ASCENT OF SAP
ASCENT OF SAP

• The water is absorbed mainly by the roots and is moved upward to all the parts of the plant via stem.
• Thus, the upward movement of water and dissolved substances through stem is called *ascent of sap*. 

Path of Ascent of Sap

After absorption by root hair cells, the water moves through several root tissues such as cortex, endodermis, pericycle and finally enters the xylem tissues.
Once the water enters the xylem it continues its upward movement until it reaches the mesophyll tissues of the leaves.
The bulk of water enters the mesophyll cells and finally evaporates and transpires through the stomata, only small amount of water is used in metabolism and growth.
Theories of Ascent of sap

• Root Pressure Theory
• Vital theories
• Physical Theories
Root Pressure Theory

If a well watered tomato plant is cut near its base, the xylem sap is seen to flow out through the cut end with a pressure. This phenomenon can be observed in many herbaceous plants. The pressure of exudation can be demonstrated by placing a vertical tube to the cut end of stem, a column of sap is seen to rise in it. This pressure is actually the hydrostatic pressure developed in the root system called root pressure.
• The root pressure is defined by Stocking in 1956 as ‘a pressure developing in the treachery elements of the xylem as a result of the metabolic activities of roots.’

• The root pressure is caused due to water potential gradients and is maintained by the activity of living cells.
The root pressure is referred to as an active process:

The pressure is not observed if the roots are placed in hypertonic and isotonic solutions. Oxygen supply and some poisons also affect the root pressure without affecting semipermeability of protoplasm. Living roots are essential for it to occur.
• It is believed that root pressure may be a factor of some significance in the ascent of sap.
• Although, it has been demonstrated that water moves to the top of plants even if the roots have been removed.
• Moreover, the magnitude of root pressure is about 2 atm. (White, 1938 observed upto 6 atm.), which is just sufficient to raise the water level upto few feets.
  – Thus, it is widely accepted that the root pressure is too weak a force to account for movement of water to the tops of tall trees.
Root Pressure theory for ascent of sap can be discarded due to the following objections:

- Strasburger observed ascent of sap in the plants in which roots are removed.
- In most of plants root pressure is about 2 atm. while tall plants require much more pressure to raise water to the tops.
- Excuded sap of detopped plant is very less as compared to the absorbed water of normal transpiring plant.
- Absorption of water is less in detopped plants as compared to the plant with apex.
- Root pressure is not observed in plants growing in cold, drought or less aerated soil, while ascent of sap is normal.
- Root pressure are not found in conifer trees under any condition.
- Root pressure does not occur when plants are exposed to relatively dry atmospheres or low soil moistures or both, because water in their stems is under tension.
VITAL THEORIES OF ASCENT OF SAP

• According to these theories living cells are required for the ascent of sap.
• These theories have been proposed by several workers viz., Godlewski (1884), Bose (1923) and Molish (1929).
• Godlewski (1884) proposed ‘relay pump theory’, according to which living cells of xylem parenchyma show rhythmic change in the osmotic pressure which causes upward movement of water.
Sir J.C. Bose (1923) invented an electrical probe by which the activity of cell inside the plant body can be detected.

He inserted the needle of electric probe upto certain distance in the stem and found a pulsating movement in the innermost cells of cortex i.e. cells outside the endodermis shows simultaneous expansion and contraction.

He came to the conclusion that cells associated with xylem show pumping action and pump its sap into the xylem cells.

Several other vital theories have been proposed from time to time but most of them were discarded because it was discovered at that time that even some poisons like picric acid and carbolic acid can also be translocated through xylem and ascent of sap is not stopped.

Thus fundamental basis of vital theories fails.
Imbibition Theory

- First proposed by Unger in 1868 and then supported by Sachs in 1878.
- According to this theory, the rise of water takes place due to imbibitional forces through the walls of xylem cells.
- Magnitude of imbibitional force is 100-1000 atm. Which is sufficient to raise water upto top of tall trees.
- Later on ringing experiments proved that water moves through the lumen of cell and not through the walls and therefore, this theory was discarded.
Capillary Theory

• Theory of capillary force responsible for ascent of sap was given by Boehm in 1809.
• Since the water moves upward through the lumen of xylem cells, it was proposed that capillary force must be playing a definite role.
• This theory been rejected because the magnitude of capillary force is too low to account for rise of water in tall trees.
• Vessels which are broader than the tracheids can conduct more water.
• Moreover the vessels of springwood provide much conduction of water as compared to the vessels of autumn wood.
• This is against the law of capillary and therefore, this theory was discarded.
Atmospheric Pressure Theory

• The water transpires from the leaves which reduces the pressure in the xylem cells and this gap is filled by the water just below it due to atmospheric pressure.

• Objections to this theory are:
  ➢ pressure of free surface at the lower end of plant is required for the atmospheric pressure to operate which is not found in roots.
  ➢ the atmospheric pressure can raise the water only upto 34 feet.
  ➢ It will not be possible for it to raise water beyond that so this theory also did not get much support.
Cohesion-tension theory was originally proposed by Dixon and Joly (1894), Askensay (1895), Curtis and Clark (1951), Bonner and Galston (1952) and Gramer and Kozlowski (1960).

The theory is based on the following features:

- Cohesive and adhesive properties of water molecules to form an unbroken continuous water column in the xylem.
- Transpiration pull or tension exerted on this water column.
• Xylem vessels are tubular structures from roots to the top of the plants.
• Cells are placed one above the other, with their end walls perforated forming a continuous tube.
• These are supported by xylem tracheids which are characterized by having pores in their walls.
• One end of xylem tube is connected with the root hairs via pericycle, endodermis and cortex and another end is connected with the substomatal cavity in the leaves via mesophyll cells.
• This tube is filled with water.
FIGURE 4.4. Xylem elements: A—vessels, and B—tracheids.
• The water is filled inside the xylem capillaries and due to cohesion (a force holding a solid or liquid together owing to attraction between the molecules) and adhesion (sticking to a surface) properties of water, it forms a continuous water column.

• The water column cannot be broken or pulled away from the xylem walls because of cohesion and adhesion of water.

• The water column is subjected to various forces which try to break it.

• These forces are
  – Weight of the column itself
  – The resistance put to it during translocation

Since the magnitude of the cohesive force is much high (upto 350 atm) the column is not broken by other forces.
• An important factor which can discontinue the water column is the introduction of air bubbles in the xylem.

• Copeland (1902) believed that air bubbles enter into the xylem which break the tensile strength of water column, but Scholnder et al, (1957) have shown that the air does not block the entire conducting system.

• Even if air bubbles were introduced, the individual water columns were unbroken and continuous with each other both in the vertical and lateral directions through the pits present in cell walls.
• It is clear that water columns in the xylem are continuous.
• They extend from substomatal cavities in leaves to the roots.
• These unbroken water columns are just like steel ropes which are extended from leaves to the roots.
• If this rope is pulled from the top, the entire rope will move upward.
• In plants the pull is generated by the process of transpiration which is known as transpiration pull.
• The water vapours evaporate from mesophyll cells to the intercellular spaces as a result of active transpiration.
• The water vapours are transpired through the stomatal pores.
• Loss of water from mesophyll cells causes a decrease in the water potentials (the cell sap of mesophyll cells becomes more concentrated and consequently their water potential decreased).
• The water moves from cell to cell along the water potential gradient (from higher water potential to lower water potential).
• Finally the movement of water within the leaf is transmitted to the water filled in the xylem elements.
• This exerts a pull and the water, filled in the xylem, comes in the state of tension.
• This pull is called **transpiration pull**.
• This tension, generated at the top of the unbroken water column, is transmitted downwards from petiole, stem and finally reaches to the roots.
• Scholander and his colleagues (1965) observed that the water filled inside the xylem capillaries is really under tension.
• They measured this tension under a variety of conditions and found that it varied from a few tenths of a megapascal below zero to more negative than -8.0 megapascals.
• The tensions created by transpiration, osmotic uptake of water by living cells and the hydration of cell walls get relieved by an upward movement of water.
• Thus, the theory strongly suggests that the cohesion of water and transpiration pull is responsible for the upward movement of sap in the plants.
Evidences in support of cohesion-tension theory

1. Scholander provided evidences in favour of continuous freely mobile sap column and absence of metabolic pump.

2. All forces combined together have been found to be 50 atm. in the tallest tree which creates obstacles, but the cohesive force of water is upto 350 atm. which prevents the breaking of the column.

3. A leafy twig cut under water and the cut end of twig sealed to the top of a mercury manometer has been shown to pull the mercury above barometric level (Thut, 192).

4. If the water is under tension, the strain in the vessels should cause their diameters to decrease. A decrease in diameter of tree stems have been observed when the transpiration is high.
Criticism

• Cohesion theory assumes tracheids to be more effective than vessels. Recent findings, however, shown that, vessels instead of tracheids, are more efficient in upward movement of water and truly so the dominant flora adapted vessels in the place of tracheids.

• Air bubbles have been found to occur frequently in the xylem tracheids and vessels and they increase in size and number with the increase in temperature, height and tension. These bubbles block the narrow water channels and should normally break the water columns.

• Milburn and Johnson in 1966 have shown that the water columns frequently break even in herbaceous plants. The ascent of sap, however, continuous under such conditions.

• Upward movement of water occurs even when the continuity of water column is broken by over-lapping cuts.
Factors affecting Ascent of sap

• Since the water transport is regulated by root pressure and transpiration pull, all those factors which affect the rate of water absorption and transpiration also influence the ascent of sap.
• Factors such as high temperature, low atmospheric humidity, high atmospheric pressure and wind velocity permit more rapid transpiration and thus these factors also promote upward transport of water.
• Deficiency of water in the soil also cause decrease in the ascent of sap indirectly by influencing the absorption of water.
• Stomatal opening and closing also regulates movement of water in plants, for example, wilting of a plant is coupled with the closure of stomata and it results in the decrease of ascent of sap.