TRANSPORT IN FLOWERING PLANTS

Uptake and transport of water.

Water is essential for photosynthetic reactions and other metabolic process, hence should be availed in sufficient amounts to the plant. Uptake and transportation of water in a plant is usually facilitated by its loss from the plant in form of vapour to the atmosphere, called ***transpiration***. Thus before we discuss uptake and transport of water in a plant lets first look at transpiration.

Transpiration.

This is the loss of water in form of vapour from the plant shoot to the atmosphere.

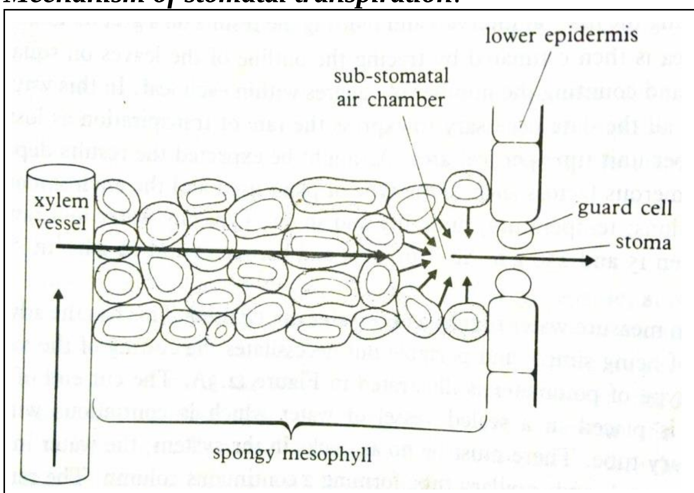
Types of transpiration: Three types according to site of plant through which water is lost. These are;

(a) ***Stomatal transpiration***, Evaporation of water from cells and diffusion of water vapour through stomata (pores found in epidermis of leaves). About 90% of the water is lost this way because leaves have: **(i)** large number of stomata mainly for gas exchange. **(ii)** Large surface area, enhanced by their large numbers. **(iii)** Thin lamina, reduces diffusion distance of water vapour. **(iv)** Large intercellular spaces in spongy mesophyll cells, easy evaporation of water from surface of neighboring cells to enhance its exit.

(b) ***Cuticular transpiration***, Evaporation of water from the outer walls of epidermal cells through the waxy cuticle covering the epidermis of leaves and stems. About 10% of the water lost, varying with thickness of the cuticle.

(c) ***Lenticular transpiration***, Evaporation of water through lenticels (Small slits on the stems and bark of trees for gas exchange). Minute proportions of the water lost, although main type of water loss in deciduous plants after leaf fall.

Mechanism of stomatal transpiration.



Each stoma opens into a ***sub-stomatal air chamber*** which is lined with ***spongy mesophyll cells***. As evaporation proceeds, water vapour accumulates in the substomatal air chambers and escapes through stomata to surrounding atmosphere. Vapour is more saturated immediately after each stoma in atmosphere and progressively diffuses away forming ***diffusion shells*** (resulting layers of decreasing saturation). As water evaporates from the spongy mesophyll cells, it's replaced by water from xylem vessels in vein.

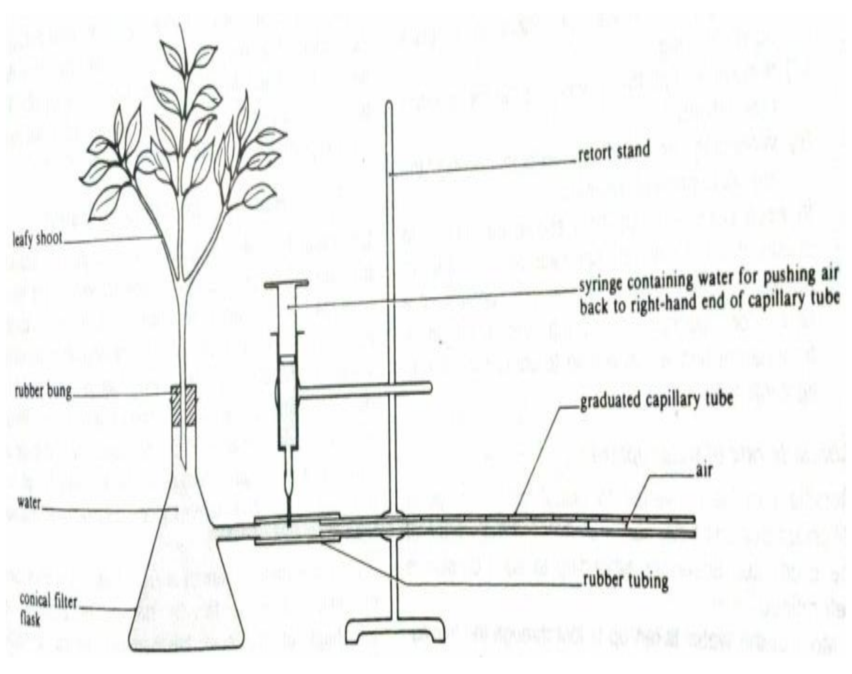
Demonstration of transpiration.

Transpiration can be demonstrated by means of absorptive paper saturated with ***cobalt thiocynate*** [cobalt (II) chloride]. In anhydrous state, copper (II) chloride is ***blue*** and on hydration turns ***pink***. **Procedure**: A piece of copper (II) sulphate is placed on each side of leaf and sandwiched between two glass slides clamped together. **Observation**: After a period of time, the paper turns pink, indicating that water has escaped from the leaf.

Measuring the rate of transpiration.

(a) **The weighing method**: Involves placing a well-watered potted plant on a weighing balance and change in mass is noted over time. Basing on an assumption that the ***mass loss is only due to water loss*** by transpiration which is expressed in terms of mass lost per unit time. The whole plant is enclosed in a polyethene bag to prevent evaporation of soil water.

(b) **The potometer**: A potometer is an instrument used to measure rate of water uptake by the shoot of a leafy plant. It does not measure rate of transpiration directly but potometer bases on an assumption that ***water uptake equals water loss*** since most of water taken up is lost by transpiration.



Procedure: The leafy shoot is cut under water to prevent the air bubbles from entering and blocking the xylem vessels. The cut end of the leafy shoot is immediately placed in the sealed vessel of water which is continuous with the capillary tube. The rate of water uptake is then measured by introducing an air bubble at the end of the graduated capillary tube and the distance moved by the air bubble per unit time is noted. To drive the air bubble back to the original position, water is introduced into the capillary tube from the reservoir by opening the tap on the reservoir.

Rate of transpiration is expressed in terms of volume water taken up per unit time such as cm^3 / hr. Rate of water loss per unit leaf area is obtained if the above expression is divided by total leaf area. Total leaf area is obtained by drawing the outline of the leaves on a squared graph paper and then counting the number of complete and incomplete squares enclosed in the outline (Number of complete squares X1 + Number of incomplete squares X 0.5). Then results can be expressed as $cm^3hr^{-1}m^{-2}$ leaf area.

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Effects of the following factors maybe investigate: (i) **Wind**, Use small electric fan though don't strongly buffet the leaves or the stomata will close. (ii) **Humidity**, Enclose the shoot in a transparent plastic bag. (iii) **Darkness**, enclose the shoot in a black polyethene bag.

Factors affecting rate of transpiration.

(1) **Environmental factors**: These are external factors which include;

(a) **Temperature**: **(i)** Temperature provides latent heat of vaporization, encourages water evaporation from mesophyll cells. **(ii)** High temperature lowers relative humidity of air outside the leaf this builds a steeper concentration gradient of water molecules from inside of leaves to external atmosphere which encourages transpiration.

(b) **Relative humidity**: This is the degree to which atmosphere is saturated with water vapour. This determines ***saturation deficit*** (humidity difference between inside and outside of a leaf). The lower the relative humidity of the surrounding atmosphere, the greater the saturation deficit and the faster the rate of transpiration. In arid areas, relative humidity is low, thus high rate of transpiration hence xerophytes must prevent excessive water loss by cutting down number of stomata and other various ways. In humid situations, such as tropical jungles, relative humidity is high, more water accumulates in leaves than can be removed by transpiration. Water may drip from leaves process called ***Guttation***. This can be through stomata or special glandular structures called ***Hydathodes*** located at edges of the leaves.

(c) **Air movements**: Air movements blow away diffusion shells (water vapour around the leaf) from immediate surface of the leaf. This increases humidity difference between inside and outside of a leaf, this encourages evaporation of water through stomata.

(d) **Atmospheric pressure**: The lower the atmospheric pressure the greater the rate of diffusion because lower atmospheric pressure increases pressure gradient between inside and outside of a leaf which favours faster water evaporation into the atmosphere.

(e) **Light**: Increase in light intensity causes stomata to open, thus increasing rate of transpiration. (f) **Water supply**; Transpiration depends on the walls of mesophyll cells being thoroughly wet, thus the plant must have an adequate water supply from the soil. If soil is too dry, sooner or later the stomata closes thereby lowering the rate of transpiration.

(2) **Non environmental factors**: Internal factors, depend on the morphology of the plant. These include;

(a) **Leaf surface area and surface area to volume ratio**. Transpiration increases with total leaf surface area and with surface area to volume ration. Reduction of leaf surface area is achieved when: **(i)** leaves are reduced to needles e.g. pinus and other conifers. **(ii)** Leaves reduced to spines e.g. in Cacti. **(iii)** Surface area to volume ratio maybe reduced by using stem as the main photosynthetic organ e.g. in cacti.

(b) **Cuticle**: Layer secreted by epidermis. Consists of fatty substance called **cutin** which is a relatively water proof. The thicker the cuticle the lower the rate of transpiration.

(c) **Stomata**: The greater the number of stomata the faster the rate of transpiration. Stomata distribution is very important. Dicot leaves have more stomata on lower surfaces than upper surfaces. Monocot leaves have similar stomata distribution on both upper and lower surfaces. Why?

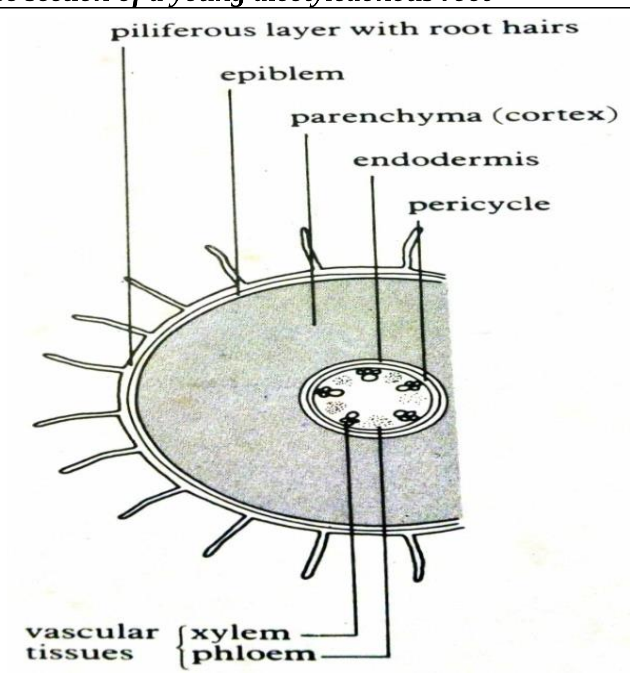
Significance of transpiration: **(i)** Cooling effect, it extracts latent heat of vaporization from the plant. **(ii)** Facilitate water absorption. **(iii)** Facilitates transportation of water and mineral salts up the stem by transpiration pull. **(iv)** Water vapour lost is useful in rain formation.

Disadvantages of transpiration. (a) **Water stress**: Condition when plant loses more water by transpiration than it absorbs from the soil. Results into ***wilting*** (drooping of parts of non woody plants as a result of loss of turgidity. Results into closure of stomata, cutting of gas exchange hence death.

Adaptations and modifications of xerophytes to minimize water loss by transpiration: possession of; **(i)** Waxy cuticle. **(ii)** Few stomata per unit leaf area. **(iii)** Stomata open at night and close during day. **(iv)** Sunken stomata. **(v)** Shedding of leaves when conditions are unfavorable. **(vi)** Hairy laminae. **(vii)** Compact mesophyll with reduced or no intercellular spaces. **(viii)** Leaves modified into thorns. Explain each adaptation?

<u>Uptake of water by the roots</u>.

Root structure.

<table>
<tr><td>Transverse section of a young dicotyledonous root</td><td rowspan="2">This is made up of: (i) Peliferous layer, one cell epidermal layer with root hairs. As root gets older, it ruptures leaving epiblem (outermost layer of parenchyma cells) to become the functional outer layer. (ii) Cortex, has parenchyma cells, starch maybe stored. (iii) Endodermis, one cell thick, has casparian strip made of suberin. (iv) Pericycle, has one to several layers of parenchyma cells, in dicots produce lateral roots. (v) Xylem and phloem found in the center of the root.</td></tr>
<tr><td>
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<u>Mechanism of water uptake by roots</u>.

The root hairs are ***slender*** and ***flexible***, penetrate between soil particles and absorb water by ***osmosis*** because: root hair saps have lower water potential than surrounding soil water due to presence of sugars and other metabolites. On addition, root hairs: (i) lack cuticle. (ii) Are numerous, increases surface area for water absorption. Water molecules pass across cellulose cell wall to protoplast to vacuole.

From root hairs, water passes to the vascular tissues in the center of the root via the intervening parenchyma cells by three possible ways.

(a) **Vacuolar**: Through sap vacuoles, water being drawn from one vacuole to the next by osmosis. This pathway offers resistance to water movement because it requires an osmotic gradient from cell to cell across the root which has never been demonstrated.

(b) **Symplast**: Through cytoplasm, water flows from cell to cell via plasmodesma strands. This pathway offers some resistance to water flow as water has to move across cellulose cell wall and plasma membrane before entering cytoplasm.

(c) **Apoplast**: Along the cell walls, water flowing within cellulose cell wall of adjacent cells and through the small intercellular spaces between them. This pathway offers least resistance to water flow and treating plants with chemicals which cause precipitation along transpiration stream, has proved that water water moves mainly by apoplast pathway. Thus is considered to be the most likely pathway by which water moves from cells to vascular tissues in a root.

Symplast and Apoplast pathways are aided by low water potential in xylem cells due to: (i) High concentration of solutes in Xylem sap. (ii) Tension built in xylem as water moves up the xylem.

Passage of water into vascular tissues of the root.

The passage of water from parenchyma cells into vascular tissues of the root can be explained by two hypotheses:

(a) **The transpiration pull hypothesis**: This believes that as a result of transpiration, the low water potential developed in leaf cells results in water being drawn into and along the vascular tissues. The prime force moving water into the vascular tissues from parenchyma cells in the root is a 'pull' exerted by the transpiring leaves.

(b) **The root pressure hypothesis**: If a stem of a plant is severed (suddenly cut), the cut end of the stump will exude copious (large) quantities of water for a considerable time, suggesting there is a force pushing water up the stem from the roots called Root pressure. This force is likely to push water from parenchyma cells to vascular tissues in the root. This force can be measured by attaching a suitable mercury manometer at the cut end of the stem. Root pressure is an active force which involves use metabolic energy evidenced by the stopping of water exudation from cut stems when: **(i)** Oxygen supply to roots is cut off. **(ii)** Roots treated with a metabolic poison such as cyanide. **(iii)** Lowering temperature. And **(iv)** numerous starch grains in endodermal cells.

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The endodermis cells possess a **casparian strip** (band of corky material runs around each cell in its radial and horizontal walls made of **suberin**). Casparian strip is impermeable to water, when water reaches endodermis cannot enter vascular cylinder via the radial and horizontal walls of the endodermis cells thus cannot move through apoplast pathway at this point, and must be diverted through the symplast.

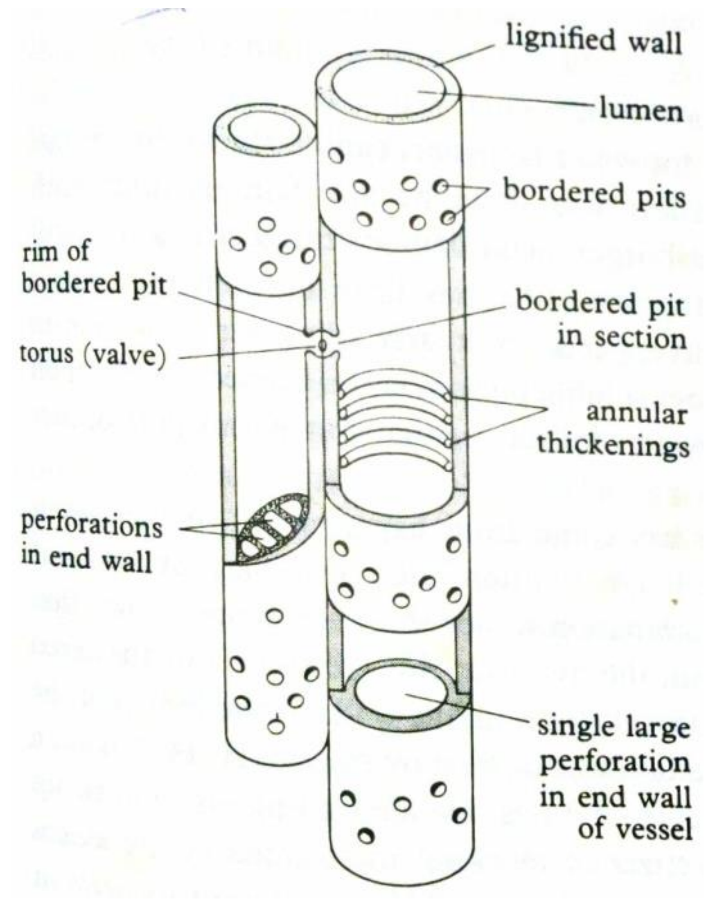
The Endodermis is believed to actively secrete salts into the vascular tissues, creating a low water potential into them. As a result water is drawn into vascular tissues by osmosis across selectively permeable membranes of endodermal cells. The casparian strip restricts water movement through cell wall and prevents outward leakage of salts from the vascular tissues.

<u>Transport of water from roots to leaves</u>.

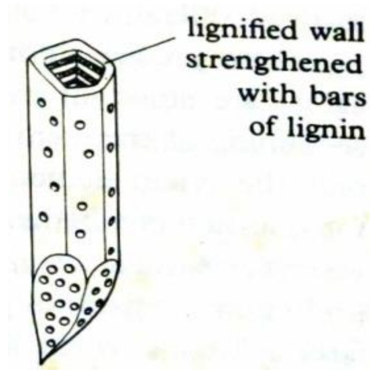
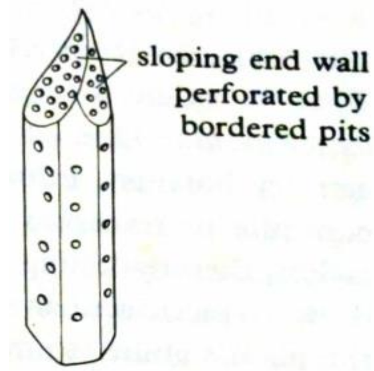
The vascular tissue responsible for water transport is the Xylem.

Xylem tissue.

The xylem tissue contains types of conducting element: (a) ***Vessel*** and (b) ***Tracheids***.



(a) **vessels**; formed from a chain of elongated, cylindrical cells placed end to end. In their course of development, the horizontal end walls breakdown partially or completely breakdown so that the cells are in open communication with each other. At the same time, the cellulose side walls become impregnated with **lignin**, rendering them impermeable to water and solutes. Unable to absorb nutrients, the protoplasmic contents of the cell ***die***, leaving a ***hollow tube of vessel***. The lignified walls are perforated by numerous ***pits*** where lignin fails to be deposited and only the primary wall remains. These pits permit passage of water in and out of the lumen. Lignin is laid down in the walls of the vessels in various ways to give rise to different forms of thickening: **(i)** annular. **(ii)** Spiral. **(iii)** Reticulate. **(iv)** Pitted. These give vessel added strength and prevent its walls from curving in.

(b) **Tracheids**: These are similar to vessels except that they are typically five or six – sided in cross section, have tapering ends and, instead of being open at each end, their tapering end walls are perforated by pits		

The Xylem and water transport.

Water transport takes place through lumina (singular; lumen) of ***dead*** vessels and tracheids. Suited by possessing: **(i)** The pits, allow horizontal movement of water in and out of the. **(ii)** Hollow lumina permit unimpeded flow of water along the tubes. **(iii)** Vessels, with their open ends offer less resistance to passage of water**. (iv)** Tracheids have end walls with perforated pits.

The Ascent of water up the stem.

Transport of water by the xylem is accounted for by: **(i)** Cohesion – tension theory and **(ii)** Root pressure.

(a) **Cohesion – tension theory**: According to this theory, water evaporation from the cells of leaves is responsible for rising of water from the roots. As water evaporates, water potential of cells near xylem in leaves lowers, water enters these cells from xylem sap (has high water potential) passing through moist cellulose cell walls of xylem vessels at the end of veins. As water leaves xylem vessels (are full of water), a **tension** is set up in the column of water. Because such a force is due to water loss by transpiration, it's called ***Transpiration pull***. This is transmitted back down the stem to the root by **cohesion** (force of attraction between like molecules) of water molecules. Water molecules have high tension (tend to stick to each other) because *are polar, are electrically attracted to each other and held held together by hydrogen bonding*. This high cohesion of water molecules requires relatively large tension to break a column of water (has high tensile strength). They also tend to stick on vessel wall by **adhesion** (force of attraction between unlike molecules). The tension in xylem vessels builds up a force capable of pulling the whole water column upwards by mass flow and water enters the base of columns in the roots from neighboring root cells.

(b) **The root pressure theory**: Root pressure as discussed earlier, this enables movement of water from the parenchyma cells of the main root into the xylem tissue due to the active pumping of cells from endodermal cells into the xylem tissue. Root pressure also ensures upward movement of water through the xylem tissues to the leaves.

NB. Movement of water through narrow vessels is also aided by capillarity.

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***Evidence that water transport occurs in xylem*.**

(i) A plant will continue to transpire even after trunk has been enclosed in a steam jacket (killing all living cells), this indicates that water transport occurs through dead cells.

(ii) Ringing experiments, when outer ring (bark) including phloem is removed from the stem of a plant in a short time, this does not affect upward movement of water. But lifting a flap of the bark, remove section of xylem and replacing flap of bark, leads to rapid wilting. Water therefore moves in xylem.

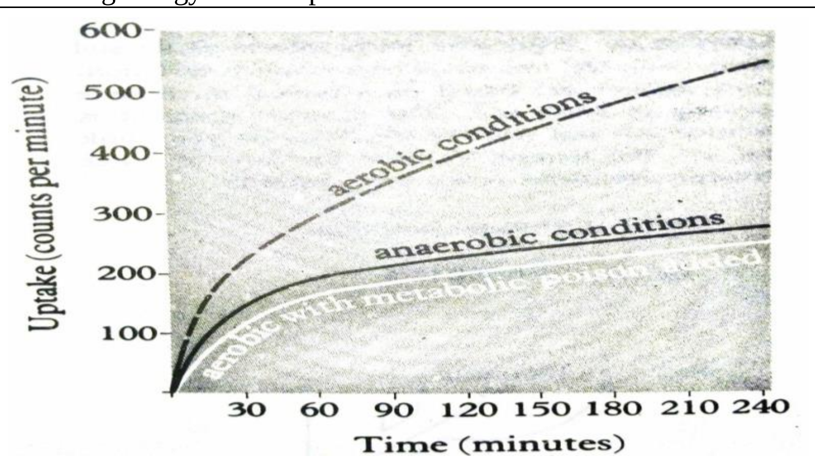
(iii) When a cut stem is placed in colored dye (eosin), and subsequently sectioned and examined under a microscope, only xylem elements contain the dyes.

(iv) Treating a plant with metabolic poison has no effect on water uptake, indicating water transported by dead cells.

Uptake and translocation of mineral salts.

In addition to carbon dioxide and water, plants require a variety of mineral elements absorbed as appropriate ions from: **(i)** water by aquatic plants and **(ii)** Soil by terrestrial plants. Ion up take is a combination of :

(a) **Active uptake**, or active transport, in which ions are taken up into root cells against a concentration gradient using energy from respiration. Occurs when ions are more concentrated in root hair cell than soil.



The influence of oxygen deprivation and metabolic poison on the uptake of sulphate ions. The much reduced uptake in anaerobic conditions and with addition of a metabolic poison suggests that active transport is involved.

***Evidence that absorption of mineral salts by plants involves active transport*.**

Absorption of ions by young roots of a plant is inhibited by: **(i)** Treatment of roots with metabolic poison. **(ii)** Reduction in temperature. **(iii)** Cutting off Oxygen supply. **(iv)** Concentration of ions may be many times greater in cells of the plant than the surrounding soil, indicating that they enter a plant against concentration gradient.

(b) **Passive uptake**, where the ions move by mass flow and diffusion through the apoplast. This occurs when concentration of mineral ions in soil is greater than its concentration in root hair cell.

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Like water, mineral ions are taken up into the root hairs and other surface cells in young parts of the root. After absorption, they move towards the vascular tissues in the center of the root, partly by diffusion and partly by active transport through the symplast.in the endodermis cells, they are actively pumped into xylem vessels. Once inside the xylem, ions are carried up the stem along with water in the transpiration stream.

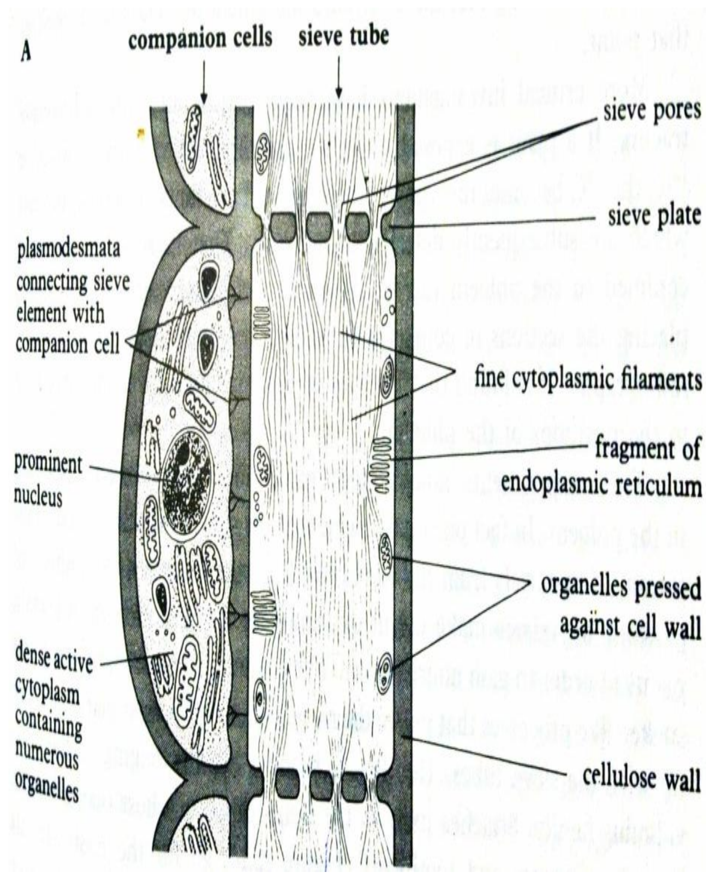
From the xylem elements, the ions are conveyed by combination of diffusion and active transport to their main destinations: **(i)** various growing points of the plant. **(ii)** Photosynthesizing cells of the leaf. Where they are put into use.

<u>Translocation of organic compounds</u>.

Organic compounds are translocated from photosynthetic organs, leaves to other parts of the plant by **phloem**.

Phloem structure.

Phloem is composed majorly of ***sieve tube elements*** and ***companion cells*** in association with parenchyma and phloem fibers.



(a) **Sieve tube elements**: are elongated cylindrical cells placed end to end to form long sieve tubes running parallel to the long axis of the plant. The nucleus of each sieve element disintegrates during development such that mature cells have no nucleus. The end walls called sieve plate are perforated by numerous pores which allows passage of materials from one sieve element to the next. The inside of the sieve element is believed to contain ***cytoplasmic filaments*** which are continuous, via the pores of the sieve plates, with similar fibers in the next sieve elements. The cytoplasm of sieve elements is structurally very simple contains no organelles, these disintegrate during development. A few such organelles persist immediately adjacent to the cellulose cell wall but absent elsewhere. (b) **Companion cells**, found on side of each sieve element, possess cell organelles, are site of intense metabolic activity. Plasmodesmata connect each sieve element with its adjacent companion cell.

Mechanism of translocation.

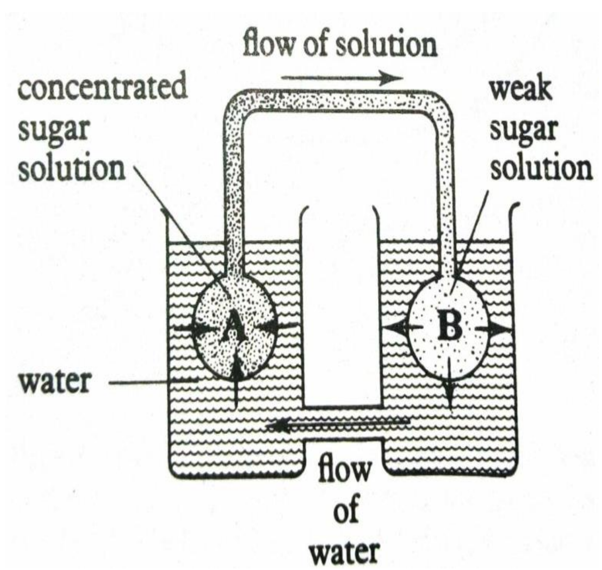
Soluble products of photosynthesis formed in the **source** (photosynthetic tissue), enter the sieve tubes by ***active transport*** in a process called ***loading*** and actively leave the tubes at the **sink** (site of storage and utilization) in a process called ***unloading***. Translocation is explained by the following hypothesis.

(a) **Mass flow hypothesis**.

According to this hypothesis, translocation occurs in phloem by passive mass flow of materials as a result of turgor pressure gradient: highest in leaves where sugar is formed (source) and lowest in roots (sink).

Evidence for supporting mass flow. **(i)** When the phloem is cut, sap exudes out by mass flow. **(ii)** Rapid and prolonged exudation of the phloem's sap from the cut mouth parts of aphids, evidence of hydrostatic pressure in sieve tubes**.** **(iii)** Most researchers have observed mass flow in microscopic sections of sieve tube elements. **(iv)** High concentration of sucrose and other materials in leaves and low in roots. **(iv)** Reduction in rate of photosynthesis causes reduction in rate of translocation. **(v)** Certain virus move in the phloem translocation stream, indicating mass flow rather than diffusion since virus is incapable of locomotion. Cannot diffuse because it is in solution.

Munch's mass flow hypothesis model.



Two semipermeable reservoirs, **A** and **B**, are joined by a tube. **A** contains a concentrated sugar solution and **B** a more dilute one. The two reservoirs are immersed in water as shown. ***Observation***: Water is drawn into **A** by osmosis and the solution flows from **A** to **B**. Water is forced out of **B** by the hydrostatic pressure so developed. The flow will cease when the concentration in **A** and **B** are equal. ***Application***: In a living plant, it is envisaged (known) that the sieve tubes are lined by a selectively permeable membrane, if sugar concentration is high, water is drawn in by osmosis at the source (leaves). Continuous flow would be maintained by continued active secretion of sugar into the sieve tubes (***loading***) at the source and its removal at the sink (***unloading***). Water return to the source from the sink via the xylem. The rate of flow of transpiration stream would certainly be sufficient to account for this.

Criticisms of mass flow hypothesis.

(i) It considers organic solutes to move in same direction and speed however it was observed that organic solutes move in different directions and different speeds. **(ii)** Does not offer explanation for presence of sieve plates which acts as series of barriers impending flow. **(iii)** No explanation for high oxygen consumption by phloem. **(iv)** No explanation for why translocation is greatly affected by presence of metabolic poisons.

(b) **Electro – osmosis**:

This is passage of water across a charged membrane. It is argued that an electrical potential might be maintained across the sieve plates, the lower side being negative relative to the upper side. Such a potential could be maintained by an active pumping of positive ions in an upward direction. A charged solution in the sieve tube element would be expected to flow through the sieve plate towards the negative side.

Evidence for supporting Electro – osmosis: **(i)** Numerous mitochondria, provide energy for active pumping of K+ ions. **(ii)** K+ ions stimulate loading in phloem.

(c) **Theory of surface spreading**.

According to this theory, translocation in phloem occurs by solute molecules spreading over the interface between cytoplasmic materials as oil spreads at a water-air interface. The molecular film formed is kept moving by molecules being added at one end and removed at the other.

Evidence: Sieve tubes do contain numerous membranes and films which collectively might provide the necessary surface.

Criticism: The film would be so thin that very large number of them would need to be formed to account for the known rates of translocation yet the amount of phloem is not that great.

(d) **The theory of cytoplasmic streaming**.

This suggests that protoplasm circulates using energy from sieve tubes elements or companion cells through the sieve tube elements from cell to cell via the sieve pores of the sieve plates. As the protoplasm circulates, it carries the whole range of the transported organic materials with it. The solutes are moved in both directions by a wave-like movement of the contractile protein of the filaments from one sieve tube element to the next using energy.

Evidence: **(i)** It has been found that materials flow in both directions. **(ii)** Explains presence of numerous mitochondria.

Loading and unloading. This is carried out by specialized parenchyma cells called transfer cells. These possess irregular intuckings (inflodings) which increase surface area and bring the plasma membrane into close association with the cytoplasm. Transfer cells are also found in: **(i)** Water secreting glands, hydathodes at the edge of certain leaves. **(ii)** Secretary tissues inside nactaries of flowers. **(iii)** In salt secreting glands on the leaves of some halophytes.

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