TRANSPORT IN PLANTS

Plants do not have interstitial fluid and circulatory system. But they need to move various substances (water, minerals, organic nutrients, growth regulators etc.) over long distances.

Direction of transport

- **Unidirectional transport:** E.g. Transport of water and minerals in xylem (from roots to the stems, leaves etc.).
- **Multidirectional transport:** E.g.
  - Transport of photosynthates (organic compounds).
  - Transport of mineral nutrients.
- Sometimes, plant hormones and other chemical stimuli are transported in a polarized or unidirectional manner from where they are synthesized to other parts.

MEANS OF TRANSPORT

1. Diffusion

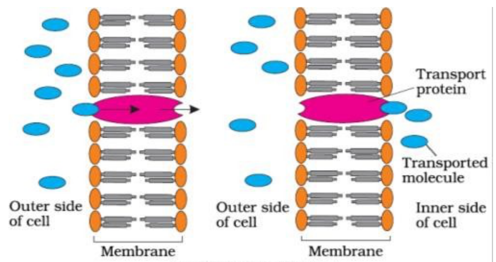
- It is the slow movement of gases, liquids and solutes from higher concentrated region to lower concentrated region without the energy expenditure.
- It may be from one part of the cell to the other or from cell to cell, or over short distances.
- It is not dependent on a 'living system'.
- It is the only means for gaseous movement in a plant body.

Factors affecting diffusion rates:

- Concentration gradient.
- Permeability of the membrane.
- Temperature and pressure.
- Size or density. Smaller substances diffuse faster.
- Solubility in lipids of the membrane. Substances soluble in lipids diffuse through the membrane faster.

2. Facilitated Diffusion

- It is the diffusion of hydrophilic substances with the help of membrane protein channels and without expenditure of energy.
- It also needs a concentration gradient.
- It is very specific. Cell selects substances for uptake. It is sensitive to inhibitors that react with protein side chains.

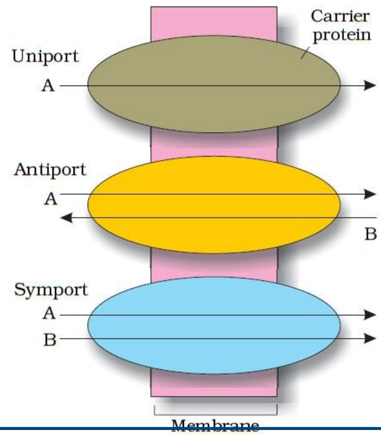


Facilitated diffusion

- Transport rate reaches a maximum when all the protein transporters are being used (saturation).
- Some protein channels are always open; others can be controlled. Some are large sized. E.g. Porins.
- **Porins** form huge pores in the outer membranes of plastids, mitochondria & some bacteria. Molecules having size of small proteins can pass through them.
- An extracellular molecule binds to the transport protein. Then it rotates and releases the molecule inside the cell. E.g. water channels – made up of 8 types of **aquaporins**.

Passive uniports, symports and antiports

- **Uniport:** A molecule alone moves across a membrane through transport or carrier protein.
- **Symport:** Two molecules together cross the membrane in same direction.
- **Antiport:** Two molecules move in opposite directions.



3. Active Transport

- It is the transport of molecules against a concentration ATP gradient (from lower concentrated region to higher concentrated region) with the expenditure of energy.
- It is carried out by **membrane-proteins.**
- Pumps are proteins that use energy to transport substances across cell membrane **('uphill' transport).**
- Transport rate reaches a maximum when all the protein transporters are being used or are saturated.
- The carrier protein is very specific. These are sensitive to inhibitors that react with protein side chains.

Comparison of Different Transport Processes

Property	Simple diffusion	Facilitated transport	Active transport
Requires special membrane proteins	No	Yes	Yes
Highly selective	No	Yes	Yes
Transport saturates	No	Yes	Yes
Uphill transport	No	No	Yes
Requires ATP energy	No	No	Yes

PLANT-WATER RELATIONS

- Water is a **universal solvent.**
- Protoplasm is mainly water in which different molecules are dissolved and suspended.
- Soft plant parts mostly contain water. E.g. watermelon has 92% water.
- Herbaceous plants have only 10 - 15% dry matter.
- Dry seeds and woody parts also contain little water.
- A mature corn plant absorbs 3 litres of water daily.
- A mustard plant absorbs water equal to its own weight in about 5 hours.

Water Potential (Ψw)

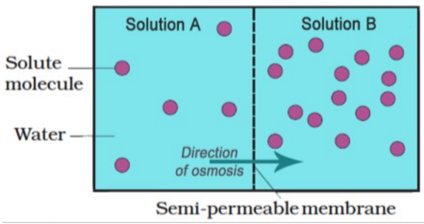
- It is the potential energy of water.
- It is the measure of the ability of water molecules to move freely in solution.
- It is expressed in pressure units such as **Pascals (Pa).**

- Water molecules have kinetic energy. In liquid & gaseous form, they show random, rapid and constant motion.
- As the concentration of water in a system increases, its kinetic energy ('water potential') also increases. Hence, pure water will have the greatest water potential.
- Water molecules move from **higher energy system (higher water potential)** to **lower energy system (lower water potential).** Such movement of substances down a gradient of free energy is called **diffusion**.
- Water potential (Ψw) of **pure water** at standard temperatures, which is not under any pressure, is **zero.**
- If a solute is dissolved in pure water, water potential decreases due to decrease in concentration (free energy) of water. Hence, Ψw of solutions is lower than pure water.
- Magnitude of lowering of water potential due to dissolution of a solute is called **solute potential (Ψs)** or **osmotic potential.**
- **Ψs** is always negative. The more the solute molecules, the lower (more negative) is the Ψs.
- For a solution at atmospheric pressure, **$\Psi w = \Psi s$.**
- If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is equivalent to pumping water from one place to another.
- When water enters a plant cell due to diffusion, it causes a pressure against the cell wall. It makes the cell **turgid.** This increases the **pressure potential (Ψp).**
- Pressure potential is usually positive, though negative potential or tension in the water column in the xylem plays a major role in water transport up a stem.
- Water potential of a cell is affected by **Solute potential** & **pressure potential**. The relationship is:

$$\Psi w = \Psi s + \Psi p$$

Osmosis

- It is the spontaneous diffusion of water across a differentially- or semi-permeable membrane.
- Cell membrane and tonoplast (membrane of vacuole) are important determinants of movement of molecules in or out of plant cell. But cell wall is not a barrier to movement as it is freely permeable to water & substances in solution.
- Vacuolar sap in large central vacuole contributes to solute potential of the cell.
- Net direction and rate of osmosis depends on **pressure gradient** & **concentration gradient**.
- Water moves from its region of higher chemical potential (concentration) to its region of lower chemical potential until equilibrium is reached. At equilibrium, the two chambers should have the same water potential.



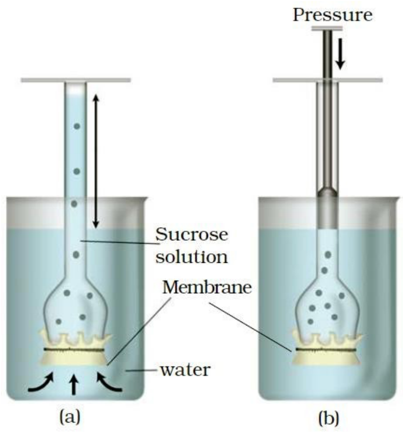
Solution A: High water potential, high solute potential.

Solution B: Low water potential, low solute potential.

Potato osmometer:

- Make a cavity in a potato tuber. In this, pour concentrated sugar solution. This setup is called potato osmometer.
- If it is placed in water, the cavity containing concentrated sugar solution collects water due to osmosis.

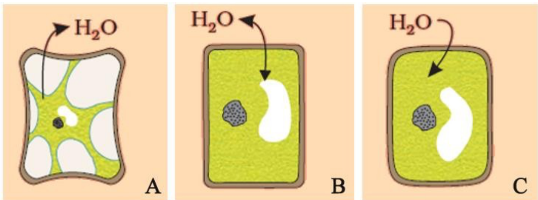
A demonstration of osmosis:



- A thistle funnel filled with sucrose solution is kept inverted in a beaker containing pure water.
- Sucrose solution is separated from water by a semi-permeable membrane (e.g. egg shell membrane).
- Water moves into the funnel. As a result, the level of the solution in the funnel rises. It continues till the equilibrium is reached (figure a).
- If an external pressure is applied from the upper part of the funnel, no water diffuses into the funnel through the membrane (figure b).
- This pressure required to prevent water from diffusing is the **osmotic pressure.** This is the function of the solute concentration. More the solute concentration, greater will be the pressure required to prevent water diffusion.
- Numerically, osmotic pressure is equivalent to the **osmotic potential,** but the sign is opposite. Osmotic pressure is positive, while osmotic potential is negative.

Plasmolysis

- If an external solution balances the osmotic pressure of the cytoplasm, it is called **isotonic**. When a cell (or tissue) is placed in isotonic solution, there is no net flow of water towards inside or outside (water flow is in equilibrium). Such cells are said to be **flaccid**.
- If the external solution is more dilute (higher water potential) than the cytoplasm, it is **hypotonic.** Cells swell (turgid) in hypotonic solution.
- If the external solution is more concentrated (more solutes) than the cytoplasm, it is **hypertonic**.



- When a cell is placed in a hypertonic solution, water moves from the cell (area of high water potential) across the membrane to outside (area of lower water potential) and the cell shrinks. It is called **Plasmolysis**. Water is first lost from the cytoplasm and then from the vacuole.
- During plasmolysis, the cell membrane and protoplast of a plant cell shrinks away from its cell wall. Such cells are said to be **plasmolysed**.
- Plasmolysis is usually reversible. When the cells are placed in a **hypotonic** solution, water diffuses into the cell. As a result, the cytoplasm builds up a pressure against the wall. It is called **turgor pressure**. The pressure exerted by the

protoplasts due to entry of water against the rigid walls is called **pressure potential (Ψ_p).** The cell does not rupture due to the rigidity of cell wall. Turgor pressure causes enlargement and extension growth of cells.

Imbibition

- It is a type of diffusion in which water is absorbed by solids (colloids) causing them to increase in volume. E.g. absorption of water by seeds and dry wood.
- The pressure due to the swelling of wood can split rocks.
- Seedlings are emerged out of the soil due to the **imbibition pressure.**
- Imbibition requires
  - Difference in concentration gradient.
  - Water potential gradient between the absorbent and the liquid imbibed.
  - Affinity between the adsorbent and the liquid.

LONG DISTANCE TRANSPORT OF WATER

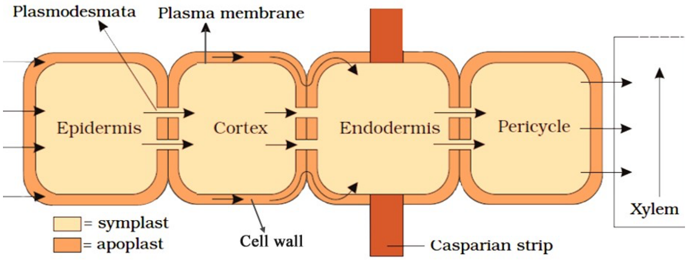
- Diffusion is a slow and short distance movement. E.g. movement of molecules across a typical plant cell (about 50 µm) takes about 2.5 s.
- Long distance transport systems are necessary to move substances faster across long distances.
- Movement of substances in bulk *(en masse)* from one point to another due to pressure differences between two points is called **Mass (bulk) flow**. E.g. movement of water, minerals and food.
- In mass flow, substances (in solution or in suspension) are swept along at the same pace as in a flowing river. But in diffusion, different substances move independently depending on their concentration gradients.
- Bulk flow is achieved either through a +ve hydrostatic pressure gradient (e.g. a garden hose) or a -ve hydrostatic pressure gradient (e.g. suction through a straw).
- Bulk movement of substances in long distance through the conducting tissues (xylem & phloem) is called **translocation.**

Absorption of Water by Plants

- Absorption of water and minerals occurs by diffusion through millions of root hairs present at the root tips.
- Root hairs increase the surface area for absorption.
- The absorbed water is moved deeper into root layers by 2 pathways: **Apoplast pathway** and **Symplast pathway.**

Apoplast pathway:

- It is a system of adjacent cell walls that is continuous except at the **casparian strips** of endodermis in the roots.
- It occurs exclusively through the intercellular spaces and cells walls. It does not cross the cell membrane.
- Water movement through apoplast is dependent on the gradient and occurs through mass flow.
- The apoplast does not provide any barrier to water movement.

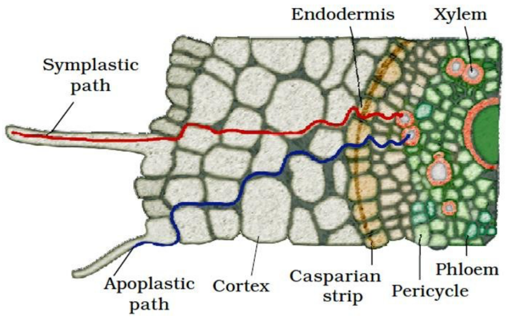


Pathway of water movement in the root

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

Symplast pathway:

- It is the system of interconnected protoplasts.
- Here, water travels through cytoplasm; intercellular movement is through the **plasmodesmata** (junction between neighbouring cells through which cytoplasmic strands extend).
- Water has to enter the cells through cell membrane; hence the movement is slower. Movement is again down a potential gradient.
- Symplastic movement may be aided by **cytoplasmic streaming.** E.g. In *Hydrilla* leaf, movement of chloroplast due to cytoplasmic streaming is easily visible.



Symplastic & apoplastic pathways

- Most of the water flow in the roots occurs via the apoplast since the cortical cells are loosely packed. So, water can move without resistance. However, the **endodermis** is impervious to water due to the **casparian strip** (a band of suberised matrix). So water molecules are directed to non-suberised wall regions. The water then moves through the symplast and again crosses a membrane to reach the xylem.
- The water movement through the root layers is ultimately symplastic in the endodermis. This is the only way water and solutes can enter the vascular cylinder.
- In young roots, water enters directly into the xylem vessels and tracheids. These are non-living conduits and so are parts of the apoplast.
- Some plants have additional structures for water and mineral absorption. E.g. **mycorrhiza** is a symbiotic association of a fungus with a root system. The fungal filaments form a network around the young root or they penetrate root cells. The hyphae absorb mineral ions & water from soil. The roots provide sugars & N compounds to mycorrhizae. Some plants have an obligate association with the mycorrhizae. E.g. *Pinus* seeds cannot germinate and establish without mycorrhizae.

Water Movement up a Plant

Water moves up a stem against gravity. So it needs energy.

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.**
- It helps to push up water to small heights in the stem.

Experiment to prove existence of root pressure:

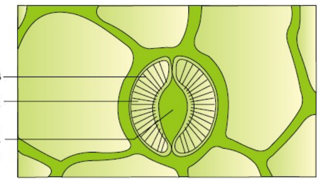
- During early morning, having atmospheric moisture, cut a soft plant stem horizontally near the base. Drops of solution ooze out of the cut stem. This is due to the positive root pressure.
- At night and early morning evaporation is low. So excess water collects in the form of droplets around special openings of veins near the tip of grass blades, and leaves of many herbaceous parts. Such water loss in liquid phase is called **guttation**.
- Root pressure can only provide a modest push in the water transport. They have no major role in water movement up tall trees. Root pressure re-establishes the continuous chains of water molecules in the xylem which often break under the tensions created by transpiration.
- In most plants, majority of water transport occurs by transpiration pull.

Transpiration pull

- In plants, the water flow upward through the xylem achieves high rates (up to 15 m /hr).
- Water is mainly pulled through the plant due to **transpiration pull.** It is a driving force due to transpiration. This is known as **cohesion-tension-transpiration pull model** of water transport.

TRANSPIRATION

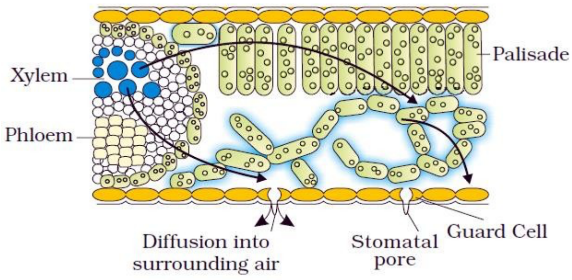
- It is the evaporative loss of water by plants through the **stomata** in the leaves.
- Less than 1% of the water reaching the leaves is used in photosynthesis and plant growth. The remaining is lost by transpiration.
- Transpiration can be studied using **cobalt chloride paper.** It turns colour on absorbing water.
- During transpiration, exchange of O_2 & CO_2 in the leaf also occurs.
- Stomata are open in the day time and close during night.
- Opening or closing of the stomata is due to change in the turgidity of the **guard cells**.



- The inner wall of guard cell lining **stomatal aperture** is thick and elastic and the outer wall is thin.
- When turgidity of guard cells increases, the outer walls bulge out and pull the inner walls into a crescent shape.
- Cellulose microfibrils in the guard cells are oriented radially rather than longitudinally making it easier for the stoma to open.
- The guard cells lose turgidity due to water loss (or water stress) and the inner walls regain their original shape. As a result, the stoma closes.
- Usually lower surface of a dicot leaf has more stomata. In monocot leaf, they are about equal on both surfaces.

Factors affecting transpiration:

- **External factors:** Temperature, light, humidity, wind etc.
- **Plant factors:** Number & distribution of stomata, number of stomata open, water status of plant, canopy structure etc.
- The transpiration-driven ascent of xylem sap depends on the following physical properties of water:
  - **Cohesion:** Mutual attraction between water molecules.
  - **Adhesion:** Attraction of water molecules to polar surfaces (e.g. surface of tracheary elements).
  - **Surface Tension:** Water molecules are more attracted to each other in liquid phase than in gas phase.
- These properties give water high **tensile strength** (ability to resist a pulling force) and **capillarity** (ability to rise in thin tubes). Capillarity is aided by small diameter of the tracheary elements – **tracheids** & **vessel elements**.
- Xylem vessels supply the water from the root to leaf vein. There is a continuous thin film of water over the cells. So as water evaporates through the stomata, water pulls into the leaf from the xylem. Concentration of water vapour in the atmosphere is lower than that in substomatal cavity and intercellular spaces. This also helps water to diffuse into the surrounding air. This creates a 'pull'.
- The forces generated by transpiration can create pressures to lift a xylem sized column of water over 130 m high.



Water movement in the leaf

Transpiration & Photosynthesis – a Compromise

- Photosynthesis is limited by available water which is swiftly depleted by transpiration.
- The humidity of rainforests is mainly due to the cycling of water from root to leaf to atmosphere and back to the soil.
- The evolution of C_4 photosynthetic system is a strategy to maximise the availability of CO_2 and minimise water loss.
- C_4 plants are twice as efficient as C_3 plants in fixing carbon (making sugar). However, C_4 plants lose only half as much water as a C_3 plant for the same amount of CO_2 fixed.

Uses of Transpiration:

- Creates transpiration pull for absorption and transport.
- Supplies water for photosynthesis.
- Transports minerals from soil to all parts of the plant.
- Cools leaf surfaces, sometimes 10 - 15°, by evaporation.
- Maintains shape & structure of plants by keeping cells turgid.

UPTAKE AND TRANSPORT OF MINERAL NUTRIENTS

Uptake of Mineral Ions

- Most minerals are **actively absorbed** by the roots because
  (i) Minerals occur in the soil as charged particles (ions) which cannot move across cell membranes.
  (ii) Concentration of minerals in the soil is lower than that in the root.
- Active uptake of ions is partly responsible for the water potential gradient in roots, and therefore for the uptake of water by osmosis.
- Some ions are absorbed passively.
- The specific membrane proteins of root hair cells actively pump ions from the soil into the epidermal cells.
- Endodermal cell membrane also has transport proteins. They allow only some solutes to cross the membrane. These proteins are control points, where a plant adjusts quantity and types of solutes that reach the xylem.
- The **suberin** in the root endodermis allows the active transport of ions in one direction only.

Translocation of Mineral Ions

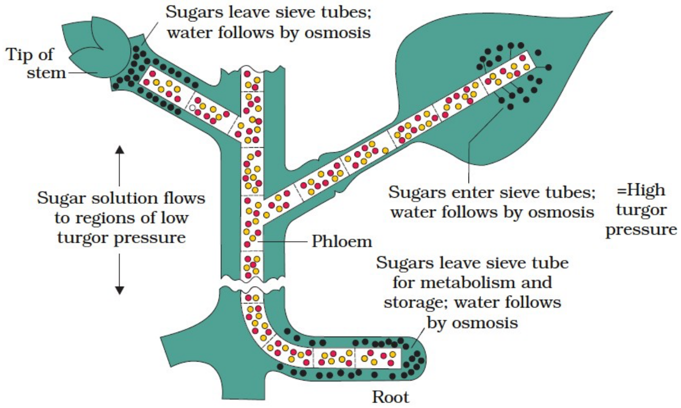
- The ions reached in xylem are further transported to all parts of the plant through the transpiration stream.
- The chief sinks for the mineral elements are
  - Growing regions such as apical and lateral meristems.
  - Young leaves.
  - Developing flowers, fruits and seeds.
  - Storage organs.
- Unloading of mineral ions occurs at the fine vein endings through diffusion and active uptake by these cells.
- Mineral ions are also remobilized, particularly from older, senescing parts (e.g. older dying leaves) to younger leaves.
- Elements most readily mobilized are phosphorus, sulphur, nitrogen and potassium. Some elements that are structural components like calcium are not remobilized.
- Nitrogen is mainly carried in organic forms such as amino acids & related compounds. Some travels as inorganic ions. Some P and S are also carried as organic compounds. There is also exchange of materials between xylem and phloem. So we cannot clearly say that xylem transports only inorganic nutrients while phloem transports only organic materials.

PHLOEM TRANSPORT: FLOW FROM SOURCE TO SINK

- It is the long-distance movement of organic substances (food, primarily sucrose) from a **source** (region of synthesis the food i.e., leaf) to a **sink** (region of storage or utilization of food) through the phloem.
- The source and sink may be reversed depending on the season or the plant's needs. E.g. In early spring, the sugar stored in roots is moved to the tree buds for growth and development of photosynthetic apparatus. Thus root becomes the source and buds the sink.
- The direction of movement in the phloem can be upwards or downwards, **(bi-directional).** In xylem, the movement is always upwards **(unidirectional).** Hence, food in phloem sap can be transported in any direction.
- Phloem sap is mainly **water and sucrose,** but other sugars, hormones and amino acids are also translocated.

The Pressure Flow (Mass Flow) Hypothesis

- It is the hypothesis that explains the mechanism of translocation of sugar (phloem transport).
- The glucose prepared at the source (by photosynthesis) is converted to **sucrose** (a disaccharide).
- Sucrose is moved into the **companion cells** and then into the living **phloem sieve tube** by **active transport (loading).** It produces a hypertonic condition in phloem (water potential decreases). Sieve tube cells form long columns with holes in **sieve plates.** Cytoplasmic strands pass through these holes forming continuous filaments.
- Water in the adjacent xylem moves into the phloem by **osmosis.** As **osmotic pressure/hydrostatic pressure** builds up, the phloem sap moves to areas of lower osmotic pressure (sink).



Diagrammatic presentation of mechanism of translocation

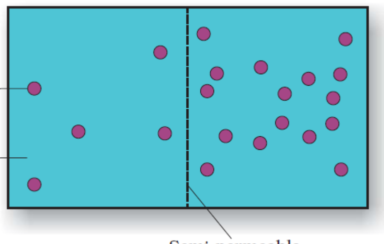
- The sucrose from the phloem sap actively moves into the cells. The cells convert the sugar into energy, starch, or cellulose (complex carbohydrates).
- As sugars are removed, osmotic pressure decreases (water potential increases) and water moves out of the phloem.

Identification of the tissue that transports food (girdling)

- Carefully remove a ring of bark (including phloem layer) from a tree trunk.
- After a few weeks, the portion of the bark above the ring on the stem becomes swollen. This is due to the absence of downward movement of food.
- This shows that phloem is responsible for translocation of food; and that transport takes place in one direction, i.e., towards the roots.

MODEL QUESTIONS

1. Study the figure and answer the following questions.



   a. Solution of which chamber has a lower water potential?
   b. Solution of which chamber has a lower solute potential?
   c. In which direction will osmosis occur?
   d. Which solution has a higher solute potential?
   e. At equilibrium which chamber will have lower water potential?
   f. If one chamber has a Ψ of – 2000 kPa, and the other – 1000 kPa, which is the chamber that has the higher Ψ?
2. Differentiate between
   a. Simple diffusion and facilitated diffusion
   b. Apoplast pathway and symplast pathway
   c. Uniport and symport
   d. Osmosis and imbibition
   e. Guttation and transpiration
3. Xylem transport is unidirectional and phloem transport is bidirectional. Give reason.
4. "Unlike water, all minerals cannot be passively absorbed by roots". Write any two reasons to justify the above statement.
5. Proteins in the membrane are responsible for facilitated diffusion and active transport and henece both show common characteristics. List any two such characteristics.
6. Match the following:

	A	B
a.	Apoplast	Phloem transport
b.	Transpiration	Semipermeable membrane
c.	Mass flow hypothesis	Cell wall
d.	Osmosis	Stomata