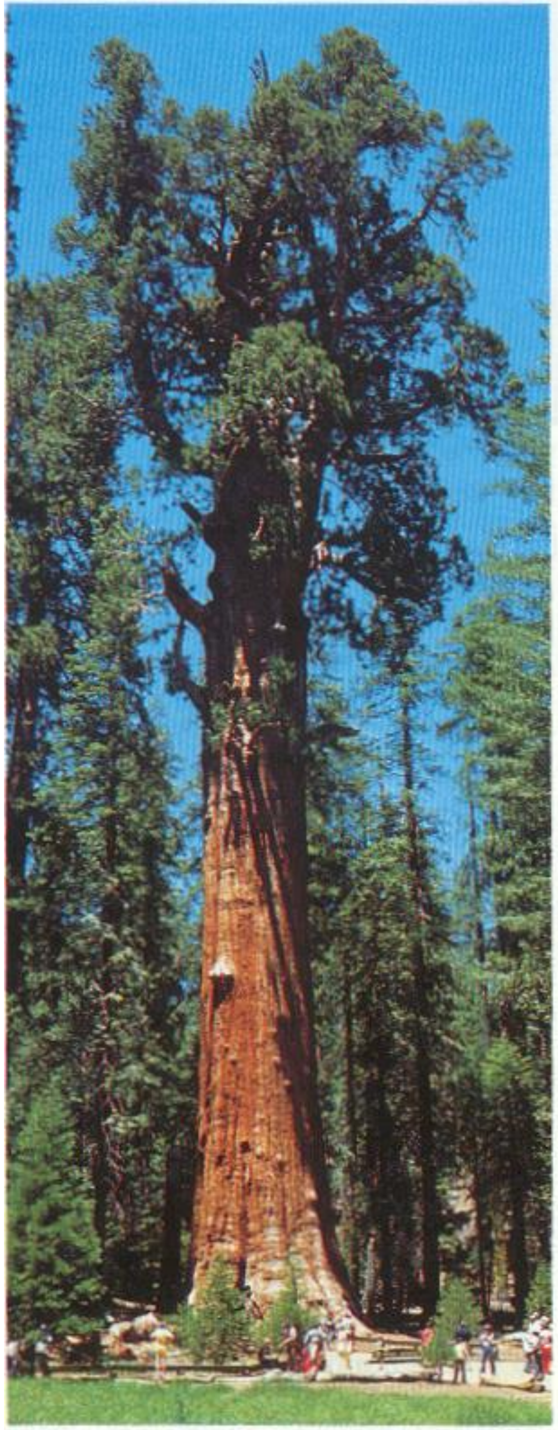
TRANSPORT IN PLANTS

How does a North American Redwood tree that grows up to 60m transport water and glucose between the roots and leaves?

Multicellular plants need mass flow systems to transport substances between different tissues.



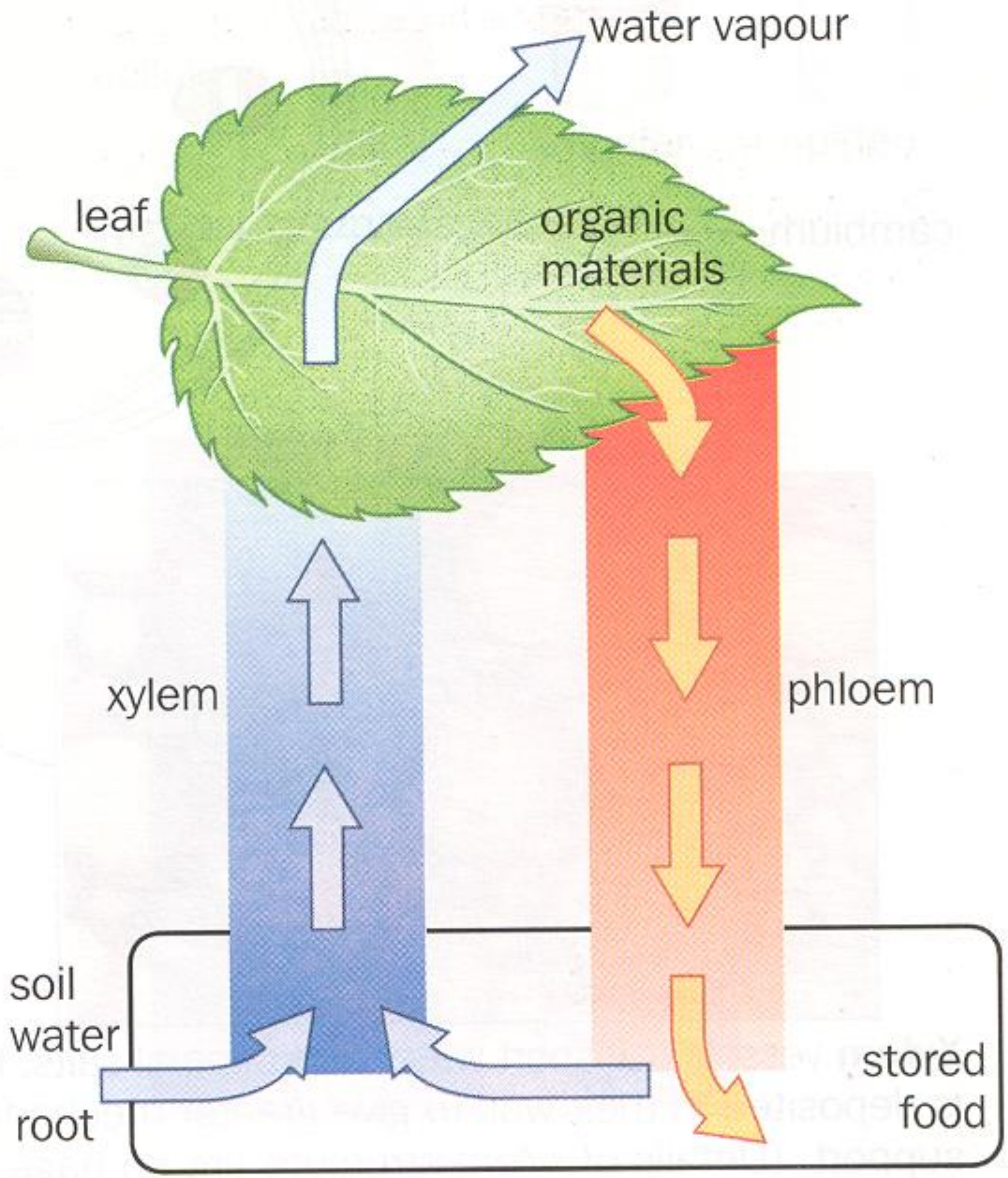
There are 2 systems:

- **XYLEM**

  transporting water and mineral ions

- **PHLOEM**

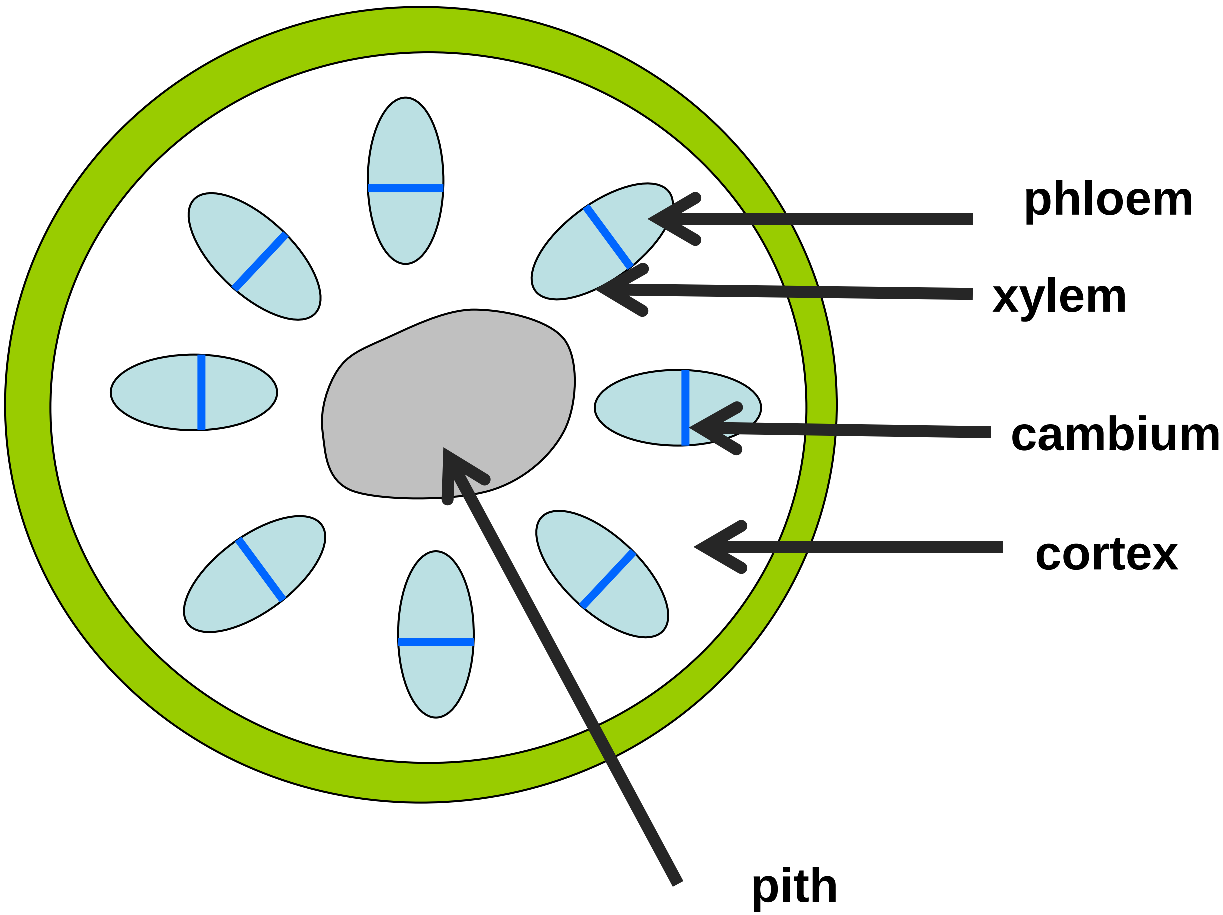
  transporting sugars and soluble organic products of photosynthesis


water vapour
leaf
organic
materials
xylem
phloem
soil
water
root
stored
food

THE STEM

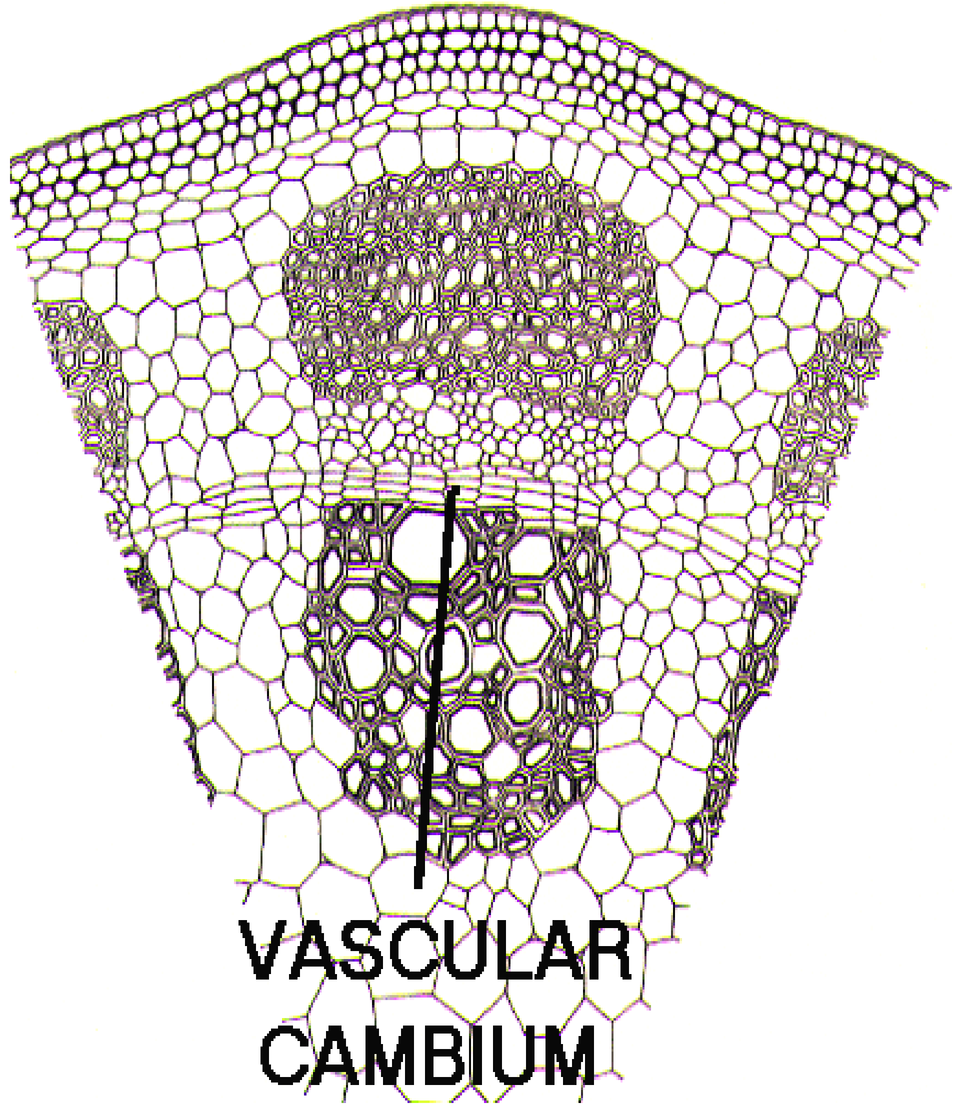
- The regions in a stem include:

- Epidermis
- Cortex
- Vascular bundles
- Pith


phloem
xylem
cambium
cortex
pith

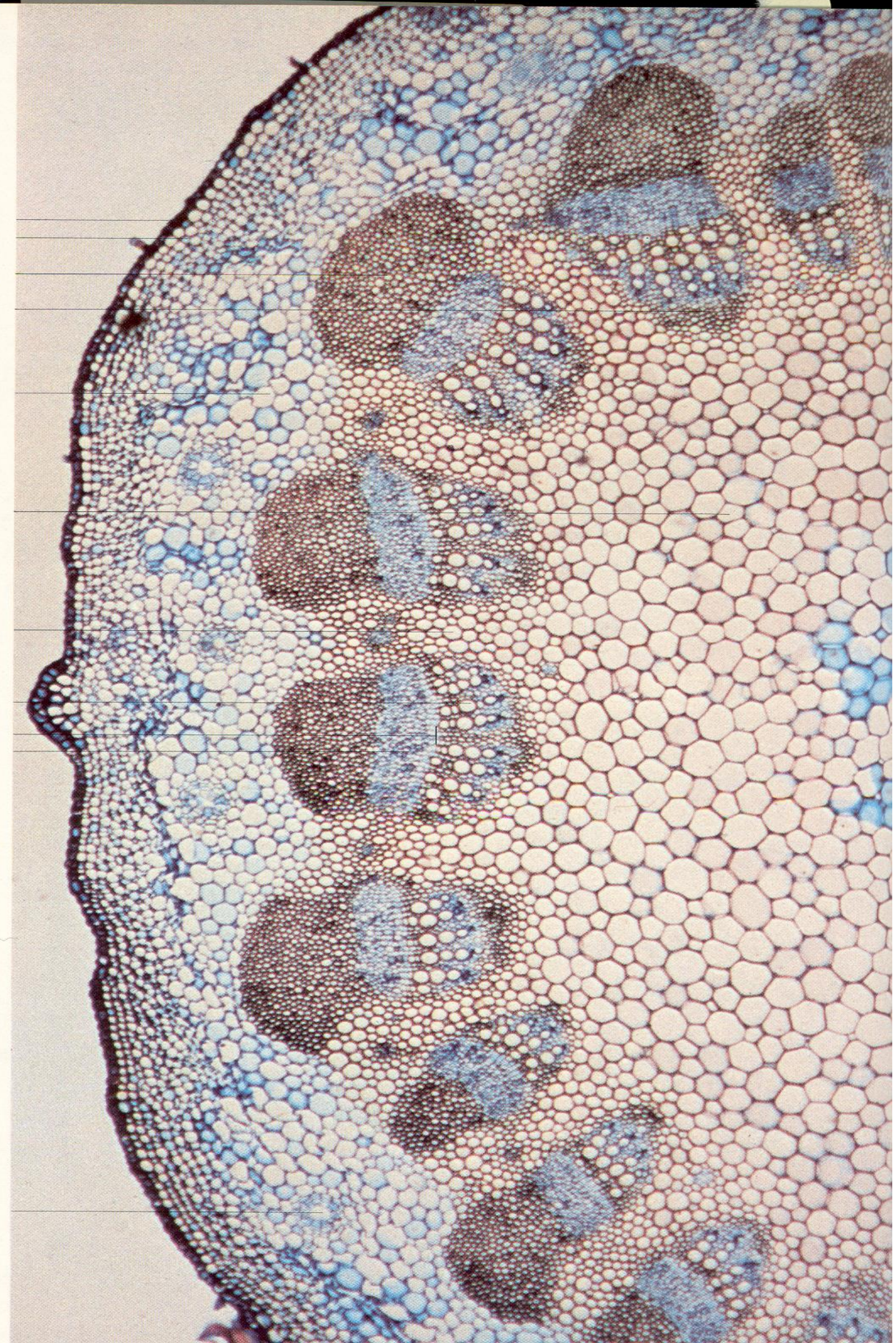
A thin layer of tissue, known as cambium, is present in the vascular bundles between the xylem and the phloem.

Cambium divides to produce new phloem cells to the outside and new xylem cells to the inside.

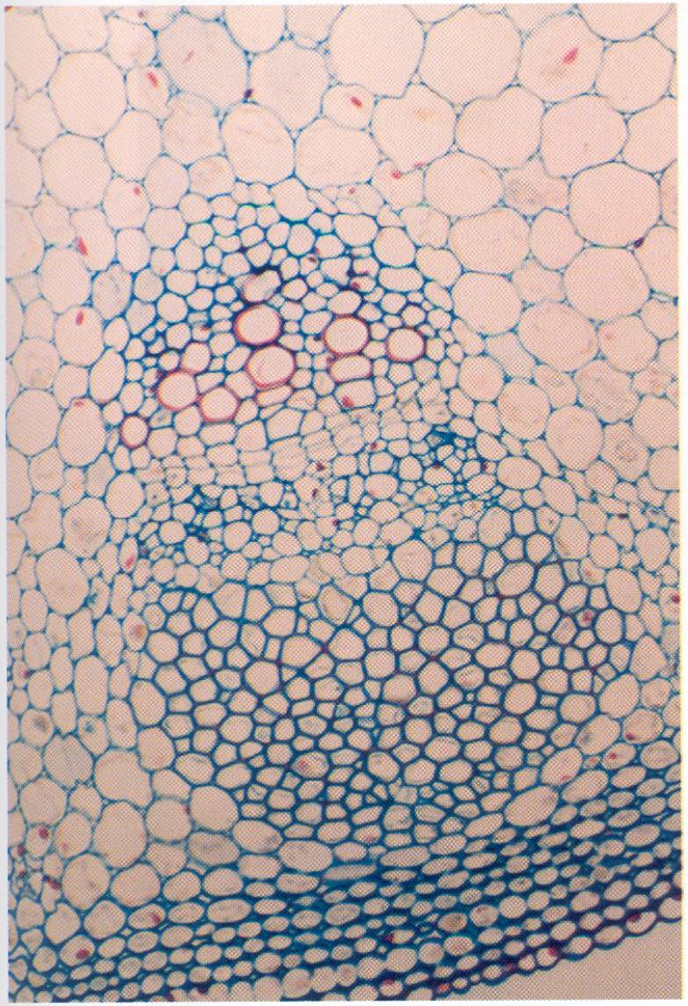


Stem (dicotyledon)

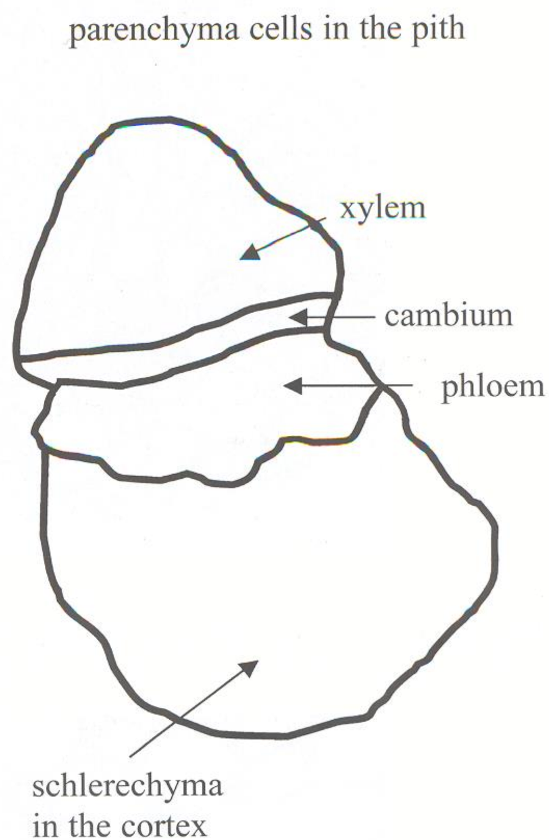
Helianthus (sunflower). × 70
Transverse section of the stem. The regular arrangement of the vascular bundles is very striking; each is strengthened by a group of sclerenchyma fibres that appears in transverse section as a cap.



Photograph



Block diagram



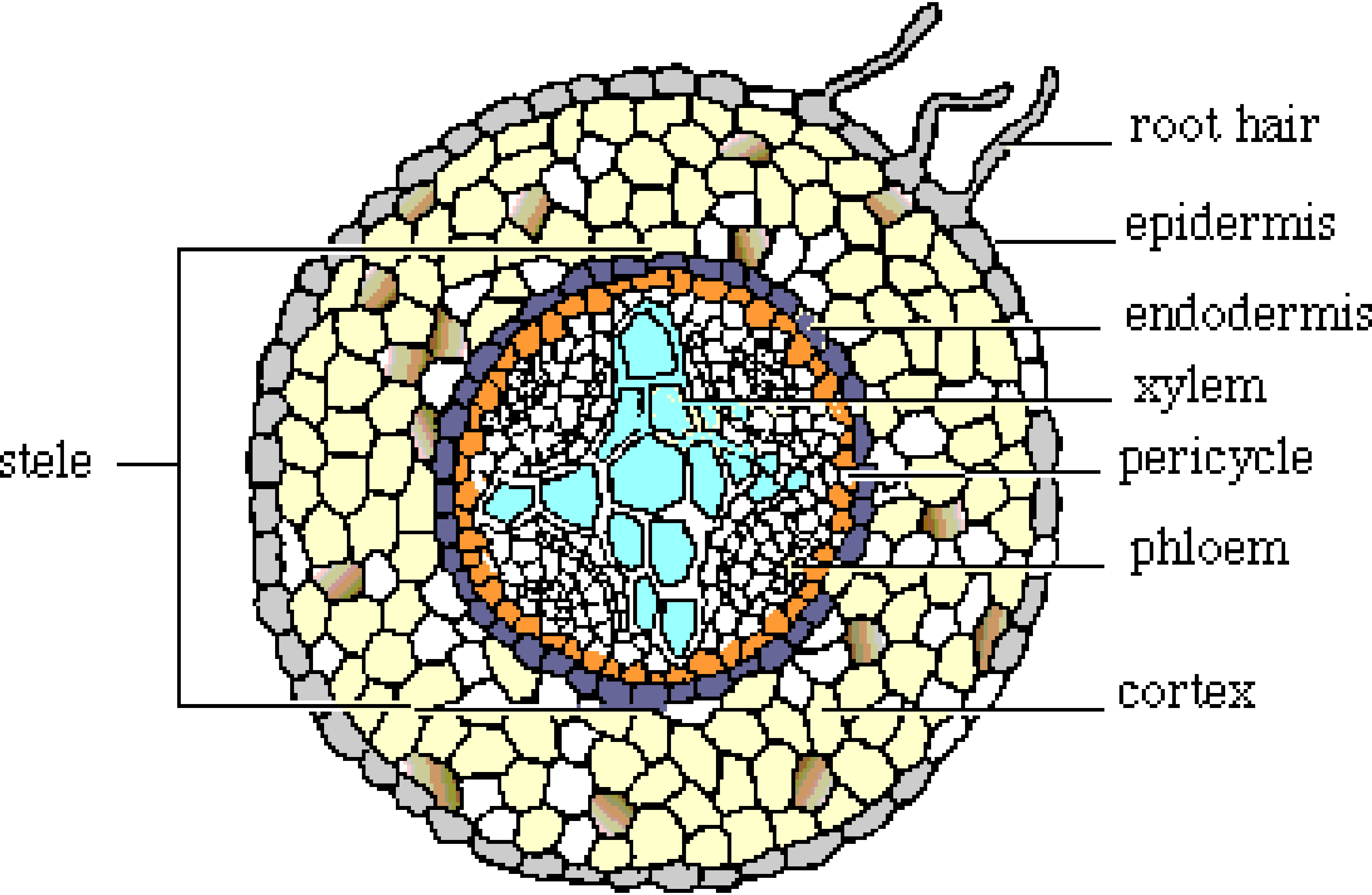
Complete transverse sections of a stem are often difficult to produce. However, small areas can show a variety of tissues.

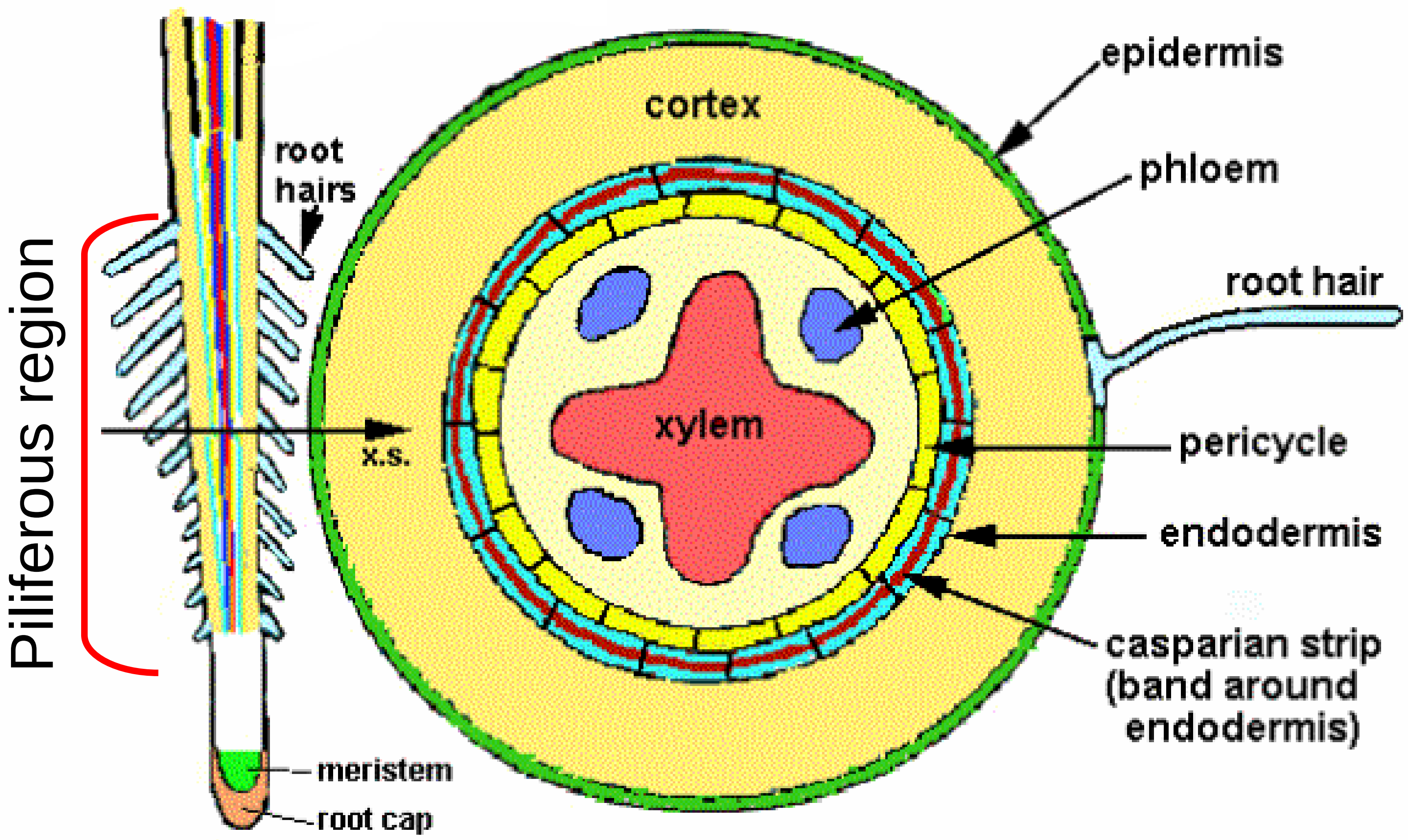
The Root

Regions in a root include:

- Piliferous layer
- Cortex
- Endodermis
- stele

Piliferous
Region
contains
root hair cells

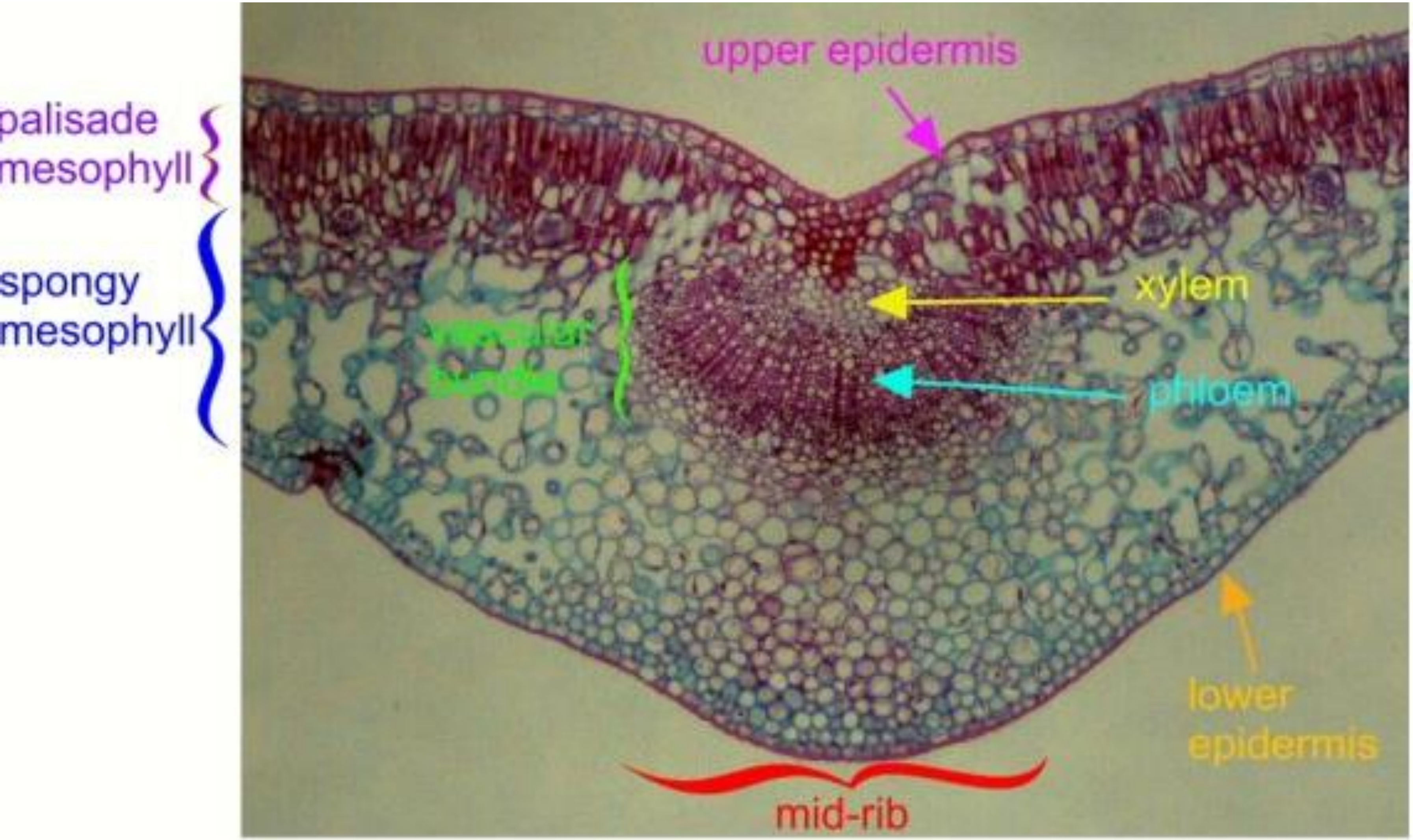

root hair
epidermis
endodermis
xylem
pericycle
phloem
cortex
stele


Piliferous region
root
hairs
x.s.
meristem
root cap
cortex
xylem
epidermis
phloem
root hair
pericycle
endodermis
casparian strip
(band around
endodermis)

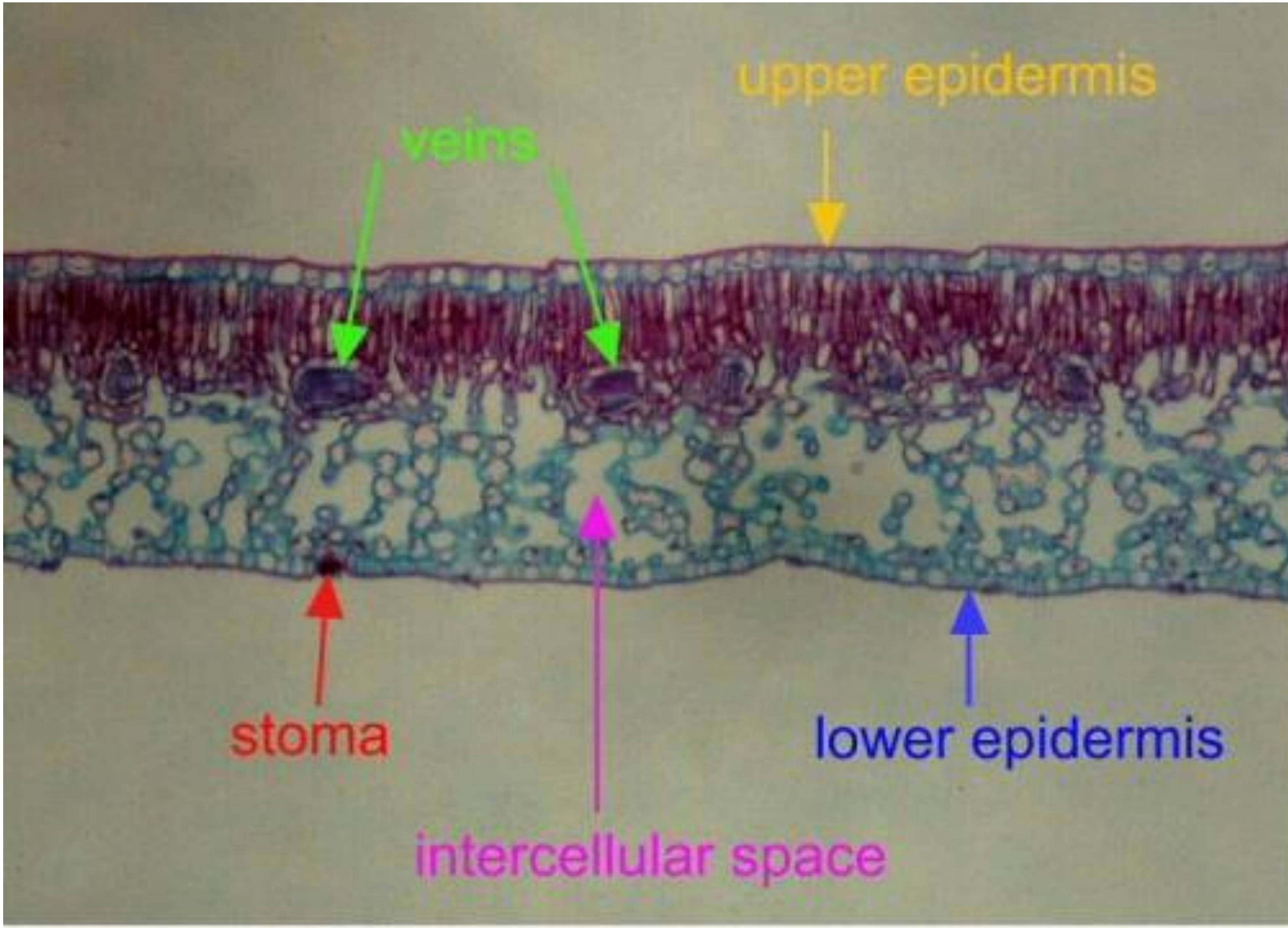
THE LEAF

Regions in a leaf include:

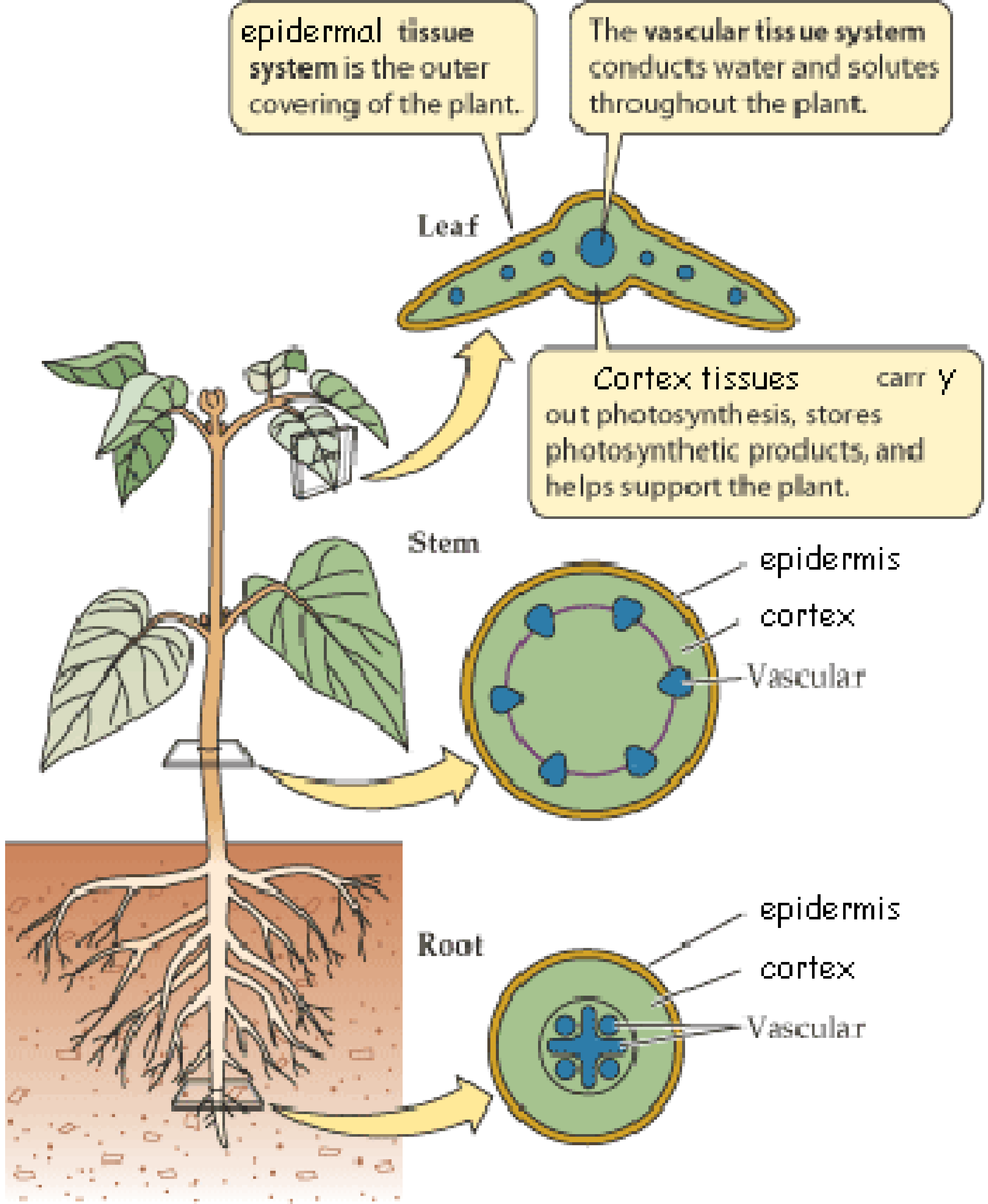
- Epidermis (+ waxy cutilcle)
- Palisade mesophyll
- Spongy mesophyll
- Vascular bundles (veins)
- Stomata + guard cells



Leaf, mid-rib region. V.S.

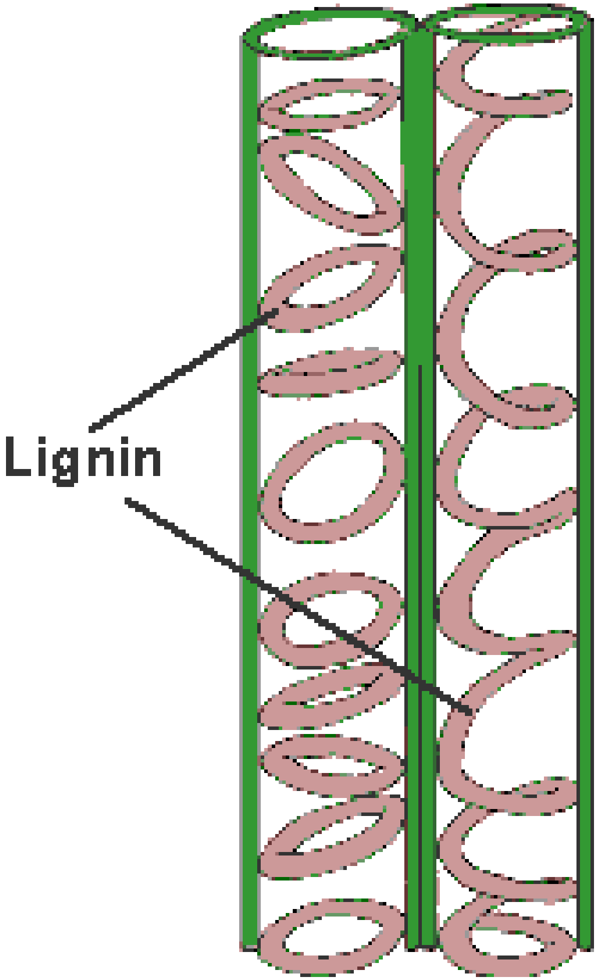


Leaf, blade region.

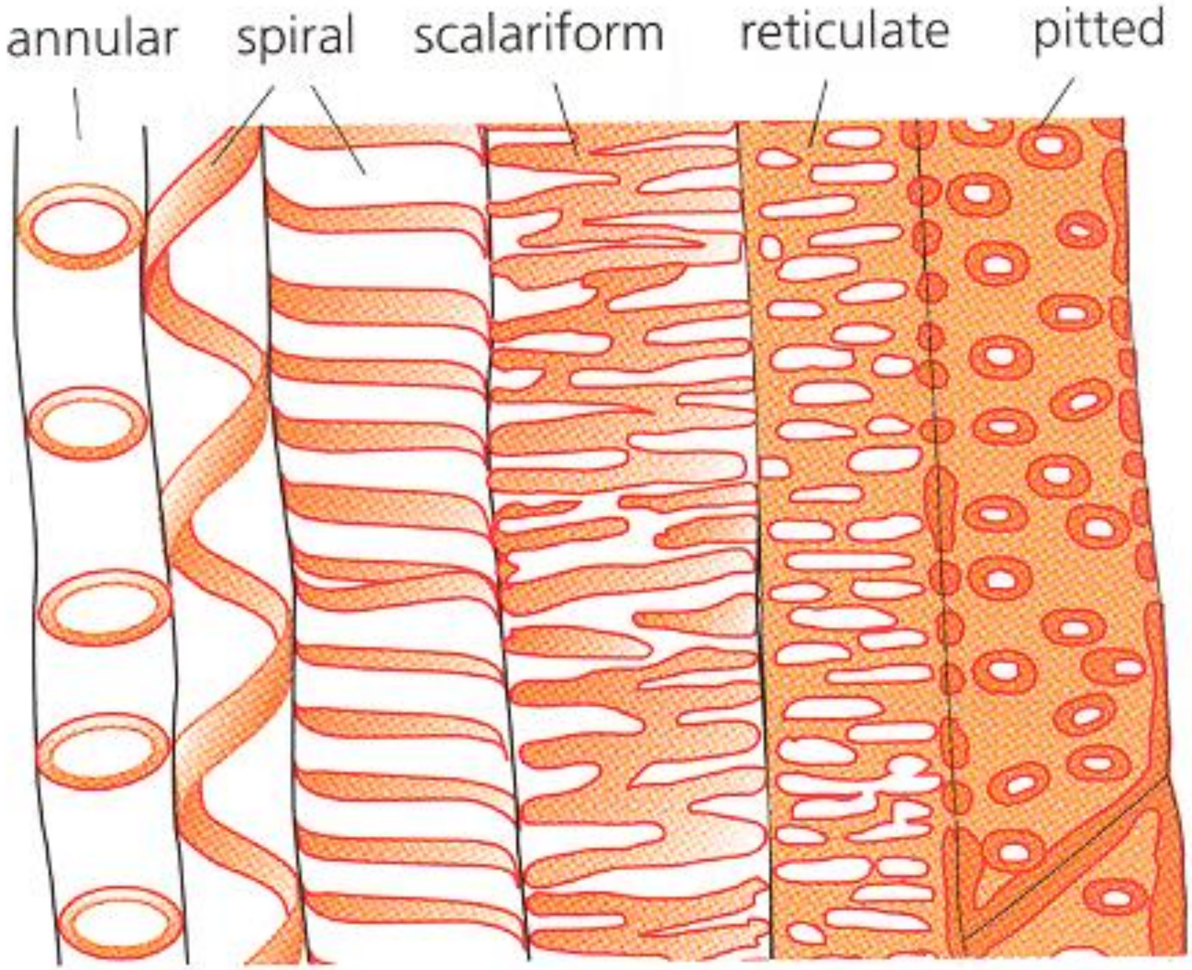

epidermal tissue system is the outer covering of the plant.
The vascular tiss ue system conducts water and solutes throughout the plant.
Leaf
Cortex tissues carr y out photosynth esis, stores photosynthetic products, and he lps support the plant.
Stem
epidermis
cortex
Vascular
Root
epidermis
cortex
Vascular

XYLEM TISSUE
is made of XYLEM VESSELS

- These are formed from a column of cells which lose their end walls.
- The walls of these tubes become strengthened by the addition of lignin.
- This increased mechanical strength is important if the vessels are to withstand the strong pressures that occur during water transport.


Lignin

- Lignin is impermeable so materials cannot pass into the xylem cells and the protoplasm dies.
- So the cells are hollow and nothing restricts the flow of water.
- No lignin is laid down where plasmodesmata were present in the original cell walls.
- These non-lignified areas are known as pits and they allow water to pass sideways between one xylem vessel and the next.



Different types of lignin deposition in xylem vessels

PRIMARY XYLEM

the first xylem in a young stem, root or leaf.
There are 2 types:-

- Protoxylem – the first xylem to develop behind the root and shoot tips. Lignin is added in rings or spirals to form annular vessels (rings) and spiral vessels.

- Metaxylem – is more mature and the walls are fully lignified (with the exception of pits).

SECONDARY XYLEM

formed from the ring of cambium in the stem.

- Secondary xylem allows woody plant to increase their girth each year.
- This is known as secondary thickening.
- This seasonal growth shows up as annual rings.
- A ring formed in the previous year transports little water, it main function being to support the plant's increasing biomass.

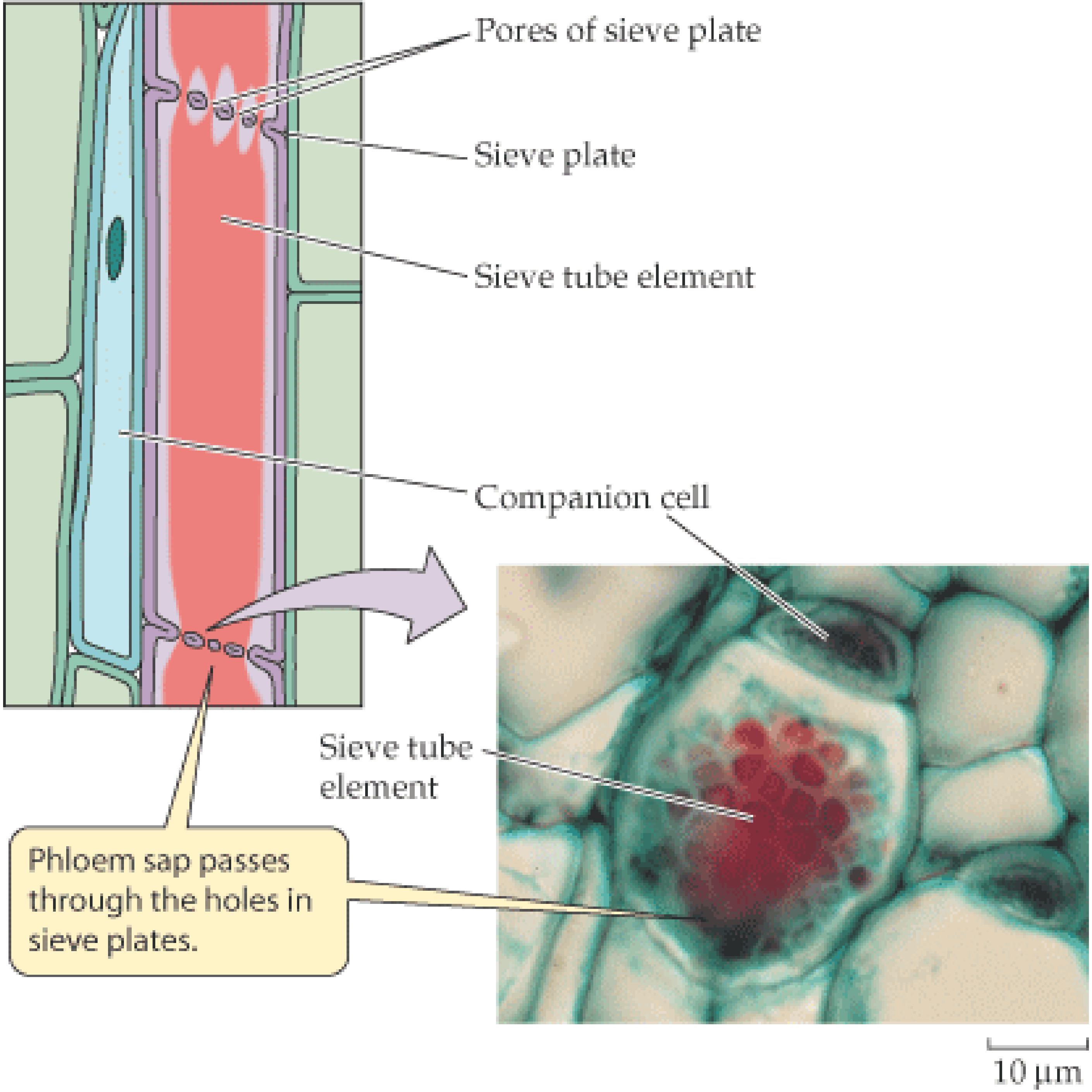
Functions of xylem:-

- Conduction of water and mineral salts - water is drawn up under tension due to evaporation from leaves. Thickening prevents collapse of vessels.
- Mechanical support.

PHLOEM

- Transport of water through the xylem is a passive process but transport of materials such as sugars and amino acids is an active process that requires energy.
- It is not surprising then that phloem is a living tissue.
- The most important phloem tissues in terms of transport are the

sieve tube elements and **companion cells**.

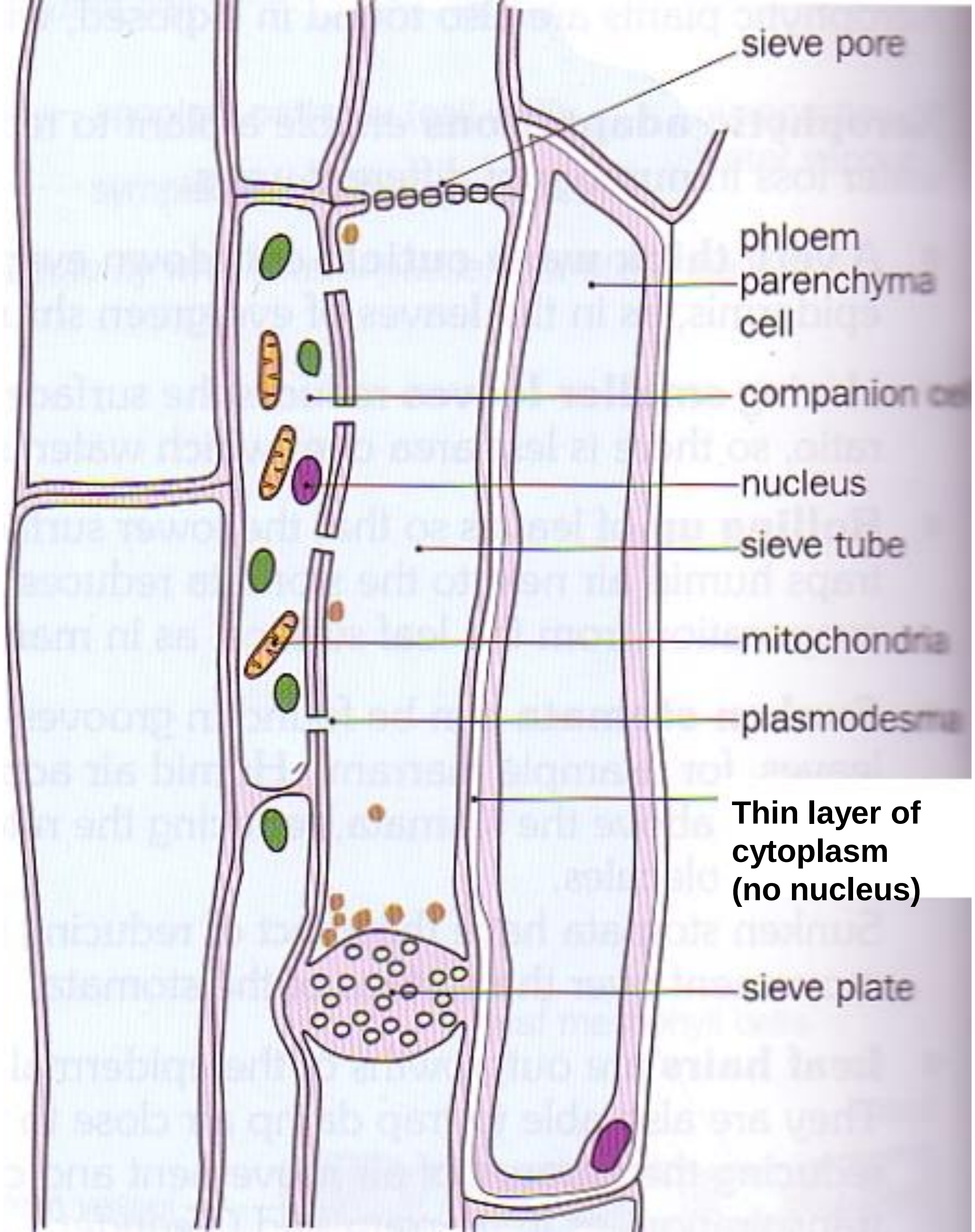

Pores of sieve plate
Sieve plate
Sieve tube element
Companion cell
Sieve tube
element
Phloem sap passes
through the holes in
sieve plates.
10 µm

SIEVE TUBES

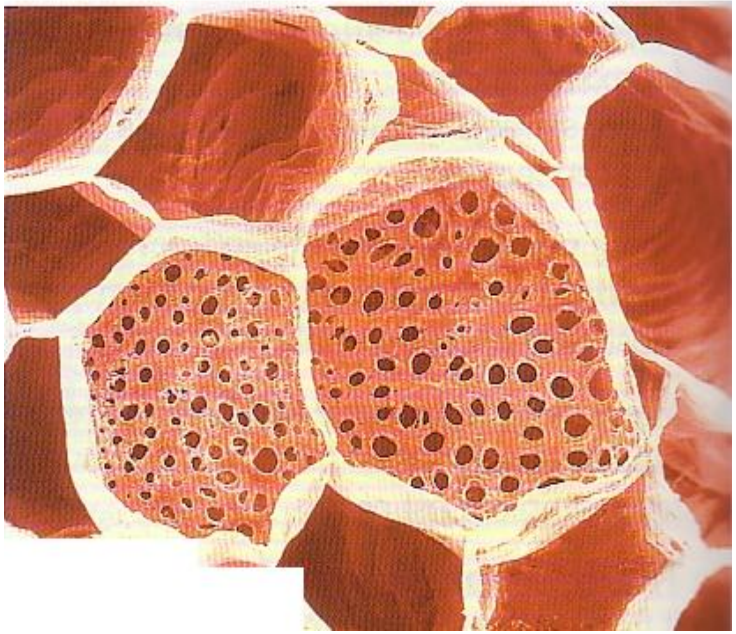
- Phloem tissue is made from columns of cells.
- Each cell is adapted to form a sieve element.
- A column of sieve elements joined together form a sieve tube.
- Sieve tubes allow the mass flow of materials.

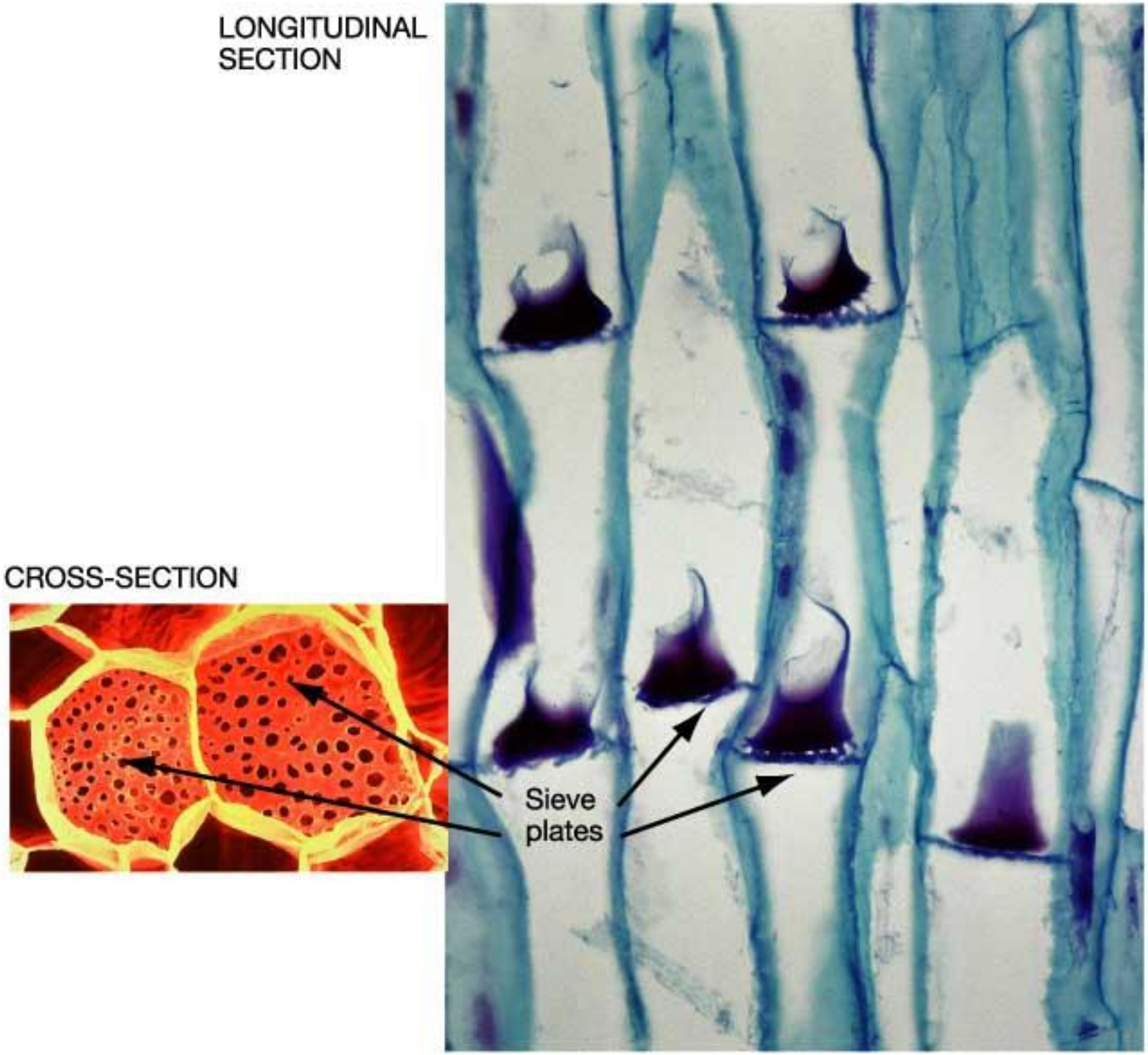
- Unlike xylem vessels – the sieve tube is alive, although as it matures it loses several of the usual plant cell organelles.
- The nucleus, ribosomes and Golgi bodies all degenerate.
- So the sieve element (like the red blood cell) has no nucleus.
- The loss of these structures allows material to flow more easily.

- They do have a cell wall, a cell surface membrane and cytoplasm, containing endoplasmic reticulum and mitochondria.
- There is, in fact, only a slight amount of cytoplasm lining the inside of the cellulose cell wall.

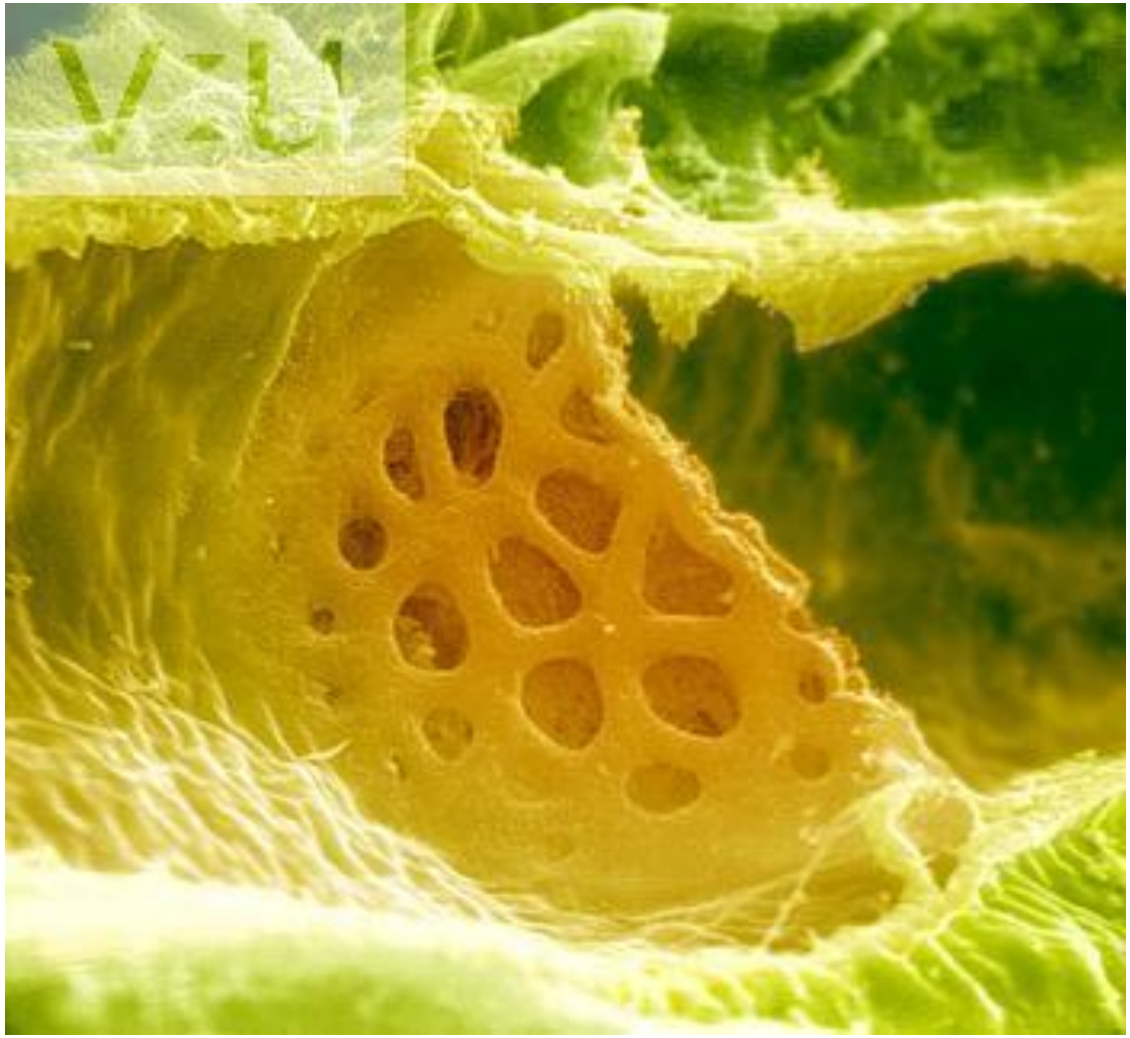

sieve pore
phloem parenchyma cell
companion ce
nucleus
sieve tube
mitochondria
plasmodesma
Thin layer of cytoplasm (no nucleus)
sieve plate

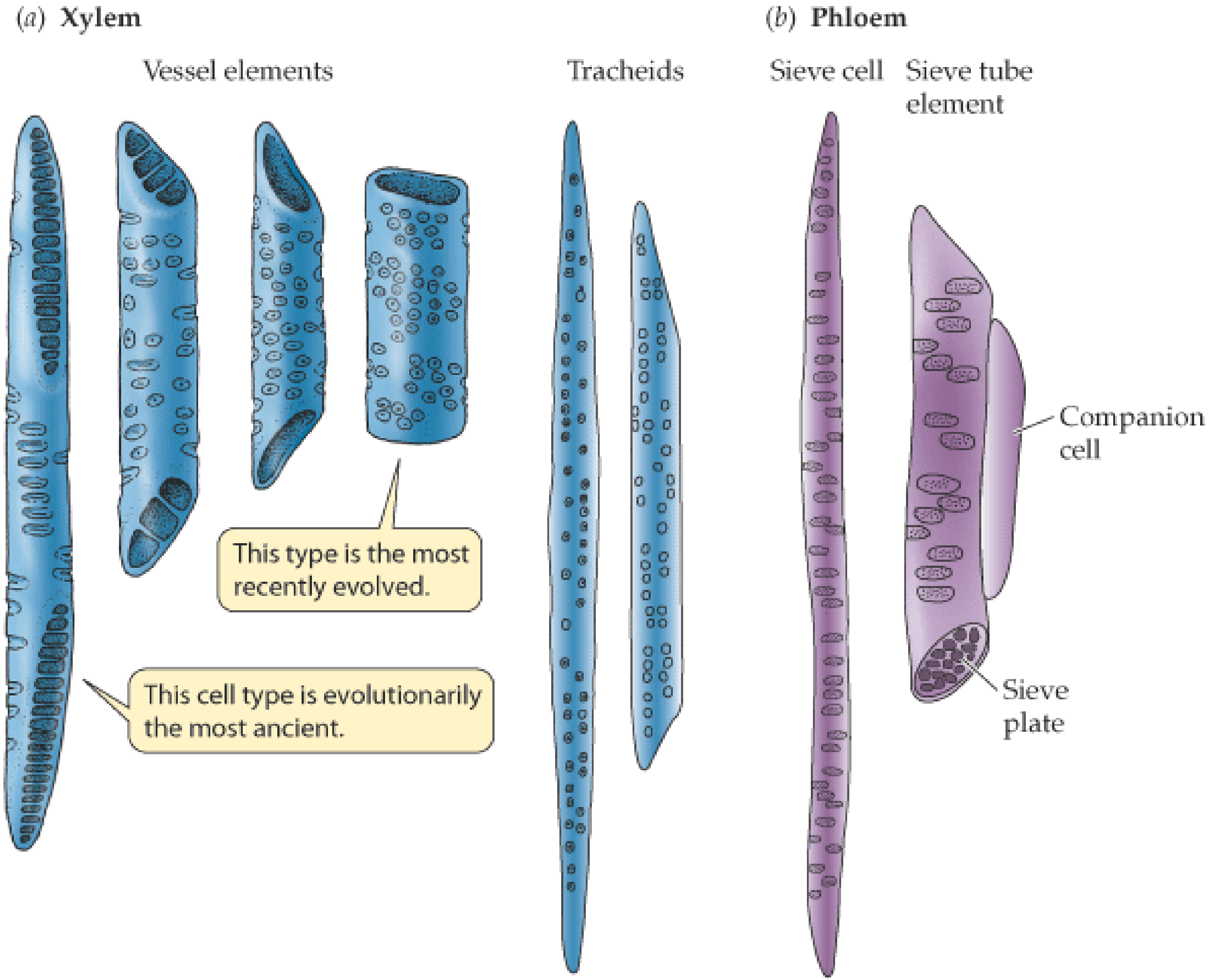
- The end walls, where two sieve elements meet, form the sieve plate.
- These are perforated by a number of large pores (not completely broken down as in xylem).





LONGITUDINAL SECTION
CROSS-SECTION
Sieve plates




(a) Xylem
Vessel elements
Tracheids
This type is the most recently evolved.
This cell type is evolutionarily the most ancient.
(b) Phloem
Sieve cell
Sieve tube element
Companion cell
Sieve plate

COMPANION CELLS

- Each sieve element has at least one companion cell adjacent to it.
- Companion cells have a typical cell structure with the exception of having more mitochondria and ribosomes than the usual plant cell.
- This reflects the fact that they are very metabolically active.

- Companion cells are linked to sieve elements by numerous plasmodesmata.
- The fact that the sieve element has lost so many of its organelles means that it needs a companion cell with a nucleus to help it survive.

Transport of water across the root

- Any solution has a negative water potential
- Water will always move from a more dilute solution with a high water potential less negative) to a concentrated solution with a lower water potential (more negative).
- Water will move form a cell of water potential -150kPa to an adjacent cell with water potential of -300kPa

- Where does water enter the root?

    root hair cells in the piliferous layer

- What is special about this area that prevents water entering other areas of the root?

    doesn't have a cuticle so that it is permeable to water

- What is the process that allows the root to take up water?

    osmosis

- When water enters a root hair cell, its water potential rises compared to the adjacent cells.
- Water moves into the next cell by osmosis.
- The water potential in the xylem is lower than that in the root hairs, so water travels across the cortex to the xylem vessels at the centre of the root.

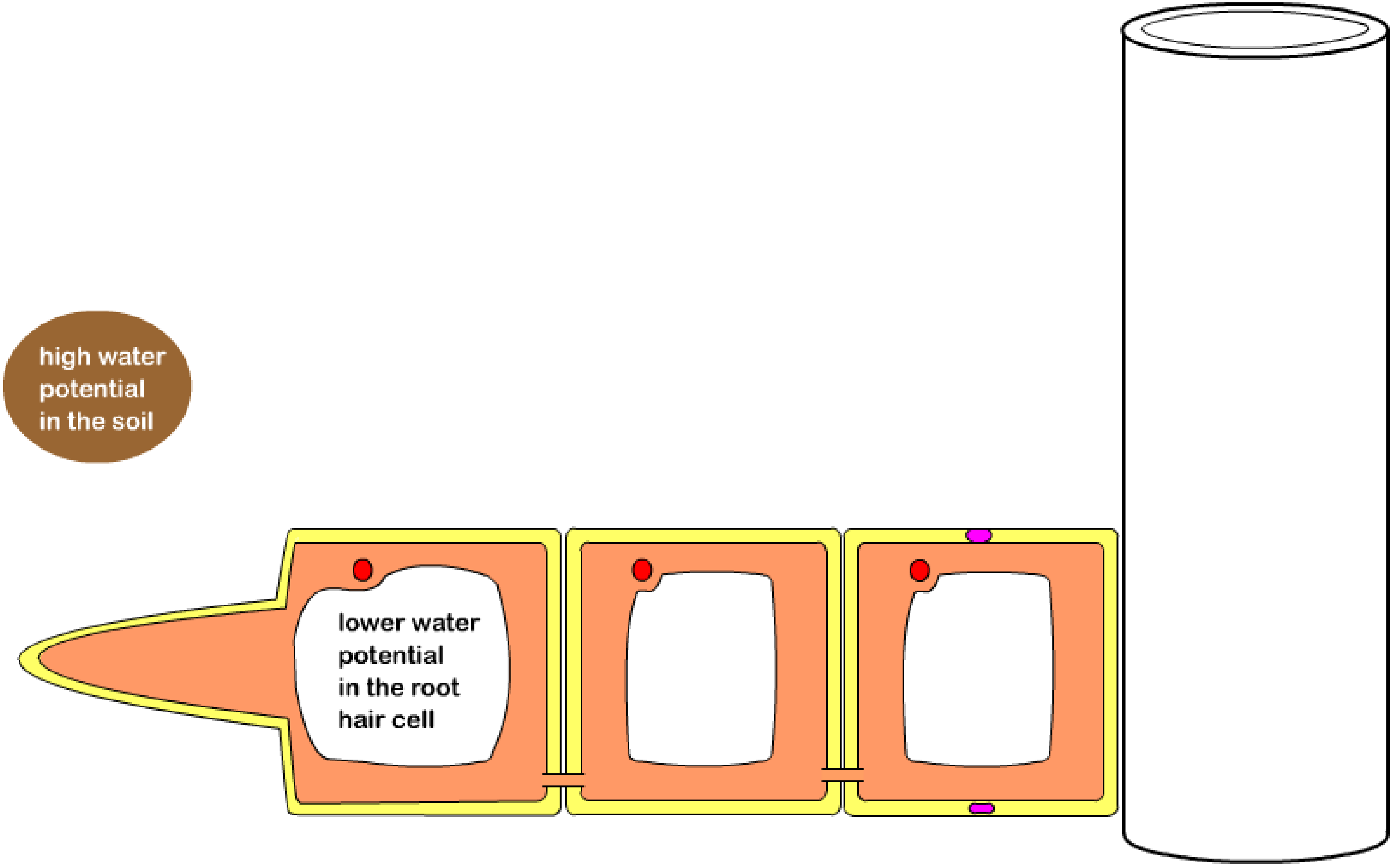
- Water moves through these cells by 2 routes:

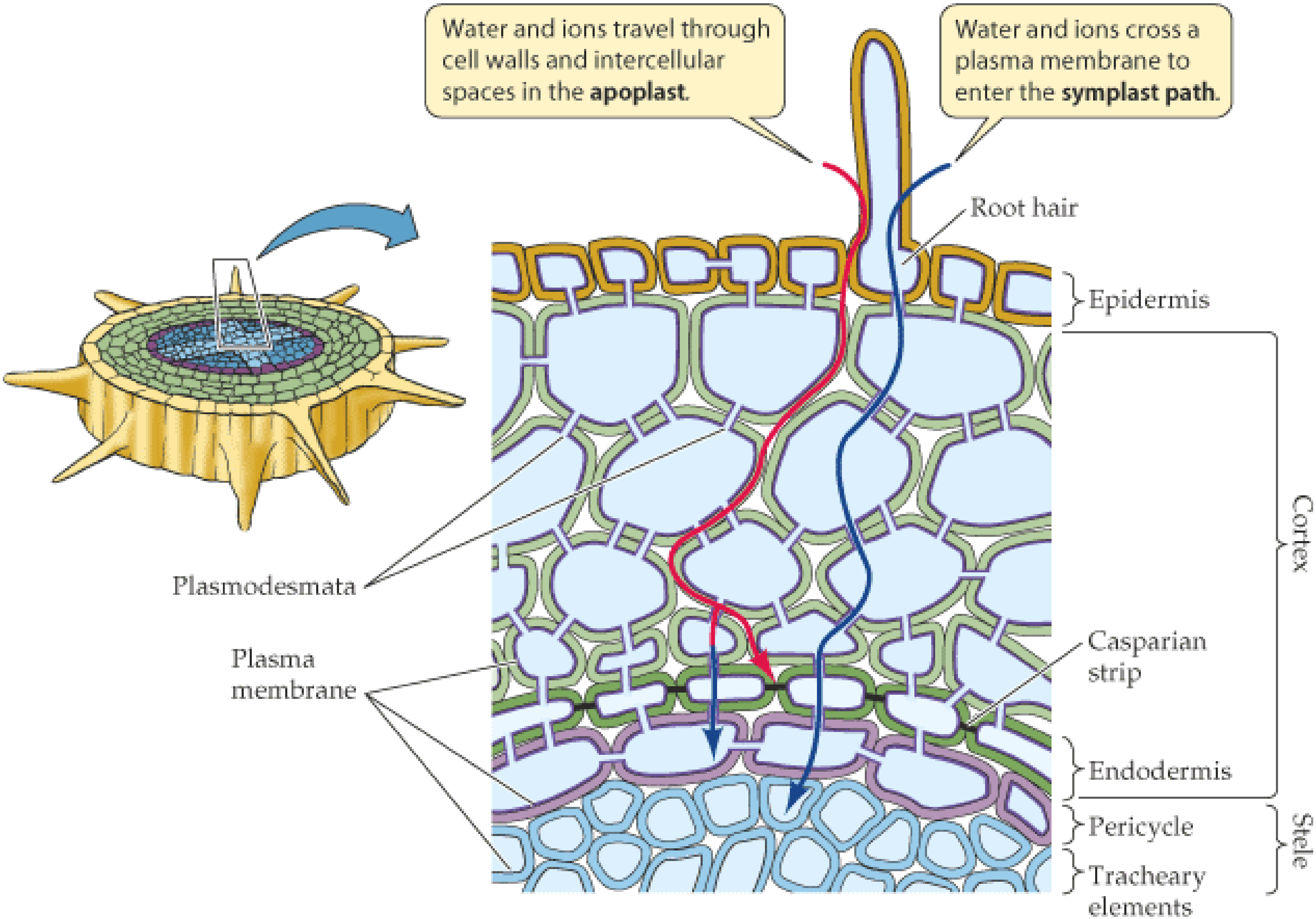
symplast route

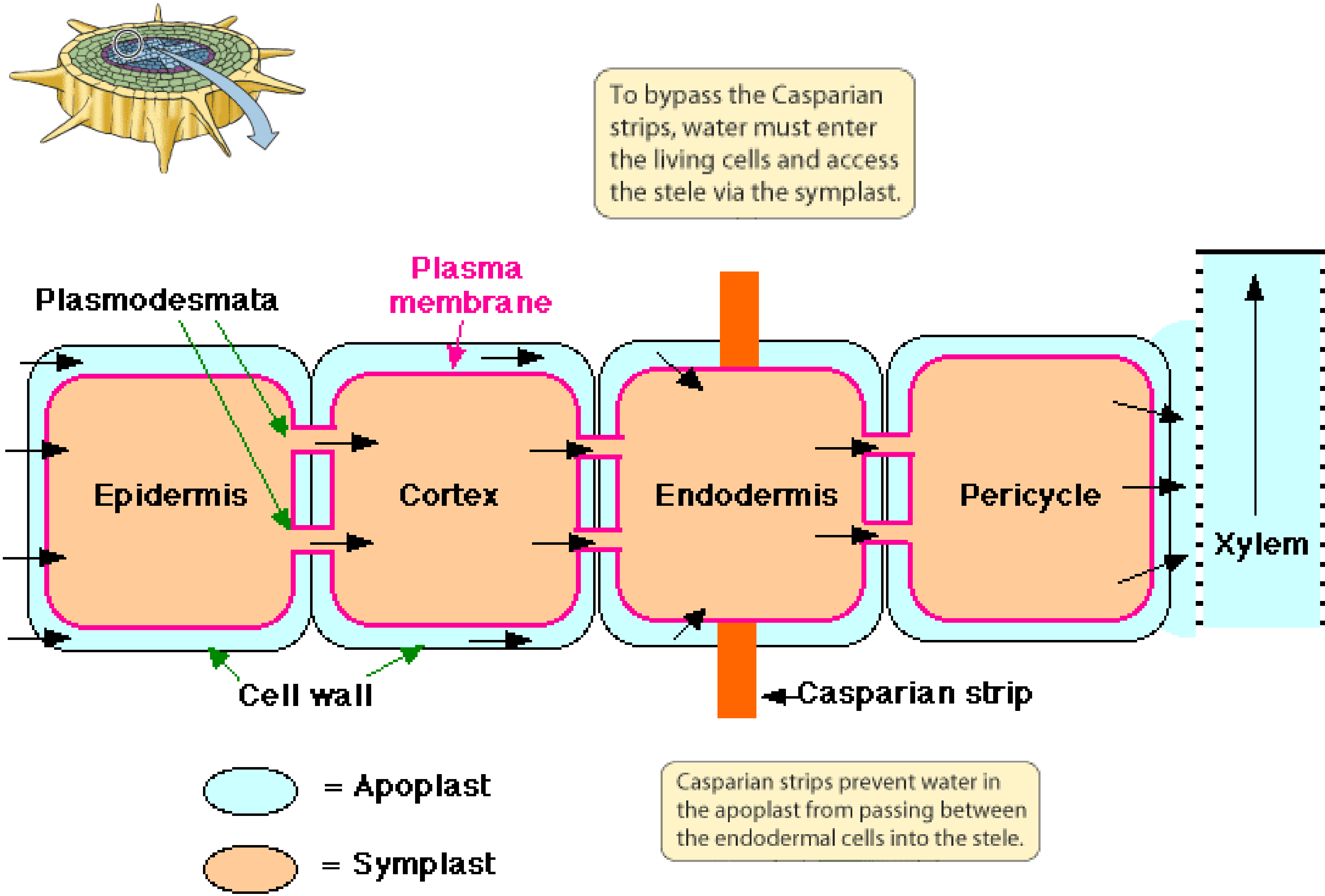
- Water moves through the **PROTOPLASTS** of the cortex cells
- Water can move along the **plasmodesmata** that connect one cell to the next.

apoplast route

- Water moves through the **CELL WALLS** of the cortex cells
- As water passes through the spaces between the cellulose fibres the cohesive forces between the water molecules means more water is pulled along the apoplastic route.


high water
potential
in the soil
lower water
potential
in the root
hair cell


Water and ions travel through cell walls and intercellular spaces in the **apoplast**.
Water and ions cross a plasma membrane to enter the **symplast path**.
Root hair
Epidermis
Cortex
Plasmodesmata
Plasma membrane
Casparian strip
Endodermis
Pericycle
Stele
Tracheary elements



To bypass the Casparian strips, water must enter the living cells and access the stele via the symplast.
Plasmodesmata
Plasma membrane
Epidermis
Cortex
Endodermis
Pericycle
Xylem
Cell wall
Casparian strip
= Apoplast
= Symplast
Casparian strips prevent water in the apoplast from passing between the endodermal cells into the stele.

- The apoplast route is blocked at the endodermis.
- The cell walls of the endodermis are impregnated with waxy **SUBERIN**.
- This forms a band of wax around the cells called the **CASPARIAN STRIP**.
- As suberin is **waterproof** the Casparian strip stops water passing along the cell walls.
- To pass through the CS water must cross the cell membrane and pass into the cytoplasm and continue along the symplast route into the stele.

transpiration

- This is the evaporation of water from a plant
  - Most through stomata of the leaves
  - Small amount through cuticle of leaves
- Water evaporates from the moist cell walls of the spongy mesophyll cells into the air spaces
- The spaces become saturated with water vapour
- When the water potential of the air is less than the air spaces water diffuses out of the leaf.

- Diagram top p 202

Factors affecting the rate of transpiration

Internal factors:

- Leaf surface area
- Stomatal density
- Cuticle thickness

External factors:

- Light intensity (influencing stomatal aperture)
- Air currents
- Temperature
- Humidity
- Soil water availability

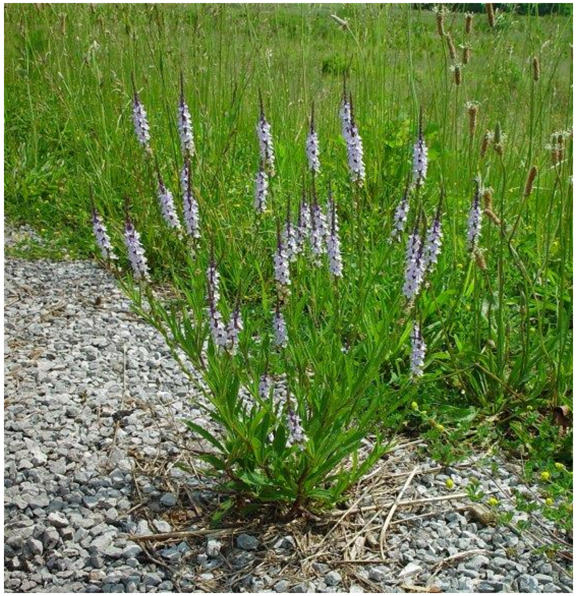
the movement of water through the xylem

Root Pressure Theory

PUSHes water up the xylem.

Seen when you cut the stem of a potted plant near the base, water seeps out.

This plays a minor role in the movement of water up the stem.



- Mineral ions dissolved in the water travelling along the apoplast route cannot diffuse across the cell membrane and are actively secreted into the cytoplasm and xylem.
- This lowers the water potential in the xylem, causing water to be drawn through the endodermis.
- This pulling of water from the surrounding cells produces a positive hydrostatic pressure inside the xylem, forcing the water upwards.
- This is called **ROOT PRESSURE**.

Cohesion-Tension theory

Transpiration creates a negative pressure within the leaf xylem vessels resulting in the transpiration stream which

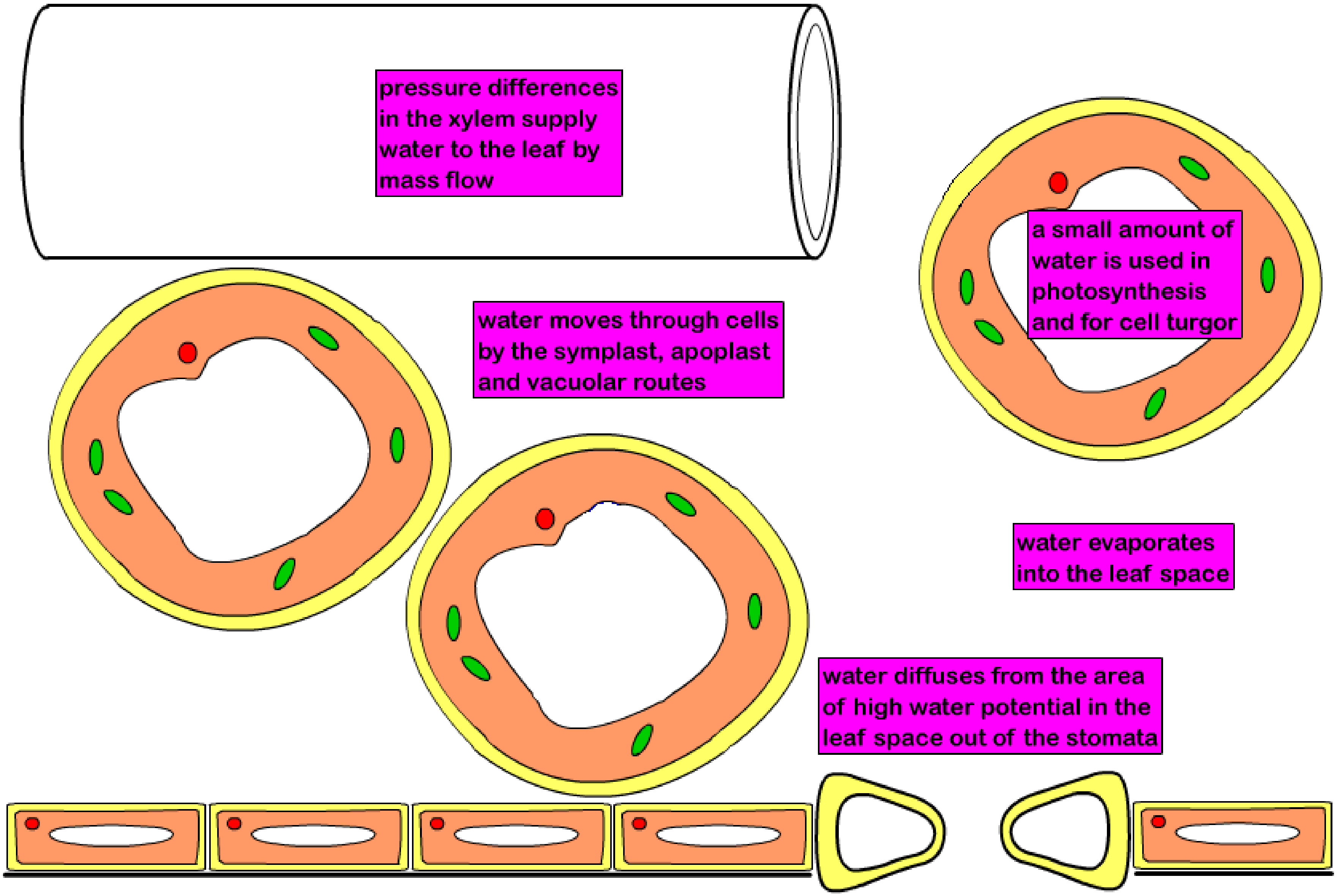
PULLs water up the xylem

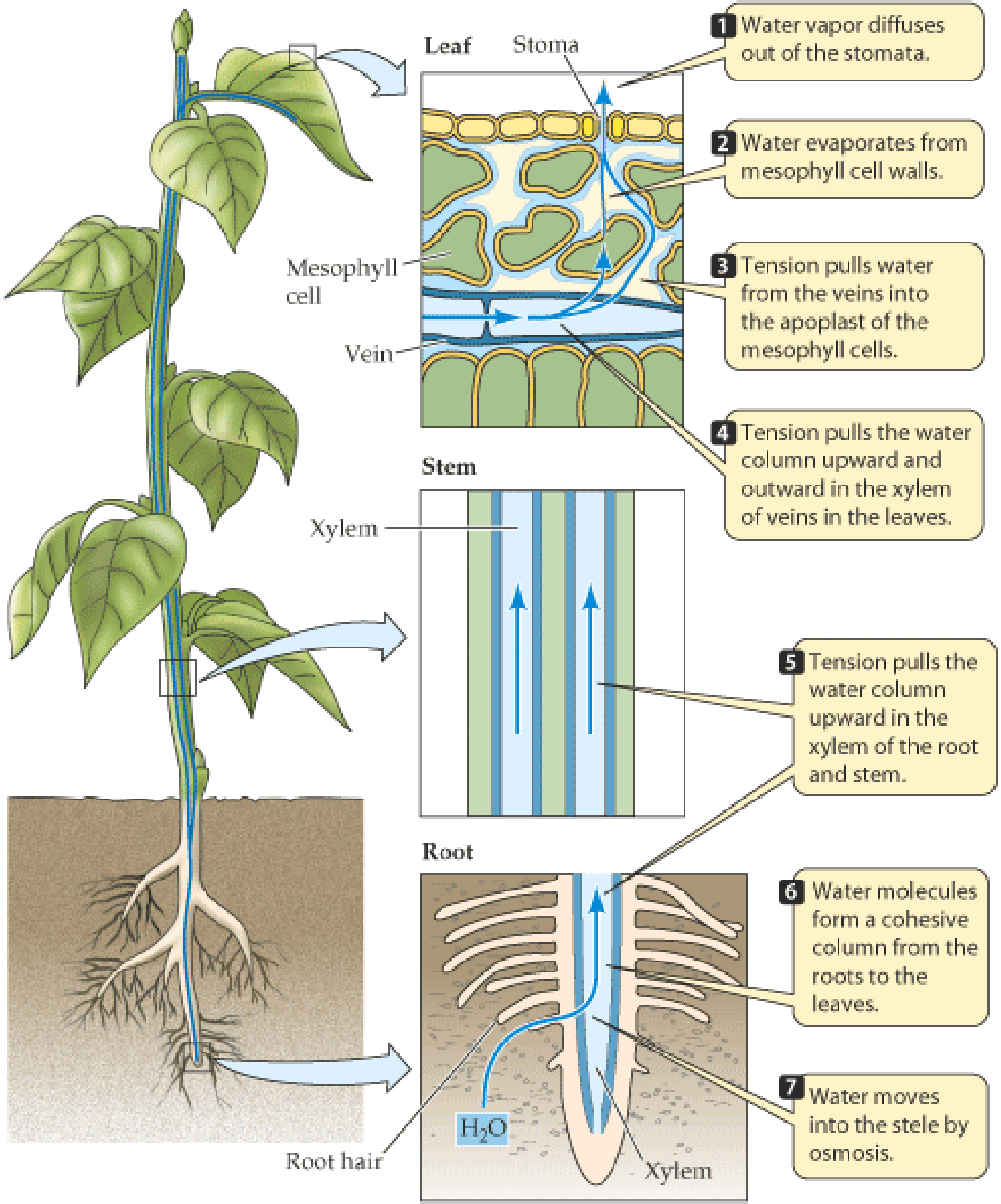
This is due to:

COHESION: water molecule stick together due to H bonds

ADHESION: water molecules stick to the sides of the xylem vessels

TENSION: pressure created as molecules pull on each other


pressure differences in the xylem supply water to the leaf by mass flow
a small amount of water is used in photosynthesis and for cell turgor
water moves through cells by the symplast, apoplast and vacuolar routes
water evaporates into the leaf space
water diffuses from the area of high water potential in the leaf space out of the stomata



Leaf
Stoma
Mesophyll cell
Vein
1 Water vapor diffuses out of the stomata.
2 Water evaporates from mesophyll cell walls.
3 Tension pulls water from the veins into the apoplast of the mesophyll cells.
4 Tension pulls the water column upward and outward in the xylem of veins in the leaves.
Stem
Xylem
5 Tension pulls the water column upward in the xylem of the root and stem.
Root
6 Water molecules form a cohesive column from the roots to the leaves.
7 Water moves into the stele by osmosis.
H_2O
Root hair
Xylem

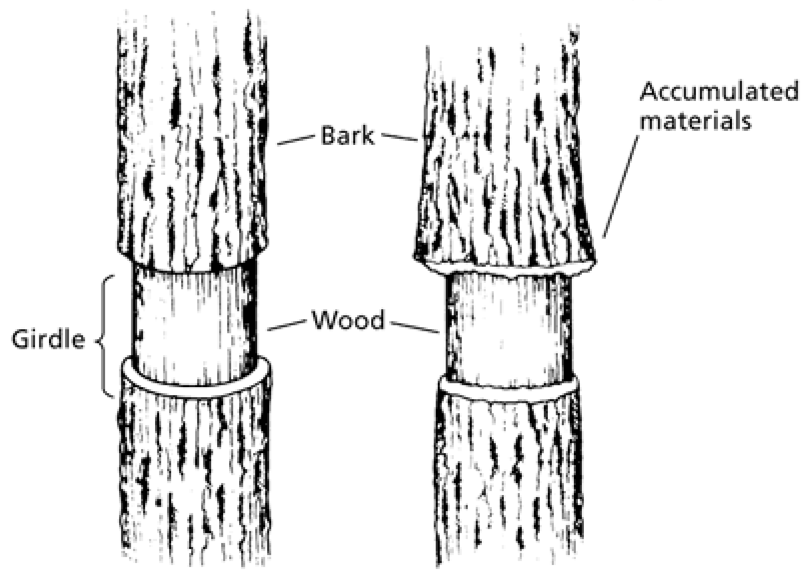
the cohesion-tension theory

Read page 206

translocation

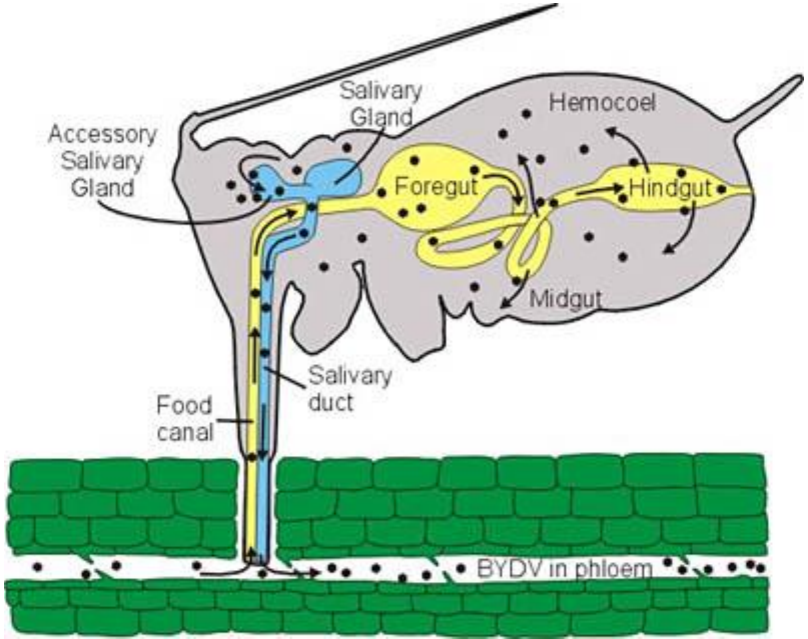
- This is the movement of organic solutes through the phloem.
- It involves energy expenditure (companion cells) and two way flow.
- Evidence exists from a number of experiments.

1. Bark ringing - When a ring of bark is removed that includes the phloem tissue, sugars accumulated above the cut area.

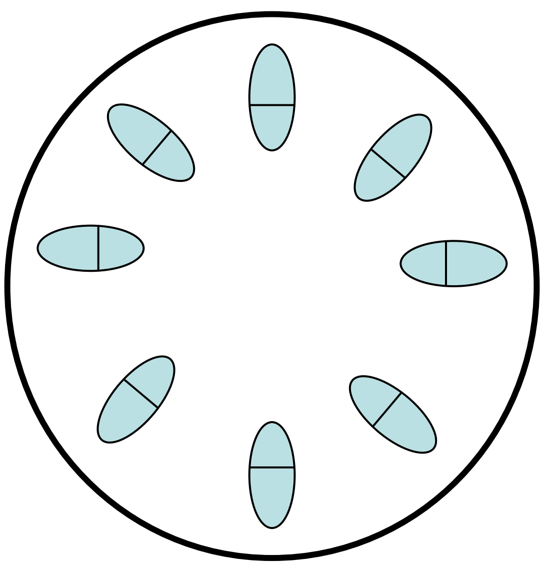


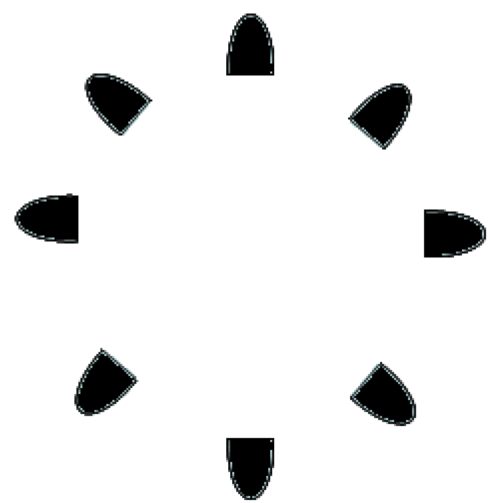
The tree did not wilt, so the xylem must be undamaged. Bark ringing will eventually lead to the death of the tree as the roots are deprived of sugars.

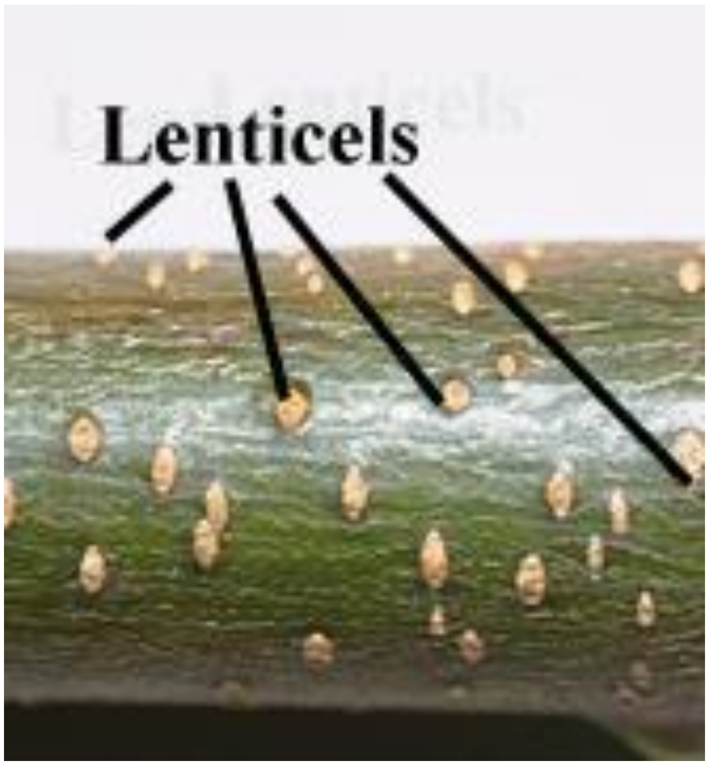
2. Aphid mouthparts - are hollow and needle-like. The aphids can be removed leaving the mouthparts in situ in the plant stems where the aphids have been feeding. The sap drained out through the mouthpart is analysed and shown to contain sugars, while the position of the mouthpart shows that the aphid was feeding from the phloem.

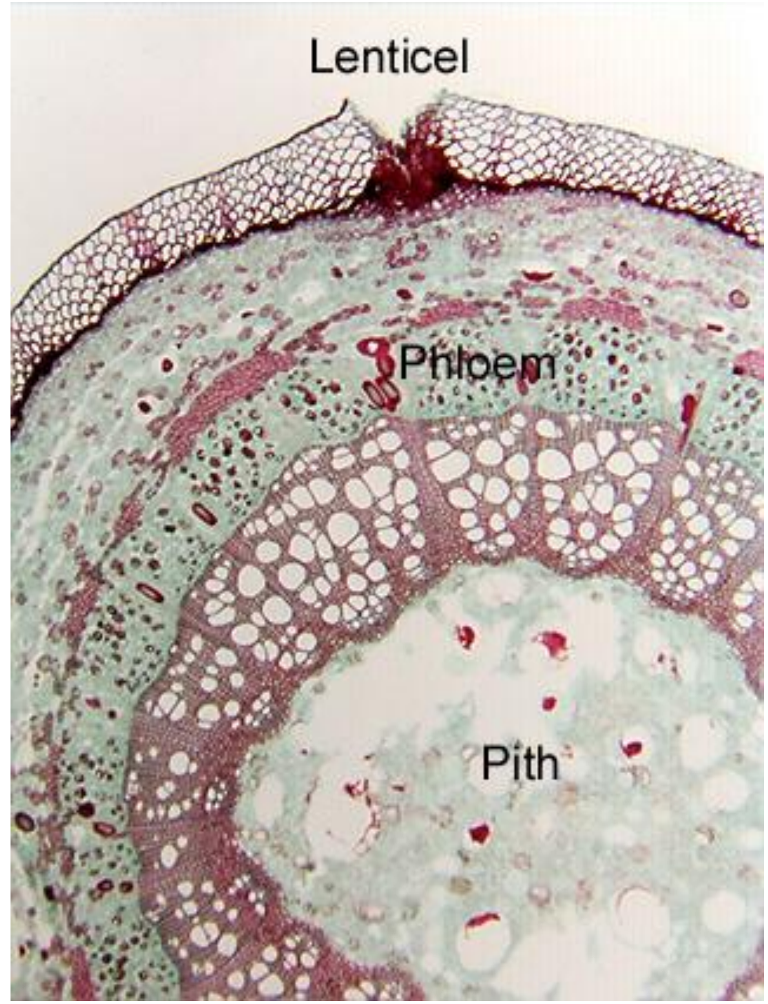


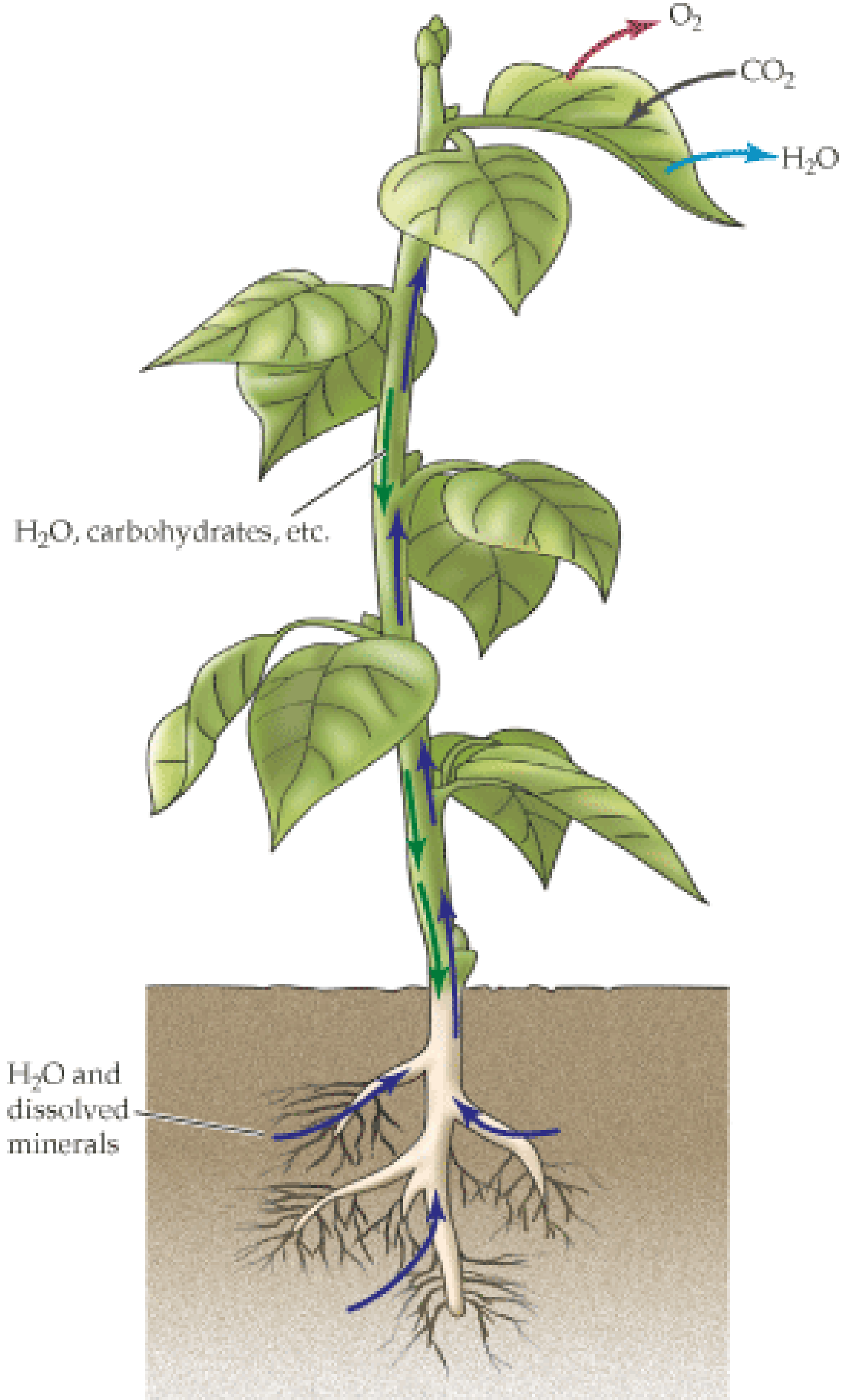
- 3. Radioactive tracers – Carbon dioxide is labelled using radioactive Carbon 14 and given to plants. It becomes converted to radioactive sugars. The movement of these sugars can be detected by taking autoradiographs of plant sections.



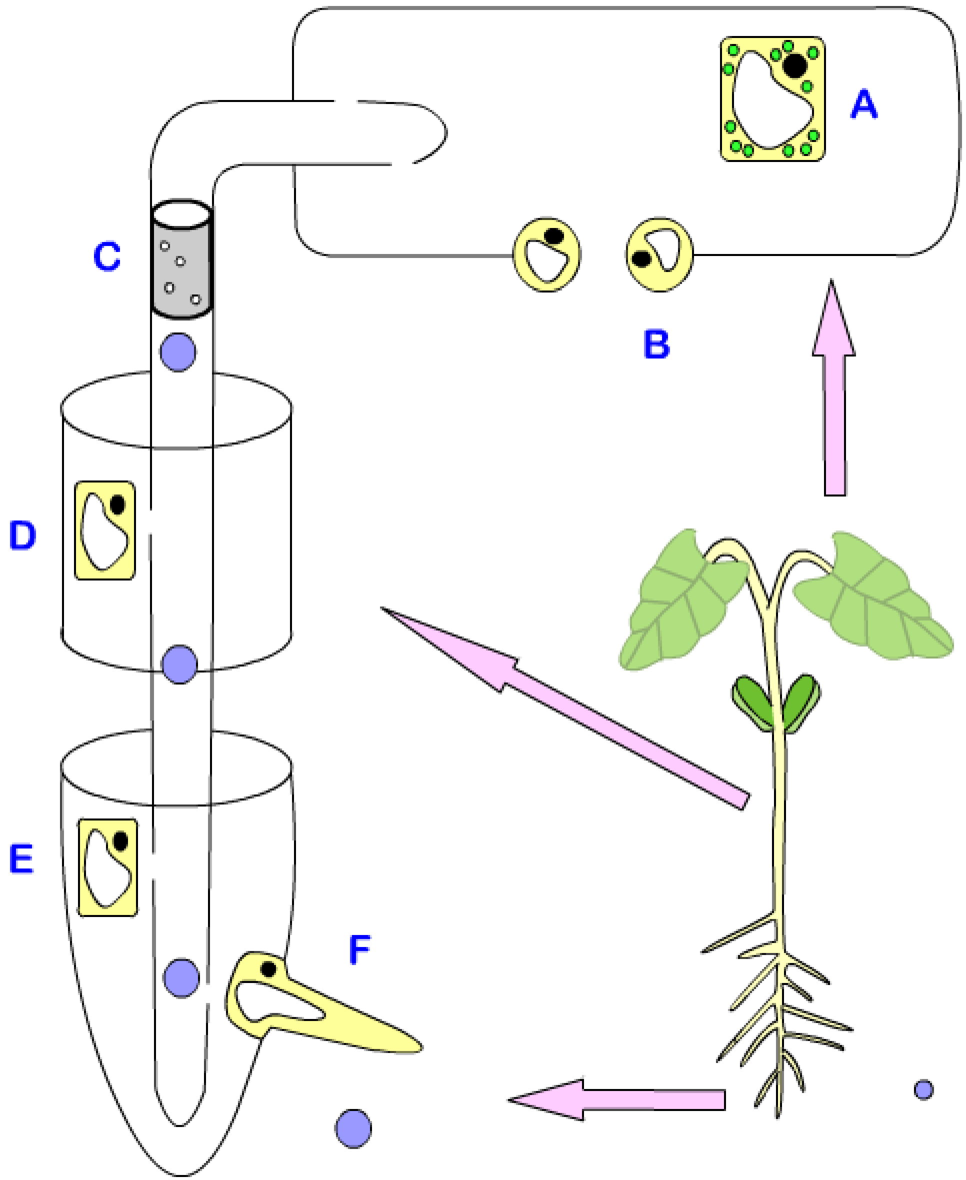



Lenticels

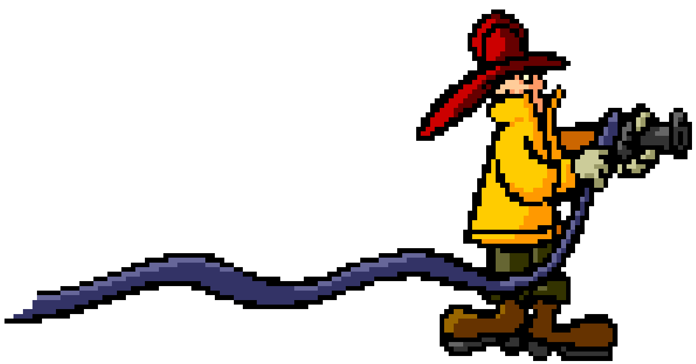

Lenticel
Phloem
Pith

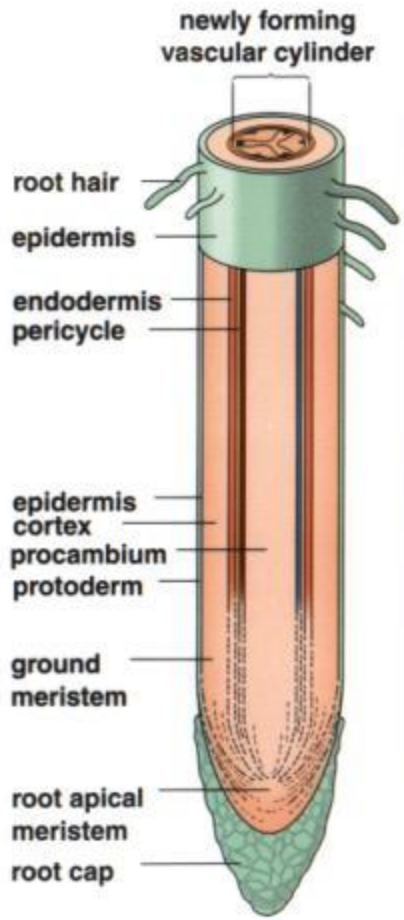


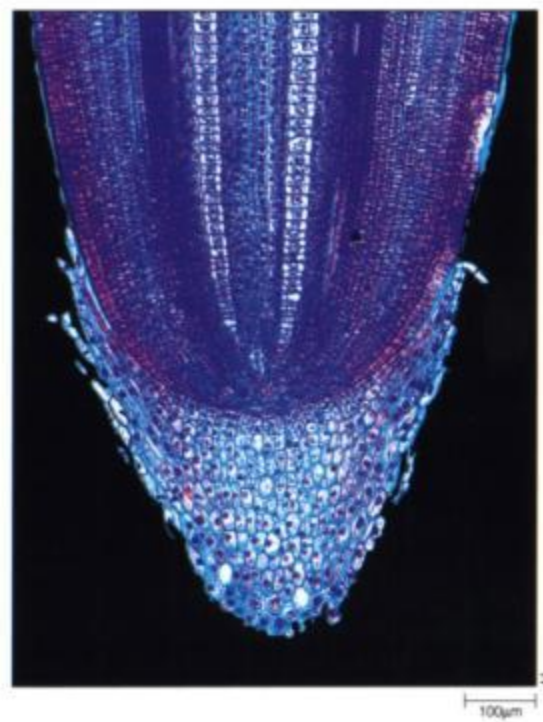
O_2
CO_2
H_2O
H_2O, carbohydrates, etc.
H_2O and dissolved minerals

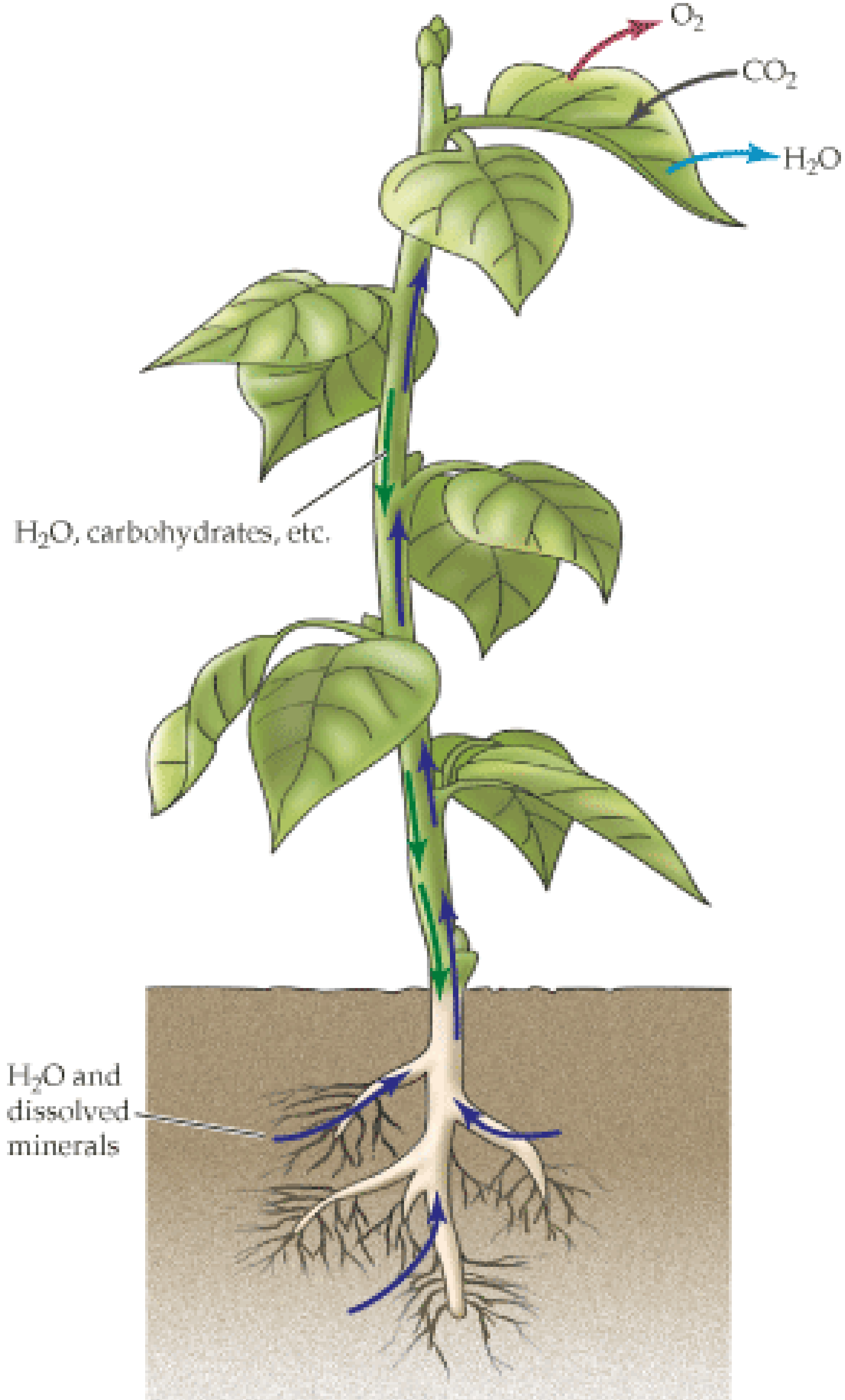

A
B
C
D
E
F

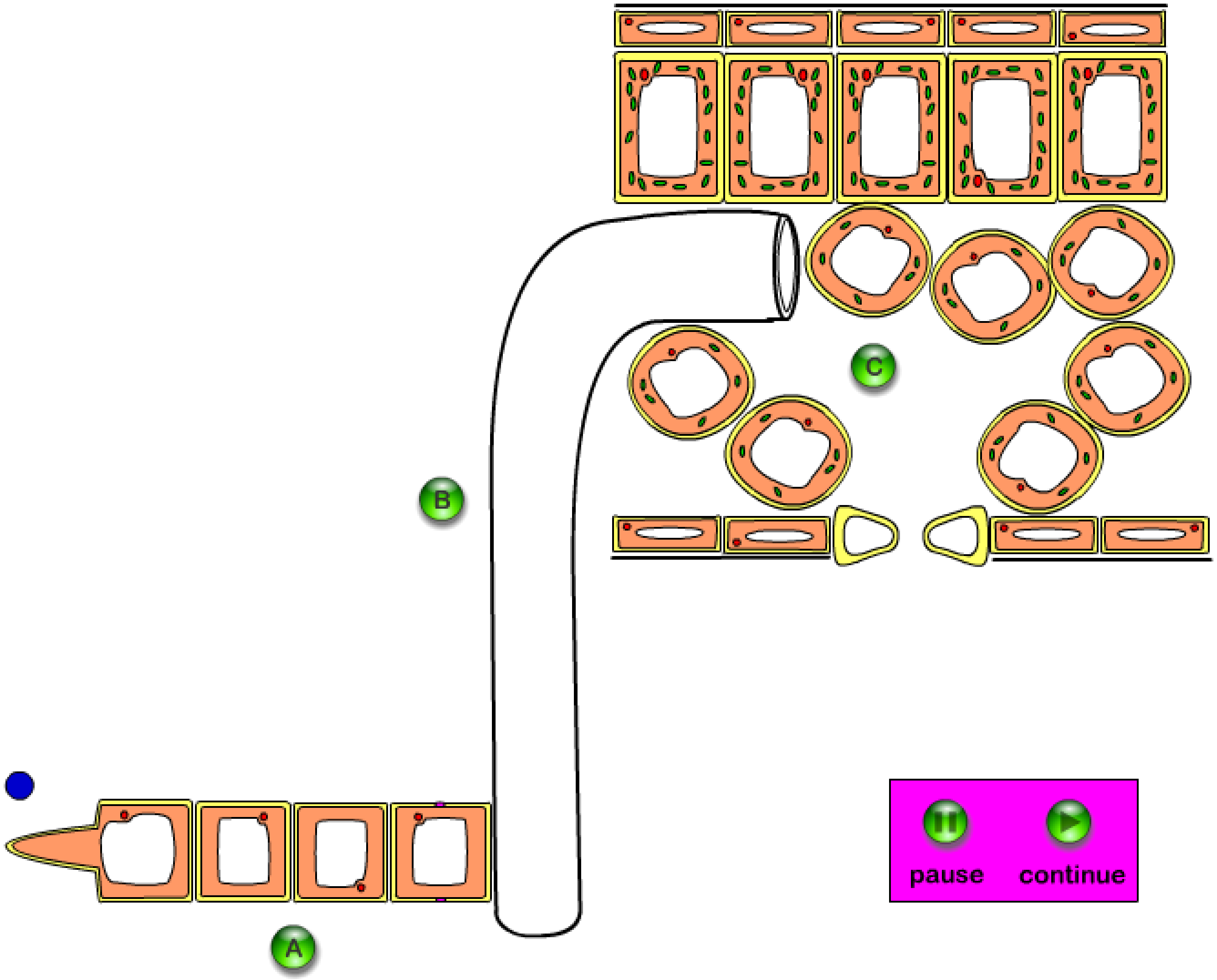
Hose activity




newly forming
vascular cylinder
root hair
epidermis
endodermis
pericycle
epidermis
cortex
procambium
protoderm
ground
meristem
root apical
meristem
root cap


100μm


O_2
CO_2
H_2O
H_2O, carbohydrates, etc.
H_2O and dissolved minerals



pause continue