314en08

8

ABSORPTION, TRANSPORT AND WATER LOSS (TRANSPIRATION) IN PLANTS

Water is the most important component of living cells. It enters the plants through roots and then moves to other parts. It is also lost by transpiration through the aerial parts of plants, mainly through the leaves. There are several phenomena involved in the movement of water about which you will study in this lesson.

OBJECTIVES

After completing this lesson, you will be able to :

- *define the terms permeability, diffusion, osmosis and plasmolysis;*
- *define and differentiate between the active and passive absorption;*
- *explain imbibition, water potential, turgor pressure and wall pressure, wilting;*
- *describe the pathways of water from root hair up to leaf;*
- *describe the mechanism of translocation of solutes in plants;*
- *explain the process and significance of transpiration;*
- *list the factors affecting the rate of transpiration;*
- *explain the opening and closing mechanism of stomata (potassium ions theory) and list the factors affecting stomatal movement;*
- *explain the process of guttation and list the factors affecting rate of guttation.*

8.1 FOUR BASIC PHENOMENA-PERMEABILITY, DIFFUSION, OSMOSIS AND PLASMOLYSIS

8.1.1 Permeability

Permeability is the property of a membrane to allow the passage of the substances through it. The plant cell wall is **permeable** because it allows both solvent and solute molecules to pass through it. Cuticle layer is impermeable. All biological membranes (cell membrane, mitochondrial membrane, nuclear membrane etc.) are **selectively permeable** as they allow penetration of only solvent molecules but not the solute molecules.

8.1.2 Diffusion

If a can containing volatile substance, such as ethyl ether, is opened in a room, their molecules will soon be distributed in the room until their concentration is the same throughout the room. In other words, ether molecules diffuse into the air in the room. Similarly the fragrance of incense sticks or agarbatti spreads from one corner of the room to the other due to diffusion. Another example is placing a small crystal of a water soluble dye (copper sulphate) at the bottom of a test tube and then pouring water carefully over the crystal. Dye molecules will dissolve and the colour will spread slowly throughout water, partly because of the movement of dye molecules through the water and partly because of the movement of water molecules into a region close to the crystal.

Thus diffusion is the intermingling of molecules of the same or different substances as a result of their random movement. It is dependent on the difference in concentration of molecules of different substances in the adjacent areas and this difference is called **diffusion gradient**.

Diffusion is an effective method of transport of matter over short distances. For diffusion to take place no membrane is required. If a membrane is present, it should be fully permeable. The cell membranes are permeable to both gases CO_2 and O_2 and hence the two gases are able to diffuse freely (Fig. 8.1).

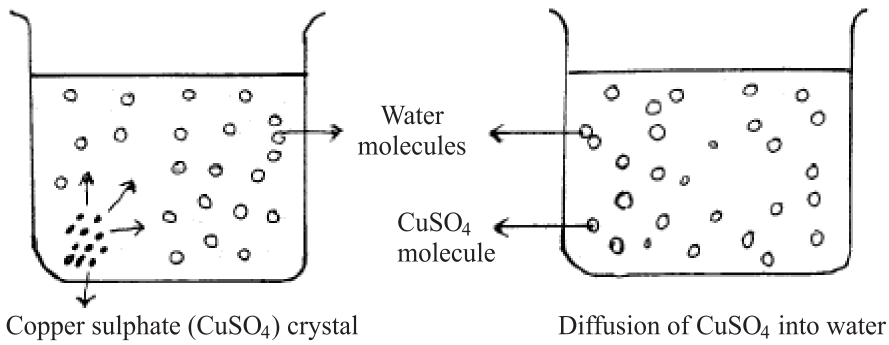

Fig. 8.1 Diffusion of copper sulphate (CuSO4) in water.

8.1.3 Osmosis

Osmosis can be regarded as a special kind of **diffusion of water molecules** from a region of their high concentration to their region of low concentration through a semipermeable membrane (Fig. 8.2). In osmosis, the water molecules move, and the presence of a semipermeable membrane is essential.

Experiment to demonstrate Osmosis

Experiment : To demonstrate the phenomenon of osmosis through plant membrane with the help of potato osmoscope (Fig. 8.3)

Requirements. A large potato tuber, 10% sugar solution, beaker, water, scalpel, pin.

Method. Take a large potato tuber and peel off its outer skin with the help of scalpel. Cut its one end to make the base flat. Now make a deep hollow cavity on the opposite side. Pour some sugar solution to fill half of the cavity and mark the level by inserting a pin in the wall of the tuber. Put the potato in the beaker containing a small amount of water and allow the apparatus to stand for some time. Make sure that the level of water in the beaker is below the level of sugar solution in the cavity of potato osmoscope. (Fig. 8.3)

Observation and Conclusion. The level of sugar solution in the cavity rises. It is because of the movement of water molecules into the cavity from pure water in the beaker. This experiment shows the phenomenon of osmosis.

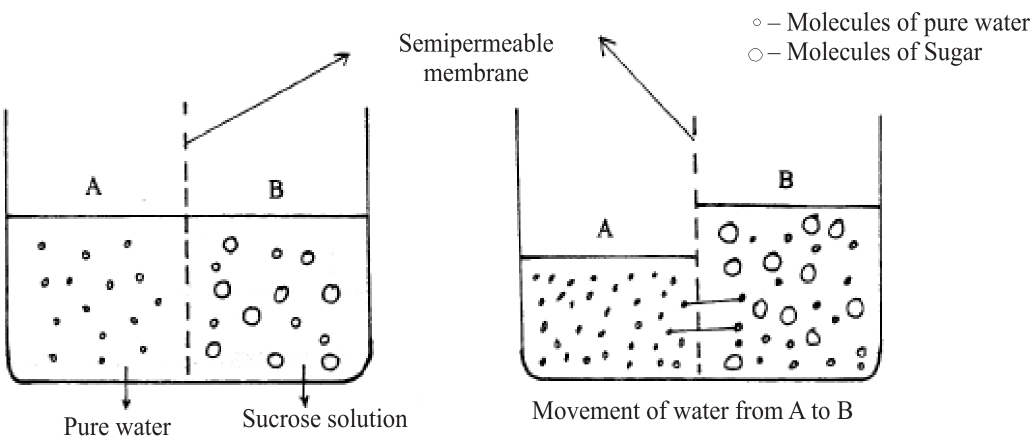

Fig. 8.2 Osmosis - Movement of water molecules through a semipermeable membrane.

Explanation. The living cells of potato tuber collectively act as differentially permeable membrane (membrane which permits movement of certain molecules only through it). The two solutions i.e. pure water in the beaker and sugar solution in the cavity are separated by living cells of potato. Water molecules continue to move through the cell-membranes, into the sugar solution till the concentration of water molecules in the beaker becomes equal to that in the cavity of the osmoscope. If sugar solution is taken in the beaker and pure water in the cavity, the result will be reversed. The movement of water will not occur if the skin of potato is not removed because the skin, being waxy, is impermeable to water.

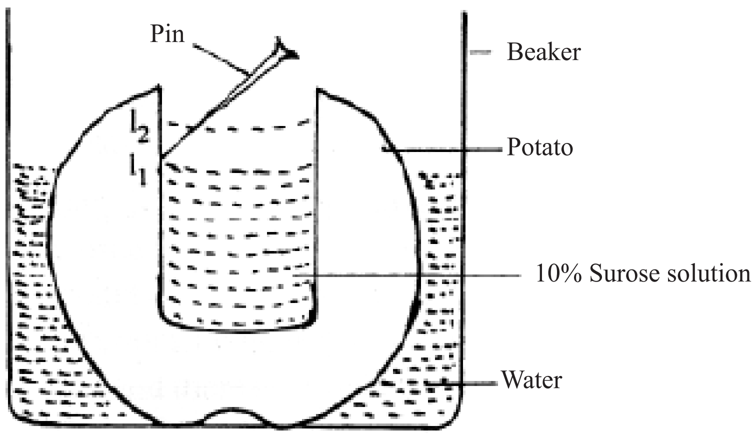

Fig. 8.3 Experiment to demonstrate osmosis by using potato osmoscope.

Difference between Diffusion and Osmosis

Diffusion	Osmosis
1. Diffusion is the movement of a given substance from the place of its higher concentration to an area of its lesser concentration, irrespective of whether separated or not separated by a semipermeable membrane.	**1.** Osmosis is a special type of diffusion of solvent molecules such as water from lower concentration of solution to higher concentration of solution when the two are separated by a semi permeable membrane.
2. The diffusion may occur in any medium. The moving particles may be solid, liquid or gas.	**2.** It occurs in liquid medium and only the solvent molecules such as water move from one place to another.

If you place a cell in a solution, it may shrink, swell or remain unchanged on the basis of relative concentration of water and solutes with respect to their concentration in the cell. On the basis of which solution can be of 3 types:

- **Isotonic** **solution** has the same concentration of water and solutes as inside a cell. Cell remains stable in isotonic solution or there is no entry or exit of water from the cell.
- **Hypotonic** **solution** outside has lower solute concentration than inside the cell. The cell swells as water enters the cell, through the process called **endosmosis**.
- **Hypertonic** **solution** outside has higher solute concentration than inside the cell. Water from cell moves out so the protoplasm of the cell shrinks and collects in the centre of the cell, through the process called **exosmosis**.

Osmotic Pressure and Osmotic Potential

When pure water is separated from a solution by a semipermeable membrane, pure water tends to enter the solution by osmosis. Now the maximum pressure required to prevent the osmotic entry of water in a solution even though the concentration of water in the solution is low as compared to that in pure water, is called **osmotic pressure**.

Imbibition

Before cooking chick pea or gram, it is soaked in water overnight. Next morning the dry chick pea looks well swollen as it has imbibed water.

Imbibition in plant cells refers to the absorption and **adsorption** of water by protoplasmic and cell wall constituents. Water is absorbed as a result of both diffusion and capillary action. Imbibition is a process that accounts for only when solid plant material (dry wood, dead or living air dried seeds) comes in contact with water. In case of living dry seeds water is initially adsorbed by imbibition and thereafter water entering into the inner tissues, is absorbed by osmosis.

Imbibition produces a large pressure, so much so that dry wood can even break a piece of rock in the presence of water. Because of imbibition, the wooden doors, during rainy season, swell up and it becomes difficult to close the door.

Importance of Imbibition

- Imbibition is the initial step in the germination of seeds.
- It causes swelling of seeds and breaking of seed coat.

8.1.4 Plasmolysis

When a cell is placed in a solution, it will either shrink, swell or will remain unchanged depending upon the concentration of the bathing solution or the solution in which the cell is placed.

(i) When a cell is placed in a **hypertonic** solution i.e. when the concentration of the outer solution is higher than the cell sap, water from the cell move out resulting in shrinkage of the protoplasm in the centre of the cell. This phenomenon is known as **plasmolysis.** The space between the cell wall and the protoplast is occupied by the bathing solution as the cell wall being dead, is permeable to the outer solution.

(ii) When such a plasmolysed cell is placed in a **hypotonic** or dilute solution or pure water, water moves into the cell causing the protoplasm to stretch and get back to its original shape. This phenomenon is known as deplasmolysis. The cell after deplasmo-lysis, becomes fully turgid.

(iii) When a cell is placed in an **isotonic** solution or a solution with similar concentration as that of the cell sap, there is no change in the shape of the protoplasm or the cell.

Plasmolysis is a physical phenomenon. A cell can become plasmolysed and deplasmolysed depending upon the concntration of the outer solution in which the cell is placed. No chemical change is caused to the cell. Plasmolysis is a kind of defense mechanism against adverse (stress) conditions such as hypertonic soil solution.

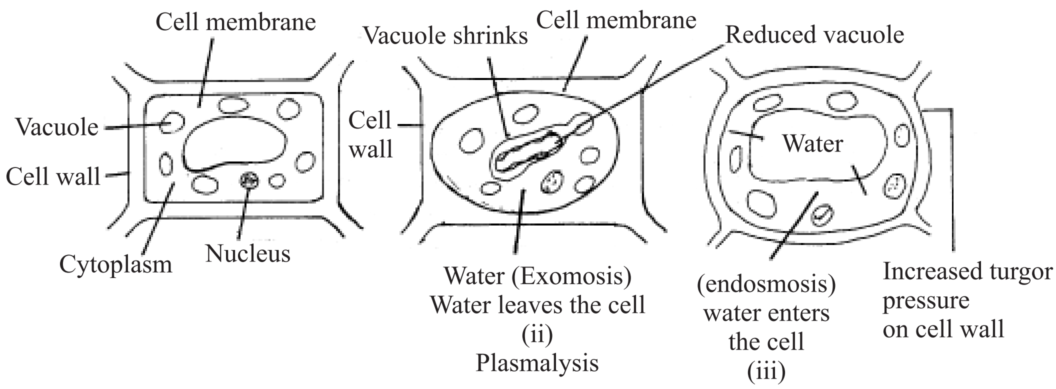

Fig. 8.4 Changes in a plant cell when placed in hypertonic isotonic (i), (ii) and hypotonic solution (iii).

INTEXT QUESTIONS 8.1

1. Define diffusion.

   ....

2. Give one point of difference between osmosis and diffusion.

   ....

3. Name the process because of which crystals of $KMnO_4$ added to water makes it purple.

   ....

4. If blood cells are placed in salt water what will happen to them ? Based on your answer state if salt solution is isotonic, hypotonic or hypertonic?

   ....

5. When does plasmolysis occur in plant cells?

   ....

6. Name the phenomenon which makes it difficult to close a wooden door after monsoon?

   ....

8.2 WATER POTENTIAL

Water-Potential or chemical potential of water is the energy of water molecules or tendency of water to leave a system or the ability of free water molecules to do work or move. Water moves from a region of high water potential to a region of low water potential.

Water-Potential of pure water is taken as zero. When solutes are dissolved in pure water or in a solution some water molecules are used in dissolving the solutes thus less number of the water molecules are available to do the work. Hence a solution has less energy or potential as compared to pure water. The water potential of a dilute solution is more than that of a concentrated solution. The value of water potential of a solution is less than that of pure water or zero i.e. a negative number. Water potential is designated by a Greek letter ψ (psi). Pure water has highest water potential or $\psi = 0$ for pure water.

Water potential determines the water status in plant cells and tissues. The lower the water potential in a plant cell or tissue, the greater is its ability to absorb water. Conversely, the higher the water potential, the greater is the ability of the tissue to supply water to other more desiccated cells or tissues.

8.3 TURGOR PRESSURE

Turgor Pressure is the pressure exerted by the protoplasm against the cell wall.

In a turgid cell, the turgor pressure is equal to the back pressure exerted by the cell wall against the protoplasm. This back pressure exerted by the cell wall onto the protoplasm or the cell contents, is called as **wall pressure (WP).** These two pressures are equal and opposite in direction (Fig. 8.5). When TP becomes more than the WP the cell or will burst.

Turgor pressure is maximum when the cell wall cannot stretch any more. Such a cell is said to be fully turgid. At this point a dynamic equilibrium reaches i.e. the amount of water entering the cell is equal to amount of water leaving the cell.

Turgor pressure develops in the plant cells only because of the presence of cell wall which is able to resist the pressure generated by the protoplasm due to entry of water. It is a real pressure not a potential one and can occur to a great extent. In case of animal cells, where the cell wall is lacking, the plasma membrane bursts if the turgor pressure increases.

Turgor pressure plays a very important role in plants:

- Turgor pressure helps in maintaining the shape and form of the plant.
- The stems of herbaceous plants and the ones with non-woody tissues like maize, sugarcane and banana are held straight by fully turgid cells packed tightly together.
- Turgor pressure holds the leaves in a flat and horizontal position by keeping the mesophyll cells turgid.
- Turgor pressure helps in cell enlargement and consequently in stretching of the stems.
- Opening and closing of stomata is governed by turgidity and flaccidity of the guard cells.
- Certain plants like bean and Touch Me Not plant- *Mimosa pudica* show quick response of leaves due to change in light intensity or by touch stimulus followed by changes in the turgidity of cells present at the bases of leaves and leaflets.

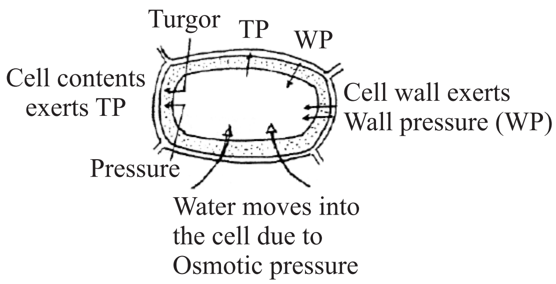

Fig. 8.5 A turgid cell showing osmotic pressure, turgor pressure and wall pressure.

Availability of water in the soil

The plants absorb water through the root hairs from the soil. The soil contains water in three forms (Fig. 8.6)

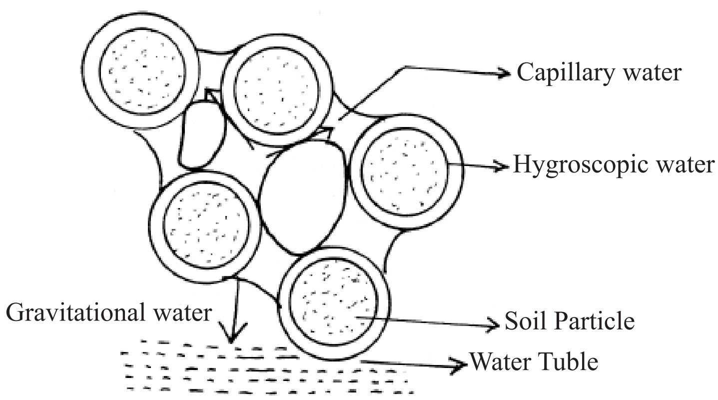

Fig. 8.6 Types of soil water.

(i) **Gravitational Water.** It is the water that drains downwards through the soil. The level to which it drains is called the water table. The water table of a place differs in depth due to rainfall.

The gravitational water lies far below and is generally not available to plant roots. It is of extreme importance as it causes washing out of minerals and nutrients from the soil through the process called leaching.

Part of water that is retained by soil could be hygroscopic water and/or capillary water.

(ii) **Hygroscopic Water.** It is the water that is retained as a thin film around the individual soil particles. Strong adhesive forces between the soil particles and the water molecules hold this water tightly. This is the water least available to the plant and is generally the water left in the dry soils. In the clay soils, it amounts to about 15% and in the sandy soils, it amounts to about 0.5%.

(iii) **Capillary Water.** The soil particles always have very fine pores in between, forming a very fine capillary system As the water spreads, it fills the finer pores and is held round the soil particles by capillary forces against the force of gravity, due to high surface tension of water. It is this water, which is readily available and is easily utilized by the plant roots. The clay soil being very fine textured holds much more water than sandy soil. When a soil rich in organic matter, is watered, it retains good amount of capillary water and this condition is known as **field capacity.**

8.4 ABSORPTION OF WATER BY PLANTS

- Major portion of water required by plants is absorbed by roots but in some cases water may be absorbed by leaves and stems also.
- Root hair is a specially modified epidermal cell meant for absorption of capillary water of the soil.
- The plasma membrane and the vacuolar membrane (tonoplast) act as semipermeable membranes and water is absorbed by osmosis.
- Soil solution should have a higher water potential as compared to root hair cell, then only water will enter the root hair cell. Once into the root hair, water will pass into cortical cells, endodermis, pericycle and into the xylem vessel. The movement of water is purely dependent on water potential gradient.
- Water movement into the plant follows two pathways – **symplast** and **apoplast** (Fig. 8.7a).
- Cytoplasm of the entire plant is connected through plasmodesmata which are the protoplasmic strands forming the **symplast system**. Water movement through the cells take this symplast pathway by osmosis.

  The cell wall and the intercellular spaces form the apoplast pathway which allows water movement inside the plant by the phenomenon of capillarity and adsorption.
- The water absorbed through the roots is transferred radially to the xylem, from where it reaches to all the other parts of the plant body by vertical conduction of water through the xylem vessels (Fig. 8.7b).

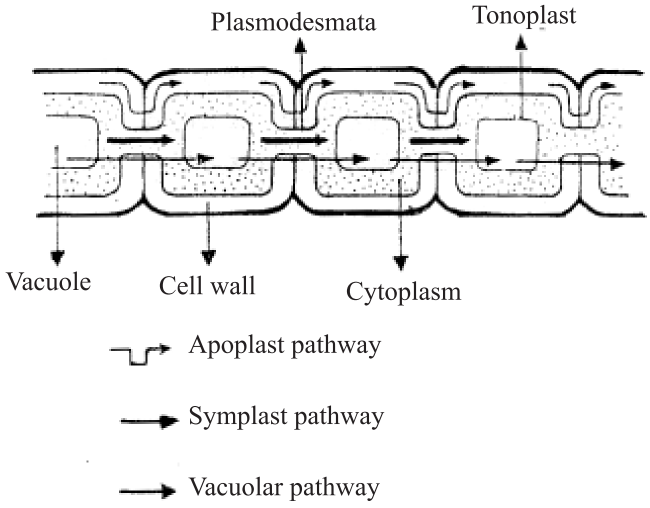

Fig. 8.7a various pathways of water movement

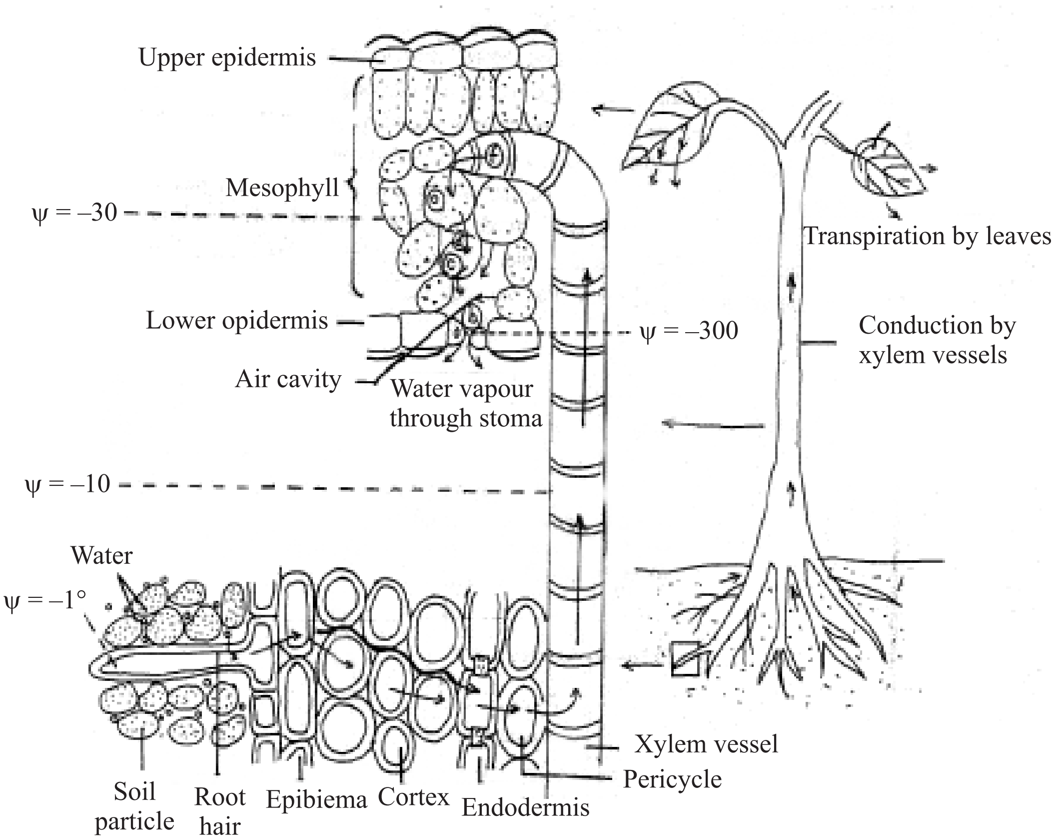

Fig. 8.7b Diagram to show absorption of water bvy root hair, its radial transport to cortex, and upward transport to leaves through xylem

Conduction of water through the xylem

The content of xylem vessels is known as xylem sap. Various theories have been postulated to describe the lifting of the xylem sap or ascent of sap in the xylem.

Root Pressure Theory

If a stem is cut few inches above from the ground with a sharp knife, xylem sap is seen flowing out through the cut end. This phenomenon is known as **exudation** and this is due to the positive pressure developed within the root system due to continuous absorption of water by osmosis which develops a positive pressure known as root pressure. This pressure can be measured and ranges from 3 to 5 atmospheres. But this pressure is enough to raise water to small heights in herbaceous plants, but it does not explain rise of water in stems of tall trees that are taller measuring 10 to 100 meters.

Physical Force Theory or Cohesion Theory

This theory takes into account the physical forces which explain uplift of water to great heights in very tall trees. The three forces that act together are force of cohesion (attraction between water molecules), force of adhesion (attraction between water and lignocellulose walls of xylem) and transpiration pull which lifts the water column by creating a tension inside the xylem vessel. Water forms an unbroken column starting from the intercellular space of the leaf mesophyll to the xylem of the leaf, through stem and root to the water in the soil. A water potential gradient exists between the leaf to the root and transpiration causes a pull of the entire water column. So long as the column is an unbroken one from the outer atmosphere, through the plant upto the soil, water is lifted up by the force of **transpiration pull.**

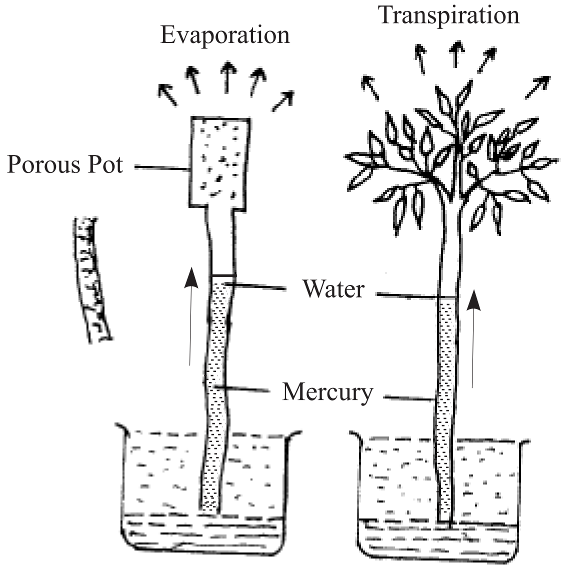

Fig. 8.8 Effect of evaporation and transpiration on absorption of water

8.5 TRANSLOCATION OF ORGANIC SOLUTES

Movement of organic and inorganic solutes from one part of the plant to another is known as translocation, e.g. transport of sugar in sieve tubes of leaves to stem or fruit.

There are experimental evidences to suggest that phloem is the tissue involved in translocation of products of photosynthesis i.e. sugars.

Sugar is produced in photosynthesis in the leaves and then sent to all part of the plants for the growth and development of the plant. Leaf is known as the "source", where the food is produced and all other parts of the plant which receive this food is known as the "sink". Sink can be root, stem, fruits and storage organs like tuber, bulbs and, rhizomes. Thus unlike conduction of water in xylem which takes place in one direction from the root to upwards in the aerial parts of the plant, phloem translocation from a leaf takes place in all directions.

Mechanism of translocation

Sugar solution in the phloem sieve tube moves along the water potential gradient created between the source (leaf) and sink (storage) cells

Here we find a mass movement of sugar solution from the leaf mesophyll to sieve tubes of leaf, and then, to all parts of the plant.

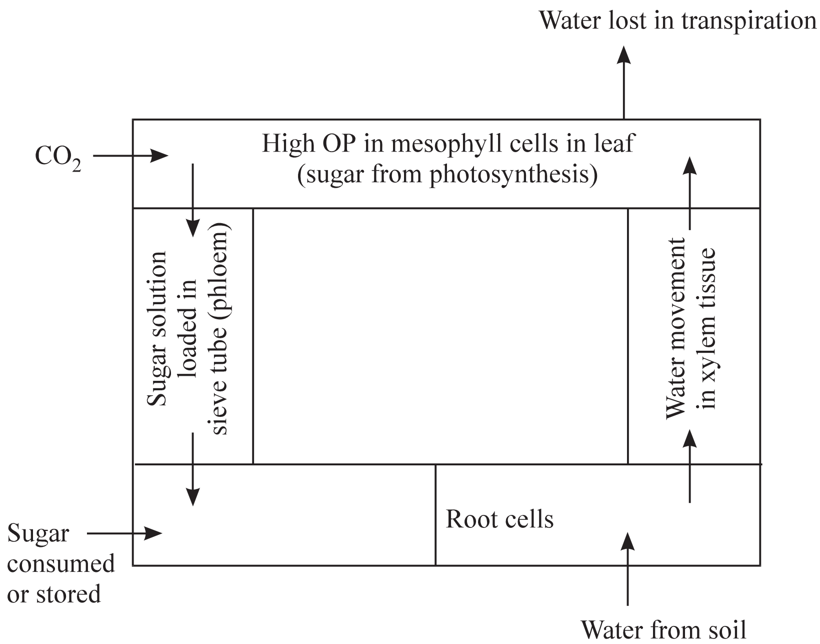

Fig. 8.9 Mechanism of translocation

This model known as Munch hypothesis or Mass flow theory is most acceptable model for phloem translocation.

INTEXT QUESTIONS 8.2

1. Which part of the plant absorbs water and minerals?

   ....

2. What are plasmodesmata?

   ....

3. How does translocation occur in plants?

   ....

4. What is the process of ascent of sap?

   ....

5. Which are three different forms in which water is present in the soil?

   ....

8.6 TRANSPIRATION

8.6.1 What is transpiration

The loss of water from aerial parts of the plant in the form of water vapour is termed **transpiration** and, when transpiration is low and absorption of water by roots is high, loss of water from leaves in the form of liquid is termed **guttation**.

Transpiration may occur through three main sites in the plant : 1. cuticle 2. lenticels and, 3. stomata.

(i) **Cuticle :** Cuticle is the waxy covering of the epidermis of leaves and green herbaceous stems. Though it is meant to check transpiration, still about 10% of the total transpiration may take place through fine cuticular pores, and he process is known as cuticular transpiration.

(ii) **Lenticels :** Lenticels are areas in the bark of stems, branches and fleshy fruits which are made up of loosely arranged cells that account for about 0.1 percent of water loss. It is known as lenticular transpiration.

(iii) **Stomata :** Stomata are minute pores on the epidermis of leaves, or tender green stems, whose opening and closing are controlled by guard cells. About 90 percent of water loss from plants takes place through stomata by the process known as stomatal transpiration.

8.6.2 Mechanism of transpiration

Transpiration occurs in two stages :

(i) Evaporation of water from the cell walls of mesophyll cells into the intercellular spaces.

(ii) Diffusion of this water vapour of the inter cellular spaces into the outside atmosphere, through cuticles, lenticels and stomata, when the outside atmosphere is drier.

8.6.3 Factors affecting transpiration

There are many external and internal factors that affect the process :

(i) Temperature : The increase in temperature increases the rate of transpiration by increasing the rate of evaporation of water from cell surface and decreasing the humidity of the atmosphere.

(ii) Wind velocity : The increase in wind velocity increases the rate of transpiration by removing the water vapour of the atmosphere and lowering the relative humidity, around the aerial parts of a plant.

(iii) Light : Light has got no direct effect on the rate of transpiration but indirectly it affects the rate in two ways, firstly by controlling the stomatal opening and secondly by affecting the temperature. With increase in intensity of light rate of transpiration increases because stomata get opened and the temperature increases.

(iv) Water supply : Deficiency of water supply in the soil decreases the rate of transpiration by decreasing the rate of absorption. When the deficiency of water in the soil becomes too much then the plants wilt and do not recover from wilting unless water is supplied in the soils. This is known as **permanent wilting**. When in a hot and dry summer day the plant transpires more causing higher water loss by the leaves than the roots are able to absorb, even though there is enough water in the soil, the plants wilt exhibiting **temporary wilting** as the plant recovers from such wilting in the late afternoon or at night.

(v) Atmospheric pressure : Reduction of atmospheric pressure reduces the density of external atmosphere thus permitting more rapid diffusion of water. Plants growing on high altitudes will show higher rate of transpiration hence they develop xerophytic characters.

(vi) Atmospheric humidity : Humidity means the amount of water vapour present in the atmosphere. The diffusion and evaporation of water depends on the vapour pressure gradient or the difference of water potential gradient between the atmosphere and the inside of the leaf. More the difference more will be the rate of transpiration.

Internal plant factors

Certain plant adaptations reduce transpiration

- Reduced size of the leaves, thereby reducing transpiring surface. Some xerophytic plants have needle like or spine like leaves (*Pinus* and *Opnuntia*)
- thick deposition of cutin (wax like substance) on the leaf surface.
- stomata found sunken in the cavities surrounded by epidermal hairs as in *Nerium* and *Cycas*.
- root shoot ratio, when there is more root and less of shoot system or leaves, there will be more of transpiration. Root is the water absorbing surface and shoot or leaves represent the transpiring surface; high root shoot ratio will cause more transpiration.

8.6.4 Role of Stomata in Transpiration

Since most of the water is lost through stomata, plants regulate the degree of stomatal opening and closing to reduce the water loss, with the help of guard-cells.

It has been seen that stomata show periodic opening and closing during the day (diurnal variation) depending upon the heat and light, water content of the cell and humidity. The stomata are generally closed during the night, and remain open during the day in the presence of sunlight.

From early morning till midday, the stomata are open and hence the transpiration increases till midday.

During the sunny mid-day, the stomata are closed and leaves get wilted to transpiration. From late afternoon till evening, the stomata are open again and hence the transpiration increases. At night, the stomata are closed and hence the transpiration is very low.

8.6.5 Stomatal-Apparatus

Structure of Stomatal-Apparatus

Each stoma represents a minute pore surrounded by two **guard cells**. Which in turn, are closely surrounded by two or more subsidiary cells. The stoma acts as a *turgor-operated valve,* which closes and opens according to alternate change in the flaccidity and the turgidity of guard cells and subsidiary cells. The guard cells have unevenly thickened walls. The cell wall **around stoma is tough and flexible** and the one away from stoma is thinner. The shape of guard cells differs in dicots and monocots, though the mechanism remains the same.

Mechanism of Stomatal action

The opening and closing of stomata depends upon the turgidity and flaccidity alternately in the guard cells and subsidiary cells. When the **guard cells are turgid, and subsidiary cells are flaccid, the stoma opens,** and, when **guard cells lose water** into subsidiary cells so that guard cells become flaccid and subsidiary cells become turgid, the **stoma closes.** The mechanism of opening and closing of stomata in dicots and monocots is as give below:

(a) The **dicotyledonous** plants have kidney shaped guard cells. The inner walls around the stoma are thicker than the outer walls.

A. When guard cells get distended by turgor pressure → Guard cells expand → Tough inner walls become convex → Stomata open

B When the turgor pressure in guard cells decreases → Guard cells sag → Inner cell walls come closer. → Stomata close

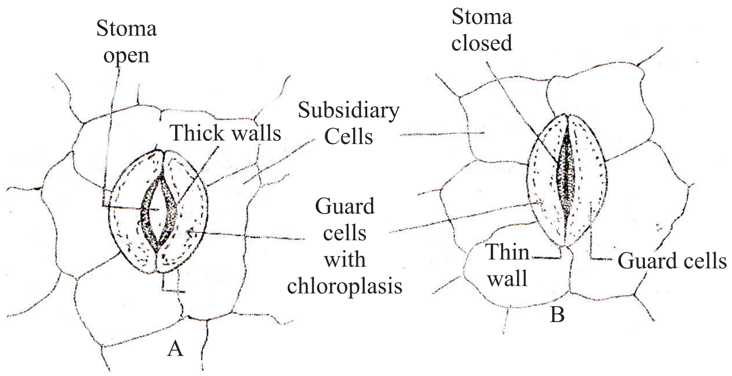

Fig. 8.10 Stomatal action in Dicots.

(b) In **monocotyledonous** plants, the guard cells are **dumb bell shaped** with thickened walls towards and nearest the stoma and thinner walls towards the inflated region.

A. When the guard cells become turgid → The region with thin walls bulges and gets inflated → The thick walls move apart → Stoma opens

B. When the guard cells lose water → The inflated part sags → The thick walls collapse → Stoma close

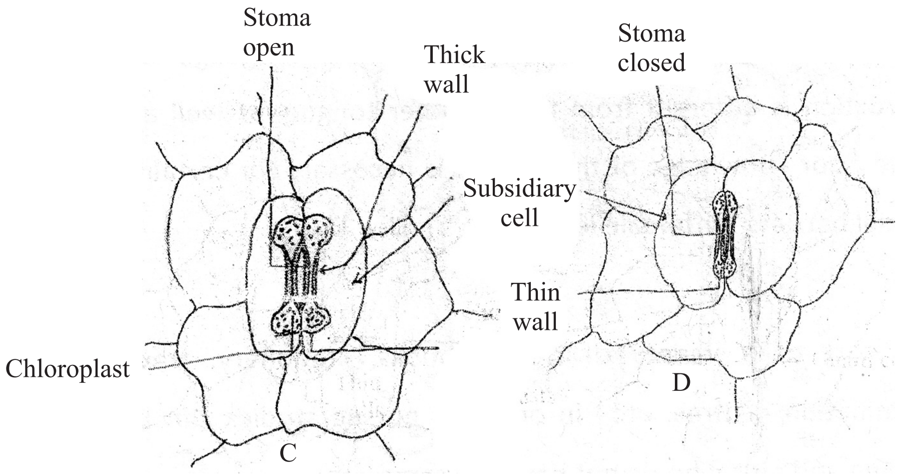

Fig. 8.11 Stomatal action in monocot.

Changes in turgidity and flaccidity, alternately involving guard cells and subsidiary cells, in bringing about opening and closing of stomata has been known for a long time but the mechanism that leads to turgidity needs to be explained.

(i) Starch- Sugar Hypothesis

This hypothesis goes by the basis that the increase in sugar concentration due to photosynthesis in guard-cells and hence endosmosis of water during the day leads to turgidity of guard cells leading to opening of stomata and the reverse i.e. decrease in sugar concentration followed by exosmosis leads to closing of the stomata at night. The changes in guard cells during the day i.e. in light and at night in the dark are as given below.

Reaction in Light

Utilization of CO_2 during photosynthesis in guard cells

↓

Drop in CO_2 leads to increase in pH or protoplasm becoming alkaline

↓

Conversion of starch into sugar

↓

Increased concentration of solute

↓

Endosmosis of water from subsidiary cells to the guard cells

↓

Increased turgor pressure of the guard cells leads to turgidity of guard cells accompanied by flaccidity of subsidiary cells

↓

Stoma opens

↓

A. Stoma opens during light

Reaction in Dark

Accumulation of CO_2 due to absence of photosynthesis in guard cells

↓

Increased acidity or decrease in pH due to formation of carbonic acid

↓

Conversion of sugar into starch

↓

Decreased concentration of solutes in guard cells

↓

Exosmosis of water from guard cells to subsidiary cells

↓

Decreased turgor pressure in guard cells leads to flaccidity of guard cells, accompanied by increased T.P. and turgidity of subsidiary cells.

↓

Stoma closed

↓

B. Stoma closed at dark

This theory can not explain stomatal movement where starch is absent in the guard cells or guard cells lack chloroplasts and opening of stomata at night and closing by the day in some plants like succulents (e.g. cacti).

(ii) Effect of potassium ions (K^+) on stomatal opening and closing

It has been convincingly proved that the accumulation of K^+ ions in guard cells brings about the opening of stomata and loss of K^+ ions from guard cells into subsidiary cells brings about, the closing of stomata.

During Day Light	During Night/Dark
Accumulation of K^+ ions by the guard cells	Loss of K^+ ions by the guard cells
↓	↓
Increased solute concentration	Decreased solute concentration
↓	↓
Endosmosis of water	Exosmosis of water
↓	↓
Increased turgidity	Decreased turgidity
↓	↓
Stoma opens	Stoma closes

The uptake of K^+ ions is balanced by one of the following.

(a) **Uptake of chloride (Cl^-) ions** as anions. The subsidiary cells lack chloroplast and take up Cl^- ions as anions to balance the influx of K^+ ions.

(b) **Transport of H^+ ions released from organic acids.** In some plants the guard cells contain starch, There is accumulation of organic acid like malate by conversion of starch into malic acid in light. The organic acid dissociates into malate and H^+. Potassium reacts with malate to form potassium malate which increases the solute concentration.

(c) Entry of K^+ is balanced by exit of protons (H^+).

(iii) Role of Abscisic Acid (ABA)

It has been observed that during water shortage in the soil or by intense solar radiation, a plant hormone abscisic acid accumulates in the leaves leading to closing of stomata, thus preventing an excessive water loss. Under experimental conditions also, when abscisic acid is applied to the leaves, stomata get closed and check water loss.

8.6.6 Significance of transpiration

(i) **Absorption of water.** Transpiration pull influences the rate of absorption of water from the soil.

(ii) **Water movement.** By transpiration, water moves upwards and as it passes into the cell vacuoles, it makes the cells turgid. This gives a form and shape to the cells and to the plants as a whole.

(iii) **Mineral salt transport.** The water stream moving upwards also carries the dissolved minerals required for the development of the plant. Transpiration also helps in distributing these minerals through out the plant body.

(iv) **Cooling.** The evaporation of water during transpiration cools the leaves.

(v) **Protection from heat injury.** Some plants like Cacti retain water by reducing transpiration. This saves the plants from high temperatures and strong sunlight.

Transpiration is a necessary evil

Stomata remain open during day time for the absorption of carbon dioxide and release of oxygen for a very important process of photosynthesis. When the stomata remain open for this important gaseous exchange, escape of water vapour cannot be controlled. Thus loss of water is a wasteful process which cannot be avoided because stomata must remain open to do some thing more important that is absorption of carbondioxide during day time for photosynthesis. It is for this reason that Curtis in 1926 has referred transpiration as a necessary evil.

Factor affecting stomatal movement : Any condition which causes turgidity of the guard cell will cause stomatal movement.

1. Increased Solute concentration of the guard cells, which will allow endosmosis of water into the guard cells making them turgid.
2. Light causes photosynthesis in guard cell by the chloroplasts and hence accumulation of sugar in the guard cells would increase concentration of solutes in guard cells.
3. Entry of potassium ions from subsidiary cells into guard cells would further increase solute concentration in guard cells.

8.6.7 Anti-transpirants

Many crop plants give poor yield in dry seasons, as the water lost by transpiration is much more than the water uptake by the roots. The rate of transpiration can be reduced by the application of certain chemicals known as anti transpirants. These chemicals however, should not affect the CO_2 uptake. The reduction in transpiration is achieved by two means.

(i) Chemicals like phenyl mercuric acetate – PMA and abscisic acid –ABA cause partial closure of stomata checking transpiration to some extent.

(ii) Some waxy substances like silicon emulsions form a thin film over the leaf and cover the stomata without affecting the uptake of CO_2.

Guttation. It is seen in early morning in the form of water-drops at the margins or tips of leaves of herbaceous plants (Fig.8.12a). The plants in which transpiration is low and the root pressure is high, the liquid water droplets are seen at the vein ending.

– It occurs through specialized pores called hydathodes present near the vein endings (Fig. 8.12b).

– It is quite common in young grass seedlings and in the tropical rain forests due to warm and humid nights. Tomato and *Nasturtium* are some common examples.

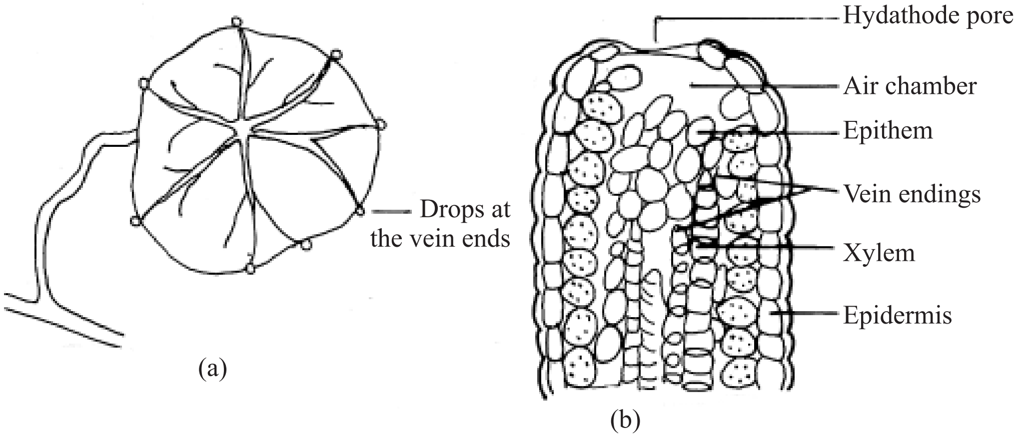

Fig. 8.12 (a) *Nasturtium* leaf showing guttation at the margin of leaf (b) A vertical section of a leaf showing hydathode.

8.6.8 Difference between Transpiration and Guttation

Transpiration	Guttation
(i) Water is lost in the form of water vapor.	(i) Water is lost in the form of water drops.
(ii) Occurs through stomata, cuticle and lenticels.	(ii) Occurs through special pores, called hydathodes.
(iii) Occurs during day time and at high temperature.	(iii) Occurs at night and early in the mornings at low temperature.
(iv) Water vapour lost is pure water and does not contain minerals.	(iv) Water lost has substances dissolved in water. It contains sugars, salts and amino acids.
(v) Increased transpiration is physical process (see cohesion physical force theory)	(v) It is due to increased root pressure that develops in the aerial shoot system when water absorption by roots is more and transpiration by aerial plant parts is low.

INTEXT QUESTIONS 8.3

1. Name the pressure in guard cells responsible for opening and closing of stomata.

   ....

2. Mention the shape of guard cells in monocots and dicots.

   ....

3. Give a point of difference between a stoma and a hydathode

   ....

WHAT YOU HAVE LEARNT

- The movement of water from one cell to another depends upon the water potential of the cells.
- Water always moves from a region of lower solute concentration (higher water potential) to the region of higher solute concentration (lower water potential) i.e. along the water potential gradient.
- A more concentrated solution has a higher osmotic potential (earlier termed osmotic pressure).
- Osmotic pressure is expressed in terms of energy. Water always moves from a region of higher free energy to a region of lower free energy.
- Water potential is the capacity of a solution to give out water. It is represented by the word Psi ψ. It is affected by the solute concentration and external pressure.
  - ψ of pure water = zero.
  - More solute means low water potential.
  - A solution has lower water potential than pure water.
  - Water potential of a solution is a negative number i.e. less than zero.
- Plants absorb water by their roots (mainly by root hair) from the soil through osmosis. The increased water content inside the protoplasm exerts a turgor pressure on the cell wall.
- The equal and opposite force exerted by the cell wall onto the cell contents is termed as wall pressure.
- Water is present in the soil as gravitational water, hygroscopic water (least available to the plant) and capillary water (most readily available to the plant).
- The water absorbed by root hairs flows to the xylem vessels mainly by the apoplast pathway.
- The water moves up through the xylem vessels to the leaf along the water potential gradient as explained by the cohesion- tension theory (most acceptable). Transpiration or evaporation of water from the plant through stomata, causes a pull and water moves up like a water column due to the force of cohesion and tension created by transpiration.
- Certain plants show guttation due to high root pressure and low transpiration.
- Turgidity of guard cells is explained by the increased conversion of starch into sugar and by the accumulation of K^+ ions.

- Various environment factors like temperature, light, wind, humidity and internal factors like structure of leaf and root-shoot ratio affect the transpiration.
- Transpiration not only brings about ascent of sap but also has a cooling effect and saves the plant from heat injury.
- When the transpiration rate exceeds the water absorption rate, it leads to **temporary wilting** of the plant.
- When a plant undergoes wilting due to water deficit in the soil, it is called **Permanent Wilting.**

TERMINAL EXERCISES

1. Name two types of passive absorption in plants.
2. In what ways diffusion is important to a plant ?
3. Name various factors that affect osmosis in plants.
4. Differentiate between turgor pressure and wall pressure.
5. Discuss the mechanism of stomatal opening in dicot plants.
6. Explain any four factors that affect transpiration in plants.
7. Describe an experiment to demonstrate osmosis by potato osmometer.
8. Discuss the cohesion tension theory for uptake of water in plants.
9. Describe the mechanism of translocation of solutes. Name the most appropriate theory for the translocation of solutes in plants. Who proposed this theory ?
10. Differentiate between symplast and apoplast pathway of water movement in plants.
11. Define transpiration.
12. Name the holes in the bark through which transpiration in the bark of old trees takes place ?
13. Why is transpiration considered to be a necessary evil ?
14. Give one way by which desert plants prevent transpiration.
15. State one point of difference between transpiration and guttation.

ANSWERS TO INTEXT QUESTIONS

8.1

1. Movement of molecules from their region of higher concentration to the region of lower concentration.
2. A semipermeable membrane is required for osmosis and not necessarily for diffusion.
3. Diffusion

4. Water will move out from the blood cells and they will shrink.
5. When the cell is placed in a hypertonic solution.
6. Imbibition

8.2
1. Root
2. Cytoplasmic connections between plant cells
3. Through the phloem
4. Movement of water and minerals from roots to leaves, that is from the ground to tip of plant.
5. Gravitational, Hygroscopic and capillary

8.3
1. Turgor pressure
2. Dicot : Kidney shaped

   Monocots : Dumb bell shaped
3. Stomata – are pores on the leaf surface through which water diffuses as vapour

   Hydathodes – special pores in leaf margins through which water is lost as water droplets.