Chapter - 5
Plant Water Relations

Water has been considered as one of the five fundamental elements in Indian mythology water is a major component of all living cells and it works like a specific favourable medium for all biological reactions. Water is an extra ordinary compound. It has many features like - polar nature, hydrogen bonds, universal solvent, high cohesive & adhesive forces, high specific heat, neutral pH (pH = 7), high density at 4^0C.

The availability of all the three states i.e. solid, liquid, gas in the limited range of temperature, dielectric constant etc.

Cell is the structural and functional unit of every organism. Different biological activities of the cell are due to the presence of protoplasm. Therefore, it is necessary to understand the properties of the protoplasm, to understand the physical, chemical methods which affect it. Diffusion permeability, osmosis, plasmolysis imbibition are such a few activities.

Diffusion

The smell of ammonia spreads to the entire room when the open bottles of ammonia are kept in the room. Similary the crystal of copper sulphate in the beaker filled with water turns water blue. This is because the molecules of the substances remain in constant motion due to their kinetic energy and try to distribute evenly in the available space. As molecules moves from the region of high concentration to region of low concentration which is called as Diffusion. The trend of diffusion is found to be similar to the molecules, particle & Ions of gas, liquids and solids but the rate of diffusion varies. The direction and speed of diffusion of molecules of two or more substances present in the same system does not depend on each other. For example if the concentrated sugar solution is kept in contact with pure water then molecules of sugar move towards water and water molecules move toward sugar solution.

Thus, the diffusion of the different substances in any system depends on the concentration of their own molecules. It is not influenced by the presence and concentration of other substances. It is known as independent diffusion. For example diffusion of water vapours, oxygen, carbon dioxide from the plants depends on the concentration of the related molecules in the atmosphere not on the presence and concentration of other molecules.

Factors affecting diffusion

Many factors affect the process of diffusion. Following are some of the major factor :-

1. Temperature : Increase in temperature increases the kinetic energy of the molecules, which also increases the rate of diffusion.

2. Density of diffusing particles : The rate of diffusion of any substance is inversely proportional to the square root of its density

$$\text{Rate of diffusion (R)} = \frac{1}{\sqrt{density\ (d)}}$$

Therefore, the diffusion gas with high density is less than the gas with low density.

3. Diffusion pressure gradient : The

molecules always move from the region of high diffusion pressure to region of low diffusion pressure that is molecules move from the high concentration area to low concentration area.

Significance of diffusion in plants

1. Exchange of O_2 & CO_2 gases between the atmosphere and plants.
2. Vaporization of water vapour in the atmosphere
3. Absorption of mineral salts.

PERMEABILITY

The process of entry and exit of any substance in the cell depends on the permeability of a particular cell membrane.

The layer which allows the movement both solute and solvent molecules is called permeable. Example Cell wall. The cell membrane present in the organisms is more permeable for water molecules and relatively less permeable for solute dissolved in water. Such membranes are called selectively permeable or differentially permeable. Example plasma membrane, tonoplast etc. In some circumstances the cell membrane is only permeable to solvent (water) molecules and it is compeletly impermeable for solute molecules. Such membranes are called semipermeable. Thus, the cell membrane or plasma membrane can behave as both semipermeable and selective permeable according in the need. Such layer which is resistant to both solute and solvent, that is nothing can move across, it is called impermeable. Example cuticle, cork.

OSMOSIS

The diffusion of solvent molecules by semipermeable membrane is called osmosis in other words, it is the process in which the diffusion of solvent (water) molecules from a higher concentration of solvent to low concentration of solvent across a semi permeable membrane.

Therefore, osmosis is also a form of diffusion in which the presence of semipermeable membrane in between the two systems is necessary.

The method of osmosis can be understood using the thistle funnel.

According to the picture the inverted thistle funnel is filled with sugar solution. Parchment paper is tied is the mouth of thistle funnel. Parchment membrane works as a semi permeable membrance & only allows solvent molecules to pass through it. This funnel when kept in the beaker filled with water, the water starts to diffuse in the funnel through the parchment paper or membrane. Thereby, the amount of solution increase in the funnel.

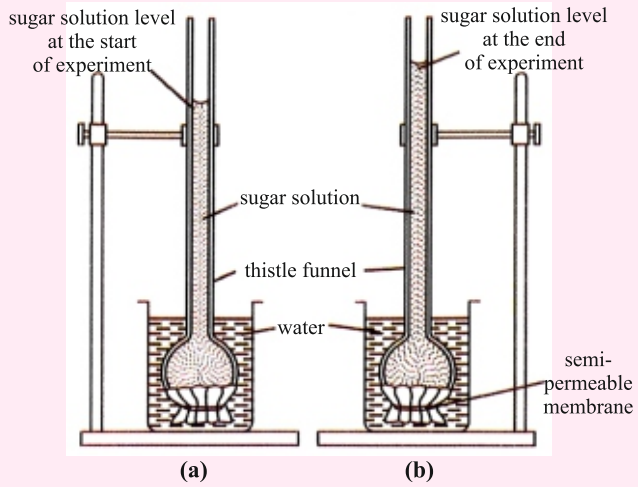

Fig. 5.1 Demonstration of osmosis by thistle funnel

There are two types of osmosis :-

1. Endosmosis: When a cell is placed in hypotonic solution (solution whose concentration is lower than the concentration of cell sap) water molecules enter the cell from the hypotonic solution. This process is called as endosmosis. In other words, osmotic entry of water in any system is called endosmosis.

2. Exomosis : When a cell is placed in hypertonic solution (solution whose concentration is higher than the concentration of cell sap) water molecules move out from the cell. This process is called as exosmosis. In other words, osmotic exit of water from any system is called exosmosis.

Importance of Osmosis

1. Absorption of water by the root hairs and the diffusion of water from one cell to another cell in plants is by the process of osmosis.

2. Turgidity depends on the osmosis. This phase is necessary for all cellular activities.
3. Water is distributed to the various parts of the plants by the osmosis.
4. The growth of young cells depends on this action.
5. This process in plants makes them resistance to freezing and desiccation.

PLASMOLYSIS AND DEPLASMOLYSIS

Plant : When the plant is kept in hypertonic solution (solution whose concentration is more than cell sap) for a longer time water start moving out of the cell by which the protoplasm of the cell starts shrinking.

And finally the contracted protoplasm is visible in the middle of the cell or in the corner of the cell. The condition of the cell is called plasmolysed and this process is called plasmolysis.

Preliminary stage of plasmolysis is known as incipient plasmolysis. If preliminary plasmolysed cell is kept in water or hypotonic solution, the water again entering in the cell by endosmosis and after some time the protoplasm spreads in the cell. This process is known as deplasmolysis.

The demonstration of plasmolysis process can be done with the help of violet colored lower epidermal cell of *Rhoeo discolor* leaf.

Separate the lower epidermis of the plant leaf and take two pieces. The purple color is spread in these cells. Put one piece in water and another piece in sugar solution.

After some time, when these pieces are looked under the microscope, the fragment which was submerged in the water, its cells appeared turgid but the purple colored cytoplasm of the cells of epidermis other the piece which was immersed in the sugar solution, gets compressed and collected in the middle. This process is called plasmolysis. Plasmolysed protoplasm spreads again in to the cell when plasmolysed cell was placed again in pure water for some time.

Different types of pressure generated in the cell

(I) Osmotic pressure : The pressure, which is necessary to stop the molecules of pure water from entering to the solution located at another side of semipermeable membrane is called osmotic pressure. The osmotic pressure of any solution is directly proportional to the molecules of the solute that are present in the solvent.

OP $\propto$ member of molecules of solute in solution.

(ii) Turgor pressure and wall pressure (TP, WP) : On keeping the cell in water the water molecules enters in to the cell due to the osmotic pressure. As a result, the plasma membrane or cell membrane pushes the cell wall outwards. Such centirifugal pressure on the cell wall is called turgor pressure (TP). Cell wall stays under stress due to turgor pressure and exerts a equal inward pressure in the opposite direction (outwards to inwards) which is called wall pressure.

(iii) Diffusion Pressure Deficit (DPD) : Pure water or solvent's diffusion pressure is highest. If solute is mixed in water, diffusion pressure of the forming solutions is lesser as compared to water. The more the solute, lesser will be the diffusion pressure. The difference in the diffusion pressure of solution in comparision to the pure solvent (water) is called diffusion pressure deficit.

This deficincy occurs in the diffusion pressure of the solvents here it is important that diffusion pressure decrease during the formation of solution from solvent but osmotic pressure increases. Diffusion pressure deficit shows the capacity of solution to absorbs solvent (water).

Due to this, DPD is also known as suction pressure (SP).

$$DPD = OP - TP$$

Relation between various pressures :

The tendency to enter the water molecule in the cell is called diffusion pressure deficit.

(i) These is no pressure on the cell wall in the flaccid cell, so the turgor pressure of such cell is zero. At this time, osmotic pressure of cell sap is

equal to the diffusion pressure deficit i.e.

If TP = 0

then DPD = OP

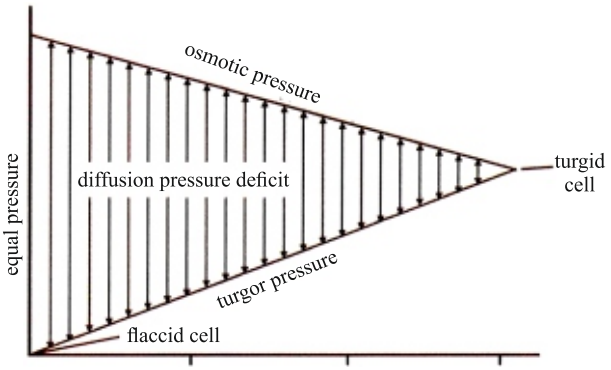

Fig. 5.2 Relationship between osmotic pressure, turgor pressure, diffusion pressure deficit

(ii) The relationship between turgor pressure, osmotic pressure and diffusion pressure deficit and their effect on cell volume.

Now, if this cell is placed in hypotonic solution then the water molceules enters into the cell, which cause the turgor Pressure of cell to increase gradually.

The concentration of cell sap starts decreasing with the entry of water in the cell so osmotic pressure of cell sap starts decreasing. Due to the increase in turgor pressure and decrease in osmotic pressure, the diffusion pressure deficit also decreases. When the cell is completely turgidm the osmotic pressure is equal to turgor pressure and the DPD becomes zero.

i.e. DPD = OP - TP → SP = 0 in turgid stage of cell

OP = TP (because DPD = 0)

Hypothesis of water potential

The concept of water potential was presented by R.K. Slatyr and SA Taylor (1960).

According to thermodynamic laws every component of a system possesses free energy which is available for doing work.

In osmosis, water molecules move in and out through semipermeable membrane for which free energy is required. If the cell is kept in water then the difference in the free energy of the water molecules and that of water molecules present in the solution is called water potential. The term water potential is represented by the Greek alphabet psi (ψ) and its unit is Bar or atm (atmosphere)

Calculating absolute value of water potential is imposible. So it is considered to be zero. If any solute is mixed in water then its water potential will reduce. So, free energy of any solution will be less than pure water (-ve). We know that the osmotic pressure of a solution is due to the molecules of the solute present in it and the water potential reduces as mix molecules of solute the water. Therefore, we can say that osmotic pressure of any solution.

Is indicative of its decreasing water potential. In the thermodynamic terminology, it is called osmotic potential and expressed as ψ_s.

The value of osmotic potential and osmotic pressure is same. The only difference is that the value of osmotic pressure value is positive and that of osmotic potential is negative.

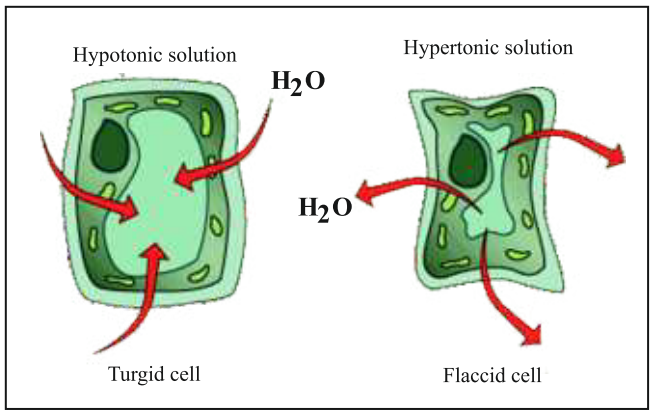

Fig. 5.3 (A) Turgid cell (B) Flaccid cell

Now, imagine an osmotic system. A concentrated sugar solution is put in the pouch made from semi permeable membrane and kept in a beaker with dilute sugar solution. By osmosis water molecule from the dilute solution will enter the concentrated solution filled in pouch. As a result the pouch will become turgid in a short time and will put pressure on wall which prevents water molecules

from coming in. This pressure is known as turgor pressure and the impact of turgor pressure in water potential is known as pressure potential ψ_p. Pressure potential is positive and increases the water potential. Water potential, osmotic potential and pressure potential are related to each other in such a way $\psi_w = \psi_s + \psi_p$.

The surface of the cell which adsorbs water is called matrix. Therefore potential generated by matrix is known as matrix potential ψ_m. It is negative and reduces the water potential of the cell. The matrix potential is important in soil, but it is not important in cellular osmosis. Pressure potential is positive and due to this the water potential increases so,

Water potential $\psi_w = \psi_m + \psi_s + \psi_p$

where, matrix potential is ψ_m osmotic potential is ψ_s and Pressure potential is ψ_p

Since, in cellular osmosis ψ_m is negligible, so $\psi_w = \psi_s + \psi_p$

Imbibition

Wooden doors swell up in rainy season or when remains in water This type of absorption of water by colloidal and dry solids is called imbibition and the water absorbing substance is called imbibant. Primary and secondary cell walls in plant are made up of cellulose and pectin which is hydrophilic colloid and absorbs water in high amount.

Definition - Absorption of fluid by solid, without forming any solution is called imbibition. In fact, this type of absorption is called adsorption. The rate of imbibition is influenced by many factors such as temperature, texture of imbibant, difference of affinity and water potential etc.

Importance of Imbibition -

(1) Water adsorbed by sprouted seeds is mainly by imbibition. Similarly this action also contributes in seed dehiscence during germination.

(2) The action of resurrection in many plants is due to the presence of hydrophilic colloids.

Important Points

1. Water is an extra ordinary and unique substance whose physical and chemical characteristics are helpful in the existence of life.
2. The tendency of spreaded gas, liquid and solid molecules to spread in the available space is called diffusion. The action of diffusion is from the higher concentration to lower concentration.
3. The rate of diffusion depends on the nature, temperature of medium, size and density of diffused molecules.
4. The permeability of different types of membranes and walls in cell is also different. Some are permeable (cell wall), semi-permeable and selectively permeable (cell membrane, tonoplast) and impremeable (cuticle).
5. The diffusion of solvent (water) by semipermeable membrane is called osmosis.
6. The osmotic pressure of the solution is proportional to the number of solute molecules present in it.
7. Osmosis plays an important role in absorption of water, turgidity and other activities in plants.
8. The cell when placed in hypertonic solution shows plasmolysis but if the cell is kept in the hypotonic solution again deplasmolysis happens.
9. When osmosis occurs, different types of pressure are generated in the cell like turgor pressure (TP), wall pressure (WP), somotic pressure (OP), suction pressure (SP) or diffusion pressure deficit (DPD) etc.
10. Osmosis depnds of many factors like temperature, permeability, size of molecules etc.
11. The difference in the free energy of water molecules present in the pure water and solution is called water potential. Water

potential of pure water is considered to be zero.

12. Absorption of fluid by a solid substance without forming solution is called imbibition. This process has special significance in seed germination.

Practice Question

Multiple choice questions

1. The action of exchange of CO_2 and O_2 from the atmosphere by leaves is called-

(a) osmosis (b) diffusion

(c) imbibition (d) endosmosis

2 Which of the following is permeable-

(a) cell membrane (b) tonoplast

(c) cuticle (d) cell wall

3 The value of the DPD in the flaccid stage will be-

(a) equal to OP (b) more than OP

(c) zero (d) less than OP

4 Which pressure is zero in flaccid cell-

(a) suction pressure

(b) diffusion pressure

(c) wall pressure

(d) osmotic pressure

5 Adsorption of water by hydrophillic colloids substances is called-

(a) imbibition (b) osmosis

(c) diffusion (d) plasmolysis

Very short answer questions

1. Give an example of semipermeable membrane
2. Give one importance of osmosis.
3. Define diffusion.
4. Define imbibition.
5. Explain TP & WP.

Short answer questions

1. Explain the water potential.
2. Differentiate endosmosis and exosmosis.
3. Explain the difference between plasmolysis and deplasmolysis.
4. Differentiate between hypertonic & hypotonic solution.
5. Explain diffusion pressure gradient
6. Explain diffusion pressure deficit
7. Explain imbibition with example.

Essay type questions

1. Explain the osmotic potential, pressure potential and water potential and their inter-personal relationships.
2. Define the process of osmosis with the help of an experiment illustrating it.
3. Describe the roll of osmosis diffusion and imbibition in plant physiology while briefly explaining them.

Answer Key-

1. (b) 2. (d) 3. (a) 4. (c) 5. (a)