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Lecture No: 3 & 4

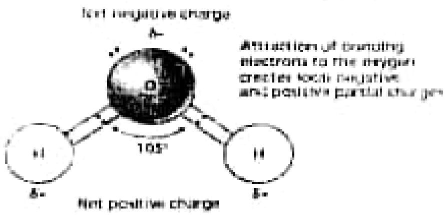
Role and significance of water – Diffusion, imbibition, osmosis and its significance, plasmolysis, Absorption of water and path of water, Ascent of sap and theories of ascent of sap.\

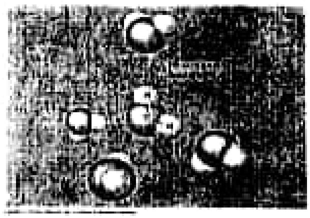
Water is known as the liquid gold or elixir of life. Water is the major constituent of all living cells. Water content in cell ranges from 70 to 90 per cent. Water is dynamic in plant. It forms the major constituent of living things (cells) and all the vital processes of the life are carried out in it. In living tissue, water is the medium for many biochemical reactions and extraction processes. Inorganic nutrients, photosynthates and hormones are transported in aqueous solution. Movement of water form soil solution to root, stem and then to atmosphere, this continuous movement from soil to atmosphere is called as soil-plant-atmosphere water continuum [SPAC]. Evaporation of water can control the temperature of leaf on canopy. Soil nutrients are available to plant roots only when dissolved in water.

Water is one of the most plentiful chemicals available in the earth and the chemical formula is H_20. It is a tiny V-shaped molecule that contains three atoms which do not stay together as the hydrogen atoms are constantly exchanging between water molecules. The water molecule consists of an oxygen atom covalently bonded to two hydrogen atoms. The two O—H bonds form an angle of 105° (Figure). Because the oxygen atom is more **electronegative** than hydrogen, it tends to attract the electrons of the covalent bond. This attraction results in a partial negative charge at the oxygen end of the molecule and a partial positive charge at each hydrogen.

Water has special properties that enable it to act as a solvent and to be readily transported through the body of the plant. These properties derive primarily from the polar structure of the water molecule.

- The Polarity of water molecules gives rise to hydrogen bonds
- The Polarity of water makes an excellent solvent
- The Thermal properties of water result from hydrogen bonding
- The Cohesive and adhesive properties of water are due to hydrogen bonding





Importance of water to plants:

1. Water typically constitutes 80 to 95% of the mass of growing plant tissues.
2. Water is the main constituent of protoplasm comprising up to about 90-95 per cent of its total weight. In the absence of water, protoplasm becomes inactive and is even killed.
3. Different organic constituents of plants such as carbohydrates proteins, nucleic acid and enzymes etc. lose their physical and chemical properties in the absence of water.
4. Water participates directly in many metabolic processes. Inter conversion of carbohydrates and organic acids depend upon hydrolysis and condensation reaction.
5. Water increases the rate of respiration. Seeds respire fast in the presence of water.
6. Water is the source of hydrogen atom for the reduction of CO_2 in the reaction of photosynthesis.
7. Water acts as a solvent and acts as a carrier for many substance. It forms the medium in which several reactions take place.
8. Water present in the vacuoles helps in maintaining the turgidity of the cells which is a must for proper activities of life and to maintain the form and structure.

semi permeable nature of the plasma membrane.

2. It is used to determine the osmotic pressure of the cell sap.
3. Plasmolysis is used in salting of meat and fishes. Addition of concentrated sugar solution to jam and jellies check the growth of fungi and bacteria which become plasmolysed in concentrated solution

Field capacity or water holding capacity of the soil:

After heavy rain fall or irrigation of the soil some water is drained off along the slopes while the rest percolates down in the soil. Out of this water, some amount of water gradually reaches the water table under the force of gravity (gravitational water) while the rest is retained by the soil. This amount of water retained by the soil is called as field capacity or water holding capacity of the soil.

Field capacity is affected by soil profiles soil structure and temperature
The effective depth of a soil, as determined by physical and chemical barriers, together with the clay content of the soil within that depth, determine the water holding capacity of the profile, and how much of the water is available to plants. Effective soil depth varies between plant species. Wheat is used as the benchmark plant in this assessment. Available water holding capacity rankings are estimated from soil texture, structure and stone content within the potential root zone of a wheat plant.

Water-holding capacity is controlled primarily by soil texture and organic matter. Soils with smaller particles (silt and clay) have a larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water. In other words, a soil with a high percentage of silt and clay particles, which describes fine soil, has a higher water-holding capacity. The table illustrates water-holding-capacity differences as influenced by texture. Organic matter percentage also influences water-holding capacity. As the percentage increases, the water-holding capacity increases because of the affinity organic matter has for water.

It is the water content of the soil after downward drainage of gravitational water. It is the capillary capacity of a soil. It is the upper limit of soil water storage for the plant growth. At field capacity, the soil water potential is –0.1 to –0.3 bars.

Water potentials:

Every component of a system possesses free energy capable of doing work under constant temperature conditions. For non-electrolytes, free energy / mole is known as chemical potential. With reference to water, the chemical potential of water is called as water potential. The chemical potential is denoted by a Greek letter Psi (ψ)

For pure water, the water potential is zero (O). The presence of solute particles will reduce the free energy of water or decrease the water potential. Therefore it is expressed in negative value.

It is therefore, water potential of solution is always less than O so is negative value.

For solutions, water potential is determined by three internal factors i.e.

ψ_w $= \psi_s + \psi_p + \psi_m$

ψ_s = is the solute potential or osmotic potential

ψ_p = pressure potential or turgor potential

ψ_m = is the matric potential. Matric potential can be measured for the water molecules adhering on the soil particles and cell wall.

In plant system, the matric potential is disregarded.

Therefore,

$\psi_w = \psi_s + \psi_p$

1. Large quantities of water are absorbed by roots ...
2. Cell to cell movement of waster and other substances dissolved involves osmosis
3. Opening and closing of stomata depend upon the turgor pressure of guard cells
4. Due to osmosis, the turgidity of the cells and hence the shape or form of the organs is maintained.
5. The resistance of plants to drought and frost increases with increase in osmotic pressure to later cells
6. Turgidity of the cells of the young seedling allows them to come out of the soil.

Differences between diffusion and osmosis:

Diffusion	Osmosis
• It is defined as the movement of molecules or ions of a solute or a solvent, be it a solid, liquid or gas from the region of its higher concentration to the region of lower concentration	• The movement of molecules of water or solvent from the region of higher potential to lower potential through a semi permeable membrane
• The diffusion may occur in any medium and the diffusing particle may be solid, liquid or gas.	• Osmosis occurs only in liquid medium and only the solvent molecules move from one place to another.

Imbibition:

Certain substances if placed in a particular liquid absorb it and swell up. For example, when some pieces of grass or dry wood or dry seeds are placed in water they absorb the water quickly and swell up considerably so that their volume is increased. These substances are called as imbibants and the phenomenon as imbibition, certain force of attraction is existing between imbibants and the involved substance. In plants, the hydrophilic colloids *viz.*, protein and carbohydrates such as starch, cellulose and pectic substance have strong altercation towards water.

Imbibition plays a very important role in the life of plants. The first step in the absorption of water by the roots of higher plants is the imbibition of water by the cell walls of the root hairs. Dry seeds require water by imbibition for germination.

As a result of imbibition, a pressure is developed which is called as imbibition pressure or matric potential (ψ_m). It is analogous to the osmotic potential of a solution. With reference to pure water, the values of ψ_m are always negative. The water potential of an imbibant is equal to its matric potential plus any turgor or other pressure (pressure potential) which may be imposed upon the imbibant.

$$\psi_w = \psi_m + \psi_p$$

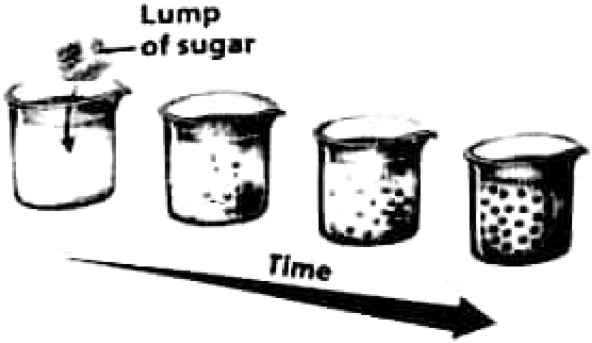
If the imbibant is unconfined to turgor or such pressure, the equations can be significant to

$$\psi_w = \psi_m$$

Plasmolysis:

When a plant cell or tissue is placed in hypertonic solution water comes out from the cell sap into the outer solution by exosmosis and the protoplasm begins to shrink or contract. The protoplasm separate from the cell wall and assumes a spherical form and this phenomenon is called plasmolysis. Incipient plasmolysis is stage where protoplasm begins to contract from the cell wall. If a plasmolysed cell or tissue is placed in water, the process of endosmosis take place. Water enters into the cell sap, the cell becomes

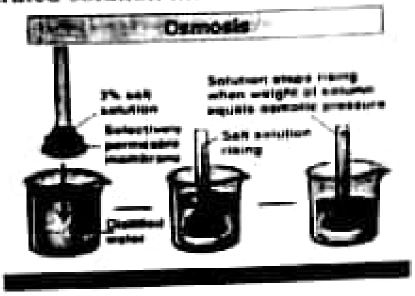
It is important in stomatal transpiration as the last step in the process, where diffusion of water vapour from the intercellular space into the outer atmosphere



occurs through open stomata.

Osmosis:

The diffusion of solvent molecules into the solution through a semi permeable membrane is called as osmosis (some times called as *Osmotic diffusion*). In case there are two solutions of different concentration separated by the semi permeable membrane, the diffusion of solvent will take place from the less concentrated solution into the more concentrated solution till both the solutions attain equal concentration.



Osmotic pressure:

As a result of the separation of solution from its solvent (or) the two solutions by the semi permeable membrane, a pressure is developed in solution by dissolved solutes in it. This is called as osmotic pressure (O.P). OP is measured in terms of atmospheres and is directly proportional to the concentration of dissolved solutes in the solution. More concentrated solution has higher O.P. O.P of a solution is always higher than its pure solvent.

During osmosis, the movement of solvent molecules takes place from the solution whose osmotic pressure is lower (i.e., less concentrated as hypotonic) into the solution whose osmotic pressure is higher (i.e., more concentrated as hypertonic).

Osmotic diffusion of solvent molecules will not take place if the two solutions separated by the semi permeable membrane are of equal concentration having equal *Osmotic pressures* (i.e., they are isotonic). In plant cells, plasma membrane and tonoplast act as selectively permeable or differentially permeable membrane.

Endosmosis:

If a living plant cell is placed in water or hypotonic solution whose O.P is lower than cell sap, water enters into the cell sap by osmosis and the process is called endosmosis. As a result of entry of water within the cell sap, a pressure is developed which press the protoplasm against the cell wall and become turgid. This pressure is called a turgor pressure.

Consequence of the turgor pressure is the wall pressure which is exerted by the elastic cell wall against the expanding protoplasm. At a given time, turgor pressure (T.P) equals the wall pressure (W.P).

T.P = W.P

9. Water helps in translocation of solutes
10. In tropical plants, water plays a very important role of thermal regulation against high temperature.
11. The elongation phase of cell growth depends on absorption of water.

Properties of water:

1. Solvent for electrolyte & non electrolyte
2. High specific heat
3. High latent heat of vaporization (540 cal g^{-1})
4. Cohesive and Adhesive Properties
5. High surface tension
6. High Tensile Strength
7. Stabilizes temperature
8. Transparent to visible radiation
9. Low viscosity

HOW IT HELPS IN PLANTS?

WATER PLAYS A CRUCIAL ROLE in the life of the plant. For every gram of organic matter made by the plant, approximately 500 g of water is absorbed by the roots, transported through the plant body and lost to the atmosphere. Even slight imbalances in this flow of water can cause water deficits and severe malfunctioning of many cellular processes. Thus, every plant must delicately balance its uptake and loss of water.

Diffusion, osmosis and imbibitions:

The movement of materials in and out of the cells in plants takes place in a solution or gaseous form. Although the exact process of this is not very clear, three physical processes are usually involved in it. They are diffusion, osmosis and imbibition.

Diffusion:

The movement of particles or molecules from a region of higher concentrations to a region of lower concentration is called as diffusion. The rate of diffusion of gases is faster than liquids or solutes. The diffusion particles have a certain pressure called as the diffusion pressure which is directly proportional to the number or concentration of the diffusing particles. These forms the diffusion takes place always from a region of higher diffusion pressure to a region of lower diffusion pressure (i.e.) along a diffusion pressure gradient. The rate of diffusion increases if,

i) Diffusion pressure gradient is steeper
ii) Temperature is increased
iii) Density of the diffusing particles is lesser
iv) Medium through which diffusion occurs is less concentrated.

Diffusion of more than one substance at the same time and place may be at different rates and in different direction, but is independent of each other. A very common example of this is the gaseous exchange in plants.

Beside osmotic diffusion the above mentioned simple diffusion also plays a very important role in the life of the plants.

Role of diffusion in the life of the plants:

- It is an essential step in the exchange of gases during respiration and photosynthesis
- During passive salt uptake, the ions are absorbed by diffusion

D.P.D = O.P – T.P

Due to the entry of the water the osmotic pressure of the cell sap decreases while its turgor pressure is increased so much so that in a fully turgid cell T.P equals the O.P

O.P = T.P   – D.P.D = O

In fully plasmolysed cells: T.P = O

So   D.P.D = O.P

D.P.D. incase of plant cells is not directly proportional to their osmotic pressure or the concentration of the cell sap but depend both on O.P and T.P. Higher osmotic pressure of the cell sap is usually accompanied by lower turgor pressure so that its D.P.D is greater and water enters into it. But sometimes it is possible that two cells are in contact with each other one having higher O.P and also higher turgor pressure than the other cell and still its does not draw water. It is because of its lower D.P.D., no matter is O.P is higher.

Cell a		→	Cell b		
O.P	= 25 atm		O.P	= 30 atm	
T.P	= 15 atm		T.P	=10 atm	
D.P.D	= 10 atm		D.P.D	= 20 atm.	A

Cell a		←	Cell b		
O.P	= 35 atm		O.P	= 40 atm	
T.P	= 10 atm		T.P	= 20 atm.	
D.P.D	= 25 atm		D.P.D	= 20 atm.	B

Entry of water into the cell depends on D.P.D and not on O.P only

Absorption of water - mode of water absorption – active and passive absorption and factors affecting absorption

Mechanism of absorption of water:

In higher plants water is absorbed through root hairs which are in contact with soil water and form a root hair zone a little behind the root tips. Root hairs are tubular hair like prolongations of the cells of the epidermal layer (when epidermis bears root hairs it is also known as pilloferous layer) of the roots. The walls of root hairs are permeable and consist of pectic substances and cellulose which are strongly hydrophilic in nature. Root hairs contain vacuoles filled with cell sap. When roots elongate, the older root hairs die and new root hairs are developed so that they are in contact with fresh supplies of water in the soil.

Mechanism of water absorption:

1. Active absorption of water:

In this process the root cells play active role in the absorption of water and metabolic energy released through respiration is consumed. Active absorption may be of two kinds.

(A) Active Osmotic absorption:

Water is absorbed from the soil into the xylem of the roots according to osmotic gradient.

(B) Active Non-osmotic absorption:

Water is absorbed against the osmotic gradient.

2. Passive absorption of water:

It is mainly due to transpiration, the root cells do not play active role and remain passive.

I. Active osmotic absorption of water:

First step in the osmotic absorption of water is the imbibition of soil water by the hydrophilic cell walls of root hairs. Osmotic pressure of the cell sap of root hairs is usually higher than the OP of the soil water. Therefore, the DPD and suction pressure in the root hairs become higher and water from the cell walls enters into them through plasma membrane by osmotic diffusion. As a result, OP, suction pressure and DPD of root hairs now become lower, while their turgor pressure is increased.

Now the cortical cells adjacent to root hairs have high OP, SP & DPD in comparison to the root hairs. Therefore, water is drawn into the adjacent cortical cells from root hairs by osmotic diffusion. In the same way, by cell to cell osmotic diffusion gradually reaches the inner most cortical cells and the endodermis. Osmotic diffusion of

Osmotic pressure:

Osmotic pressure is equivalent to osmotic potential but opposite in sign.

Osmotic pressure in a solution results due to the presence of solutes and the solutes lower the water potential. Therefore osmotic pressure is a quantitative index of the lowering of water potential in a solution and using thermodynamic terminology is called as osmotic potential.

Osmotic pressure and osmotic potential are numerically equal but opposite in sign.

Osmotic pressure has positive sign

Osmotic potential has negative sign (ψ_s)

For eg.

If O.P. = 20 atm.

ψ_s = - 20 atm

Turgor pressure:

In plant cell, the pressure result due to the presence of water molecules is turgor pressure. The potential created by such pressures is called pressure potential (ψ_P).

In a normal plant cell, the water potential

$\psi_w = \psi_s + \psi_p$ – partially turgid cell
(High)

ψ_w = Zero - Fully turgid cell
(Highest)

$\psi_w = \psi_s$ - Flaccid cell or plasmolysed cell
(Lowest)

Water relation:

Water form the major constituent of living (cells) things and the cells originated in a highly aqueous medium and all the vital processes of the life are carried out in it. Besides, water predominately arts as a source of hydrogen to plants and is released by the photolysis of water during photosynthesis.

In living tissue, water is the medium for many biochemical reactions and extraction process. Inorganic nutrients, photosynthates, bases and hormones are all transported in aqueous solution. Evaporation of water can control the temperature of leaf on canopy soil nutrients are available to plant roots only when dissolved in water. In short, water is essential for life and plays a unique role in virtually all biological process.

Example:

There are 2 cells A and B in contact with each other, cell A has a pressure potential (turgor pressure) of 4 bars and certain sap with an osmotic potential of -12 bars.

Cell B has presume potential of 2 bars and certain sap with osmotic potential of -5 bars.

Then,

ψ_w of cell A = $\psi_s + \psi_p$
= -12 + (+4)
= -8 bars

ψ_w of cell B = -5+(+2)
-3 bars

Hence, water will move from cell B to cell A (i.e., towards lower or more negative water potential) with a form of [-8-(-3)] = -5 bars.

Diffusion Pressure Deficit (DPD): (Suction pressure):

Diffusion pressure of a solution is always lower than its pure solvent. The difference between the diffusion pressure of the solution and its solvent at a particular temperature and atmosphere conditions is called as diffusion pressure deficit (D.P.D). If the solution is more concentrated D.P.D increases but it decreases with the dilution of the solution.

D.P.D of the cell sap or the cells is a measure of the ability of the cells to absorb water and hence is often called as the suction pressure (S.P). It is related with osmotic pressure (O.P) and turgor pressure (T.P) of cell sap and also the wall pressure (W.P) as follows.

D.P.D (S.P) = O.P – W.P

But

W.P = T.P

water into endodermis takes place through special thin walled passage cells because the other endodermis cells have casparian strips on thin walls which are impervious to water.

Water from endodermis cells is down into the cells of pericycle by osmotic diffusion which now become turgid and their suction pressure in decreased.

In the last step, water is drawn into xylem from turgid pericycle cells (In roots the vascular bundles are radical and protoxylem elements are in contact with pericycle). It is because in the absence of turgor pressure of the xylem vessels, the SP of xylem vessels become higher than SP of the cells of the pericycle. When water enters into xylem from pericycle a pressure is developed in the xylem of roots which can raise the water to a certain height in the xylem. This pressure is called as root pressure.

(b) Active non-osmotic absorption of water:

Sometimes, it has been observed that absorption of water takes place even when OP of soil water is high than OP of cell sap. This type of absorption which is non-osmotic and against the osmotic gradient requires the expenditure of metabolic energy probably through respiration.

2. Passive absorption of water:

Passive absorption of water takes place when rate of transpiration is usually high. Rapid evaporation of water from the leaves during transpiration creates a tension in water in the xylem of the leaves. This tension is transmitted to water in xylem of roots through the xylem of stem and water rises upward to reach the transpiring surfaces. As a result soil water enters into the cortical cells through root hairs to reach the xylem of roots to maintain the supply of water. The force of this entry of water is created in leaves due to rapid transpiration and hence, the root cells remain passive during this process.

External factors affecting absorption of water:

1. Available soil water:

Sufficient amount of water should be present in the soil in such form which can easily be absorbed by the plants. Usually the plants absorb capillary water i.e water present in films in between soil particles. Other forms of water in the soil e.g. hygroscopic water, combined water, gravitational water etc. is not easily available to plants.

Increased amount of water in the soil beyond a certain limit results in poor aeration of the soil which retards metabolic activities of root cells like respiration and hence, the rate of water absorption is also retarded.

2. Concentration of soil solution:

Increased concentration of soil solution (due to presence of more salts in the soil) results in higher OP. If OP of soil solution will become higher than the OP of cell sap in root cells, the water absorption particularly the osmotic absorption of water will be greatly suppressed. Therefore, absorption of water is poor in alkaline soils and marshes.

3. Soil air:

Absorption of water is retarded in poorly aerated soils because in such soils deficiency of O_2 and consequently the accumulation of CO_2 will retard the metabolic activities of roots like respiration. This also inhibits rapid growth and elongation of the roots so that they are deprived of fresh supply of water in the soil. Water logged soils are poorly aerated and hence, are physiologically dry. They are not good for absorption of water.

4. Soil temperature:

Increase in soil temperature up to about 30°C favours water absorption. At higher temperature water absorption is decreased. At low temperature also water absorption decreases so much so that at about 0°C, it is almost decreased. This is probably because at low temperature,

1. The viscosity of water and protoplasm is increased
2. Permeability of cell membrane is decreased
3. Metabolic activity of root cells are decreased
4. Root growth and elongation of roots are checked.

Differences between active and passive water absorption:

Active water absorption	Passive water absorption
1. It is due to the activity of the roots and particularly root hairs	It is due to the activity of the upper part of the plant such as shoot system.

2. Osmotic and non osmotic mechanisms are involved	Passive absorption is due to transpiration in the upper part
3. In active absorption, the osmotic process involves diffusion pressure deficit (DPD) of the cells. The root hairs have more DPD as compared to soil solution.	It occurs due to the *tension* created in the xylem sap by transpiration pull
4. Active absorption involves *symplastic* movement of water in root hairs. The water first enters the cell sap and then passes from one cell to another. Such type of movement, where living protoplasm involved is called as *symplast*	In passive absorption, water moves probably through the free spaces or *apoplast* of root. The *apoplastic* movement of water includes cell wall and intercellular spaces, which are fully permeable. The water can reach up to endodermis through *apoplast* but it moves through the endodermis by *symplast*
5. The evidences for active absorption are root pressure, bleeding and guttation.	5. The evidence for passive absorption can be given by cutting the roots under water. The absorption of water continued even if all the roots are removed.

Path of water, Ascent of sap and theories of ascent of sap.

ASCENT OF SAP:

The water after being absorbed by the roots is distributed to all parts of the plants. In order to reach the topmost part of the plant, the water has to move upward through the stem. The upward movement of water is called as Ascent of sap.

Ascent of sap can be studied under the following two headings.

1. Path of ascent of sap
2. Mechanism of ascent of sap.

1. Path of ascent of sap:

Ascent of sap takes place through xylem. It can be shown by the experiment

A leafy twig of Balsam plant (it has semi transparent stem) is cut under water (to avoid entry of air bubble through the cut end of the stem) and placed in a beaker containing water with some Eosine (a dye) dissolved in it.

After sometimes coloured lines will be seen moving upward in the stem. If sections of stem are cut at this time, only the xylem elements will appear to be filled with coloured water.

2. Ringing experiment:

A leafy twig from a tree is cut under water and placed in a beaker filled with water. A ring of bark is removed from the stem. After sometime it is observed that the leaves above the ringing part of the stem remain fresh and green. It is because water is being continuously supplied to the upper part of the twig through xylem.

B. Mechanism of ascent of sap:

In small trees and herbaceous plants, the ascent of sap can be explained easily, but in tall trees like Eucalyptus and conifers reaching a height of 300-400 feet, where water has to rise up to the height of several hundred feet, the ascent of sap, in fact, becomes a problem. To explain the mechanism of Ascent of sap, a number of theories have been put forward.

a. vital theory
b. root pressure theory
c. physical force theory
d. transpiration pull and cohesion of water theory

A. Vital theories:

According to vital theories, the ascent of sap is under the control of vital activities in the stem.

1. According to Godlewski (1884) – Ascent of sap takes place due to the pumping activity of xylem tissues which are living.
2. According to Bose (1923) – upward translocation of water takes place due to pulsatory activity of the living cells of the inner must cortical layer just outside the endodermis.

B. Root pressure theory:

Although, root pressure which is developed in the xylem of the roots can raise water to a certain height but does not seem to be an effective force in ascent of sap due to the following reasons.

Magnitude of root pressure is very low (about 2 atm). Even in the absence of root pressure, ascent of sap continues. For example, when leafy twig is cut under water and placed in a beaker full of water it remains fresh and green for sufficient long time.

C. Physical force theories:

Various physical forces may be involved in Ascent of sap.

1. Atmospheric pressure:

This does not seem to be convincing because it cannot act on water present in xylem in roots. In case it is working, and then also it will not be able to raise water beyond 34 feet.

2. Imbibition:

Sachs (1878) supported the view that ascent of sap could take place by imbibition through the walls of xylem. But imbibitional force is insignificant in the ascent of sap because it takes place through the lumen of xylem elements and not through walls.

3. Capillary force:

In plants the xylem vessels are placed one above the other forming a sort of continuous channel which can be compared with long capillary tubes and it was thought that as water rises in capillary tube due to capillary force in the same manner ascent of sap takes place in the xylem.

D. Transpiration pull and cohesion of water theory:

This theory was originally proposed by Dixon and Jolly (1894) later supported and elaborated by Dixon (1924). This theory is very convincing and has now been widely supported by many workers.

Although H- bond is very weak (Containing about 5 Kcal – energy) but they are present in enormous numbers as incase of water, a very strong mutual force of attraction or cohesive force develops between water molecules and hence they remain in the form of a continuous water column in the xylem. The magnitude of this force is very high (up to 350 atm), therefore the continuous water column in the xylem cannot be broken easily due to the force of gravity or other abstractions offered by the internal tissues in the upward movement of water.

The adhesive properties of water i.e. attractions between the water molecules and the containers walls (here the walls of xylem) further ensure the continuity of water column in xylem.

When transpiration takes place in the leaves at the upper parts of the plant, water evaporates from the intercellular spaces of the leaves to the outer atmosphere through stomata. More water is released into the intercellular spaces from mesophyll cells. In turn, the mesophyll cells draw water from the xylem of the leaf. Due to all this, a tension is created in the xylem elements of the leaves. This tension is transmitted downward to water in xylem elements of the root through the xylem of petiole and stem and the water is pulled upward in the form of continuous unbroken water column to reach the transpiring surfaces up to the top of the plant.