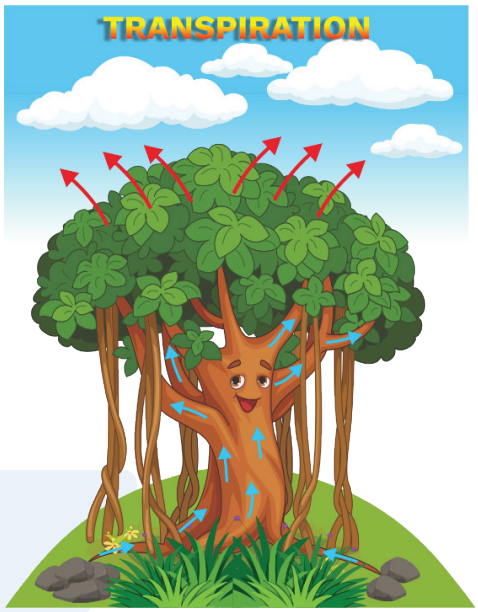
Transport in Plants

- Transport of water and various ions in plants occur over very long distances, from roots to the tips of growing stem (upward direction), with or without metabolic energy through complex plant tissue called **xylem**.
- The photosynthetic plants synthesise their food mainly in the green leaves. This food or photosynthates move to all parts of the plant through **phloem** tissue in upward, downward, and lateral direction (multidirectional transport).
- Transport of substances like mineral nutrients, organic nutrients, water, plant growth regulators, etc., also occurs within a plant cell and from one cell to the other by either simple diffusion or cytoplasmic streaming or through intercellular channels.
- Angiosperms (flowering plants), therefore, consist of a well organised, complex, continuous traffic of various substances moving in different directions in order to maintain their integrity.



Definition

Diffusion: The process of movement of substances down a concentration gradient without using energy.

MEANS OF TRANSPORT

Diffusion

- Diffusion is a **physical process** (independent of a living system) where solids, liquids or gases move **passively** (without energy expenditure) from a region of higher concentration to a region of lower concentration through the space available.
- In a plant, many substances move from one part of the cell to the other, or from cell to cell, or **over short distances** by the process of diffusion.
- Since diffusion is a **slow process**, the diffusing particles move slowly across a **concentration gradient** in a **random** fashion without any energy expenditure.
- **Different** types of **particles** can diffuse **simultaneously** through the same space.
- Carbon dioxide from the surrounding environment (produced as a by-product of respiration) is used for photosynthesis in the leaves, during which oxygen is also released. This short-distance

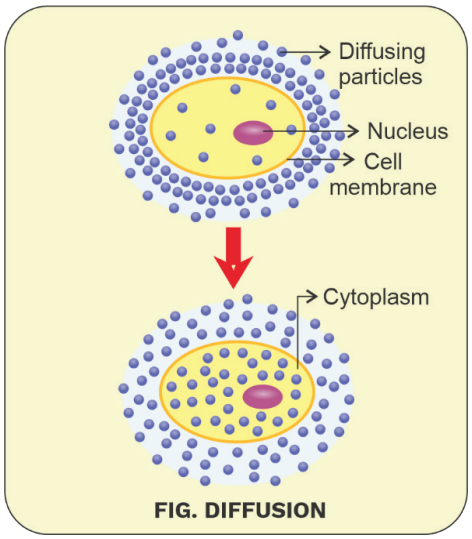


FIG. DIFFUSION

gaseous movement of carbon dioxide and oxygen within the plant parts and between the plant and its environment occurs solely by diffusion.

- Rate of diffusion of different substances is affected by:
  - the concentration gradient of the diffusing particles
  - the membrane permeability through which the diffusing particles move
  - size of the diffusing particles (smaller substances diffuse faster)
  - temperature
  - pressure

Facilitated Diffusion

- Since the biological membranes are made of a lipid bilayer, the substances which are highly soluble in lipids (**hydrophobic**) can easily diffuse through a cell membrane along an already existing concentration gradient.
- Contrary to this movement, **hydrophilic** substances cannot pass through a biological membrane mainly due to the polar nature of water, thus their movement **along a concentration gradient** is facilitated by certain **membrane proteins**, a process called facilitated diffusion.
- Facilitated diffusion of specific substances occurs through special proteins present in the plant cell membrane **without** expenditure of **ATP** energy from a high concentration area of the substances in consideration to a low concentration area.
- Membrane proteins are **highly specific** for a specific molecule to be diffused. This property of membrane proteins allows the cell to selectively uptake and release substances across its membrane according to its requirements.
- Rate of transportation of a specific diffusing particle will reach a maximum when all the transport proteins are used up (saturated), thus **showing saturation effect.**

Definitions

Hydrophobic: Water-repelling property or no affinity for water.
Hydrophilic: Water-attracting property or having an affinity for water.

Gray Matter Alert!!!

Two hydrogen atoms and one oxygen atom of a water molecule are bound together by polar covalent bonds. The attractive property or polarity of water is due to the presence of a slightly negative charge on oxygen atom and a slightly positive charge on hydrogen due to electron loving nature of oxygen atom.

Rack Your Brain

Why are polar molecules attracted by water as compared to lipid molecules?

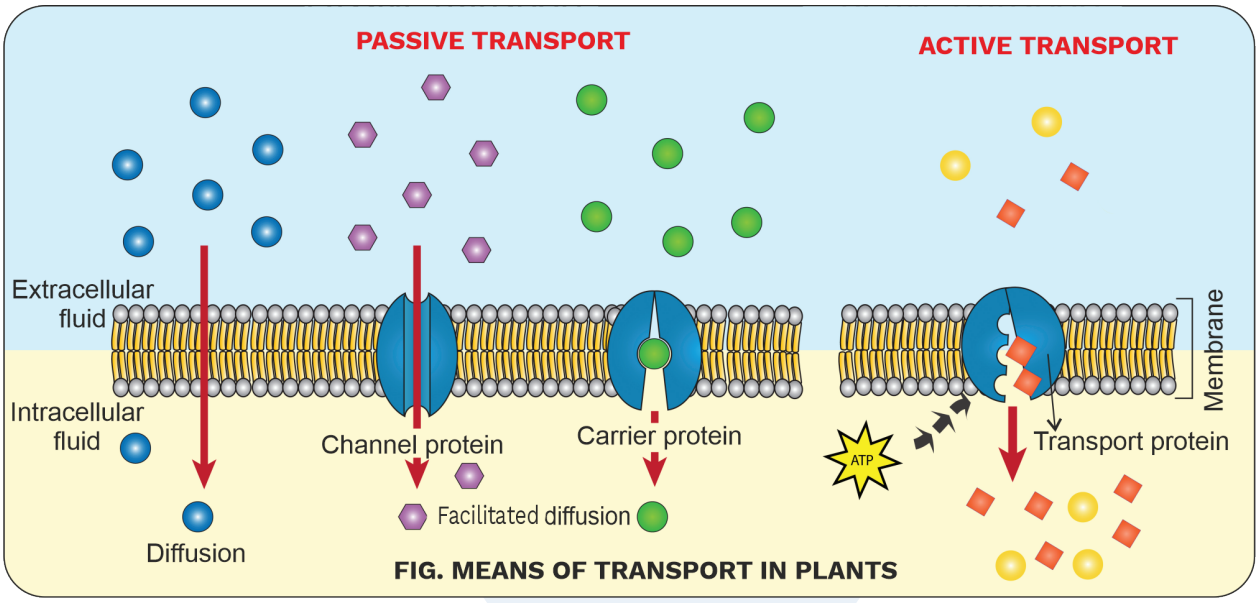


FIG. MEANS OF TRANSPORT IN PLANTS

- Facilitated diffusion is **sensitive** to **inhibitors** of the membrane proteins.
- The membrane proteins form channels for molecules to pass through. Some of these channels are always open; others can be controlled.
- For example, **porins** are large membrane proteins present in the outer membranes of the plastids, mitochondria, and some bacteria through which many molecules equivalent to the size of small proteins can pass.
- **Aquaporins** or water channels are membrane proteins for passive transport of water and water-soluble substances. There are **eight** different types of aquaporins recorded.
- There are two major types of membrane proteins:
  - **Carrier proteins** (carriers or transporters): They bind to a specific diffusing particle and deliver it to the other side of the membrane.
  - **Channel proteins**: They allow passive diffusion of specific particles of an appropriate size through them.

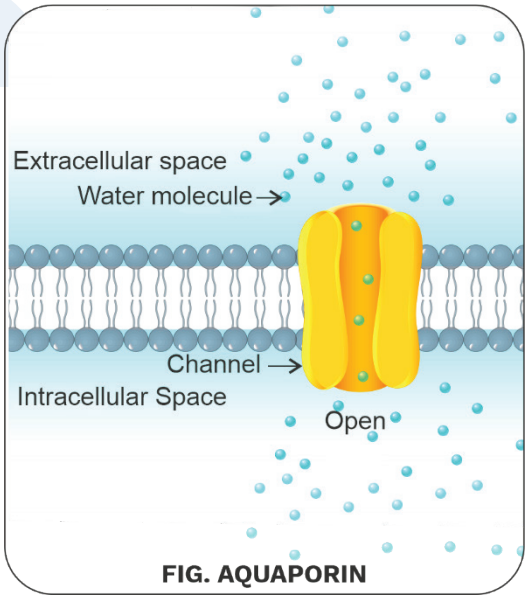


FIG. AQUAPORIN

- Some carrier proteins allow movement of a molecule across a membrane independent of other molecules, the process is called **uniport** whereas some allow movement only if two types of molecules move together through them simultaneously. This is called **cotransport**.
- Cotransport is of two types:
  - In a **symport**, both molecules cross the membrane in the same direction at the same time.
  - In an **antiport**, both molecules cross the membrane in opposite directions simultaneously.

Rack Your Brain

Do membrane proteins set up a concentration gradient for diffusion of hydrophilic molecules through them?

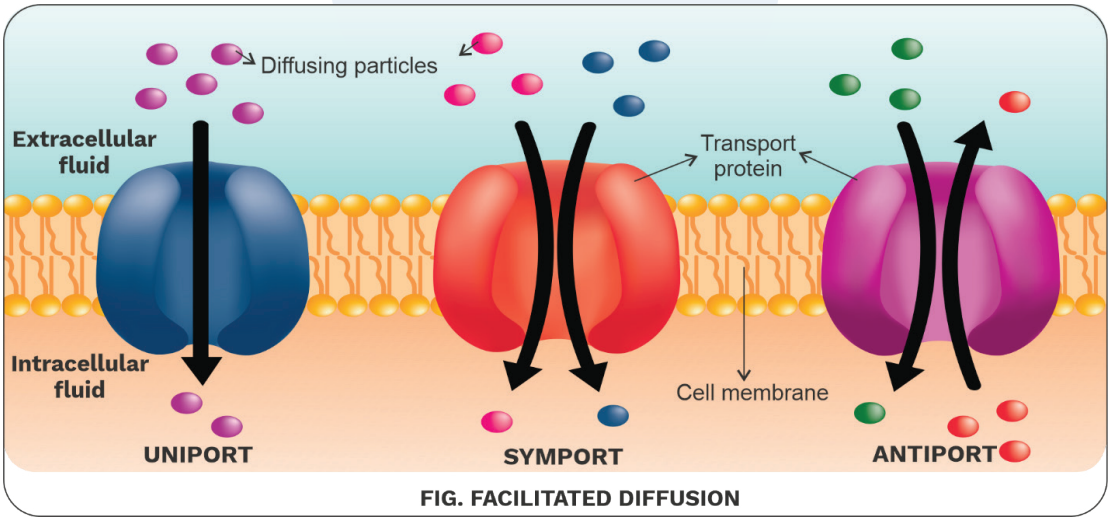


FIG. FACILITATED DIFFUSION

Active Transport

- Many substances are moved (pumped) across a biological membrane through carrier membrane proteins by **utilising energy** from ATP **against** a **concentration gradient**. This is called active transport.
- Carrier proteins used in active transport are called **pumps**. They are **highly specific** and **sensitive** to inhibitors that react with protein side chains.
- These pumps use energy to carry substances across the cell membrane from a lower concentration to a higher concentration (**uphill transport**). They also exhibit **saturation effect**.

Previous Year's Question

Which of the following is not a feature of active transport of solute in plants?

(1) occurs against concentration gradient
(2) non-selective
(3) occurs through membrane
(4) requires ATP

- Active transport is **faster** than the passive transport (diffusion or facilitated diffusion).
- Membrane proteins responsible for both facilitated diffusion and active transport are under hormonal regulation.

A Comparison of Different Transport Processes

PLANT-WATER RELATIONS

- According to the theories of origin of life on Earth, life originated in water. Thus, **water** is a major component of a living cell.

Rack Your Brain

Does a dormant seed also contain water?

- Substances involved in all the metabolic reactions occurring in a living cell (protoplasm) are present (dissolved) in a water **medium**. Water is, therefore, essential for all physiological activities of the plant.
- On an average, the water content in a watermelon is over **92 per cent**. Most herbaceous plants have about **85 to 90 per cent** water in them (approximately **10 to 15 per cent** of their fresh weight is dry matter).
- The roots of terrestrial plants perform uptake of large quantities of water on a daily basis. This water travels along the entire length of the plants through xylem tissue but most of it is lost to the surrounding air in vapour form from the stomata of the leaves (**transpiration**).
- About **three litres** of water is absorbed by a mature **corn plant** in a day, while a **mustard plant** absorbs water equal to its own weight in about **5 hours**.

Water Potential

- Water molecules in a liquid or gaseous state are in constant and rapid random motion. Thus, these water molecules possess kinetic energy. The measure of this energy possessed by the water molecules is its **water potential** or **chemical potential**.
- The greater the concentration of water in a system, the greater is its water potential. Hence, **pure water** has the **greatest water potential** as compared to a solution.
- Water potential is denoted by the Greek symbol **Psi** or Ψ **(Ψw)** and is expressed in pascals (Pa), bars or atmospheres.
- Chemical potential or water potential of pure water at normal pressure and temperature is **zero**.
- The water potential of a **solution** will always be **negative** (less than zero). This is because, in a

Gray Matter Alert!!!

Water is an important limiting factor for the growth and productivity of plants.

Definition

Water potential: The difference in the chemical potential per unit molal volume of water in a system and that of pure water at same temperature and pressure.

Previous Year's Question

The water potential of pure water at standard temperature is equal to
(1) 10
(2) 20
(3) Zero
(4) None of the above

solution, the amount of water molecules will be less than the number of molecules present in pure water due to the presence of solute particles.

- If two systems containing water are in contact, water molecules randomly move from the system with higher energy (higher water potential) to the one with lower energy (lower water potential), i.e., from less negative water potential to a more negative water potential.
- On addition of solute particles in pure water, its chemical potential or water potential will decrease. This decrease in the water potential of pure water due to addition of solute particles is called **solute potential** or **osmotic potential**.
- Solute potential is denoted by Ψs and it is always **negative**. The more the solute molecules, the lower (more negative) is the Ψs.
- Solute potential **does not** depend on the **nature** of the **solute particles**. It is a function of the number of solute particles in a solution.
- For a solution at atmospheric pressure,

(Water potential) $\Psi w = \Psi s$ (Solute potential)

- Water potential of pure water or any other solution will increase if a pressure greater than atmospheric pressure is applied.
- The pressure that develops in a plant cell due to entry or exit of water from it, due to diffusion, is called **pressure potential** or **hydrostatic potential**.
- **Increased pressure potential** or the pressure that the water (which enters a plant cell) builds up against the cell wall makes the cell **turgid**.
- Pressure potential is denoted by Ψp and is usually **positive**.
- Both solute potential and pressure potential affect the water potential of a cell as:

Gray Matter Alert!!!

Water moves from the soil into the plant root cells because the water potential of a plant cell is more negative than pure water.

Gray Matter Alert!!!

In terrestrial plants, the water column in the xylem consists of negative pressure potential. This is one of the reasons for water transport up a stem.

Rack Your Brain

Plant cell wall does not provide any barrier to movement of water and other substances. Why?

$$\Psi_w = \Psi_s + \Psi_p$$

Water potential = Solute potential + Pressure potential

Osmosis

- A plant cell controls movement of different molecules in and out of it because of the presence of a **selectively permeable cell membrane** as the cell wall of a plant cell is freely permeable to water and ions.
- Inside a plant cell, a large central vacuole is present which contains the **vacuolar sap** or **cell sap**. The vacuolar sap contains water, glucose, amino acids, salts, etc., which is responsible for the solute potential of a plant cell.
- The movement of molecules in and out of the central vacuole is controlled by its membrane called the **tonoplast**.
- The movement or diffusion of water molecules from a region of their higher chemical potential or water potential or concentration (as present in pure state of water or a dilute solution) to its lower chemical potential (as present in a solution or a stronger solution) without diffusion of any solute particle, by means of a differentially or selectively permeable membrane is called **osmosis**.
- A driving force produced by the development of concentration gradient of water molecules across a selectively permeable membrane is responsible for the spontaneous occurring of osmosis.
- The net direction and rate of osmosis are affected by both the **pressure gradient** and **concentration gradient**.
- Water will move from its region of higher chemical potential (or concentration) to its region of lower chemical potential until **equilibrium** is reached, e.g., in a potato osmometer, the cavity in the potato tuber containing a concentrated solution of sugar collects water due to osmosis.

Definition

Cell sap: The liquid present in the central vacuole of a plant cell.

Rack Your Brain

Name two components of a plant cell which are responsible for the movement of molecules across the cell.

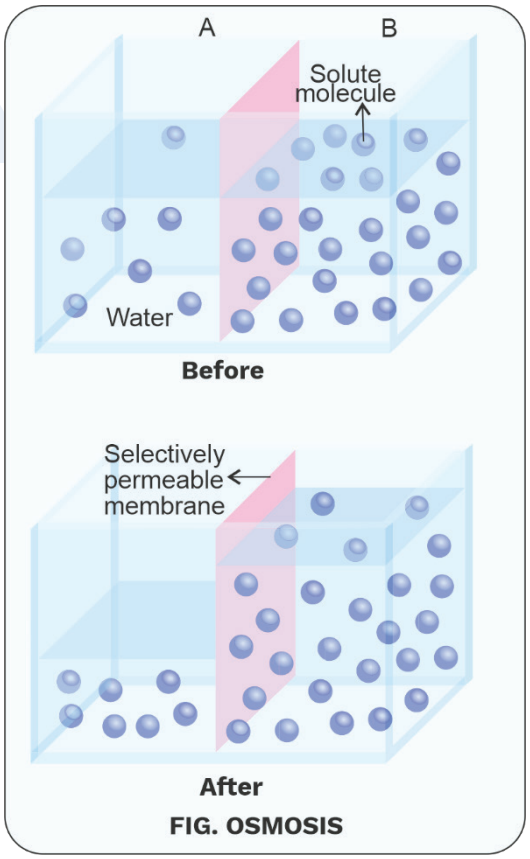


FIG. OSMOSIS

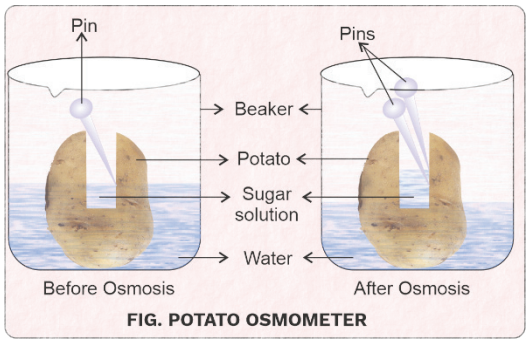


FIG. POTATO OSMOMETER

- The pressure required to completely prevent the entry of water into an osmotically active solution across a selectively permeable membrane is called **osmotic pressure**.
- Osmotic pressure is denoted by π (pi) and is measured in pascals, bars, or atmospheres.
- Osmotic pressure is numerically equivalent to osmotic potential (solute potential, Ψs) as it is the function of the solute concentration.
- Greater the solute concentration, greater will be the pressure required to prevent water from diffusing in.
- Osmotic pressure is the positive pressure applied; thus, it has a positive value as compared to the negative value of the osmotic potential.

(Osmotic potential) Ψs = - π (Osmotic pressure)

Plasmolysis

- Water from the surrounding solution moves into or out of a plant cell based on the **osmotic concentration** of the solution.
- The solution surrounding a plant cell can be **hypotonic**, **isotonic**, or **hypertonic** in comparison to the protoplasm of the plant cell.

Previous Year's Question

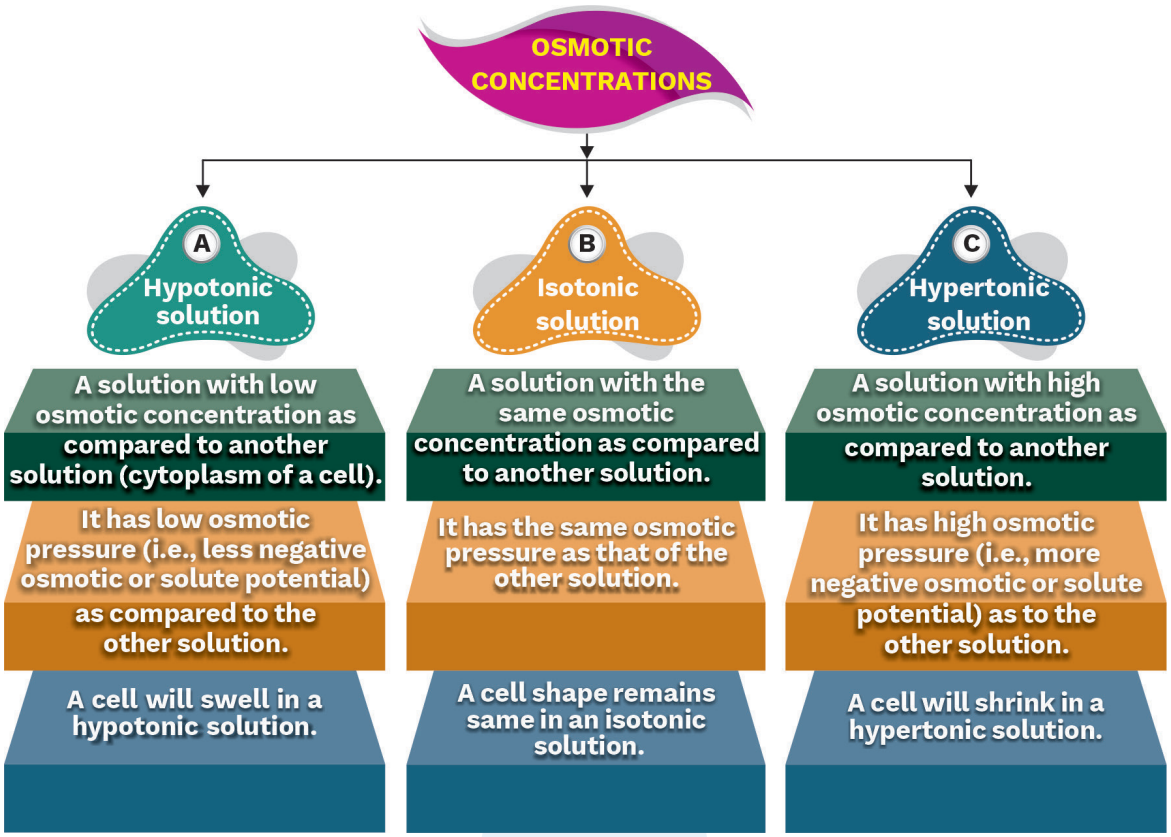
Which statement is correct?

(1) Osmotic pressure of solution is greater than pure solvent
(2) Osmotic pressure of solution is lower than the pure water
(3) Osmotic pressure of solution is equal to that of pure solvent
(4) None of these

Previous Year's Question

What will be the direction of flow of water when a plant cell is placed in a hypotonic solution?

(1) Water will flow in both directions
(2) Water will flow out of the cell
(3) Water will flow into the cell
(4) No flow of water in any direction



- **Plasmolysis** is the process of **shrinkage** of the **protoplast** or the living part of a plant cell (nucleus and the cytoplasm, surrounded by a cell membrane) from its cell wall due to diffusion of water out of the plant cell when it is placed in a **hypertonic** solution.
- The space between the cell wall and the shrunken protoplast in the plasmolysed cell is occupied by the hypertonic solution.
- The process of plasmolysis is usually **reversible**. If a plasmolysed cell is placed in a hypotonic, the water from the solution diffuses into the cell.
- This increase in the cytoplasm builds up a pressure called **turgor pressure** (pressure potential, Ψp) against the cell wall. The cell is said to be **turgid**.
- Enlargement and extension of plant cells occur due to this turgor pressure.

Previous Year's Question

A plasmolysed cell can be deplasmolysed by placing it in
(1) Isotonic solution
(2) Hypertonic solution
(3) Saturated solution
(4) Pure water or hypotonic solution

- The **pressure potential** (Ψp) or turgor pressure of a plant cell kept in an isotonic solution is **zero** as there is a continuous in and outflow of water (equilibrium attained) and so the protoplast does not exert any pressure against the cell wall. Such a cell is said to be **flaccid**.

Rack Your Brain

Does exosmosis occur during plasmolysis?

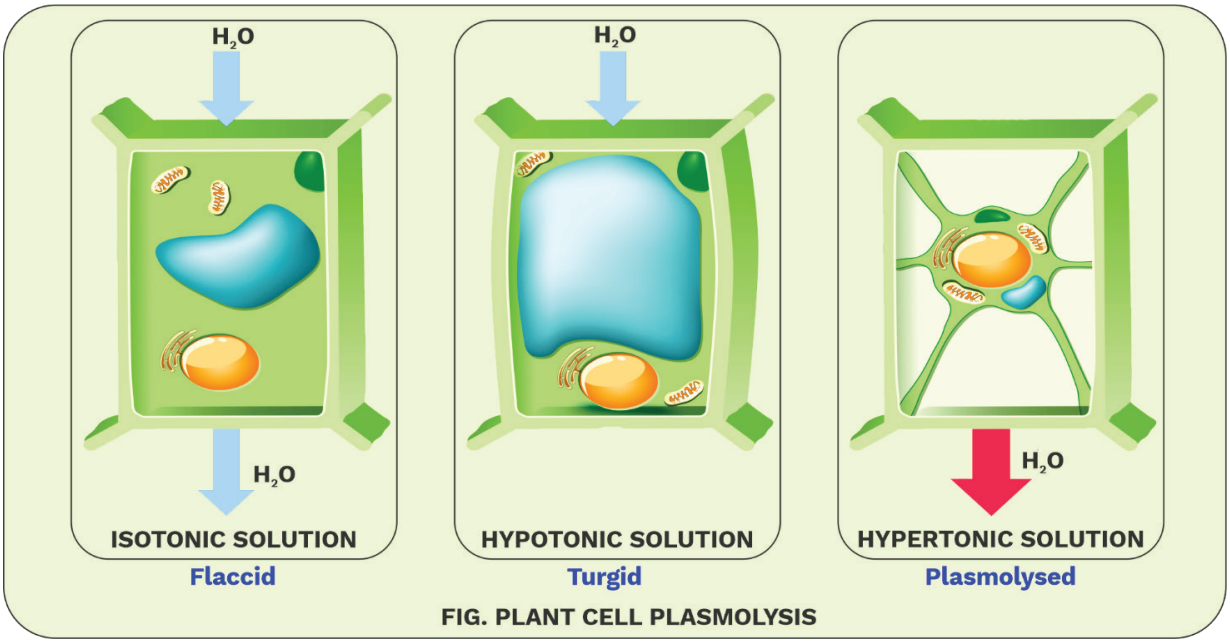


FIG. PLANT CELL PLASMOLYSIS

Imbibition

- Imbibition is a special type of **diffusion** in which water moves from a region of higher water potential and is absorbed by the solid particles of an adsorbent having a lower water potential, causing it to enormously increase in volume without forming a solution. **Seeds** and **dry wood** are examples of **imbibants**.
- The **imbibate** (water) is held in between the surface of solid particles of the adsorbent.
- The germinating seeds can emerge out of the soil due to the pressure that is produced by their swelling.
- Imbibition **depends** on **water potential gradient** between the adsorbent and the liquid (usually

Previous Year's Question

During rainy season, the doors get wet due to
(1) Imbibition
(2) Absorption
(3) Diffusion
(4) Endosmosis

water) imbibed and the **affinity** between the adsorbent and the liquid.

LONG DISTANCE TRANSPORT OF WATER

- Terrestrial plants require special long distance transport systems to move substances across long distances and at a much faster rate as it cannot be accomplished by a slow process like diffusion alone.
- Unlike diffusion, water and minerals, and food are generally swept along in a mass or bulk (**mass or bulk flow system**) from one region of plant to another due to the pressure differences between these regions.
- We can observe bulk flow through a **positive hydrostatic pressure gradient** like in a garden hose or through a **negative hydrostatic pressure gradient** during suction through a straw.
- **Translocation** is the movement of substances through the vascular tissues (xylem and phloem) of plants in a bulk flow or mass flow.
- **Xylem** translocates water, mineral salts, some organic nitrogen, and hormones, from roots to the aerial parts of the plants whereas **phloem** helps in translocation of a variety of organic and inorganic solutes, mainly from the leaves to other parts of the plants.

Absorption of Water by Plants

- Water and minerals present in between the soil particles initially enters in a plant root through millions of root hairs by simple diffusion.
- After entering in the root hairs, it moves deeper into root layers by:
  - apoplast pathway
  - symplast pathway

Rack Your Brain

Why does long-distance transport of water and other substances in a plant cannot be accomplished by diffusion?

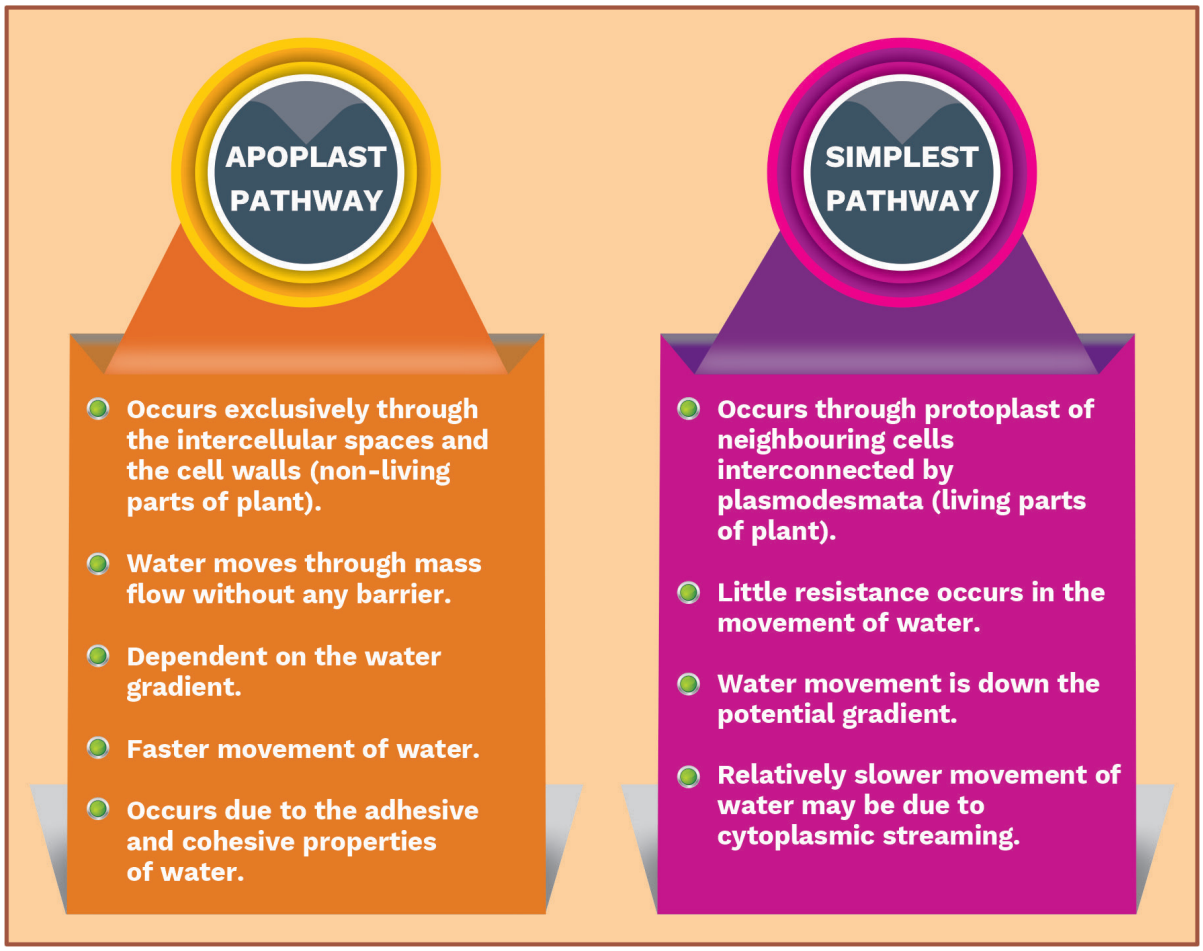
Previous Year's Question

Root system in a plant is well developed

(1) Due to deficiency of auxin
(2) Due to deficiency of cytokinins
(3) Due to deficiency of minerals
(4) For increased absorption of water

Definition

Root hair: Thin-walled slender extensions of some epidermal cells of plant roots which greatly increase the surface area for absorption of water and minerals.



- In **apoplast** pathway, the water moves along a system of adjacent **cell walls** that is continuous throughout the plant, except at the casparian strips of the endodermis in the roots.
- In **symplast** pathway, water moves through a system of protoplasts (**intercellular movement**) of various neighbouring cells which are connected through **plasmodesmata**.
- Mostly, water moves through the loosely packed **cortical cells** via **apoplast** pathway.

Previous Year's Question

Apoplastic movement of water in plants occurs through
(1) Casparian strips
(2) Plasma membrane
(3) Intracellular spaces
(4) Plasmodesmata

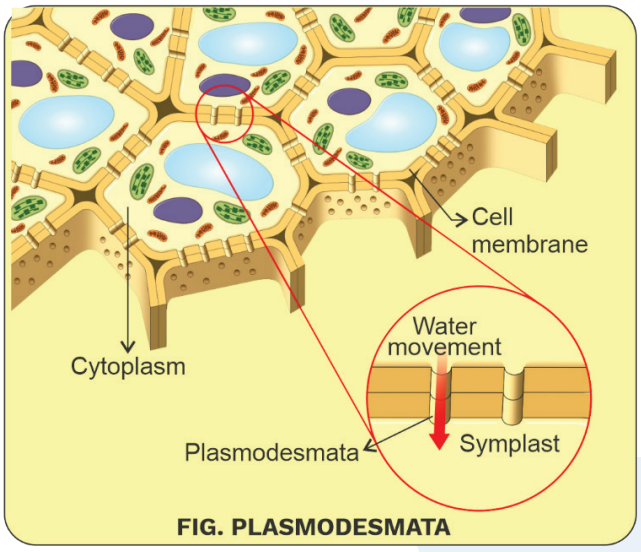


FIG. PLASMODESMATA

Definition

Plasmodesmata: Fine cytoplasmic channels between neighbouring plant cells which pass through the intervening cell walls and allow cell to cell communication.

- As the water reaches the endodermis, it travels via **symplast** pathway. This shift occurs due to the presence of an impermeable band of suberised matrix called the **casparian strip** in the **endodermis** of roots.
- The water finally moves in the xylem through symplast pathway.
- In certain plants, the roots are associated with fungal hyphae that aids in water and mineral absorption.
- A **mycorrhiza** is a symbiotic association of a fungus with a root system.

Gray Matter Alert!!!

In young roots, water diffuses directly into the xylem vessels and/or tracheids via the apoplast pathway mainly because xylem tissue is non-living.

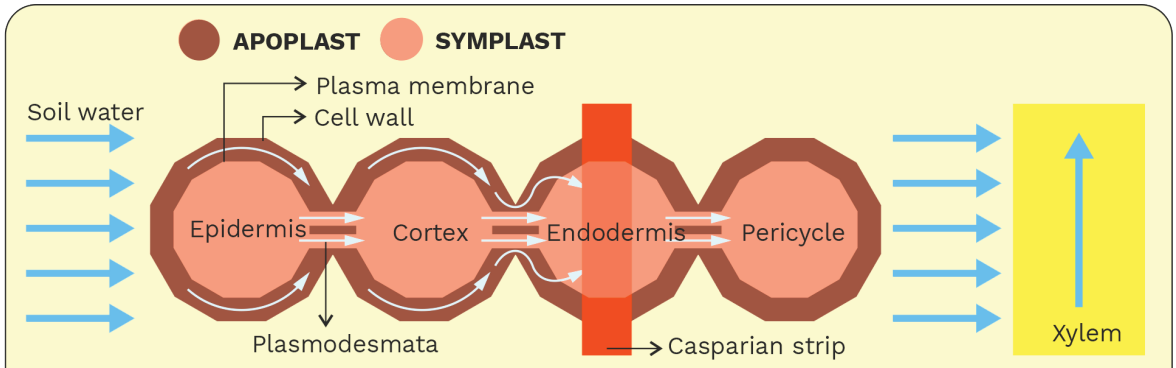


FIG. PATHWAYS OF WATER MOVEMENT IN THE ROOT

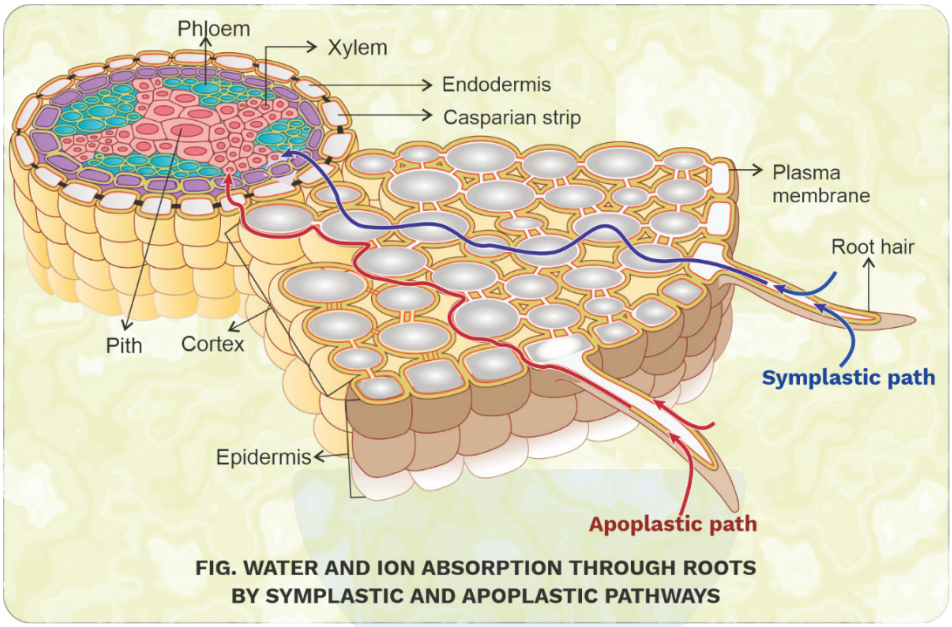


FIG. WATER AND ION ABSORPTION THROUGH ROOTS BY SYMPLASTIC AND APOPLASTIC PATHWAYS

- The fungal hyphae have large surface area through which water and minerals are absorbed and handed to the roots. In return, roots provide sugars and N-containing compounds to the fungus.
- Plants like *Pinus* have an obligate association with the mycorrhizae.

Movement of Water up a Plant (Translocation of Water)

- Once the water from the root hairs reaches the xylem, it moves upwards towards the tips of stem and leaves against the gravitational force. This process is called **ascent of sap**.
- The translocation of water and minerals (sap) through the xylem is brought about by root pressure (to a certain extent) and transpiration pull (majorly).

Root Pressure

- There is an increase in the osmotic potential of the sap present in the root xylem due to active

Previous Year's Question

Root pressure develops due to
(1) Active absorption
(2) Low osmotic potential in soil
(3) Passive absorption
(4) Increase in transpiration

Previous Year's Question

Root pressure is maximum when
(1) Transpiration is high and absorption is very low
(2) Transpiration is very low and absorption is high
(3) Transpiration is very high and absorption is also high
(4) Transpiration and absorption both are low

uptake of various ions from the soil.

- This causes the water to diffuse along its concentration gradient (water potential gradient) and increases the pressure inside the xylem.
- This positive pressure in the xylem of roots is called root pressure.
- It is responsible for moving water against the force of gravity up to small heights in the stem.
- At night and early morning since the rate of evaporation is low, excess water in the xylem collects in the form of droplets (under root pressure) around special openings of veins (called **hydathodes**) near the tip of grass blades and leaves of about 345 genera of marshy and mesophytic herbaceous plants.
- This loss of water in the form of droplets from the leaves is called **guttation**.

FIG. GUTTATION

Previous Year's Question

The pressure responsible for facilitating loss of water in liquid form from the tip of grass blades at night and early morning is

(1) Root pressure
(2) Imbibition
(3) Plasmolysis
(4) Transpiration

Transpiration pull

- In plants, water can move upwards through the xylem as a **continuous water column** at a rate of about **15 metres** per hour.
- But the water absorbed by the roots of a plant does not stay in it for a long time. Most of this water is lost to the surrounding through the stomata and only less than **1 per cent** of the water reaching the leaves is used in photosynthesis and plant growth.
- This loss of water in vapour form through the stomata of leaves is known as **transpiration**.

TRANSPIRATION

- Stomata are the main site for transpiration (stomatal transpiration) along with exchange of oxygen and carbon dioxide.
- Small amount of transpiration also occurs continuously (day and night) through the cuticle or epidermal cells of the leaves (**cuticular transpiration**), lenticels (**lenticular transpiration**), and through corky covering of stem, i.e., bark (**bark transpiration**).

Previous Year's Question

Transpiration and root pressure cause water to rise in plants by

(1) Pulling it upward
(2) Pulling and pushing it, respectively
(3) Pushing it upward
(4) Pushing and pulling it, respectively

- Stomata are tiny openings or pore complexes found in the epidermis of leaves and other soft aerial plant parts.
- Each **stoma** is surrounded by two guard cells which are connected with the adjacent epidermal cells through plasmodesmata.
- **Guard cells** consist of chloroplasts, small vacuoles, microbodies, etc. The inner wall of each guard cell, towards the pore or stomatal aperture, is **thick** and **elastic**. The cell wall of guard cells also contains **microfilaments** which are oriented specifically to help in stomatal opening and closing.
- Cellulose microfibrils are oriented **radially** rather than longitudinally for easier opening of the stoma.
- Normally, stomata open during the day and close during the night.
- Change in the turgidity of the guard cells is mainly responsible for the opening or closing of the stomata.

Gray Matter Alert!!!

Usually, a greater number of stomata occurs on the lower surface of a dorsiventral (often dicotyledonous) leaf, whereas in an isobilateral (often monocotyledonous) leaf they are about equal on both surfaces.

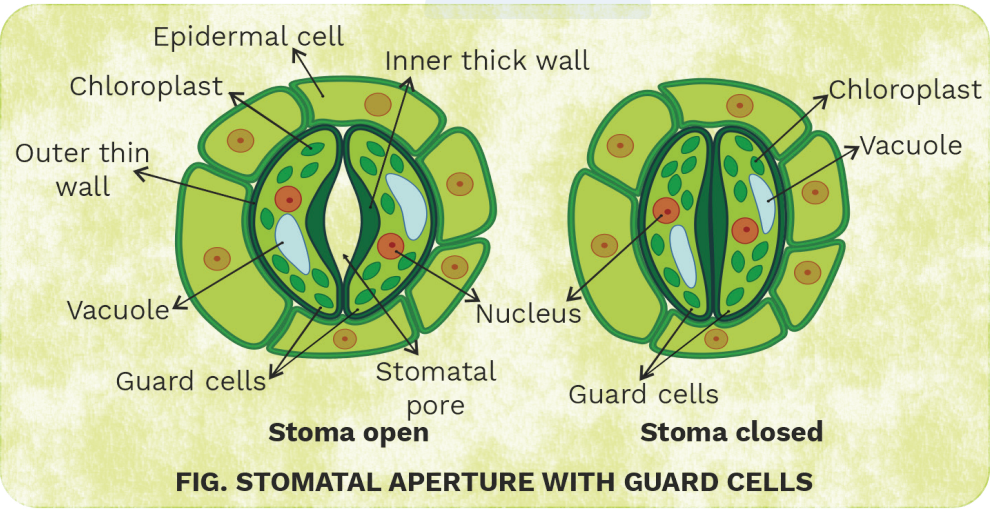


FIG. STOMATAL APERTURE WITH GUARD CELLS

- When **turgidity increases**, the **thin outer walls** bulge out and force the inner walls into a crescent shape.
- **Decreased turgidity** (due to water loss) causes the elastic inner walls to regain their **original shape**, thereby, making the guard cells **flaccid**. This **closes** the **stoma.**
- Light, temperature, atmospheric humidity, water availability, mechanical shock, CO_2 concentration, oxygen, pH, growth hormones, minerals, etc., are some of the factors that affect stomatal movement.
- Transpiration is affected by several external factors.
- Ascent of xylem sap through transpiration depends mainly on the three physical properties of water, i.e., cohesion, adhesion, and surface tension (**cohesion-tension-transpiration pull model of water transport**).

Previous Year's Question

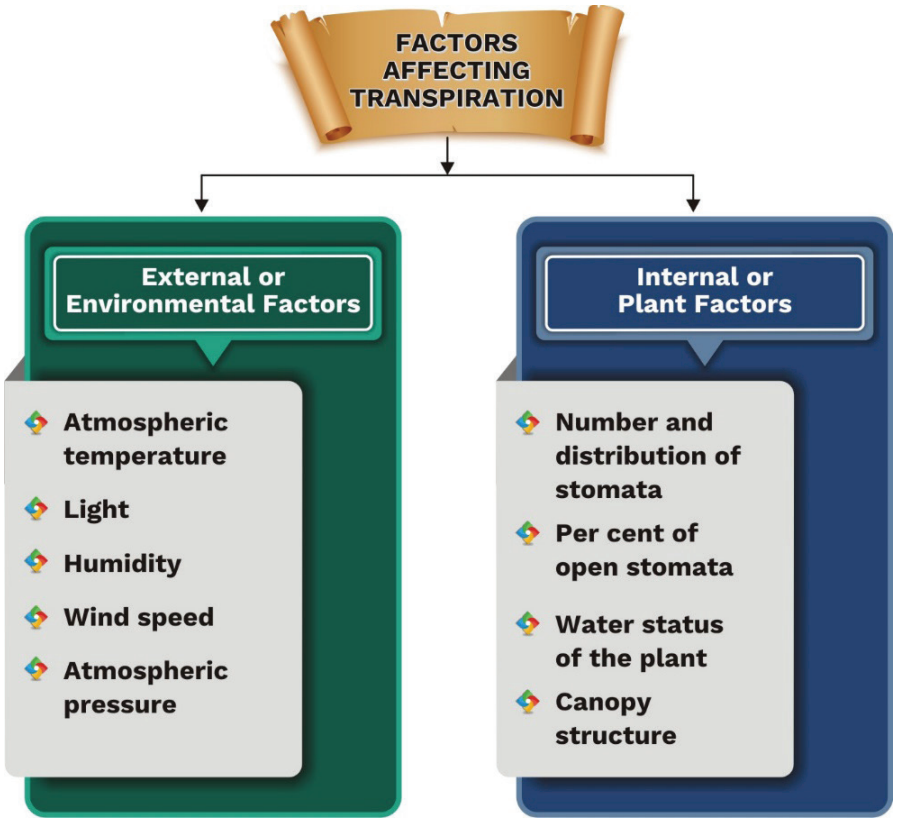
Which of the following facilitates opening of stomatal aperture?

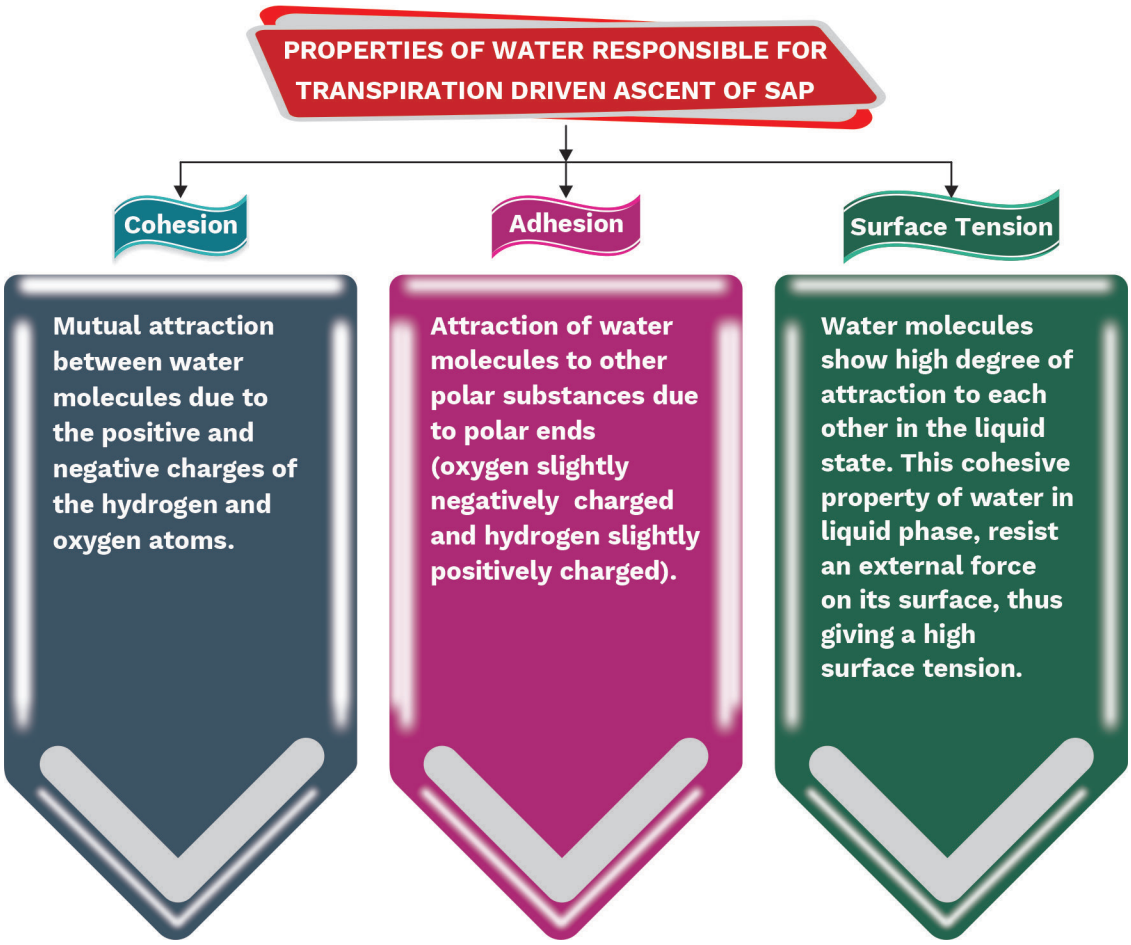
(1) Contraction of outer guard cells.

(2) Decrease in turgidity of guard cells.

(3) Radial orientation of cellulose microfibrils in the cell wall of guard cells.

(4) Longitudinal orientation of cellulose microfibrils in the cell wall of guard cells.





- These properties give water **high tensile strength**, i.e., the ability to resist a pulling force, and **high capillarity**, i.e., the ability to rise in thin tubes.

Development of Transpiration Pull

- Mesophyll cells in the leaves possess **water vapours** in the **intercellular spaces** between them.
- These intercellular spaces are exposed to the outside air through stomata.
- Since the atmospheric air has a lower water potential than that present inside the leaf, the **water vapours diffuse** out of the leaf along the water potential gradient through the **stomata**.
- As water evaporates through the stomata, since the thin film of water over the cells is continuous,

Previous Year's Question

The rupture and fractionation do not usually occur in the water column in vessel/tracheids during the ascent of sap because of

(1) lignified thick walls
(2) cohesion and adhesion
(3) weak gravitational pull
(4) transpiration pull

it results in **pulling of water**, molecule by molecule, into the leaf from the xylem (**tracheary elements**).

- The water column in the tracheary elements of the phloem comes under **tension**. This tension creates a passive **'pull'** called the transpiration pull under which the water column is pulled up to the top of the plant.
- Measurements reveal that the forces generated by transpiration can create tension sufficient to lift a water column to over **130 m**.

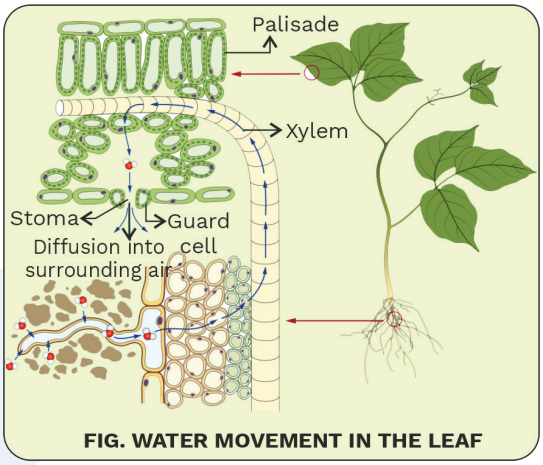


FIG. WATER MOVEMENT IN THE LEAF

Functions of Transpiration

1. Ascent of sap by transpiration pull for absorption & transport of substances
2. Removal of excess water
3. Provides H_2O for photosynthesis
4. Distribution of minerals in the plant
5. Evaporative cooling
6. Maintenance of the shape and structure of plant parts by keeping cells turgid.

Previous Year's Question

The force generated by transpiration can create pressure sufficient to lift water even uo to the height of

(1) 130 feet
(2) 130 metre
(3) 230 feet
(4) 230 metre

UPTAKE AND TRANSPORT OF MINERAL NUTRIENTS

Uptake of Mineral Ions

- Mineral ions are absorbed from the soil by both **passive** and **active** transport.
- Some mineral ions move into the epidermal cells passively along their concentration gradient while most minerals are actively absorbed at an expense of energy mainly because:
  - they are present in the soil as charged particles (ions) and thus cannot move across cell membranes.
  - the concentration of minerals in the root is usually higher than the concentration of minerals in the soil.
- This active transport of ions through specific **membrane protein channels** is partly responsible for the water potential gradient in roots and therefore causing **osmotic entry** of water in the roots.
- There is active transport of ions through the endodermis of roots in only **one direction** because of the suberin deposition.

Translocation of Mineral Ions

- Once the mineral ions reach the xylem, their further transport is accomplished through the transpiration stream.
- Plant utilises these minerals at the **growing regions** (e.g., apical and lateral meristems, young leaves, developing flowers, fruits and seeds) and **the storage areas**.
- The mineral ions are unloaded at the **fine vein endings** through diffusion and active uptake by the cells of the growing and storing regions.
- There is constant movement of minerals in a plant, especially from older, senescing parts to younger leaves.
- Some elements like **phosphorus, sulphur, nitrogen** and **potassium** are most readily **mobilised**, whereas **calcium** and other such elements that are structural components are **not remobilised**.

Previous Year's Question

Xylem translocates
(1) Water, mineral salts, some nitrogen and hormones
(2) Water only
(3) Water and mineral salts only
(4) Water, mineral and some organic nitrogen only

Gray Matter Alert!!!

Transport membrane proteins of endodermal cells act as check or control points, where the plant selectively allow the movement of different solutes.

Previous Year's Question

Which one of the following elements in plants is not remobilised?
(1) Calcium (2) Potassium
(3) Sulphur (4) Phosphorus

Rack Your Brain

Unlike traditional belief, why we cannot clearly categorise xylem as transporter of inorganic nutrients and phloem as transporter of organic nutrients?

- **Nitrogen** is carried through xylem as inorganic ions and transported through phloem in organic form as amino acids and related compounds. Also, some phosphorus and sulphur are carried as organic compounds.
- This shows that there is a small amount of exchange of materials that occurs between xylem and phloem.

PHLOEM TRANSPORT: FLOW FROM SOURCE TO SINK

- In plants, food (primarily sucrose) is transported by **phloem** from a **source** (region of manufacture or storage) to a **sink** (region of utilisation).
- Usually, the photosynthetic leaves act as the source.
- But the source and sink may be **reversed** depending on the need of the plant.
- Sugar stored in roots is moved to become a source of food in the early spring when the buds of trees, act as a sink; as they need energy for their growth and development.

Previous Year's Question

Select the incorrect statement.

(1) Transport of molecules in phloem can be bi-directional.

(2) The movement of minerals in the xylem is unidirectional.

(3) Unloading of sucrose at the sink does not involve the utilisation of ATP.

(4) Elements most easily mobilised in plants from one region to another are phosphorus, sulphur, nitrogen, and potassium.

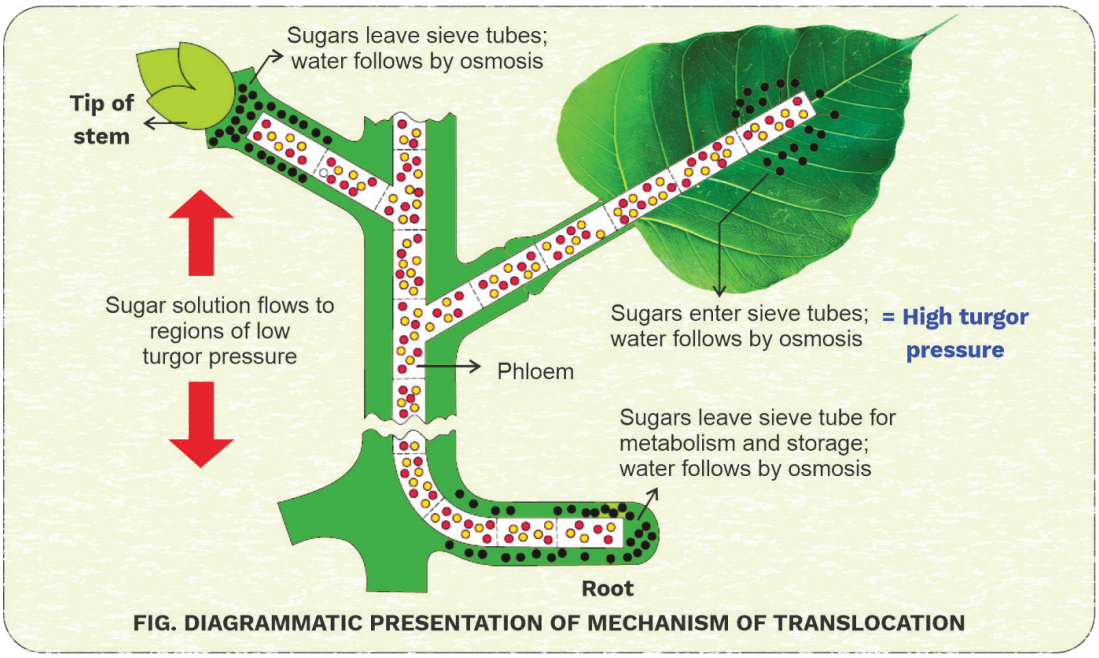


FIG. DIAGRAMMATIC PRESENTATION OF MECHANISM OF TRANSLOCATION

- The direction of movement of food in phloem is either upwards or downwards (**bi-directional**) based on the variable source-sink relationship, whereas the movement of sap is always upwards (**unidirectional**).
- Phloem sap consists of mainly water and sucrose, although other sugars, hormones and amino acids are also translocated.
- Translocation of organic solutes occurring through sieve tubes of phloem can be studied by performing **girdling** or **ringing** experiment.
- If a ring of bark is cut from a stem, the phloem is also removed. In the absence of downward movement of food, the nutrients collect above the ring, making this area swollen. Vigorous growth occurs along with growth of adventitious roots at this site.

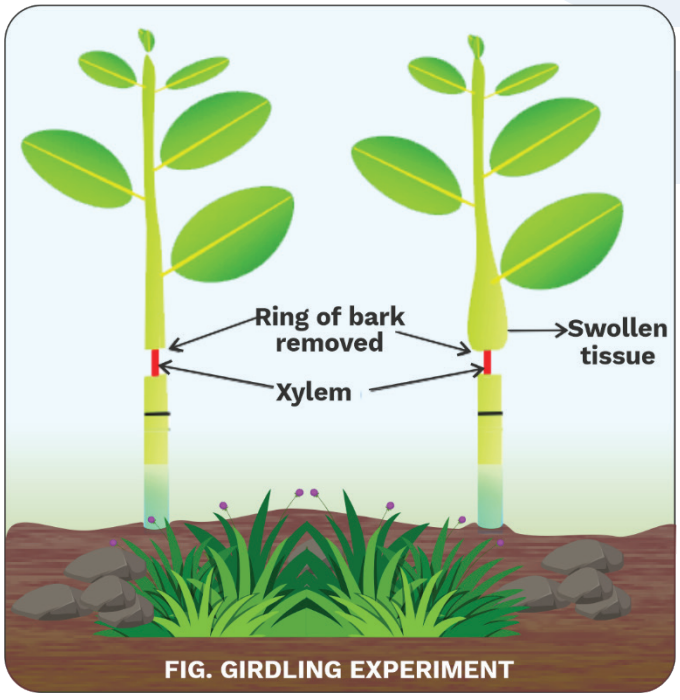


FIG. GIRDLING EXPERIMENT

- Contrary to this, the region below the ring showed stoppage of growth and began to shrivel, clearly indicating the movement of organic solutes occurs through the phloem.

Previous Year's Question

What is the direction of movement of sugars in phloem?
(1) Bi-directional
(2) Non-multidirectional
(3) Upward
(4) Downward

Previous Year's Question

In a ring girdled plant
(1) The shoot dies first
(2) The root dies first
(3) The shoot and root die together
(4) Neither root nor shoot will die

The Pressure Flow or Mass Flow Hypothesis

- The mechanism of translocation of sugars in phloem can be best explained by the pressure flow or mass flow hypothesis.
- The photosynthetic product, **glucose**, is first converted to **sucrose**. This is because sucrose is comparatively more stable than glucose as it does not have a **reducing end** and so it cannot react with other molecules during its transportation.
- Also, since sucrose is a **disaccharide**, it **stores more energy** than single residues of glucose (monosaccharide). Sucrose is **soluble** to several molar concentrations in water, making it an excellent candidate for translocation.
- From **leaves**, sucrose moves into the **companion cells** and then into the living phloem **sieve tube cells** by **active transport**.
- This sucrose loading generates a **hypertonic** condition in the phloem (more sucrose or solute particles as compared to water molecules).
- Thus, mass **water diffusion** occurs into the phloem from the adjacent xylem along the water potential gradient (osmosis).
- Phloem tissue is composed of sieve tube cells, which form long columns with holes in their end walls called sieve plates through which cytoplasmic strands from adjacent cells pass.
- As osmotic pressure (negative osmotic potential) builds up or hydrostatic pressure decreases, the phloem sap moves through phloem to regions of lower pressure (sink).
- At the sink, incoming sucrose actively moves out of the phloem sap and enters cells for its metabolisation.
- Because of this sucrose removal, the osmotic pressure decreases (water potential increases) in the phloem, causing the water to return to the adjacent xylem.

Previous Year's Question

The translocation of organic solutes in sieve tube members is supported by

(1) Root pressure and transpiration pull
(2) P-proteins
(3) Mass flow involving a carrier and ATP
(4) cytoplasmic streaming

Previous Year's Question

Which of the following is not correct in mass flow hypothesis?

(1) As hydrostatic pressure in the phloem sieve tube increases pressure flow stops and sap is accumulated in phloem.
(2) The sugar is moved bi-directionally.
(3) The sugar which is transported is sucrose.
(4) Loading of the phloem sets up a water potential gradient that facilitates the mass movement in the phloem.

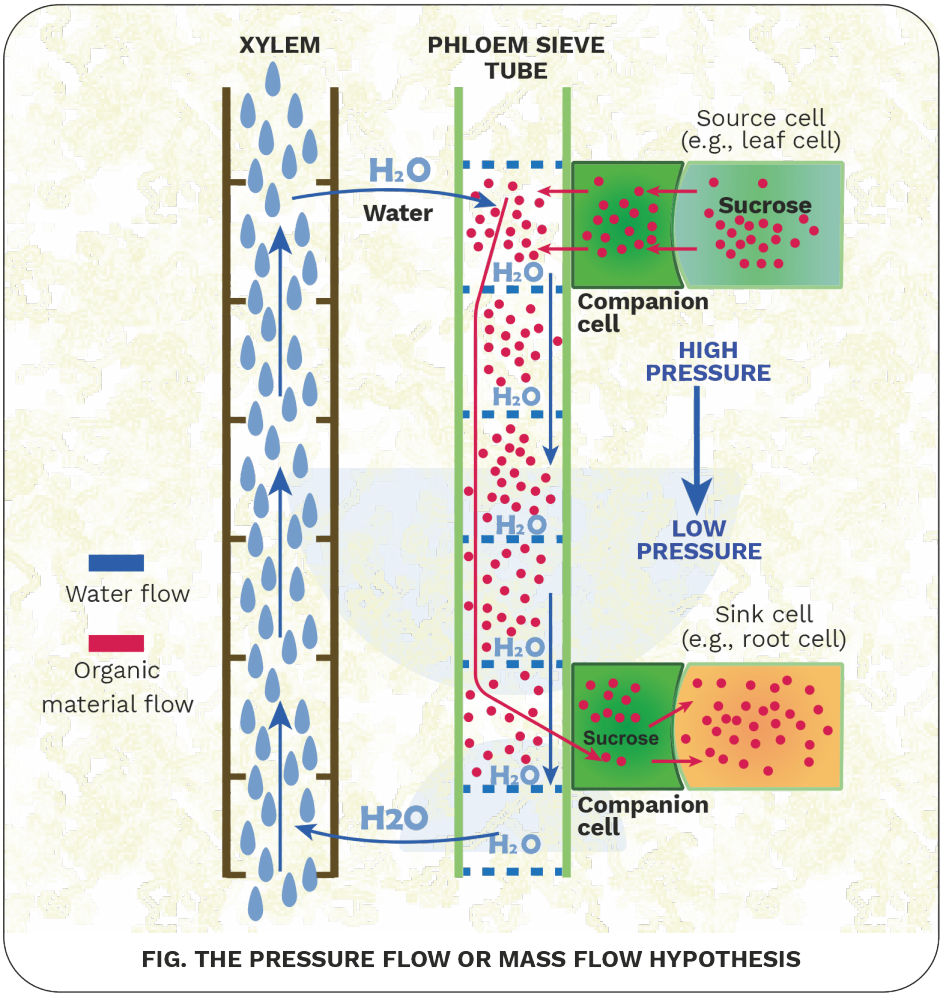
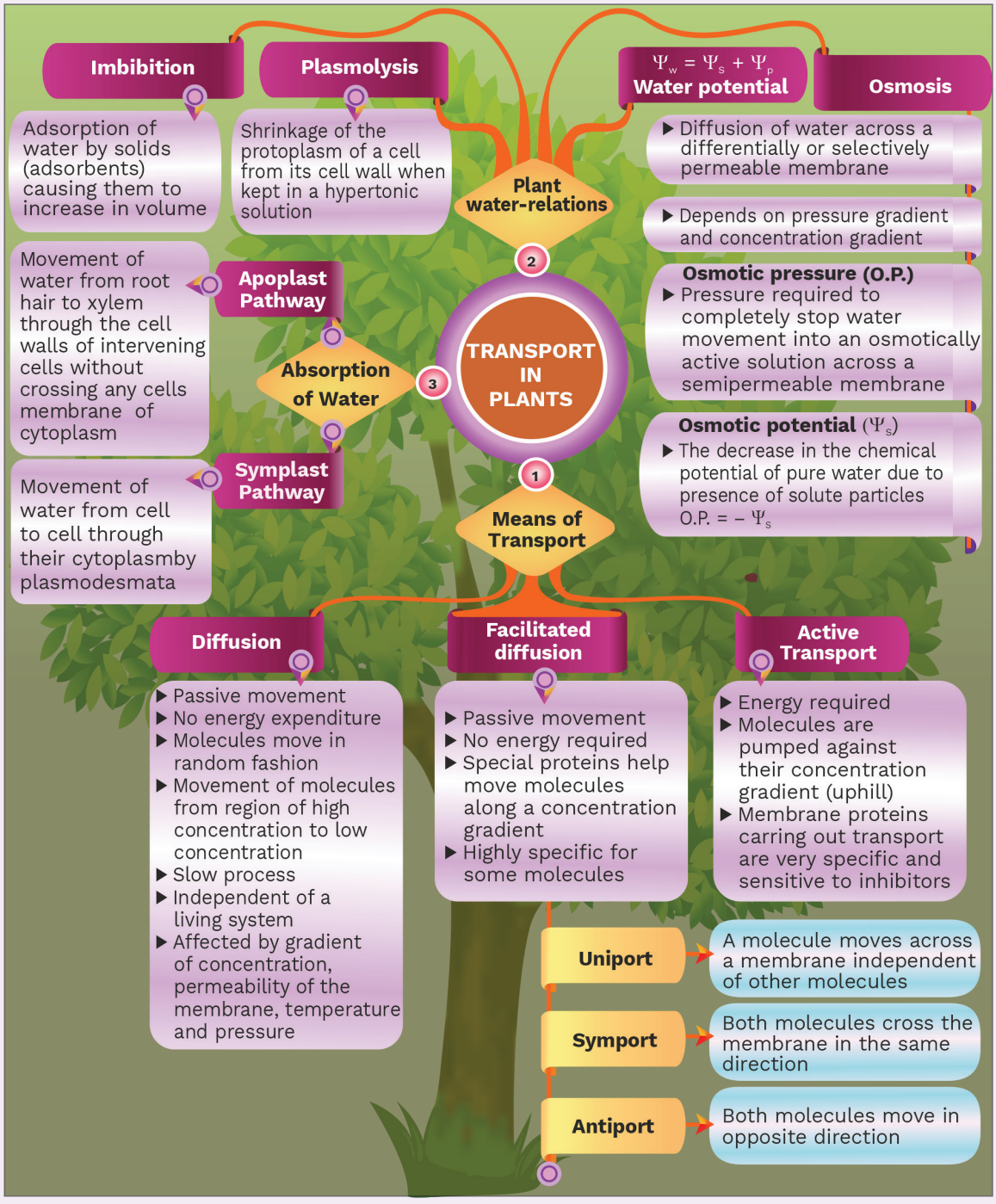
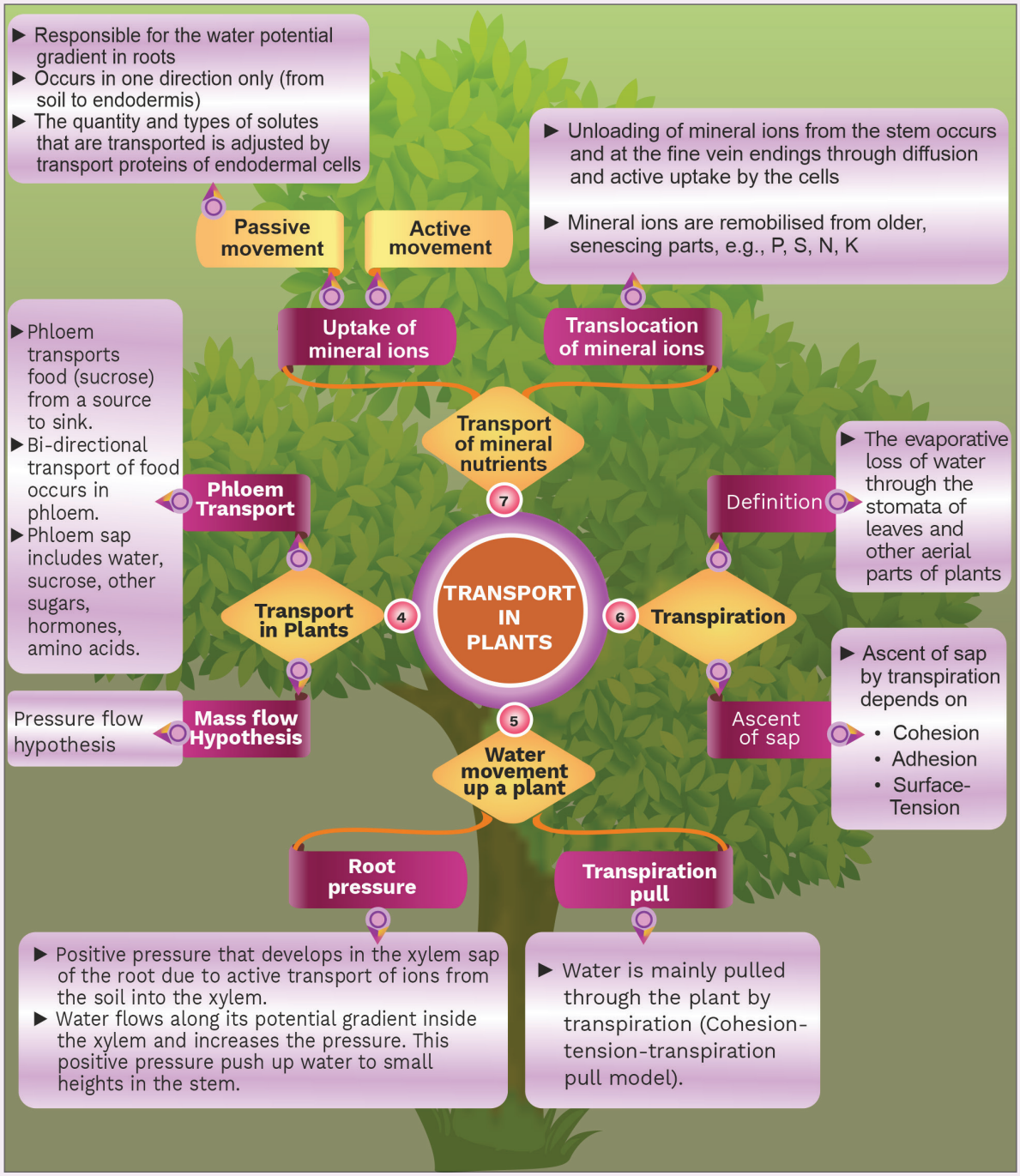


FIG. THE PRESSURE FLOW OR MASS FLOW HYPOTHESIS

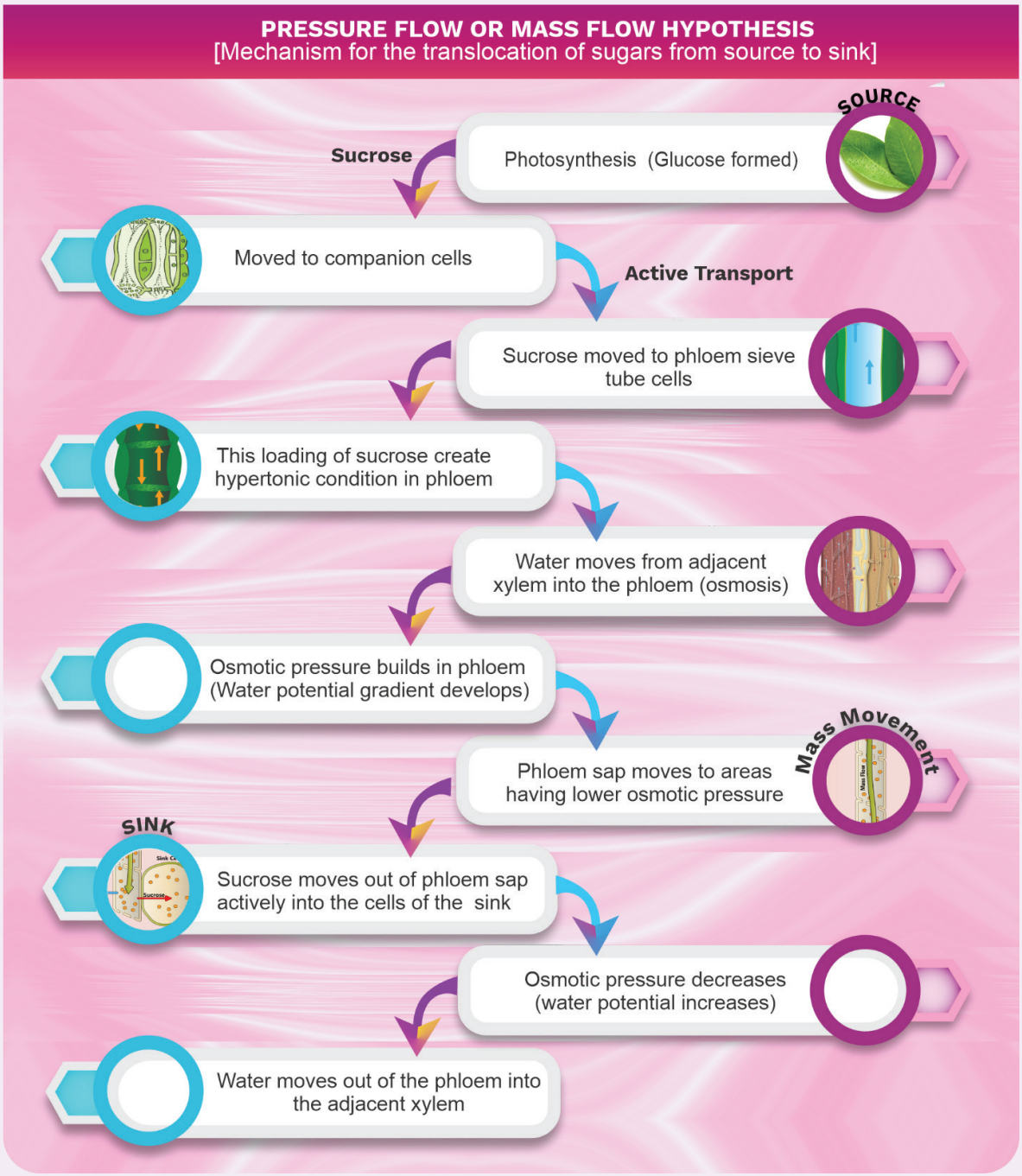
Summary


TRANSPORT IN PLANTS
1
Means of Transport
2
Plant water-relations
3
Absorption of Water
Imbibition
Adsorption of water by solids (adsorbents) causing them to increase in volume
Plasmolysis
Shrinkage of the protoplasm of a cell from its cell wall when kept in a hypertonic solution
$\Psi_w = \Psi_s + \Psi_p$
Water potential
Osmosis
Diffusion of water across a differentially or selectively permeable membrane
Depends on pressure gradient and concentration gradient
Osmotic pressure (O.P.)
Pressure required to completely stop water movement into an osmotically active solution across a semipermeable membrane
Osmotic potential (Ψ_s)
The decrease in the chemical potential of pure water due to presence of solute particles
O.P. = – Ψ_s
Apoplast Pathway
Movement of water from root hair to xylem through the cell walls of intervening cells without crossing any cells membrane of cytoplasm
Symplast Pathway
Movement of water from cell to cell through their cytoplasmby plasmodesmata
Diffusion
Passive movement
No energy expenditure
Molecules move in random fashion
Movement of molecules from region of high concentration to low concentration
Slow process
Independent of a living system
Affected by gradient of concentration, permeability of the membrane, temperature and pressure
Facilitated diffusion
Passive movement
No energy required
Special proteins help move molecules along a concentration gradient
Highly specific for some molecules
Active Transport
Energy required
Molecules are pumped against their concentration gradient (uphill)
Membrane proteins carring out transport are very specific and sensitive to inhibitors
Uniport
A molecule moves across a membrane independent of other molecules
Symport
Both molecules cross the membrane in the same direction
Antiport
Both molecules move in opposite direction

Summary


TRANSPORT IN PLANTS
Transport of mineral nutrients
7
Uptake of mineral ions
Passive movement
Active movement
Responsible for the water potential gradient in roots
Occurs in one direction only (from soil to endodermis)
The quantity and types of solutes that are transported is adjusted by transport proteins of endodermal cells
Translocation of mineral ions
Unloading of mineral ions from the stem occurs and at the fine vein endings through diffusion and active uptake by the cells
Mineral ions are remobilised from older, senescing parts, e.g., P, S, N, K
Transport in Plants
4
Phloem Transport
Phloem transports food (sucrose) from a source to sink.
Bi-directional transport of food occurs in phloem.
Phloem sap includes water, sucrose, other sugars, hormones, amino acids.
Mass flow Hypothesis
Pressure flow hypothesis
Transpiration
6
Definition
The evaporative loss of water through the stomata of leaves and other aerial parts of plants
Ascent of sap
Ascent of sap by transpiration depends on
Cohesion
Adhesion
Surface-Tension
Water movement up a plant
5
Root pressure
Positive pressure that develops in the xylem sap of the root due to active transport of ions from the soil into the xylem.
Water flows along its potential gradient inside the xylem and increases the pressure. This positive pressure push up water to small heights in the stem.
Transpiration pull
Water is mainly pulled through the plant by transpiration (Cohesion-tension-transpiration pull model).

Summary


PRESSURE FLOW OR MASS FLOW HYPOTHESIS
[Mechanism for the translocation of sugars from source to sink]
SOURCE
Photosynthesis (Glucose formed)
Sucrose
Moved to companion cells
Active Transport
Sucrose moved to phloem sieve tube cells
This loading of sucrose create hypertonic condition in phloem
Water moves from adjacent xylem into the phloem (osmosis)
Osmotic pressure builds in phloem (Water potential gradient develops)
Mass Movement
Phloem sap moves to areas having lower osmotic pressure
SINK
Sucrose moves out of phloem sap actively into the cells of the sink
Osmotic pressure decreases (water potential increases)
Water moves out of the phloem into the adjacent xylem

Solved Examples

1. **Water channels are made up of _____ different types of aquaporins.**
(1) 8 **(2) 4**
(3) 10 **(4) 6**

Ans. (1)
Water channels are made of 8 different types of aquaporins.

2. **Which of the following is not highly selective?**
(1) Simple diffusion
(2) Facilitated transport
(3) Active transport
(4) None of these

Ans. (1)
Simple diffusion is not a selective process. Different types of particles can diffuse simultaneously through the same space.

3. **In a day, how much water is absorbed by a mature corn plant?**
(1) 2 litres
(2) 3 litres
(3) 4 litres
(4) 5 litres

Ans. (2)
A mature corn plant absorbs almost 3 litres of water in a day.

4. **The water potential of pure water is**
(1) Negative
(2) Positive
(3) Zero
(4) None of these

Ans. (3)
The water potential of pure water at standard temperature, which is not under any pressure, is taken to be zero.

5. **Diffusion of water across a selectively permeable membrane is**
(1) Plasmolysis
(2) Guttation
(3) Imbibition
(4) Osmosis

Ans. (4)
Osmosis is specifically the diffusion of water across a differentially or selectively permeable membrane.

6. **In a hypotonic solution, a plant cell wall**
(1) Swell
(2) Shrink
(3) First swell then shrink
(4) First shrink then swell

Ans. (1)
Cells swell in hypotonic solutions and shrink in hypertonic ones.

7. **In plants, water, minerals, and food are generally moved by**
(1) Transpiration
(2) Root pressure
(3) Mass flow system
(4) Osmosis

Ans. (3)
In plants, water, minerals, and food are generally moved by mass or bulk flow system.

8. **Which of the following has an obligate association with mycorrhizae?**
(1) *Marchantia*
(2) *Pinus*
(3) *Cycas*
(4) *Gelidium*

Ans. (2)
Pinus has an obligate association with mycorrhizae.

9. **Opening of a stoma is aided by**
(1) Parenchyma cell
(2) Microfibrils in guard cells
(3) Light
(4) Wind

Ans. (2)
The opening of the stoma is aided due to the orientation of the microfibrils in the cell walls of the guard cells.

10. **The direction of movement in the phloem is**
(1) Unidirectional
(2) Bi-directional
(3) Both (1) and (2)
(4) None of the above

Ans. (2)
The direction of movement in the phloem is upwards and downwards, i.e., bi-directional.