms.
- Water is a very good solvent and provide medium in which different molecules are dissolved and suspended.

Some examples showing that how much water is important :

- A watermelon has over 92 percent water.
- Most herbaceous plants have 85-90% water (they have about 10-15 percent of its fresh weight as dry matter).
- Distribution of water within a plant varies because woody parts have relatively very little water. While soft parts contain most of water.
- A seed may appear dry but it still has water otherwise it would not be alive and respiring.
- A mature corn plant absorbs almost three litres of water in a day while a mustard plant absorbs water equal to its own weight in about 5 hours.

Membrane permeability : On the basis of permeability, membranes are of four types :

Membrane	Definition and examples
Permeable membrane	A membrane which allows transport of both solutes and solvents across it. Example : primary cell wall
Semi permeable membrane	A membrane which allows transport of soivent but not solute across it. Example : Animal urinary bladder, cellophane, copper ferricyanide membrane, parchment paper etc.
Selective or differentially permeable membrane	A membrane which allow transport of some selected solutes along with solvent Example: cell membrane (plasma membrane), tonoplast, organellar membrane.
Impermeable membrane	A membrane which neither allow solutes nor solvent. Example: Suberinised cell wall (cork), cutinised cell wall (epidermis), polythene, glass, plastic etc.

Types of solution : They are of three types :

Solution	Definition
Hypertonic	If the external solution is more concentrated than that of cytoplasm of cell
Hypotonic	If the external solution is more dilute than that of cytoplasm of cell
Isotonic	If external solution balances the osmotic concentration of cytoplasm

Osmosis

Term coined by Nollet. Osmosis is the term used to refer specifically to the diffusion of water across a differentially or semi-permeable membrane.

Some facts about osmosis :

(i) Osmosis is a type of diffusion.

(ii) It occurs spontaneously in response to a driving force.

(iii) The net direction and rate of osmosis depends on both the pressure gradient and concentration gradient.

(iv) Water will move from its region of higher chemical potential (or concentration) to its region of lower chemical potential until equilibrium is reached.

(v) At equilibrium the two chambers should have the same water potential.

Osmotic pressure

This term was coined by O. Pfeiffer.

A pressure develop in an osmotically active solution (hypertonic solution) when this solution is separated from hypotonic solution or its solvent by means of semipermeable membrane. Osmotic pressure is denoted by π.

Mathematical expression of osmotic pressure : (Vont Hoff formula)

$\pi = iCRT$

i = ionisation constant

C = concentration

R = gas constant [0.082 mole/molecule]

T = absolute temperature .

Q. Calculate the value of osmotic pressure of 1 mole glucose solution at 0°C temperature ?

Sol. $\pi = 1 \times 0.082 \times 273$

$\pi = 22.4$ atm.

Some facts about osmotic pressure :

(i) Osmotic pressure is the function of solute concentration. Thus, more the solute concentration, greater will be the pressure required to prevent water diffusing in.

(ii) Numerically osmotic pressure is equivalent to the osmotic potential (solute potential) but the sign is opposite.

$\Psi_S = -iCRT$

Thus, $\Psi_S = -\pi$

(iii) Osmotic pressure of electrolytes is greater than non electrolytes.

(iv) Osmotic pressure is variable in plants of different habitat.

Ascending order of osmotic pressure :

Hydrophytes < Neophytes < Xerophytes < Halophytes

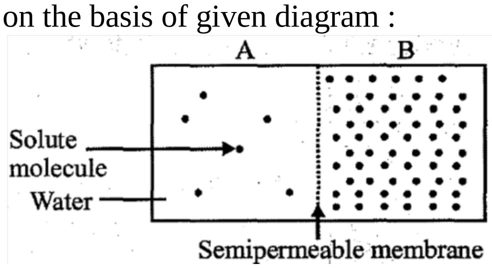
(v) Highest osmotic pressure is reported in a halophytic plant A triplex confertifolia. (202.5 atm)

(vi) Osmotic pressure of pure water is taken to be zero.

(vii) Osmotic pressure is measured by osmometer.

(viii) Osmotic pressure of a cell is measured by plasmolytic method.

Answer the following questions on the basis of given diagram :



Q. (a) Solution of which chamber has a lower water potential ?

Ans. Chamber B.

(b) Solution of which chamber has a lower solute potential ?

Ans. Chamber B.

(c) In which direction will osmosis occur ?

Ans. Osmosis will occur from chamber A to chamber B.

(d) Which solution has a higher solute potential ?

Ans. Chamber A.

(e) At equilibrium which chamber will have lower water potential ?

Ans. At equilibrium the two chambers will have the same water potential.

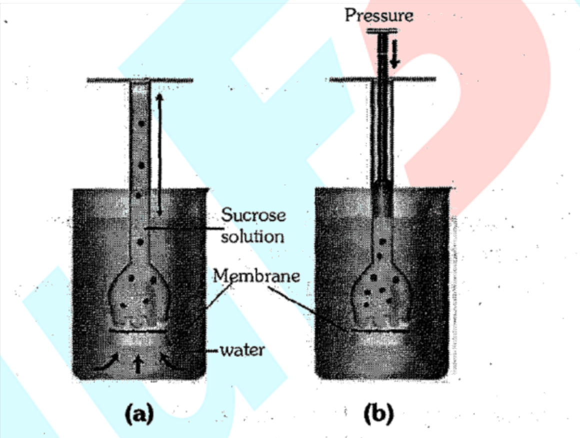
(f) If one chamber has Ψ of –2000 kPa, and the other –1000 kPa, which is the chamber that has the higher Ψ?

Ans. Chamber with Ψ of –1000 kPa has higher Ψ.

Experimental demonstration of osmosis and osmotic pressure :

Let us discuss an experiment where a solution of sucrose in water taken in a funnel is separated from pure water in a beaker through a semi-permeable membrane.

- Water will move into the funnel. resulting in rise in the level of the solution in the funnel. This will continue till the equilibrium is reached.
- External pressure can be applied from the upper part of the funnel such that no water diffuses into the funnel through the membrane. This pressure required to prevent water from diffusing is in fact, the osmotic pressure.



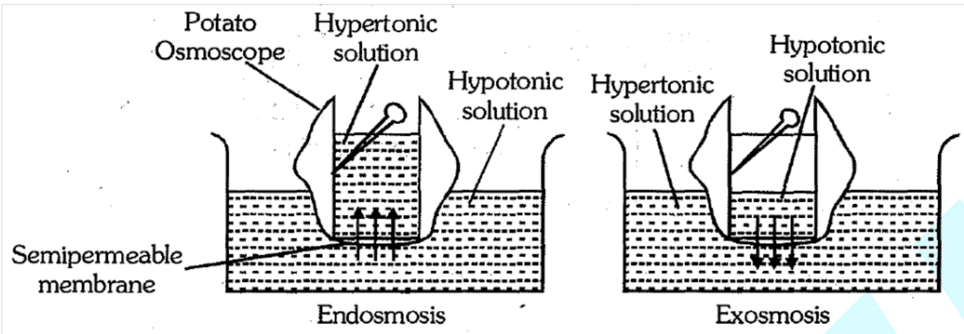
A demonstration of osmosis and osmotic pressure.

A thistle funnel is filled with sucrose solution and kept inverted in a beaker containing water.

(a) Water will diffuse across the membrane (as shown by arrows) to raise the level of the solution in the funnel

(b) Pressure can be applied (as shown) to stop the water movement into the funnel

Demonstration of osmosis by potato osmometer : If the potato tuber is placed in water, the cavity in the potato tuber containing a concentrated solution of sugar collects water due to osmosis.



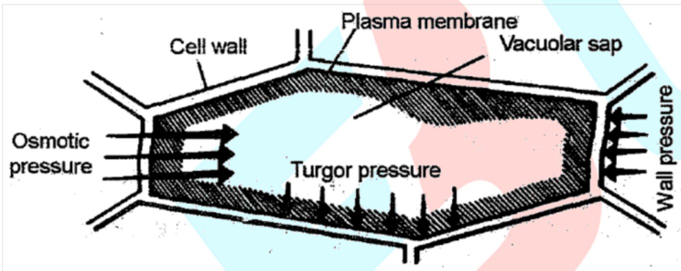
Demonstration of Osmosis by potato osmometer

Turgor pressure

When a cell is placed in a hypotonic solution. Water diffuses into the cell causing the protoplast to build up a hydrostatic pressure against the cell wall. This pressure is called turgor pressure. The pressure exerted by the cell wall against turgid protoplast is called wall pressure.

Hence, for a turgid cell :

TP = WP



TURGOR PRESSURE AND WALL PRESSURE

Some facts about turgor pressure :

(i) Turgor pressure is a centrifugal force.

(ii) The highest value of turgor pressure is found in fully turgid cell and it is equalto osmotic pressure of the cell.

(iii) The value of turgor pressure for a plasmolysed cell is negative while taken to be zero for flaccid cell.

(iv) Turgor pressure is not applicable for a free solution {solution in a vessel). This is only applicable for osmotic system (a system delimited by semipermeable membrane.)

Significance of turgor pressure :

(a) Maintain shape of cells.

(b) Responsible for enlargement and extension growth of cells.

Q. What would be the Ψp of a flaccid cell ?

Ans. Zero.

Q. Which organisms other than plants possess cell wall ?

Ans. All bacteria, some protists and all fungi

Q. What would happen when plant cell is placed in hypotonic solution ?

Ans. Water diffuses into the cell and cell become turgid. Because of the rigidity of the cell wall, the cell does not rupture.

Q. What would happen when RBCs are placed in hypotonic solution ?
Ans. RBCs will burst, because they lack cell wall.

Plasmolysis Behaviour of plant cell in hypertonic solution.

Shrinkage of protoplast under the influence of hypertonic solution is called plasmolysis.

Some facts about plasmolysis :

(i) Plasmolysis occurs when water moves out of the cell and cell membrane or protoplast of a plant cell shrink away from its cell wall.
(ii) Water moves from high water potential (inside cell) to low water potential (external solution).
(iii) During plasmolysis water is first lost from the cytoplasm and then from the vacuole.
(iv) Plasmolysis is a property of living cells only.
(v) The process of plasmolysis is usually reversible.

Applications of plasmolysis :

(i) For identification of a living cell. (Plasmolysis ~ Deplasmolysis)
(ii) Food preservation.
(iii) Elimination of weeds.
(iv) As a method for measurement of osmotic pressure.

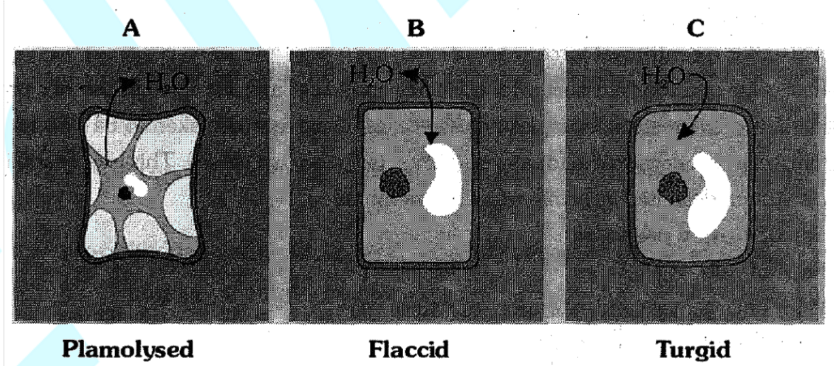
Q. What occupies the space between the cell wall and the shrunken protoplast in the plasmolysed cell?
Ans. Hypertonic solution.

Behaviour of cell in isotonic solution :

When the cell (or tissue) is placed in an isotonic solution, there is zero net flow of water towards the inside or outside. When water flows into the cell and out of the cell and are in equilibrium, the cells are said to be flaccid.

Behaviour of cell in hypotonic solution :

When a plasmolysed cell placed in hypotonic solution, water diffuse into the cell. As a result cell become turgid, this process is called deplasmolysis.



DPD (Diffusion pressure deficit)

DPD is the decrease in the diffusion pressure of any system due to addition of solute particles. DPD is also called suction pressure (SP).

- DPD is directly proportional to the solute concentration of the system. Therefore, greater the concentration of solutes, higher will be the DPD.
- DPD shows demand of water in a cell. Water always moves from the region of lower DPD to the region of higher DPD.

Mathematical expression :

DPD = OP – TP

(i) DPD of free solution (solution in a vessel) :

The value of TP for free solution is taken to be zero.

Thus, DPD = OP

(ii) DPD of a partially turgid or nonnal cell : Normally the value of osmotic pressure is greater than the turgur pressure of the cell.

Thus, DPD = OP – TP

(iii) DPD for fully turgid cell :

When turgor pressure of cell balances the osmotic pressure then cell is called fully turgid.

Thus, DPD = Zero

because OP = TP

(iv) DPD for a flaccid cell :

Turgor pressure of flaccid cell is taken to be zero.

Thus, DPD = OP

(v) DPD for a plasmolysed cell :

Turgor pressure of a plasmolysed cell is taken to be negative.

Thus, DPD = OP + TP

WATER POTENTIAL

- In thermodynamics free energy of water is called water potential. It is denoted by the greek symbol Ψ_w and is expressed in pressure units such as pascals (Pa), atmosphere (atm), bars etc.
- Water potencial (Ψ_w) is a fundamental concept to understand water movement.
- Two main components that determine water potential are :
  (a) Solute potential or osmotic potential (Ψ_S).
  (b) Pressure potential (Ψ_P)
- Water molecules possess kinetic energy. In liquid and gaseous form they are in random motion that is both rapid and constant. The greater the concentration of water in a system, the greater is its kinetic energy or 'water potential'. Hence, it is obvious that pure water will have the greatest water potential.
- If two systems containing water are in contact, random movement of water molecules will result in net movement of water molecules from the system with higher kinetic energy to the one with lower kinetic energy. Thus water will move from the system containing water at higher water potential to the one having low water potential. This process of movement of water down a gradient of free energy is called diffusion.

Case-1 : The water potential of pure water at standard temperatures, which is not under any external pressure (other than atmospheric pressure), is taken to be zero.

Case-II : If some solute is dissolved in pure water, the solution has fewer free water and the concentration (free energy) of free water decreases, reducing its water potential. The magnitude of this lowering due to dissolution of a solute is called solute potential or osmotic potential (Ψ_S).

For a solution at atmospheric pressure :

$$\Psi_W = \Psi_S$$

Conclusion :

(a) All solutions have a lower water potential than pure water.

(b) Ψ_S is always negative. The more the solute molecules, the lower (more negative) is the Ψ_S.

Case-III : If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. Pressure potential is usually positive. (negative pressure potential reported inside xylem and plasmolysed cell). Pressure potential is denoted as Ψ_p.

Water potential of a cell is affected by both solute and pressure potential. The relationship between them is as follows :

$$\Psi_W = \Psi_S + \Psi_P$$

Imbibitions

It is a special type of diffusion. It occurs when water is adsorbed by solids (hydrophillic colloids).

Result of imbibition :

- Volume of imbibant enormously increases.
- A pressure is exerted by imbibant.

Pre-requisite for success of imbibition :

(i) Water potential gradient between the absorbent and the liquid imbibed is essential.

(ii) Affinity between the adsorbant and the liquid is essential.

Example : The classical examples of imbibition are absorption of water by dry seeds and dry wood.

Application of imbibitions :

(i) The pressure that is produced by the swelling of the wood had been used by prehistoric man to split rocks and boulders.

(ii) Seedlings emerge out of the soil into the open and establish due to imbibitions.

Some facts about imbibitions :

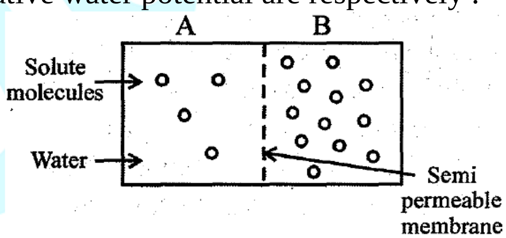
(a) During rainy season wooden doors and windows swell due to imbibitions.

(b) Power of imbibitions is variable in different substances:

Agar-agar > pectin > protein > starch > cellulose

BEGINNER'S BOX-1

1. Represented below is the system containing two chambers A and B with different concentrations. In the given system the chamber with less negative solute potential and the chamber with more negative water potential are respectively :-

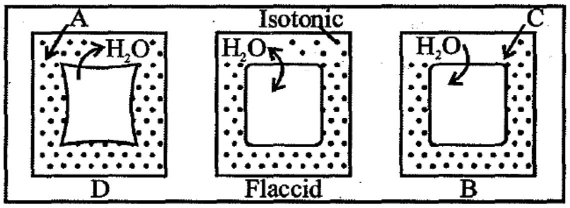


(1) A and B (2) A and A (3) B and B (4) B and A

2. Most of the herbaceous plants have about __ of its fresh weight as water :-

(1) 10 to 15 percent (2) 92 percent (3) 50 to 60 percent (4) 85 to 90 percent

3.



Choose the correct match of the labelling for above diagram :-

	A	B	C	D
(1)	Hypotonic	Turgid	Plasmolysed	Hypertonic
(2)	Hypertonic	Plasmolysed	Turgid	Hypotonic
(3)	Hypertonic	Turgid	Hypotonic	Plasmolysed
(4)	Plasmolysed	Hypotonic	Plasmolysed	Hypertonic

4. The values of osmotic potential ('I' J and pressure potential ('I'P) of cells A, B, C and Dare given below:

	Ψ_S	Ψ_P
Cell 'A'	–0.8	0.4
Cell 'B'	–1.2	0.6
Cell 'C'	–0.6	0.3
Cell 'D'	–1.0	0.5

Identify the correct sequence for movement of water:-

(1) $A \rightarrow C \rightarrow B \rightarrow D$ (2) $B \rightarrow D \rightarrow A \rightarrow C$ (3) $C \rightarrow A \rightarrow D \rightarrow B$ (4) $D \rightarrow B \rightarrow C \rightarrow A$

5. Diffusion is a slow process and may dependent on:

(1) Concentration gradient (2) Membrane permeability
(3) Temperature and pressure (4) All of the above

Transpiration

Evaporative loss of water in the form of vapours from aerial parts of a plant. Besides the loss of water vapour in transpiration, exchange of carbon dioxide arid oxygen in the leaf also occurs through pores called stomata (sing. : stoma).

Types of transpiration :

(i) Stomatal transpiration : Transpiration occur through stomata is calleds tomatal transpiration. Stomata, are mainly present on leaves, and also present on other delicate organs (sepal, herbaceous stem). Stomatal transpiration is 50-90% of total.

(ii) Cuticular transpiration : Loss of water vapours via thin cuticle (cuticle is a wax layer present on epidermis of aerial parts). It is account for 9- 9.9 percent of total transpiration.
In mesophytes cuticular transpiration is goes up to 40 to 50 percent.

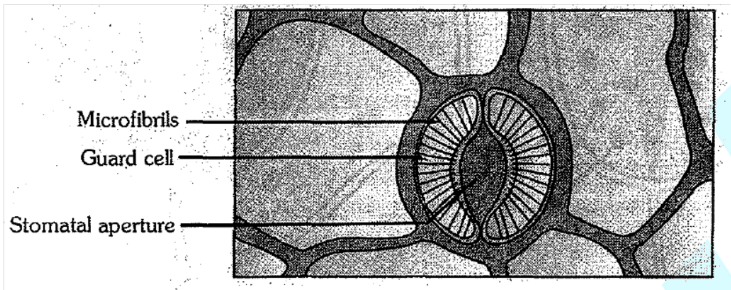
(iii) Lenticular transpiration : Lenticels are minute pores on woody stem and epidermis of fruits. Lenticels account for 0.1 to 1 percent of total transpiration.

Foliar transpiration :

Total transpiration takes place through surface of leaves (stomatal and cuticular).

Structure of stomata :

Stomata are part of epidermal tissue system of aerial parts. Adjacent epidermal cells become kidney shaped or dumbbell shaped and encloses a pore in between, kidney or dumbbell shaped cells, are called guard cells and the whole apparatus is called stomata or stomatal apparatus. Guard cells are surrounded by subsidiary cells or accessory cells.



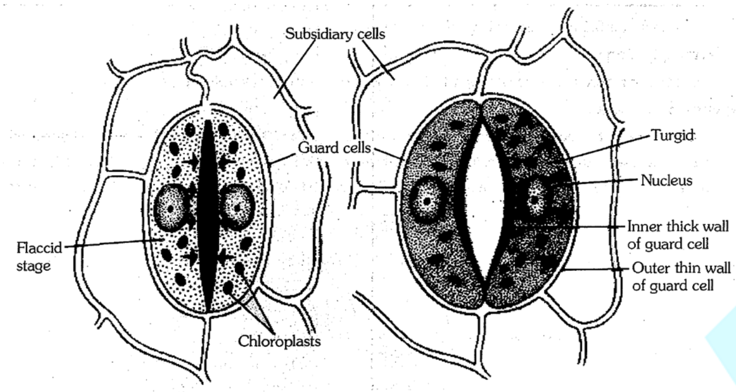
A stomatal aperture with guard cells

Guard cells		Other epidermal cells	
(1)	In dicots, guard cells are bean shaped or kidney shaped or crescent shape, while in monocot they are dumbel shaped.	(1)	Epidermal cells are barrel shaped.
(2)	Intercellular space (stomata aperture) is present.	(2)	Intercellular spaces are absent.
(3)	Cuticle is absent.	(3)	Cuticle is present.
(4)	Outer wall is thin and elastic while inner wall (towards the stomatal aperture) is thick and elastic.	(4)	Walls are uniformally thickened.
(5)	Chloroplasts are present.	(5)	Chloroplasts are absent.

Note : (a) In the cell wall of guard cells cellulosic micro fibrils are oriented radially.
(b) In guard cells PEP case is present.

MECHANISM OF OPENING AND CLOSING OF STOMATA

- ♦ The cause of the opening or dosing of the stomata is a change in the turgidity of the guard cell. When guard cells become turgid, stomata opens and when guard cells become flaccid, stomata closes.
- ♦ When osmotic concentration (OP) of guard cells is high, then guard cells become turgid by absorption of water through endosmosis from near by cells (Subsidiary cells).
- ♦ When osmotic concentration (OP) of guard cells decreases then guard cells become flaccid. Due to flaccidity of guard cells, inner thick walls of both guard cells become fused and stomata closes.
- ♦ The opening of the stoma is also aided due to the orientation of the micro fibrils in the cell walls of the guard cells. Cellulose micro fibrils are oriented radically rather than longitudinally making it easier for the stoma to open.

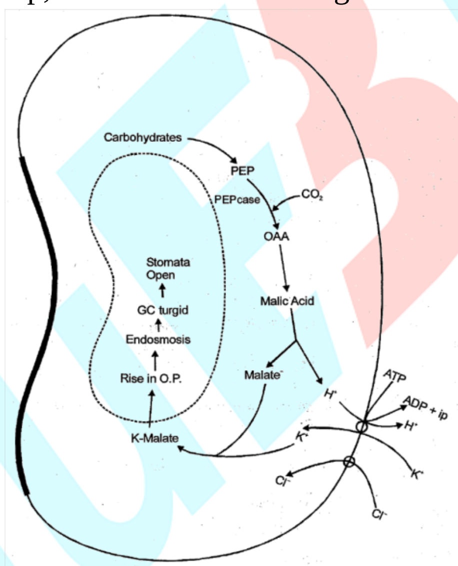


The cell wall bordering the stomatal pore is thicker than that of next to the surrounding cells
(A) Aperture closed (B) Aperture open

K^+ ion pump theory : This theory was put forwarded by Levitt, 1974. This theory is considered as the most accepted theory for stomatal movement.

Modem theory or ABA theory :

It is an integrated part of K^+ ion pump theory. According to this theory ABA in guard cells interfere the K^+ ƒ H^+ pump, which result in closing of stomata.



$K^+ \rightleftharpoons H^+$ ion theory

Factors affecting the rate of transpiration :

Transpiration is affected by several factors, they are broadly divided into two categories :

(A) External· factors :

(1) Atmospheric humidity : This is the most important factor. Rate of transpiration is inversely proportional to atmospheric humidity.

$$\text{Rate of transpiration} \propto \frac{1}{\text{Humidity}}$$

(2) Temperature : Upto a limit increase in temperature result in increase in rate of transpiration. At very high temperature transpiration decreases.

(3) Light : Light stimulates transpiration through favouring opening of stomata.

- Action spectrum of transpiration is blue and red. Blue light is slightly more effective than red light.

(4) **Wind velocity:** Transpiration is less in still air, rate of transpiration increases along with increase in wind velocity. Although at very high velocity rate of transpiration decreases.

(5) **Atmospheric pressure :** Rate of transpiration is inversely proportional to atmospheric pressure.

(B) Internal or plant factors :

(1) Stomata:

(i) Number of stomata : Rate of transpiration is directly proportional to number of stomata.

(ii) Distribution of stomata : Distribution of stomata is variable usually the lower surface of a dorsiventral (often dicotyledonous) leaf has a greater number of stomata while in an isobilateral (Often monocotyledonous) leaf, they are about equal on both surfaces. Therefore, monocots transpire more than dicots.

(iii) Percentage of open stomata : Rate of transpiration is directly proportional to percentage of open stomata.

(2) Anatomy of leaf :

(i) Mesophyll : Occurence of pallisade tissue in cortex of leaf (mesophyll) helps to reduce transpiration, while spongy mesophyll favour high rate of transpiration.

(ii) Cuticle: Rate of transpiration is inversely proportional to thickness of cuticle. In xerophytes thick cuticle is an adaptation to minimise the loss of water.

(3) Water status of the plant :

Less than one percent of the water reaching the leaves is used in photosynthesis and plant growth. Most of absorbed water lost through transpiration, thus a good status of water favours high rate of transpiration. Due to water stress ABA forms in gaurd cells and stimulates closing of stomata (hence, decrease in transpiration).

(4) Canopy structure : Dense canopy causes decrease in transpiration because such canopy obstruct air flow.

(5) Root shoot ratio: Transpiration per unit area is directly proportional to root shoot ratio.

Some facts about transpiration :

Antitranspirants : Substances which reduce the rate of transpiration are known as antitranspirants. They are very useful in dry farming. Examples : Phenyl Mercuric Acetate [PMA], aspirin (salicylic acid), ABA, oxy-ethylene, silicon oil, C02 and low viscocity wax.

Transpiration ratio: Rate of the loss of water to the photosynthetic C02 fixed is called transpiration ratio.

$$\text{Transpiration ratio : } \frac{\text{Moles of } H_2O \text{ transpired}}{\text{Moles of } CO_2 \text{ assimilated}}$$

This ratio is low for C_4 plants (200-350) while high for C_3 plants (500-1000) which indicates C_4 plants conserve water with efficient photosynthesis. Transpiration ratio of CAM plants is minimum (50-100).

- In xerophytes stomata are sunken to minimise the loss of water.
- According to Curtis "transpiration is an essential evil."
- According to Steward "transpiration is an unavoidable evil."
- At higher humidity although transpiration is negligible but stomata remain completely open.

Transpiration and photosynthesis-a compromise :

Transpiration has more than one purpose: it :

(i) Creates transpiration pull for absorption and transport of plants

(ii) Supplies water for photosynthesis
(iii) Transports minerals from the soil to all parts of the plant
(iv) Cools leaf surfaces sometimes 10 to 15 degrees, by evaporative cooling
(v) Maintains the shape and structure of the plants by keeping cells turgid.

An actively photosynthesising plant has an insatiable need for water. Photosynthesis is limited by available water which can be swiftly depleted· by transpiration. The humidity of rainforests is largely due to this vast cycling of water from root to leaf to atmosphere and back to the soil.

Potometer : An apparatus used to measure rate of transpiration. This apparatus work on principle - rate of water absorption is equal to rate of transpiration.

Porometer : An apparatus used to measure area of stomata on leaf.

Cobalt-chloride test : This test is used for comparison of transpiration by two surfaces of a leaf.

Long distance transport

Long distance transport of substances within a plant cannot be by diffusion alone.

Reasons:

(i) Diffusion is a slow process. It can ac`count for only short distance movement of molecules.

Example : The movement of a molecule across a typical plant cell (about 50 urn) takes approximately 2.5 second.

(ii) Sometime the site of production or absorption and sites of storage are too far from each other thus diffusion and active transport would not suffice. Therefore, special long distance transport systems become necessary so as to move substances across long distances and at a much faster rate. Water, minerals and food are generally moved by a mass or bulk flow system.

Bulk or mass flow is totally different from diffusion :

Mass flow or bulk flow	Diffusion
It is the movement of substances in bulk or en masse from one point to another as a result of pressure differences between the two points. It is a characteristic of mass flow that substance, whether in solution or in suspension, are swept along at the same pace, as in a flowing river.	In diffusion different substances move independently depending on their concentration gradients.

Bulk flow can be achieved either through any of following :

(a) Positive hydrostatic pressure gradient. Example : Garden hose
(b) Negative hydrostatic pressure gradient. Example : Suction through a straw.

How do plants absorb water :

The roots absorb most of the water that goes into plants. The responsibility of absorption of water and minerals is more specifically the function of the root hairs that are present in millions at the tips of roots.

"Water is absorbed along with mineral solutes, by the root hairs, purely by diffusion."

Once water is absorbed by the root hairs, it can move deeper into root layers by two distinct pathways :

(i) Apoplast pathway

(ii) Symplast pathway

(i) Apoplast pathway : The apoplast is the system of adjacent cell walls that is continuous throughout the plant, except at the casparian strips of the endodermis in the roots.

Features of apoplastic pathway :

(i) The apoplastic movement of water occurs exclusively through the intercellular spaces and the walls of the cells.

(ii) Movement through the apoplast does not involve crossing the cell membrane.

(iii) This movement is dependent on the water potential gradient.

(iv) The apoplast does not provide any barrier to water movement and water movement is through mass flow.

Mechanism or driving force for apoplastic movement :

As water evaporates into the intercellular spaces or the atmosphere, tension develop in the continuous stream of water in the apoplast, hence mass flow of water occurs due to the adhesive and cohesive properties of water.

(ii) Symplast pathway :

The symplastic system is the system of interconnected protoplasts. Neighbouring cells are connected through cytoplasmic strands that extend through plasmodesmata.

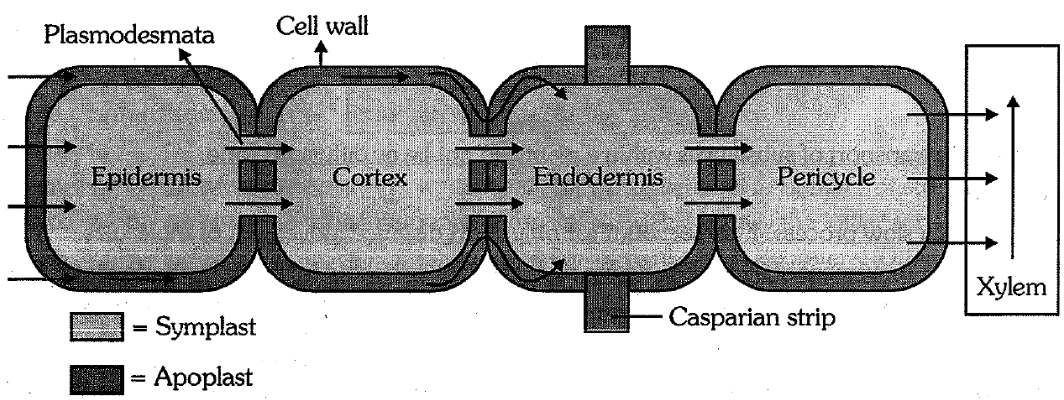
Features of symplast pathway :

(i) The water travels through the cells i.e. through their cytoplasm; intercellular movement is through the plasmodesmata.

(ii) Movement through the symplast involve crossing the cell membrane, hence the movement is relatively slower.

(iii) Symplastic movement occurs down a potential gradient.

(iv) Symplastic movement may be aided by cytoplasmic streaming, eg., cells of Hydrilla leaf.



Pathway of water movement in the root

Some facts about water absorption :

- In young roots, water enters directly into the xylem vessels and/or tracheids. These are non living conduits (canals or tubes) and so are parts of the apoplast.
- Some plants have additional structures associated with them that help in water and mineral absorption. Such structure called mycorrhiza. It is a symbiotic association of a fungus with a root system. In this association fungus provides minerals and water to the root in turn the roots provide sugars and N-containing compounds to the fungus.

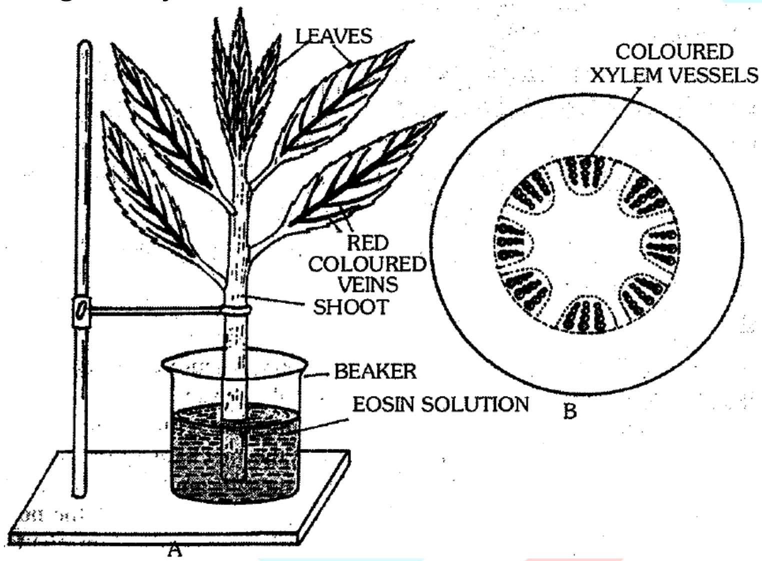
  Example : Pinus seeds can not germinate and establish without the presence of mycorrhizae.

Water movement up a plant (Ascent of sap)

The water has to be moved up a stem against gravity. The path of water movement is through the/vascular bundles, more specifically, the xylem.

Experiment :

Place a twig bearing white flowers.(Balsam plant) in coloured water (eosin solution). On examining the cut end of the twig after a few hours we will notice the region through which the coloured water moved. This experiment very easily demonstrates that the path of the water movement is through the xylem.



Transpirational pull :

It is a negative hydrostatic pressure develop in aerial parts due to evaporative loss of water. Due to this pressure rate of ascent of sap in plants is fairly high (15 meter per hour).

Water is mainly pulled through this transpiration pull and this is referred to as the cohesive-tension-transpiration pull model of water transport. (put forward by Dixon and Jolly)

The transpiration driven ascent of xylem sap depends mainly on the following physical properties of water :

(a) **Cohesion :** Mutual attraction between water molecules.

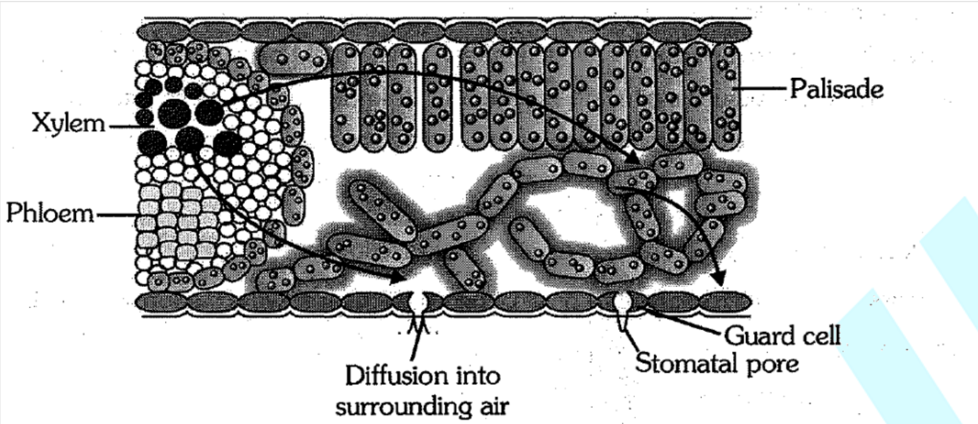
(b) **Adhesion :** Attraction of water molecules to polar surfaces (such as the surface of tracheary elements).

(c) **Surface Tension :** Water molecules are attracted to each other in the liquid phase more than to water in the gas phase.

These properties give water high tensile strength (an ability to resist a pulling force) and high capillarity (the ability to rise in thin tubes). In plants capillarity is aided by the small diameter of the tracheary elements (the tracheids and vessel elements).

Mechanism:

As water evaporates through the stomata. since the thin film of water over the cells is continuous. it results in pulling of water. molecule by molecule. into the leaf from the xylem. Also, because of lower concentration of water vapour in the atmosphere as compared to the substomatal cavity and intercellular spaces, water diffuses into the surrounding air. This creates a 'pull' Measurements reveal that the forces generated by transpiration can create pressures sufficient to lift a xylem sized column of water over 130 metres high.



Water movement in the leaf. Evaporation from the leaf sets up a pressure gradient between the outside air and the air spaces of the leaf. The gradient is transmitted into the photosynthetic cells and on the water-filled xylem in the leaf vein.

Root pressure :

As various ions from the soil are actively transported into the vascular tissues of the roots, water follows its potential gradient and increases the pressure inside the xylem. This positive pressure is called root pressure.

Experiment for demonstration of root pressure :

Choose a small soft-stemmed plant on a day, when there is plenty of atmospheric moisture and cut the stem horizontally near the base with a sharp blade, early in the morning, soon we will see drops of solution ooze out from the cut stem: this comes out due to the positive root pressure. By fixing a rubber tube to the cut stem as a sleeve we can actually collect and measure the rate of exudation, and also determining the composition of the exudates.

Conditions that favour root pressure :

(i) Low rate of evaporation and transpiration.
(ii) High atmospheric humidity.
(iii) Root pressure exist from evening till early morning in some plants.

Application of root pressure :

(i) Responsible for pushing up water to small heights in the stem.
(ii) Responsible for guttation and exudation.
(iii) Provide a modest push in the overall process of water transport.
(iv) The greatest contribution of root pressure may be to reestablish the continuous chains of water molecules in the xylem which often break under the enormous tensions created by transpiration.

Some facts about root pressure :

(a) Root pressure do not play a major role in water movement up tall trees.
(b) Root pressure does not account for majority of water transport: most plants meet their need of water by transpirational pull.
(c) Manometer is used to measure root pressure.

GUTTATION

Loss of xylem sap in the form of liquid drops from the uninjured margins of leaves is called guttation.

Some facts about guttation :

(i) Guttation takes place through hydathodes, they are special type of stomata called water stomata. Hydathodes remain open throughout day and night.
(ii) Guttation drops contain dissolved organic and inorganic substances.
(iii) Guttation is driven by root pressure, which is seen in late night or early morning.
(iv) Loose parenchymatous tissue lie beneath hydathodes, is known as epithem tissue.

Examples : Grasses, tomato, balsam, garden nasturtium, colocasia and some plants of cucurbitaceae family.

Exudation/bleeding

The term exudate derived from a latin word exude means 'to ooze'.·
Exudation is emission of liquid from injured parts of plant. Root pressure is responsible for exudation.

Application of exudation :
(a) Sugar is obtained from sugar maple.
(b) Opium (latex) is obtained from Palaver.
(c) Rubber (latex) is obtained from rubber tree.
(d) Toddy is obtained from toddy palm (Caryota urens). In toddy palm highest bleeding is reported i.e. 50 liter/day.

Phloem transport – flow from source to sink

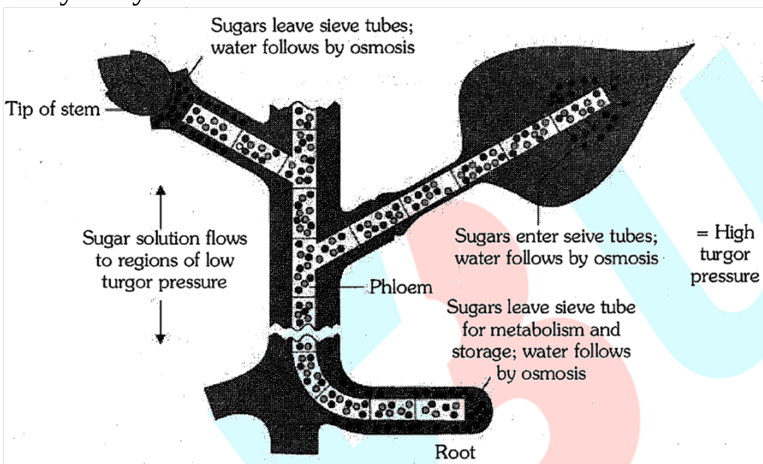
Food (primarily sucrose) is transported by the vascular tissue (phloem) from a source to a sink.
Source : Part of the plant which synthesises or store the food. Example : leaves.
Sink : Part of the plant that needs the food. Example : root.
The source and-sink may be reversed depending upon the season or the plant's need.

- Usually leaves are source and root acts as sink, but in the early spring root become a source of food and buds of trees, acts as sink because they need energy for growth and development of photosynthetic structure.
- Since the source - sink relationship is variable, the direction of the movement of food in the phloem can be upwards or downwards. (bi-directional)
- Chemical nature of phloem sap is alkaline.
- Phloem sap is mainly composed of water and sucrose but other sugars. hormones and amino acids are also translocated through phloem.

The pressure flow or mass flow hypothesis : It is put forward by Munch.
It is the most accepted mechanism used for the translocation of sugars from source to sink is called the pressure flow hypothesis.

- Glucose is prepared at the source (by photosynthesis) it is converted to sucrose (a disaccharide).
- The sugar is then moved in the form of sucrose into the companion cells and then into the living phloem sieve tube cells by active transport. (loading)
- This process of loading at the source produces a hypertonic condition in the phloem. (Decrease in water potential.

- Water from the adjacent xylem moves into the phloem by osmosis. An turgor pressure build up in the phloem. Due to this pressure phloem sap move from region of high pressure (source) to the region of low pressure (sink).
- Ultimately sucrose reaches to sink. Active transport is necessary to move the sucrose out of phloem sap (unloading).
- Cells of sink will use the sugar by three ways :
  (a) Converting it into energy
  (b) Converting it into starch
  (c) Converting it into cellulose
- As sugar are removed, the osmotic pressure decreases and water moves out of the phloem, returning eventually to xylem.



Girdling ringing experiment :

Aim : This experiment was used to identify the tissues through which food is transported. On the trunk of a tree a ring of bark upto a depth of phloem layer, can be carefully removed. In the absence of downward movement of food the portion of the bark above the ring on the stem becomes swollen after a few weeks. Girdling explains unidirectional flow of solutes.

Conclusion : This simple experiment shows that phloem is the tissue responsible for translocation of food.

BEGINNER'S BOX-2

1. The inner wall of each guard cell, towards the pore or stomatal aperture, is :
   (1) thick and nonelastic (2) thick and elastic
   (3) thin and elastic (4) thin and nonelastic

2. Xylem is associated with translocation of which of the following substances ?
   (i) Water (ii) Hormones (iii) Sucrose
   (iv) Mineral salts (v) Organic nitrogen
   Choose the correct option :-
   (1) (i), (ii) and (iii) (2) (i), (iv) and (v)
   (3) (i), (ii), (iv) and (v) (4) (ii), (iii) and (iv)

3. Which of the following is not correctly matched?
   (1) Water loss from leaves in liquid phase = due to root pressure
   (2) Ascent of xylem sap = by transpiration pull

(3) Cooling of plant = by transpiration surface
(4) Closing of stomata = due to increased turgidity of guard cells

4. Transpiration cools leaf surfaces ___ by evaporative cooling.
Choose the correct option from the following for above blank :-
(1) 40 to 50 degrees (2) 10 to 15 degrees (3) 30 to 40 degrees (4) More than 50 degrees

5. Most of the water flow in the roots occurs via the apoplast because :-
(1) cortical cells are loosely packed in roots and hence offer no resistance to water movement.
(2) in the apoplast, flow of water occurs due to the adhesive and cohesive properties of water.
(3) the apoplastic movement of water may be aided by cytoplasmic streaming.
(4) in apoplast the movement of water occurs according to water potential gradient.

ANSWER KEY

BEGINNER'S BOX-1

1.	(1)	**2.**	(4)	**3.**	(3)	**4.**	(3)	**5.**	(4)

BEGINNER'S BOX-2

1.	(2)	**2.**	(3)	**3.**	(4)	**4.**	(2)	**5.**	(1)