Chapter 7: Transport in plants

▼ 7.1. The transport needs of plants

▼ Transport system is needed for what in plants

▼ To move substances from where they are absorbed to where they are needed

E.g. water and mineral ions are absorbed by roots and transported in the xylem to other parts of the plant.

▼ To move substances from where they are produced to where they are needed for metabolism

E.g. glucose can be moved in phloem as part of the sucrose molecule as glucose is needed for respiration in all parts of the plant and for converting to cellulose for making cells walls in areas of growth.

▼ To move substances to a different part of the plant for storage

E.g. to move sugars into a potato tuber for storage in the form of starch.

▼ Carbon dioxide and oxygen diffuse into the plant

When photosynthesizing CO_2 is diffused while, when not photosynthesizing oxygen is needed. Plants respire at much lower rate than animals so lower energy is demanded. Plants also often produce more than enough oxygen for their own needs.

▼ Transport system is needed for others

Transport systems are needed for distribution of water, inorganic and organic nutrients, as well as other substances such as plant hormones.

▼ 7.2. Two systems: xylem and phloem

▼ Xylem

Xylem is a tissue containing tubes called vessels and other types of cell. responsible for the transport of water and mineral salts through a plant and for support.

Xylem sap can move in only one direction.

▼ Phloem

Phloem is a tissue containing tubes called sieve tubes and other types of cell, responsible for the transport through the plant of organic solutes(assimilates) such as glucose.

Phloem sap carries substances from storage organs to other parts of the plant.

The fluid in the phloem can be moving in different directions in different tubes of the phloem, up or down the plant.

▼ 7.3. Structure of stems, roots and leaves

▼ Monocotyledons and dicotyledons

Flowering plants(angiosperms) may be **monocotyledons** (monocots) or **dicotyledons** (dicots). There are differences in their distribution of xylem and phloem in their roots.

▼ Dicotyledons

Flowering plants can be classified as monocotyledons or dicotyledons; the seeds of dicotyledonous plants contain an embryo with two cotyledons(seed leaves) in their seeds and the adult plant typically has leaves with a blade (lamina) and a stalk (petiole).

▼ Monocotyledons

Monocotyledons, such as grasses, have long narrow leaves.

▼ Low-power plan diagrams

▼ Stem

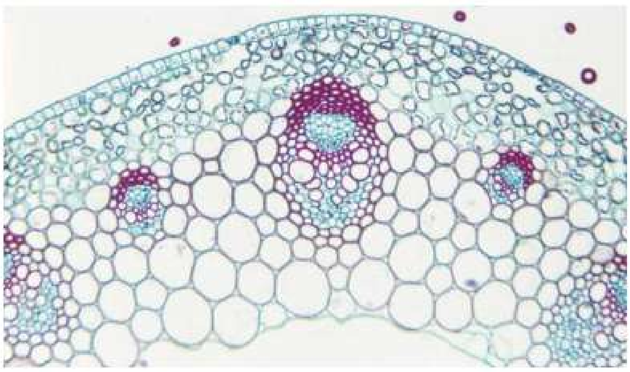


Figure 7.2 Light micrograph of part of a transverse section of a young *Ranunculus* (buttercup) stem (×60).

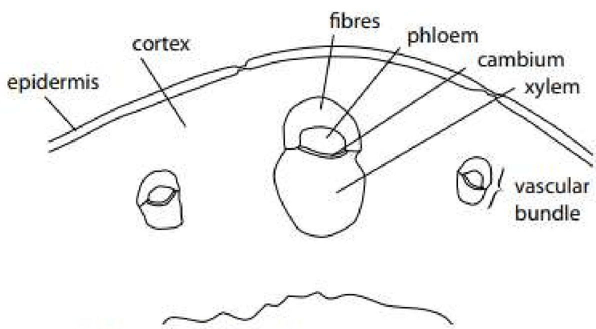


Figure 7.3 Low-power plan of the *Ranunculus* stem shown in Figure 7.2.

▼ Root

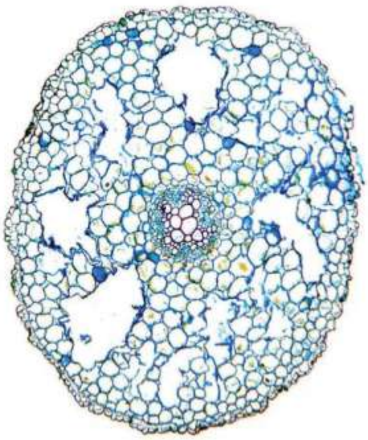


Figure 7.5 Light micrograph of a transverse section of *Ranunculus* (buttercup) root (×35).

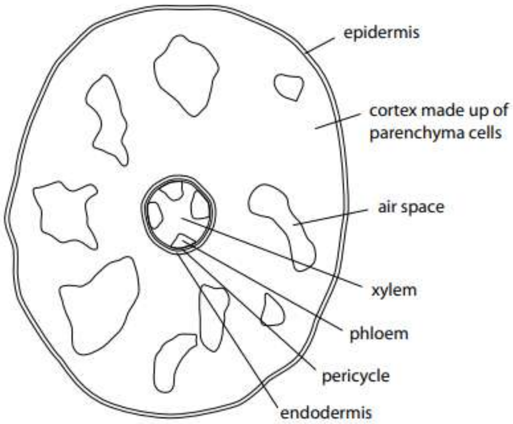


Figure 7.6 Low-power plan of the *Ranunculus* root shown in Figure 7.5.

▼ Leaf

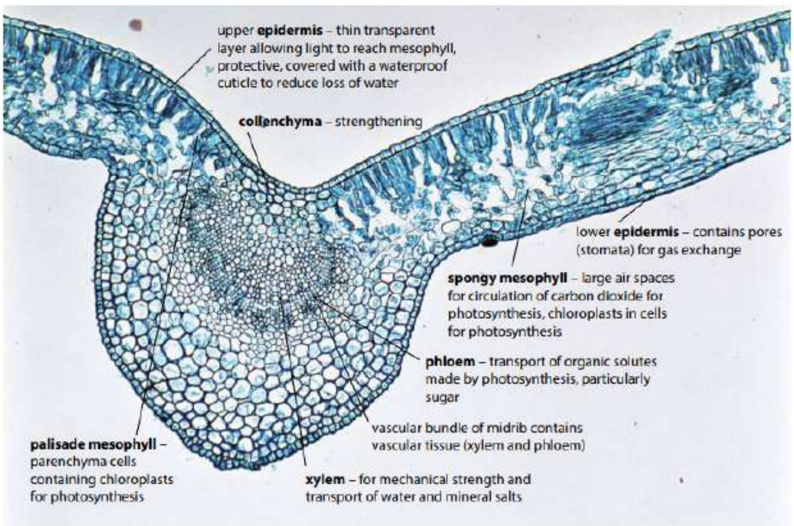


Figure 7.7 Transverse section through the midrib of a dicotyledonous leaf, *Ligustrum* (privet) (×50). Tissues are indicated in bold type.

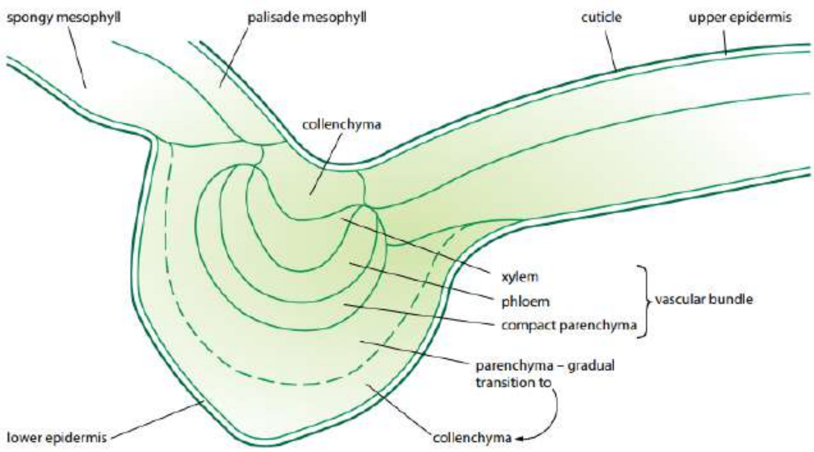


Figure 7.8 A plan diagram of the transverse section through a privet leaf shown in Figure 7.7. Parenchyma is a tissue made up of unspecialised cells. Collenchyma is made up of cells in which the walls are thickened with extra cellulose, especially at the corners, providing extra strength for support.

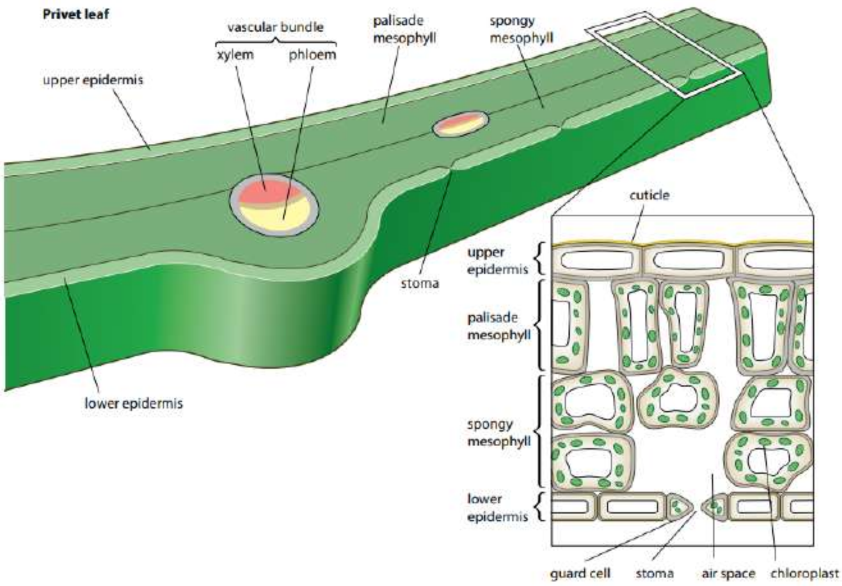


Figure 7.15 The structure of a dicotyledonous leaf. Water enters the leaf as liquid water in the xylem vessels and diffuses out as water vapour through the stomata.

▼ High-power detail diagrams

▼ Epidermis

Epidermis is the continuous layer on the outside of the plant, one cell thick, that **provides protection.**

Cuticle is the waterproof outer layer that covers stems and leaves and protect the organ from drying out and from infections.

Stomata pore on the leaves that allows the entry of carbon dioxide for photosynthesis.

Root hairs is the extension of epidermis in the roots that increases the area of absorption of water and mineral salts.

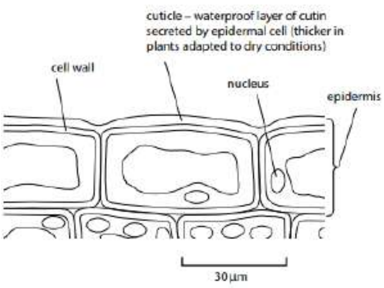


Figure 7.9 High-power detail of a transverse section of leaf epidermis.

▼ Parenchyma

Parenchyma is a one cell thick packing tissue that has multiple of functions:

- Storage of food like starch.
- Help to support the cell when turgid.
- Allows gas exchange through its air spaces.

Parenchyma forms the cortex of stems and roots, and the pith in stems.

Parenchyma contains chloroplasts and is modified to form the spongy and palisade mesophyll.

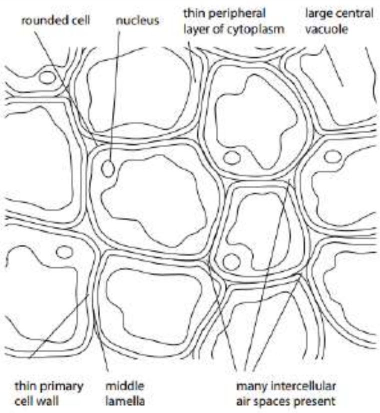


Figure 7.10 High-power detail of a transverse section of parenchyma. Cells are usually roughly spherical, though may be elongated. The average cell diameter is about 25 μm.

▼ Collenchyma

Collenchyma is a modified parenchyma cell that contains extra cellulose at the corners of the cell to provide strength.

The midrib of leaves contains collenchyma.

▼ Endodermis

Endodermis is one cell thick and surrounds the vascular tissue in stems and roots.

In roots (function of endodermis)

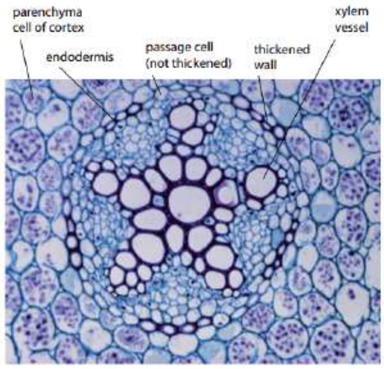


Figure 7.11 Light micrograph of part of a transverse section of a young dicotyledonous root. The endodermis with its thickened walls is shown. Note also the passage cell which allows the passage of water (×250).

▼ Mesophyll

Mesophyll is a special parenchyma cell that contains chloroplast and is situated between the upper and lower epidermis.

There are two types: **spongy mesophyll** (has many air spaces) and **palisade mesophyll** (column-shaped).

Palisade mesophyll is nearer to the upper surface of the leaf where sunlight is received. So it has greater chloroplasts than spongy mesophyll.

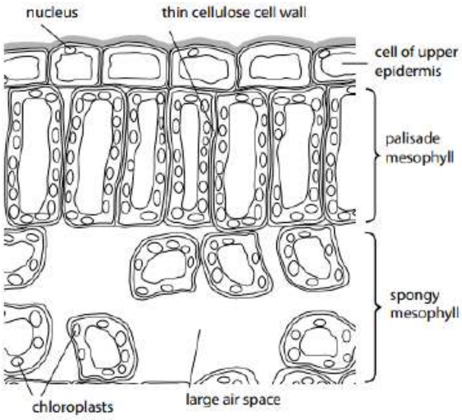


Figure 7.12 High-power detail of palisade and spongy mesophyll cells seen in transverse section.

▼ Pericycle

Pericycle is a layer of cells(one to several cells thick) just inside the endodermis and next to the vascular tissue.

In roots, pericycle is one cell thick and new roots can grow from this layer.

In stems, it is formed from cells called sclerenchyma which are dead, lignified cells for extra strength.

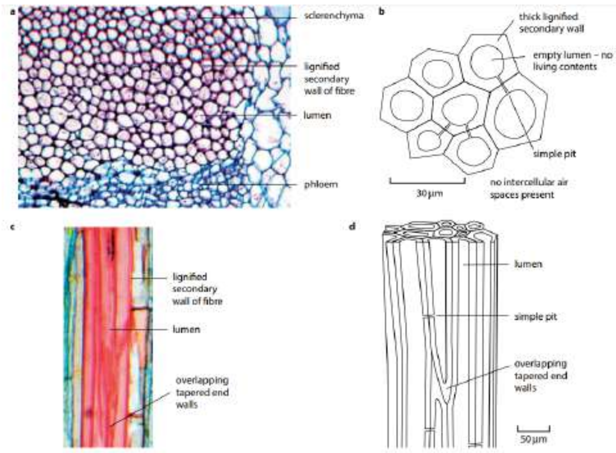


Figure 7.13 Structure of sclerenchyma cells. **a** light micrograph in TS (×100), **b** drawing in TS, **c** light micrograph in LS (×200) and **d** drawing in LS.

▼ Vascular tissue

Xylem and phloem both contain more than one type of cell and together they make of the vascular tissue.

Xylem contains tubes called vessels made from dead cells called **xylem vessel elements.** The walls are strengthened with waterproof material called lignin.

1. Xylem allows long distance transport of water and mineral salts.
2. Xylem provides mechanical support and strength.

In roots, xylem is at the center and has ‘arms’ between which phloem is found.

In stems, the xylem and phloem are found in bundles called vascular bundles. The outsides of these bundles have caps made of sclerenchyma fibers which provide extra support for the stem.

Sclerenchyma is like xylem vessel elements that are long, dead, empty cells with lignified walls, but does not transport.

Phloem contains tubes called sieve tubes made from living cells called **sieve tube elements**.

Phloem allows long distance transport of organic compounds, particularly the sugar sucrose.

▼ 7.4. The transport of water

▼ Transpiration

Transpiration is the loss of water vapor from a plant to its environment, by diffusion down a water potential gradient; most transpiration takes place through the stomata in the leaves.

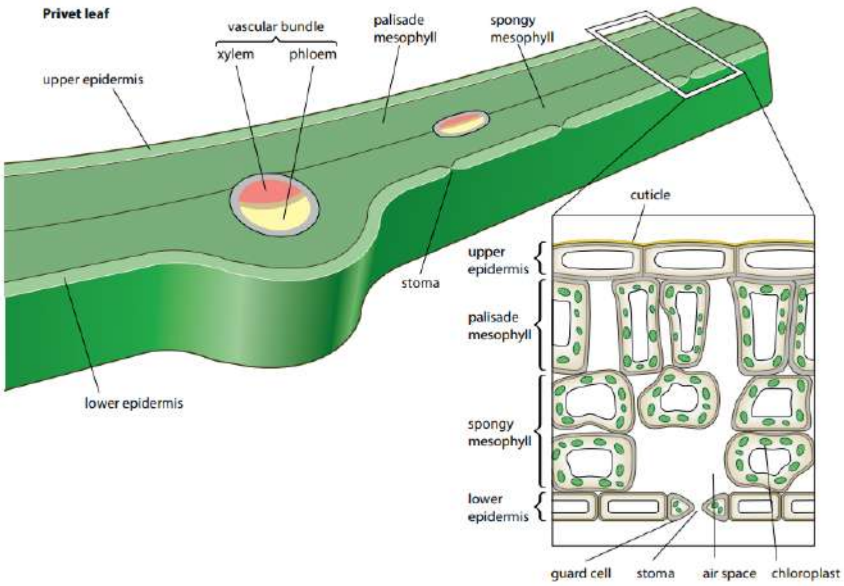


Figure 7.15 The structure of a dicotyledonous leaf. Water enters the leaf as liquid water in the xylem vessels and diffuses out as water vapour through the stomata.

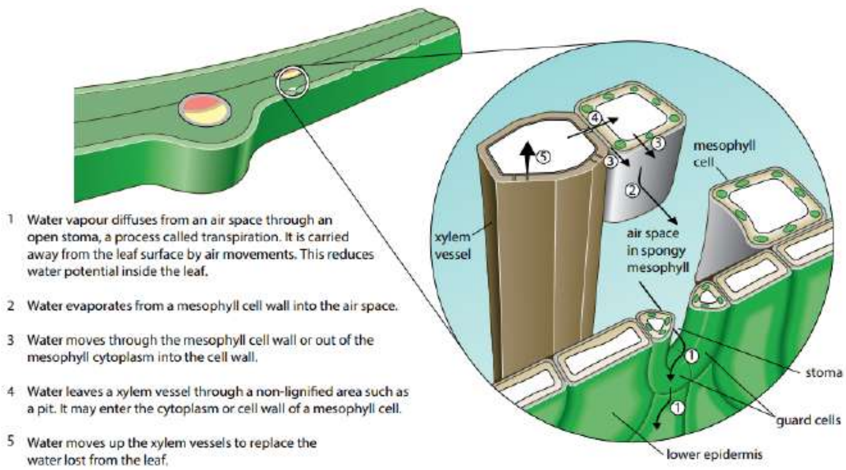


Figure 7.16 Water movement through a leaf. Water is, in effect, being pulled through the plant as a result of transpiration and evaporation. Movement of water through the plant is therefore known as the transpiration stream.

▼ Factors affecting transpiration

▼ Humidity

In low humidity the water potential gradient becomes steeper, so transpiration takes place more quickly than in high humidity.

▼ Wind speed and temperature

Increase in wind speed and temperature increases the rate of transpiration.

▼ Light intensity

In most plants, stomata opens during the day and closes during the night. So the rate of transpiration is almost zero at night.

▼ Very dry conditions

The water potential gradient is steep in very dry conditions, the stomata is partially or completely closed to prevent the plant from drying out even if it reduces the rate of photosynthesis.

In hot conditions, transpiration plays an important role in cooling the plant. The water molecules evaporated absorbs the heat energy from the cells thus reducing the temperature.

If the rate of loss of water exceeds the uptake of water the plants cells become less turgid. The plant becomes soft and lose its support. In this situation plant will also close its stomata.

▼ Xerophytes

Xerophytes or xerophytic plants are plants that live in places where water is short in supply. Many xerophytes have evolved special adaptations of their leaves that keep water loss down to a minimum.

1. Thick cuticles that prevent water loss - **cutin** which is a fatty, relatively waterproof substance is contained in the cuticle. Also the shiny surface of the cuticle reflects heat, lowering temperature.
2. Rolled leaf - Increases humidity around stomata reducing the water potential gradient.
3. Hairs/ trichomes on surfaces - Trap moisture to reduce water potential gradient.
4. Sunken stomata/ stomata in pits - Moist air trapped in pits reduces water loss.
5. No stomata on upper surface - Not exposed to sunlight, reducing evaporation rate.
6. Small leaves, reduced to spines - Reduce surface area for transpiration.

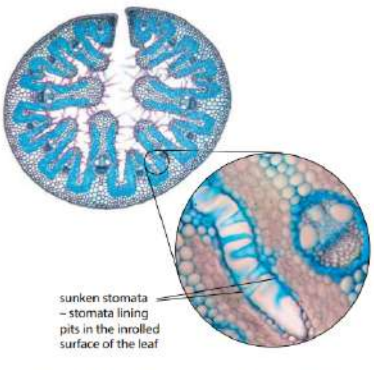


Figure 7.22 Light micrograph of a transverse section of a rolled marram grass leaf.

▼ From xylem across the leaf

When the water evaporates from the mesophyll cells, water moves through the unlignified parts of the xylem vessel walls to the mesophyll cells.

The water moves along two pathways; **symplastic pathway** and **apoplastic pathway.**

▼ Xylem tissue

Xylem is a tissue containing tubes called vessels and other types of cell. responsible for the transport of water and mineral salts through a plant and for support.

Xylem sap can move in only one direction.

Xylem vessels have:

1. They are made from cells joined end to end to form tubes.
2. The cells are dead.
3. The walls of the cells are thickened with a hard, strong material called lignin($C_{81}H_{92}O_{28}$).

▼ In flowering plants, xylem tissue contains vessel elements, tracheids, fibres and parenchyma cells.

1. Vessel elements and tracheids are the main transporters of water.
2. Sclerenchyma cells are elongated cells with lignified walls that help to sipport the plant. They are dead cells; they may have no living contents at all.
3. Parenchyma cells:

   Parenchyma is a one cell thick packing tissue that has multiple of functions:

   - Storage of food like starch.
   - Help to support the cell when turgid.
   - Allows gas exchange through its air spaces.

   Parenchyma forms the cortex of stems and roots, and the pith in stems.

   Parenchyma contains chloroplasts and is modified to form the spongy and palisade mesophyll.

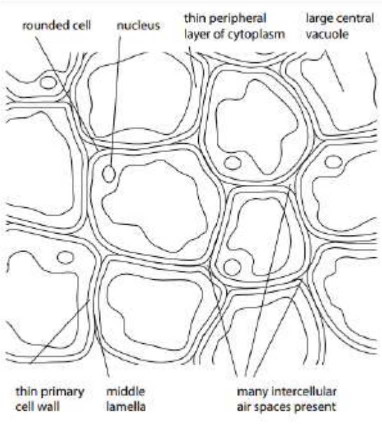


Figure 7.10 High-power detail of a transverse section of parenchyma. Cells are usually roughly spherical, though may be elongated. The average cell diameter is about 25µm.

▼ Xylem vessels and vessel elements

Xylem vessels are made up of many elongated cells called vessel elements, arranged to end to end.

Each vessel element begins life as a normal plant cell in whose wall lignin is laid down. As lignin builds up around the cell, the contents of the cell die, leaving a completely empty space called lumen inside.

Pits are unlignified areas of the cell where group of plasmodesmata are found.

Pits are not open pores; they are crossed by permeable, unthickened cellulose cell wall.

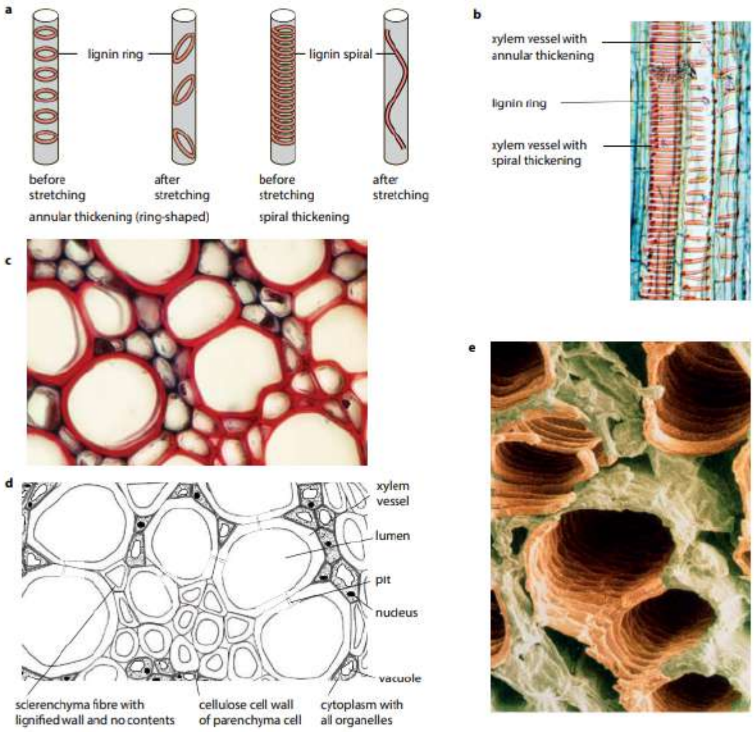


Figure 7.23 Structure of xylem. **a** Diagrams to show different types of thickening. **b** Micrograph of xylem as seen in longitudinal section. Lignin is stained red (×100). **c** and **d** Micrograph and diagram of xylem as seen in transverse section; lignin is stained red. Small parenchyma cells are also visible between the xylem vessels (×120). **e** Scanning electron micrograph of mature xylem vessels, showing reticulate (net-like) pattern of lignification (×130).

▼ From root to stem and leaf in the xylem

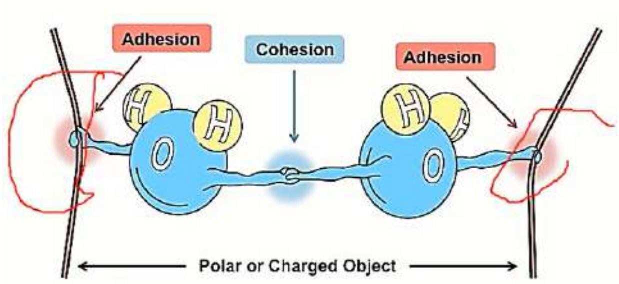
Hydrostatic pressure causes water to move up the xylem vessels in continuous columns.

▼ Adhesion

Adhesion is the attraction of water molecules to the cellulose and lignin in the walls of the xylem vessels.

▼ Cohesion

Cohesion is the hydrogen bonding between the water molecules.



Cohesion and adhesion keep the water in the xylem vessel moving as a continuous column.

Pits allow water to move out of xylem vessels to surrounding living cells.

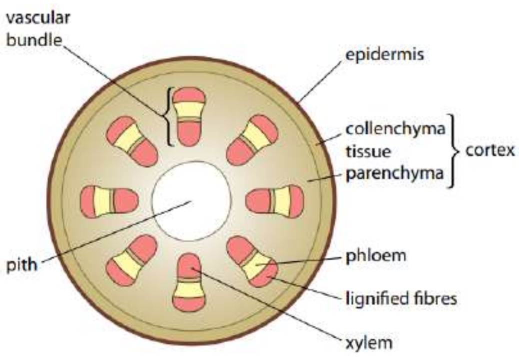
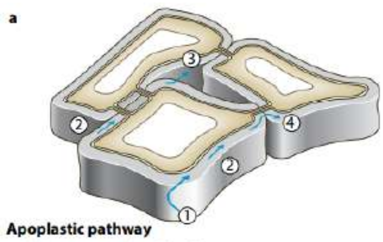


Figure 7.24 TS of a young sunflower (*Helianthus*) stem to show the distribution of tissues. The sunflower is a dicotyledonous plant.

▼ How does water move from the root hair to the xylem?

▼ Apoplastic pathway

Apoplastic pathway is the pathway which water soaks through the cell wall to cell wall without ever entering the cytoplasm of the cells.



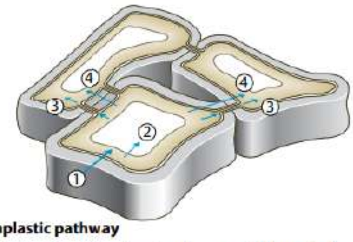
Apoplastic pathway

1 Water enters the cell wall.
2 Water moves through the cell wall.
3 Water may move from cell wall to cell wall through the intercellular spaces.
4 Water may move directly from cell wall to cell wall.

▼ Symplastic pathway

Symplastic pathway is a pathway that water moves into the cytoplasm or vacuole by osmosis and then into other cells through the plasmodesmata.

b



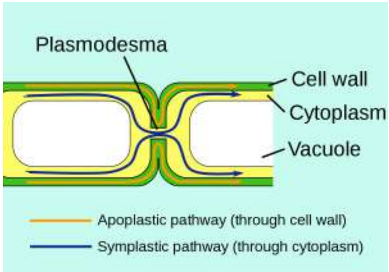
Symplastic pathway

1 Water enters the cytoplasm by osmosis through the partially permeable cell surface membrane.

2 Water moves into the sap in the vacuole, through the tonoplast by osmosis.

3 Water may move from cell to cell through the plasmodesmata.

4 Water may move from cell to cell through adjacent cell surface membranes and cell walls.



🌱 From root hair to xylem

▼ What will happen if an air bubble forms in a xylem?

The column of water will break and the difference in hydrostatic pressure between the top and the bottom will not be transmitted. This is called an air lock- water stops moving upwards.

▼ How does the xylem prevent air locks?

The small diameter of the xylem helps prevent breaks between the water column.

Pits in the vessel walls allow water to move out into neighbouring vessels.

Pits also allow water to move into the neighbouring living cells.

▼ 7.5. Transport of mineral ions

The movement of ions are same as water. Apart from moving through the apoplastic and symplastic pathways, mineral ions can also move through **diffusion** and **active transport.**

▼ 7.6. Translocation

▼ Translocation

Assimilates, which are substances which the plant itself has made, are transported in sieve elements. Sieve elements are found in phloem tissue, along with several other types of cells including companion cells, parenchyma and fibers.

Assimilates are transported in sieve elements. Sieve elements are found in phloem tissue along with other types of cells including companion cells, parenchyma and fibers.

▼ Sieve tubes and sieve elements

The phloem which is the main vessel used for the translocation or mineral ions consists of tubes called sieve tubes.

These tubes consists of **living cells.** A sieve tube is made up of several sieve elements joined from end to end.

Sieve elements have cellulose cell walls, cell surface membranes and cytoplasm containing endoplasmic reticulum and mitochondria.

Each sieve element has a minimum of one companion cells next to it.

Companion cells are alive and are metabolically active.

Plasmodesmata help with exchange between the cytoplasm of the companion cell and the sieve elements.

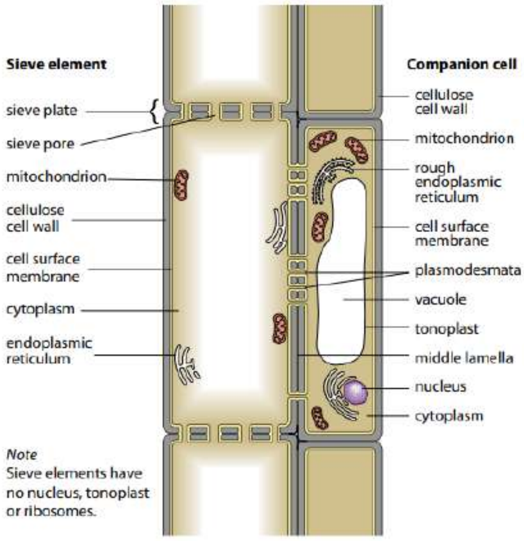


Figure 7.30 A phloem sieve tube element and its companion cell.

▼ Structure of phloem

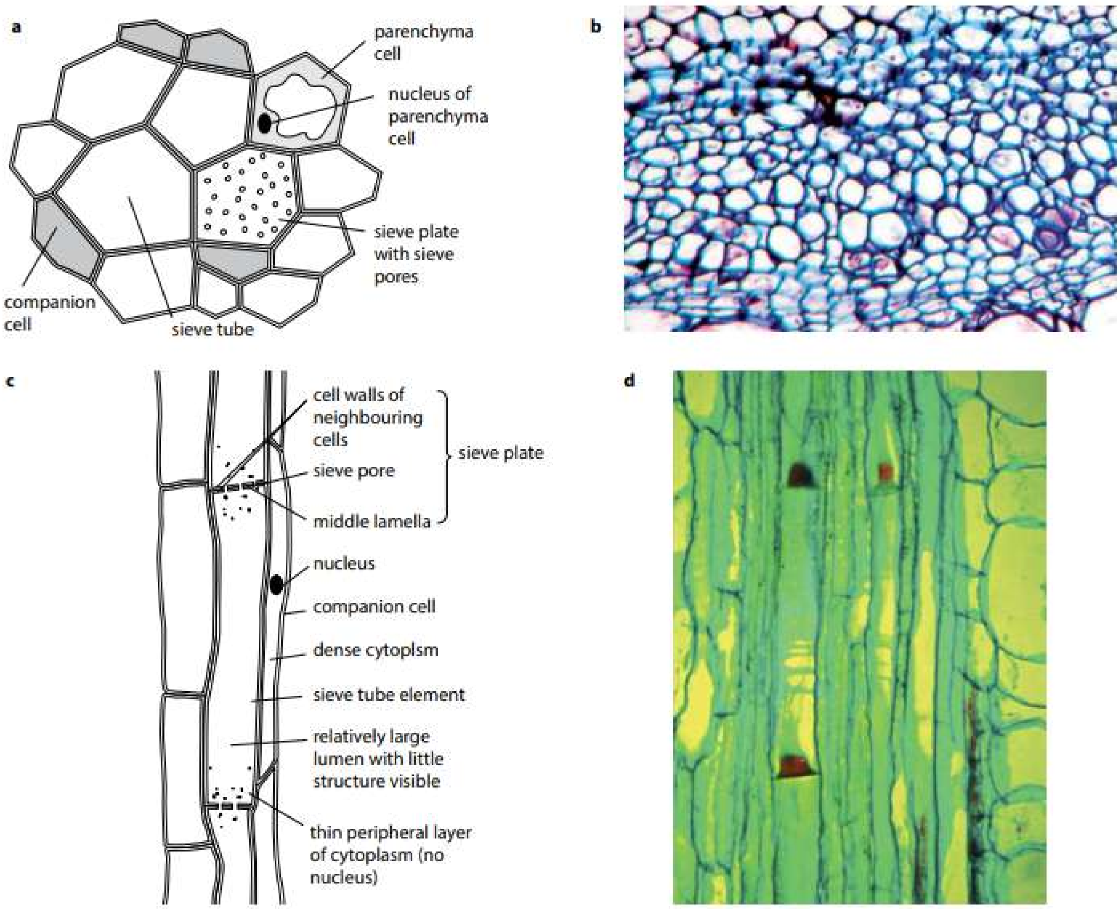


Figure 7.31 Structure of phloem. **a** Diagram in TS, **b** light micrograph in TS (×300), **c** diagram in LS, **d** light micrograph in LS (×200). The red triangles are patches of callose that formed at the sieve plates between the sieve tube elements in response to the damage done as the section was being cut. You can see companion cells, with their denser cytoplasm, lying alongside the sieve tube elements. On the far right are some parenchyma cells.

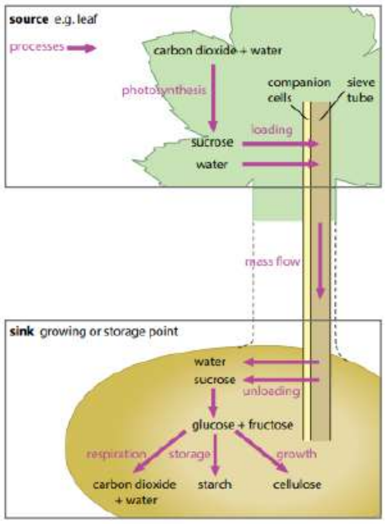
▼ How does translocation occur?

Mass flow in xylem vessels is dependent on the difference in water potential between the roots and the upper parts of the plant. Hence, it is a form of **passive transport.**

In phloem, mass flow is not passive. It involves the active loading of sucrose into the sieve elements from the point where sucrose is to be transported, i.e. a **source**. **active transport.**

Any part of the plant where sucrose is taken out of the phloem to be used is called a **sink.**

This loading decrease the water potential in the sieve elements, causing water to enter the sieve element through osmosis. This creates a pressure difference which causes a mass flow of water to move through the sieve tubes.



The sink is a growing point, e.g. young leaf, bud, flower or root, or a storage point, e.g. seed, fruit or tuber.

Figure 7.34 Sources, sinks and mass flow in phloem.

▼ Loading sucrose into phloem

Sucrose ism loaded into a companion cell or directly into a sieve element by active transport.

Hydrogen ions (H+) are pumped out of the companion cells into its cell wall, using ATP as an energy source. This creates a large excess of hydrogen ions in the apoplastic pathway outside the companion cell.

The hydrogen ions can move back into the cell down their concentration gradient, through a protein which acts as a carrier for both hydrogen ions and sucrose at the same time. The sucrose molecules are carried through this co-transporter molecule into the companion cell, against the concentration gradient for sucrose. The sucrose molecules can then move from the companion cell into the sieve tube, through the plasmodesmata which connect them (symplastic pathway).

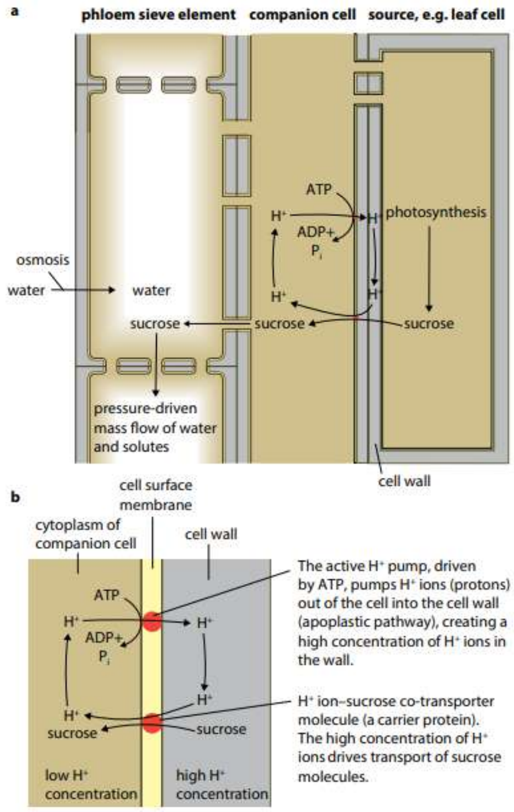
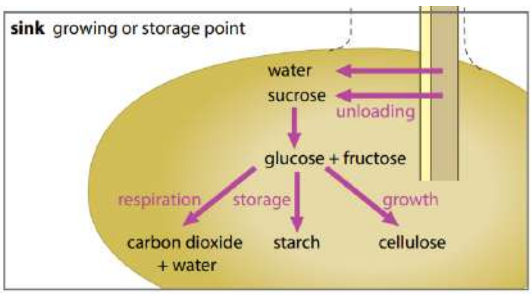


Figure 7.35 Loading phloem. **a** One of the possible methods by which sucrose is loaded and a pressure gradient generated. **b** Detail of the H^+ ion-sucrose co-transporter system.

▼ Unloading sucrose from phloem

Phloem unloading requires energy.

Once in tissue, the sucrose is converted into something else by enzymes, so decreasing its concentration gradient and maintaining a concentration gradient. E.g. one such enzyme is invertase, which hydrolyses sucrose to glucose and fructose.



▼ 7.7. Difference between sieve tubes and xylem vessels

Phloem sieve tubes	Xylem vessels
Made up of living cells	Made up of dead cells
No lignified cell walls	Have lignified cell walls
End walls form sieve plates	No end walls

Sieve plates allow phloem to seal itself with callose if damaged	No sieve plates

▼ Ch7. End-of-chapter questions

▼ Pit vs. Pith

As nouns the difference between pit and pith is that **pit is a hole in the ground or pit can be a seed inside a fruit; a stone or pip inside a fruit while pith is the soft, spongy substance in the center of the stems of many plants and trees**.

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Differentiate 'pith and pit'. - Justlearn

▼ What are the importance in difference in sieve tubes and xylem vessels?

1. If phloem cells were dead cells, sucrose would leak out of them because they would not have membranes. Dead xylem cells are also empty, therefore allowing water to flow without any obstruction.
2. The lignified cell walls of xylem vessels help them support the plant.
3. Sieve plates in phloem sieve tubes help to maintain the pressure in the tubes
4. Sieve plates allow phloem cells to quickly clot sap to prevent loss of sucrose and vulnerability of diseases.

▼ Specification

▼ 1 state that some mineral ions and organic compounds can be transported within plants dissolved in water

Sucrose, potassium ions, amino acids, chloride ions, phosphate ions, magnesium ions, sodium ions, ATP, nitrate ions and plant growth substances like auxin and cytokinin

▼ 2 describe the transport of water from the soil to the xylem through the:

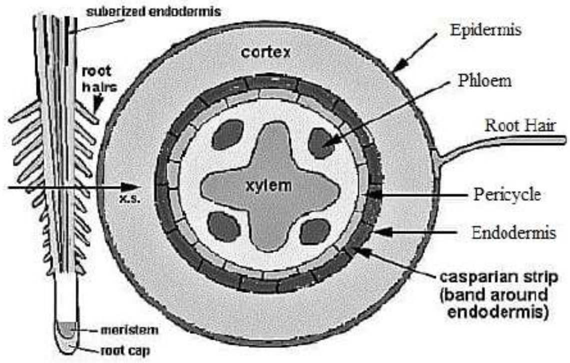
Water travels through the root hair till it reaches the endodermis.

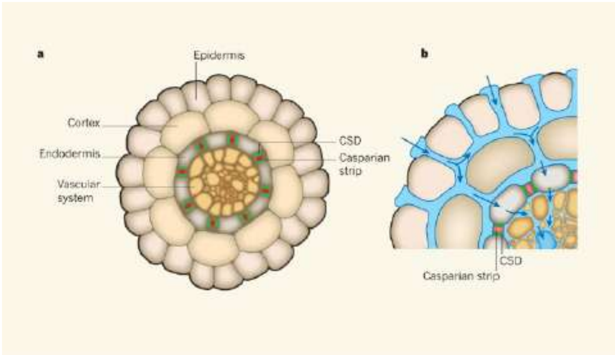
The cells in the endodermis have a thick waterproof band called Casparian strip.

The casparian strip forms an impenetrable barrier to water forcing water to travel through the cytoplasm of the cells of the endodermis.

Through this, plants control the mineral ions that pass into the xylem vessels. This can also help generate root pressure.

Once across the endodermis, water moves through the pericycle into the xylem vessels.





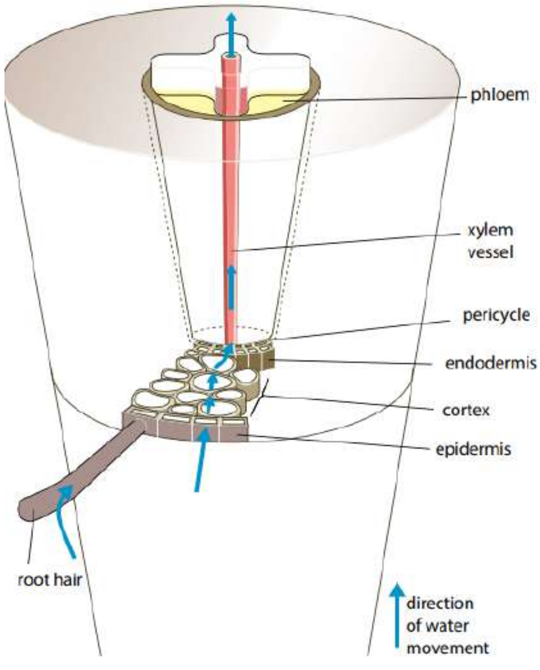


Figure 7.25 The pathway of water movement from root hair to xylem.

▼ 3 explain that transpiration involves the evaporation of water from the internal surfaces of leaves followed by diffusion of water vapor to the atmosphere

Transpiration is the loss of water vapor from a plant to its environment, by diffusion down a water potential gradient; most transpiration takes place through the stomata in the leaves.

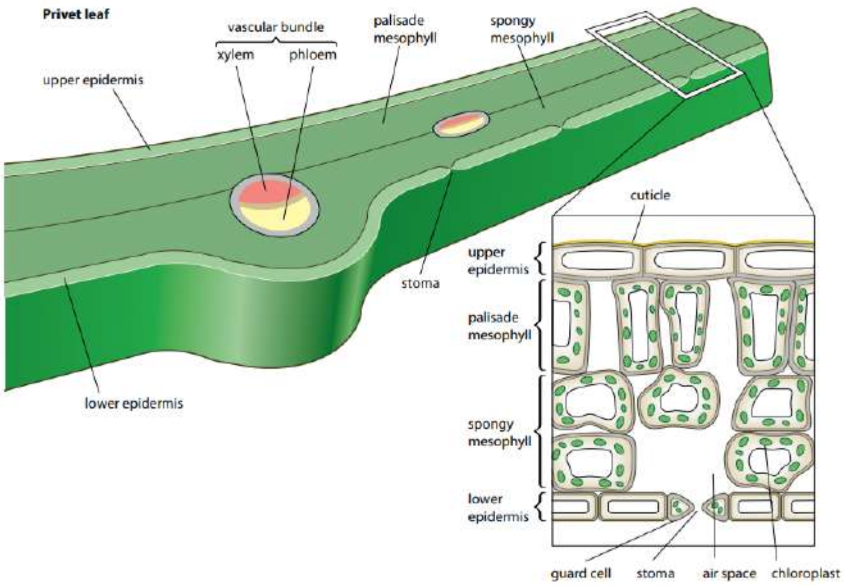


Figure 7.15 The structure of a dicotyledonous leaf. Water enters the leaf as liquid water in the xylem vessels and diffuses out as water vapour through the stomata.

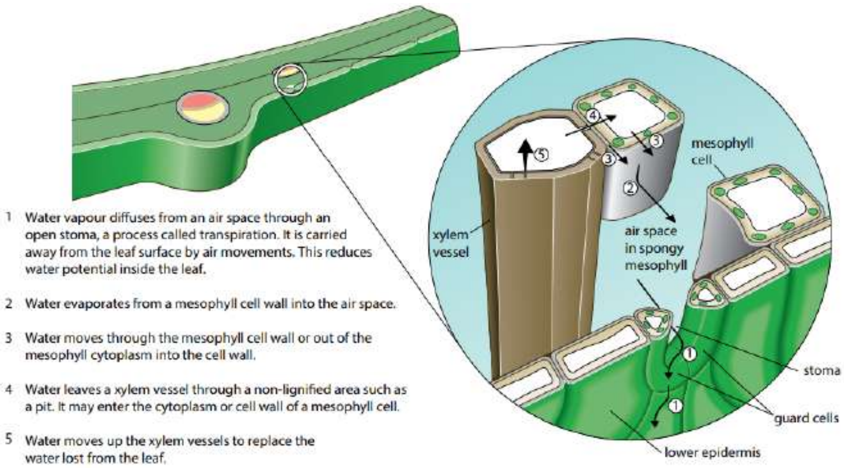


Figure 7.16 Water movement through a leaf. Water is, in effect, being pulled through the plant as a result of transpiration and evaporation. Movement of water through the plant is therefore known as the transpiration stream.

▼ 4 explain how hydrogen bonding of water molecules is involved with movement of water in the xylem by cohesion-tension in transpiration pull and by adhesion to cellulose in cell walls

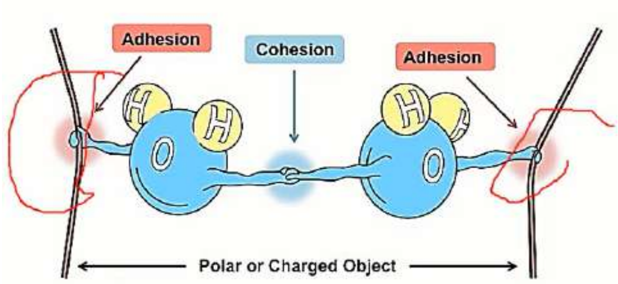
Hydrostatic pressure causes water to move up the xylem vessels in continuous columns.

▼ Adhesion

Adhesion is the attraction of water molecules to the cellulose and lignin in the walls of the xylem vessels.

▼ Cohesion

Cohesion is the hydrogen bonding between the water molecules.



Cohesion and adhesion keep the water in the xylem vessel moving as a continuous column.

Pits allow water to move out of xylem vessels to surrounding living cells.

▼ 5 make annotated drawings of transverse sections of leaves from xerophytic plants to explain how they are adapted to reduce water loss by transpiration

Xerophytes or xerophytic plants are plants that live in places where water is short in supply. Many xerophytes have evolved special adaptations of their leaves that keep water loss down to a minimum.

1. Thick cuticles that prevent water loss **-** **cutin** which is a fatty, relatively waterproof substance is contained in the cuticle. Also the shiny surface of the cuticle reflects heat, lowering temperature.
2. Rolled leaf **-** Increases humidity around stomata reducing the water potential gradient.
3. Hairs/ trichomes on surfaces **-** Trap moisture to reduce water potential gradient.
4. Sunken stomata/ stomata in pits - Moist air trapped in pits reduces water loss.
5. No stomata on upper surface - Not exposed to sunlight, reducing evaporation rate.
6. Small leaves, reduced to spines **-** Reduce surface area for transpiration.

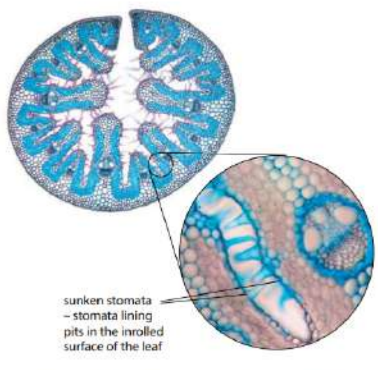


Figure 7.22 Light micrograph of a transverse section of a rolled marram grass leaf.

▼ 6 state that assimilates dissolved in water, such as sucrose and amino acids, move from sources to sinks in phloem sieve tubes

The phloem which is the main vessel used for the translocation or mineral ions consists of tubes called sieve tubes.

These tubes consists of **living cells.** A sieve tube is made up of several sieve elements joined from end to end.

Sieve elements have cellulose cell walls, cell surface membranes and cytoplasm containing endoplasmic reticulum and mitochondria.

Each sieve element has a minimum of one companion cells next to it.

Companion cells are alive and are metabolically active.

Plasmodesmata help with exchange between the cytoplasm of the companion cell and the sieve elements.

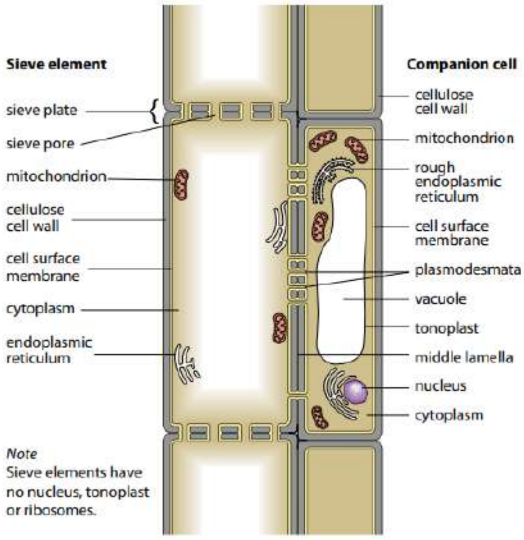


Figure 7.30 A phloem sieve tube element and its companion cell.

▼ 7 explain how companion cells transfer assimilates to phloem sieve tubes, with reference to proton pumps and cotransporter proteins

▼ 8 explain mass flow in phloem sieve tubes down a hydrostatic pressure gradient from source to sink

Sucrose ism loaded into a companion cell or directly into a sieve element by active transport.

Hydrogen ions (H+) are pumped out of the companion cells into its cell wall, using ATP as an energy source. This creates a large excess of hydrogen ions in the apoplastic pathway outside the companion cell.

The hydrogen ions can move back into the cell down their concentration gradient, through a protein which acts as a carrier for both hydrogen ions and sucrose at the same time. The sucrose molecules are carried through this co-transporter molecule into the companion cell, against the concentration gradient for sucrose. The sucrose molecules can then move from the companion cell into the sieve tube, through the plasmodesmata which connect them (symplastic pathway).

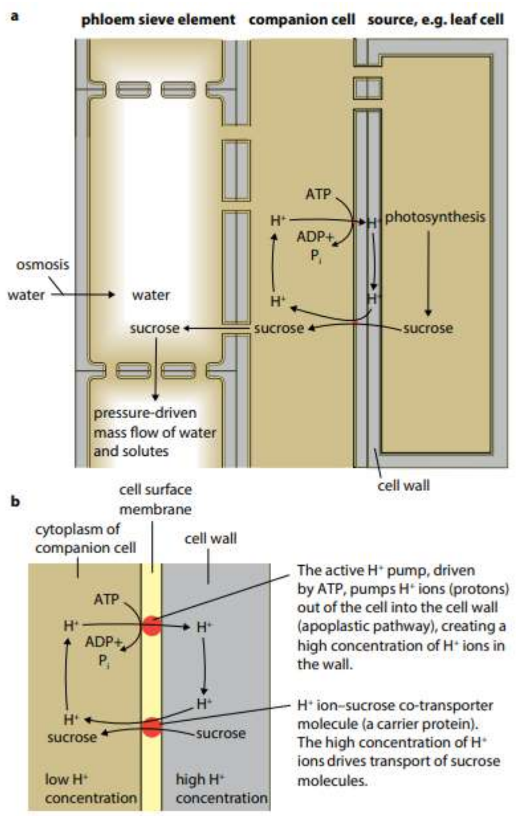
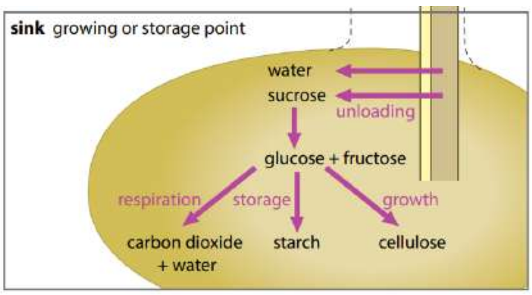


Figure 7.35 Loading phloem. **a** One of the possible methods by which sucrose is loaded and a pressure gradient generated. **b** Detail of the H^+ ion-sucrose co-transporter system.

Phloem unloading requires energy.

Once in tissue, the sucrose is converted into something else by enzymes, so decreasing its concentration gradient and maintaining a concentration gradient. E.g. one such enzyme is invertase, which hydrolyses sucrose to glucose and fructose.



If you have any questions reach out to**: 23C Chinguun.M, IG: @chinguun__0511, FB: Chinguun Tsetsgee.**
Or post questions on the discord server for help!