Plant physiology

Ascent of sap

Ascent of sap:

The ascent of sap in the xylem tissue of plants is the upward movement of water and minerals from the root to the crown.

Mechanism of Ascent of Sap:

In small trees and herbaceous plants the ascent of sap can be explained easily, but in tall trees like Australian Eucalyptus, some conifers such as mighty Sequoias (Sequoia, Sequoia Dendron, Metasequoia are the tallest and thickest trees of the present day flora, sometimes reaching a height of 300-400′) where the water has to rise up to the height of several hundred feet, the ascent of sap, in fact, becomes a problem. Although the mechanism of ascent of sap is not well understood, a number of theories have been put forward to explain it.

Theories of Ascent of SAP:

(A) Vital Theories:

Supporters of vital theories think that the ascent of sap is under the control of vital activities in the stem.

Two such theories are common but they are not very convincing:

(1)According to Emil Godlewski(senior) (1884) ascent of sap takes place due to the pumping activity of the cells of xylem parenchyma which are living(Relay pump theory or clamberinh force theory).

The cells of the medullary rays which are also living, in some way change their O.P. When their O.P. becomes high they draw water from the lower vessel and their O.P. becomes low.

Now due to the low O.P., water from the cells of xylem parenchyma is pumped into the above vessel. This process is repeated again and again and water rises upward in the xylem.

This theory seemed only hypothetical, and was further discarded by the experiments of Strasburger. (1891, 1893) who demonstrated that ascent of sap continues even in the stems in which living cells have been killed by the uptake of poisons.

(2) According to J. C. Bose (1927) upward translocation of water takes place due to the pulsatory activity of living cells of inner most cortical layer just outside the endodermis.

This theory was also rejected because many workers could not repeat his experiment and many others found no correlation between pulsatory activity and the ascent of sap.

(Bose, in his experiment used an electric probe which was connected to a galvanometer. When the needle of the electric probe was inserted into the stem slowly and slowly, the needle of the galvanometer showed some oscillations but when the electric probe needle reached the innermost layer of cortex, the needle of galvanometer showed violent oscillations. He attributed this to the pulsating activity of these cells.)

(B) Root Pressure Theory:

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

(i) Magnitude of root pressure is very low (about 2 atms).

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

(iii) In gymnosperms root pressure has rarely been observed.

(C) Physical Force Theories:

Various physical forces may be involved in the ascent of sap:—

(1) Atmospheric Pressure:

This does not seem to be convincing because:

(i) It cannot act on water present in xylem in roots,

(ii) In case it is working, then also it will not be able to raise water beyond 34′.

(2) Imbibition:

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

(A leafy twig is cut under water and the cut end is dipped in melted paraffin wax for some time. A thin section of stem near cut end is removed to expose the cell walls. The twig is transferred to a beaker containing water. The twig soon wilts because the lumens of xylem elements have been plugged by wax).

(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 xylem.

There are many objections to this theory:

(i) For capillarity a free surface is required.

(ii) The magnitude of capillary force is low.

(iii) In spring when there is more requirement of water due to the development of new leaves, the wood consists of broader elements. While in autumn, when water supply decreases, the wood consists of narrow elements. This is against capillarity.

(iv) In Gymnosperms usually the vessels are absent. Other xylem elements do not form continuous channels.

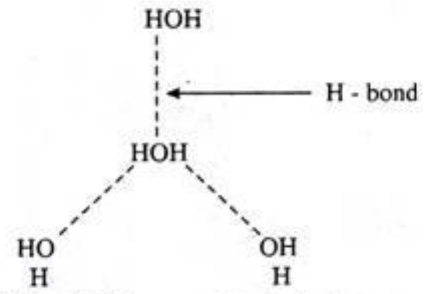
(D) Transpiration Pull and Cohesion of Water Theory:

This theory was originally proposed by Dixon and Joly (1894) and greatly supported and elaborated by Dixon (1914, 1924). This theory is very convincing and has now been widely supported by many workers.

It is based on the following features:

(i) Cohesive and Adhesive properties of water molecules to form a continuous water column in the xylem.

(ii) Transpiration pull exerted on this water column.



H-bonds between water molecules.

Water molecules remain joined to each other due H-bonds between water molecules, to the presence of H-bonds between them. (Whenever a H-atom comes between two electro-negative atoms a bond is established between the two which is called as H bond and is represented by dotted lines. In case of water, the electropositive H-atoms of one water molecule are connected with electronegative O-atoms of other water molecules by H-bonds).

Although H-bond is very weak (containing about 5k. cal. energy) but when they are present in enormous numbers as in case 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 (sometimes up to 350 atmos.), therefore the continuous water column in the xylem cannot be broken easily due to the force of gravity or other obstructions offered by the internal tissues in the upward movement of water.

The adhesive properties of water i.e. the attraction between the water molecules and the container’s walls (here the walls of xylem) further ensure the continuity of water column in xylem.
When transpiration takes place in leaves at the upper parts of the plant, water evaporates from the intercellular spaces of the leaves to the outer atmosphere through the stomata. More water is released into the intercellular spaces from the mesophyll cells. In turn, the mesophyll cells draw water from the xylem of the leaf.

Due to all this, a tension is created in water in the xylem elements of the leaves. This tension is transmitted downward to water in xylem elements of the roots 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 plants.

According to some workers, the main objection against this theory is that certain air bubbles present in the conducting channels will break the continuity of the water column.

This has been counteracted by others who say that there are no air bubbles and if at all are present, they will not break the water column which will remain continuous through other elements of the xylem (Fig. 6.2).

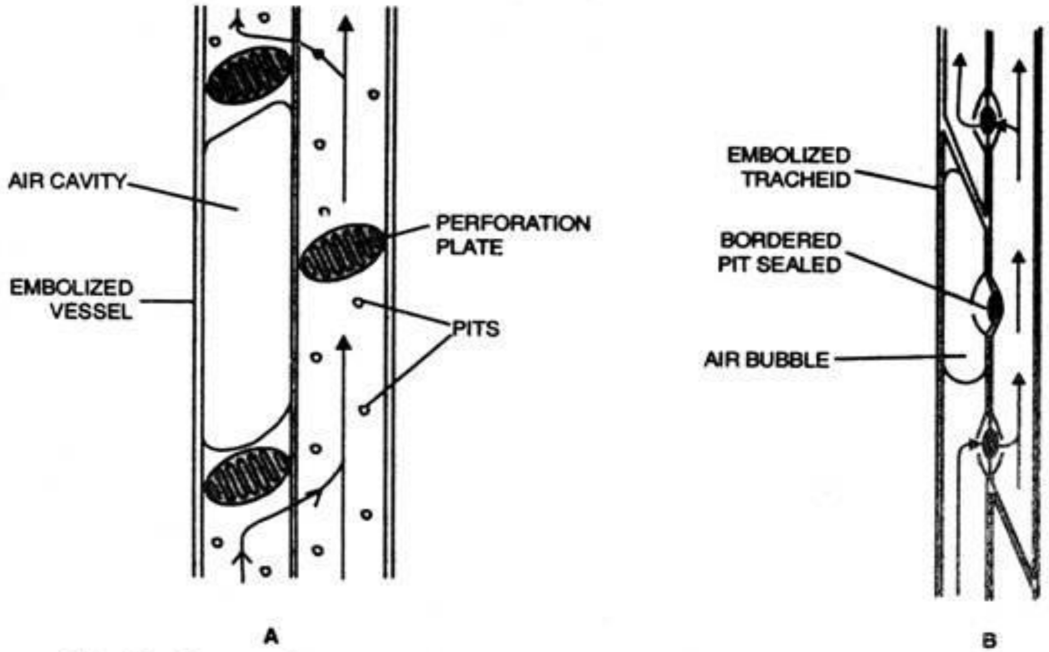


Fig. 6.2. Diagrammatic representation of upward movement of water (shown by arrows) in xylem vessels (Fig. A) and tracheids (Fig. B) bypassing the embolized ones.

References:
https://en.m.Wikipedia.org/wiki/Ascent_of_sap