CHAPTER-11

TRANSPORT IN PLANTS

Introduction

Plant physiology is the branch of botany that deals with the study of life activities of plants. It includes the functional aspects of life processes both at the cellular as well as subcellular levels.

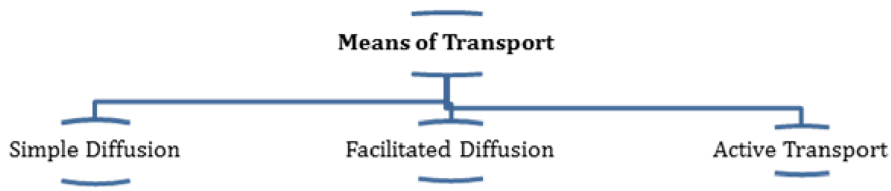
Plants need to move molecules over very long distances, much more than animals do; they also do not have a circulatory system in place. Water taken up by the roots has to reach all parts of the plant, up to the very tip of the growing stem. The photosynthates or food synthesized by the leaves have also to be moved to all parts including the root tips embedded deep inside the soil.

Movement across short distances, say within the cell, across the membranes, and from cell to cell within the tissue has also to take place. To understand some of the transport processes that take place in plants, one would have to recollect one's basic knowledge about the structure of the cell and the anatomy of the plant body. We also need to revisit our understanding of diffusion, besides gaining some knowledge about chemical potential and ions. When we talk of the movement of substances we need first to define what kind of movement we are talking about, and also what substances we are looking at. In a flowering plant, the substances that would need to be transported are water, mineral nutrients, organic nutrients, and plant growth, regulators. Over small distances, substances move by diffusion and by cytoplasmic streaming supplemented by active transport. Transport over longer distances proceeds through the vascular system (the xylem and the phloem) and is called **translocation**. An important aspect that needs to be considered is the direction of transport. In rooted plants, transport in xylem (of water and minerals) is essentially unidirectional, from roots to the stems. Organic and mineral nutrients, however, undergo multidirectional transport.

Organic compounds synthesized in the photosynthetic leaves are exported to all other parts of the plant including storage organs. From the storage organs, they are later re-exported. The mineral nutrients are taken up by the roots and transported upwards into the stem, leaves, and the growing regions. When any plant part undergoes senescence, nutrients may be withdrawn from such regions and moved to the growing parts.

Hormones or plant growth regulators and other chemical stimuli are also transported, though in very small amounts, sometimes in a strictly polarised or unidirectional manner from where they are synthesized to other parts. Hence, in a flowering plant, there is complex traffic of compounds (but probably very orderly) moving in different directions, each organ receiving some substances and giving out some others.

Means of transport



Diffusion

There are three methods of transport of materials across the cells - **diffusion**, **facilitated diffusion,** and **active transport**. Both types of diffusion constitute passive transport.

The movement of molecules or atoms or ions of materials from an area of higher concentration to an area of their lower concentration is called diffusion.

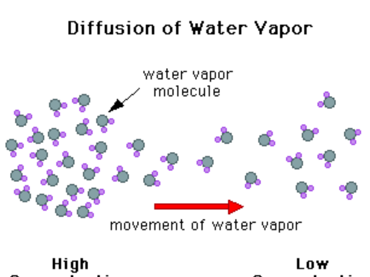
The diffusion is continued until the dynamic equilibrium is not established. At this stage, the net movement of molecules is equal in both directions. The kinetic energy, which is present in the molecules of material is distributed equally in their available space by their nature.

The diffused molecules or ions exert pressure on the substance or medium in which diffusion takes place, known as **diffusion pressure**. This is developed due to differences in the concentration of molecules of the material.

A pure solvent thus, possess maximum diffusion pressure and it decreases with the addition of solute in the solvent. Water molecules move from their higher concentration to their lower concentration in plants.

The rate of diffusion decreases with the increasing size of molecules.

Gases have the highest rate of diffusion, followed by liquid and solid.



Diffusion rates are affected by the gradient of concentration, the permeability of the membrane separating them, temperature, and pressure.

Significance of diffusion

Exchange of gases like CO_2, O_2 takes place through diffusion.

The distribution of hormones in the plants takes place through diffusion.

The process of transpiration is a diffusion process. The evaporation of water from the intercellular spaces is linked with diffusion during transpiration.

The ions of the minerals may diffuse into the plant body.

Facilitated diffusion

It is diffusion along the concentration gradient through specific sites present in cell membranes without the cell spending any energy on the movement.

The rate of diffusion depends on the size of substances; smaller substances diffuse faster. Lipid soluble substances diffuse faster.

The substance that has a hydrophobic moiety, find it difficult to pass through the membrane. The movement of such molecules is facilitated by transporter proteins present in cell membranes which allow the passage of substances.

In facilitated diffusion, the concentration gradient must be present.

It is very specific and allows selected substances through the cell. It is also sensitive to inhibitors that react with protein side chains.

Some protein channels present on the membrane are always open; others can be controlled. The **porins** are proteins that form huge pores in the outer membranes of the plastids, mitochondria, a The transport, and some bacteria.

An extracellular molecule bound to the transport protein; the transport protein then rotates and releases the molecule inside the cell, e.g., water channels – made up of eight different types of aquaporins.

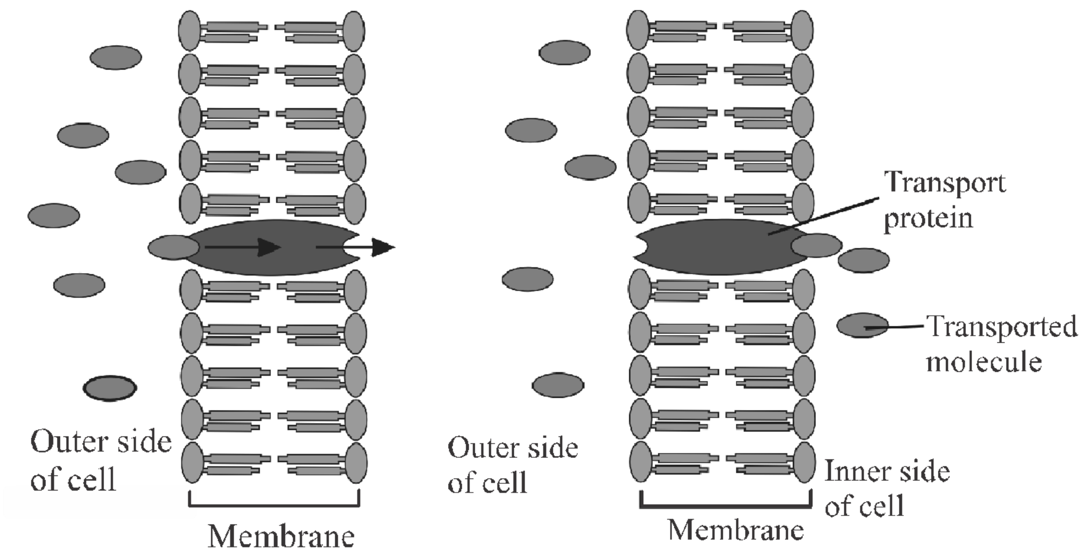
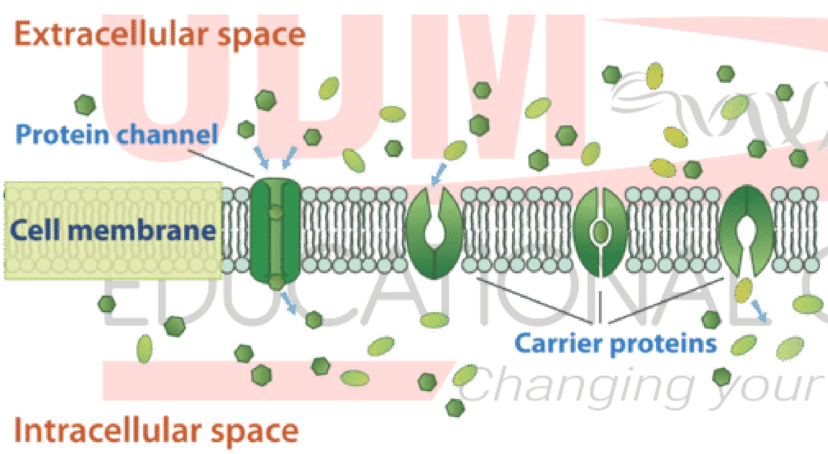
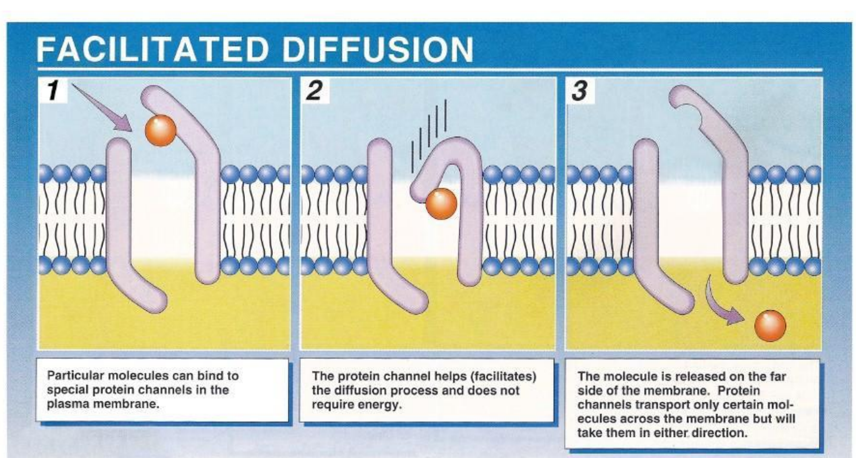


Fig. : Facilitated diffusion





Passive symports and antiports

Few transport proteins or carrier proteins permit diffusion only if two types of molecules move together.

In **symport**, both molecules cross the membrane in the same direction.

In **antiport**, both molecules cross the membrane in opposite directions.

In **uniport**, a molecule moves across a membrane independent of other molecules.

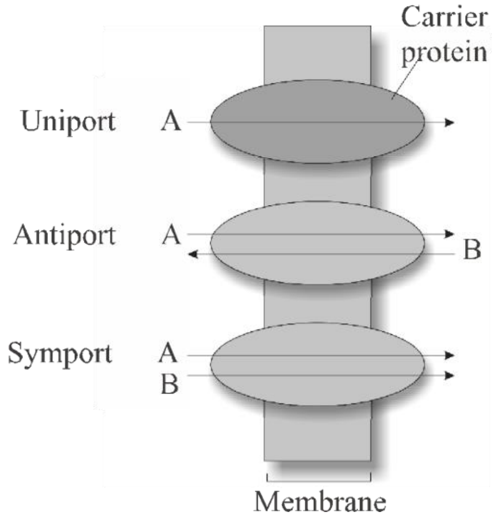
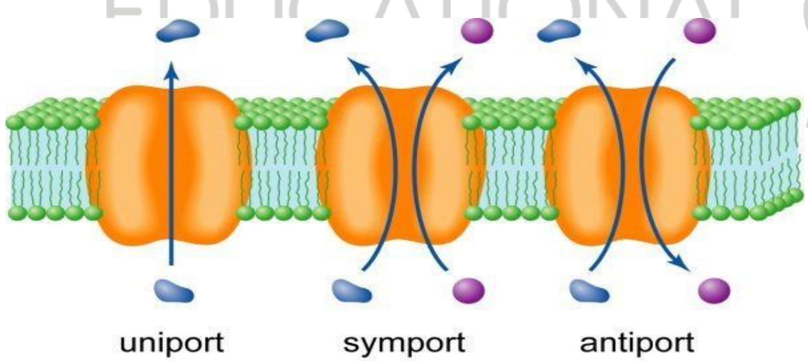


Fig. : Types of facilitated diffusion



Active transport

Active transport uses **energy** to pump molecules against a concentration gradient.

It is carried out by membrane-bound proteins.

Hence different proteins in the membrane play a major role in both active as well as passive transport. Pumps are proteins that use energy to carry substances across the cell membrane.

These pumps can transport substances from a low concentration to a high concentration ('uphill' transport). The transport rate reaches a maximum when all the protein transporters are being used or are saturated. Like enzymes, the carrier protein is very specific in what it carries across the membrane. These proteins are sensitive to inhibitors that react with protein side chains.

Pumps are proteins that can transport the substances by using energy. These pumps can transport the proteins from lower concentration to a higher concentration.

Comparison of Different Transport Processes

Proteins in the membrane are responsible for facilitated diffusion and active transport and hence show common characteristics of being highly selective; they are liable to saturate, respond to inhibitors, and are under hormonal regulation. But diffusion whether facilitated or not – take place only along a gradient and does not use energy.

Table: Differences between Diffusion, Facilitated diffusion, and Active Transport :

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

Plant-water relations

Water is essential for all physiological activities of the plant and plays a very important role in all living organisms. It provides the medium in which most substances are dissolved. The protoplasm of the cells is nothing but water in which different molecules are dissolved and (several particles) suspended. A watermelon has over 92 per cent water; most herbaceous plants have only about 10 to 15 per cent of its fresh weight as dry matter. Of course, the distribution of water within a plant varies – woody parts have relatively very little water, while soft parts mostly contain water. A seed may appear dry but it still has water – otherwise, it would not be alive and respiring! Terrestrial plants take up a huge amount of water daily but most of it is lost to the air through evaporation from the leaves, i.e., transpiration. A mature corn plant absorbs almost three litres per cent of water in a day, while a mustard plant absorbs water equal to its weight in about 5 hours. Because of this high water demand, it is not surprising that water is often the limiting factor for plant growth and productivity in both agricultural and natural environments.

Thus, water is vital for the following point:

- Water is essential for all physiological activities of plants.
- Water acts as an excellent solvent and helps in the uptake and distribution of mineral nutrients and other solutes.
- Water is useful for maintaining the turgidity of cells which is essential for cell enlargement, growth & development.

Water Potential

To comprehend plant-water relations, an understanding of certain standard terms is necessary. Water potential (Ψw) is a concept fundamental to understanding water movement. Solute potential (Ψs) and pressure potential (Ψp) are the two main components that determine water potential. Water molecules possess kinetic energy. In liquid and gaseous form they are in random motion that is both rapid and constant. The greater the concentration of water in a system, the greater is its kinetic energy or 'water potential'. Hence, it is obvious that pure water will have the greatest water potential. If two systems containing water are in contact, random movement of water molecules will result in a net movement of water molecules from the system with higher energy to the one with lower energy. Thus water will move from the system containing water at higher water potential to the one having low water potential. This process of movement of substances down a gradient of free energy is called diffusion. Water potential is denoted by the Greek symbol Psi or Ψ and is expressed in pressure units such as pascals (Pa). By convention, the water potential of pure water at standard temperatures, which is not under any pressure, is taken to be zero. If some solute is dissolved in pure water, the solution has less free water, and the concentration of water decreases, reducing its water potential.

Hence, all solutions have a lower water potential than pure water; the magnitude of this lowering due to the dissolution of a solute is called solute potential or Ψs. Ψs is always negative. The more the solute molecules, the lower (more negative) is the Ψs. For a solution at atmospheric pressure (water potential) Ψw = (solute potential) Ψs. 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. Can you think of any system in our body where pressure is built up? Pressure can build up in a plant system when water enters a plant cell due to diffusion causing a pressure built up against the cell wall, it makes the cell turgid; this increases the pressure potential. Pressure potential is usually positive, though in plants negative potential or tension in the water column in the xylem plays a major role in water transport up a stem. Pressure potential is denoted as Ψp. The water potential of a cell is affected by both solute and pressure potential.

The relationship between them is as follows: $\Psi w = \Psi s + \Psi p$

- The difference between the free energy of molecules of pure water and free energy of the solution is called the water potential of the system.
- The water potential of pure water is maximum. Pure water has greater free energy. The free energy is lowered down by the addition of solute.
- Water always flows from higher water potential to lower water potential.
- Water potential is represented by the Greek word ψ (Psi)/ψ_w and it is measured in bars or Pascal (Pa).
- Water potential is equal to DPD but opposite in sign. Its value is negative.

So $\boxed{\Psi_W = -DPD}$

Water potential has the following components –

Osmotic potential

Osmotic pressure is also called **solute potential** or **osmotic potential**.

Osmotic pressure and osmotic potential are numerically equal, but the osmotic potential has a negative sign.

$\Psi_s = -\pi$ [when Ψ_s = Osmotic potential of solution;

Π = osmotic pressure].

Osmotic potential or solute potential is measured in bars. [1 bar = 0.987 atmospheric pressure].

Osmotic pressure = 22.4 atm

⇒ Osmotic potential = – 22.4 atm

(For 1M glucose solution)

Pressure potential

It is shown by a positive sign (+ve).

If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is also known as **Turgor pressure**.

Matric potential

Matric is the term used for the surface (such as soil particles, cell walls, protoplasms, etc.) To which water molecules are adsorbed. The matric potential (ψ_m) is the component of water potential influenced by the presence of a matrix. It has a negative value.

According to this concept, their relationship is as follows.

Water potential = Osmotic potential + Pressure potential + Matric potential

$\Delta\psi$ or $\psi_w = \psi_s + \psi_p + \psi_m$

$\Psi_w = \psi_s + \psi_p$

As ψ_m and ψ_g (Matric potential and gravitational potential are negligible).

$\Psi_w = -ve$, $\psi_s = -ve$, $\psi_p = +ve$

According to the above concept, the relation of the three phases of the cell by the water potential will be as follows:

In case of fully turgid cell :

There is no flow of water in a turgid cell because the cell is in equilibrium with water which is present outside the cell, so that water potential will be zero at this state and because osmotic potential and pressure potential are equal in the cell.

For example, if the value of the osmotic potential of a cell is –10 and pressure potential (ψ_p) is +10 then water potential will be zero as :

$\Psi_w = \psi_s + \psi_p, \psi_w = -10 + 10, \psi_w = 0$

In the case of flaccid cell :

Turgor pressure is zero at this stage. It means the pressure potential is zero.

$\Psi_w = \psi_s$

If osmotic potential of the cell is –10 bars then,

$\Psi_w = \psi_s + \psi_p$

$\therefore \psi_p = 0 = TP$

$\Psi_w = -10 + 0$ bar

$\Psi_w = -10$ bar

In plasmolyzed cell :

The pressure potential (ψ_p) means turgor pressure is negative in this stage. Therefore, the water potential (ψ_w) of this cell will be more negative. If the value of osmotic potential is –10 bars of a plasmolyzed cell and the value of pressure potential is 2 bars then its water potential (ψ_w) will be – 12 bars.

$\Psi_w = \psi_s + \psi_p$, $\psi_w = -10 + (-2)$ bars, $\psi_w = -12$ bars

So, it is concluded that water always moves from higher water potential towards the lower water potential.

For example, if the water potential of cell A is –10 bars and the water potential of cell B is – 12 bars in two cells, then water will flow from cell A to cell B.

Osmosis

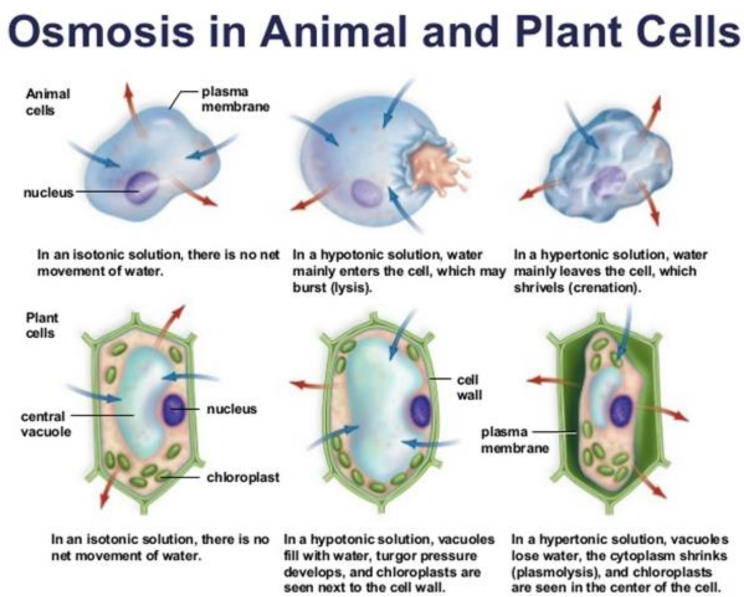
The plant cell is surrounded by a cell membrane and a cell wall. The cell wall is freely permeable to water and substances in solution hence is not a barrier to movement. In plants, the cells usually contain a large central vacuole, whose contents, the vacuolar sap, contribute to the solute potential of the cell.

In-plant cells, the cell membrane, and the membrane of the vacuole (i.e., tonoplast) together are important determinants of movement of molecules in or out of the cell.

The ability of a membrane to permit or restrict the passage of substances through it is called **membrane permeability**.

Osmosis is a **type of diffusion** in which water molecules diffuse from the region of **higher chemical potential** (or concentration) to its region of **lower chemical potential** (concentration) across a permeable membrane.

The net direction and rate of osmosis depend on the pressure gradient and concentration gradient.



The two chambers, A and B, containing solutions are separated by a semi-permeable membrane.

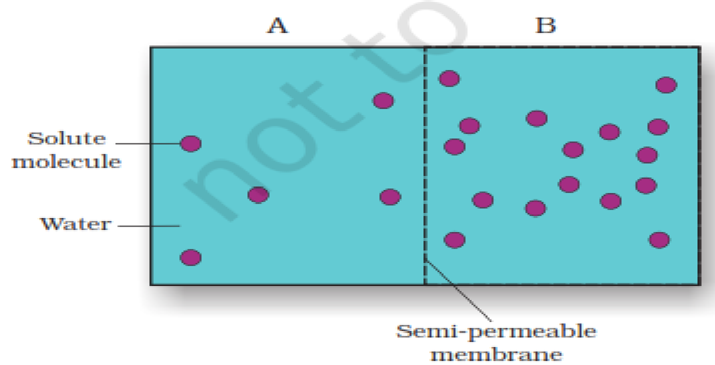


Figure 11.3

(a) The solution of which chamber has a lower water potential?

(b) The 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?

Thistle funnel experiment - In the experiment, sucrose solution is taken in the funnel which is separated from water through a semipermeable membrane. Water will move into the funnel until the equilibrium is reached.

You can get this kind of a membrane in an egg. Remove the yolk and albumin through a small hole at one end of the egg, and place the shell in a dilute solution of hydrochloric acid for a few hours. The eggshell dissolves leaving the membrane intact. Water will move into the funnel, resulting in a rise in the level of the solution in the funnel. This will continue until the equilibrium is reached.

External pressure can be applied from the upper part of the funnel such that no water diffuses into the funnel through the membrane. This pressure required to prevent water from diffusing is in fact, the osmotic pressure and this is the function of the solute concentration; the more the solute concentration, the greater will be the pressure required to prevent water from diffusing in. Numerically osmotic pressure is equivalent to the osmotic potential, but the sign is the opposite. Osmotic pressure is a positive pressure applied, while the osmotic potential is negative.

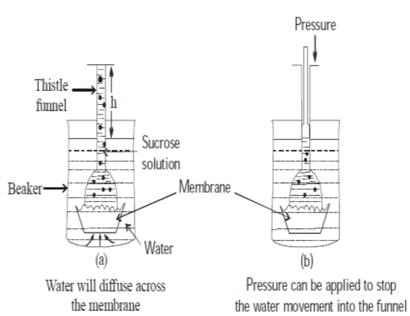
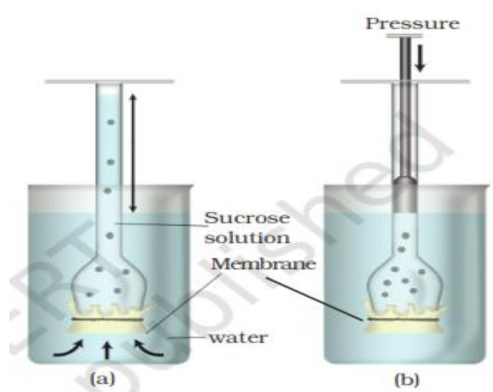


Fig. : A demonstration of osmosis theory 'Thistle funnel experiment'.



The experiment proves that the sugar solution is osmotically active and can absorb water when it is separated from the water by a semipermeable membrane.

Potato osmoscope - Experiment useful for demonstrating osmosis by using living tissue is a potato osmoscope. When the potato tuber is placed in water, the cavity in the potato tuber containing a concentrated sugar solution collects water due to osmosis. The entry of water into the sugar solution proves that sugar solution is osmotically active. The cytoplasm of the cells of the tuber that lie between the sugar solution and the water acts as a single semi-permeable membrane.

Types of osmosis

Depending upon the movement of water into or outside of the cell, osmosis is of two types - **endosmosis** & **exosmosis**.

The osmotic flow of water into a cell, when it is placed in a solution whose solute concentration is less than that of the cell sap, is called **endosmosis**. E.g., swelling of raisins when they are placed in water.

The osmotic outflow of water from a cell, when it is placed in a solution whose solute concentration is more than that of the cell sap is called **exosmosis**. E.g., shrinkage of grapes when they are placed in a concentrated sugar solution.

Osmotic pressure (a term proposed by Pfeffer) is the pressure required to prevent the entry of water into a solution.

The osmotic pressure of pure water is zero.

The osmotic pressure of a solution is directly proportional to the concentration of solute in it.

The osmotic pressure in the following plants are as follows:

Hydrophytes < Mesophytes < Xerophytes < Halophytes

Generally, osmotic pressure is less during the night and higher at noon.

The osmotic pressure of a solution is measured by **Osmometer**.

O.P. of the cell is measured by incipient plasmolysis.

The formula of Vont Hoff for measuring O.P. :

$$O.P. = mRT$$

Here, m = molar concentration

R = Gas constant [0.082 mole/molecules]

T = Absolute temperature

The osmotic pressure of 1 mole. Glucose solution at 0°C, O.P. = $1 \times 0.082 \times 273 = 22.4$ atm., for non electrolytes.

The O.P. of electrolytes is calculated by the following formula,

$$O.P. = mRT\,I$$

Where I is the constant of ionization of electrolytes.
The osmotic pressure of electrolytes is higher than that of non-electrolytes.

For example - a solution of 1 M NaCl and 1 M glucose. The molar concentration of both solutions is equal but O.P. of 1 M NaCl is higher than the solution of 1 M glucose.

Water moves from lower O.P. towards the higher O.P.

Significance of osmosis

Root hairs of the roots absorb water from the soil through the process of osmosis.

The conduction of water from one cell to another cell in a plant and distribution of water in the plant is through osmosis.

Turgidity is developed by the process of endosmosis which helps to maintain a definite shape of leaves, stems, and flowers. Turgidity also provides mechanical strength to the plants.

The opening and closing of stomata are also dependent on the process of osmosis.

The leaves of Mimosa pudica ("Touch me not") are drooping down only by contact and dehiscence of fruits depends upon turgor changes after osmosis.

The resistance power increases due to high osmotic concentration against the dry climate and cold temperature.

Table: Differences between Diffusion and Osmosis.

S. No.	Diffusion	Osmosis
1.	Movement of molecules of solid, liquid and gas occurs in this process.	Movement of only solvent molecules occurs in this process.
2.	This process can occur in any medium solid, liquid or gas.	It can occur only in liquid medium.
3.	No membrane is required.	Semi-permeable or diffused permeable membrane is needed for this process.
4	Diffusion process takes place through high diffusion pressure to low diffusion pressure.	Osmosis takes place through solution of low osmotic pressure to solution of high osmotic pressure.

Plasmolysis

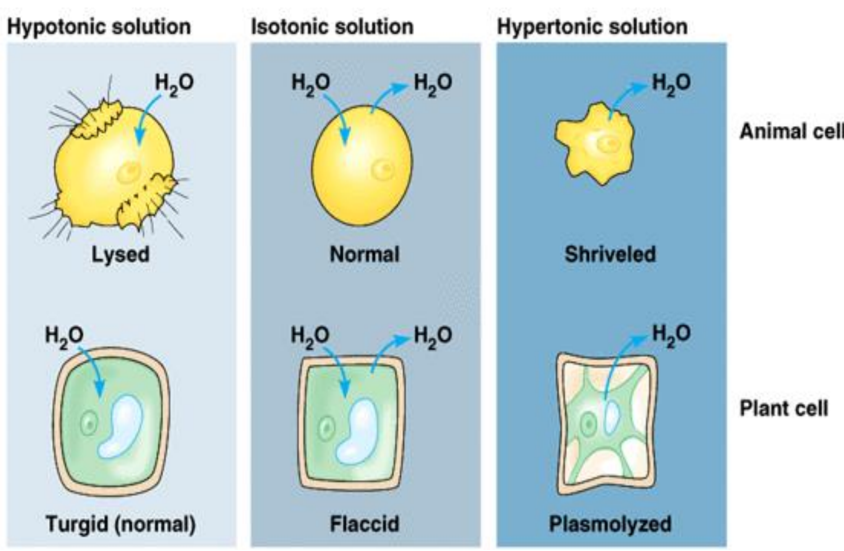
The term Plasmolysis is defined as *"the contraction of the protoplasm of cells within plants due to loss of water through osmosis."*

In other words, the behaviour of plant tissues or cells regarding the movement of water depends on the surrounding solution and this process occurs when water is drawn out of the cell through the process of osmosis. Osmosis occurs when the cell has a higher concentration as compared to its surroundings.

Plasmolysis depends on the three types of solution:

- **Isotonic** – It is the condition when the external solution balances the osmotic pressure of the cytoplasm.
- **Hypotonic** – In this case, the external solution is diluted as compared to the cytoplasm.
- **Hypertonic** – In hypertonic, the external solution is more concentrated.

The cell swells in case of hypotonic while it shrinks in hypertonic ones. The following figure shows the three type of solution:



ISOTONIC VS HYPOTONIC VS HYPERTONIC

Isotonic	Hypotonic	Hypertonic
Isotonic solutions are solutions having equal osmotic pressures	Hypotonic solutions are solutions having lower osmotic pressures	Hypertonic solutions are solutions having comparatively higher osmotic pressures
Have equal solute concentrations	Have a low concentration	Have a high concentration
Isotonic environments show no effect on cells	Hypotonic environments cause cells to swell	Hypertonic environments cause cells to shrink
Isotonic solutions are not helpful in food preservation	Hypotonic solutions are not helpful in food preservation	Hypertonic solutions are helpful in food preservation

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When the cell (or tissue) is placed in an **isotonic** solution, there is no net flow of water towards the inside or outside. If the external solution balances the osmotic pressure of the cytoplasm it is said to be isotonic.

When water flows into the cell and out of the cell and is in equilibrium, the cells are said to be **flaccid**.

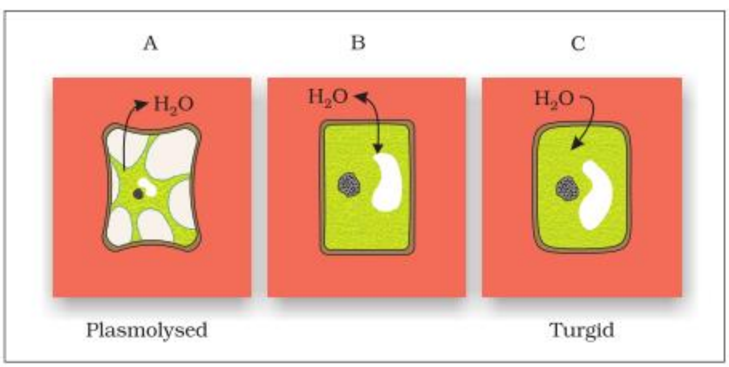


Figure 11.5 Plant cell plasmolysis

The process of plasmolysis is usually reversible. When the cells are placed in a **hypotonic** solution (higher water potential or dilute solution as compared to the cytoplasm), water diffuses into the cell causing the cytoplasm to build up a pressure against the wall, that is called **turgor pressure**. The pressure exerted by the protoplasts due to the entry of water against the rigid walls is called pressure potential Ψ_p. Because of the rigidity of the cell wall, the cell does not rupture. This turgor pressure is ultimately responsible for the enlargement and extension growth of cells.

The various sequences of plasmolysis are as follows:

The first stage of plasmolysis or limiting plasmolysis: In this stage, protoplasm just begins to contract away from the cell wall. There is a gradual loss of water from the cytoplasm and central vacuole decreases, TP or ψ_p to zero.

Incipient Plasmolysis: Continued exosmosis beyond limiting plasmolysis decreases the size of protoplasm further. However, the cell wall cannot contract more. Therefore, contracting protoplasm withdraws from the cell wall. Contraction is initially from the corners.

Evident Plasmolysis: The stage when the cell wall has reached its limit of contraction and the protoplasm has detached from the cell wall attaining spherical shape is called evident plasmolysis.

Significance of plasmolysis

- A living cell is distinguished from the non-living (dead) cell through plasmolysis because plasmolysis does not occur in dead cells.
- The osmotic pressure of any cell can be measured by incipient plasmolysis.
- If plasmolysis continues for a long duration in a cell then it dies. By salting, the weeds can be killed and the growth of plants can be prevented in the cracks of walls. Fishes and meats are prevented from spoilage by salting, which inhibits the growth of bacteria and fungus.
- A higher concentration of sugar in jams and jellies stops the growth of bacteria and fungus.
- The high amount of chemical fertilizers near the root causes of death or browning of the plant due to plasmolysis.
- The freshwater growing plants are either wilted or die when they are kept in marine water.

The swelling up of a plasmolyzed protoplast due to endosmosis under the influence of a hypotonic solution or water is called deplasmolysis. **Deplasmolysis** is possible only immediately after plasmolysis otherwise the cell protoplast becomes permanently damaged. The value of T.P. becomes zero at the time of limiting plasmolysis and below zero during incipient and evident plasmolysis. Leaf of Tradescantia is used for the demonstration of plasmolysis in the laboratory.

Table : Differences between Osmosis and Plasmolysis.

S. No.	Osmosis	Plasmolysis
1.	This process occurs between solutions of different concentrations or between protoplasm and surrounding solution or the cells of different osmotic pressure.	This process occurs between the living plant cell and hypertonic solution.
2.	Semi-permeable membrane or diffused permeable membrane is essential in this process.	Protoplasm cell and tonoplast act as a semi-permeable membrane.
3.	Osmosis can be of two types-endosmosis and exosmosis.	Plasmolysis is an exosmosis process in which water moves from cell-sap to the surrounding hypertonic solution.
4.	In endosmosis, water is absorbed through root hair, cells become turgid, while in exosmosis, cells become flaccid.	Due to plasmolysis, cells are always in flaccid condition. Sometimes bacteria and fungi etc. die due to the plasmolysis of protoplasm.

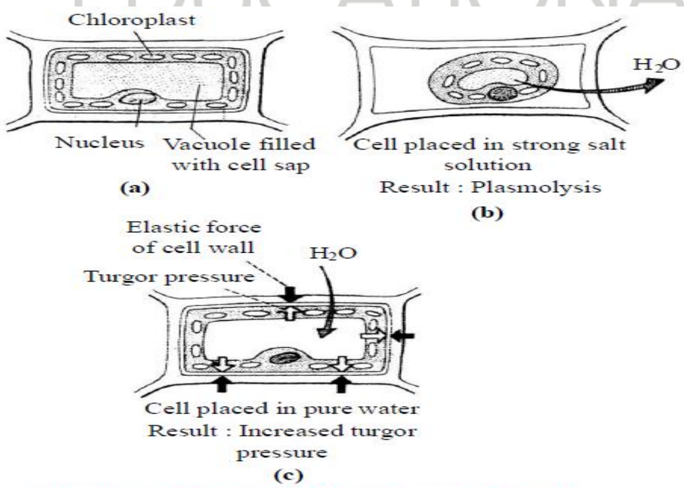


Fig.: Plasmolysis and deplasmolysis (a) Normal cell (b) Plasmolysed cell (c) Deplasmolysed cell and increased turgor pressure

Turgor pressure (T.P.)and wall pressure (W.P.)

When a cell is immersed in water, then water enters into the cell because the osmotic pressure of the cell sap is higher. The cell contents develop pressure against the cell wall which is called **turgor pressure**.

Turgor pressure is also known as **hydrostatic pressure**.

Turgor pressure is not applicable for free solution. This is only applicable to the osmotic system.

The turgor pressure is balanced by an equal but opposite pressure of the thick cell wall on the enclosed solution or protoplasm is known as **wall pressure**. It means the amount of pressure exerted by cytoplasm on the cell wall is the same and in the opposite direction as the pressure exerted by the cell wall towards the inner side on the cytoplasm.

Therefore, wall pressure and turgor pressure are equal to each other but W.P. is inward in direction.

$$\boxed{T.P. = W.P.}$$

Plant cell does not burst when placed in pure water due to wall pressure but an animal cell bursts when placed in pure water because wall pressure is absent due to the absence of a cell wall.

For example, the consequence of endosmosis on animals can be demonstrated by placing RBCs of human blood in distilled water contained in a dish. When examined after some time, the RBCs are found to burst upon leaving their cell membranes as empty cases.

A flaccid cell has zero turgor pressure.

The highest value of turgor pressure is found in the fully turgid cell and it is equal to the osmotic pressure.

Significance of T.P.

- The protoplasm of the cell is attached to the cell wall due to the turgidity of the cell in the stretched condition. It maintains the normal shape of the cell in which physiological processes are going on.
- The spatial 3-D structure of mitochondria, chloroplast, and microbodies is maintained due to turgor pressure which is essential for their physiological activities.
- Turgor pressure is essential for maintaining a definite shape of delicate organs.
- Turgor pressure helps in cell elongation or growth of the cell.
- Plant movement like the movement of guard cells of stomata, and seismonastic movements, etc. Are dependent upon turgor pressure change.
- Turgor pressure provides essential power to the plumule to come out from the soil and help in the penetration of radicle into the soil.

Diffusion pressure deficit (DPD) or suction pressure (SP)

The difference between the diffusion pressure of the solution and it's pure solvent at a particular temperature is called DPD or suction pressure.

DPD determines the direction of osmosis and it is the power of absorption of water for the cell.

This is also known as the demand for water in the cell.

DPD is directly proportional to the concentration of the solute.
The diffusion of water takes place from the region of lower DPD to the region of higher DPD in the process of osmosis.

Normally, osmotic pressure is greater than the turgor pressure in a cell. The difference between osmotic pressure and turgor pressure is called suction pressure or DPD.
DPD = OP – TP or WP

The DPD of any free solution is equal to the osmotic pressure of that solution.
DPD = OP, because TP is zero in the solution.

DPD in partially turgid or in normal cell
DPD = OP – TP

DPD for fully turgid cell
When a cell is placed in pure water or hypotonic solution, then water enters into the cell, as a result, turgor pressure develops in the cell. The cell starts swelling due to the turgor pressure. Simultaneously, the concentration of cell sap decreases due to the continuous inflow of water. Therefore, OP decreases, and T.P. increases when the value of TP is equal to the OP then DPD will be zero.
At this stage, the cell becomes fully turgid.
Therefore, in a fully turgid cell
When, OP = TP or, OP – TP = 0
DPD = OP – TP
So that, DPD = 0

DPD in flaccid cell
If the cell is in the flaccid state then its T.P. or W.P. would be zero and the value of DPD would be equal to OP.
TP or WP = 0
Therefore, DPD or SP = OP

If a flaccid cell is placed in water then water enters into the cell because the DPD of the cell sap is higher than water.

DPD for plasmolysed cell

Sometimes the value of turgor pressure is negative as in plasmolysed cell. In this state,

DPD = OP – TP

∴ TP = –ve

DPD = OP – [–TP] = OP + TP

DPD = OP + TP

So that the DPD of the plasmolyzed cell is greater than osmotic pressure.

The DPD in the following cells are as follows: Plasmolysed cell > Flaccid cell > Partially turgid cell > Fully turgid cell

Imbibition

It is a special type of diffusion which includes the absorption of water by solids, called colloids, resulting in an enormous increase in volume.

Example of Imbibition: Absorption of water by dry wood and seeds are examples of imbibition.

Itis a special type of diffusion when water is absorbed by solids – colloids – causing them to enormously increase in volume. The classical examples of imbibition are the absorption of water by seeds and dry wood.

The pressure that is produced by the swelling of wood had been used by prehistoric man to split rocks and boulders. If it were not for the pressure due to imbibition, seedlings would not have been able to emerge out of the soil into the open; they probably would not have been able to establish!

Imbibition is also diffusion since water movement is along a concentration gradient; the seeds and other such materials have almost no water hence they absorb water easily. The water potential gradient between the absorbent and the liquid imbibed is essential for imbibition. Also, for any substance to imbibe any liquid, affinity between the adsorbant and the liquid is also a pre-requisite.

The various factors which influence the rate of imbibitions are the **nature of the imbibant**, **the surface area of imbibant**, **temperature**, **degree of dryness of imbibant**, the **concentration of solutes**, **ph of imbibant,** etc.

Imbibition capacity in the following compounds are as follows : Agar-Agar > Pectin > Protein > Starch > Cellulose.

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

Imbibition is less in compactly arranged material like wood, and more in lighter or soft material like gelatin.

Significance of imbibition

- Absorption of water during the seed germination is only initiated through imbibition.
- Breaking of seed coat during seed germination is due to imbibition.
- The initial process of water absorption in roots by root hairs is imbibition.
- Resurrection in many plants like Selaginella, lichen, takes place due to the process of imbibition.
- Water enters into the aerial roots and dry fruits due to imbibition.

Movement of water molecules :
Higher D.P.→ Lower D.P.
Lower O.P.→ Higher O.P.
Lower DPD→ Higher DPD
Higher ψ_w → Lower ψ_w
Higher T.P.→ Lower T.P.
Hypotonic solution → Hypertonic solution
Lower concentration of solution → Higher concentration of the solution.

Long-distance transport of water

On examining the cut end of the twig after a few hours you had noted the region through which the coloured water moved. That experiment very easily demonstrates that the path of water movement is through the vascular bundles, more specifically, the xylem. Now we have to go further and try and understand the mechanism of movement of water and other substances up a plant. Long-distance transport of substances within a plant cannot be by diffusion alone. Diffusion is a slow process. It can account for only short-distance movement of molecules. For example, the movement of a molecule across a typical plant cell (about 50 µm) takes approximately 2.5 s.

In large and complex organisms, often substances have to be moved across very large distances. Sometimes the sites of production or absorption and sites of storage are too far from each other; diffusion or active transport would not suffice. Special long-distance transport systems become necessary to move substances across long distances and at a much faster rate. Water and minerals, and food are generally moved by a mass or bulk flow system. Mass flow is the movement of substances in bulk or en masse from one point to another as a result of pressure differences between the two points. It is a characteristic of mass flow that substances, whether in solution or suspension, are swept along at the same pace, as in a flowing river. This is unlike diffusion where different substances move independently depending on their concentration gradients. Bulk flow can be achieved either through a positive hydrostatic pressure gradient (e.g., a garden hose) or a negative hydrostatic pressure gradient (e.g., suction through a straw).

The bulk movement of substances through the conducting or vascular tissues of plants is called **translocation**.

The higher plants have highly specialized vascular tissues – xylem and phloem. Xylem is associated with the translocation of main water, mineral salts, some organic nitrogen, and hormones, from roots to the aerial parts of the plants. The phloem translocates a variety of organic and inorganic solutes, mainly from the leaves to other parts of the plants.

How do Plants Absorb Water?

Water situated in the soil has to reach up to the xylem of the root. Root hairs remain in contact with water. First of all, water is adsorbed on the pectin wall of root hairs, then water enters into the epidermis of root hairs. From here, water reaches up to the endodermis through the cortex.

Soil solution → Root hair → Epiblema/Epidermis → Cortex (Epiblema) → Cortex → Endodermis (Passage cell) → Pericycle cell → Protoxylem → Metaxylem

The walls of the endodermis are suberised. But cells that lie in front of the protoxylem are thinly walled known as **passage cells**. These cells transfer water to the xylem. From here, water reaches the xylem from endodermal cells through the thin-walled **pericycle cells**.

Water is absorbed along with mineral solutes, by the root hairs, purely by diffusion. Once water is absorbed by the root hairs, it can move deeper into root layers by two distinct pathways

Apoplast pathway

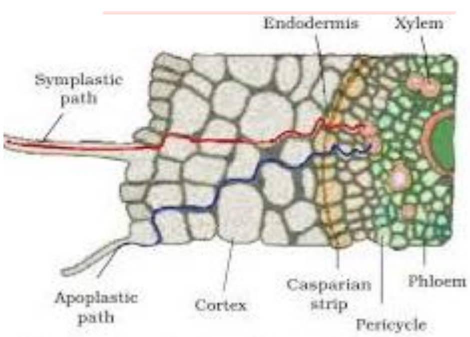
Symplast pathway

The apoplastic movement of water occurs exclusively through the cell wall and intercellular spaces; without crossing any membrane.

This movement is dependent on the gradient. The apoplast does not provide any barrier to water movement and water movement is through the mass flow. As water evaporates into the intercellular spaces or the atmosphere, tension develops in the continuous stream of water in the apoplast, hence the mass flow of water occurs due to the adhesive and cohesive properties of water.

Symplastic movement

The symplastic system is the system of interconnected protoplasts. Neighbouring cells are connected through cytoplasmic strands that extend through plasmodesmata. During the symplastic movement, the water travels through the cells – their cytoplasm; intercellular movement is through the plasmodesmata. Water has to enter the cells through the cell membrane, hence the movement is relatively slower. Movement is again down a potential gradient. Symplastic movement may be aided by cytoplasmic streaming. You may have observed cytoplasmic streaming in cells of the Hydrilla leaf; the movement of chloroplast due to streaming is easily visible. Most of the water flow in the roots occurs via the apoplast since the cortical cells are loosely packed, and hence offer no resistance to water movement. However, the inner boundary of the cortex, the endodermis, is impervious to water because of a band of suberised matrix called the Casparian strip. Water molecules are unable to penetrate the layer, so they are directed to wall regions that are not suberised, into the cells proper through the membranes. The water then moves through the symplast and again crosses a membrane to reach the cells of the xylem. The movement of water through the root layers is ultimately symplastic in the endodermis. This is the only way water and other solutes can enter the vascular cylinder. Once inside the xylem, water is again free to move between cells as well as through them. In young roots, water enters directly into the xylem vessels and/or tracheids. These are non-living conduits and so are parts of the apoplast.



Mycorrhizal water absorption

In mycorrhiza, a large number of fungal hyphae are associated with young root and also extend into the soil. The hyphae have a large surface area for absorption. The hyphae absorb water and minerals and hand over them to the root. Root provides the fungus with sugar and nitrogenous compounds.

Transmembrane pathway: Water after passing through the cortex is blocked by **Casparian strips** present on **endodermis**. The Casparian strips are formed due to the deposition of a wax-like substance, suberin. In this pathway, water crosses at least two membranes from each cell in its path. These two plasma membranes are found on the entry and exit of water. Here, water may also enter through the tonoplast surrounding the vacuole i.e., also called a **vacuolar pathway**.

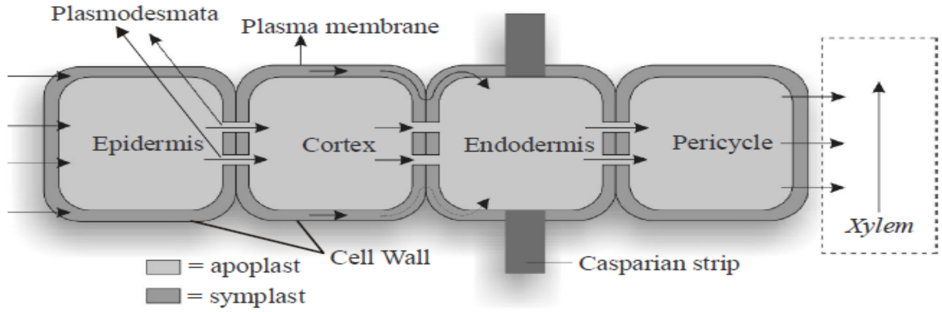


Fig. : Absorption of water (pathway of water movement in root)

Mechanism of water absorption

Water is absorbed in two different ways :

- Active water absorption
- Passive water absorption

Active water absorption

According to this method, water is absorbed due to the activity of roots or by an expenditure of ATP.

Osmotically active: According to this method, water is absorbed due to the osmotic activity of roots in order of OP and DPD. No direct ATP is consumed in this method.

Non-osmotically active: According to this method, absorption of water occurs against the osmotic concentration by direct investment/expenditure of metabolic energy in the form of ATP. Generally, this process is found in halophytes.

Passive water absorption

According to this method, forces for the absorption of water originates in the aerial parts by rapid transpiration, and roots remain as a passive organ. According to Kramer, water absorption in plants is followed by transpiration. About 96% of water is absorbed by the passive method.

Due to rapid transpiration, DPD of leaf cells increases results in a suction force which sucks the water from roots

The different factors which influence the rate of water absorption by a plant can be divided into external or environmental and internal factors.

External or environmental factors

(amount of soil water, the concentration of the soil solution, soil temperature, rate of transpiration)

Internal factors (efficiency of the root system, metabolic activity of roots

Ascent of sap

The upward movement of absorbed water against the gravitational force up to the top parts of plants is called as the ascent of sap. Xylem is the water-conducting tissue in plants.

Experiments which prove that water is conducted through xylem vessels and xylem tracheids in plants are as follows :

Girdling or Ringing experiment: Girdling (ringing) a stem is removing tissues external to the xylem in a ring. It does not prevent the movement of water to organs attached to the stem above the ring. On the contrary, cutting through the xylem tissue of the stem results in almost immediate wilting of leaves attached to the stem above the ring.

Mechanism of the ascent of sap

Various theories are given to explain the mechanism of the ascent of sap.

Vital force theories

According to these theories, living cells are involved in the ascent of sap.

Root pressure theory

The metersRoot pressure theory was proposed by Priestley (1916).

According to this theory, the water which is absorbed by the root-hairs from the soil collects in the cells of the cortex. The cortical cells become fully turgid. In such circumstances, the elastic walls of the cortical cells exert pressure on their fluid-contents and force them towards the xylem vessels. Due to this loss of water, cortical cells become flaccid, again absorb water, become turgid and thus again force out their fluid contents. This pressure forces water up the xylem vessels.

Effects of root pressure are also observable at night and early morning when evaporation is low, and excess water collects in the form of droplets around special openings of veins near the tips of grass blades, and leaves of many herbaceous parts. Such water loss in its liquid phase is known as guttation (a term coined by Bergerstein) which takes place through hydathodes.

Objection :

- Root pressure is absent in woody plants.
- When root pressure is high, during the night, then the ascent of sap is low.
- Root pressure does not account for the majority of water transport; most plants meet their needs by transpiration pull.

Physical force theories

(capillary force theory, transpiration pull and cohesion force theory, cohesion, adhesion, transpiration pull)

Water Movement up a Plant

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 and can be responsible for pushing up water to small heights in the stem

Choose a small soft-stemmed plant and on a day, when there is plenty of atmospheric moisture, cut the stem horizontally near the base with a sharp blade, early in the morning. You will soon see drops of solution ooze out of the cut stem; this comes out due to the positive root pressure. If you fix a rubber tube to the cut stem as a sleeve you can collect and measure the rate of exudation, and also determine the composition of the exudates. Effects of root pressure are also observable at night and early morning when evaporation is low, and 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 its liquid phase is known as **guttation.**

Root pressure can, at best, only provide a modest push in the overall process of water transport. They do not play a major role in water movement up tall trees. The greatest contribution of root pressure may be to re-establish the continuous chains of water molecules in the xylem which often break under the enormous tensions created by transpiration. Root pressure does not account for the majority of water transport; most plants meet their need by the transpiratory pull.

Transpiration pull

Despite the absence of a heart or a circulatory system in plants, the flow of water upward through the xylem in plants can achieve fairly high rates, up to 15 meters per hour.

A long-standing question is, whether water is 'pushed' or 'pulled' through the plant. Most researchers agree that water is mainly 'pulled' through the plant and that the driving force for this process is transpiration from the leaves. This is referred to as the cohesion-tension-transpiration pull model of water transport.

Water is transient in plants. Less than 1 per cent of the water reaching the leaves is used in photosynthesis and plant growth. Most of it is lost through the stomata in the leaves. This water loss is known as transpiration.

Transpiration

Loss of water in vapour form, from the aerial parts(organs) of living plants, is known as **transpiration**.

Only a few percentages (1-2%) of absorbed water is used by the plants while the remaining (98-99%) of water is lost in the atmosphere.

Minimum transpiration is found in succulent xerophytes and no transpiration is found in submerged hydrophytes.

Maximum transpiration is found in mesophytes.

Stomata are found on the aerial organs and outer surface of the leaves in the form of minute pores.

The stomatal pore is surrounded by two specialized epidermal cells called **guard cells**. They are kidney-shaped. The guard cells in **monocots** (Gramineae) are dumb-bell shaped.

Guard cells are epidermal cells. But due to the presence of chloroplast, they are different from epidermal cells.

The outer wall of the guard cells is thin and elastic while the inner wall is thick and non-elastic.

Guard cells are surrounded by some specialized epidermal cells called **subsidiary cells** or **accessory cells**.

Stomata are found on both the upper and lower surface of leaves. Stomata are attached with air chambers and form a cavity called **substomatal-cavity**.

In **xerophytic plants**, the position of stomata is deep in the surface of the leaf. These types of stomata are called **sunken stomata**.

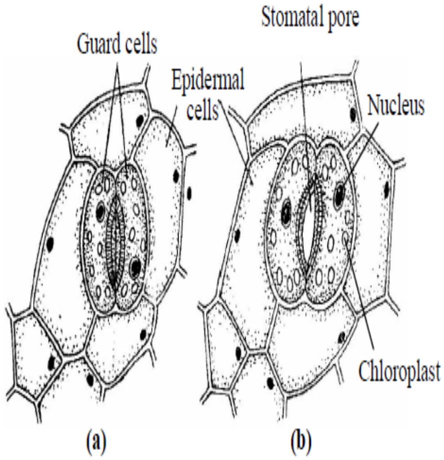
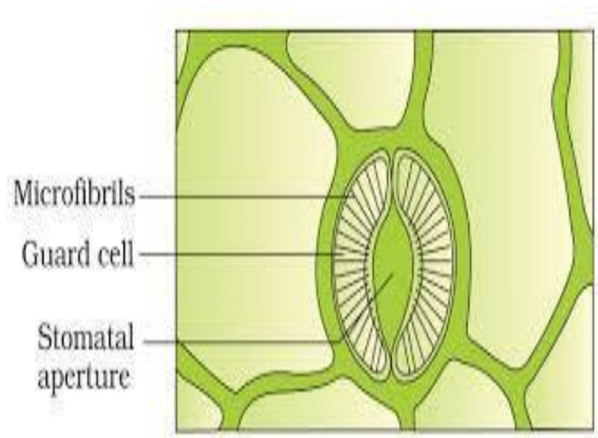


Fig. : Stomatal apparatus (a) Closed (b) Open

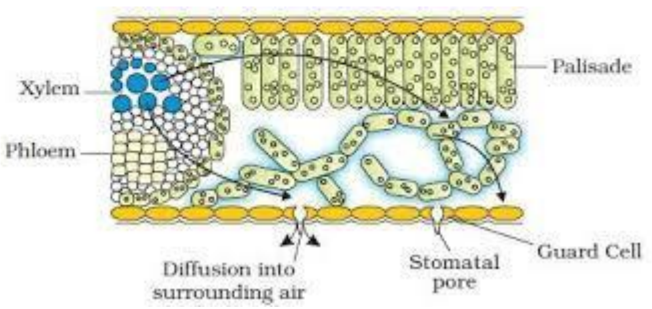


Usually, the lower surface of a dorsiventral (often dicotyledonous) leaf has a greater number of stomata while in an isobilateral (often monocotyledonous) leaf they are about equal on both surfaces. Transpiration is affected by several external factors: temperature, light, humidity, wind speed. Plant factors that affect transpiration include the number and distribution of stomata, per cent aluminium stomata, water status of the plant, canopy structure, etc.

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

- Cohesion – mutual attraction between water molecules.
- Adhesion – the attraction of water molecules to polar surfaces (such as the surface of tracheary elements).
- Surface Tension – water molecules are attracted to each other in the liquid phase more than to water in the gas phase.

These properties give water high tensile strength, i.e., an ability to resist a pulling force, and high capillarity, i.e., the ability to rise in thin tubes. In plants, capillarity is aided by the small diameter of the tracheary elements – the tracheids and vessel elements. The process of photosynthesis requires water. The system of xylem vessels from the root to the leaf vein can supply the needed water. But what force does a plant use to move water molecules into the leaf parenchyma cells where they are needed? As water evaporates through the stomata, since the thin film of water over the cells is continuous, it results in pulling of water, molecule by molecule, into the leaf from the xylem. Also, because of the lower concentration of water vapour in the atmosphere as compared to the substomatal cavity and intercellular spaces, water diffuses into the surrounding air. This creates a 'pull'



Measurements reveal that the forces generated by transpiration can create pressures sufficient to lift a xylem sized column of water over 130 meters high.

Transpiration and Photosynthesis – a Compromise

Transpiration has more than one purpose; it

- creates transpiration pull for absorption and transport of plants
- supplies water for photosynthesis
- transports minerals from the soil to all parts of the plant
- cools leaf surfaces, sometimes 10 to 15 degrees, by evaporative cooling
- maintains the shape and structure of the plants by keeping cells turgid.

An actively photosynthesizing plant has an insatiable need for water. Photosynthesis is limited by available water which can be swiftly depleted by transpiration. The humidity of rainforests is largely due to this vast cycling of water from root to leaf to atmosphere and back to the soil. The evolution of the C_4 photosynthetic system is probably one of the strategies for maximizing the availability of CO_2 while minimizing water loss. C_4 plants are twice as efficient as C_3 plants in terms of fixing carbon (making sugar). However, a C_4 plant loses only half as much water as a C_3 plant for the same amount of CO_2 fixed.

Factors affecting transpiration

It is of two types:

External factors (environmental factors) (atmospheric humidity, temperature, light, wind velocity, anti transpirant)

Internal factors (leaf area, leaf structure,root-shoot ratio, age of plants, the orientation of leaves)

Advantages of transpiration

- Transpiration influences the absorption of water from the soil.

- Transpiration exerts tension or pulls on the water column in xylem which is responsible for the ascent of sap.
- Transpiration helps in the movement of water and minerals absorbed by the roots of the other parts of the plant.
- The evaporation of water during transpiration contributes to the cooling of leaves (and also the surrounding air) and protects leaves from heat injury particularly under conditions of high temperature and intense sunlight.

Disadvantages of transpiration

Transpiration often results in water deficit which causes injury to the plants by desiccation.

Guttation

Loss of water from the aerial parts or leaves of the plant in the form of water droplets is called guttation.

The term guttation was coined by Burgerstein.

The Exuded liquid of guttation along with water contains some organic and inorganic (dissolved) substances. It means it is not pure water.

Normally, the guttation process is found in herbaceous plants like grasses, tomato, Balsam, Colocasia, Saxifraga, and in some of the plants of the Cucurbitaceae family.

Guttation occurs from the margins of the leaves through the special pore (always open) like structure are called **Hydathodes** or **Water stomata**.

Generally, guttation occurs during the night or early morning.

The process of guttation takes place due to the root pressure, developed in cortex cells of the root.

Table : Differences between Transpiration and Guttation.

S. No.	Transpiration	Guttation
1.	It normally occurs in day time.	It occurs during cooler periods of night and early morning.
2.	Water comes out in the form of vapour.	Water is lost in the form of droplets.
3.	Released water vapour is in the pure form	Water which is exuded, is a mixture of organic and inorganic substances.
4.	It occurs through stomata, cuticles and lenticles.	It occurs through hydathodes.
5.	It occurs through aerial parts of plant.	It occurs through leaves.
6.	It becomes very slow and even stops in humid conditions.	It occurs in humid conditions.

Uptake and transport of mineral nutrients

Plants obtain their carbon and most of their oxygen from CO_2 in the atmosphere. However, their remaining nutritional requirements are obtained from minerals and water for hydrogen in the soil.

Uptake of Mineral Ions

Unlike water, all minerals cannot be passively absorbed by the roots.

Two factors account for this: (i) minerals are present in the soil as charged particles (ions) which cannot move across cell membranes and (ii) the concentration of minerals in the soil is usually lower than the concentration of minerals in the root.

Therefore, most minerals must enter the root by active absorption into the cytoplasm of epidermal cells. This needs energy in the form of ATP. The 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 also move into the epidermal cells passively. Ions are absorbed from the soil by both passive and active transport. Specific proteins in the membranes of root hair cells actively pump ions from the soil into the cytoplasms of the epidermal cells. Like all cells, the endodermal cells have many transport proteins embedded in their plasma membrane; they let some solutes cross the membrane, but not others. Transport proteins of endodermal cells are control points, where a plant adjusts the quantity and types of solutes that reach the xylem. Note that the root endodermis because of the layer of suberin can actively transport ions in one direction only.

Translocation of mineral ions

After the ions have reached xylem through active or passive uptake, or a combination of the two, their further transport up the stem to all parts of the plant is through the transpiration stream. The chief sinks for the mineral elements are the growing regions of the plant, such as the apical and lateral meristems, young leaves, developing flowers, fruits and seeds, and the storage organs. Unloading of mineral ions occurs at the fine vein endings through diffusion and active uptake by these cells. Mineral ions are frequently remobilized, particularly from older, senescing parts. Older dying leaves export much of their mineral content to younger leaves. Similarly, before leaf fall in deciduous plants, minerals are removed to other parts. Elements most readily mobilized are phosphorus, sulphur, nitrogen, and potassium. Some elements that are structural components like calcium are not remobilized. An analysis of the xylem exudates shows that though some of the nitrogen travels as inorganic ions, much of it is carried in the organic form as amino acids and related compounds. Similarly, small amounts of P and S are carried as organic compounds. Besides, a small amount of exchange of materials does take place between xylem and phloem. Hence, it is not that we can clearly make a distinction and say categorically that xylem transports only inorganic nutrients while phloem transports only organic materials, as was traditionally believed.

Phloem transport: flow from source to sink

Food, primarily sucrose, is transported by the vascular tissue phloem from a source to a sink. Usually, the source is understood to be that part of the plant which synthesizes the food, i.e., the leaf, and sink, the part that needs or stores the food. But, the source and sink may be reversed depending on the season, or the plant's needs. Sugar stored in roots may be mobilized to become a source of food in the early spring when the buds of trees, act as a sink; they need energy for growth and development of the photosynthetic apparatus. Since the source-sink relationship is variable, the direction of movement in the phloem can be upwards or downwards, i.e., bi-directional. This contrasts with that of the xylem where the movement is always unidirectional, i.e., upwards. Hence, unlike the one-way flow of water in transpiration, food in phloem sap can be transported in any required direction so long as there is a source of sugar and a sinkable to use, store or remove the sugar. Phloem sap is mainly water and sucrose, but other sugars, hormones, and amino acids are also transported or translocated through the phloem.

Food/organic material conduction in plants mainly occurs by phloem. (Proved by Girdling experiment).

In plants, food production occurs mainly in green plants but translocated to all parts of a plant.

Food conduction occurs between the source and sink. The source is a net exporter while the sink is a net importer.

Generally, green photosynthetic plant parts act as a source like leaves while non-photosynthetic parts like root, shoot, fruits act as a sink.

The transfer of food depends on the requirement and seasonal activities. For example in germinating potato tuber, the tuber acts as the source, and developing buds acts as a sink, similarly, in early spring, roots act as source and developing buds as the sink.

Food conduction may be in any required direction, unlike the water conduction which is a unidirectional process.

Translocation of food mainly occurs in the form of sucrose or non-reducing sugar and chemically inert in its pathway of conduction.

Pressure flow/Mass flow hypothesis of food/sucrose translocation :

This hypothesis is given by Munch.

This is the most accepted theory of food conduction in plants.

According to it, food translocation between source and sink follows the turgor pressure gradient i.e. High T.P. to low T.P.

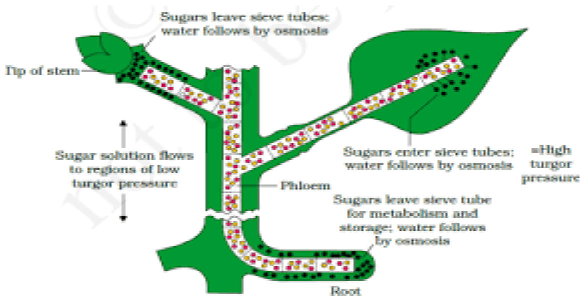
Phloem loading/sucrose loading at source: It is an active process helped by carrier molecules. At the source, due to sucrose loading, the concentration of cell sap of sieve cells increases. It results in the increase of osmotic pressure and water moves from nearby xylem into sieve cells resulting in increased turgor pressure (T.P.) and an increase in water potential (ψ_w). It establishes a higher T.P. at source and in sieve tubes. Sucrose moves from the source in sieve tubes towards the sink from high T.P. (high ψ_w) towards the low T.P. (low ψ_w).

Phloem unloading/sucrose unloading at the sink: It is an active process helped by carrier molecules. At the sink, sucrose is unloaded, which results in a decrease in osmotic pressure (O.P.). It results in the exit of water into nearby xylem leading to a decrease in turgor pressure (T.P.) and water potential (ψ_w) of phloem. In sink cells, the unloaded sucrose is either changed into starch (as starch does not change O.P.) or consumed, to maintain low O.P. and continuous unloading.

So, the process of sucrose loading at the source and unloading at the sink continues. This turgor pressure difference will be maintained and water will continue to move in at source and out at the sink.

This mechanism was experimentally demonstrated by the Bimodal experiment of Munch.

According to evidence of modern research, phloem conduction is an active process and it requires metabolic energy in phloem cells.



To summarise, the movement of sugars in the phloem begins at the source, where sugars are loaded (actively transported) into a sieve tube. Loading of the phloem sets up a water potential gradient that facilitates the mass movement in the phloem.

Phloem tissue is composed of sieve tube cells, which form long columns with holes in their end walls called sieve plates. Cytoplasmic strands pass through the holes in the sieve plates, so forming continuous filaments. As hydrostatic pressure in the phloem sieve tube increases, pressure flow begins, and the sap moves through the phloem. Meanwhile, at the sink, incoming sugars are actively transported out of the phloem and removed as complex carbohydrates. The loss of solute produces a high water potential in the phloem, and water passes out, returning eventually to the xylem.

Important terms

Translocation

Transport of substances in plants over long distances through the vascular tissue (Xylem and Phloem) is called translocation.

Means of transport

The transport of material into and out of the cells is carried out by some methods. These are diffusion, facilitated diffusion, and active transport. Diffusion: Diffusion occurs from a region of higher concentration to a region of lower concentration across the permeable membrane. It is a passive and slow process. No energy expenditure takes place.

Simple Diffusion

In this system, the molecules move from a region of higher concentration to a region of lower concentration. This process requires no energy.

Facilitated Transport

Here, the system moves molecules from a region of higher concentration to a region of lower concentration with the help of a carrier, usually a protein. This process does not require any energy and hence is known as the passive process.

Active Transport

This mechanism transfers molecules from a region of lower to a region of higher concentration with the help of membrane proteins. This system is termed as active transport because it requires ATP to function.

Water potential

The chemical potential of water is called water potential. It is denoted by Ψ (Psi) and measured in pascals (Pa). The water potential of a cell is affected by solute potential (Ψ W s) and pressure potential (Ψ). Ψ W = Ψ s + Ψ p Water potential of pure water at a standard temperature which is not under any pressure is taken to be zero (by convention). p

Osmosis

Osmosis is the movement of solvent or water molecules from the region of their higher diffusion pressure or free energy to the region of their lower diffusion pressure or free energy across a semi-permeable membrane. Water molecules move from higher water potential to lower water potential until equilibrium is reached. Plasmolysis: Process of shrinkage of protoplasm in a cell due to exosmosis in a hypertonic solution.

Endosmosis

This is the movement of water molecules enters into the cell when the cell is placed in a hypotonic solution.

Exosmosis

This is the movement of water molecules out of the cell when the cell is placed in a hypertonic solution.

Mass flow

Mass flow is the movement of substances (water, minerals, and food) in bulk from one point to another as a result of pressure differences between two points.

Transport of water in plants

Water is absorbed by root hairs, then water moves up to the xylem by two pathways – apoplast and symplast pathway. The transport of water to the tops of trees occurs through xylem vessels. The forces of adhesion and cohesion maintain a thin and unbroken column of water in the capillaries of xylem vessels through which it travels upward. Water is mainly pulled by transpiration from leaves.

Root pressure

A hydrostatic pressure existing in roots which pushes the water up in xylem vessels. Guttation: The water loss in its liquid phase at night and early morning through special openings of the vein near the tip of leaves.

Guttation

The water loss in its liquid phase at night and early morning through special openings of the vein near the tip of leaves.

Transpiration

The loss of water through stomata of leaves and other aerial parts of plants in the form of water vapour.

Plasmolysis

Process of shrinkage of protoplasm in a cell due to exosmosis in a hypertonic solution.

Isotonic

This refers to two solutions with the same osmotic pressure across the semi-permeable membrane.

Hypotonic

This is the solution that has a lower osmotic pressure than another solution.

Hypertonic

This is the solution with higher osmotic pressure than another solution.

Casparian strip

It is the tangential as well as radial walls of endodermal cells having the deposition of water-impermeable suberin. Imbibition: Imbibition is the phenomenon of adsorption of water or any other liquid by the solid particles of a substance without forming a solution.

Pressure potential (ψp)

It is the positive pressure developed in a system because of the osmotic entry of water into it.

Osmotic pressure

Itis the pressure required to prevent the passage of pure water into an aqueous solution through a semi-permeable membrane, thereby preventing an increase in the volume of the solution.

Turgor pressure (TP)

It is the pressure developed in an osmotic system because of the entry of water which causes swelling of the system.

Plasmolysis

It is the withdrawal of the protoplast of a plant cell from its cell wall because of excessive loss of water from the cell.

Imbibition

It is the phenomenon of adsorption of water or any other liquid by solid particles of a substance without forming a solution.

Soil water

The chief source of soil water is rain. The total amount of water present in the soil is called **holard**, of this, the water available to the plant is called **chresard** and the water which cannot be absorbed by the plants is called **echard**.

Gravitational water

When water enters the soil and passes to spaces between the soil particles and reaches the water table, the type of soil water is called gravitational water.

Capillary water

It is the water that is held around soil particles in the capillary space present around them due to the capillary force of surface tension.

Hygroscopic water

This is the form of water that is held by soil particles due to imbibition. As imbibition force is several times higher than osmotic potential found in plant roots, hygroscopic water is largely unavailable to plants.

Run-away water

After the rain, water that does not enter the soil but drained along the slopes is called run-away water. Plants fail to avail of this water.

Chemically combined water

Some of the water molecules are chemically combined with soil minerals (e.g., silicon, iron, aluminium, etc.). This water is not available to the plants.

Water holding capacity

The amount of water retained by the soil is called field capacity or water holding capacity of the soil. It is about 25-35% in common loam soil. The excess amount of water beyond the field capacity produces water

Stomatal Transpiration

Transpiration which takes place through the stomata which are present on the leaves of the plants and aerial organs is called stomatal transpiration. The maximum amount of water is lost by this type of transpiration. About 80% to 90% transpiration occurs through the stomata.

Cuticular Transpiration

Loss of water through the cuticle which is present on the herbaceous stem and leaves is called cuticular transpiration. The cuticle is a wax-like thin layer present on the epidermis. About 9% of transpiration is cuticular.

Lenticular Transpiration

Minute pore-like structures found on the stem of some woody plants and the epidermis of some fruits are called lenticels. Some amount of water lost by lenticels is known as lenticular transpiration. However, it is approximately 0.1% to 1% of the total water lost.

Bark Transpiration

It occurs through the corky covering of the stem. The amount is 0.5% of the total transpiration.