Transport in Plants

Means of Transport

Transport in Plants

- Short distance transport: By diffusion and cytoplasmic streaming, supplemented by active transport

- Long distance transport: Translocation (occurs through vascular system)

- Transport of water and minerals through the xylem: Unidirectional

- Transport of organic and mineral nutrients through the phloem: Multidirectional

Need of Water and Minerals for Plants

- Water is an essential requirement for sustaining life of all the living organisms, including plants. In plants, water is needed for four main purposes:
- **Photosynthesis** : Water is used as raw material for photosynthesis.
- **Transpiration** : To maintain the temperature of plants, water is needed.
- **Transportation** : Various substances are transported inside the plants through water.
- **Mechanical stiffness** : Water provides turgidity to plant tissues.
- **Need of Minerals :** Minerals are needed as nutrients for the plants,
- They act as important constituents of the cell and its organelles.
- They are required for the synthesis of a variety of compounds and enzymes inside the cell.

Means of Transport

Three means of transport in plants:

- Diffusion

- Facilitated Diffusion

- Active Transport

Diffusion

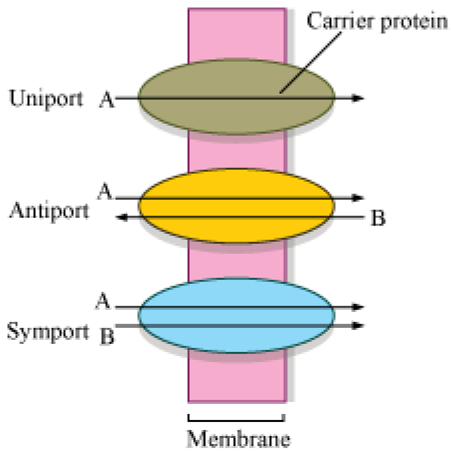
- An important means of transport inside the plant body

- Movement of molecules in a random manner, across the concentration gradient

- Slower process, involving no expenditure of energy
- Not dependent on the living system
- Depends upon:
- Concentration gradient
- Permeability of the membrane
- Temperature
- Pressure

Facilitated Transport

- Diffusion depends upon solubility in lipids. Therefore, substance having hydrophilic moiety finds it difficult to diffuse through the membrane. Hence, their movement has to be facilitated.
- In facilitated diffusion, the membrane proteins are involved. They provide a site for hydrophilic molecules to pass through the membrane.
- Concentration gradient is not provided through such proteins. It must already be present. In this case, no ATP (energy) expenditure is required.
- However, for diffusion against the concentration gradient, ATP expenditure is required.
- Proteins involved in the process form channels which may always be opened or controlled.
- Facilitated diffusion is very specific.
- Porins: Proteins that forms huge pores in the outer membranes of plastids, mitochondria, etc.
- Aquaporins: Proteins that facilitate diffusion of water molecules
- Some transport proteins allow diffusion only if two types of molecules move together (symport and antiport).



- Symport – both molecules move in the same direction
- Antiport – both molecules move in opposite directions
- Uniport – independent movement of molecules
- Maximum transport: When all proteins involved are saturated

Active transport

- Requires energy to pump molecules against the concentration gradient
- Requires special proteins which are very specific and sensitive to inhibitors
- Pumps proteins, using energy to transport substances through uphill transport
- Maximum transport: When all proteins involved are saturated
    - Comparison between simple diffusion, facilitated diffusion and active transport:

Characteristic	**Simple diffusion**	Facilitated
Requirement of special membrane proteins	×	√
Selectivity	×	√
Saturation of transport	×	√

Uphill transport	×	×
Requirement of ATP	×	×

Water Potential

Water Potential (ψ_W)

- Greater the concentration of water in a system, greater is its kinetic energy and greater is the water potential.
- Unit → Pascal (Pa)
- Symbol denomination – ψ_w
- If two systems are in contact, then there is movement of water from the solution with greater ψ_w to lower ψ_w.
- Solute potential (ψ_s) – Magnitude of lowering of water potential when a solute is added to the water
- Pressure Potential (ψ_p) – Magnitude of increase of water potential when pressure greater than atmospheric pressure is applied to pure water or a solution
- $\psi_w = \psi_s + \psi_p$
- ψ_w of pure water not under any pressure is zero.
  ψ_s is always negative and ψ_p is always positive.

Osmosis, Plasmolysis and Imbibition

Osmosis

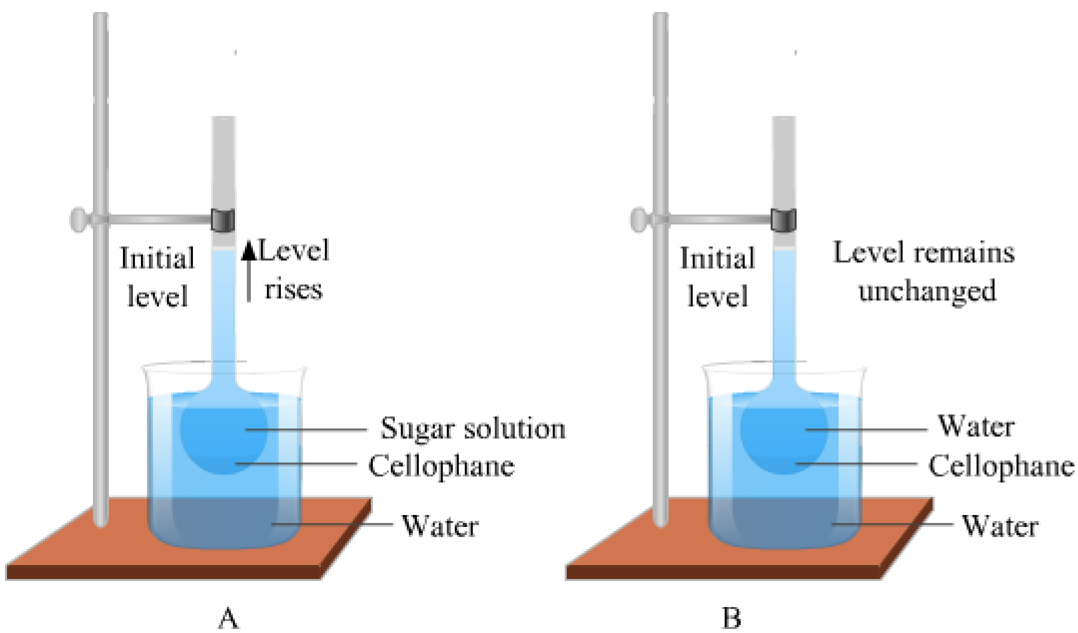
- It refers to the diffusion of water across a semi-permeable membrane.
- **Semi-permeable membrane** : It is a selectively-permeable membrane that allows only some substances to pass through it, hence, behaving as a barrier for different substances.
- Direction and rate of osmosis depends upon pressure gradient and concentration gradient.
- Water diffuses from its region of higher chemical potential to lower chemical potential until equilibrium is reached.
- Osmosis is of two types depending on concentration of solution around the cell.

- **Endosmosis**: It is the inward flow of water through a semi-permeable membrane when the surrounding solution is less concentrated. This causes swelling of the cell.
- **Exosmosis**: It is the outward flow of water through a semi-permeable membrane when the surrounding solution is more concentrated, resulting in shrinking of cell.

An Experiment to Understand Osmosis

Take some concentrated sugar solution inside a thistle funnel (say A). Using a cellophane paper cover its mouth and tie it securely. Take some water in a beaker; invert the funnel A and suspend it into the beaker. Mark the level of sugar solution in thistle funnel. Take another thistle funnel (say B) and repeat the same procedure with water solution inside the thistle funnel.

- After few hours, we will observe that:
- The level of sugar solution has increased in funnel A.
- The level of water solution is same in funnel B.
- The level of water in the beaker has decreased in which funnel A was suspended.
- When the water of beaker with sugar solution is tasted, it does not taste sweet.



Conclusions:

- Some water has passed through the cellophane paper to enter the funnel A.
- Sugar from thistle funnel A has not passed to the beaker.
- The cellophane paper acts as a semi-permeable membrane and allows only water to pass through, not sugar.
- This happens because of difference in concentration.

- **Osmotic pressure** – External pressure applied to prevent the diffusion of water
  It depends upon solute concentration.
  Osmotic pressure ∝ Solute concentration

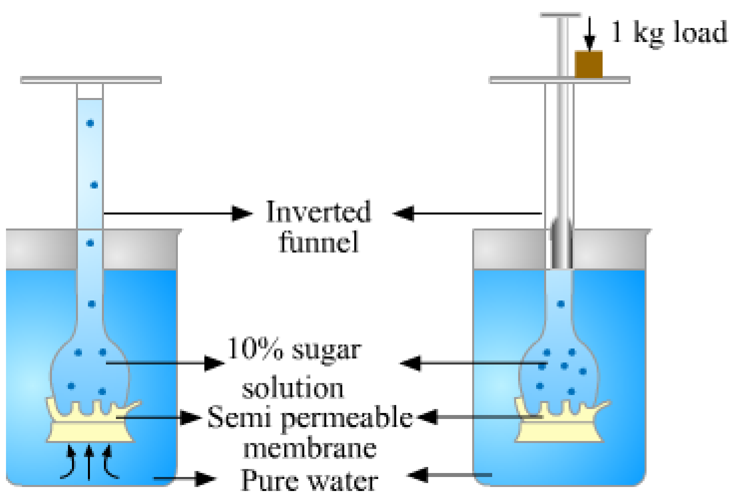
- Numerically: osmotic pressure = osmotic potential

- Osmotic pressure has positive sign.
- Osmotic potential has negative sign

An Experiment to Understand Osmotic Pressure

Take a thistle funnel containing sugar solution and place an airtight piston bearing some weight on its one end. Cover the other end with a cellophane paper and suspend it into a beaker containing water. Leave it undisturbed for a few hours.

After few hours, you will see that no change has occurred this time. Osmosis did not take place. This is all because of the Osmotic pressure applied by the piston which did not allow the water to pass through as it built pressure on the funnel.



Conclusion:

- Osmotic pressure does not allow osmosis to take place.

Tonicity

It is the relative concentration of solution and its surroundings to find the direction and extent of diffusion performed by the solution.

Behaviour of Plant Cell Depending Upon the Surrounding Solution

1. **Isotonic solution**

1. When concentration of external solution = Concentration in cytoplasm

2. No change in cell size

2. **Hypotonic solution**

1. When concentration of external solution < Concentration in cytoplasm

2. Cells swell.

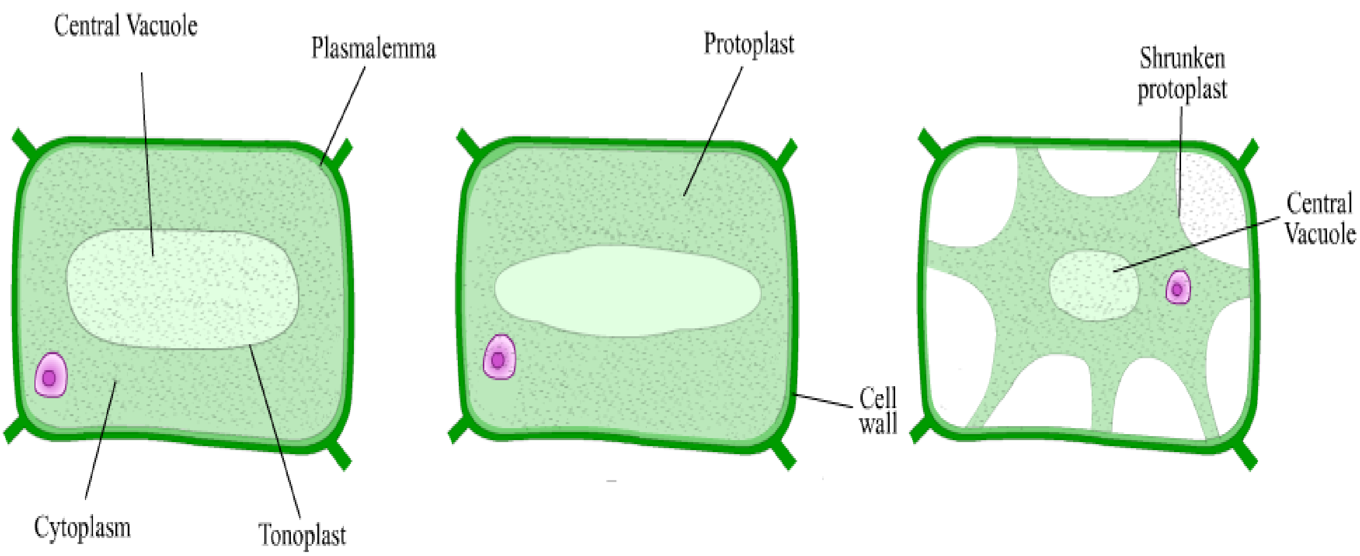
3. **Hypertonic solution**

1. When concentration of external solutions > Concentration in cytoplasm

2. Cells shrink

Plasmolysis

- It occurs when cell is placed in hypertonic solution.
- Water moves out, first from cytoplasm and then from vacuole.
- Cell membrane shrinks away from the cell wall.
- This phenomena of shrinkage of plasma membrane from cell wall is called plasmolysis.
- The cells in this state are called **flaccid** and this condition of cells is called **flaccidity.**



Deplasmolysis

- It refers to reversal of plasmolysis by placing the flaccid cells in water.
- If not dead, the protoplasm will absorb water
- The cells will thus return to their original state.

In isotonic solution, water flowing into the cell = water flowing out of the cell.

In hypotonic solution, water diffuses into the cells and cells enlarge and extension growth of cells occurs.

As water diffuses in, cytoplasm builds up a pressure against the cell wall. This pressure is called **turgor pressure**.

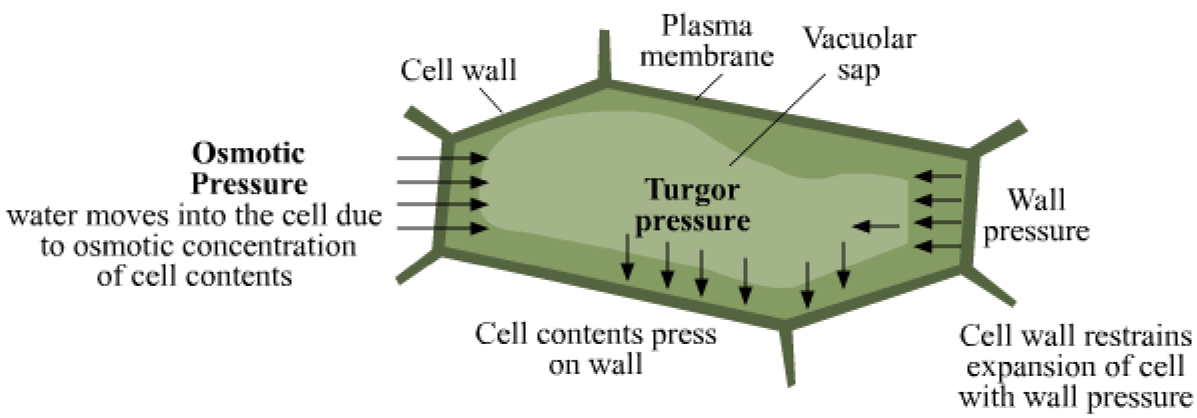
Because of rigidity of cell wall, the cell does not rupture but enlarges.

Turgid : When the cell cannot accommodate any more water, it is referred as a **turgid** cell and this condition is called **turgidity.**

Uses of Turgidity

- Provides rigidity to soft tissues
- Helps plant growth in hard ground
- Builds root pressure
- Helps in opening and closing of stomata
- Promotes turgor movement

Wall pressure: The pressure exerted by the cell wall on the contents of the cell.



A plant cell showing osmotic pressure, turgor pressure and wall pressure represented together

Imbibition

- Diffusion in which water is absorbed by solids i.e. colloids, causing them to enormously increase in volume
- Substances are absorbed without forming a solution.
- Diffusion is along the concentration gradient and depends upon affinity between adsorbent and liquid being adsorbed.

  Example – Imbibition of water by seeds that causes seedling to emerge out of soil

Difference between Diffusion and Osmosis

Diffusion	Osmosis
It refers to the movement of substances from higher concentration to lower concentration.	It refers to the movement of water through a semi-permeable membrane.
It may occur in any medium.	It occurs in liquid medium.
It helps in equalising the concentration in the available space.	It does not equalise the concentration of solvent on either sides.
It does not depend on solute potential	It depends on the solute potential.

Mechanism of Water Absorption by Plants

Long Distance Transport of Water

- Diffusion: Slow process and cannot account for the transport of molecules in a 10-m-tall tree
- Mass flow system:
- Movement of water, minerals and food in bulk from one part to the other in a plant
- Results due to pressure difference between two points (either positive hydrostatic pressure gradient or negative)
- Translocation: Bulk flow through conducting or vascular tissues of plants
- Conducting tissues – 2 types

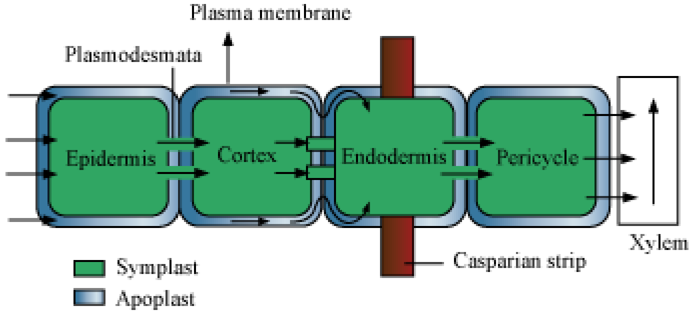
Xylem	**Phloem**

Transports water, salts, nitrogen and hormones	Transports organic and inorganic solutes
From roots to the other parts – unidirectional	From the source to the sink – multidirectional

Absorption of Water by Plants

- Water is absorbed through roots by diffusion.
- Root hairs (slender, thin-walled extensions of root epidermal cells) increase the surface area for absorption.
- Once absorbed by root hairs, water moves into deeper layers by 2 pathways – Apoplast Pathway or Symplast Pathway.

Apoplast Pathway	**Symplast Pathway**
Apoplast is a system of adjacent cell walls that are continuous, except at the casparian strips of the endodermis.	Symplast is a system of interconnected protoplasts.
Movement occurs through these intercellular spaces or walls of the cells, without entering the cytoplasm.	Water enters the cell through the cell membrane and travels intracellularly through plasmodesmata.
As water evaporates into the atmosphere, tension develops in the continuous stream of water in Apoplast, and mass flow occurs due to adhesive and cohesive properties.	The movement may be aided by cytoplasmic streaming.
Movement is fast.	Movement is slow as water has to enter the cell.
Most of the water flow in roots occurs via apoplast, except at the casparian strip.	At the casparian strip region, water moves through the symplast.



- Some additional structures may also be associated with plants for water absorption.
  E.g.
  Mycorrhiza – symbiotic fungus living with the roots of higher plants.
  Hyphae provide a large surface area for absorption of molecules. In return, the fungus gets sugar and nitrogen-containing compounds from the roots.
  Pinus shows an obligate association with mycorrhiza.

Water Movement up in a Plant

As the water is absorbed by the roots from the soil and moved to the vascular system, it has to be transported to various parts of the plant.

Two forces responsible for transporting the water up in a plant are root pressure and transpiration pull.

Root Pressure

- Positive pressure created inside the xylem when water follows the ions transported along the concentration gradients into the vascular system

- Guttation – Loss of water in its liquid phase from special openings near tip of grass blades and leaves of herbaceous plants
  This is an effect of root pressure and is observable at night and early morning when rate of transpiration is low.

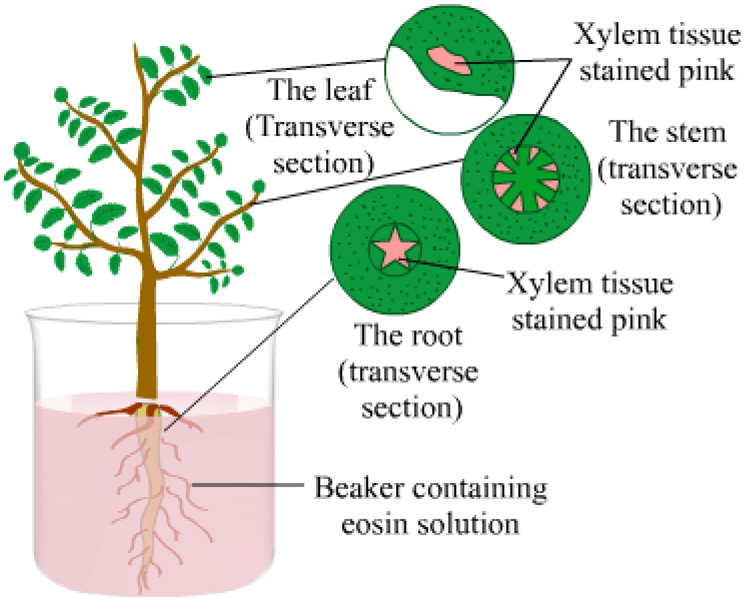
- Does not account for majority of water transport
  It works to re-form the broken chains of water molecules in xylem that may break under enormous tension created by transpiration.

  Majority of water is transported through transpiration pull.

An experiment to show that water is conducted upwards through xylem:

Take a medium sized Balsam plant. Wash it and place in a beaker containing a pink coloured stain, called eosin solution in water. Submerge the roots completely in the solution. Leave it undisturbed for 4-5 hours .

After 4-5 hours, take out the plant from the solution and wash it thoroughly. After that, make transverse sections of root, leaf and stem and examine them under the microscope. In all of the sections, xylems vessels will be stained red by the dye and thus will appear distinct from rest of the tissues.



Conclusion:

- Water and salt are transported from the roots to the other parts of a plant through xylem.

Transpiration pull

- Pull of water as a result of tension created by transpiration is the major driving force of water movement upwards in a plant. (cohesion – tension – transpiration pull)
- Transpiration accounts for loss of 99% of water taken by the plant. Loss is mainly through stomata.
- 3 physical properties of water affect the ascent of xylem sap due to transpiration pull.
- *Cohesion* – Mutual attraction between water molecules
- *Adhesion* – Attraction of water molecules to polar surface (xylem cell wall surfaces)
- *Surface tension* – Attraction of water to each other in liquid phase to a greater extent than to water in gaseous phase
- These properties give water high tensile strength and high capillarity.

- *Tensile strength* – Ability to resist pulling force

- *Capillarity* – Ability to rise in thin tubes (Aided by small diameter of tracheary elements such as tracheids and vessel elements)

Transpiration and Its Types

Transpiration
The loss of water in the form of water vapours from the leaves and aerial parts of plant is called transpiration.

Types of Transpiration

- Stomatal transpiration- Occurs through stomata
- Cuticular transpiration- Occurs through surface of stem and leaves
- Lenticular transpiration- Occurs through lenticels

Occurs mainly through openings called **stomata**.

Stomata are the minute openings found in the epidermal layer of the leaves. A stoma is surrounded by two bean shaped guard cells which regulate its opening and closing.

Stomatal Transpiration

In plants, water is absorbed through the roots, This absorbed water has to be transported throughout the plant's body for various physiological functions. It rises up in the stem through xylem and reaches the tissues of leaves through veins. The mesophyll cells of the leaves have their surfaces exposed to the intercellular spaces. Some amount of water forms a thin layer over these surfaces. The water from this film gets evaporated and form water vapours. These water vapours can diffuse through the intercellular space and reach the sub stomatal space and finally escape through stomata.

Regulation of Stomatal Transpiration

- Stomata:

- Open in the day and close during the night

- Also contribute in the exchange of O_2 and CO_2

- Opening and closing of stomata is influenced by the turgidity of the guard cells.

- Inner walls of the guard cells (towards stomatal opening): Thick and elastic

- When turgidity increases within two guard cells flanking each stomatal pore, the thin outer walls bulge out, and the inner walls assume a crescent shape.
- Radial orientation of microfibrils in the cell wall of the guard cells makes it easier for the stoma to open.
- When turgidity decreases within the guard cells, the inner walls regain their original shape, the guard cells become flaccid and stoma closes.
- Based on the distribution of stomata, 2 types of leaves:
- Dorsiventral: More number of stomata on the lower surface of leaves; found in dicots.
- Isobilateral: Equal number of stomata on both sides of leaves; found in monocots.

Differences between Evaporation and Transpiration

Evaporation	Transpiration
Loss of water from surface of water bodies in the form of vapours	Loss of water from aerial parts of plants in the form of vapours
A fast process	A slow process
A physical change controlled by temperature and pressure	A partly physical and vital process controlled by internal and external factors of leaves

Uptake and Transport of Mineral Nutrients

Uptake of Mineral Nutrients

- Minerals are absorbed from the soil by active transport. They cannot follow passive transport unlike water mainly because of 2 factors.
- They are charged. Hence, they cannot cross the cell membranes.
- Concentration of minerals in soil < Concentration of minerals in roots Hence, concentration gradient is not present.
- Active transport generates water potential gradient in roots and this is responsible for uptake of water by osmosis. Some ions also move by passive transport.
- Certain proteins in the membranes of root hair cells actively pump ions from soil to cytoplasm of epidermal cells.

- For endodermal cells, because of the suberin layer, transport of ions occurs in one direction only. Transport proteins of endodermal cells act as control points that adjust the quantity and types of solutes that reach the xylem.

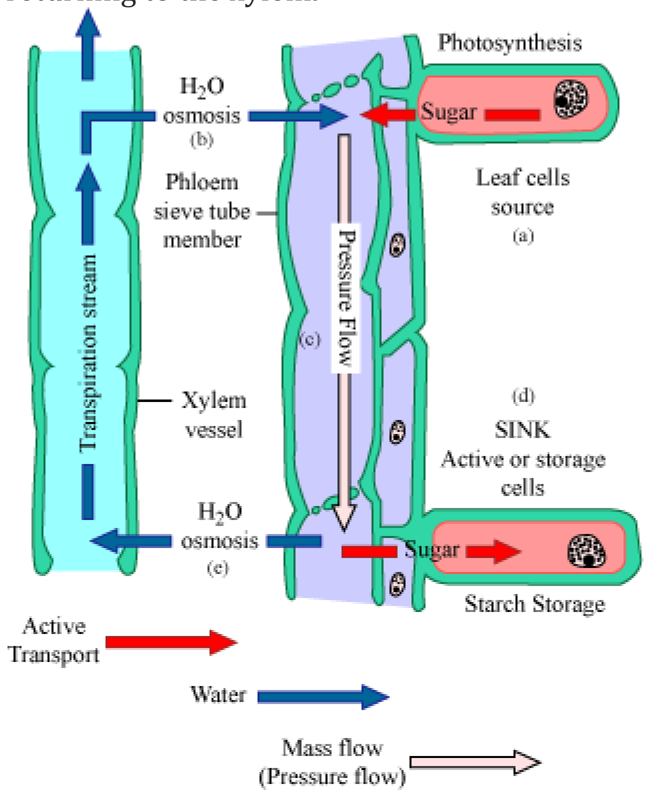
Transport of Mineral Nutrients

- After being up taken, the mineral nutrients are translocated through transpirational stream.
- Unloading of mineral ions occur at fine vein endings of the sink through diffusion.
- Some minerals are also remobilised from old senescing parts N, P K, S. Minerals forming structural components (example Ca) are not remobilised.
- Phloem transports food from source to sink, but this source-sink relationship is reversible depending upon the season. Therefore, phloem transport is bi-directional unlike unidirectional xylem transport.

Pressure Flow or Mass Flow Hypothesis

- This is the accepted mechanism used for translocation of sugars from the source to the sink.
- Source cell: Cells which are the supplier of the food material; mainly leaves
- Sink cell: Cells which require food material for growth and repair
- Glucose prepared at the source is converted into sucrose. Sucrose is moved to the companion cells, and then to the living phloem sieve tube cells by active transport. This process of loading creates a hypertonic condition in the phloem.
- Water in the adjacent xylem moves into the phloem by osmosis. Osmotic pressure builds phloem sap.
- As hydrostatic pressure on the phloem sieve tube increases, pressure flow begins and sap moves through the phloem.
- At the sink, incoming sugars are actively transported out of the phloem as complex carbohydrates.

- Loss of solute produces a high water potential in the phloem, and water passes out, returning to the xylem.



- Water moves up in the xylem due to transpiration pull.