# Cambridge (CIE) AS Biology

Your notes

## Transport Mechanisms

### Contents

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# Water & mineral ion transport: pathways & mechanisms

- Plant roots have **root hairs** to **increase the surface area** for absorption of water and mineral ions from the soil
  - Root hair cells take in mineral ions from the soil; this can occur either by diffusion or by active transport depending on the mineral concentrations in the soil
  - The uptake of minerals **lowers the water potential** of the root hair cells
  - The uptake of water then occurs by **osmosis**
- After the uptake of water and dissolved mineral ions into the root hair cells, the solution needs to move across the plant root and into the **xylem vessels**
- There are two pathways that water (and dissolved solutes) can take to move across the root cortex:
  - **Apoplast** (also known as apoplastic)
  - **Symplast** (also known as symplastic)

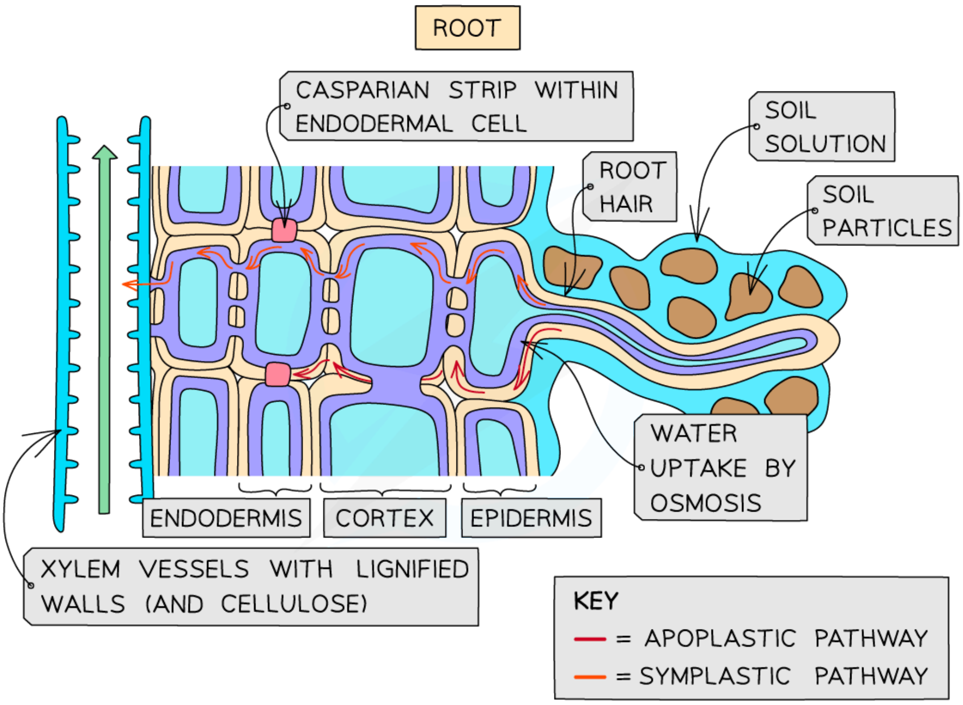
## The apoplast pathway

- Most water travels via the apoplast pathway, which involves the series of **spaces** running through the **cellulose cell walls**, dead cells, and the hollow tubes of the xylem
  - The cellulose cell walls form a network of **microscopic channels** and **pores** that allow water to move freely between cells
  - Their structure provides a **continuous, unbroken route** for water and dissolved minerals through the plant
- Water in the apoplast pathway moves by **diffusion**, as it does not cross any partially permeable membranes
- The movement of water through the apoplast pathway occurs **more rapidly** than in the symplast pathway
- When the water reaches the endodermis of the root, its progress is blocked by a waterproof, waxy band of **suberin** within the cell walls
  - This band is called the **Casparian strip**
- When the water and dissolved minerals reach the Casparian strip they move into the symplast pathway.
  - The presence of this strip is not fully understood, but it is thought that forcing water into the symplast pathway, and therefore across cell membranes, may help the plant control which mineral ions reach the xylem

- Within the xylem vessels, the cell walls are strengthened and waterproofed by **lignin**
  - This lignin **prevents water from leaking out of the vessels** and helps maintain the continuous column of water under tension, allowing efficient upward transport

## Symplast pathway

- A **smaller volume of water** travels via the symplast pathway, which involves the **cytoplasm**, plasmodesmata**,** and vacuoles of the cells
- The water moves by **osmosis** into the cells and vacuoles, and by diffusion between cells through the plasmodesmata
- The movement of water in the symplast pathway is **slower** than the apoplast pathway




***The Casparian strip prevents the movement of water via the apoplast pathway and forces it to move via the symplast pathway***

### Examiner Tips and Tricks

Remember water moves through the apoplast and symplast pathways in the leaves as well as the roots.

Water **does not move by osmosis in the apoplast pathway** as the molecules are in the cell wall, which is freely permeable.

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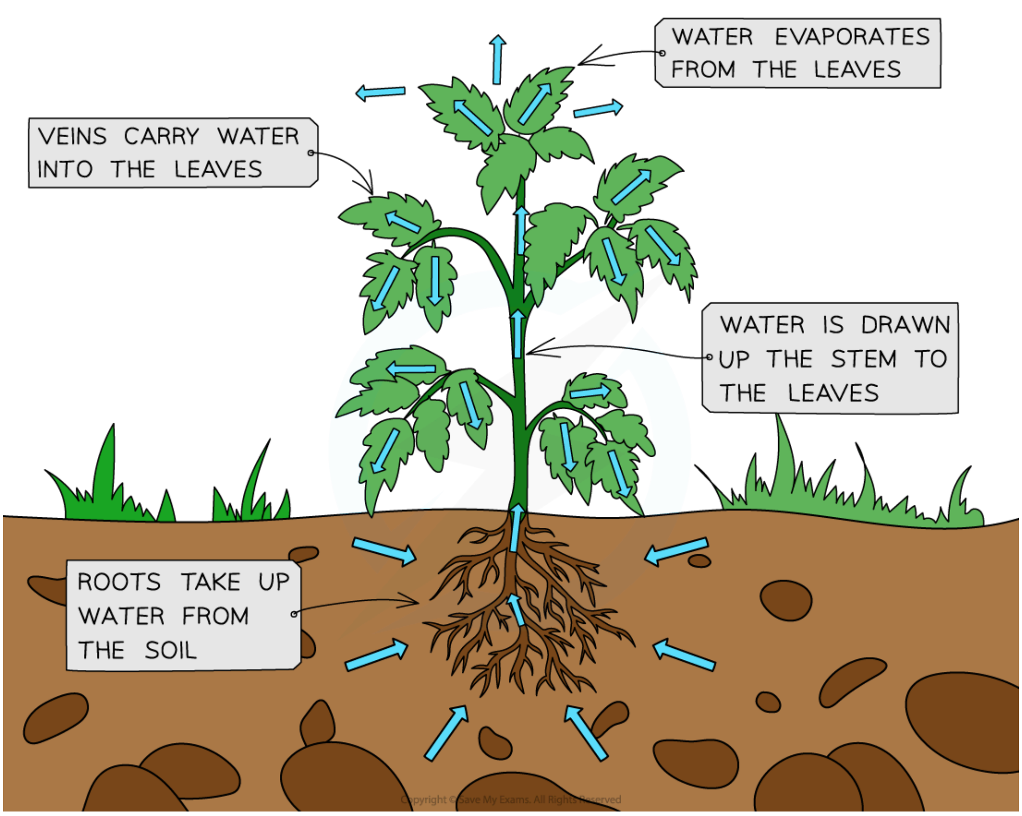
# Transpiration explained

- The movement of water through a plant's xylem occurs due to the **evaporation of water vapour** from the **leaves** and the **cohesive** and **adhesive** properties exhibited by water molecules
- The **water potential gradient** is the driving force behind the movement of water from the soil (**high water potential**) to the atmosphere (**low water potential**), via the plant's cells
  - Plants are constantly taking water in at their roots and losing water via the **stomata** (in the leaves), maintaining the water potential gradient between the roots and the leaves
- Around 99 % of the water absorbed is lost through evaporation from the plant's stem and leaves in a process called **transpiration**
- Transpiration refers to the **loss of water vapour via the stomata by diffusion**
  - Note that this is different to the **transpiration stream** which is **the movement of water from the roots to the leaves**
- Transpiration is important to the plant in the following ways
  - It provides a means of **cooling** the plant via evaporative cooling
  - The transpiration stream is helpful in the **uptake of mineral ions**
  - The turgor pressure of the cells (due to the presence of water as it moves up the plant) provides **support** to leaves (enabling an increased surface area of the leaf blade) and the stem of non-woody plants




*The loss of water vapour from the leaves of plants (transpiration) results in a lower water potential in the leaves. This creates a concentration gradient between the roots and leaves and causes water to move upwards*

## Movement of water through leaves

- Certain environmental conditions (e.g. low humidity, high temperatures) can cause a water potential gradient between the air inside the leaves (**higher** water potential**)** and the air outside (**lower** water potential) which results in water vapour **diffusing** out of the leaves through the stomata (transpiration)
- The water vapour lost by transpiration **lowers the water potential** in the air spaces surrounding the mesophyll cells
- The water within the mesophyll cell walls **evaporates** into these air spaces resulting in a transpiration pull
- This transpiration pull results in water moving through the mesophyll cell walls or out of the mesophyll cytoplasm
    - Movement of water **through the cell walls** of a plant is said to occur via the **apoplast**, or apoplastic, pathway
    - Movement of water from the **cytoplasm of a cell** occurs via the **symplast**, or symplastic, pathway
- The pull from the water moving through the mesophyll cells results in water leaving the xylem vessels through **pits** (non-lignified areas), which then causes water to move **up** the

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xylem vessels to replace this lost water (due to the cohesive and adhesive properties of the water). This movement is called the **transpiration stream**

    - When rates of transpiration are high the walls of the xylem are pulled inwards by the faster flow of water

## The role of the stomata

- Transpiration is mainly controlled by the pairs of guard cells that surround **stomata** (singular **stoma**)
- **Guard cells** open the stomata when they are **turgid** and close the stomata when they lose water
- When the stomata are **open** there is a greater rate of transpiration and of gaseous exchange
- When the stomata **close**, transpiration and gaseous exchange decrease
- As stomata allow gaseous exchange ($CO_2$ in and $O_2$ out) they are generally **open during the day**

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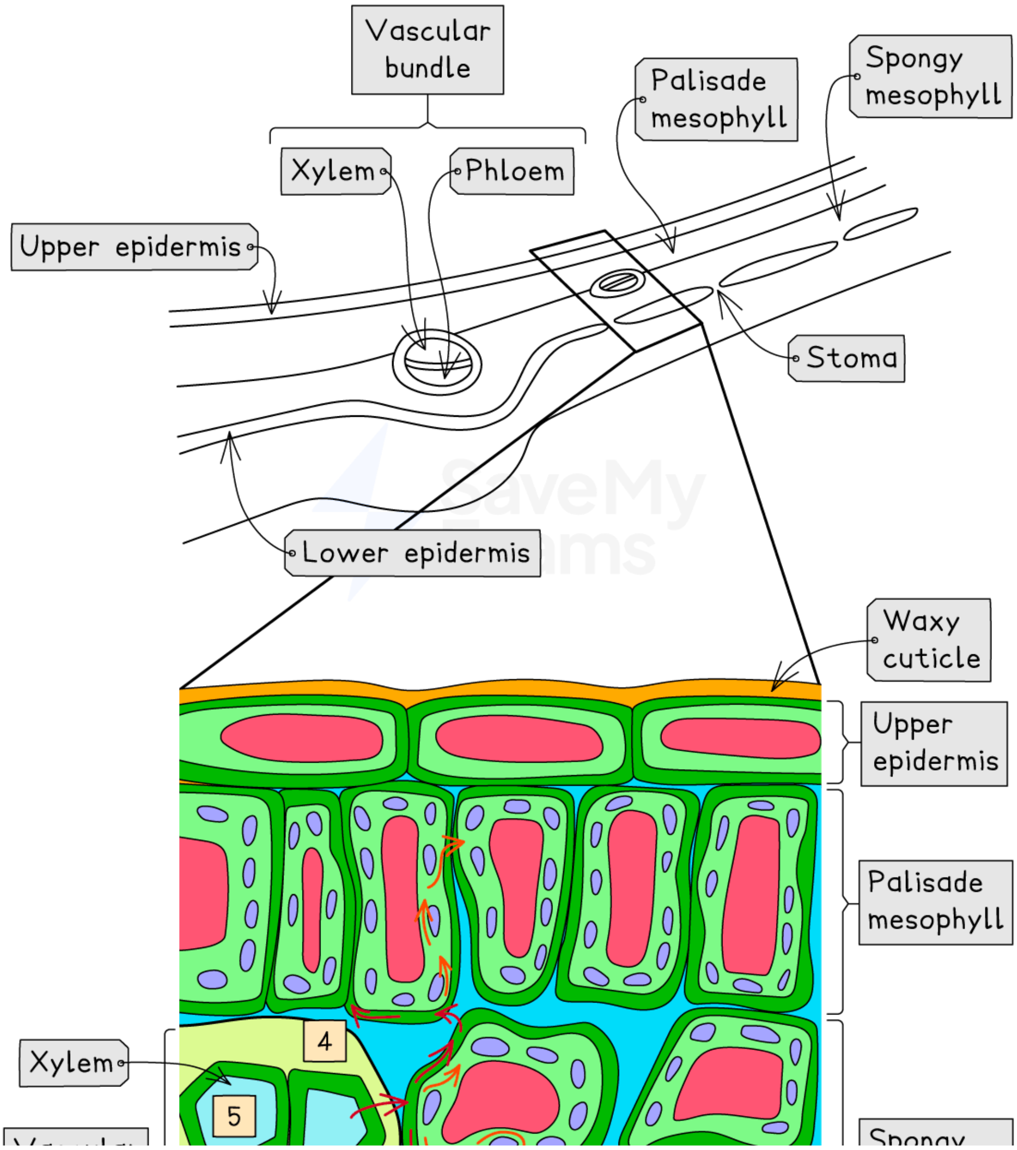
1 Water vapour diffuses from air spaces through a stoma by a process called transpiration, lowering the water potential

2 Water evaporates from a mesophyll cell wall into the air spaces, creating a **transpiration pull**

3 Water moves through the mesophyll cell wall (apoplastic pathway) or out of the mesophyll cytoplasm into the cell wall (symplastic pathway)

4 Water leaves a xylem vessel through a non-lignified area (e.g. pit). It may travel by a symplastic pathway or by an apoplastic pathway

5 Water moves up the xylem vessels (transpiration stream) to replace the water lost from the leaf

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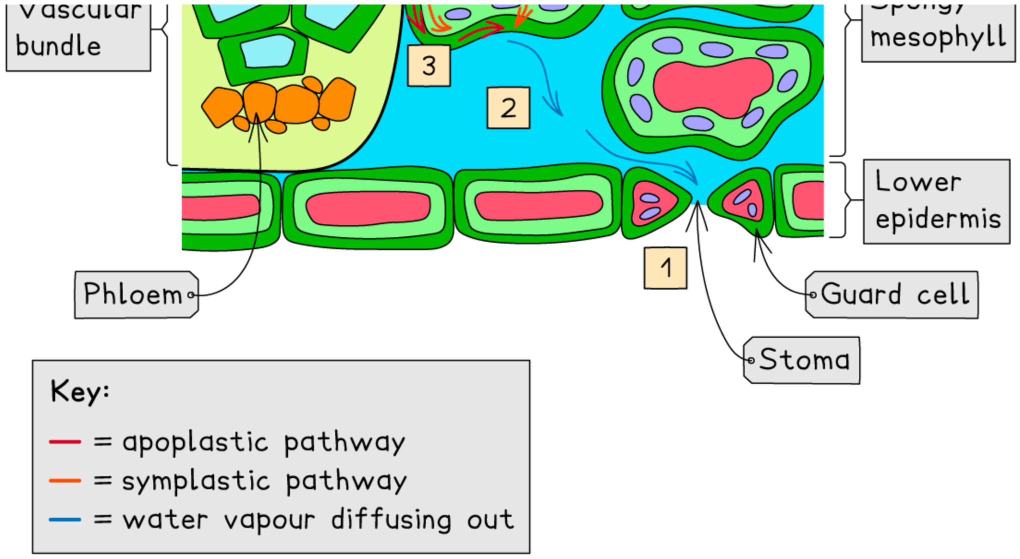



***Water enters the leaf as a liquid from the xylem and diffuses out as water vapour through the stomata. This loss of water by evaporation and transpiration results in a water potential gradient between the leaves (low) and roots (high) causing water to move up the plant in the transpiration stream***

### Examiner Tips and Tricks

Remember that **water evaporates** from the mesophyll cells into the air spaces in the leaf and then **water vapour diffuses** through the stomata.

**Transpiration** and the **transpiration stream** are different:

- **Transpiration** is the **loss of water vapour** from the leaves or stem
- Whereas the **transpiration stream** is the **movement of water** through the xylem tissue and mesophyll cells.

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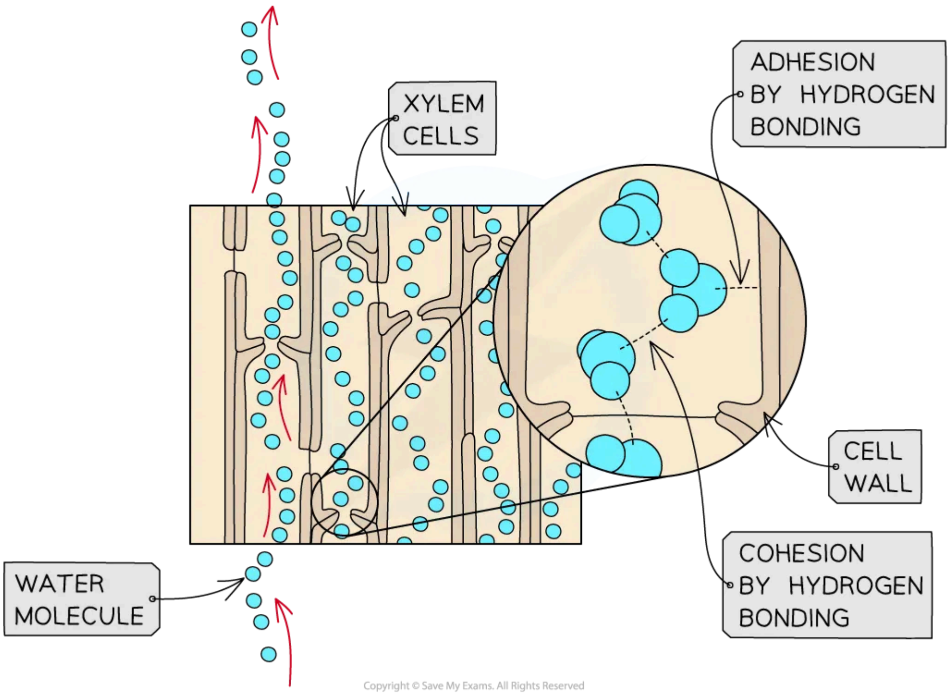
# Water & the transpiration pull

## The movement of water

- The **mass flow** of water in a plant is helped by the polar nature of water
  - Hydrogen bonds (H-bonds) form between water molecules which results in cohesion between water molecules and adhesion between the **cellulose** in the cell walls and the water molecules
- Water moves from the roots to the leaves because of a **difference in water potential** between the top and bottom of the plant
  - This **gradient** is present due to the constant **loss of water from the leaves** by transpiration and the constant **uptake of water at the roots** by osmosis
- The evaporation of water into the air spaces in the leaves creates **tension** in the xylem tissue which is transmitted all the way down the plant because of the cohesive nature of water molecules
  - The cohesive force results in a **continuous column of water** with high tensile strength (it is unlikely to break) and the adhesive force stops the water column from pulling away from the walls of the xylem vessels
  - This mechanism is called the **cohesion-tension theory**
- Xylem vessels have **lignified** walls to prevent them from collapsing due to the pressure differences created by the **mass flow** of water down its water potential gradient



*Water molecules move in a continuous stream due to their cohesive nature caused by hydrogen bonds*

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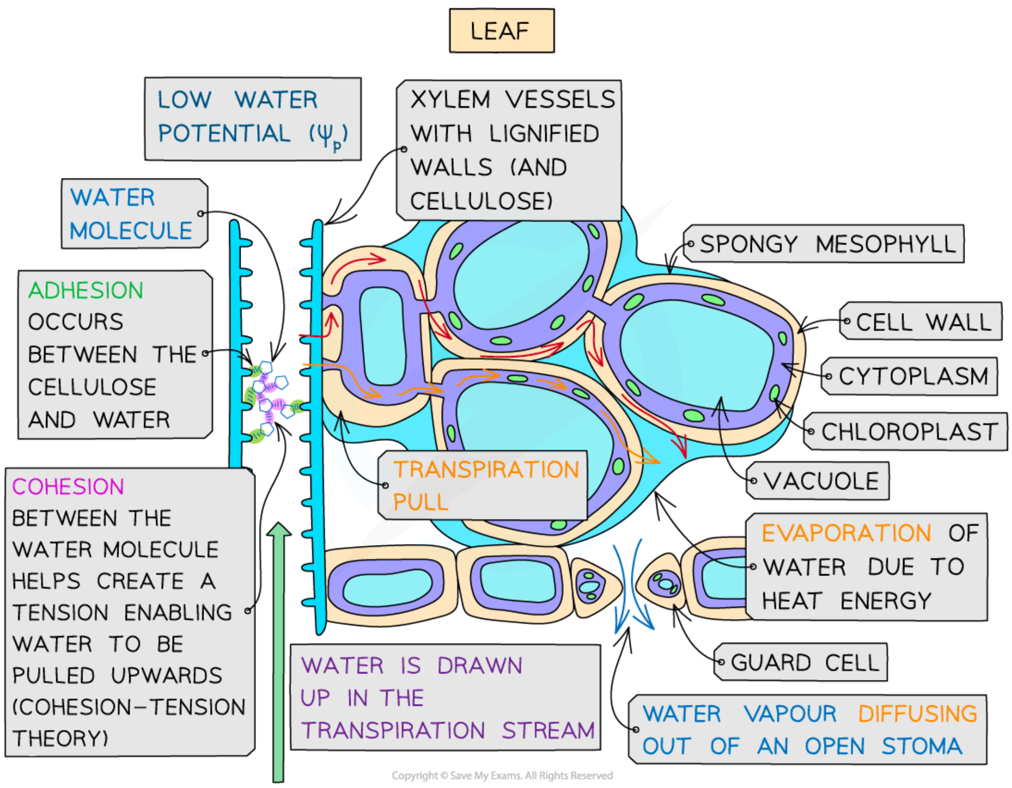
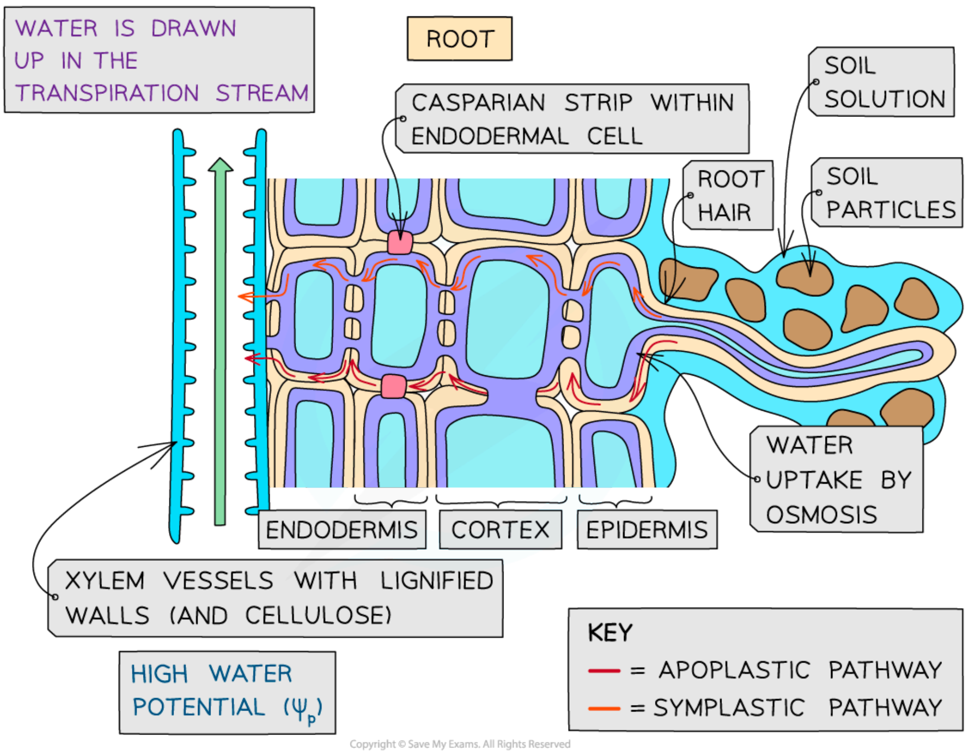
## The transpiration stream

- The pathway of the water from the soil through the roots up the xylem tissue to the leaves is the **transpiration stream**
- Plants aid the movement of water upwards by raising the water pressure in the roots; this is known as **root pressure**
    - Water enters the roots **down a water potential gradient** from the surrounding soil
        - Root cells **actively** transport solutes (e.g. mineral ions) from the cells of the root into the xylem vessels; this lowers the water potential within the xylem
        - Water is **drawn into the xylem** by **osmosis** from the surrounding cells, thus increasing the water pressure (root pressure)
- Water travels across the root either via the **apoplast pathway** or the **symplast pathway**
    - Note that water in the apoplast pathway does not cross cell membranes, so does not move by osmosis






***The transpiration stream involves the movement of water across the roots, up the xylem, and across the leaves of plants***

### Examiner Tips and Tricks

When answering questions about transpiration it is important to include the following keywords:

- **Water potential gradient** (between leaves and roots),
- **Diffusion** (of water vapour through the stomata)
- **Transpiration pull** (evaporation of water from the mesophyll cells, of leaves, pulls other water molecules from the xylem tissue)
- **Cohesion** (between water molecules)
- **Adhesion** (between water molecules and cellulose within the cell walls)
- **Cohesion-tension theory** (tension present in xylem vessels causes a continuous column of water and is due to cohesive and adhesive forces)
- **Osmosis** (water moving via the symplast pathway across the roots and leaves)

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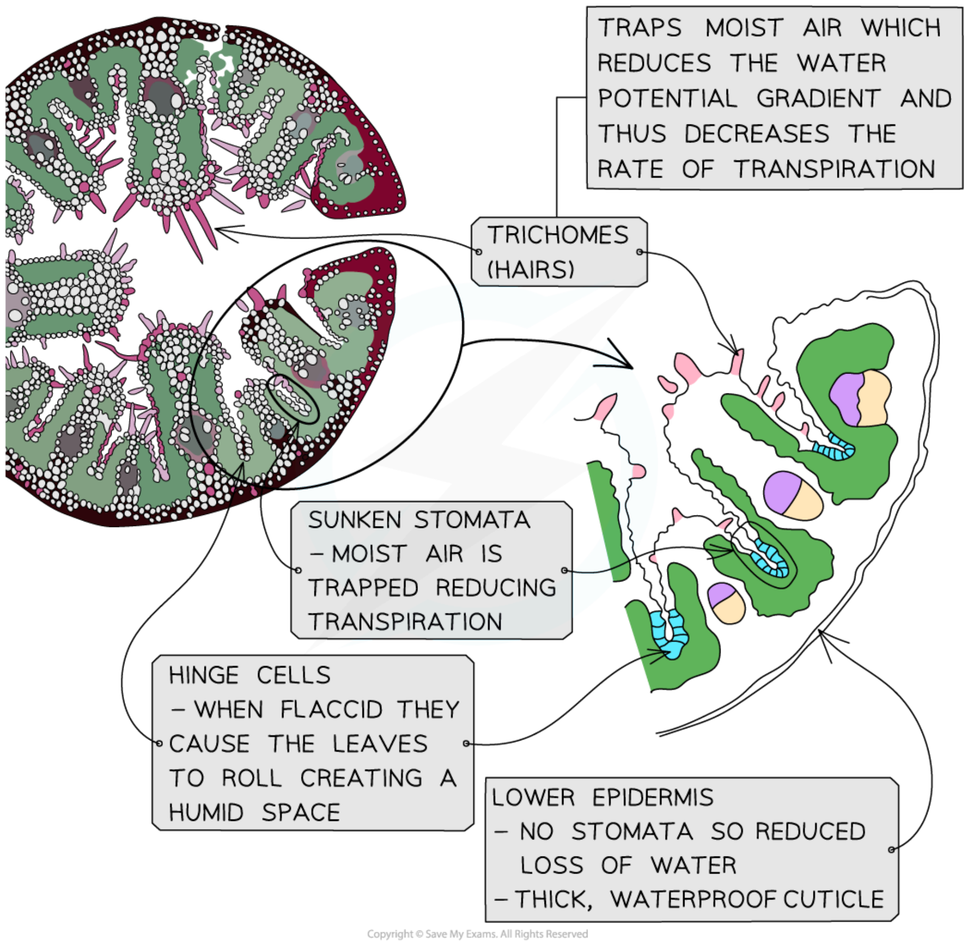
# Xerophytic plant leaf adaptations

- 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 Adaptations of Leaves | Effect of Adaptation | Example |
|---|---|---|
| Fleshy succulent leaves | Store of water for times of low availability | Bryophyllum |
| "Hinge cells" shrink when flaccid | Causes leaves to roll, exposing thick cuticle to the air and creating a humid space in the middle of the rolled leaf | Marram Grass (*Ammophila arenaria*) |
| Leaves reduced to scales, spines, needles.<br><br>Leaves curled, rolled or folded when flaccid | Reduced transpiration due to reduced surface area exposed | Cactus (*Opuntia*)<br><br>Marram Grass (*Ammophila arenaria*) |
| Stomata closed during daylight<br><br>Stomata open during night | Daytime water loss minimised<br><br>Carbon dioxide fixed at night | Pineapple, Yucca, American Aloe |
| Sunken stomata and leaf surface covered in fine hairs | Water loss minimised as moist air is trapped and diffusion gradient reduced | Pine, Nerium |
| Reduced numbers of stomata | Less water loss as fewer pores | Nerium, Prickly pear |
| Thick waxy cuticles | Water loss reduced via cuticle distance | Pine, Prickly pear |




***Photomicrograph and annotated drawing showing the xeromorphic features of a leaf of Ammophilia arenaria (Marram grass)***

### Examiner Tips and Tricks

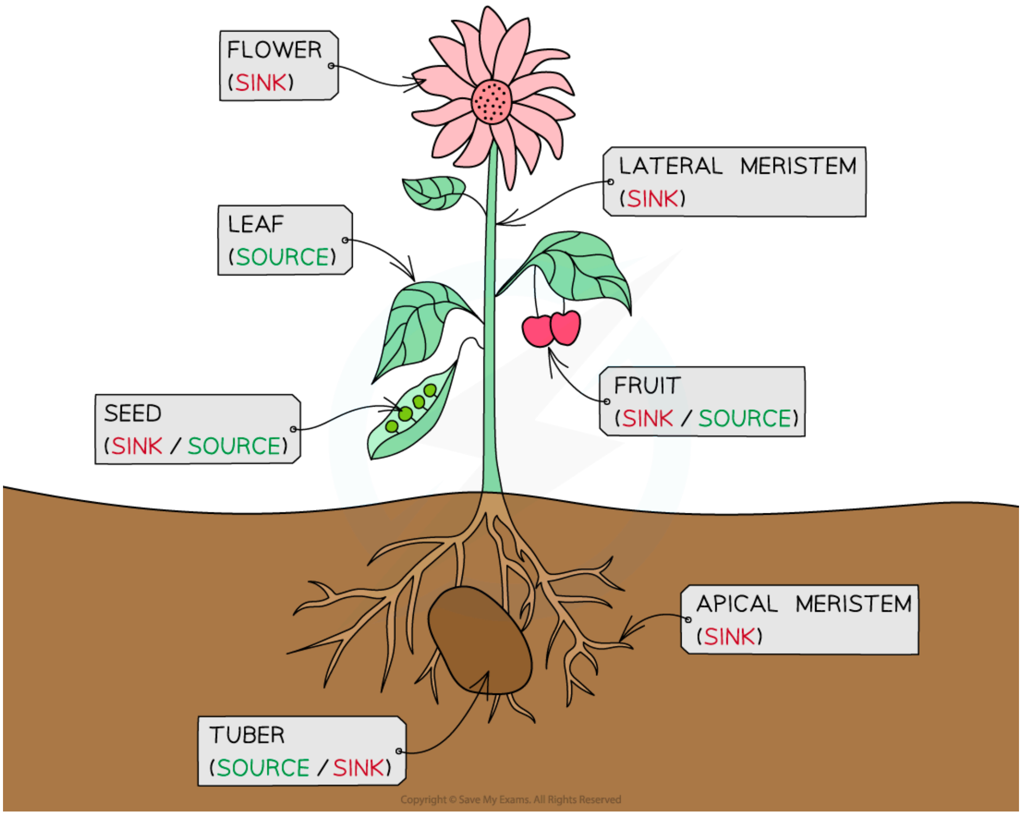
You will be expected to make annotated drawings of transverse sections of leaves from xerophytic plants to explain how they are adapted.

Remember not all leaves will have every feature listed above so if you are looking at an unfamiliar image consider whether the adaptations you can see will help reduce water being lost from the leaf.

# Movement in the phloem

- Translocation is connected with the transport of assimilates in the phloem tissue
- Thus **translocation** within phloem tissue can be **defined** as the transport of assimilates from **source** to **sink** and requires the **input of metabolic energy** (ATP)
- The liquid that is being transported (found within phloem sieve tubes) is called **phloem sap**
- This phloem sap consists not only of sugars (mainly sucrose) but also of water and other dissolved substances such as amino acids, hormones and minerals
- The **source** of the assimilates could be:
  - Green leaves and green stem (photosynthesis produces glucose which is transported as sucrose, as sucrose has less of an osmotic effect than glucose)
  - Storage organs e.g. tubers and tap roots (unloading their stored substances at the beginning of a growth period)
  - Food stores in seeds (which are germinating)
- The **sinks** (where the assimilates are required) could be:
  - Meristems (apical or lateral) that are actively dividing
  - Roots that are growing and / or actively absorbing mineral ions
  - Any part of the plant where the assimilates are being stored (e.g. developing seeds, fruits or storage organs)




***Assimilates are moved through a plant by the process of translocation. They are moved from source to sink. Here are examples of sources and sinks***

- The loading and unloading of the sucrose from the source to the phloem, and from the phloem to the sink is an **active** process
- It can be slowed down or even stopped at high temperatures or by respiratory inhibitors
- Translocation of assimilates is not fully understood yet by scientists. The understanding they do have has come from studies such as:
  - On plants whose sap 'clots', so that it is still possible to collect and study the sap (e.g. castor oil plants)
  - Using aphids to collect the sap – after the aphid inserts its stylet (tubular mouthpart) scientists remove the aphids head and collect the sap that continues to flow
  - Using radioactively labelled metabolites (e.g. Carbon-14 labelled sugars) which can be traced during translocation
  - Advances in microscopes enabling the adaptations of companion cells to be seen
  - Observations about the importance of mitochondria to the process of translocation

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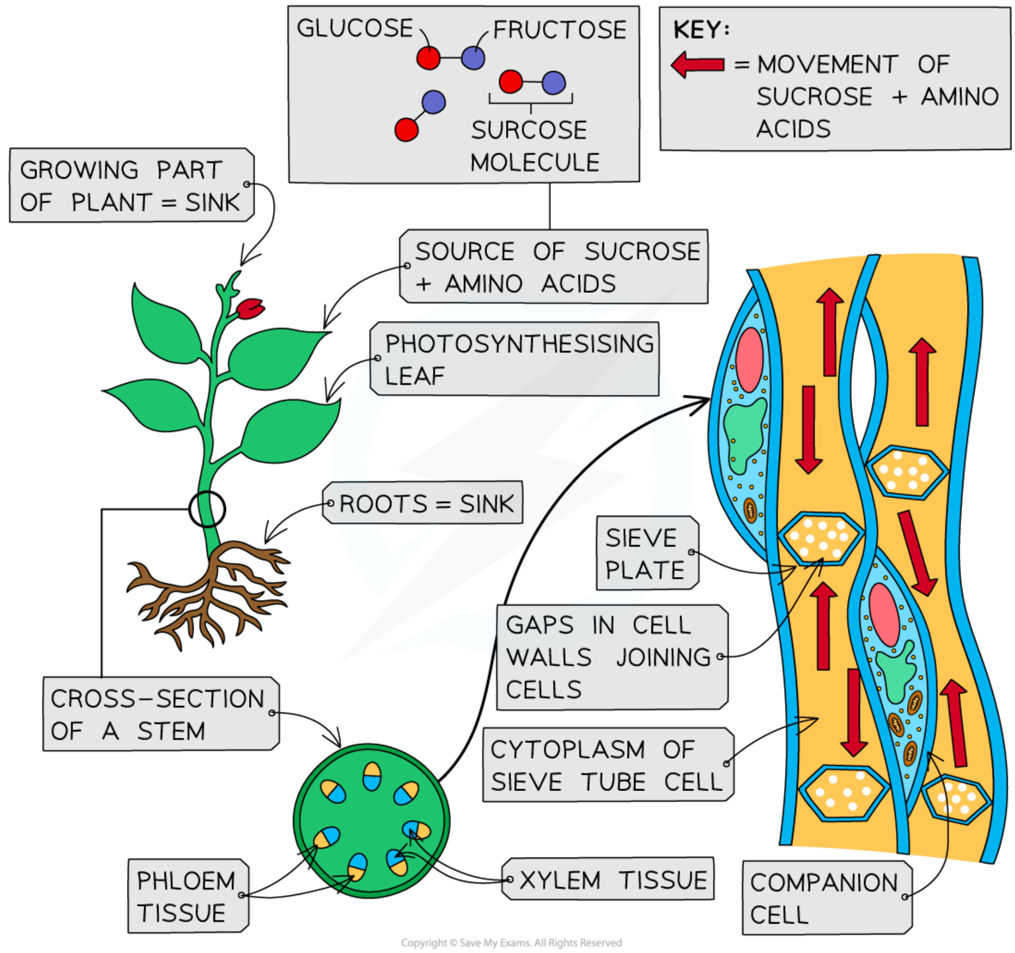



*The translocation of assimilates from source to sink within phloem tissue*

## Examiner Tips and Tricks

Assimilates can move upwards or downwards in the phloem sieve tubes as they move from source to sink.

# The sucrose loading mechanism

- Assimilates such as sucrose are **transported from source to sink** through the phloem sieve tubes
- Carbohydrates are generally transported in plants in the form of **sucrose** because:
  - It allows for efficient **energy transfer and increased energy storage** (sucrose is a disaccharide and therefore contains more energy)
  - It is **less reactive** than glucose as it is a non-reducing sugar and therefore no intermediate reactions occur as it is being transported

## Loading of assimilates

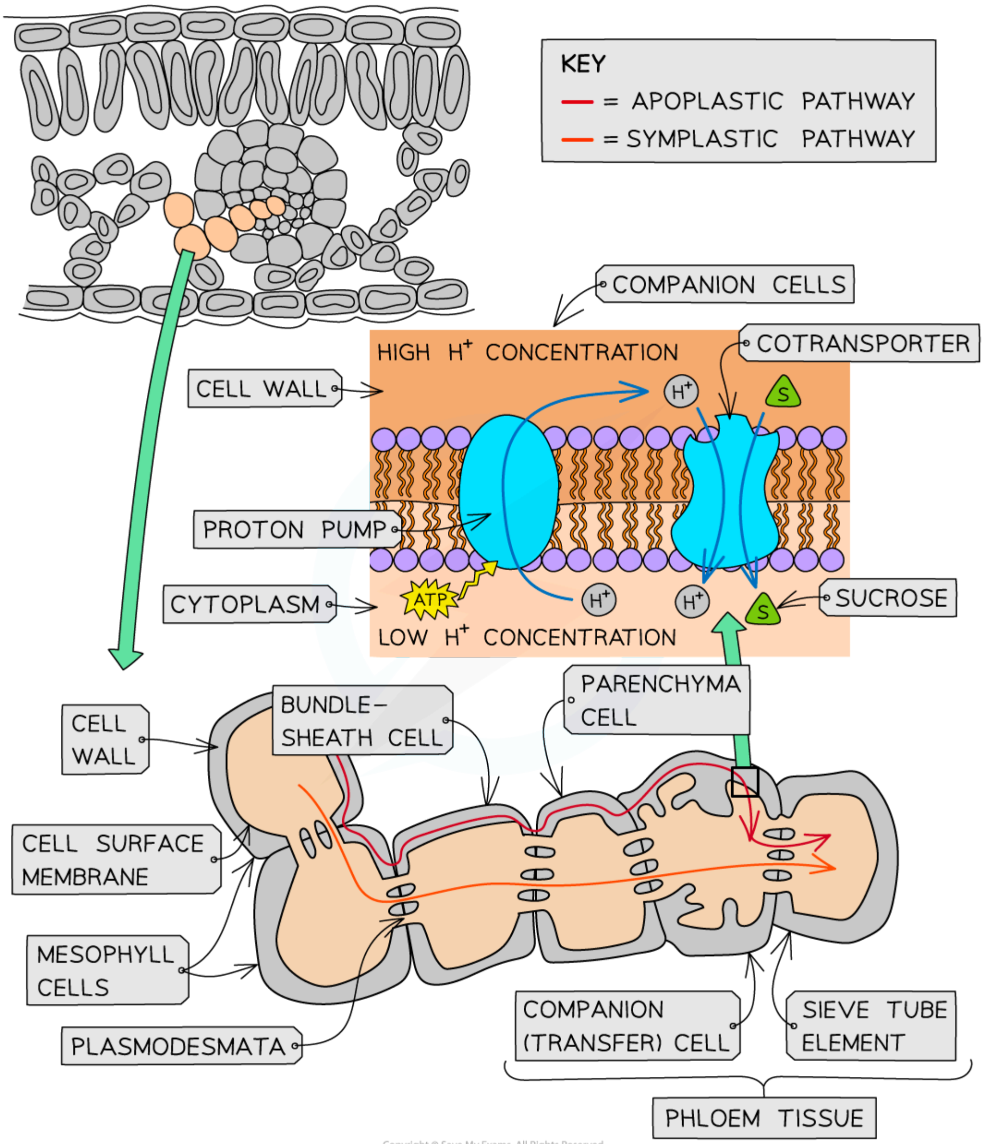
- The pathway that sucrose molecules use to travel to the sieve tubes is not fully understood yet. The molecules may move by the:
  - **symplastic pathway** (through the cytoplasm and plasmodesmata) which is a **passive** process as the sucrose molecules move by diffusion
  - **apoplastic pathway** (through the cell walls) which is an **active** process
- If the sucrose molecules are taking the apoplastic pathway then modified **companion cells** (called transfer cells) **pump hydrogen ions out** of the cytoplasm via a **proton pump** and into their cell walls
  - This is an **active process** and therefore requires ATP as an energy source
- The large concentration of **hydrogen ions** in the cell wall of the companion cell results in the hydrogen ions moving down the concentration gradient back to the cytoplasm of the companion cell
  - The hydrogen ions move through a **cotransporter protein**
  - While transporting the hydrogen ions this protein also carries **sucrose** molecules **into the companion cell against the concentration gradient** for sucrose
- The sucrose molecules then move into the **sieve tubes** via the plasmodesmata from the companion cells
  - Companion cells have infoldings in their cell surface membrane to increase the available surface area for the active transport of solutes and many mitochondria to provide the energy for the proton pump
- This mechanism permits some plants to build up the sucrose in the phloem to up to three times the concentration of that in the mesophyll

## Unloading of assimilates

- The unloading of the assimilates (e.g. sucrose) occurs at the **sinks**

- Scientists believe that the unloading of sucrose is similar to the loading of sucrose, with the sucrose being **actively transported out of the companion cells** and then moving out of the phloem tissue via apoplastic or symplastic pathways
- To maintain a concentration gradient in the sink tissue, sucrose is converted into other molecules. This is a metabolic reaction so requires enzymes (e.g. invertase which hydrolyses sucrose into glucose and fructose)





***The apoplast and symplast pathways used when sucrose is loaded into the phloem tissue. The enlarged portion of the companion cell shows the proton and co-transporter proteins used to actively load the sucrose***

### Examiner Tips and Tricks

Your notes

Remember that the loading of sucrose requires two protein pumps (proton and co-transporter) which are located in the companion cell surface membrane.

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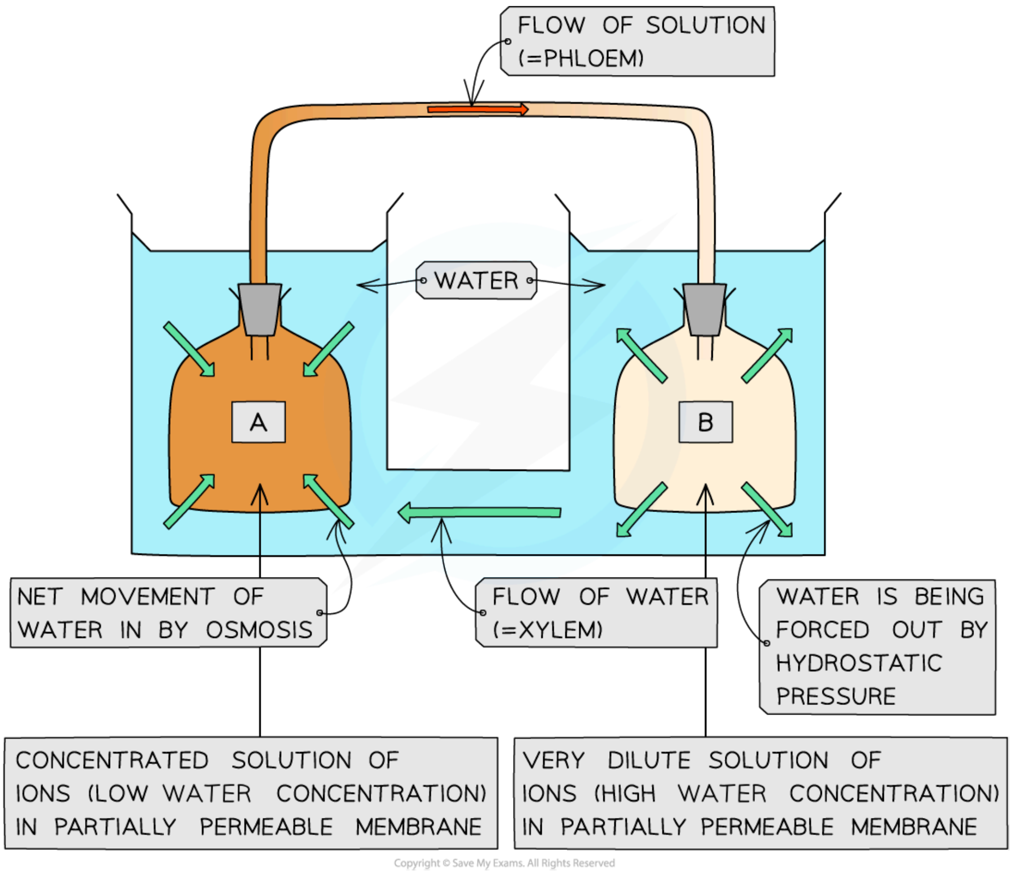
# Phloem: mass flow

- The **mass flow hypothesis** was the model initially used to explain the movement of assimilates in the phloem tissue
- The simple model consisted of:
  - Two partially permeable membranes containing solutions with **different concentrations of ions** (one dilute the other concentrated)
  - These two membranes were placed into two chambers containing water and were connected via a passageway
  - The two membranes were joined via a tube
  - As the membranes were surrounded by water, the **water moved by osmosis** across the membrane containing the more concentrated solution
  - This forced the solution towards the membrane containing the more dilute solution (where water was being forced out of due to **hydrostatic pressure**)
- Scientists now support a modified version of this hypothesis – the **pressure flow gradient**




*An illustration of Münch's model for mass flow in phloem tissue*

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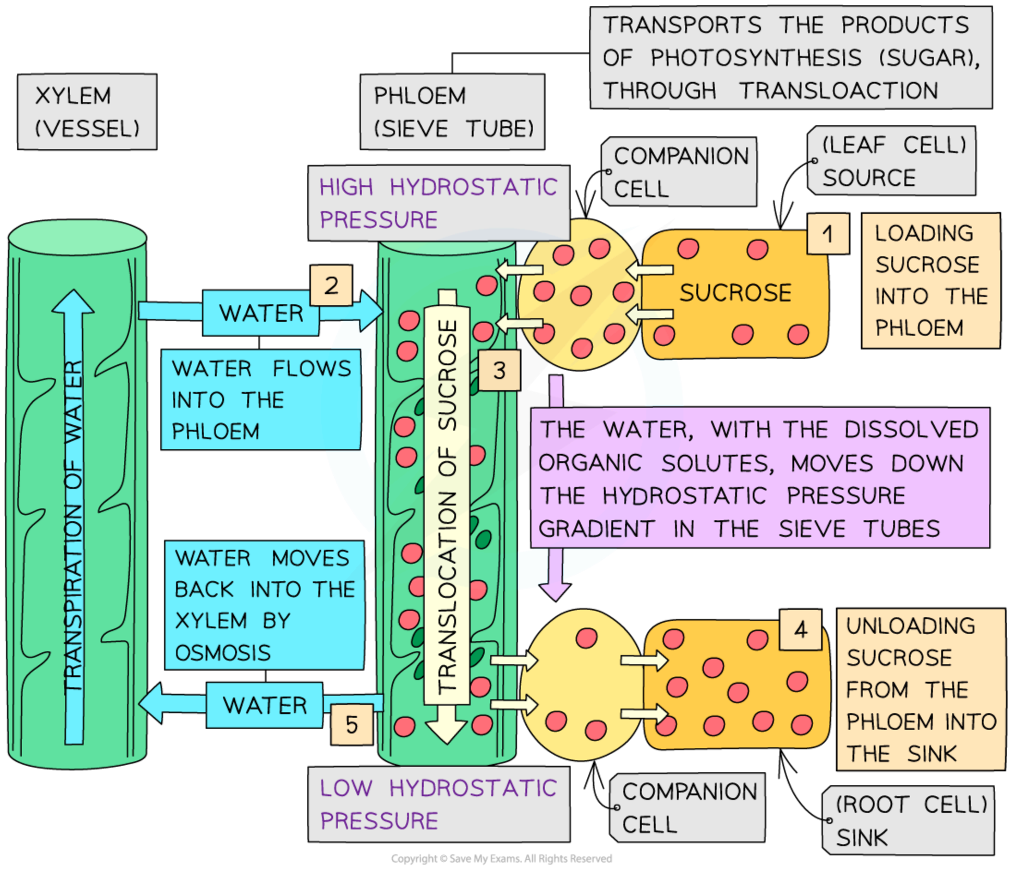
## Pressure (hydrostatic) flow gradient

- Phloem sap (containing sucrose and other organic solutes) moves by **mass flow up and down the plant**
  - The **advantage** of mass flow is that it moves the organic solutes **faster than diffusion**
- In xylem tissue the pressure difference that causes mass flow occurs because of a **water potential gradient** between the soil and leaf (this requires no energy input by the plant)
- However in phloem tissue **energy is required** to create pressure differences for the mass flow of the organic solutes
- The pressure difference is generated by **actively loading sucrose** into the **sieve elements** at the **source** (usually a photosynthesising leaf or storage organ) which lowers the water potential in the sap
- This results in **water moving into** the sieve elements as it travels down the water potential gradient by **osmosis**
- The presence of water within the sieve elements **increases** the **hydrostatic** or turgor **pressure** at the **source** and as solutes (e.g. sucrose) are removed / unloaded from the sieve elements causing water to follow by osmosis at the **sink** (creating a **low hydrostatic pressure**), a hydrostatic pressure gradient occurs
- The pressure difference between the source and the sink results in the **mass flow** of water (containing the dissolved organic solutes) **from the high hydrostatic pressure area to the low hydrostatic pressure area**
- The mass flow of organic solutes within the phloem tissue occurs above and below the sources (which is typically photosynthesising leaves). Therefore sap flows upwards and downwards within a plant




***The translocation of phloem sap (sucrose and other organic solutes) due to a hydrostatic pressure gradient from the source to the sink***

Your notes

### Examiner Tips and Tricks

Remember that the source is not necessarily the leaves and the sink is not necessarily the roots.

Phloem sap moves up and down the plant (although it will only move in one direction per sieve tube).

The hydrostatic pressure gradient is dependent on water moving in and out of the xylem vessels by osmosis.