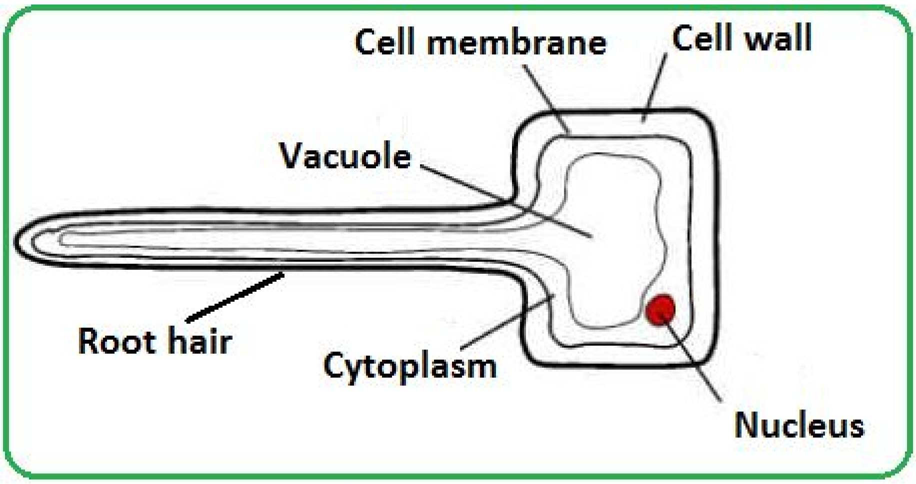
Transport of Water and Sugar in Plants

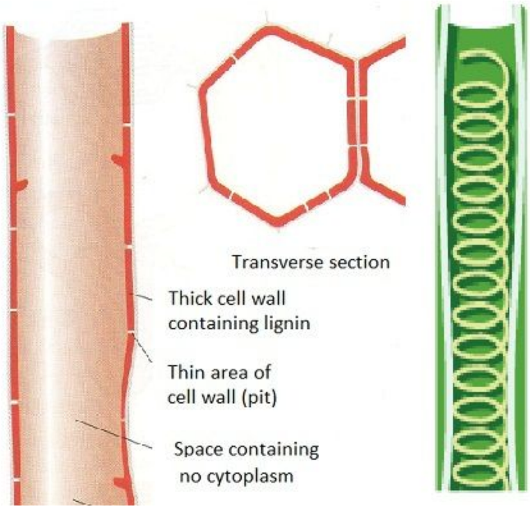
Specialised plant cells (pg 187)

1. The root hair cell



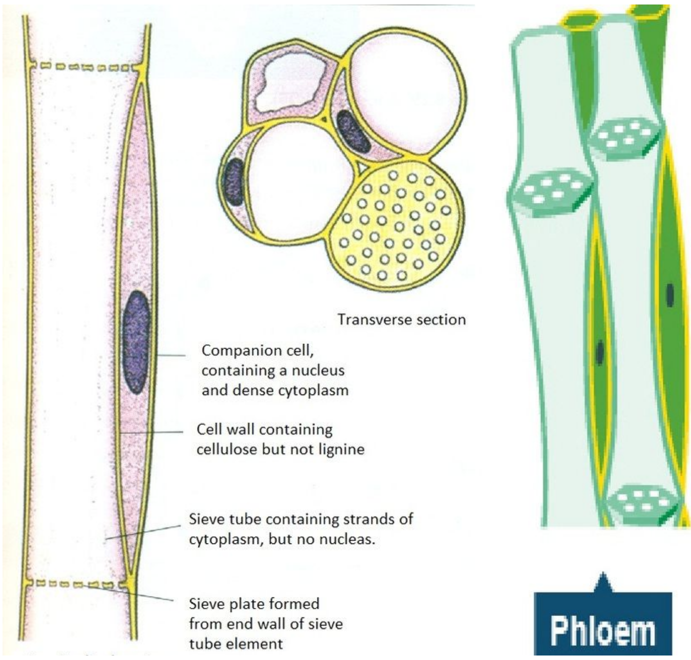
- extension of the epidermal layer
- large surface area for absorption of water and mineral ions

2. Xylem vessels (pg 187) - water transport



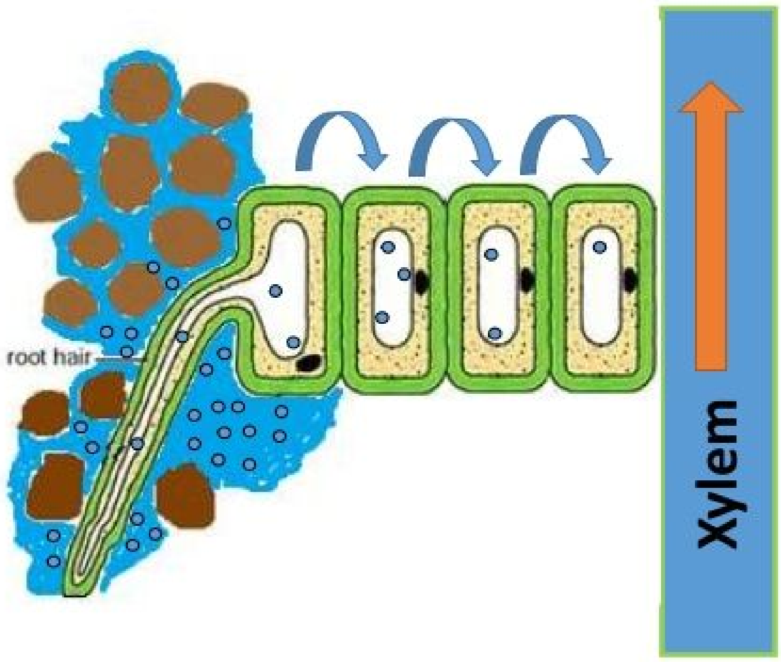
- hollow cells, with lignin on the outside
- lignin deposited as rings, allowing the xylem vessels to expand and contract
- xylem starts off as living cells, lined end-to-end
- when lignin deposited on the outside, the cells die and the inside becomes hollow
- form long hollow tubes, that run as a continuous column from the root to the leaf, and draw up water by capillary action

3. Phloem - transport of sugars



- sieve tube contains little cytoplasm, most of which is pushed to one side, no nucleus
- sieve tubes are separated by sieve plates
- attached to companion cells, which are living
- companion cells supply most of the metabolic needs of the phloem

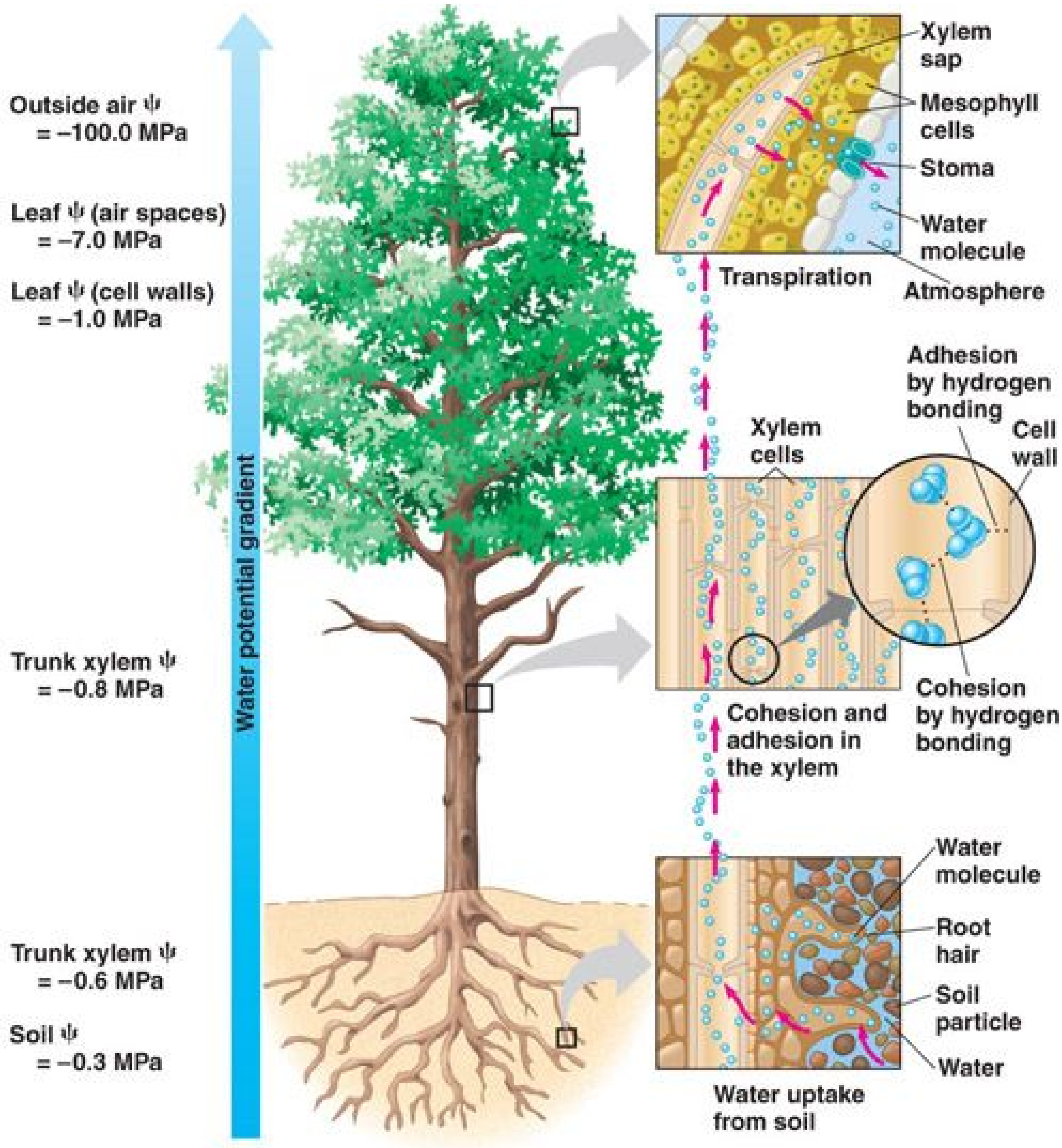
Transport of water starts at the root hairs (pg 185, Fig4)

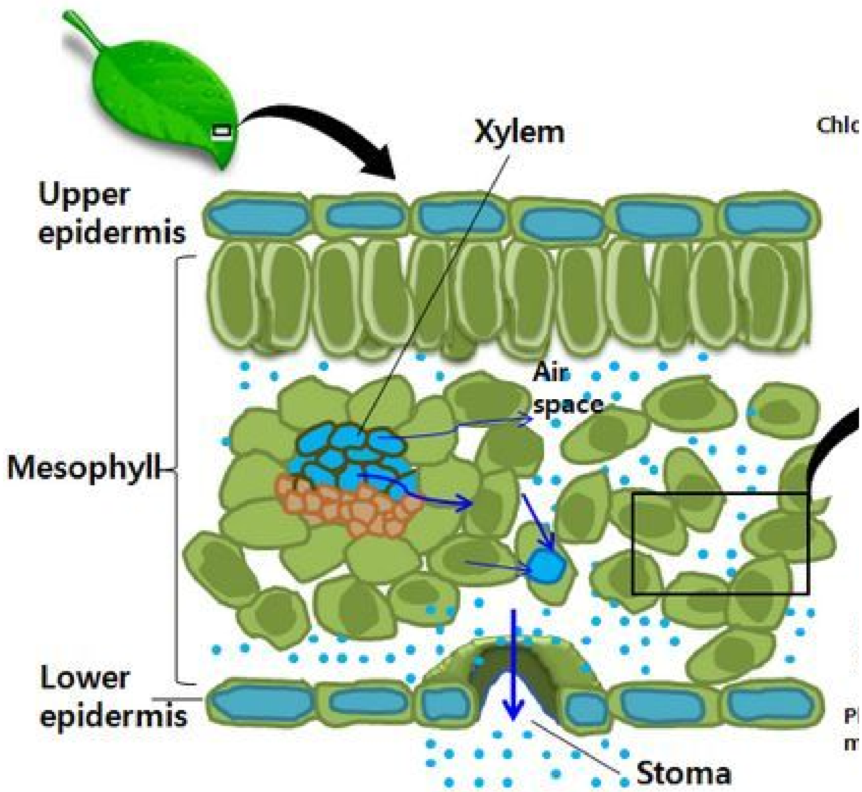


Q. Why do plants die from overwatering?

- mineral ions actively transported into root hairs
- reduces water potential inside the root hair cells
- water drawn in by osmosis
- water potential in the cortex cells is now lower than in the root hair cells
- water drawn from the root hairs into the cortex, and eventually enters the xylem

Water is transported from the roots to the leaves using the xylem (pg 183)




Xylem
Upper
epidermis
Mesophyll
Air
space
Lower
epidermis
Stoma

- when the stomata are open, water is lost from the leaf to the air outside, by the process of transpiration

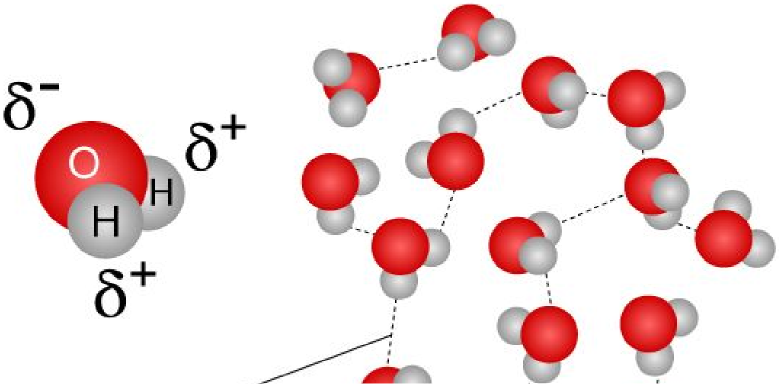
- water is pulled from the mesophyll cells to the air spaces around the stomata

- these cell snow have a lower water potential than the xylem, so water from the xylem enters the mesophyll cells by osmosis

- this establishes a water potential gradient across the leaf

- and creates negative pressure within the xylem, called as tension

- water molecules are polar and stick to each other using hydrogen bonds, this is called cohesion



- under tension, the water rises up the xylem by capillary action, in one continuous, unbroken column
- the movement of water by cohesion and tension is called 'transpirational pull'
- transpirational pull can raise water up to 100 m or more in tall trees
- this process itself is passive, but the energy for water movement ultimately comes from sunlight

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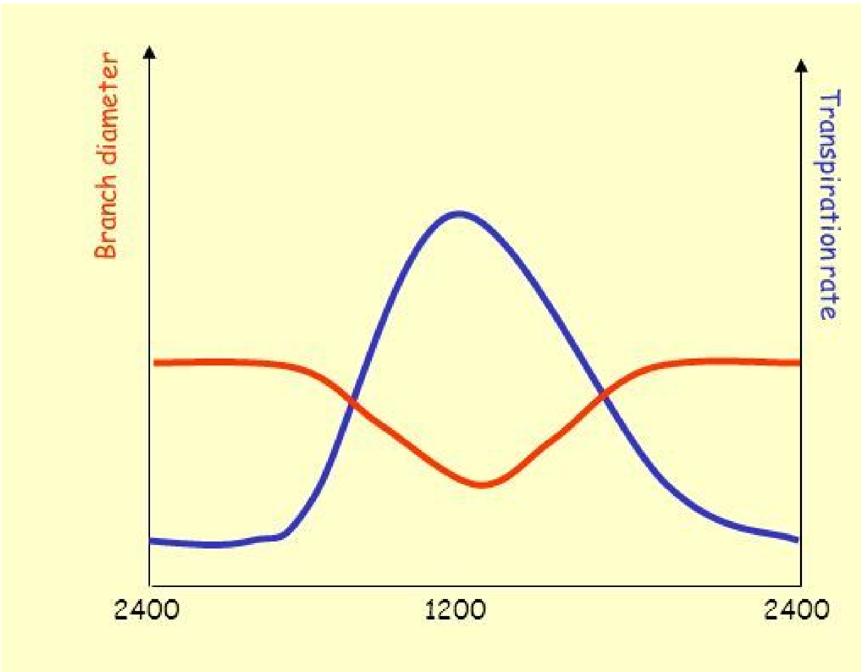
Evidence for cohesion-tension theory (pg 184)

1. The diameter of the xylem is narrower in the day than at night - more tension in the xylem during the day, when transpiration rate is high

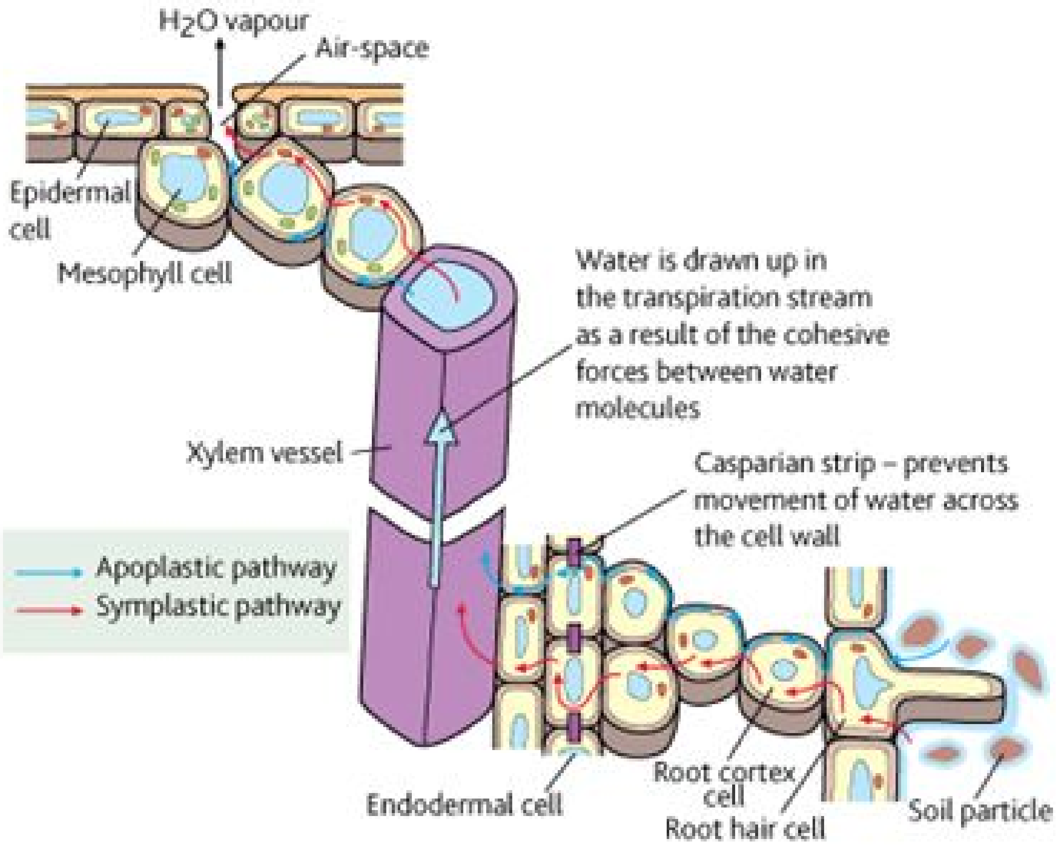


Pg 185, Fig 5

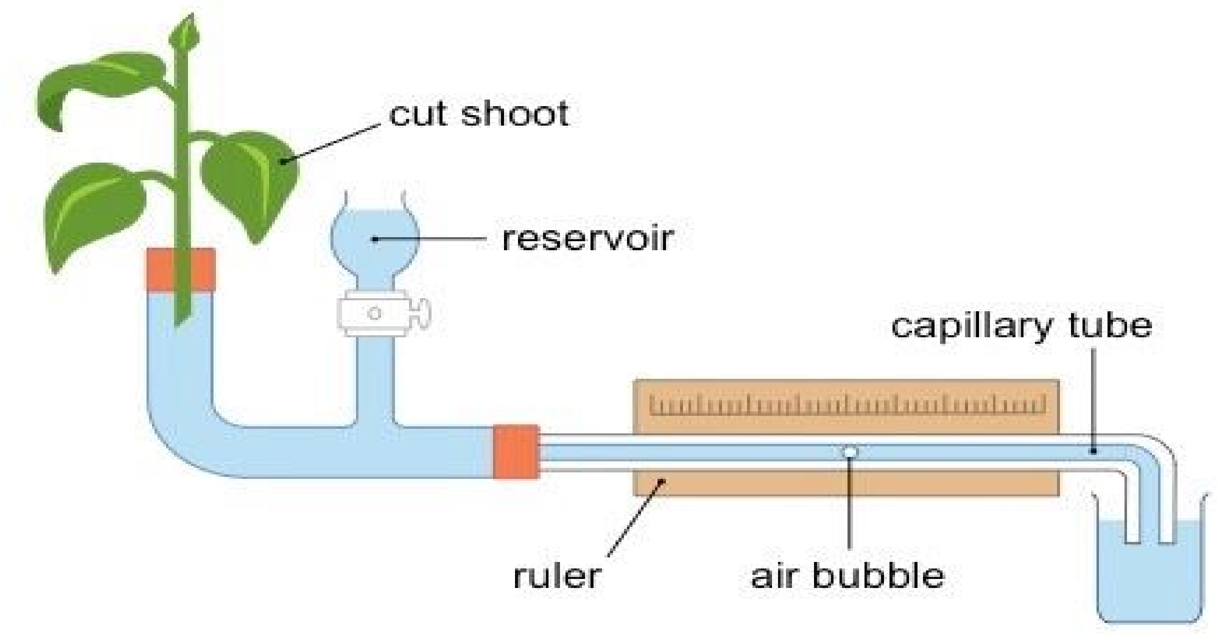
2. If air enters a xylem vessel, the vessel can no longer draw water
(why do flowers last longer if the stems are cut, and at an angle?)

3. When a tree trunk is cut, water does not leak out - instead it falls back down, indicating that it is being pulled up under tension. Air is drawn in and forces the water back down.

Summary of water transport (Fig 4, pg 185)



Measurement of transpirational pull using a potometer (pg 186)



Calculation:

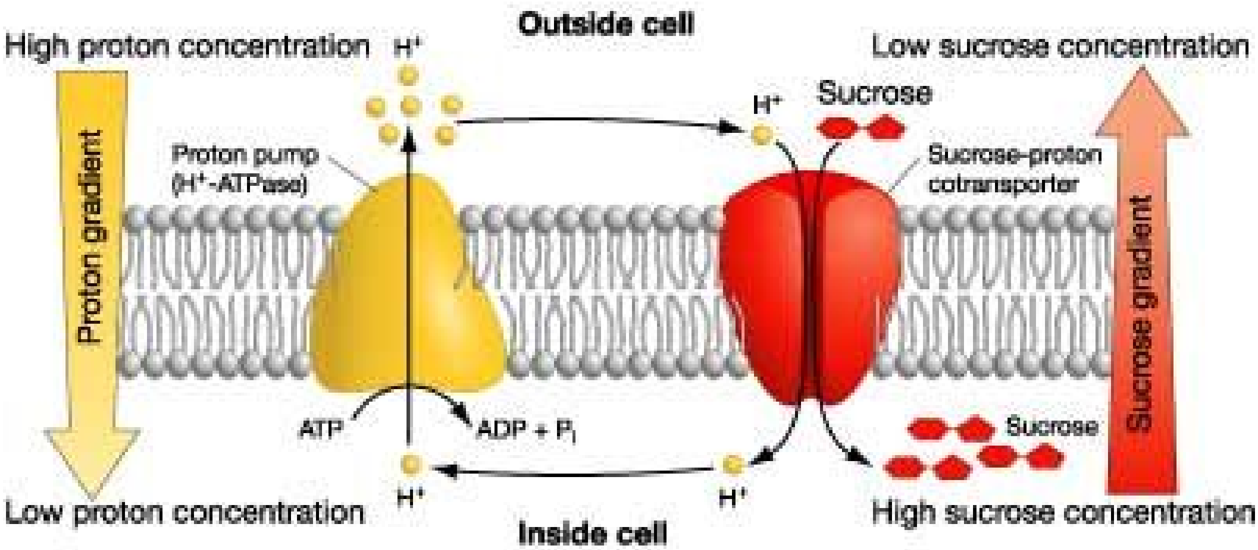
1. Volume of water taken up during the experiment
2. Time for the experiment

Units = cm^3 h^{-1}

Volume can be calculated by using the formula $\pi r^2 l$ where l = distance moved by the air bubble.

Transport of sugars in the phloem (translocation)

1. Companion cells load the sucrose from the photosynthesising tissue into the sieve elements



- sucrose is manufactured within the chloroplasts, in the process of photosynthesis (source)

- a proton pump actively transports H^+ from the cytoplasm of the companion cell to the leaf tissue

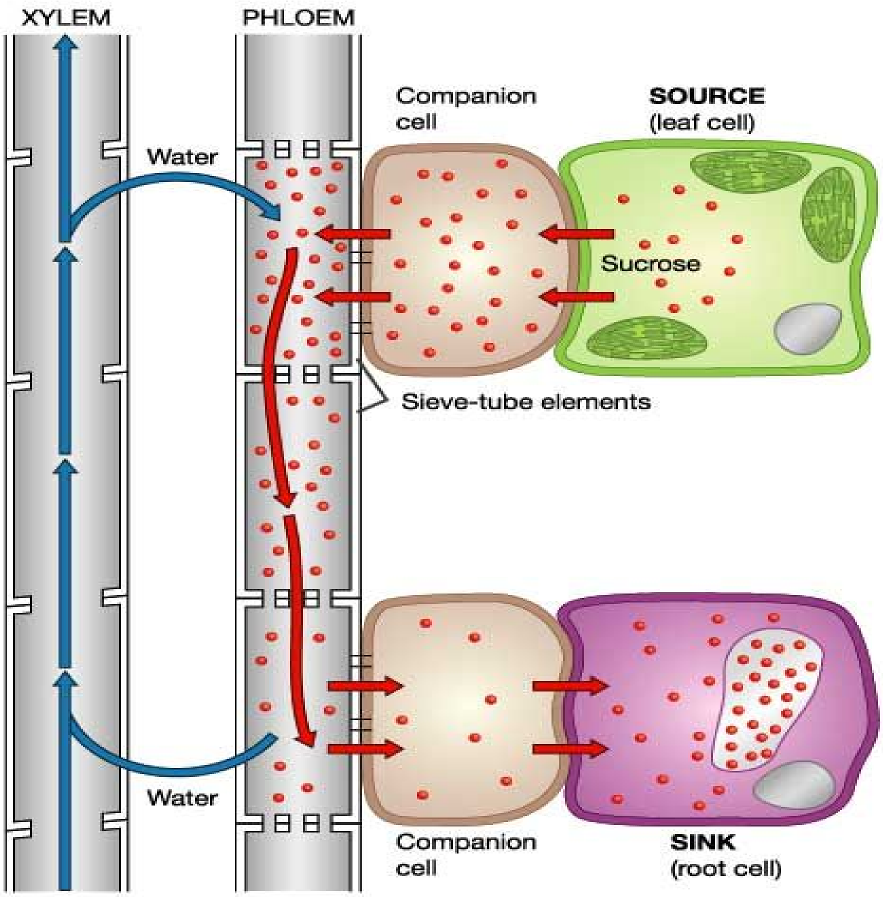
- H^+ is drawn back in down its concentration gradient

- however, it can only enter the cell via a co-transport (carrier) protein for sucrose

- thus H^+ is drawn in down a concentration gradient, but sucrose is drawn in against its concentration gradient

- sucrose diffuses from the companion cell to the sieve tube element down its concentration gradient

2. Mass flow of sucrose through the sieve tube elements (pg 188)



- When sucrose is transported into the sieve tube element, its water potential drops

- water is drawn in from the xylem by osmosis

- this increases the hydrostatic pressure within the sieve tube elements

- which forces the sucrose solution (sap) down the trunk

- at the roots (sink), sucrose is either used up in respiration, or converted to starch

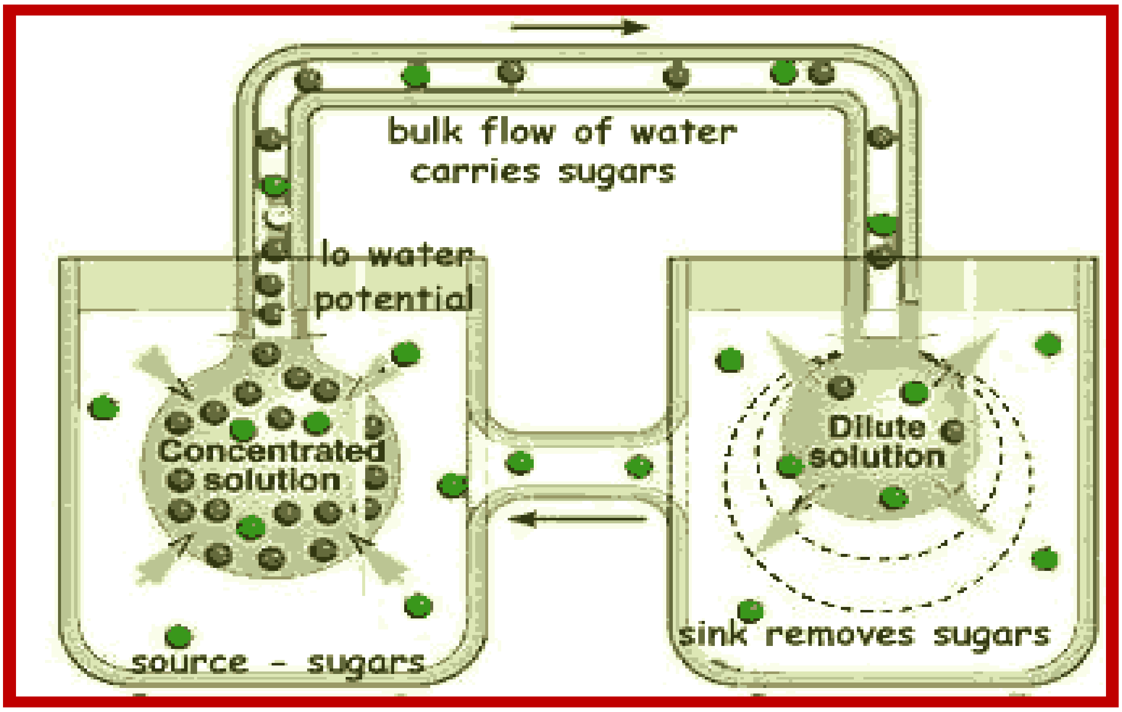
- water potential in the sieve tube elements is now more positive than the xylem

- water is drawn back into the xylem by osmosis (which lowers hydrostatic pressure in the sieve tube element)

Phloem = bidirectional flow

Xylem = unidirectional flow

Mass flow uses energy in the form of ATP, it is an active process



Model illustrating mass flow - pg 189, Fig 3

Evidence for mass flow

- there a tree trunk is cut, sap flows out, indicating it is being transported by gravity and hydrostatic pressure

- metabolic inhibitors or lack of oxygen can stop mass flow

- rate of transport of sucrose is higher in the day than at night

- Companion cells possess many mitochondria

- increase in sucrose concentration in the leaves is followed by a similar increase in the phloem in a little while

Evidence against mass flow

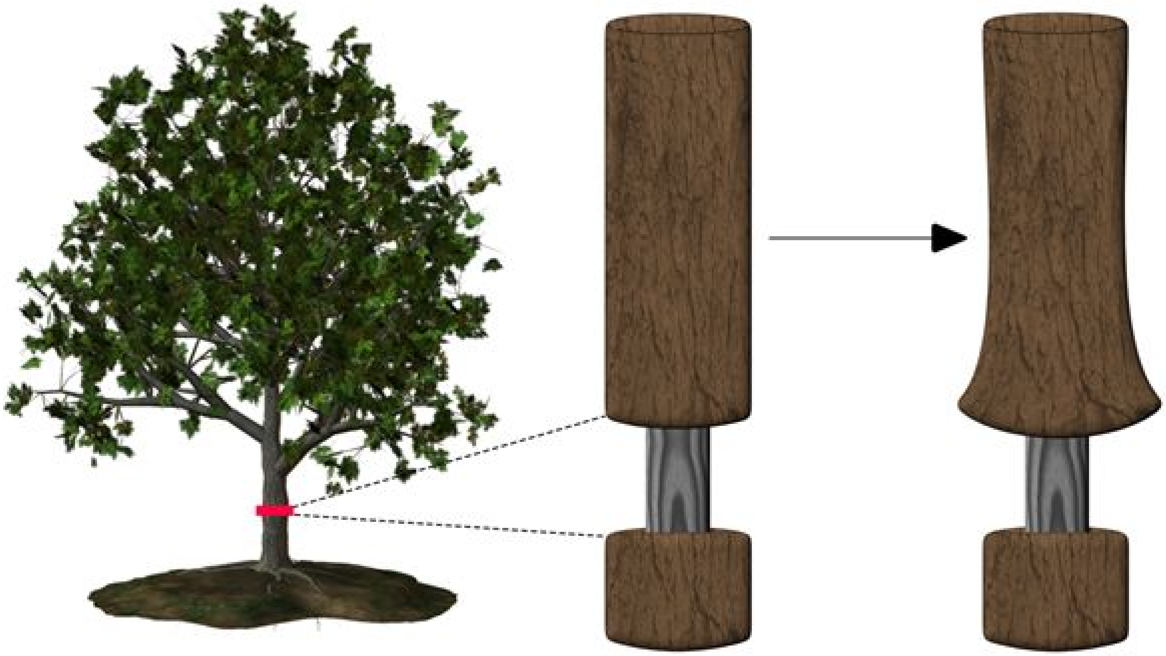
- the role of sieve plates is unclear (it has been suggested that they have a structural function, prevent the tubes from bursting under pressure. It has also been suggested that the sieve plates are essential to plug the gaps between the sieve tube elements when the trunk is cut, preventing sap from flowing out)

- some solutes move faster than others, mass flow cannot explain this discrepancy

- sucrose is delivered to all regions uniformly, instead of being delivered to the region with the lowest sucrose concentration

Experiments investigation transport in plants

1. Ringing experiments



- the outer layer of the bark and the phloem is removed, around the complete circumference of the woody plant

- After a period of time, the region of the stem immediately above the missing ring of tissue is seen to swell

- samples collected from this region are rich in sugars

- some tissue below the ring starts to die

This suggests that:

- phloem is responsible for transport of sugars

- sugars are transported downwards, and accumulate above the ring, leading to swelling in this region

- the interruption of flow of sugars to the region below the ring causes the tissue to die

2. Tracer experiments

- the plant is supplied with radioactive CO_2

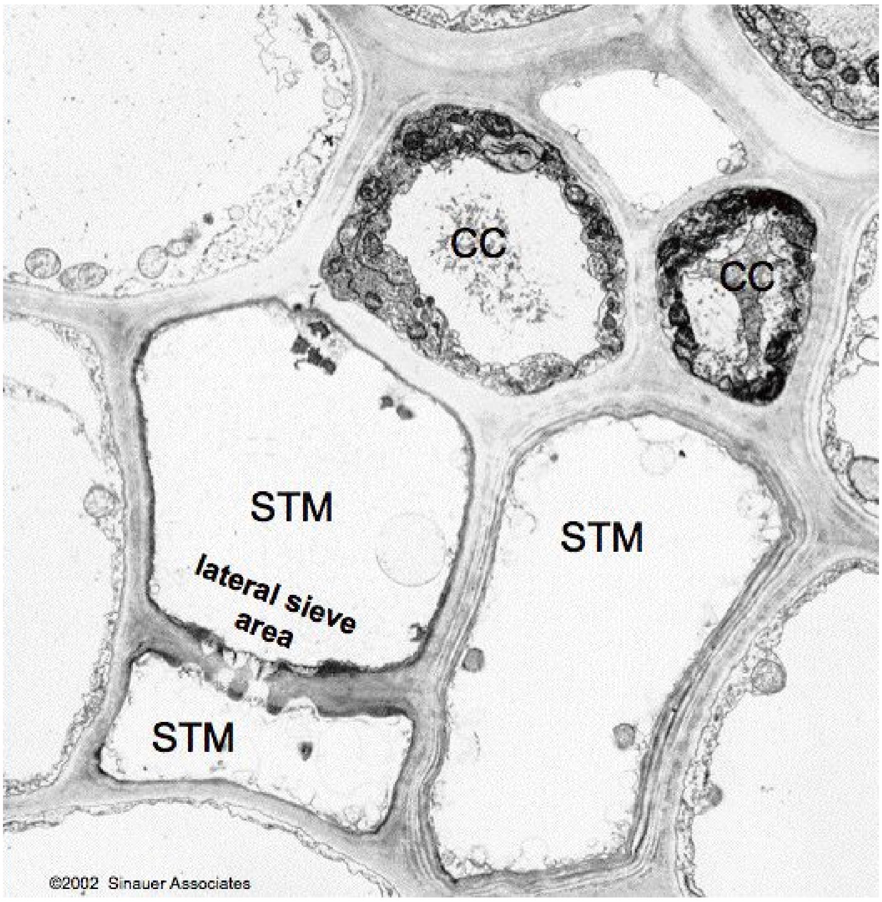
- the radioactive carbon is incorporated into the sucrose during photosynthesis

- it can then be traced as it moves within the plant, using autoradiography

- autoradiography involves exposing thin cross-sections of tissues to an X-ray film

- if there is radioactivity within the tissue, parts of the film will turn black

- blackened regions are found to correspond to the location of the phloem



Diurnal variation in sucrose content in the leaves and phloem (pg 192, Fig 2)