CHAPTER - 09
TRANSPORT IN PLANTS

Specific characteristics of plant transport

1. No special circulatory system in plants for transport of materials
2. Comparatively long distance transport
3. It is a slow process

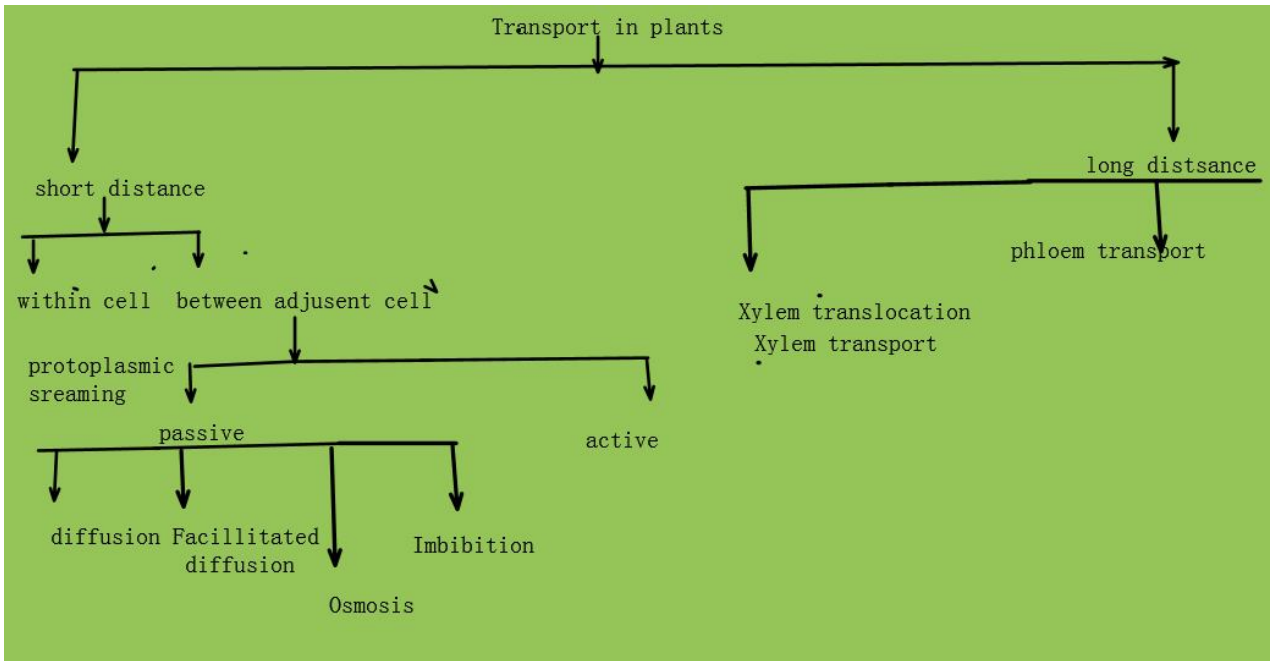
TYPES OF MATERIAL TRANSPORT

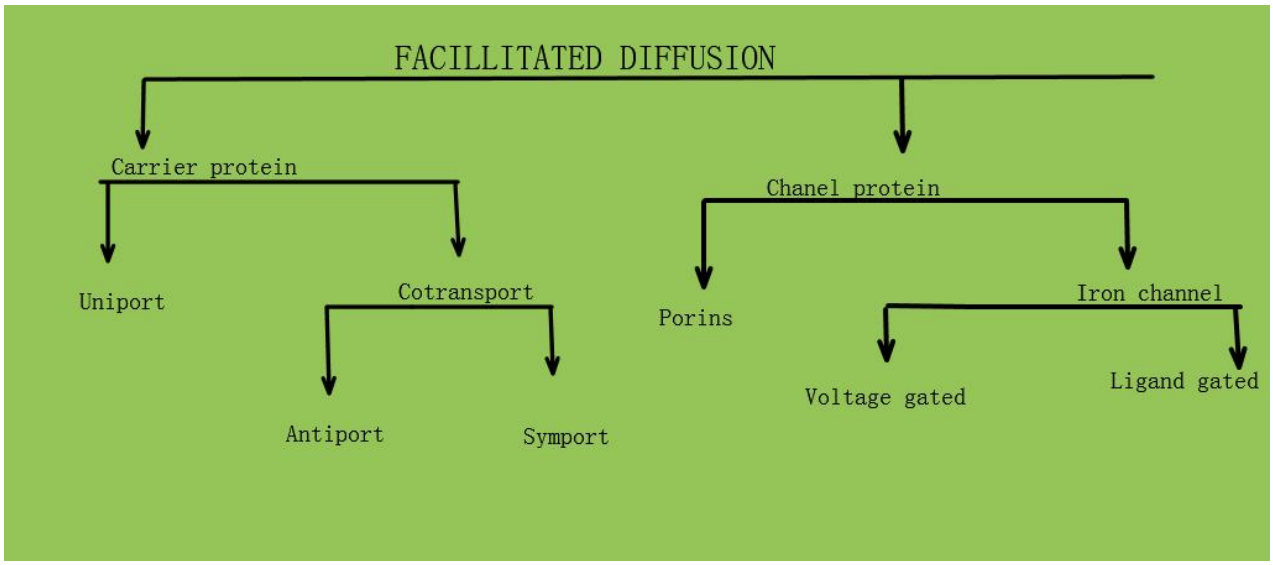
- Water and minerals (from root to different parts of plant)
- Organic food material (from leaves to different parts of plant)
- Growth regulators (from the region their synthesis to the region of action)

DIRECTION OF TRANSPORT

- Water and minerals transport through xylem unidirectionally
- Organic nutrient transport through phloem bidirectionally
- During senescence nutrients in older leaves are remobilized to growing region through phloem
- Plant hormones are transported through phloem unidirectionally
- So transport of materials in flowering plant is in different directions

MEANS OF TRANSPORT





SHORT DISTANCE TRANSPORT

A. Transport within the cell. It is by cytoplasmic streaming or cyclosis of cytoplasm .

B. Transport between adjacent cell

1. DIFFUSION

- It is the movement of any substance (solid, liquid or gas) from higher concentration to lower concentration
- It is a slow process it takes 32 years for the movement of one metre . It is independent of life
- Diffusion rate is affected by concentration gradient, temperature, pressure and size of the moving particle

Diffusion in plants

- It is an essential step in the exchange of gases during respiration and photosynthesis
- During passive ion absorption, ions are diffused into the root
- During transpiration water vapour diffused out into atmosphere through stomata

2. FACILITATED DIFFUSION

- It is the movement of substance across a membrane with the help of special membrane protein from higher concentration to lower concentration
- Since it is mediated by specific membrane protein for specific substance, it can reach saturation and it can be inhibited also
- Different types of facilitated diffusion

A. By CARRIER PROTEINS

It bind with a particular ion or molecule to be transported and delivered the same to other side of the membrane

It can be two types

i. UNIPORT

It transport ions or molecule one at a time across the membrane (uniport of NH4+ ions by root hair cells)

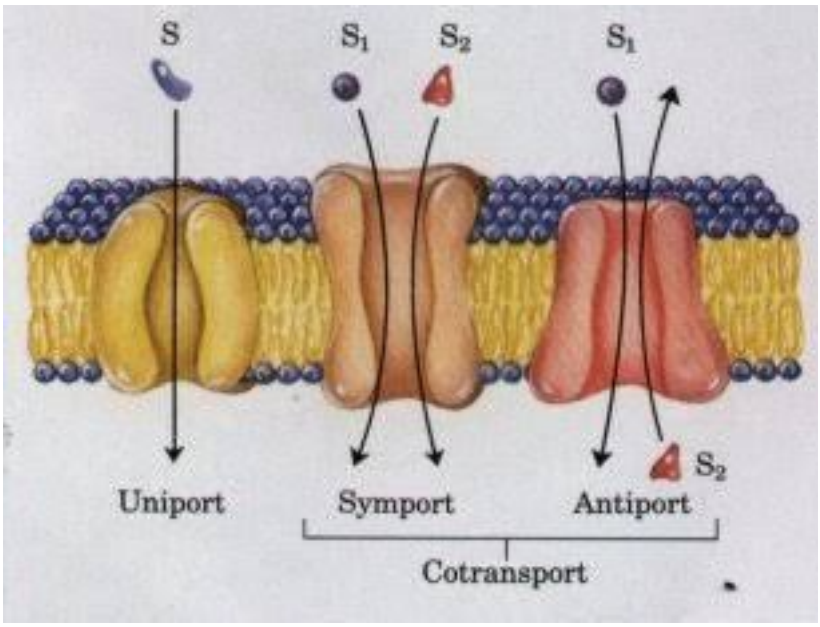
ii. COTRANSPORT

It is a transmembrane carrier protein that transport two ions or molecules one at a time

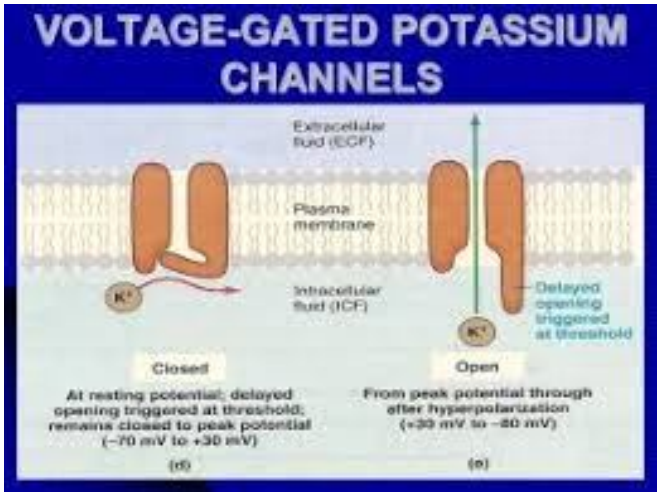
It can be two types

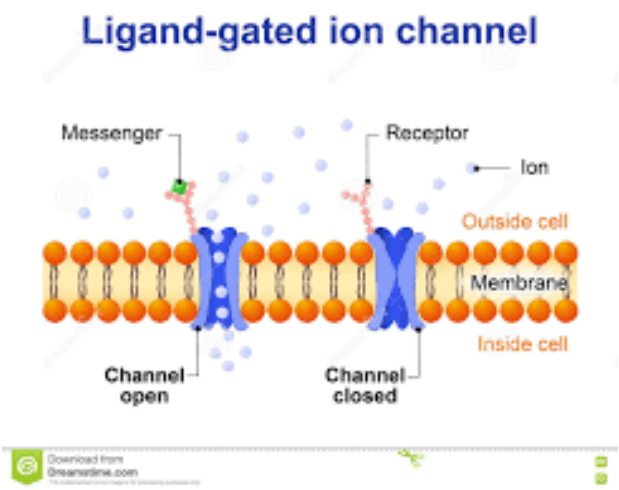
SYMPORT- movement of two ions or molecule in same direction by a carrier protein (Na+/ Ca^{2+} Transporter)

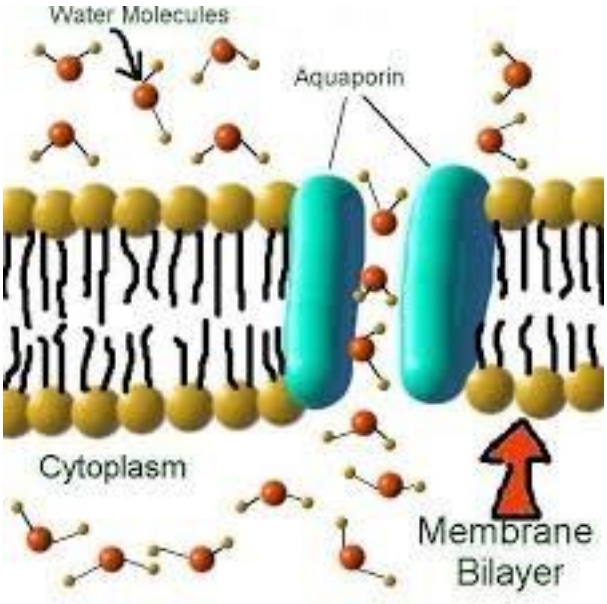
ANTIPORT- Movement of two ions or molecule in opposite direction by a carrier protein simultaneously. **(Na+/Ca++ ANTIPORTER)**



B . Channel proetins







It functions as channel for the transport of substances across the membrane and can be two types

i. **PORINS** - These are channel proteins that functions as a huge pore for the transport of substances across the membrane and is always in open condition (aquaporins present in the outer membrane of plastids, mitochondria and bacterial membrane)

ii. **ION CHANNELS** - they allow the passage of ions and open at specific conditions.

They are of two types

VOLTAGE GATED CHANNELS - They open due to membrane potential difference on both sides of the membrane **(Voltage gated K^+ channel)**

LIGAND GATED ION CHANNEL - This channel protein open in response binding a chemical messenger (ligand) at its specific site **(Na^+ activated K^+ channels)**

PLANT -WATER RELATIONS

Importance of water for plants

1. It is essential for all physiological activities of plants
2. It is the medium for all metabolic activities of the plants
3. More than 85 % of plant fresh weight is due to water present in plants
4. More than 97% of water absorbed by the plant lost in the process of transpiration

WATER POTENTIAL

The difference between the free energy of water molecule in pure form and its solution form is called water potential

FREE ENERGY OR GIBBS FREE ENERGY CONCEPT

- The free energy (kinetic energy) in a substance is to do work is called Gibbs free energy , and is maximum in a substance when it is purest form.
- So water in pure form will have maximum free energy or water potential and is taken as zero
- So water potential of a solution is always less than zero that is a negative value (Eg. -100 Pascal,- 50 Pascal etc.)
- Water potential is represented by the Greek letter ψ / ψ_w **(PSI)** .It is measured as **PASCALS, BARS** or **ATMOSPHERIC PRESSURE.**

COMPONENT OF WATER POTENTIAL

The main component of water potential is **SOLUTE POTENTIAL** and **PRESSURE POTENTIAL**.

So Water potential = solute potential + pressure potential

SOLUTE POTENTIAL (OSMOTIC POTENTIAL) - ψ_s

It is the decrease in water potential due to the presence of solute in a solution. It is always a negative value and is inversely proptional to the concentration of solute in a solution

For a solution at normal atmospheric pressure solute potential will be equal to water potential.

Water potential = solute potential $\left(\psi_w = \psi_s\right)$

PRESSURE POTENTIAL - ψ_p (HYDROSTATIC PRESSURE/TURGOR PRESSURE)

It is the pressure that develops in osmotic system or cell due to osmotic entry or exit of water. A positive hydrostatic pressure develop in a osmotic system or a cell due to the entry of water. so it is also called turgor pressure (TP).

So water potential in an osmotic system (closed system) or cell is influenced by its solute concentration (solute potential) and its pressure (pressure potential).

$$\therefore \psi_w = \psi_s + \psi_p$$

But in an open system pressure (pressure potential) is insignificant, WATER POTENTIAL WILL BE EQUAL TO SOLUTE POTENTIAL

MOVEMENT OF WATER IS ALWAYS FROM HIGH WATER POTENTIAL TO LOW WATER POTENTIAL

Importance of turgor pressure (TP)

1. Sleep movement of mimosa plant is due to change in the turgor pressure of pulvinus of its leaves
2. It is responsible for cell enlargement at the time of growth
3. Shape of cell, cell organelles,and plant organs are maintained due to TP
4. Opening and closing of stomata is due to turgidity difference of guard cells

IMBIBITION

It is the process of absorption of water or any other solvent by solid particle, without forming solution

It is a type of diffusion where water is moving from higher concentration to lower concentration with the mediation of a solid particle (dry solid material). (High water potential to low water potential).

Imbibant - the solid particle that absorb water is called imbibant (dry seed, dry wood) Imbibate - the solvent that take part in imbibition (water or any other solvent).

IMBIBITION IS INFLUENCED BY

1. Water potential gradient between imbibant and imbibate
2. Temperature- an increase in temperature increases rate of imbibition.
3. Pressure - imbibitions decreases with increase in pressure

SIGNIFICANCE OF IMBIBITION

1. Initial step of water absorption by root hair is by imbibitions
2. Initial stage of seed germination affected by imbibitions(breaking seed coat)

OSMOSIS

It is a special type of diffusion of water through selectively permeable membrane

IT IS THE MOVEMENT OF SOLVENT MOLECULE OR WATER FROM ITS HIGHER CONCETRATION TO ITS LOWER CONCETNRATION THROUGH A SELECTIVELY PERMEABLE MEMBRANE

Here the movement of water is from high water potential to low water potential.

Osmosis can be

exosmosis (water moves out of a cell) or **endosmosis** (water moves into the cell)

Direction and rate of osmosis depends on sum of two forces that is pressure gradient(pressure potential) and concentration gradient (solute potential or osmotic potential)

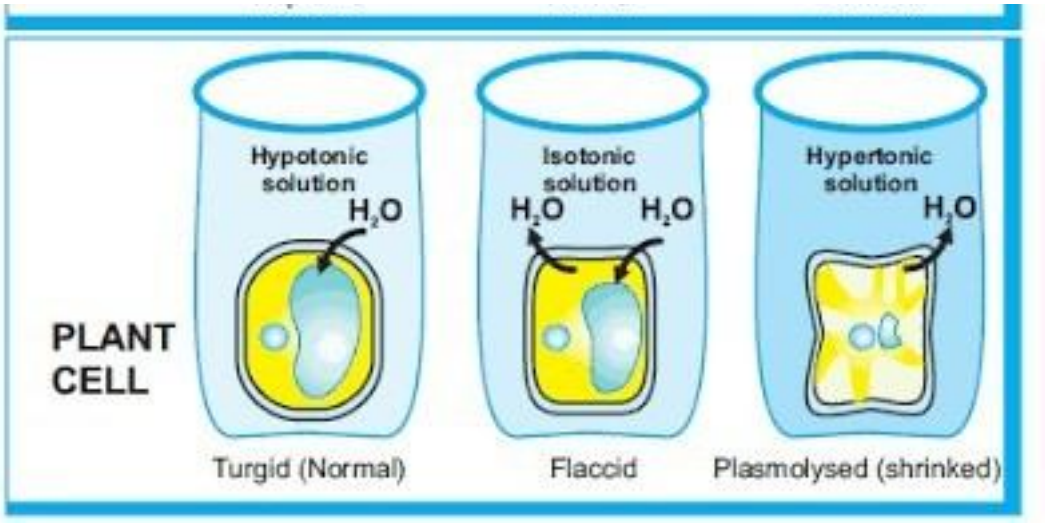
Depending on the concentration of cytoplasm of a cell the external solution can be

a) Hypotonic (concentration of external solution is less than that of cytoplasm , osmosis will

be endosmosis)

b) Hypertonic (concentration of external solution higher than cytoplasm , osmosis will be exosmosis)

c) Isotonic (concentration of external solution similar to cytoplasm, there will be no net movement of water so there will be no osmosis).



OSMOTIC PRESSURE (OP)

Osmotic pressure of a solution is equal to pressure, which must be exerted up on it, to prevent the flow of water into it, across a selectively permeable membrane. It is usually measured as Pascal, Bars or Atmospheric pressure

It is depend on the ratio between concentration of solute and solvent in a solution

OP is represented by Greek letter π (Pi). It is numerically equal to osmotic potential or solute potential but opposite in sign. (Osmotic pressure is a positive value but osmotic potential is a negative value)

FACTORS AFFECTING OSMOSIS

1. Concentration of dissolved solute (solute potential)
2. Natureof selectively permeable membrane

PLASMOLYSIS

It is the shrinkage of the protoplast of a cell from its cell wall, under the influence of hypertonic solution

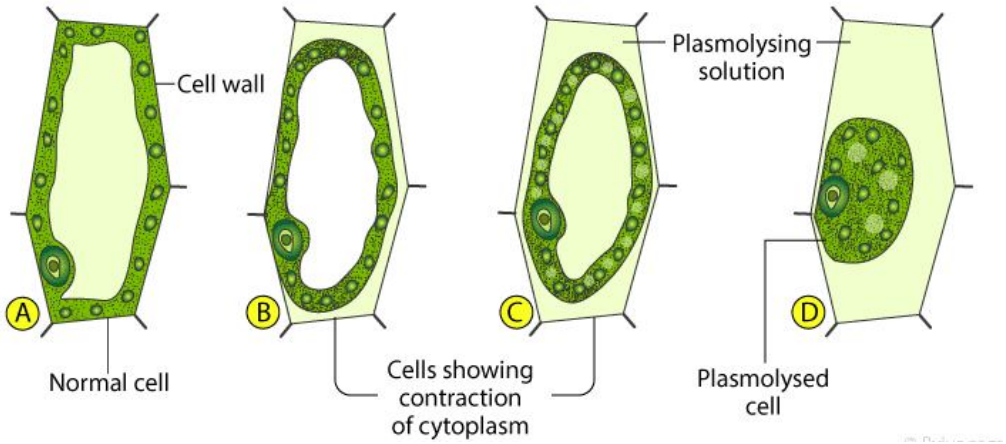
STAGES OF PLASMOLYSIS

1. Limiting plasmolysis - due to the withdrawal of water from cytoplasm, the size of protoplast

reduces

2. Incipient plasmolysis- due to continuous exosmosis, protoplast withdraws itself from the corners of cell wall
3. Evident plasmolysis-due to continues exosmosis protoplast detached completely from cell wall and attaining a spherical shape and is seen in the corner of cell wall
4. DEPLASMOLYSIS - swelling up of a plsmolysed protoplast in hypotonic solution

STAGES OF PLASMOLYSIS



IMPORTANCE OF PLASMOLYSIS

1. It is utilized in salting of meat and fish, preparation of pickles and addition of concentrated sugar solution to jam and jellies to check the growth microorganisms in stored food
2. It is used to determine the OP of cell sap

INTER RELATIONSHIP BETWEEN OP, TP AND DPD

DPD (Diffusion Pressure Deficit)

- It is the difference between diffusion pressure (DP) of a solution and its solvent at normal temperature and pressure.
- It is directly proportional to the concentration of solute in a solution
- In the case of a plant cell cytoplasm is a watery solution due to the presence of different organic and inorganic substances. So DPD of cytoplasm is high and it absorb water in order to reduce its DPD if it is placed in a hypotonic solution. So DPD is also called suction pressure (SP).
- DPD IS EQUAL TO WATER POTENTIAL BUT DPD VALUE IS POSITIVE AND WATER POTENTIAL VALUE IS NEGATIVE

- DPD is related to OP, TP and WP, where WP is wall pressure, it is a pressure exerted by cell wall against protoplasm at the time of entry of water in to the cell .It is equal to TP but opposite in direction.
- DPD = OP-WP

  Since WP = TP

  $$\therefore DPD = OP - TP$$

ACTIVE TRANSPORT

Transport of substances across the membrane with help of membrane protein against concentration gradient (lower concentration to higher concentration) utilizing ATP energy. So these membrane proteins are called ION PUMPS . (Na+/K+ pump). They can also reach saturation point and can be inhibited by specific protein inhibitors .

LONG DISTANCE TRANSPORT (BULK FLOW / TRANSLOCATION)

- BULK FLOW - It is movement of substances in bulk or in mass (en masse) from one point to other due to, pressure difference in two points.(Eg.flow of water in a river). Since diffusion is a very slow process it account for only short distance transport . But bulk flow is faster and substances move in bulk .so it is main means of long distance transport.
- BULK FLOW can be due to positive hydrostatic pressure (movement of water through garden horse) And negative hydrostatic pressure (suction through a straw)

Translocation - Bulk movement of substances through vascular tissue.

It can be **XYLEM TRANSLOCATION** and **PHLOEM TRANSLOCATION**

A. XYLEM TRANSLOCATION /XYLEM TRANSPORT

Xylem is responsible for translocation of water, minerals, some organic nitrogen and hormones. Land plants absorb water and minerals through their roots

PATHWAYS OF WATER MOVEMENTS IN ROOTS

1. **Apoplastic pathways** : it is the movement of water through cell wall and inter cellular spaces, Without entering any membrane or cytoplasm. It include non living part of plant tissues.
2. **Symplastic pathways** : it is through plasmadesmata and cytoplasm. It includes living part of plant tissues.

During the movement of water from root hairs to inner part of root, in the initial stages it is through apoplastic and symplastic pathways. But upon reaching endodermis, due to the presence of casparian strips which is impervious to water, it moves through symplastic pathways. From endodermis water passes to, pericycle and finally reaches xylem.

Mycorrhiza - It is the symbiotic association of fungus and root system of higher plants. It increase the surface area of root for absorption of water and minerals. It also inhibits the growth of other parasitic microorganisms in its vicinity.

Upward movement of water (ascent of sap) in plants.

There are different theories that explains upward movement water in plants

1. **Vital force theory by J C BOSE**. According to this theory innermost cortical cells are in a state of pulsation and are responsible for upward movement of water
2. **Root pressure theory by J.Priestly** . According to this theory root pressure is responsible for ascent of sap. (root pressure is the pressure develop in root xylem due to osmotic entry of water in it). But magnitude root pressure is very low and can account for upward translocation up to small heights in stem. Effect of Root pressure is maximum in night and in early morning when there is no transpiration. It is not account for ascent of sap in tall trees and can be applicable in the case of herbaceous plants.

   GUTTATION : It is the loss of water in the form water droplets from the leaf tips of herbaceous plant during early morning under the influence of root pressure. The special opening in leaf tip through which guttation is taking place is called water stomata or hydathode.

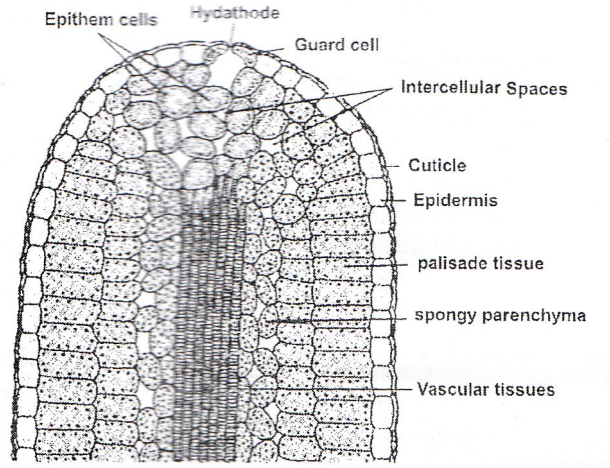


Fig:- Section of leaf showing Hydathode

   Guttation is maximum when transpiration is low and absorption of water is high. It causes development of root pressure (positive pressure) in root cells that pushes water in the xylem in upward direction, finally this water is accumulated in loosely arranged parenchymatous cells or epithem cells. Now this water is released in the form of tiny droplets by hydathode of leaf tip. Guttated water contains organic and inorganic salts and is not pure. **Eg: Cucumber, Garden Nasturtium, Tomato, Oat.**

3. **Cohesion - Tension, transpiration pull theory (Dixon and Jolly)**. This is the most accepted theory that explains upward movement of water in plants.

   Cohesion : attraction between similar molecules. According to this theory all water molecules in xylem vessels are interconnected by cohesive force (hydrogen bond between water molecule) . Thus all water molecules in xylem vessels form as chain (water column), one end which is in root and the other end in leaf

Adhesion : attraction between dissimilar molecules. There is a strong attraction between water column and wall of the xylem vessel. So water column remain upright in xylem vessels.

Transpiration pull : As a result of evaporation of water from leaf mesophyll cells, DPD increases or water potential decreases. So mesophyll cell absorb water from adjoining cells, ultimately water is absorbed from xylem vessels of leaf vascular bundle. Since xylem elements are filled with continuous water column, a negative pressure or tension (transpiration pull) develop at the top of water column. This pull or tension is transmitted downward from petiole to stem, stem to root leading to upward movement of water.

TRANSPIRATION

It is the loss of water in the form of water vapour from the living tissues of aerial parts of the plant.

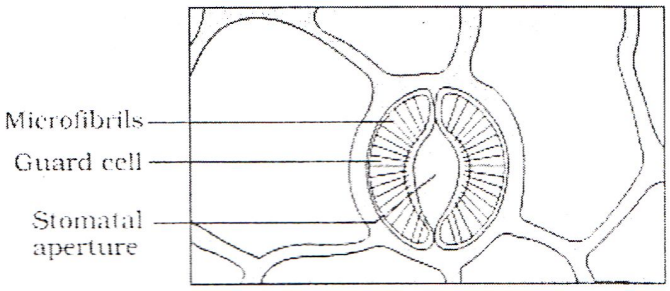
Different types of transpiration

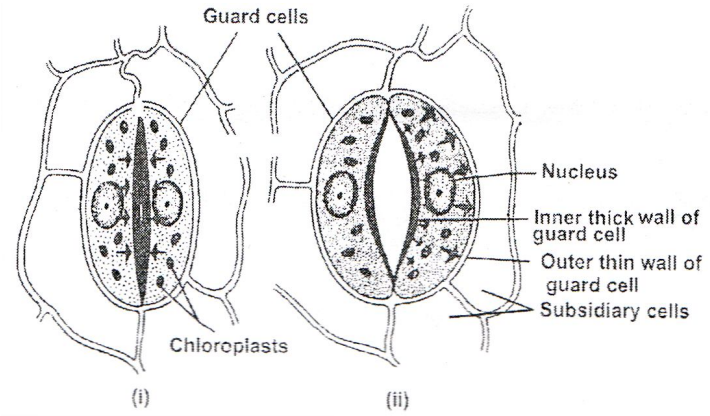
1. Cuticular transpiration- through cuticle of epidermis- only 3- 10 % of total transpiration
2. Lenticular transpiration - through lenticels of woody stem- 0.1%
3. Stomatal transpiration - through stomata - more than 90%

STOMATA : It is made up of two kidney shaped cells called guard cells. Their wall is unevenly thickened (inner wall is highly thick but outer wall is thin)and have radially oriented micro fibrils and that help opening and closing of stomata during transpiration.

Structure of stomata:

Stomata consists of two bean shaped or kidney shaped guard cells contain chloroplasts. Their inner wall is thick concave and non-elastic and outer wall is thin, convex and elastic. Modified epidermal cells which surround the guard cell called accessory or subsidiary cells. In the plants of **family Gramineae (eg. grasses)** the guard cell are **dumb-bell shaped** and their cell walls are thickened only in the middle. In xerophytic plants subsidiary cells are found over guard cells so that the position of stomata is below from leaf surface. These stomata are called **sunken stomata.**





(i) Closed stomata **(ii) Opened stomata**

STOMATAL MOVEMENTS : When atmospheric temperature increases, water vapour accumulate in the inter cellular space of leaf cells and guard cell absorb water from there. So turgidity of guard cell increases. As a result of that outer thin wall of guard cell bulges out and pulling thick inner wall slightly apart and that causes the opening of stomata. It is also helped by radial orientation of micro fibril in guard cell. When stomata open water is evaporated and turgidity of guard cell decreases and stomata remain closed.

Mechanism of stomatal movements

There are different theories that explain stomatal movements. Important theories are

1. Starch sugars inter conversion theory by Lloyd and Sayre

$$\text{Starch} \underset{\text{pH5(night), starch phosphorylase}}{\overset{\text{pH7(day), starch phosphorylase}}{\rightleftharpoons}} \text{glucose1-phosphate}$$

According to this concept during day time water insoluble starch in guard cell is converted into Soluble glucose phosphate by the enzyme starch phosphorylase, which is active only when the pH of guard cell is around 7. During day time pH of guard cell high due the absence CO_2 in leaves, whichis used for photosynthesis. Now glucose phosphate dissolve in water of guard cell and its DPD increases or water potential decreases so it absorb water from its surrounding and that leads to the opening of stomata. During night, due the absence photosynthesis CO_2 accumulate in leaf cells and pH of guard cell decreases. So in low pH starch phosphorylase enzyme convert soluble glucose phosphate in to insoluble starch, turgidity of guard cell decreases and leads to closing of stomata.

2. Potassium ion pump hypothesis by Levitt

According to this hypothesis during day time pH of guard cell (pH 7) increases because of decrease in the concentration of CO_2 (used for photosynthesis) . In high pH malic acid present in the guard cell is dissociated in to malate and hydrogen ions .Now guard cell absorb potassium ion from surrounding cell in exchange of hydrogen ion in it. Increased concentration of potassium ion in guard cell increases OP/DPD or decreases water potential . Now guard cell absorb water from surrounding tissue, its turgor pressure increases and stomata open. Opposite reaction take place during night and stomata closed

Factors affecting transpiration

1. Light -increases transpiration rate (stomata open during light)
2. Temperature- rate of transpiration is directly proportional to temperature (temperature increase evaporation of water and deceases humidity of atmosphere)
3. Relative humidity of atmosphere - inversely proportional to transpiration
4. Wind velocity - slit wind increases transpiration rate by removing humidity from leaf surface, but high wind decreases transpiration rate by closing the stomata
5. Leaf area - directly proportional to transpiration rate(more stomata more transpiration)
6. Water content of the plant -directly proportional to transpiration
7. Canopy structure of area - rate of transpiration will low in plant growing under shade than plant growing open area.

SIGNIFICANCE OF TRANSPIRATION

Transpiration is beneficial to plant because it helps absorption of water, minerals and ascent of sap. It regulate leaf surface temperature. But it is harmful to the plant since it is wastage of water (more than 97% water) absorbed by the plant transpired out.

SO CURTIS SAY TRANSPIRATION IS A NECESSARY EVIL

Antitranspirant - substance that reduces transpiration

(eg. ABA, Phenyl mercuric chloride, surface film).

ABSORPTION AND TRANSLOCATION OF MINERALS

- Minerals are absorbed mainly by active process because minerals exist in soil as ions and soil mineral concentration is less than that of cytoplasm of root cells.
- Minerals are actively absorbed by trans membrane protein utilizing ATP energy.(eg. Na+/K+ ion pump).
- Translocation of minerals. It takes place along with transpiration stream. Minerals are mainly transported to young leaves, developing fruits and flowers, seeds etc.
- There is a remobilization of minerals from old leaf to young leaves trough phloem tissue.

B. TRANSLOCATION OF ORGANIC FOOD MATERIAL (PHLOEM TRANSPORT)

It is the movement of organic food or organic nutrient in soluble form from one organ to other. The translocation is from source end (region where food is translocated like leaf, storage region etc) to sink or region of utilization (region where food is utilized or stored like root system stem etc.).

Direction of movement

The direction of movement of photosynthates in the phloem can be upwards or downwards **(bidirectional)** depending on the season or the plant's needs & they move in the form of non reducing sucrose.

Mechanism of translocation

There are different theories that explain mechanism of phloem translocation. The most accepted one is **PRESSURE FLOW/MASS FLOW OR MUNCH HYPOTHESIS**

According to this hypothesis concentration of glucose in mesophyll cell (source end) increases as a result of photosynthesis. It is then converted into soluble sucrose and is then enters phloem tissue by active transport (phloem loading). So the phloem sap becomes hypertonic and it absorbs water from xylem tissue by osmosis. So osmotic pressure increases in phloem. Now sugar along with water move to the region of low osmotic pressure (sink like root). In sink sucrose is actively removed from phloem (phloem unloading) to storage region or region of utilization. As sucrose is removed from phloem its osmotic pressure decreases, water move back to xylem again.

Girdling experiment : it showed that phloem is responsible for translocation food in plant body. In this experiment a ring of bark (Phloem) of a stem is removed from a potted plant. After few days it can be observed that the upper region of stem (stem above girdled portion) shows accumulation food (due to girdling, down ward flow of food is blocked). It proves that phloem is responsible for translocation food materials.