Transport in Plants - Part 1

Objectives

After going through this lesson, the learners will be able to understand the following:

- Means of transport in plants
- Plant - water relations, concept of water potential
- Process of diffusion, osmosis, plasmolysis and imbibition

Content Outline

- Introduction
- Short Distance Transport
- Diffusion, Osmosis
- Water Potential
- Plasmolysis
- Imbibition
- Movement of Solutes/Ions by Passive/Active Transport Through
    - Channel Proteins
    - Carrier Proteins
    - Pump

Introduction

Have you ever wondered how plants absorb water and minerals and how these molecules move from cell to cell? Or how water taken up by the roots reach all parts of the plant including the tip of the growing stem? Or how the photosynthates i.e. food synthesized by the leaves are transported to all non-photosynthetic parts of the plant, including the roots embedded deep in the soil? Transport i.e. movement of ions and molecules from one location to another is of paramount importance. Plants need to move molecules over long distances, much more than animals do; they also do not have a circulatory system.

In a flowering plant the substances that need to be transported are water, minerals, organic nutrients and plant growth regulators.

In this chapter we will try to understand –

1. How substances move through small distances (**short distance transport**) by diffusion, facilitated diffusion, osmosis, active transport and cytoplasmic streaming.
2. How **long distance transport** takes place through the vascular system (xylem and phloem). We will study the two types of long distance travel through the vascular system (called translocation):
   (a) Transport of water through the xylem
   (b) Transport of photosynthates through the phloem.

In all these processes, we will focus on the direction of transport, and try to understand whether the movement of molecules is unidirectional/bidirectional and whether it is passive or active.

Short Distance Transport

As the name suggests short distance transport is the movement of ions and molecules over short distances eg. movement of water in the cortical cells of the root till it reaches the xylem, movement of photosynthates in the mesophyll cells till it reaches the phloem or the movement of ions and molecules across the plasma membrane by simple diffusion or through carrier proteins, channels and pumps. We will discuss these processes later in the chapter.
To understand short distance transport in plants, it is essential to understand fundamental processes like diffusion and osmosis and the concept of water potential.

Short distance transport of water is driven by molecular diffusion.

Diffusion is the movement of molecules along their concentration gradient and is fast over short distances but extremely slow over long distances. Fluids diffuse spontaneously. As long as other forces are negligible, diffusion will cause molecules to move from a region of its own higher concentration to a region of its lower concentration- i.e., down the concentration gradient. As molecules are moving downhill, no energy is required and diffusion is a passive process. Diffusion rates are affected by the concentration gradient, temperature and pressure.

Osmosis is essentially diffusion across a semipermeable membrane. The term is used to refer specifically to the diffusion of water across a differentially semi-permeable membrane. It is important to emphasize a functional difference between the cell membrane and the cell wall. The cell membrane is semi permeable-it allows the free movement of some molecules (eg.water)while restricting the passage of others (e.g., sucrose). The primary cell wall on the other hand is highly permeable to all molecules. The cell membrane is semi permeable as long as it is living. If it is damaged or killed, it becomes freely permeable just like the cell wall.

Water enters the cell by osmosis when the cell is placed in a hypotonic solution or in pure water. A hypotonic solution is a solution whose solute concentration is less than that of the cell sap. Example, if the cell sap has a concentration of 0.3 M, sucrose solution of concentration less than 0.3 M or pure water, would be hypotonic to the cell sap. Under such conditions, water will move into the cell. This process is called endosmosis. As a result of endosmosis, the cell becomes turgid and a pressure called turgor pressure develops within the cell which acts against the cell wall. The turgor pressure is balanced by an equal and opposite pressure exerted by the cell wall - the wall pressure. The cell wall provides a rigidity which allows the turgor pressure to develop.

The pressure that must be applied to a cell to prevent endosmosis is a measure of the osmotic pressure. This is a function of solute concentration and increases as the solute concentration is increased. More the solute concentration, more will be the pressure required to prevent endosmosis of water.

It is important to note that osmosis occurs spontaneously in response to a driving force. The net direction and rate of osmosis depends on both the pressure gradient and concentration gradient.

Demonstration of Osmosis

The process of osmosis can be demonstrated experimentally

i. A beaker is filled with distilled water.
ii. The mouth of a thistle funnel is covered with a semipermeable membrane (this is available commercially or can be prepared by placing the empty shell of an egg in dilute HCl for a few hours. The egg shell dissolves, leaving the membrane intact).
iii. The thistle funnel is filled with sucrose solution and immersed in the beaker of water.

Observation: Water will move into the funnel by endosmosis resulting in a rise in the level of the solution in the thistle funnel.

Water Potential

The chemical potential is the free energy per mole of any substance in a chemical system. The chemical potential of pure water is known as its water potential and is a quantitative expression of the free energy associated with water. Water Potential is the difference in the free energy or chemical potential of water in a system and that of pure water at the same temperature and pressure.

By convention, the water potential of pure water that is not under any additional pressure is taken to be zero.

For example, the water potential of pure water kept in a beaker is considered to be zero.

Water potential of a cell is the sum of the solute potential (due to concentration of dissolved solutes and denoted by $^{\gamma}$s) pressure potential (due to hydrostatic pressure and denoted by $^{\gamma}$p) and matrix potential (due to binding of water to cell and cytoplasm and denoted by $^{\gamma}$m). Matrix potential is not significant in the case of osmosis and is neglected. Water potential is taken as the sum of solute potential and pressure potential. $^{\gamma}$ w= $^{\gamma}$s + $^{\gamma}$p

Water always moves from a region of higher Ψ_w to one of lower Ψ_w.

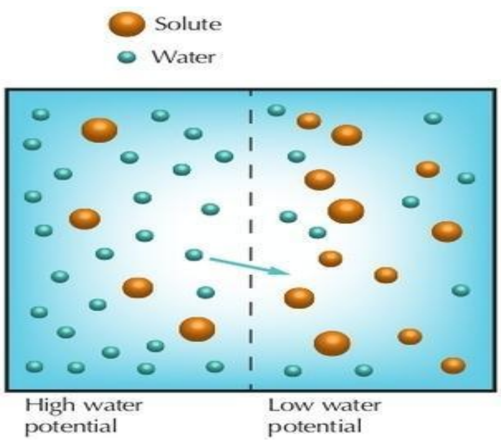


Image source: Google images

Solute potential: Solute potential also called osmotic potential represents the effect of dissolved solutes on water potential. If a solute is dissolved in pure water, for example 10 ml of 0.3 M sucrose solution, then the concentration of water is less in the solution as compared to 10 ml of pure water. So the water potential of the solution is less than that of pure water. As the water potential of pure water is taken as zero, the water potential of all solutions have a negative value.

Dissolved solutes lower the water potential and a solution always has a water potential lower than pure water.

Pressure potential: It is a measure of the hydrostatic pressure of the solution. Positive pressure increases the water potential while a negative pressure reduces it. If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. The positive hydrostatic pressure in a cell is the turgor pressure developed due to endosmosis. A negative pressure is the suction or tension developed in the xylem. As we shall study later in the chapter, this negative pressure potential is responsible for the movement of water in the xylem.

Plasmolysis

A solution may be termed isotonic, hypotonic or hypertonic with reference to the cell sap. An **isotonic solution** is one whose solute concentration is the same as that of the cell sap. When a cell is placed in an isotonic solution water will diffuse in and out of the cell but there will be no net loss or gain of water. The appearance of the cell will remain normal in every respect.

Hypotonic solution is a solution whose solute concentration is less than that of the cell sap. When a cell is placed in a hypotonic solution water enters the cell by **endosmosis** because water will move form a region where the water potential is higher (the external solution) to a region where the water potential is lower (the cell sap). As a result of endosmosis the cell will swell i.e., become turgid. A turgor pressure will act on the cell wall which will be offset by an equal and opposite wall pressure.

Hypertonic solution has a solute concentration more than the cell sap. When a cell is placed in a hypertonic solution water will move out of the cell as the water potential of the external solution is less than that of the cell sap. This outward flow of water is called **exosmosis.** The cell will shrink as a result. Such a cell is said to be flaccid. In a flaccid cell the turgor pressure is zero.

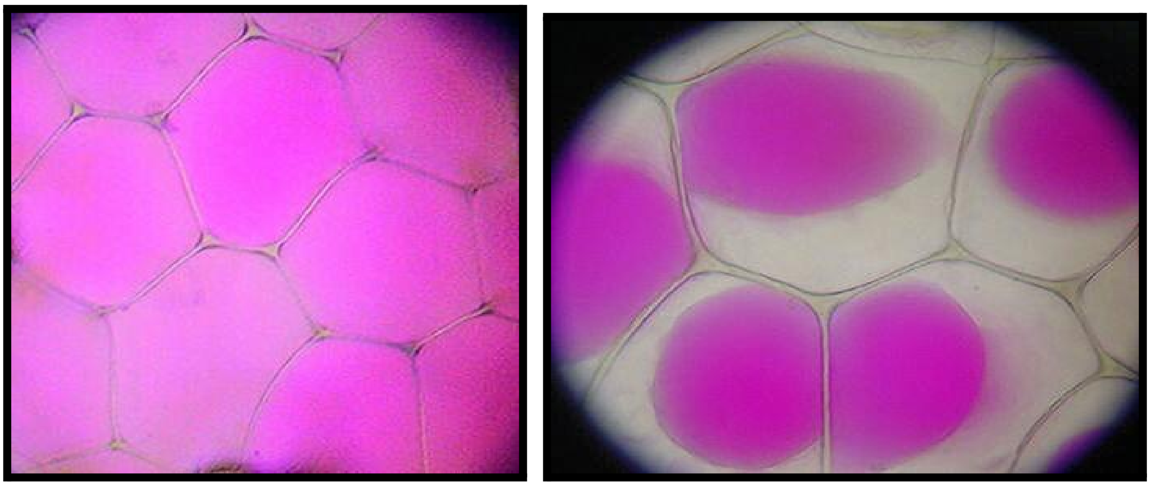
Due to exosmosis, cytoplasm shrinks and the cell membrane moves away from the cell wall. The movement of the cell membrane away from the cell wall and the shrinkage of the cytoplasm as a result of exosmosis is called **plasmolysis.**

The cell wall without its adjacent membrane is freely permeable. In a plasmolysed cell the space between the cell wall and the cell membrane is filled with the external solution.

A plasmolysed cell is flaccid and the turgor pressure i.e. pressure potential of such a cell is zero. Plasmolysis is reversible- if a plasmolysed cell is placed in pure water / hypotonic solution it will become turgid once again. This process is called deplasmolysis.

Plasmolysis can be demonstrated as follows:

1. A peel is taken from the lower epidermis of *Rhoeo discolour* leaf.
2. The peel is immersed in a hypertonic solution for 10 minutes and mounted in the same solution for observation.



A turgid cell (left) and a plasmolysed cell

Source: https://biologydictionary.net/plasmolysis/

Observation: Plasmolysis is observed in the coloured epidermal cells. Plasmolysis takes place in all the epidermal cells of the peel but is visible only in the coloured cells. The colored epidermal cells have a large vacuole that fills the cell. The vacuole shrinks due to plasmolysis and the shrinkage is visible since the vacuole is coloured.

Imbibition is essentially movement of water along a concentration gradient where the water is adsorbed by many bio-molecules like starch, cellulose proteins etc.A classical example is the imbibition of water by dry seeds. Dry seeds have very little water content and when soaked in water they imbibe water easily. Existence of a water potential gradient between the adsorbent and the liquid absorbed is essential for imbibition. In addition for any substance to imbibe any liquid, affinity between the adsorbent and the liquid is a prerequisite.

The seeds swell on imbibing water. A pressure develops due to imbibition and the resultant swelling eg. Dry wooden planks are driven into small crevices in rocks and then soaked. The dry wood imbibes water, swells and develops enough pressure to split the rock. This was a form of quarrying used in the past.

Transport of Ions and Molecules Across the Membrane

The extent to which a membrane permits the movement of a substance across it is the membrane permeability of that substance. Molecules soluble in lipids diffuse through the membrane faster than hydrophilic molecules. Some ions, water molecules are transported across the membrane by simple diffusion. As discussed, diffusion occurs in response to a concentration gradient and is a passive process.

Certain proteins called transporter proteins are present on the cell membrane. Transporter proteins facilitate the movement of ions, water and solutes across the membrane. There are 3 types of membrane transporters-

i. Channel proteins
ii. Carrier proteins
iii. Pumps

i. **Channel proteins:** These proteins form transmembrane proteins for molecules to pass through. Channel Function as selective pores. Transport through channels takes place by diffusion and is a passive process. Channel proteins may have gates that open or close the pores in response to stimuli like light, voltage changes, hormones etc. When the channel pore is open solutes diffuse through it very rapidly. Ions and water are mainly transported through channels. Water is transported through special gated channels called aquaporins.

ii. **Carrier proteins:** Carrier proteins found on the cell membrane, bind to and transport specific substances. Unlike channels, carrier proteins do not have transmembrane pores. The substance being transported binds to a specific site on the carrier protein. Binding of the solute changes the conformation of the protein and the substrate is carried across the membrane and is delivered unchanged on the other side of the membrane.

Transport by carrier proteins may be –

a. **Passive** i.e. No energy is required eg. **Facilitated diffusion**. In facilitated diffusion carrier proteins transport molecules according to their concentration gradient. In fact, a concentration gradient must exist for molecules to diffuse even though the process is facilitated by carrier proteins. Carriers are highly specific for the substance to be transported. The rate of transport by carrier proteins is slower than transport through channels.
b. **Active Transport** through carrier proteins may also be an active process requiring the expenditure of energy by the cell. Substances are carried against their concentration gradient and this uphill transport of molecules requires energy to be expended by the cell.

Carrier proteins can function as **uniporters, symporters or antiporters**.

a. **Uniport**: Some carrier proteins transport a single solute from one side of the membrane to the other. This process is called uniport.
b. **Symport**: Some carrier proteins function as coupled carriers in which the transport of one solute strictly depends on the transport of a second. The transfer of a second solute in the same direction as the first is called symport.
c. **Antiport**: Some carrier proteins transport a second molecule in the opposite direction of the first. The simultaneous transfer of two molecules in opposite directions by a carrier molecule is called antiport.

iii. Pumps: These are membrane proteins that carry out active transport. Pumps use energy to transport molecules against the concentration gradient. Energy is needed for this uphill task. Transport reaches a maximum when all the pumps are in use.

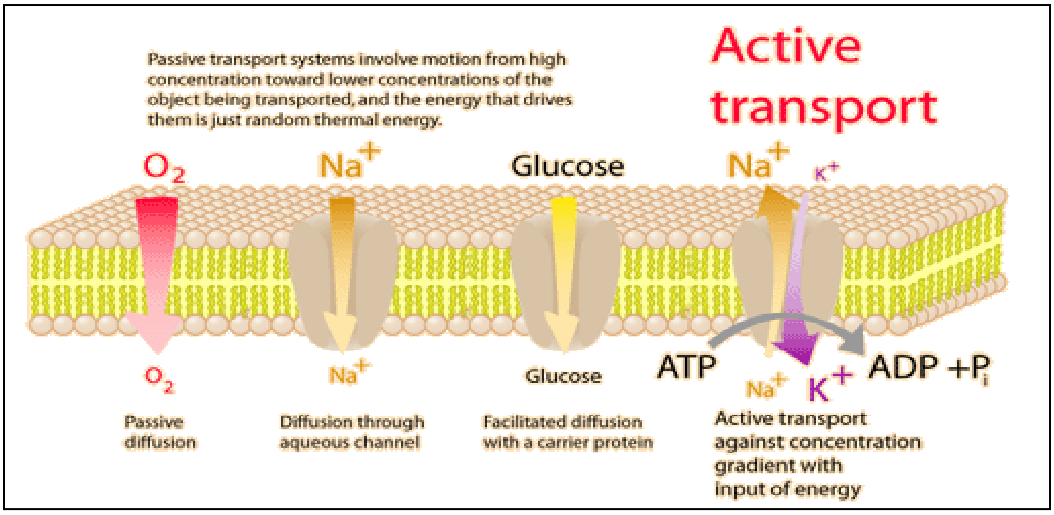


Image: Passive and Active transport

Source: http://hyperphysics.phy-astr.gsu.edu/hbase/Biology/actran.html

Summary

Plants obtain a variety of inorganic elements (ions) and salts from their surroundings especially from water and soil. The movement of these nutrients from the environment into the plant as well as from one plant cell to another plant cell essentially involves movement across a cell membrane. Transport across cell membranes can be through diffusion, facilitated transport or active transport. Water and minerals absorbed by roots are transported by xylem and the organic material synthesised in the leaves is transported to other parts of the plant through phloem. Passive transport (diffusion, osmosis) and active transport are the two modes of nutrient transport across cell membranes in living organisms. In passive transport, nutrients move across the membrane by diffusion, without any use of energy as it is always down the concentration gradient and hence entropy driven.

This diffusion of substances depends on their size, solubility in water or organic solvents. Osmosis is the special type of diffusion of water across a semipermeable membrane which depends on pressure gradient and concentration gradient. In active transport, energy in the form of ATP is utilised to pump molecules against a concentration gradient across membranes. Water potential is the potential energy of water which helps in the movement of water. It is determined by solute potential and pressure potential. The behaviour of the cells depends on the surrounding solution. If the surrounding solution of the cell is hypertonic, it gets plasmolysed. The absorption of water by seeds and drywood takes place by a special type of diffusion called imbibition.