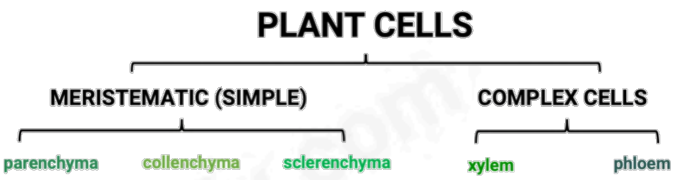
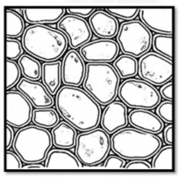
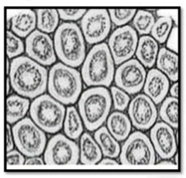
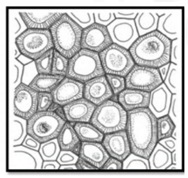
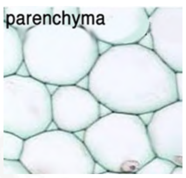
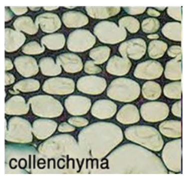
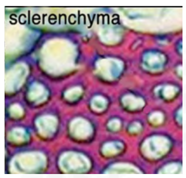
7 Transport in plants

7.1 Structure of transport tissues

Types of plant cells



PARENCHYMA	COLLENCHYMA	SCLERENCHYMA
	 Image: https://www.vedantu.com/	
	 Image: http://www.bio.miami.edu/	
found in soft parts of the plant	found in the petiole, leaves, and young stems	found in mature parts of the plant
unspecialised cells	specialised cells	specialised cells
cell wall made of cellulose	cell wall made of cellulose and pectin	cell wall made of lignin
thin cell wall	unequally thin cell wall	thick and rigid cell wall
lots of intracellular spaces are present between cells	little intracellular space	no intracellular space
consists of living cells at maturity	consists of living cells at maturity	consists of dead cells at maturity
functions include photosynthesis, food storage, gas exchange	provides mechanical support to the plant	provides mechanical support, protection, and transports substances

Structure of roots (dicot)

Transverse section

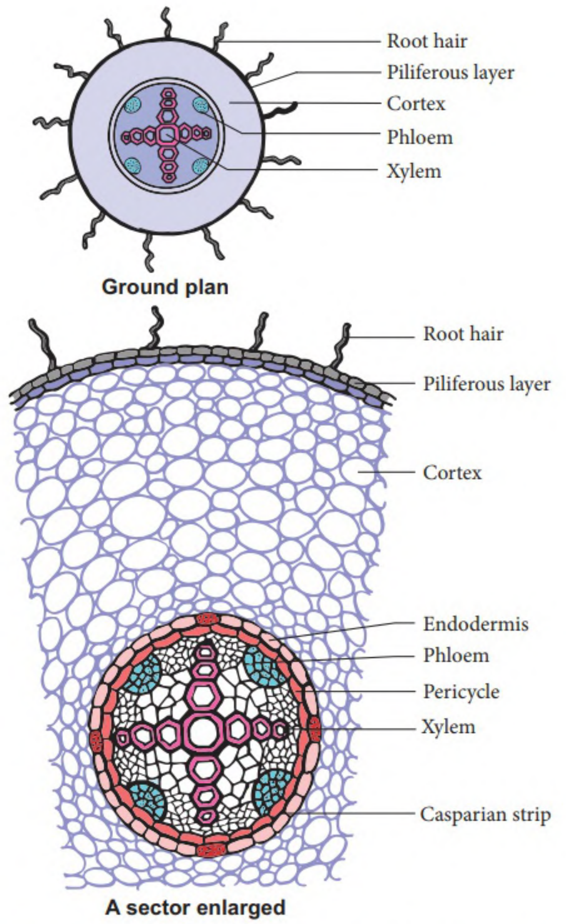


Figure 12.2 Transverse section of Dicot root

Image: https://www.brainkart.com/

- piliferous layer (also called epiblema, rhizodermis) – the outermost layer; unicellular root hairs present, cuticle and stomata absent
- cortex – it is a multi-layered large zone made of parenchymatous cells with intracellular spaces and stores food and water
- endodermis – the innermost layer of the cortex; the cells closely packed and have Casparian strips within their walls *(water-impermeable deposits of suberin)* which regulate water and mineral uptake by the roots
- pericycle – produces lateral roots when cells here divide
- stele – all tissues inner to endodermis constitute stele; here it includes pericycle and vascular bundle
- vascular bundle – xylem and phloem
- conjunctive tissue – the tissue present between xylem and phloem; in dicots, it's made up of parenchyma
- pith – absent in mature plants, present in young ones

Longitudinal section (of roots)

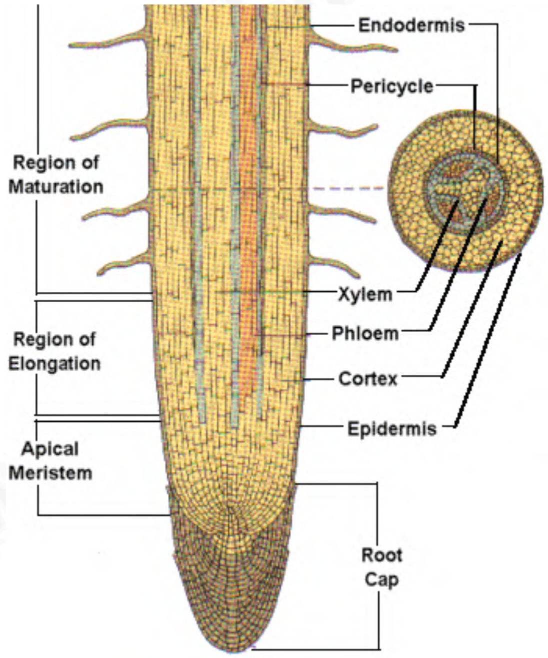


Image: https://www.anatomynote.com/

Structure of stems (dicot)

Transverse section

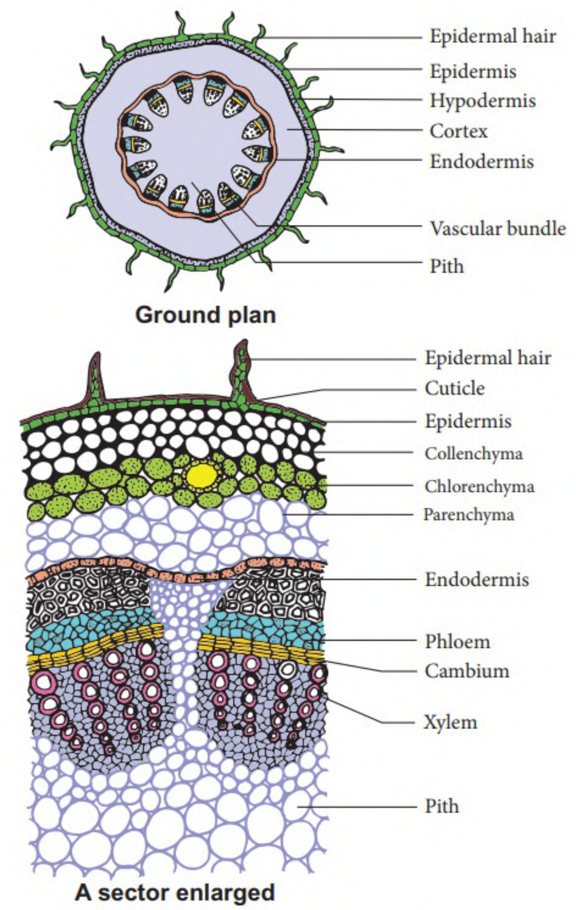


Figure 12.4 Transverse section of Dicot stem

Image: https://www.brainkart.com/

Longitudinal section

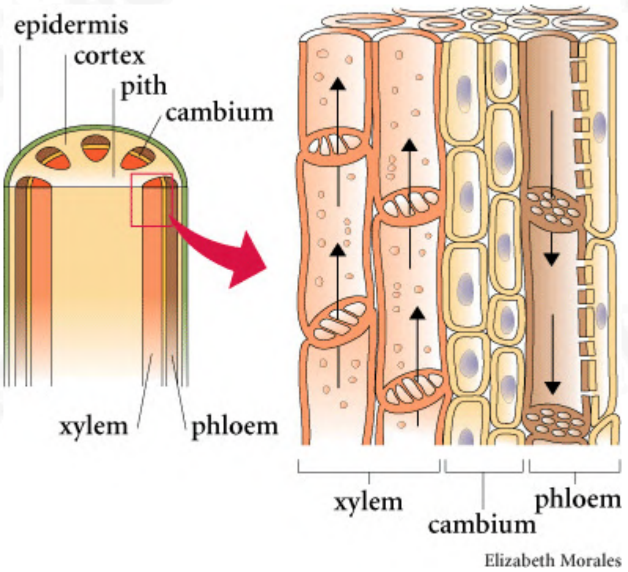


Image: http://mybiologypal.blogspot.com/

- epidermis – the outermost layer; made up of a single layer of parenchyma cells and its outer wall is covered with a cuticle
  - cuticle prevents infection of the plant by bacteria or fungi
  - also aids in reducing water loss
- cortex – divided into three regions:
  - hypodermis provides mechanical support
  - middle cortex is involved in photosynthesis
  - inner cortex helps in gaseous exchange and stores food materials
- endodermis – the innermost layer of the cortex, consists of a single layer of cells that contain starch grains
- pith – large, central, parenchymatous zone with intracellular spaces; helps in storage of food materials

Structure of leaves (dicot)

Transverse section

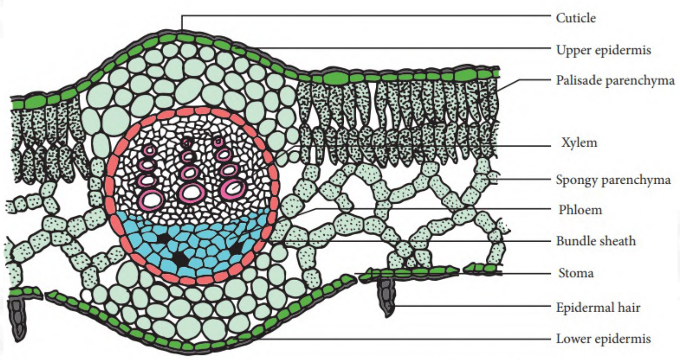


Figure 12.6 Transverse section of Dicot leaf

Image: https://www.brainkart.com/

- **upper epidermis** – the outermost layer made up of a single layer of parenchyma cells without intracellular spaces; outer walls have cuticles, stomata are less in number
- **lower epidermis** – single layer of parenchymatous cells with a thin cuticle
  - contains numerous stomata
  - chloroplasts are only present in guard cells
  - helps in exchange of gases
  - loss of water vapour is facilitated through this chamber
- **mesophyll** – tissue present between the upper and lower epidermis, differentiated into palisade parenchyma and spongy parenchyma
  - **palisade parenchyma:** tightly packed, elongated cells with lots of chloroplasts *(for photosynthesis)* just below the upper epidermis.
  - **spongy parenchyma:** spherical/oval, irregularly arranged cells with lots of intracellular spaces; helps in gaseous exchange
- vascular bundles
  - vascular bundle of midrib is larger
  - each vascular bundle is surrounded by a sheath of parenchymatous cells called bundle sheath
  - each vascular bundle consists of xylem lying towards the upper epidermis and phloem towards the lower epidermis

For more information about the structure of plant tissues and how to draw them, see Biology Paper 3 Notes.

Structure of vascular system

Xylem

- transports water and mineral ions via mass flow (passive)
- unidirectional movement (from roots → rest of the plant)
- composed of tracheids, vessel elements, xylem fibres, and xylem parenchyma *(all dead except xylem parenchyma)*

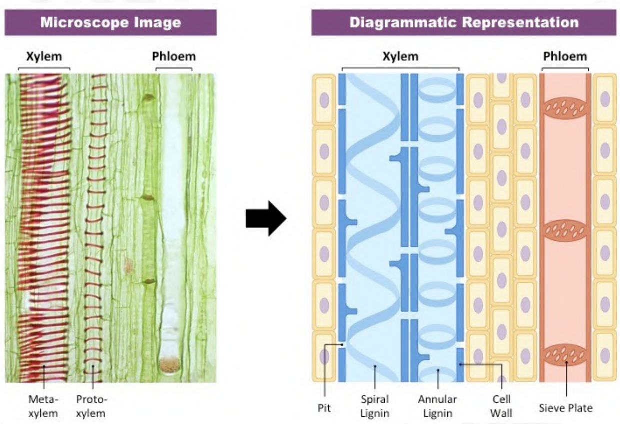


Image: https://ib.bioninja.com.au/

1) long hollow tubes with no end walls for uninterrupted transport of water and mineral ions
2) no cell contents (no protoplasm) to provide maximum space and minimum resistance
3) their walls are lignified to withstand negative pressure and provide mechanical support
4) cellulose lining is present for adhesion if water molecules which helps with their movement upwards
5) they have pitted walls (in non-lignified sections) for the lateral movement of water

Phloem

- transports sucrose and amino acids via mass flow *(active process)* from the source to the sink
- bidirectional movement *(translocation)*
- mainly composed of sieve tube elements + companion cells

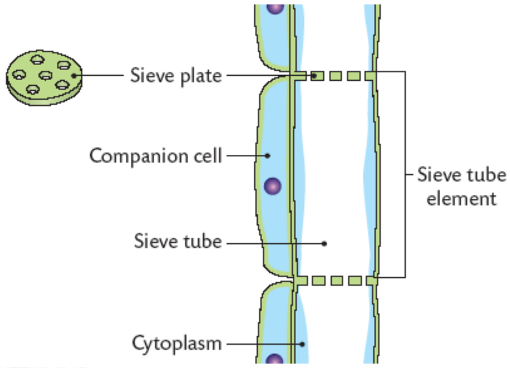


Image: https://irevise.com/i

Phloem sieve tube elements

1) contains ER, mitochondria, and cytoplasmic stands (cytoplasm reduces friction to facilitate the movement of the assimilates)
2) end-walls modified to sieve plates/perforated plates which allows for the continuous movement of the organic compounds
3) phloem tubes are present in a bundle
4) area where sucrose is loaded is source and where it's unloaded is sink

Companion cells

1) contains organelles such as nucleus, RER, mitochondria, and ribosomes which provides metabolic support to the sieve tube elements and helps with the loading and unloading of the assimilates
2) transport proteins are present in the plasma membrane which move assimilates in and out of the sieve tube elements
3) large numbers of mitochondria present which provide ATP for the active transport of assimilates into or out of the companion cells

4) plasmodesmata are present which link the cell to the sieve tube elements

Comparing the structures of xylem and phloem tissues

	XYLEM	PHLOEM
made of	mainly dead cells (tracheids, vessel elements, xylem fibres) except for xylem parenchyma	living cells (only phloem fibres are dead)
cell wall material	lignin and cellulose	cellulose
presence of end walls	no	yes (sieve plates with sieve pores)
direction of flow	unidirectional and upwards (roots → leaves)	bidirectional (source → sink)
substance transported	water and mineral ions	sucrose, amino acids, and other organic compounds
mechanical support	provides mechanical support	does not provide mechanical support

7.2 Transport mechanisms

Plants must take in a constant supply of water and dissolved minerals to compensate for the continuous loss of water via transpiration in the leaves.

Transpiration

Transpiration is the loss of water vapour from the aerial parts of the plant. Around 99% of all water absorbed is lost via this process.

1) water evaporates from cell walls of mesophyll cells into air spaces
2) water vapour diffuses (out to atmosphere)
3) through open stomata (to atmosphere)
4) down a water potential gradient

When the following factors increase, transpiration (↑/↓)

1) humidity (↓)
2) wind speed (↑)
3) light intensity (↑)
4) temperature (↑)
5) water supply (↓)

Transpiration is considered as an inevitable consequence of gas exchange as –

1) stomata are open for gas exchange
2) this gas exchange is required to uptake CO_2 for photosynthesis
3) while stomata are open, water vapour diffuses out

Advantages of transpiration

1) helps in plants pulling up water from soil through roots (transpiration pull)
2) helps in sending out excessively absorbed water by plants
3) cools the plant (via evaporative cooling)
4) helps in the absorption and transport of mineral salts
5) helps in the absorption and distribution of water in plants

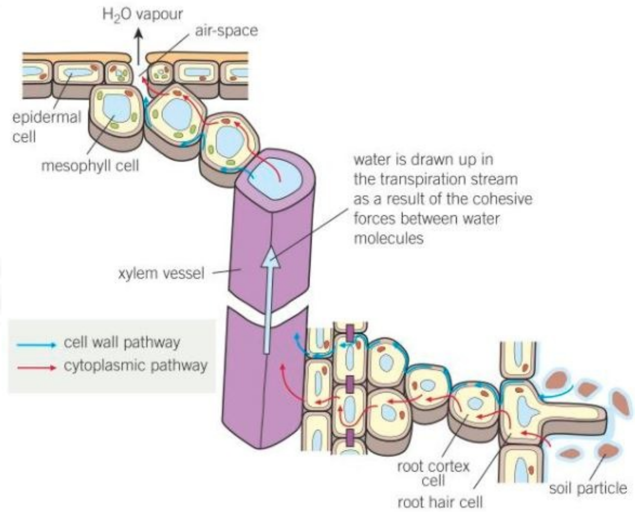


Image: https://alevelbiologystudent.weebly.com/

Transpiration pull

Transpiration pull is the force by which water ascends a plant.

- water molecules cling together by hydrogen bonds between molecules known as cohesive forces
- water molecules experience attraction towards the cellulose in the cell walls of the xylem (adhesion)

Cohesion-adhesion theory

- water molecules tend to cling to one another via hydrogen bonds (cohesion)
- when water evaporates from the surfaces of mesophyll cells, a tension is created in the xylem tissue which is transmitted all the way down the plant due to the cohesiveness of the water molecules
- the cohesive forces thus produce a continuous column of water (transpiration stream)
- the adhesive force stops the water column from pulling away from the walls of the xylem vessels, so water is pulled up the xylem tissue from the roots to replace what was lost in the leaves
- this is known as the cohesion-adhesion theory

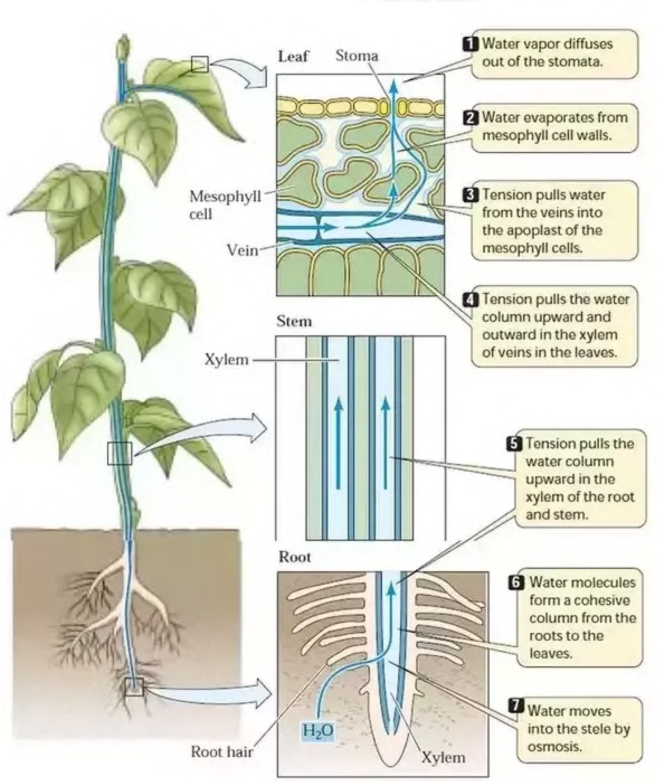


Image: https://www.quora.com/What-is-cohesion-tension-theory

Movement of water between plant cells

From soil to root hair

1) uptake of water – water moves into root hairs via osmosis down a water potential gradient (passive)
2) root hairs provide max surface area for the max absorption of water
3) the uptake of minerals can be passive or active and occurs by diffusion or active transport respectively

From root hair to xylem

1) water taken up by root hairs crosses the root cortex
   - water moving thorough cells walls – apoplastic pathway
   - water moving through plasmodesmata – symplastic pathway
2) water moves from one cell to another till it reaches xylem; movement is due to concentration gradient due to concentrated sap vacuole of cells
3) apoplastic pathway is stopped at endodermis due to cells in it having a band of suberin forming the Casparian strip (an impenetrable barrier to water)
   - suberin deposits increase with age of endodermal cells except for certain **passage cells**
   - water can pass freely through these passage cells

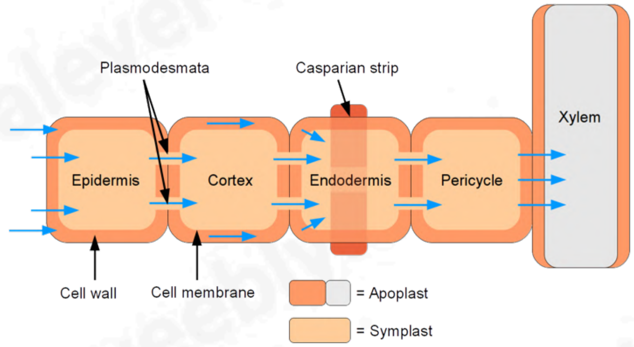
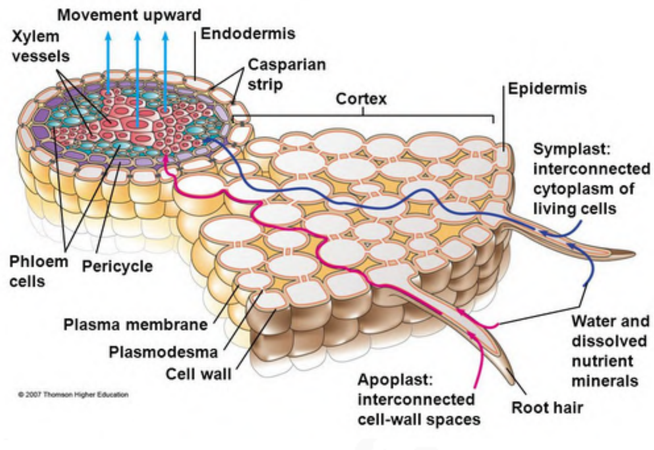


Image: By Dylan W. Schwilk - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=55396563

- this arrangement is *thought* to:
  - gives plants control over what mineral ions pass into xylem vessels (everything must cross cell membranes)
  - may help with generation of root pressure

4) once across endodermis, water moves into xylem through pits in their walls



From root → stem → leaf *via* xylem

1) removal of water from xylem vessels in leaf reduces hydrostatic pressure in xylem
2) hydrostatic pressure at top of xylem becomes less than bottom
3) pressure difference causes water to move up the xylem

Apoplastic pathway

- most water travels via the apoplastic pathway (when transpiration rates are high)
- these are the series of spaces running through the cellulose cell walls, dead cells, and the hollow tubes of the xylem
- the water moves by diffusion as it isn't crossing a partially permeable membrane
- the water can move from cell wall to cell wall directly or through the intracellular spaces
- movement of water via this pathway occurs more quickly than in the symplastic pathway

- this movement is however stopped at the endodermis due to the presence of the Casparian strip

Symplastic pathway

- movement through the cytoplasm, plasmodesmata, or vacuole of cells (crossing membranes)
- the water moves by osmosis (across partially permeable membranes)

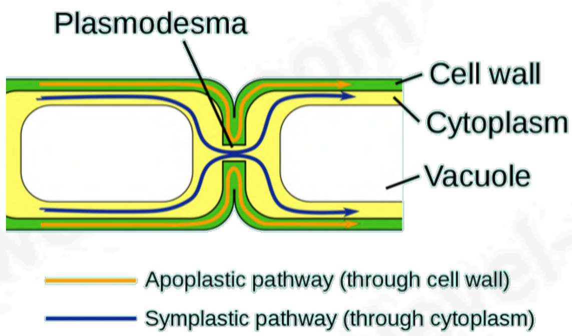


Image: Jackacon, vectorised by Smartse - Apoplast and symplast pathways.gif https://commons.wikimedia.org/w/index.php?curid=12063412

Movement in the phloem

Mass flow

Movement of fluids under a pressure gradient. Concentration gradient *does not* matter here.

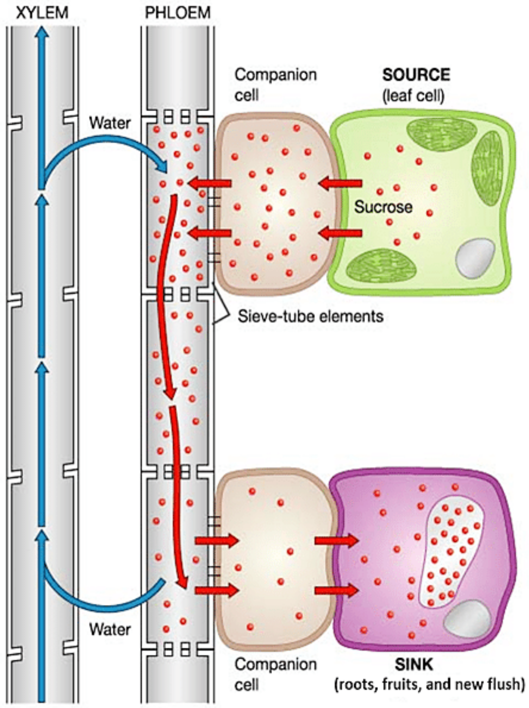


Image: https://www.researchgate.net/

Sucrose loading into phloem

This process is not fully understood yet. This is what is *thought* to happen.

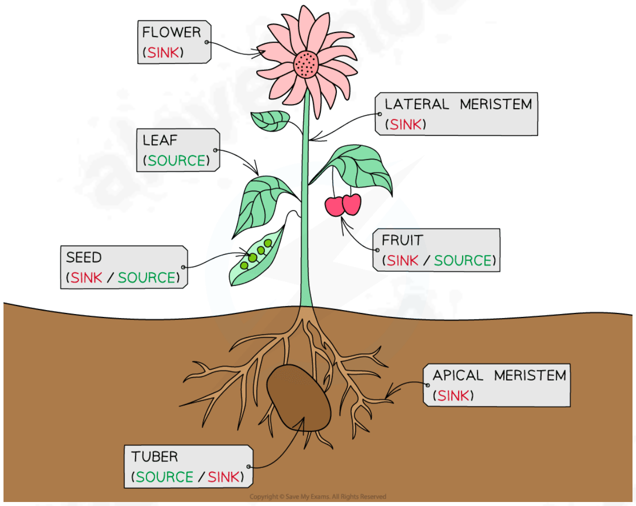
1) H^+ ions are pumped out *(active process, ATP required)* of the cytoplasm of modified companion cells (called transfer cells)
2) this creates an excess of H^+ ions in the apoplastic pathway outside the cell
3) H^+ ions move back into the cell down their concentration gradient back into the cytoplasm of the companion cell via a cotransporter protein
4) this cotransporter protein acts as a carrier for both H^+ and sucrose (so sucrose moves into the companion cell too but *against* its concentration gradient)
5) sucrose then moves into the sieve tubes via the plasmodesmata from the companion cell
   - companion cells have infoldings in their cell surface membrane to increase the available surface area for the active transport of solutes
   - many mitochondria also present provide the energy for the proton pump

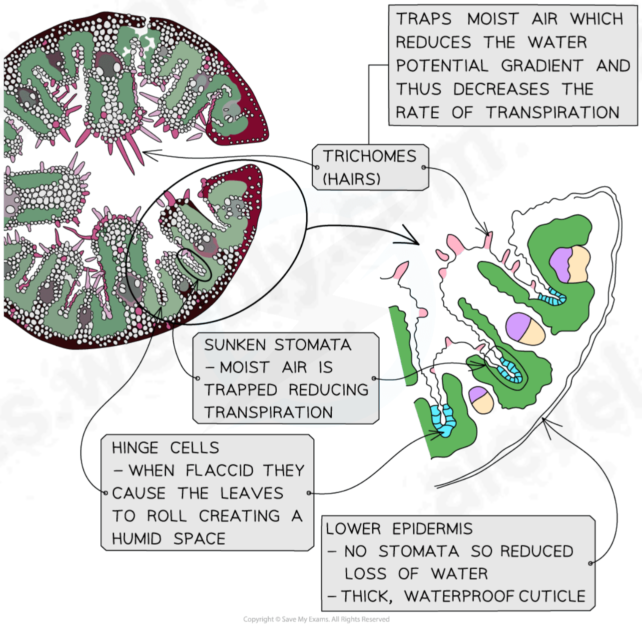
How assimilates that arrive in the phloem sieve tubes from mesophyll cells (source) can be translocated to other parts of the plant (sink)

1) when sucrose is loaded into a sieve tube element, the water potential decreases
2) this causes water from surrounding tissue to enter by osmosis
3) this increased volume increases the hydrostatic pressure at the source compared to the sink
4) assimilates move down a hydrostatic pressure gradient to the sink

Sources and sinks

- the source of the assimilates could be:
  1) green leaves and green stem (photosynthesis produces glucose which is transported as sucrose, as sucrose has less of an osmotic effect than glucose)
  2) storage organs eg. tubers and tap roots (unloading their stored substances at the beginning of a growth period)
  3) food stores in seeds (which are germinating)
- the sinks (where the assimilates are required) could be:
  1) meristems (apical or lateral) that are actively dividing
  2) roots that are growing and / or actively absorbing mineral ions
  3) any part of the plant where the assimilates are being stored (eg. developing seeds, fruits or storage organs)





Xerophytes

- xerophytes *(from the greek xero for 'dry')* are plants that are adapted to dry and arid conditions
- xerophytes have physiological and structural (xeromorphic) adaptations to maximise water conservation

Xerophytic adaptation of leaves	Effect of adaptation	Example
Fleshy succulent leaves	Water stores for times of low availability	Fleshy leaves: Bryophyllum
'Hinge cells' shrink when flaccid	Causes leaves to roll exposing the thick, waterproof cuticle to the air and creates a humid space in the middle of the rolled leaf	Ammophila arenaria (Marram grass)
Leaves reduced to scales, spines or needles Leaves curled or rolled or folded when flaccid	Reduced transpiration due to reduced surface area available	Modified leaves: Opuntia (cactus) Rolled leaf: Ammophila arenaria (Marram grass)
Stomata closed during light Stomata open in the dark	CAM metabolism to minimise photorespiration; CO_2 fixed at night, day time water loss is minimised	CAM plants: Pineapple, American aloe, Yucca
Sunken stomata /presence of stomatal crypts Leaf surface covered in fine hairs	Water loss is minimised by trapping moist air close to the area of water loss reducing the diffusion gradient	Pinus sp, Phlomis italica, Nerium sp
Reduced numbers of stomata	Less water loss due to fewer pores	Opuntia, Nerium sp
Stomata only found in the upper epidermis	Open into the humid space created by the hairs and rolled shape	Ammophila arenaria (Marram grass)
Thick waxy cuticle on leaves	Water loss reduced via the cuticle	Pinus sp, Opuntia