Transport in Plants

- Explain the need for transport systems in multicellular plants.
- Describe the distribution of xylem and phloem tissue in roots, stems and leaves of dicotyledonous plants.
- Describe the structure and function of xylem vessels, sieve tube elements and companion cells.
- Explain the movement of water between plant cells, and between plant cells and their environment.
- Describe the pathway & Explain the mechanism by which water is transported from the root cortex to the air surrounding the leaves.
- Define the term *transpiration*.
- Explain why transpiration is a consequence of gaseous exchange.
- Describe the factors that affect transpiration rate.
- Describe how a potometer is used to estimate transpiration rates.
- Describe how the leaves of some xerophytes are adapted to reduce water loss by transpiration.
- Explain translocation as an energy-requiring process.
- Describe the mechanism of transport in the phloem and the evidence for and against this mechanism.

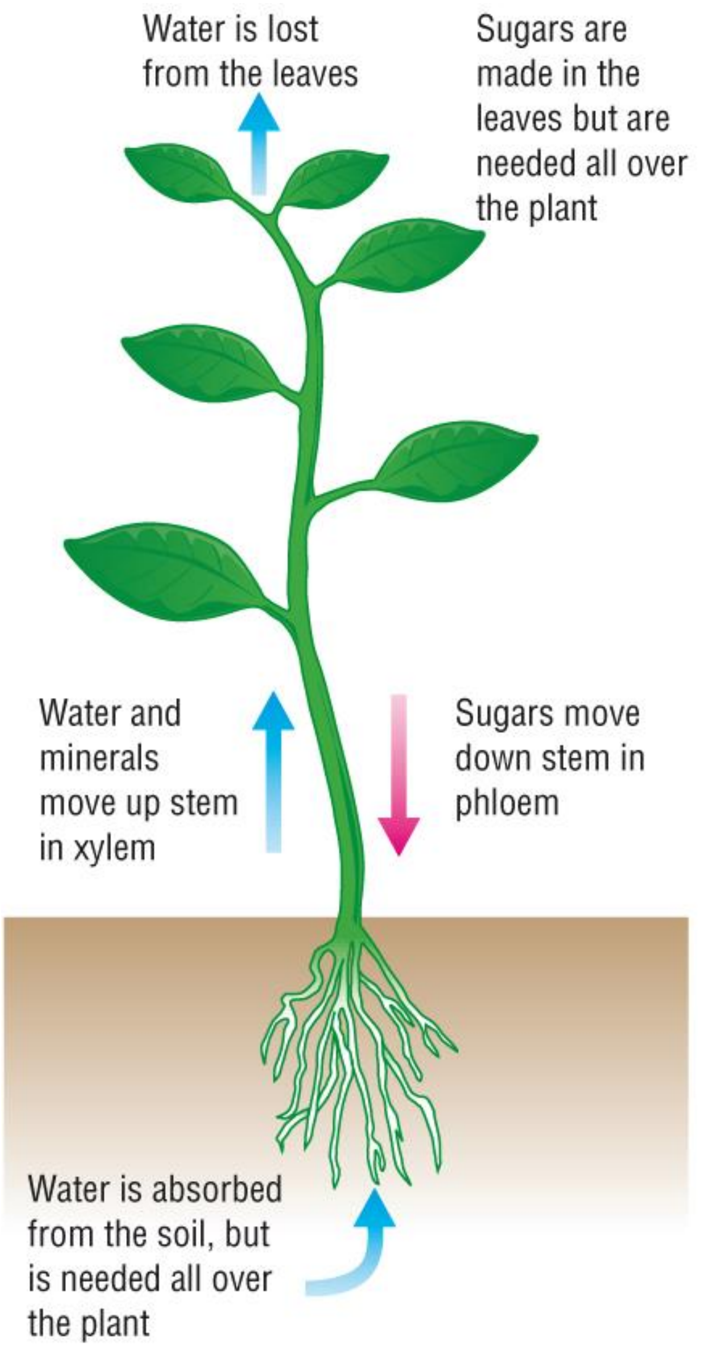
Why do plants need a transport system

- Every cell needs a supply of water & nutrients.
  - Root cells can easily get water.
  - Leaf cells can easily make sugars.
  - A transport system (vascular tissue) is needed to swap these materials.
    - Particularly in multicellular plants with high metabolic rates, large size and low surface area : volume ratios.

Vascular Tissue

- Xylem tissue
  - Water & soluble material move up from the roots.

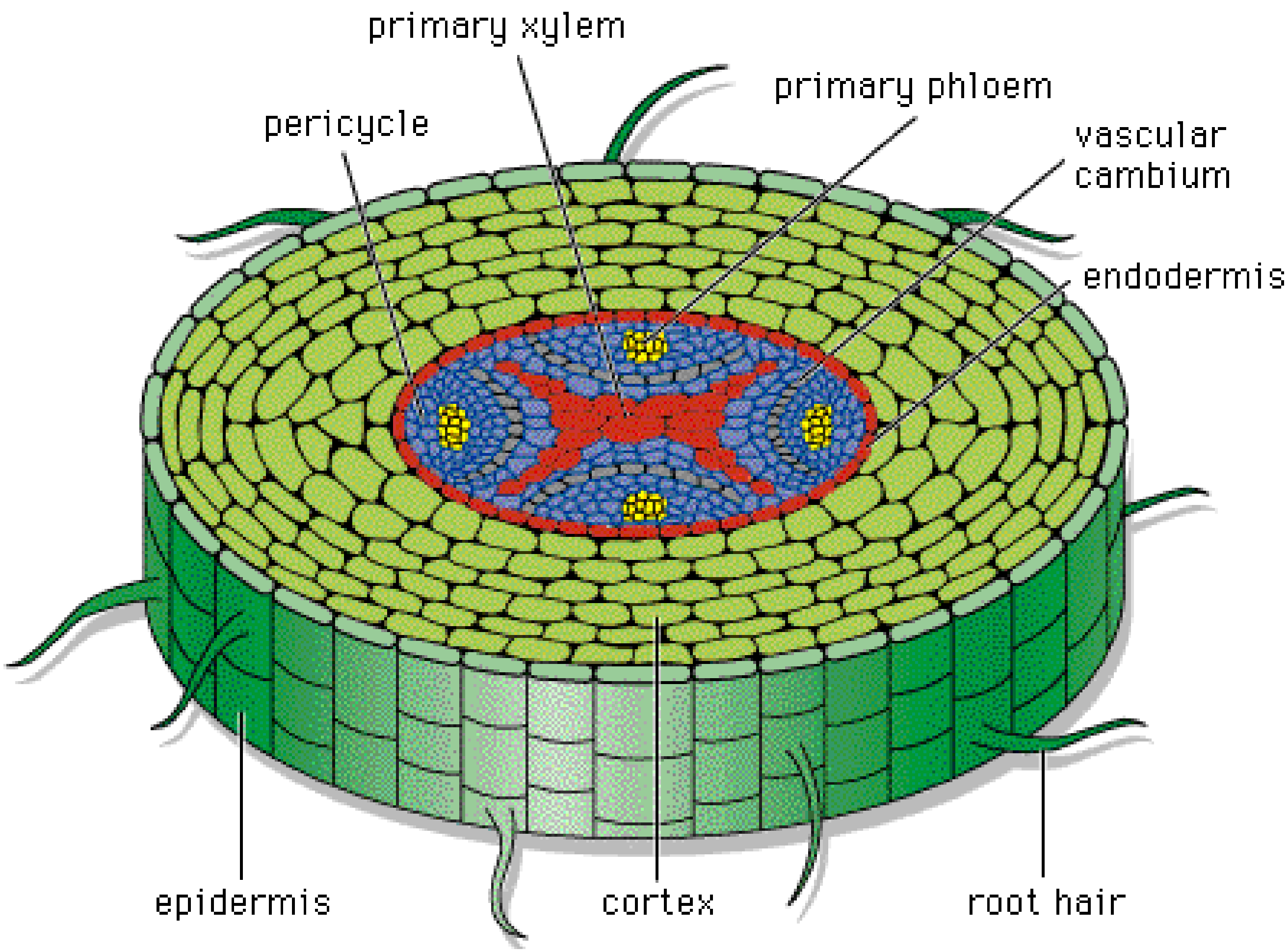
- Phloem tissue
  - Sugars travel up or down to where they are needed.



Vascular Bundles

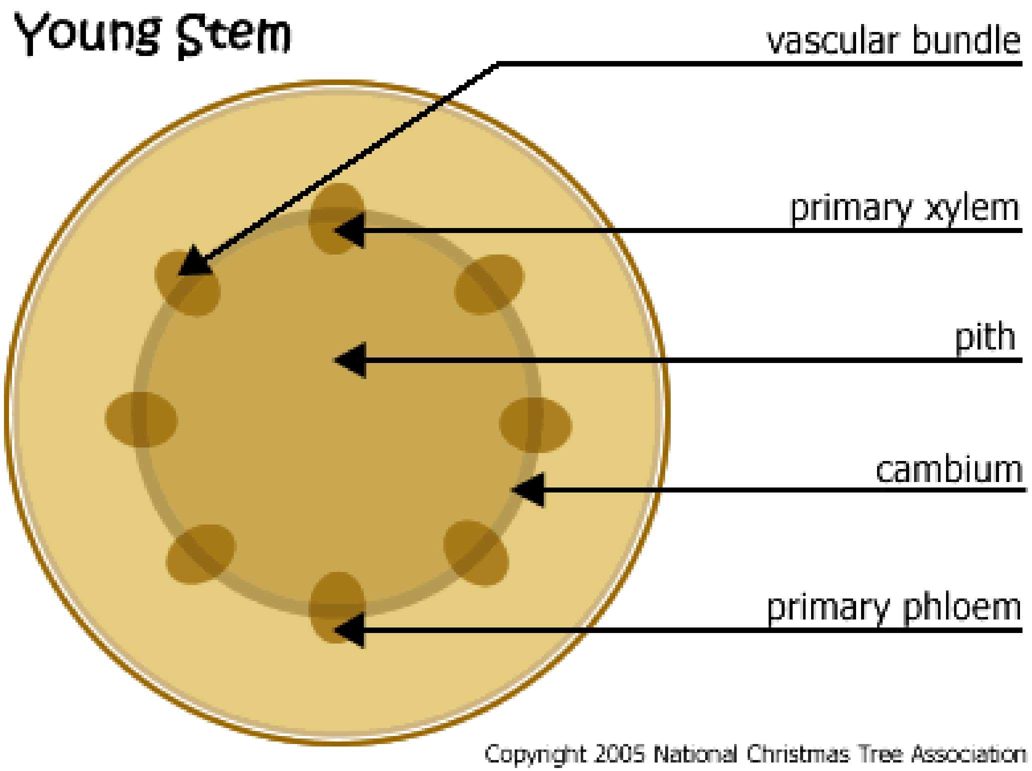
- Xylem & Phloem tissues are arranged together as vascular bundles.
- The structure of these vascular bundles differs in roots, stems & leaves.
  - Roots
    - Vascular bundles are arranged in the centre of the root.
  - Stems
    - Vascular bundles are arranged towards the outside of the stem.
  - Leaves
    - Vascular bundles are arranged within the midrib & veins of the leaf.

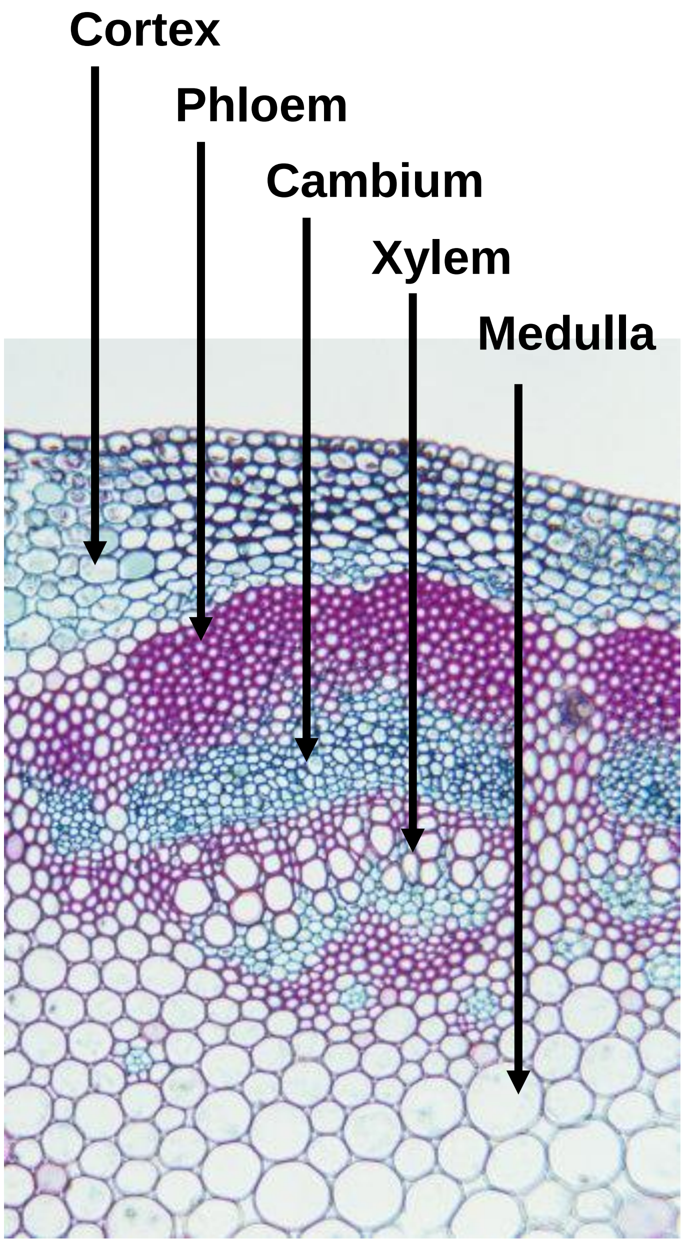
In the Root



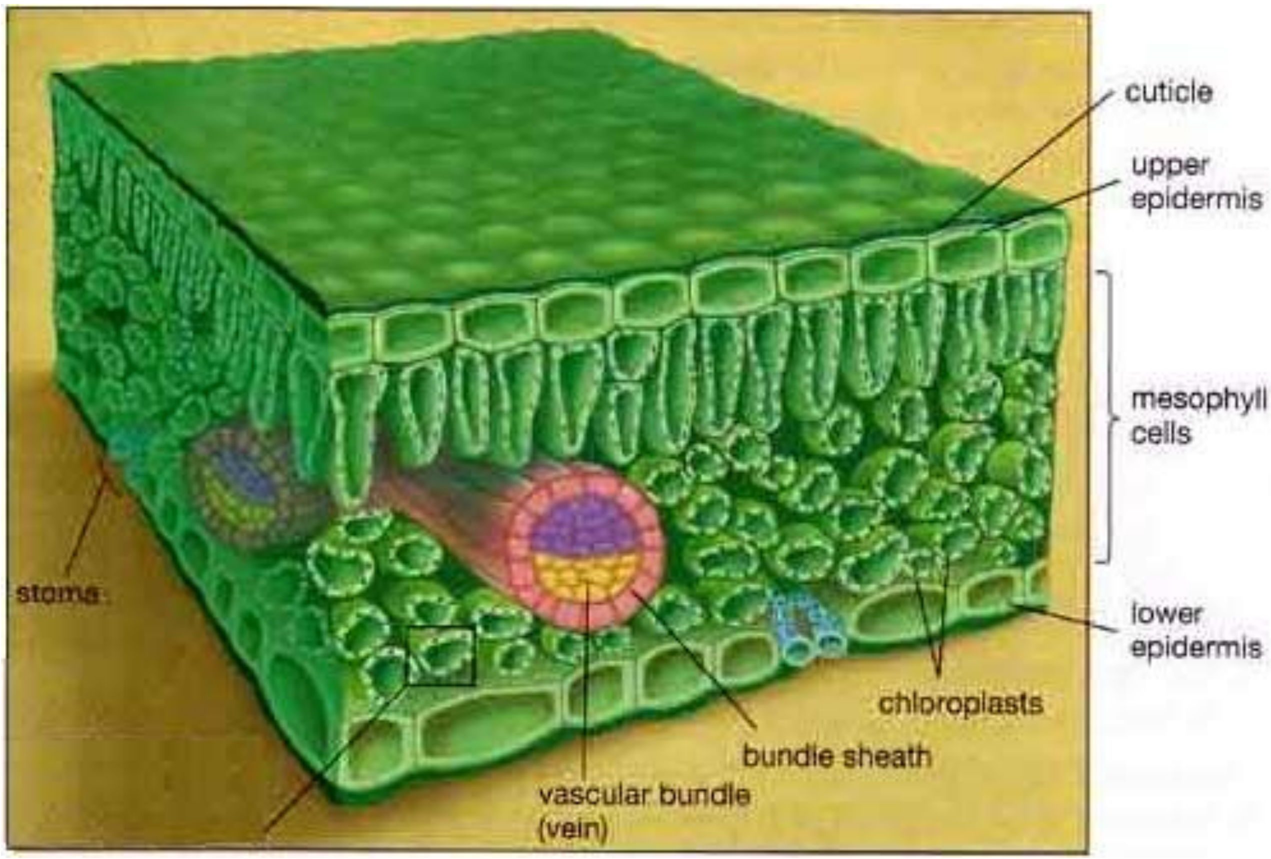
primary xylem
primary phloem
pericycle
vascular cambium
endodermis
epidermis
cortex
root hair

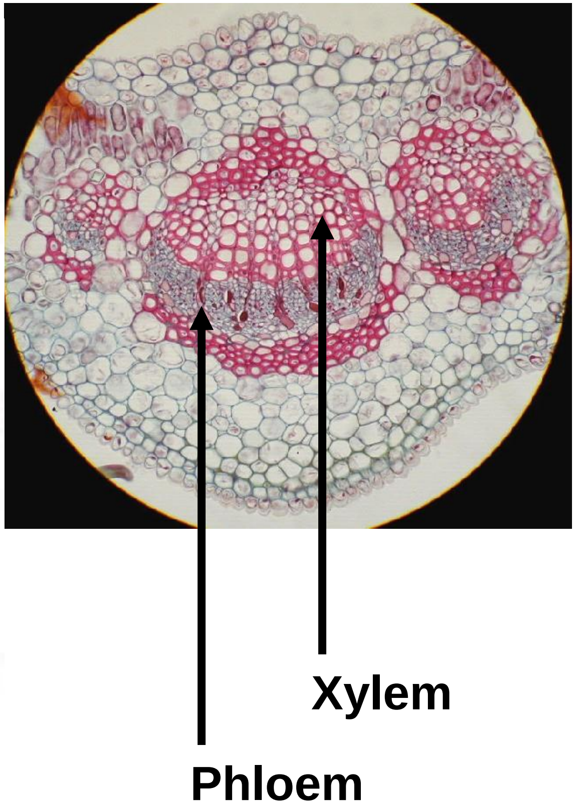
In the Stem


Young Stem
vascular bundle
primary xylem
pith
cambium
primary phloem
Copyright 2005 National Christmas Tree Association


Cortex
Phloem
Cambium
Xylem
Medulla

In the Leaves

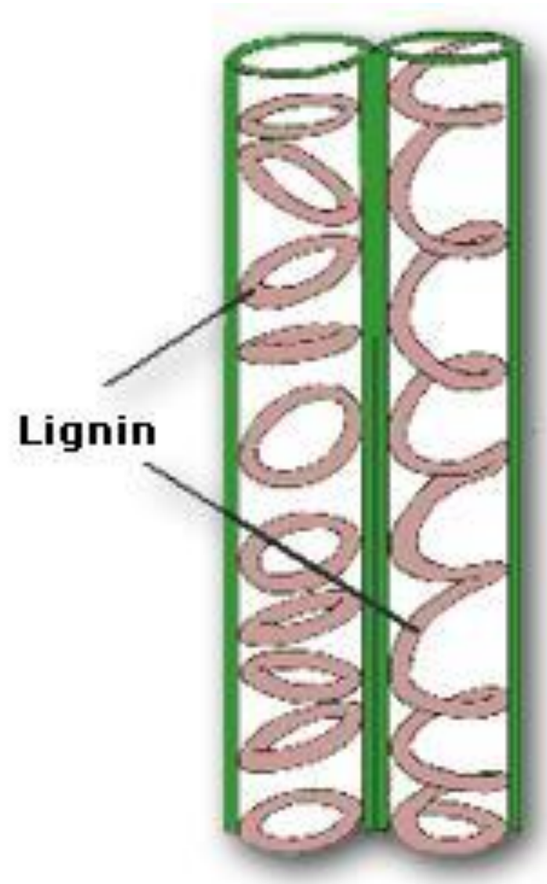




Xylem

- Carries water from roots to the rest of the plant (one way flow).
  - Elongated cells grow end to end.
  - Cell walls become waterproofed with lignin.
  - This kills the cells.
  - End walls and contents decay.

  - Left with a hollow, thick walled, strong, waterproof tube.

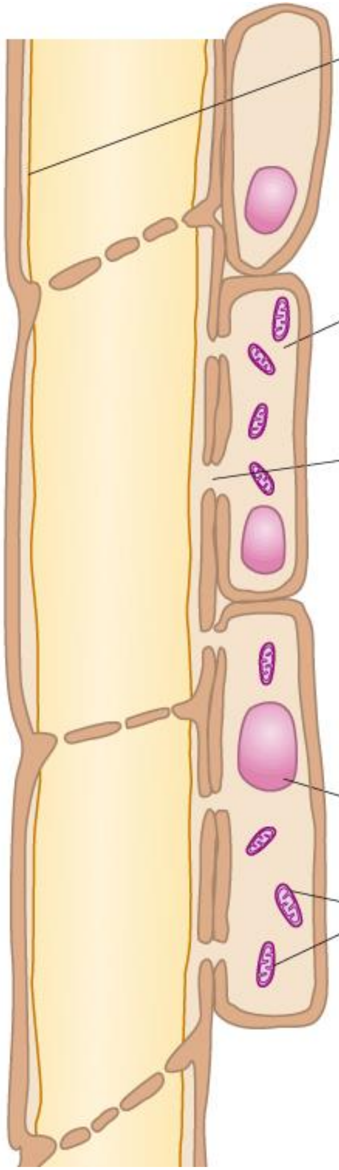


Features of Xylem

- Narrow tubes allow capillarity to transport water in an unbroken column.
- Gaps in the lignin (pits) allow water to leak out into neighbouring xylem or plant tissues.
- Lignin rings/spirals allow xylem to stretch as branch grows or bends.
- Lack of cell contents or end walls allow water to flow easily.
- Thick lignin walls prevent tubes from collapsing.

Phloem

- Carries sugars around the plant (two way flow).
- Consists of two types of cell (sieve tube elements & companion cells).



Sieve Tubes

- Cells contain little cytoplasm & no nucleus.
- Cells lined end to end.
- End walls of cells develop into sieve plates.
  - Perforated cross walls.
- Transport sugar (sucrose) solution.

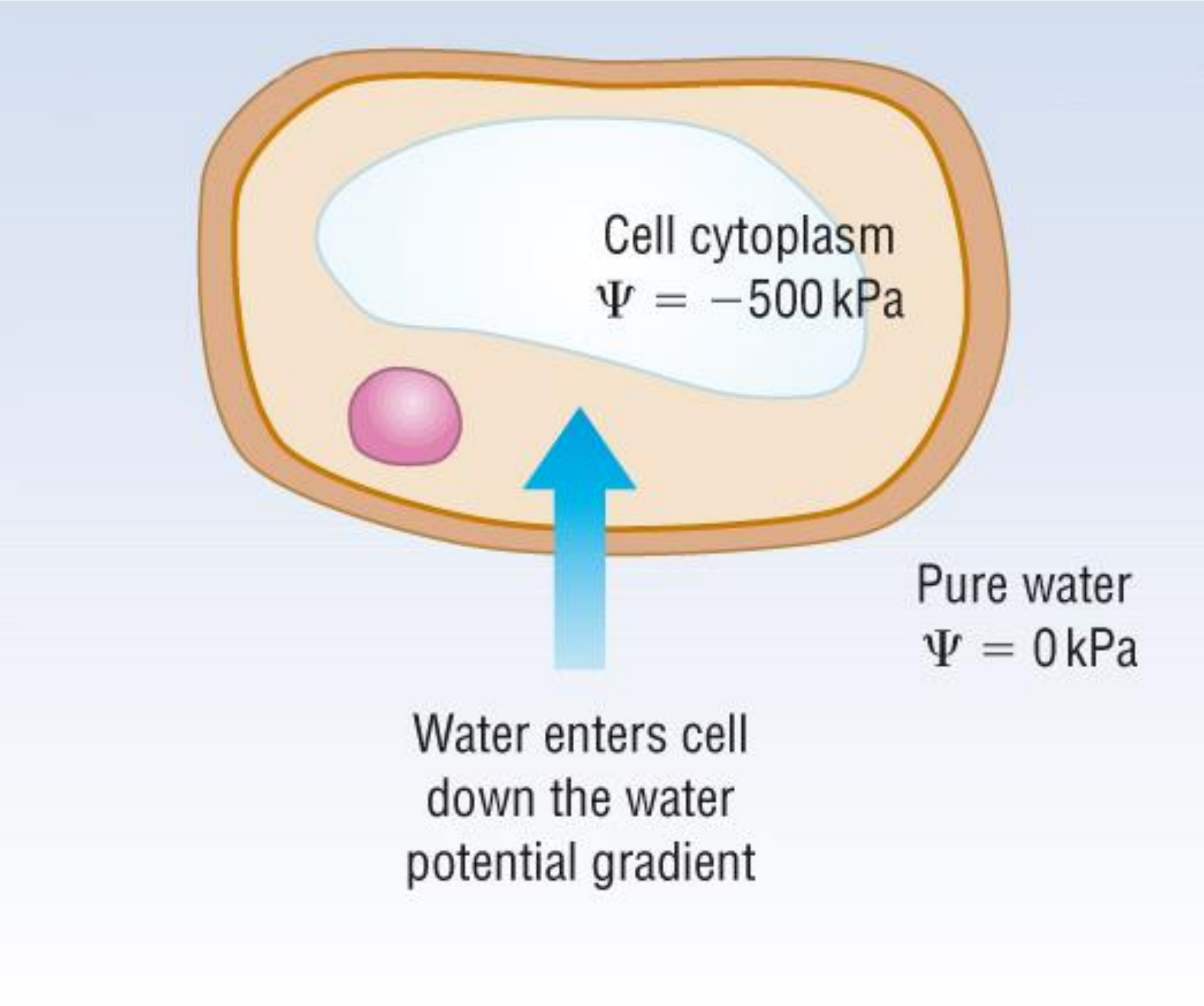
Companion Cells

- Lie parallel to sieve tubes.
- Have many mitochondria and large nucleus.
- Have plasmodesmata in walls between these and sieve tubes.
  - Gaps to allow substances to flow between them.

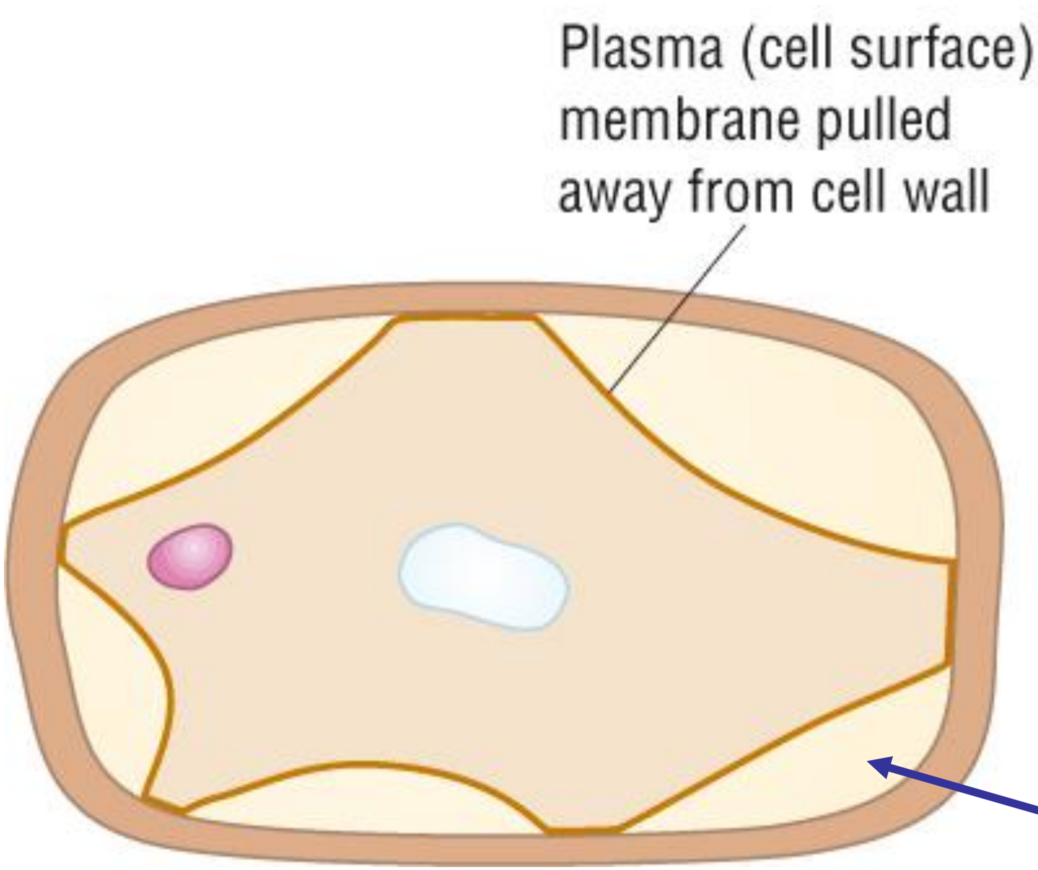
Plant Cells & Water Potential

- A plant cell placed in pure water…

- Cell becomes turgid.



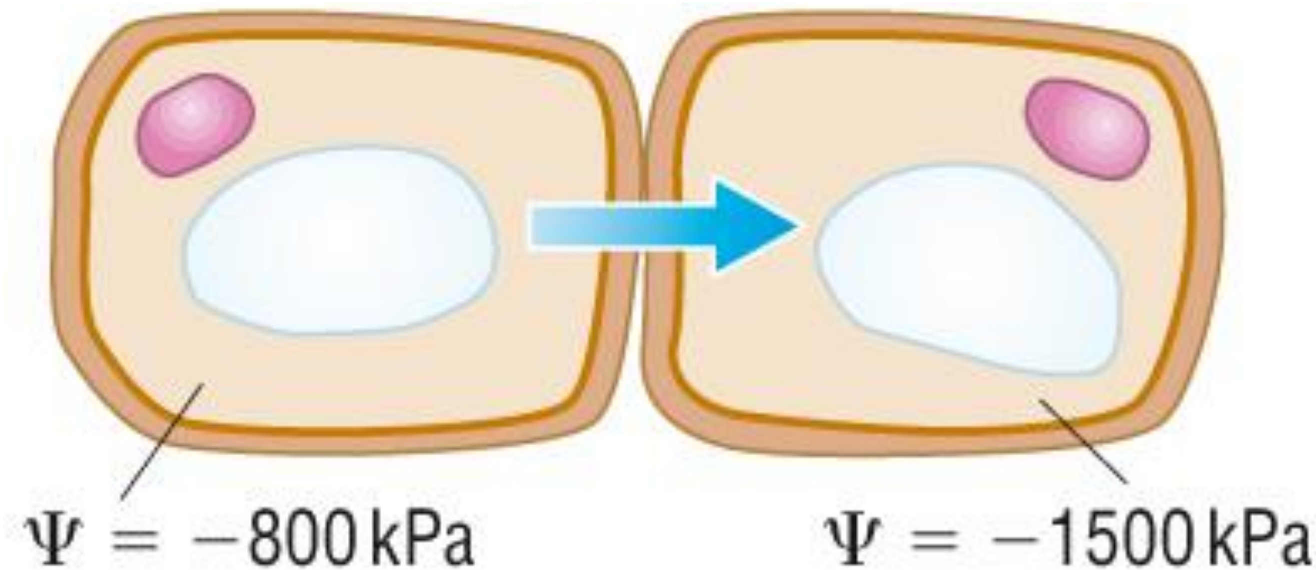
What has happened here?



- Cell placed into low water potential solution.
- Has become plasmolysed.

What is in this space?

Water Movement Between Cells



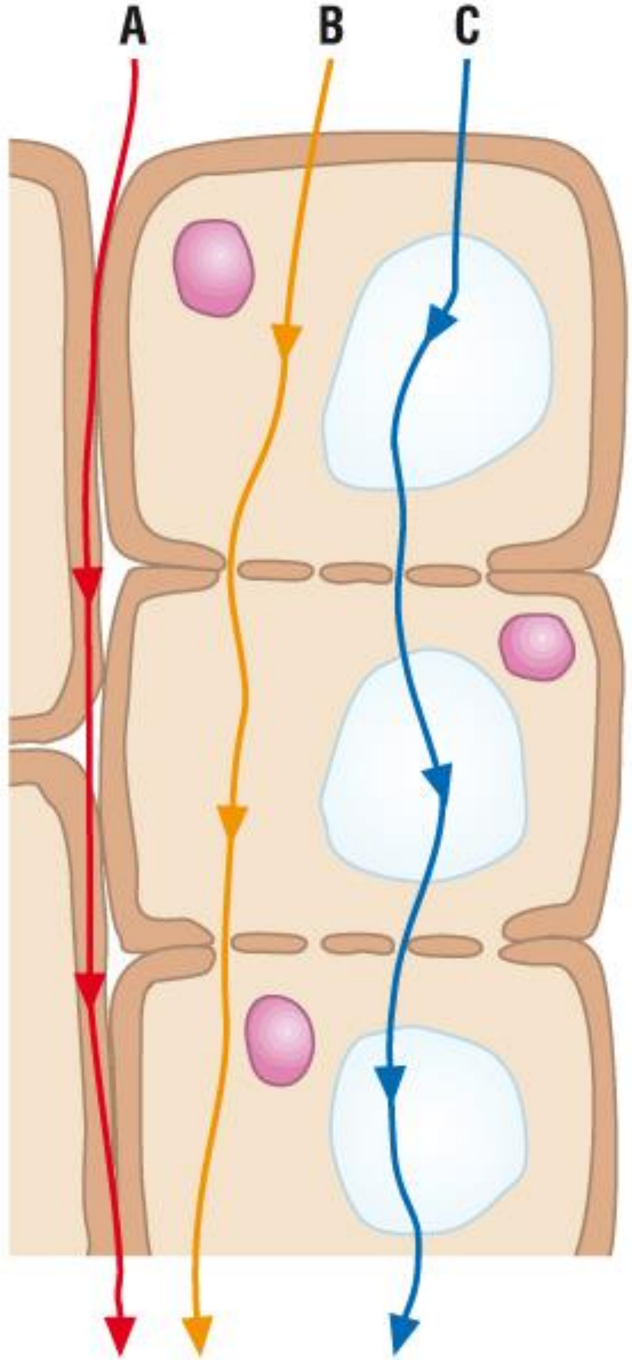
Water moves from the cell with the higher water potential (−800 kPa) to the cell with the lower (more negative) water potential (−1500 kPa)

3 ways water can move between cells

A. Apoplast pathway.

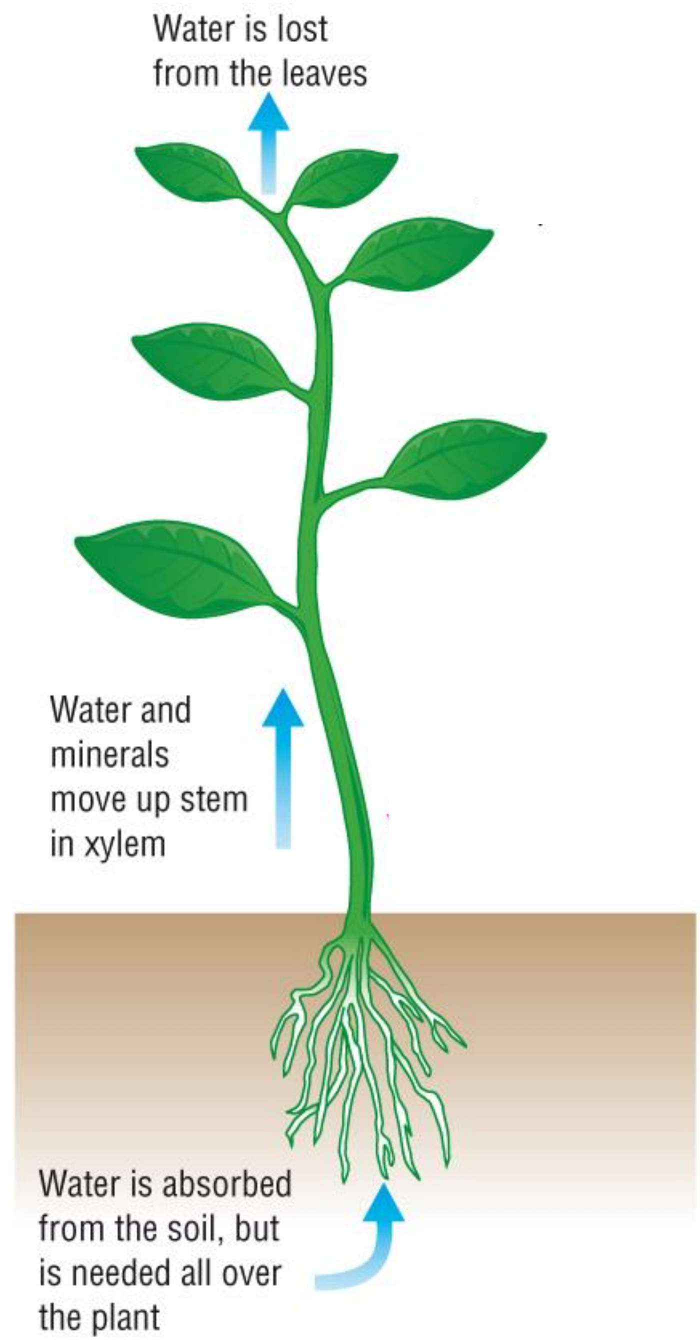
B. Symplast pathway.

C. Vacuolar pathway.



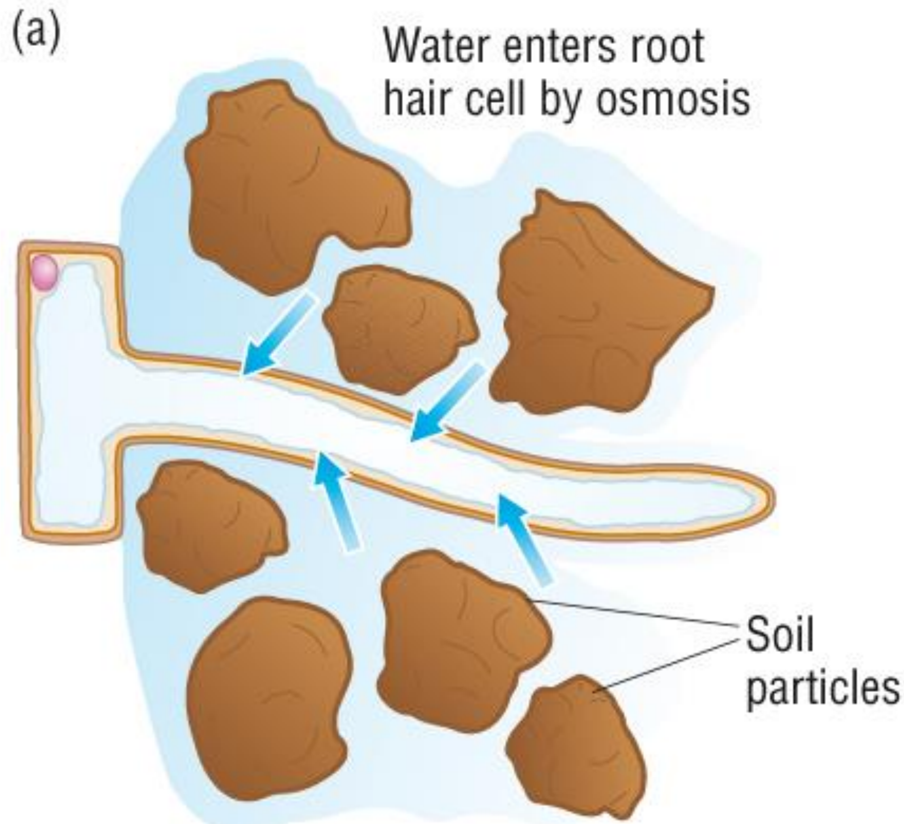
Water movement from root to leaf

- Water is taken up into roots, is transported up the Xylem to the leaves, where it is either used in photosynthesis or lost in transpiration.



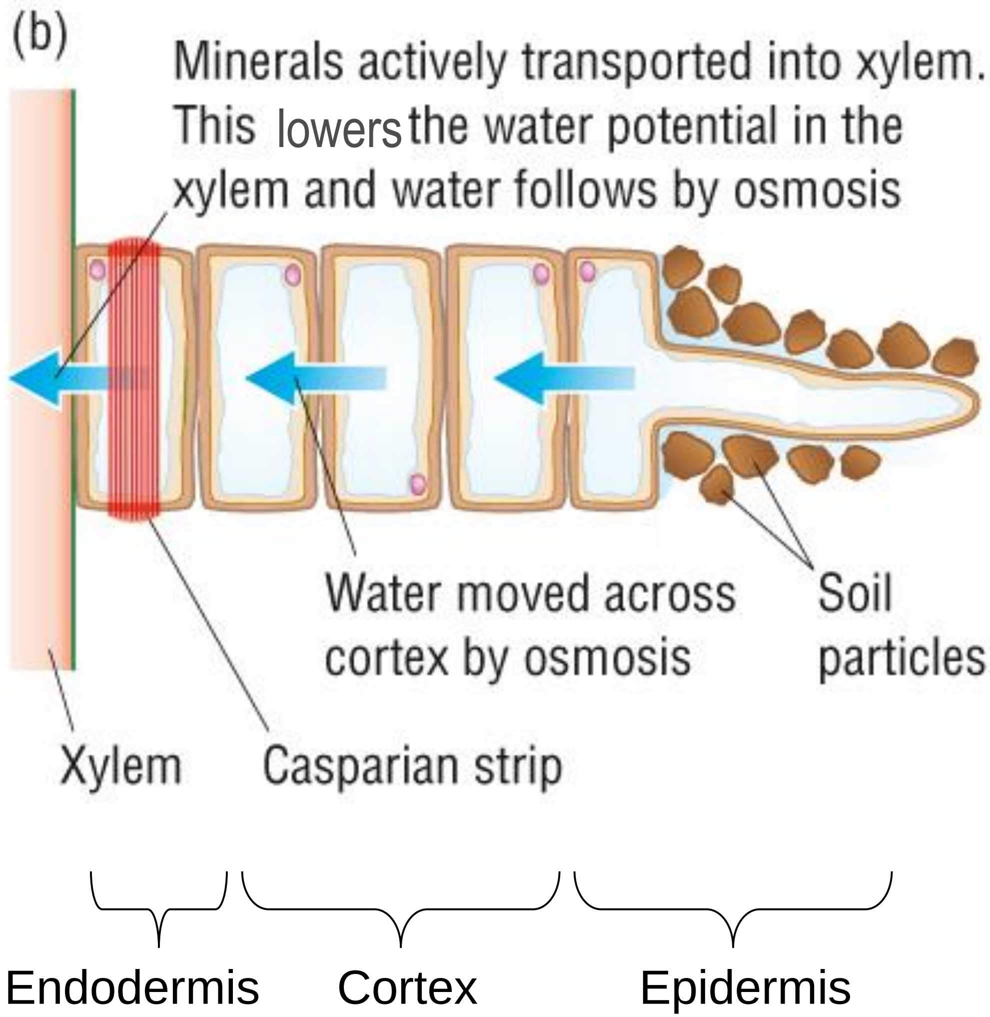
Water uptake from the soil

- Root epidermal (outermost) cells absorb minerals by active transport.
- This lowers the ψ inside the cells.
- Water follows by osmosis.



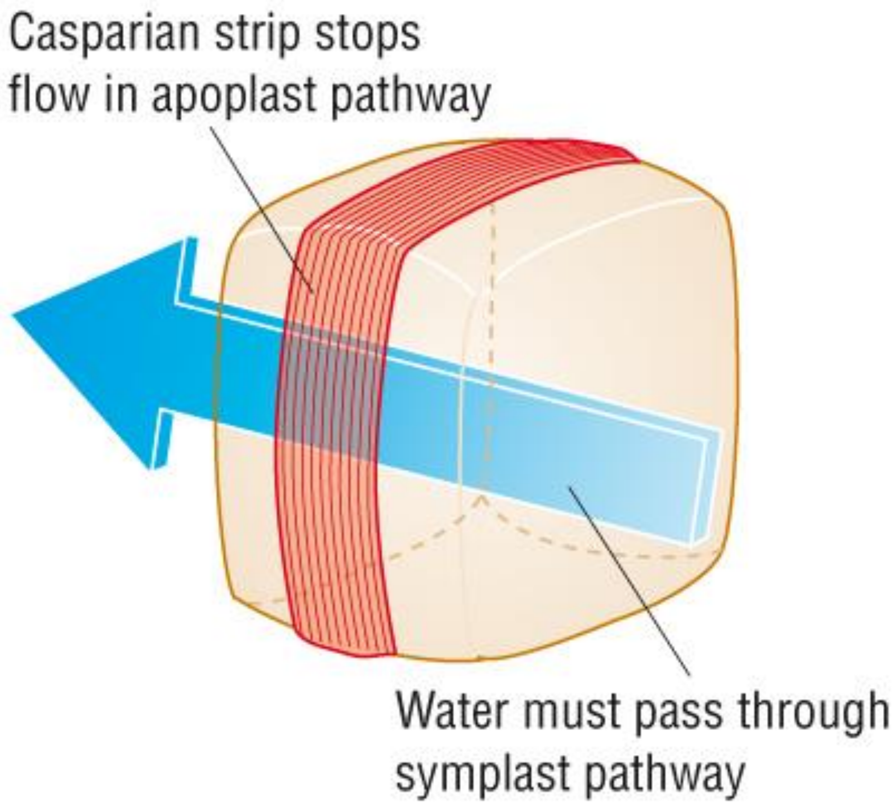
Water movement across the root

- Endodermis cells have a waterproof strip around them (Casparian Strip).
  - Blocks the apoplast pathway, forcing the symplast.
  - Water moves across cortex to xylem down ψ gradient.



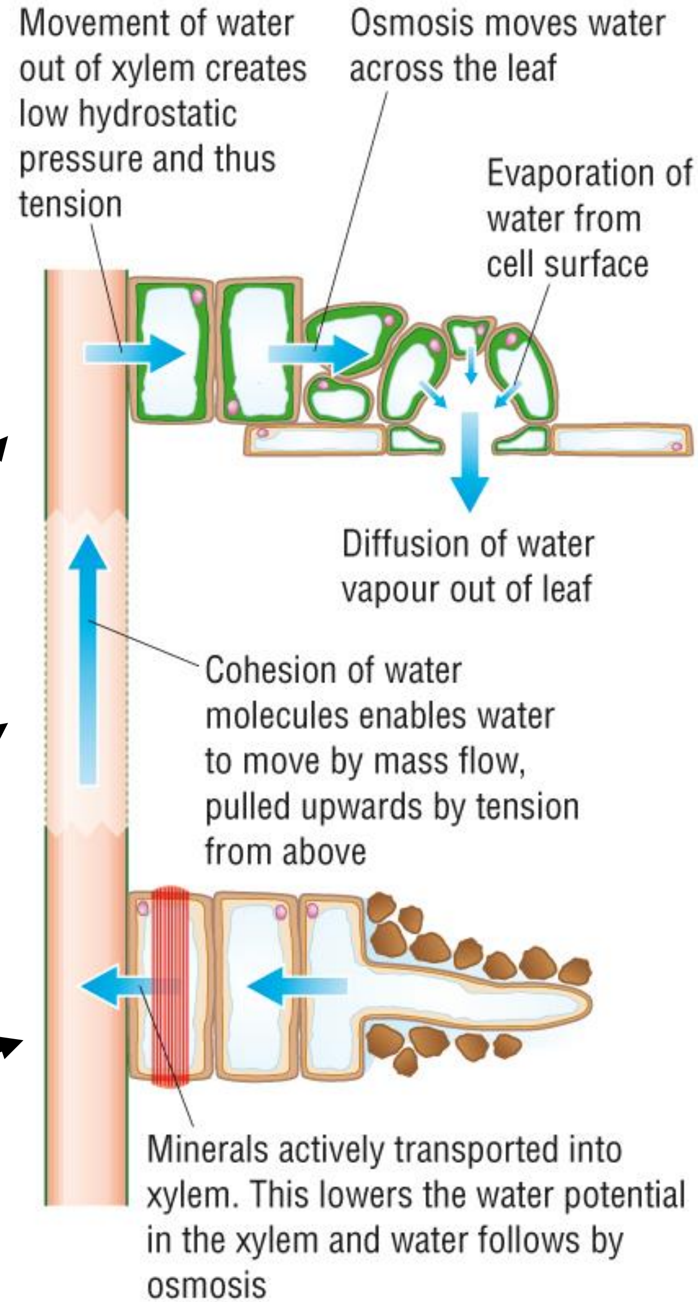
Casparian Strip

- Blocks apoplast pathway.
- Ensures water minerals have to pass through cytoplasm.
- Cell membrane has mineral transport proteins.
- Active transport ensures one-way flow of minerals.
- Water follows by osmosis.
- Water cannot pass from xylem back into cortex (no apoplast).



Water movement up the stem

- Three processes at work:
  - – Transpiration pull
  - – Capillary action
  - – Root pressure



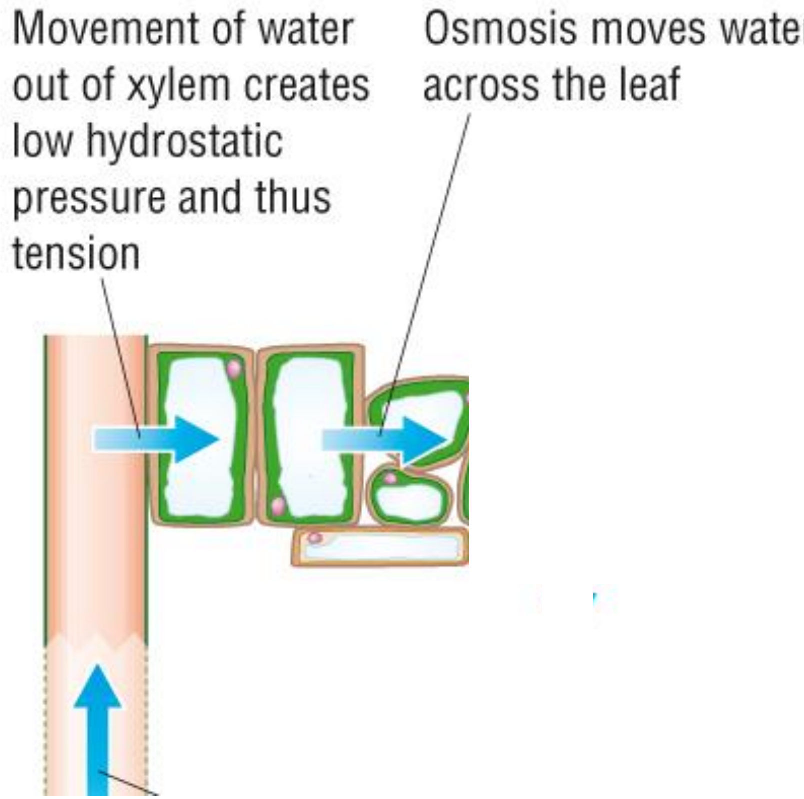
How do we know Active Transport helps maintain root pressure?

- Produce an argument

Transpiration

- The loss of water vapour from the upper parts of the plant – mainly leaves.

- Involves three processes:
  - Osmosis from xylem to spongy mesophyll.
  - Evaporation from cell surface into intercellular space.
  - Diffusion of water vapour down water potential gradient through stomata.



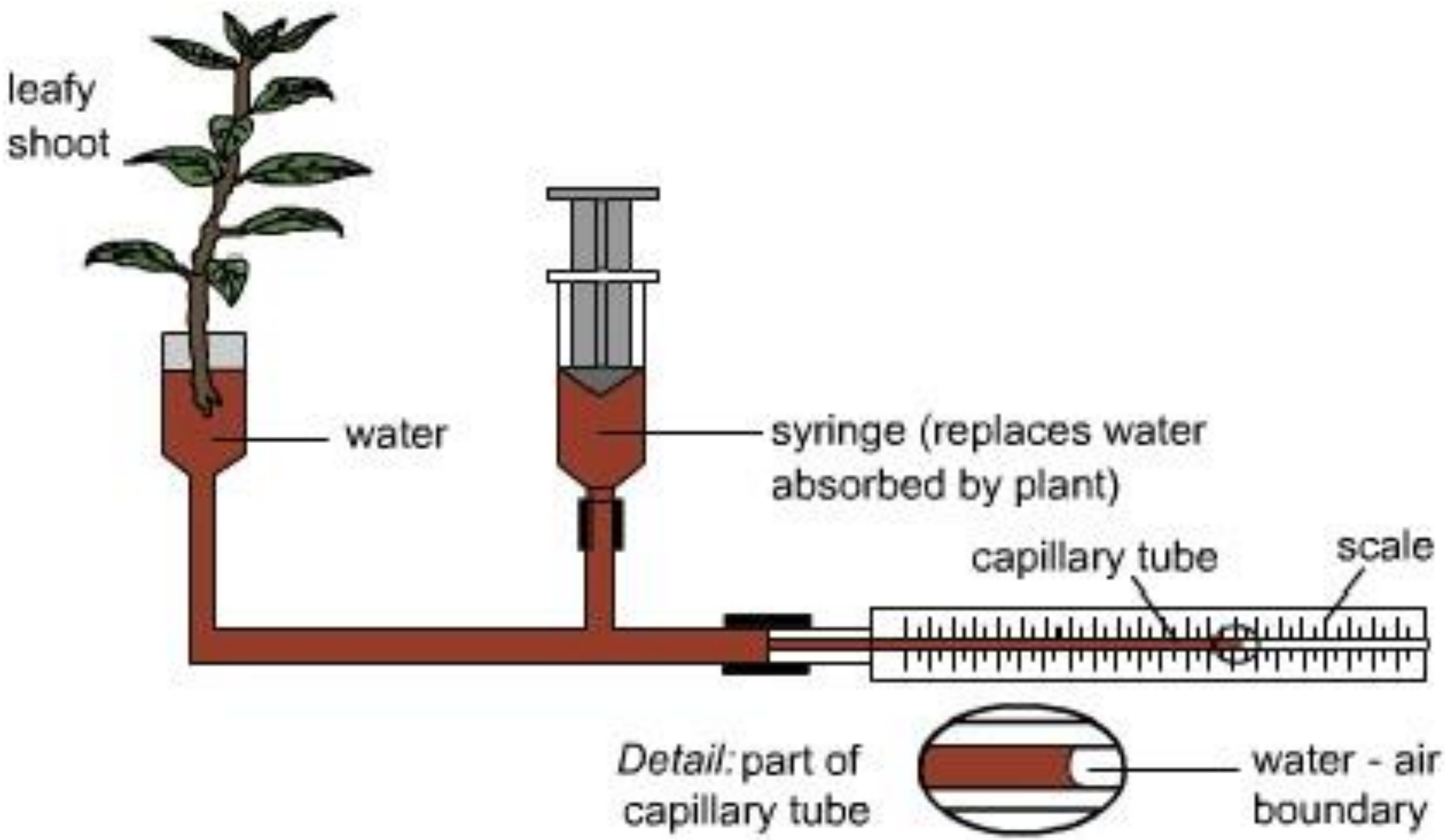
Benefits of Transpiration

- Movement of water up the stem is useful because:
  - Leaves require water for photosynthesis.
  - Cells need water for growth & elongation.
  - Water needed to keep cells turgid.
  - Water flow carries crucial minerals up the plant.
  - Evaporation keeps a plant cool.

Analysis

- Produce a summary of the mechanisms by which water moves through the plant.
  - Use terms:
    - Water Potential
    - Adhesion
    - Cohesion
    - Transpiration Stream

Measuring Transpiration Rate – The Potometer



Factor affecting transpiration rate	**How it works**
Number of leaves	More leaves = larger surface area over which water vapour loss can occur
Number, size & position of stomata	Water vapour loss increases as number & size of stomata increase. Increases if stomata are on upper leaf surface.
Presence of cuticle	Cuticle reduces evaporation from leaf.
Light	Light stimulates opening of stomata.
Temperature	• Increases evaporation rate so water vapour potential inside increases. • Increases diffusion rate due to molecular kinetic energy. • Decreases water vapour potential of air causing higher diffusion rate.
Relative humidity	Higher air humidity = lower water vapour loss due to decreased water vapour potential gradient
Wind	Wind carries away water vapour, maintaining high water vapour potential gradient
Water availability	Low water in soil = plant cells flaccid = stomata closed

Reducing Water Loss

- Water loss by transpiration is unavoidable.
  - Plants have to exchange gases via stomata.
  - So stomata have to be open during daylight.

- Most plants minimise water loss with structural or behavioural adaptations.
  - A waxy cuticle reduces evaporation through the epidermis.
  - Stomata usually found on the underside of the leaf.
    - Reduced evaporation due to direct heating from the sun.
  - Most stomata close at night.
    - No light for photosynthesis
  - Deciduous plants lose leaves in Winter.
    - Ground freezes making water unavailable.
    - Temperatures are too low for photosynthesis.

Xerophytic Plants

- Xerophytes are plants adapted to reduce water loss to enable them to live in very dry conditions.
  - Eg. Cacti, Marram grass.

Xerophytes possess some or all of these adaptations to prevent excessive water loss

- Stomata sunken in pits creates local humidity/decreases exposure to air currents;

- Presence of hairs creates local humidity next to leaf/decreases exposure to air currents by reducing flow around stomata;

- Thick waxy cuticle makes more waterproof impermeable to water;

Xerophytes possess some or all of these adaptations to prevent excessive water loss cont.

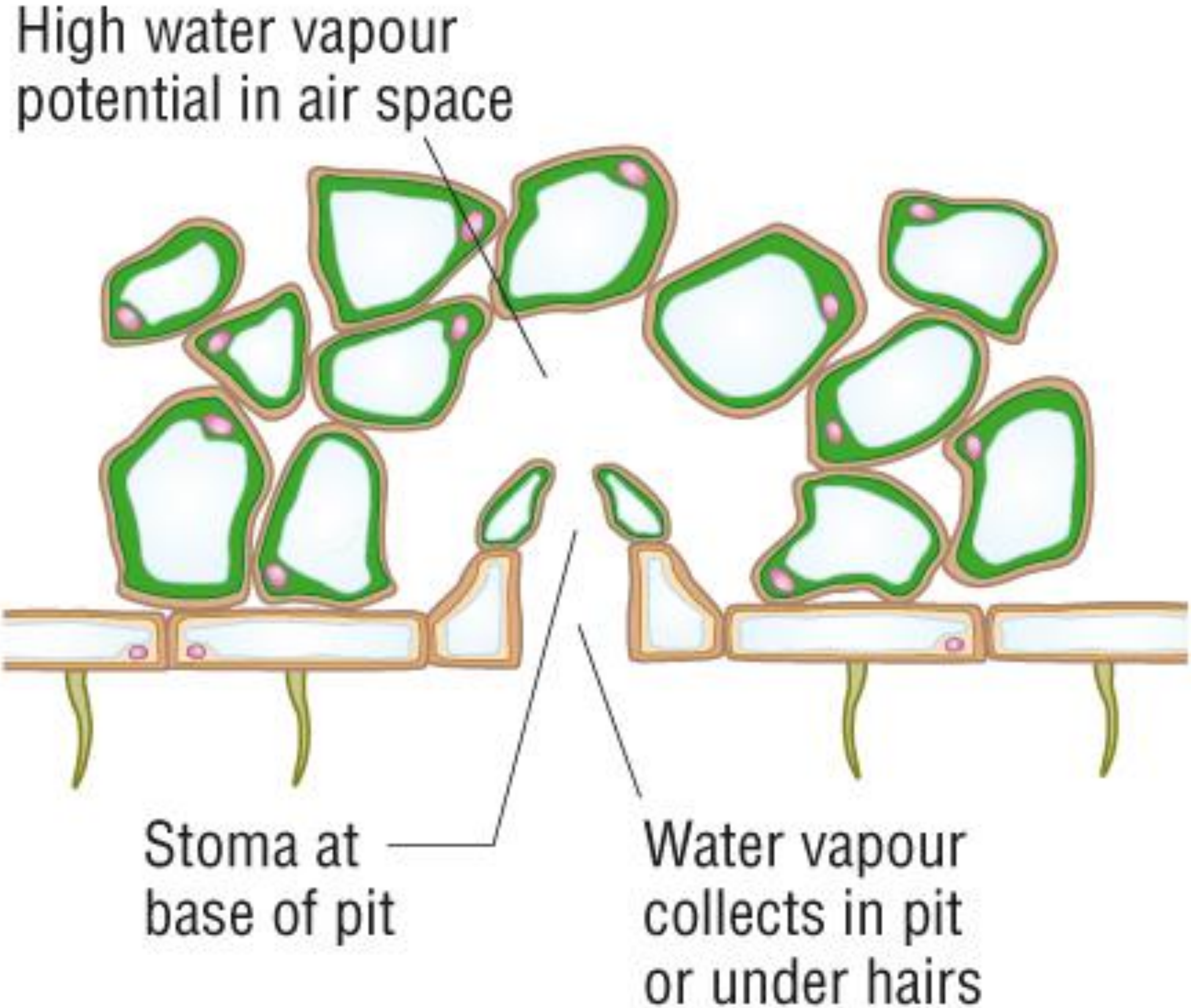
- Stomata on inside of rolled leaf creates local humidity/decreases exposure to air currents because water vapour evaporates into air space rather than atmosphere e.g. British Marram grass

- Fewer stomata decreases transpiration as this is where water is lost;

- Some plants maintain a low water potential inside the mesophyll cells.
  - Increased salt concentration in cells.
  - Reduces evaporation from cell surface.

Xerophyte adaptations summary:

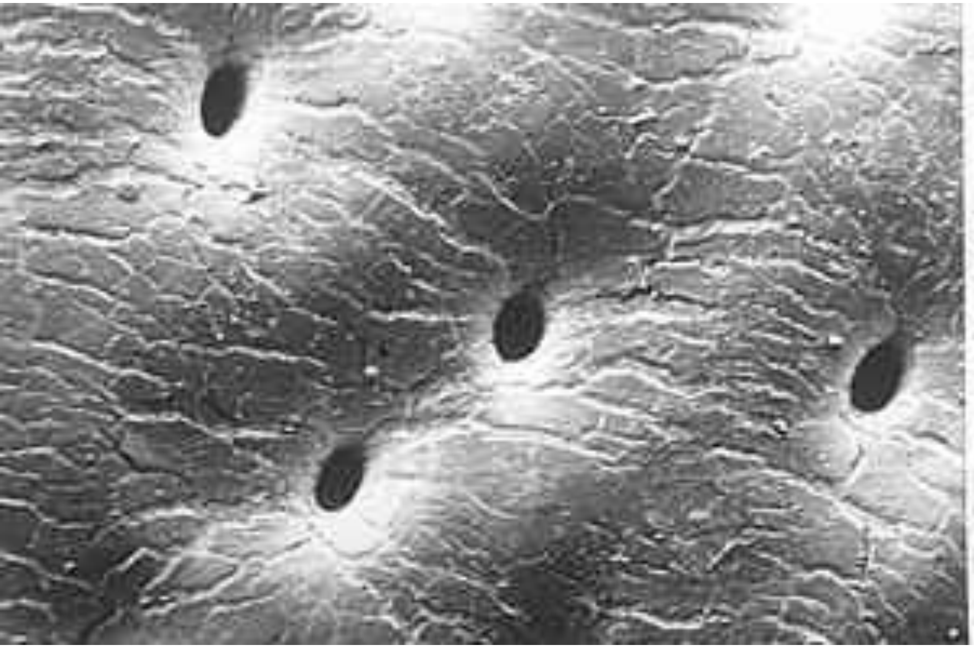
Adaptation	How it works	Example
Thick cuticle	stops uncontrolled evaporation through leaf cells	
Small leaves & small leaf surface area	less surface area for evaporation	conifer needles, cactus spines
Low stomata density	smaller surface area for diffusion	
Sunken stomata	maintains humid air around stomata	marram grass, cacti
Stomatal hairs (trichores)	maintains humid air around stomata	marram grass, couch grass
Rolled leaves	maintains humid air around stomata	marram grass,
Extensive roots	maximise water uptake	cacti

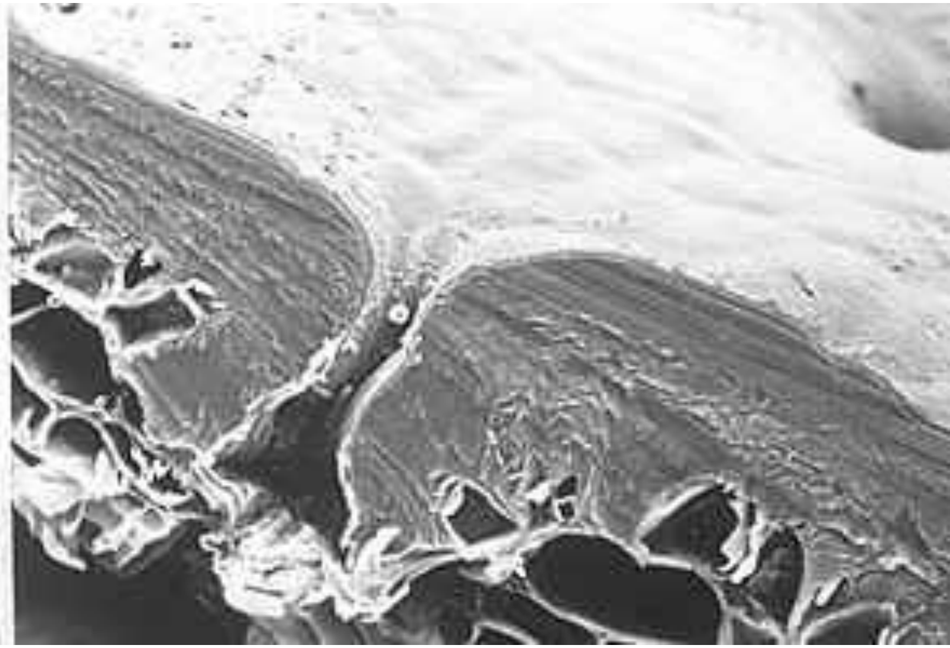

High water vapour potential in air space
Stoma at base of pit
Water vapour collects in pit or under hairs

Left and right Epidermis of the cactus *Rhipsalis dissimilis*.

Left: View of the epidermis surface. The crater-shaped depressions with a guard cell each at their base can be seen.

Right: X-section through the epidermis & underlying tissues. The guard cells are countersunk, the cuticle is thickened. These are classic xerophyte adaptations.





All Cacti are xerophytes

Marram grass possesses: **rolled leaves**, **leaf hairs** and **sunken stomata**. These adaptations make it resistant to dry conditions and of course sand-dunes which drain very quickly retain very little water.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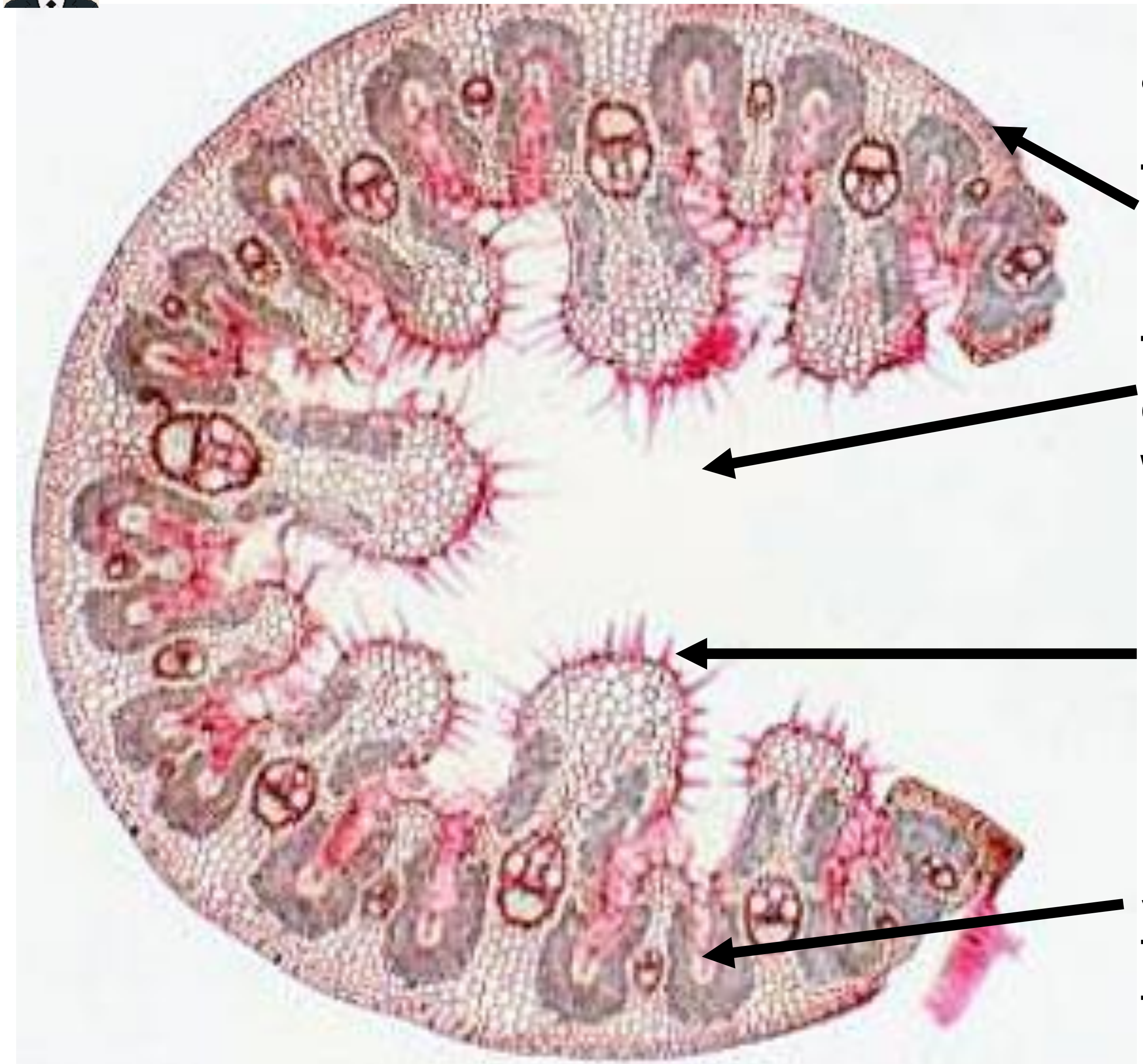


Rolled leaf to trap air inside

Thick cuticle to reduce evaporation

Trapped air in centre with high water vapour potential

Hairs reduce air movement

Stomata in pits to trap moist air next to them

BYB3 June 2001 Question 8 part c

(c) Describe and explain how **three** structural features reduce the rate of transpiration in xerophytic plants.

(3 marks)

BYB3 June 2001 Question 8 part c ANSWERS

(c) Feature and explanation required for mark, e.g.
(3 features without a suitable explanation = 1 mark)

Rolled leaves -
reduces water potential gradient / air movement across stomata / traps air which becomes saturated / moist / humid / reduces surface area;

Sunken stomata -
reduces water potential gradient / air movement across stomata / traps air which becomes saturated / moist / humid;

Thick cuticle -
Reduces cuticular transpiration / reduces evaporation / greater diffusion distance;

Hairs -
traps air which becomes saturated / moist / humid;

Reduced leaves / spines -
less surface area / fewer stomata (for evaporation). max 3

BYB3 Jan 2002 Question 6 part c

(c) Describe **two** features you would expect in the leaves of a xerophyte which would reduce the rate of transpiration.

1. ....

....

2. ....

....

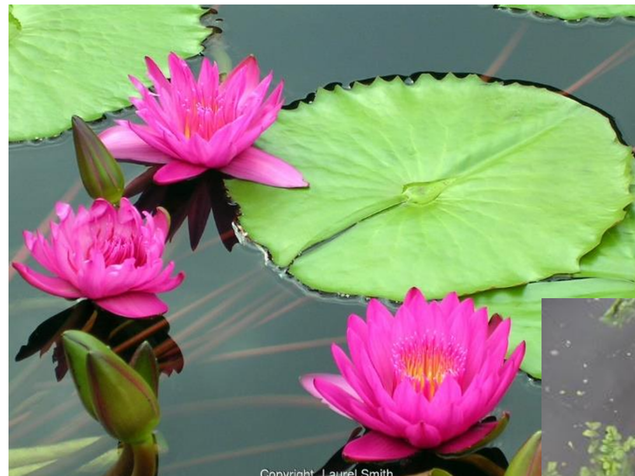
(2 marks)

BYB3 Jan 2002 Question 6 part c ANSWERS

(c)	Thick cuticle; hairs; sunken stomata; inrolled leaves; fewer stomata ; Reduced leaf surface area;	2 max

Hydrophytic Plants

- Hydrophytes are plants which actually live in water.
  - **Water lillies**
  - **Water cress**
  - **Bulrushes**

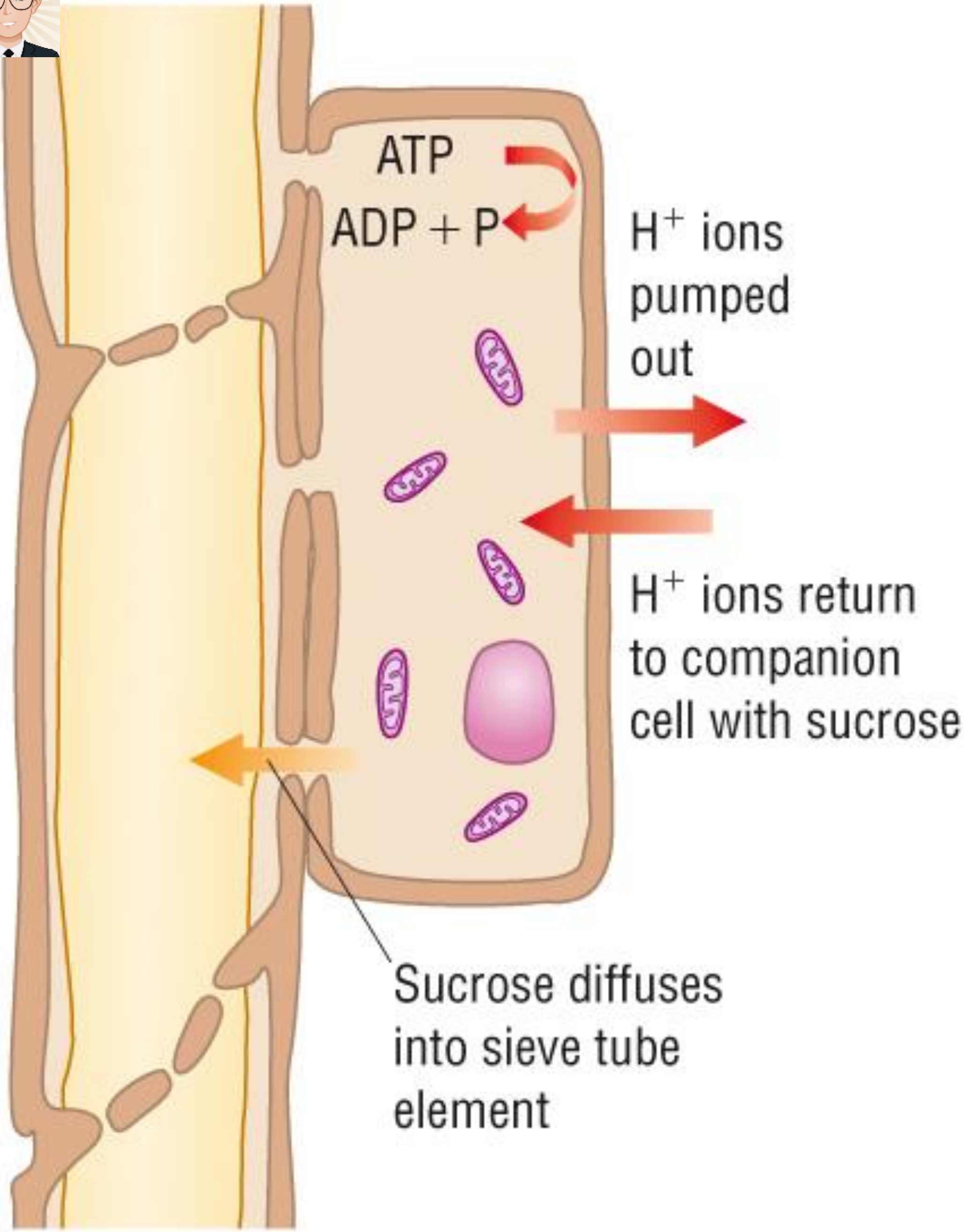


Adaptations of Hydrophytes

- Thin or no waxy cuticle
  - No need to conserve water so transpiration not a problem.
- Many always-open stomata
  - Often on upper leaf surfaces - Maximises gas exchange.
- No need for supporting structures
  - Plant is supported by the water.
- Wide, flat leaves
  - Capture as much light as possible, and float on water surfaces.
- Small roots
  - Water can diffuse directly into the stem or leaves.
- Large surface area of underwater stems/roots
  - Maximises photosynthesis.
- Air sacs in the leaves
  - Enables leaves/flowers to float.
- Large air spaces in leaf tissue
  - Provides buoyancy to leaves, allows efficient gas exchange.

Translocation

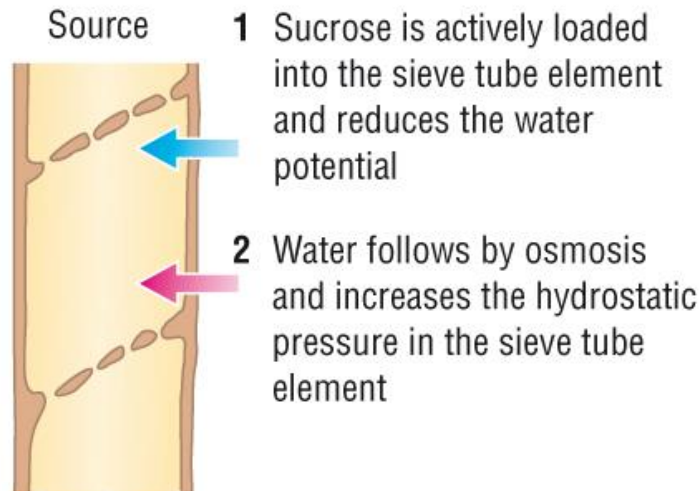
- The movement of sugars through the phloem tubes.
  - A source releases sucrose into the phloem.
  - A sink removes sucrose from the phloem.



How does sucrose enter the phloem?

- H^+ ions actively removed from companion cells.
- Sets up H^+ gradient.
- H^+ diffuse back through co-transport proteins.
- Brings sucrose with it.
- Sucrose diffuses through plasmodesmata.

Mass flow of sucrose



- At source:
  - High hydrostatic pressure created as water enters sieve tube by osmosis.
- Flow:
- At sink:
  - Sucrose used by cells for storage as starch or for respiration.
  - Sets up a sucrose gradient between sieve tube & surrounding cells.
  - Sucrose diffuses out of sieve tubes.

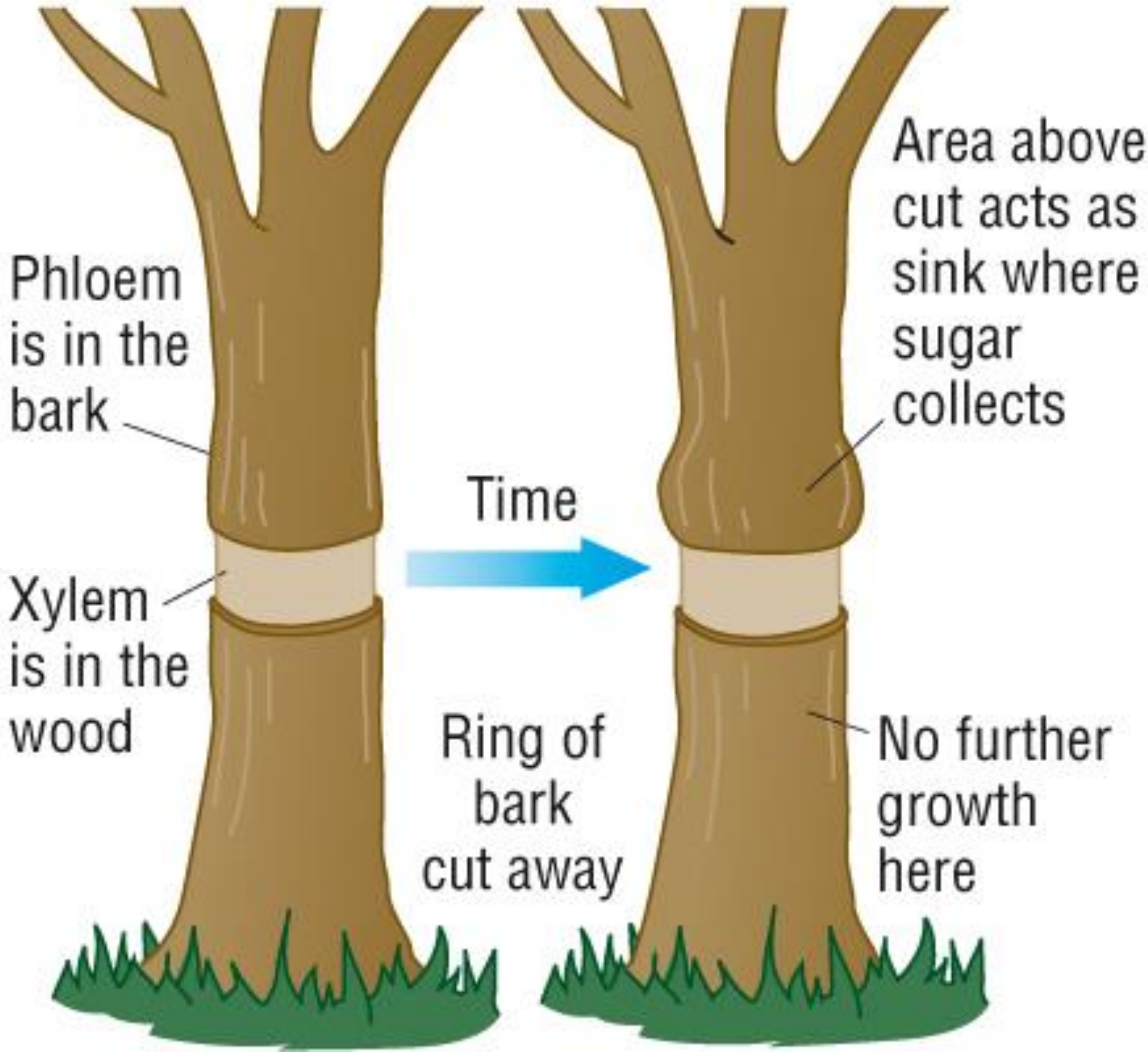
Mass flow is bidirectional

- Mass flow of water/sucrose/other assimilates can travel in both directions.
  - Depends on where the sugars are produced/used.

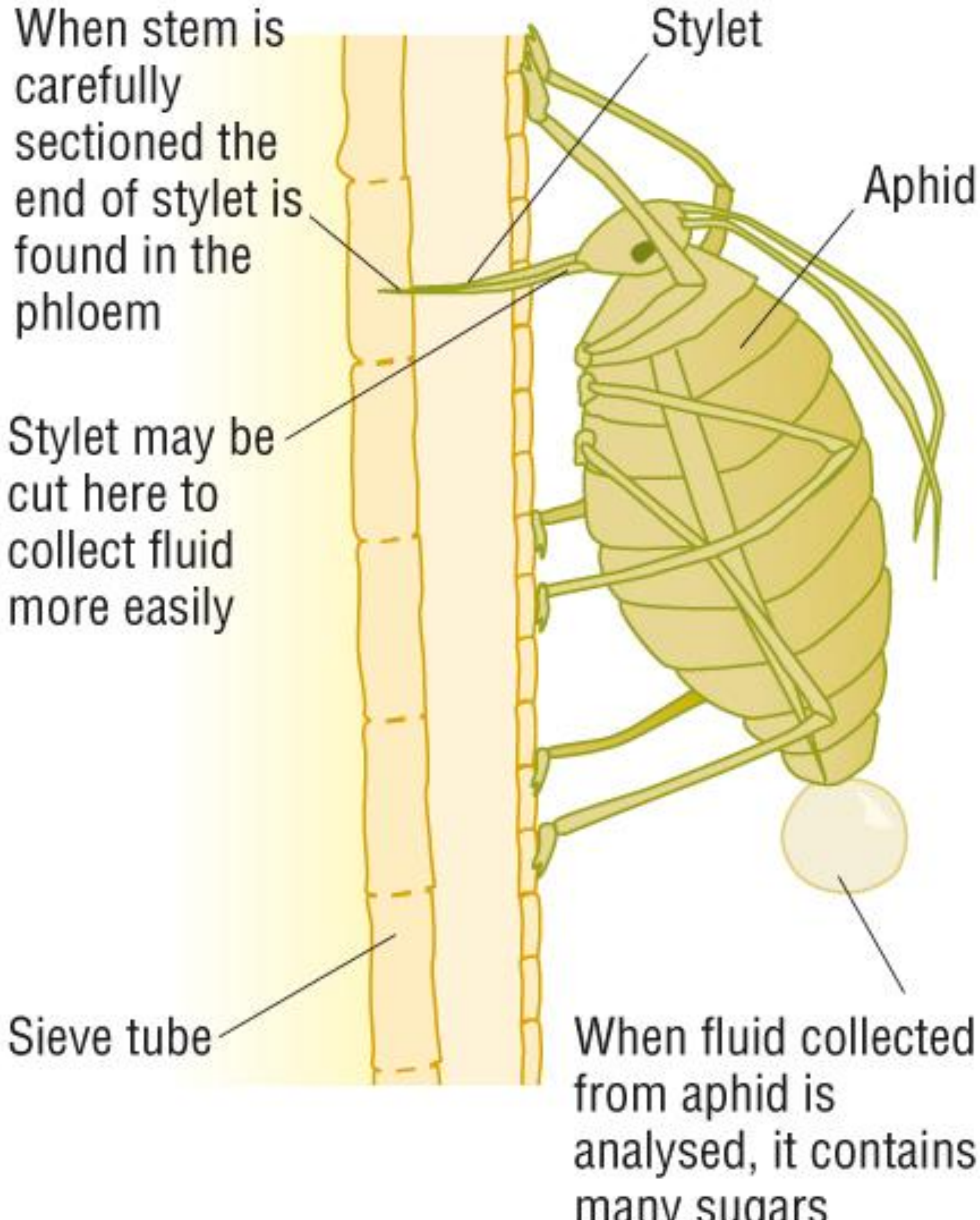
- Sources:
  - Leaves in the summer months.
  - Stored carbohydrates in roots during spring.
- Sinks:
  - Carbohydrate storage in roots in summer months.
  - Growing leaves during spring

Evidence for this method of translocation

- How do we know the phloem is used to translocate sugars?
  - A plant supplied with $^{14}CO_2$ will soon have traces of labelled carbon in the phloem.
  - Ringing (cutting out a ring of bark) a tree causes sugars to collect above the ring.
    - ie. they are unable to travel further down.
  - The mouthparts of feeding aphids are shown to be within the phloem.



Phloem
is in the
bark
Xylem
is in the
wood
Time
Ring of
bark
cut away
Area above
cut acts as
sink where
sugar
collects
No further
growth
here


When stem is carefully sectioned the end of stylet is found in the phloem
Stylet
Aphid
Stylet may be cut here to collect fluid more easily
Sieve tube
When fluid collected from aphid is analysed, it contains many sugars

Evidence for this method of translocation

- How do we know it needs energy from ATP?
  - – The companion cells have a large number of mitochondria.
  - – Translocation can be stopped using a metabolic poison.
    - This inhibits ATP production.
  - – Calculations show that sugars move through the phloem up to 10,000 times faster than could occur by diffusion alone.

Evidence for this method of translocation

- How do we know it uses this mechanism?

  – The pH of companion cells is higher than that of surrounding cells.

  – The concentration of sucrose is higher at the source than the sink.

Evidence for this method of translocation

- Is there any evidence against this mechanism?
  - Not all solutes in the phloem move at the same rate.
  - Sucrose is moved to all parts of the plant at the same rate.
    - Rather than going more quickly to areas with a lower concentration.
  - We are not sure what the role of sieve plates is.