SLE 132 – Form and Function
Plant Growth

Plant Growth

- A plant can grow throughout its life; this is called **indeterminate growth**
- Some plant organs cease to grow at a certain size; this is called **determinate growth**

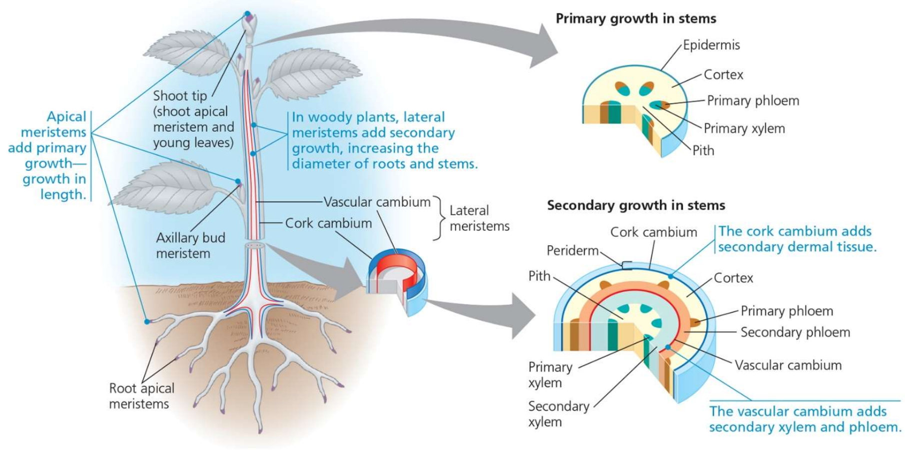
- **Annuals** complete their life cycle in a year or less
- **Biennials** require two growing seasons
- **Perennials** live for many years

Meristems

- Meristems are **perpetually embryonic tissue** (plant stem cells) and allow for indeterminate growth
- Apical meristems are located at the tips of roots and shoots and at the axillary buds of shoots
- Apical meristems **elongate shoots and roots**, a process called **primary growth**

Meristems

- Lateral meristems add **thickness to woody plants**, a process called **secondary growth**
- There are two lateral meristems: the **vascular cambium** and the **cork cambium**
- The **vascular cambium** adds layers of vascular tissue called <u>secondary xylem (wood) and secondary phloem</u>
- The **cork cambium** <u>replaces the epidermis with periderm</u>, which is thicker and tougher



▲ **Figure 35.11** An overview of primary and secondary growth.

Pith in centre with primary xylem around it
Around this the vascular cambium adds secondary xylem and phloem
(Secondary xylem, on the inside of vascular cambium, then secondary phloem on outside)

Primary phloem then cortex, then cork cambium, then periderm.

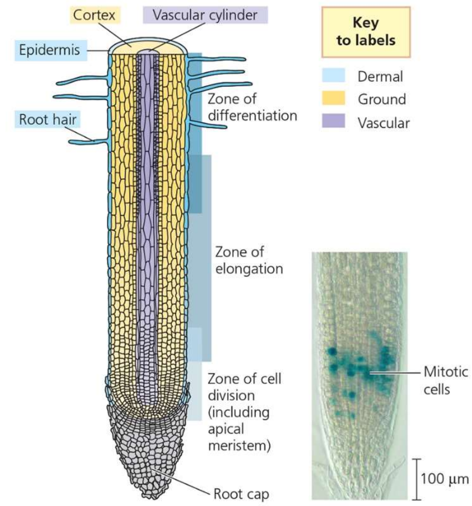
Primary Growth – Root system

- **Primary growth produces the primary plant body**, the parts of the root and shoot systems produced by apical meristems
- The root tip is covered by a **root cap**, which protects the apical meristem as the root pushes through soil.
- Root tip is **constantly degraded** by being pushed through the soil and replaced by cells from the apical meristem.
- Elongation of the cells behind the apical meristem pushes the root tip forward.

Primary Growth – Root system

Growth occurs just behind the root cap, in three zones of cells:

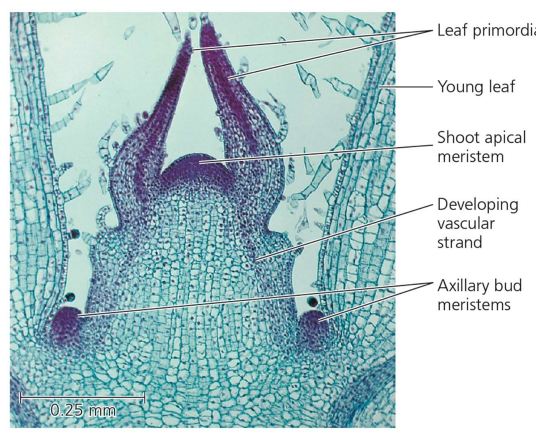
- Zone of cell division
- Zone of elongation
- Zone of maturation (differentiation)



▲ **Figure 35.13 Primary growth of a root.** The diagram depicts the anatomical features of the tip of a typical eudicot root. The apical meristem produces all the cells of the root. Most lengthening of the root occurs in the zone of elongation. In the micrograph, cells undergoing mitosis in the apical meristem are revealed by staining for cyclin, a protein that plays an important role in cell division (LM).

Primary Growth – Shoot system

- A shoot apical meristem is a dome-shaped mass of dividing cells at the shoot tip
- **Leaves develop from leaf primordia** along the sides of the apical meristem
- **Axillary buds develop from meristematic cells** left at the bases of leaf primordia
- Axillary buds are regions of meristematic cells at the node between the stem and the leaf which can later develop into a stem or flower



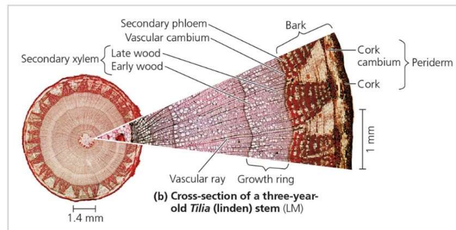
▲ **Figure 35.16 The shoot tip.** Leaf primordia arise from the flanks of the dome of the apical meristem. This is a longitudinal section of the shoot tip of *Coleus* (LM).

Secondary Growth

- Secondary growth occurs in stems and roots of woody plants but <u>rarely in leaves</u>
- The secondary plant body consists of the tissues **produced by the vascular cambium and cork cambium**
- Secondary growth is characteristic of gymnosperms and many eudicots, but <u>not monocots</u>

▲ **Figure 35.19 Primary and secondary growth of a woody stem.** The progress of secondary growth can be tracked by examining the sections through sequentially older parts of the stem.

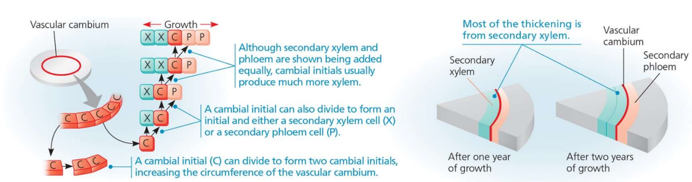
? *How does the vascular cambium cause some tissues to rupture?*



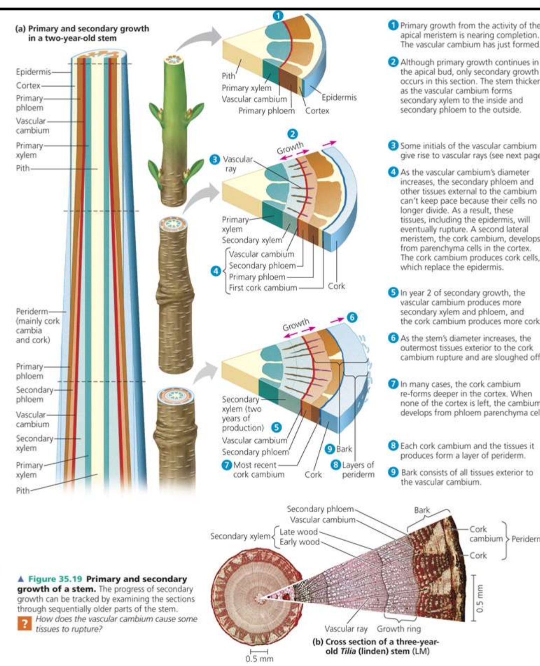
(b) Cross-section of a three-year-old *Tilia* (linden) stem (LM)

Secondary Growth

- Each years production = **growth ring**
- Rings obvious due to <u>uneven cambial activity</u> during the year
- Xylem cells produced in spring are larger than those produced in summer
- **Secondary Xylem = wood**



▲ **Figure 35.20 Secondary growth produced by the vascular cambium.**



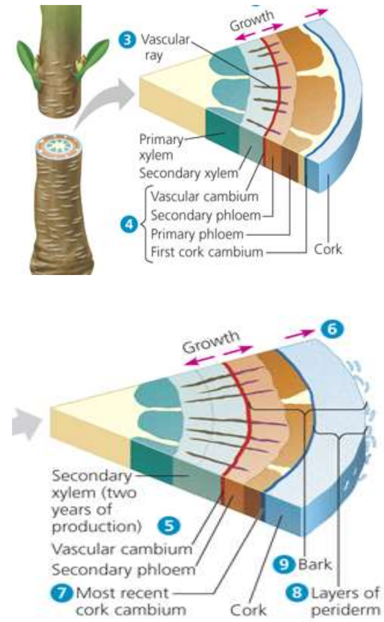
▲ **Figure 35.19 Primary and secondary growth of a stem.** The progress of secondary growth can be tracked by examining the sections through sequentially older parts of the stem.

? *How does the vascular cambium cause some tissues to rupture?*

(b) Cross section of a three-year-old *Tilia* (linden) stem (LM)

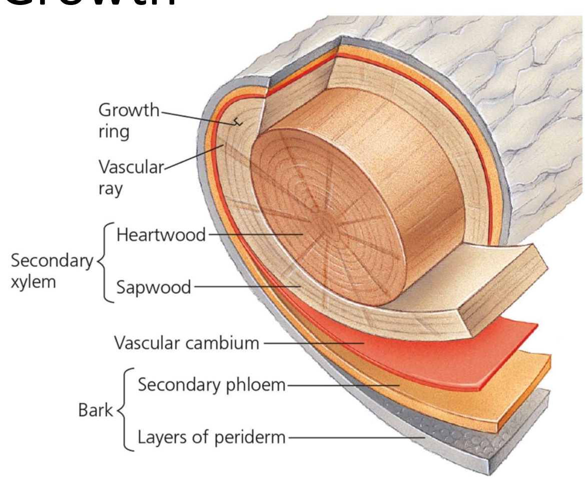
Secondary Growth

- As a tree or woody shrub ages, the older layers of secondary xylem, the inner layer, **heartwood**, **no longer transport** water and minerals
- The outer layers, known as **sapwood**, **still transport** materials through the xylem
- Older secondary phloem **sloughs off** and does not accumulate



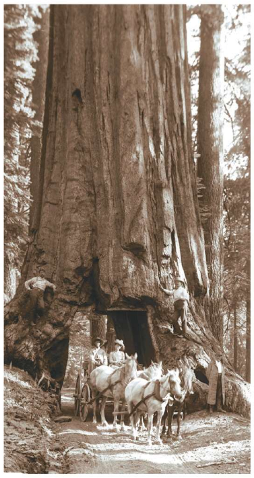
Secondary Growth

- The **cork cambium** gives rise to the secondary plant body's protective covering, or <u>periderm</u>
- Periderm consists of the cork cambium plus the layers of cork cells it produces
- **Bark** consists of <u>all the tissues external to the vascular cambium</u>, including secondary phloem and periderm



▲ **Figure 35.22** **Anatomy of a tree trunk.**

Aging a tree



▲ **Figure 35.23 Is this tree living or dead?** The Wawona Sequoia tunnel in Yosemite National Park in California was cut in 1881 as a tourist attraction. This giant sequoia (*Sequoiadendron giganteum*) lived for another 88 years before falling during a severe winter. It was 71.3 m tall and estimated to be 2,100 years old. Though conservation policies today would forbid the mutilation of such an important specimen, the Wawona Sequoia did teach a valuable botanical lesson: Trees can survive the excision of large portions of their heartwood.

Tree rings – visible where late and early wood meet, can be used to estimate a tree's age

Dendrochronology: analysis of tree ring growth patterns, can be used to study past climate change

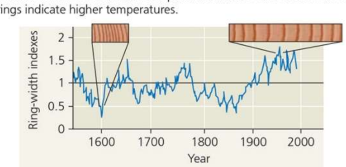
▼ Figure 35.21 Research Method

Using Dendrochronology to Study Climate

Application Dendrochronology, the science of analysing growth rings, is useful in studying climate change. Most scientists attribute recent global warming to the burning of fossil fuels and release of CO_2 and other greenhouse gases, whereas a small minority think it is a natural variation. Studying climate patterns requires comparing past and present temperatures, but instrumental climate records span only the last two centuries and apply only to some regions. By examining growth rings of Tasmanian Huon pine dating back over 3,500 years, Edward Cook, of the Lamont-Doherty Earth Observatory, and colleagues sought to learn whether Tasmanian Huon pines experienced similar warm periods in the past.

Technique Researchers can analyse patterns of rings in living and dead trees. They can even study wood used for building long ago by matching samples with those from naturally situated specimens of overlapping age. Core samples, each about the diameter of a pencil, are taken from the bark to the centre of the trunk. Each sample is dried and sanded to reveal the rings. By comparing, aligning, and averaging many samples from the Huon pines, the researchers compiled a chronology. The trees became a chronicle of environmental change.

Results This graph summarises a composite record of the ring-width indexes for the Tasmanian Huon pines from 1600 to 2000. Wider tree rings indicate higher temperatures.



Source: E. R. Cook et al. (2000), Warm-season temperatures since 1600 CE reconstructed from Tasmanian tree rings and their relationship to large-scale sea surface temperature anomalies, *Climate Dynamics* 16:79–91.

INTERPRET THE DATA *What does the graph indicate about environmental change during the period 1500–2000?*

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Quick Question

1. Which of the following is responsible for the increase in girth (width) of trees?

A. Primary growth
B. Secondary Growth
C. Growth in apical meristems
D. An increase in the width of vessel elements

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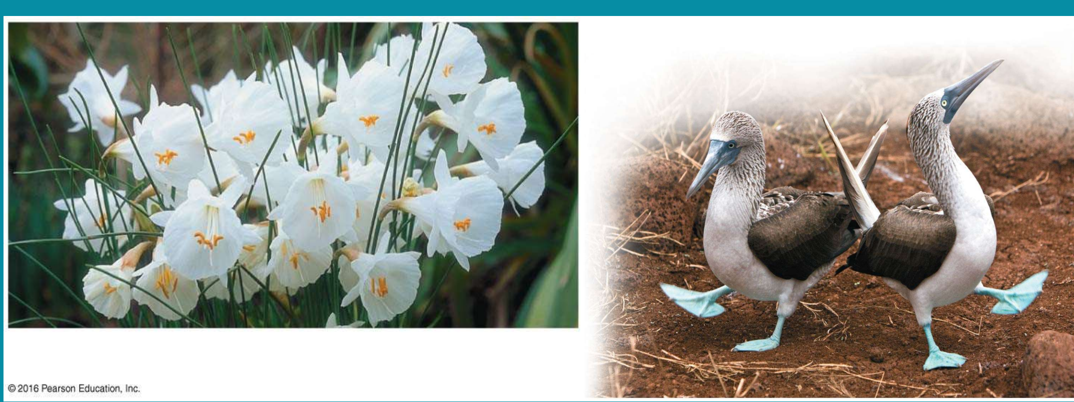
Quick Question

2. Where is primary growth occurring in an old tree?

A. Closed to the ground level at the base of the tree
B. In young branches where leaves are forming
C. Where the vascular cambium and cork cambium are located
D. Nowhere. Trees more than a year old have only secondary growth

SLE 132 – Form and Function
Transport in Plants



Water Transport in Plants

- The total quantity of water absorbed by any plant is enormous
- 99% of the water absorbed is lost via water vapour in transpiration

Plant	Litres/plant/growing season
Potato	95
Wheat	95
Tomato	125
Corn	206

- In summer a 20 meter Maple can loose 200 litres/hour

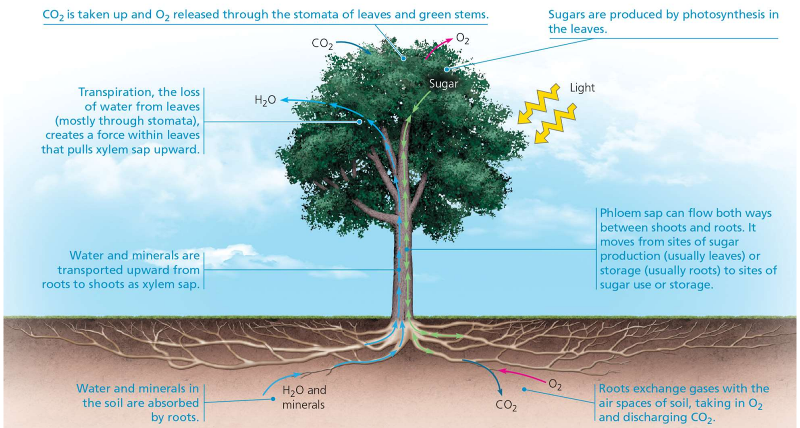
Review Water Transport in Plants

https://www.youtube.com/watch?v=5CMrK8rlzZw

Transpiration

- Transpiration is the water movement through the plant and its evaporation from the leaves, roots and flowers.

▼ **Figure 36.2** An overview of resource acquisition and transport in a vascular plant.



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Water Transport in Plants

Transpiration occurs from any above ground plant part but **mainly from the leaf**

- Can occur through the <u>cuticle</u>
  - but only very little water is lost as the cuticle is impervious to water
- Through <u>lenticels</u> (spongy regions in bark)
  - only a small amount lost here
- Mainly through <u>stomata</u>
  - openings in the epidermis each surrounded by 2 guard cells.

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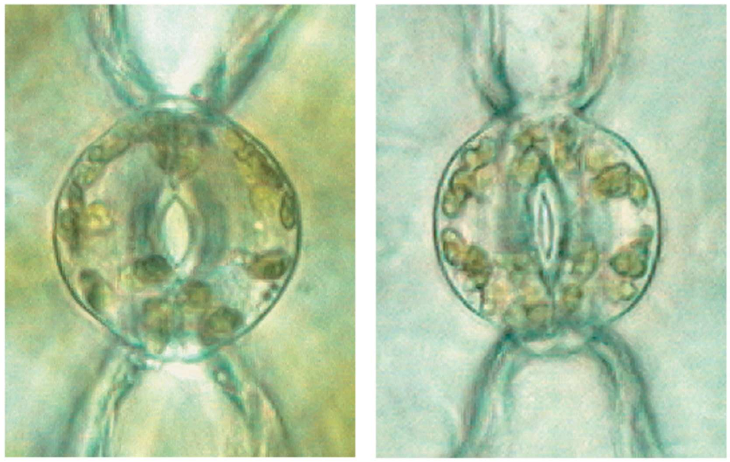

▲ **Figure 36.12** An open stoma (left) and a closed stoma (LMs).

Stomata open and close to limit or allow movement of water, oxygen, and carbon dioxide

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Transpiration

- Stomatal transpiration involves two steps

1. **Evaporation** of water from the cell wall surfaces bordering air spaces within the leaf
2. **Diffusion** of resultant water vapour from the intercellular spaces into the atmosphere by way of the stomata

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Stomata

- Large number of stomata on any leaf
  - e.g. 1200 stomata per cm^2 in tobacco
- Although numerous they only cover about 1% of the total leaf surface area
- Air spaces make up about 15% to 40% of total leaf volume
- Closure of stomata prevents water loss but **limits photosynthesis as no carbon dioxide can enter the leaf**
- Transpiration/photosynthesis compromise

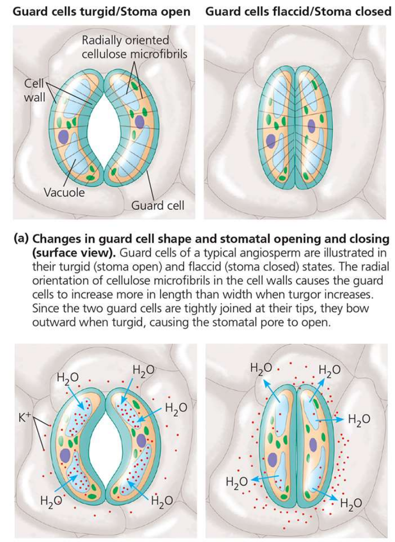
Mechanism of stomatal movement

Generally:

- Stomata open and close with changes in **turgor of guard cells** (remember turgid = swollen)
- Stomata are **open when turgid** and **closed when flaccid**.
- The radial orientation of the microfibrils allow for <u>increase in length rather than width</u> as they are resistant to stretching and compression in the directional parallel to the microfibrils.

Remember diffusion/osmosis…water and solute balance?

- Guard cells close when **K^+ ions are transported** across the tonoplast (vacuole membrane) and plasmalemma (membrane of guard cells) to adjacent cells.
- **Water then follows** by osmosis.
- Stomata open when guard cells **accumulate K^+ ions** which causes **uptake of water** by osmosis.



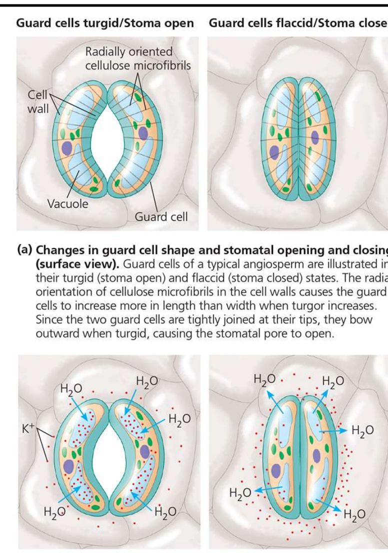
(a) Changes in guard cell shape and stomatal opening and closing (surface view). Guard cells of a typical angiosperm are illustrated in their turgid (stoma open) and flaccid (stoma closed) states. The radial orientation of cellulose microfibrils in the cell walls causes the guard cells to increase more in length than width when turgor increases. Since the two guard cells are tightly joined at their tips, they bow outward when turgid, causing the stomatal pore to open.

(b) Role of potassium ions (K^+) in stomatal opening and closing. The transport of K^+ (symbolised here as red dots) across the plasma membrane and vacuolar membrane causes the turgor changes of guard cells. The uptake of anions, such as malate and chloride ions (not shown), also contributes to guard cell swelling.

▲ **Figure 36.13** **Mechanisms of stomatal opening and closing.**

Remember diffusion/osmosis…water and solute balance?

- **K^+ ions are actively transported** from guard cells, which become hypotonic
- **Water moves** from the now hypotonic guard cells to the solution with high concentration of solutes (the adjacent cells now filled with K^+)
- Guard cells **become flaccid and close**



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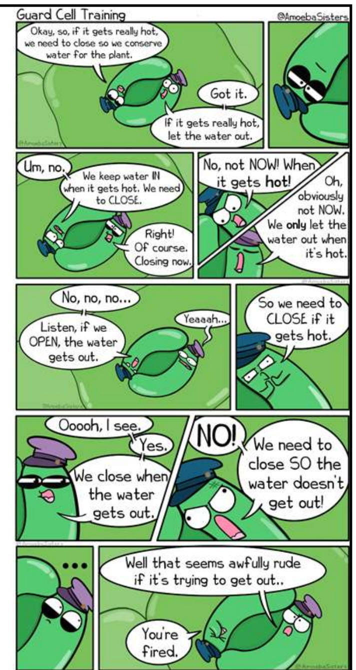
▲ **Figure 36.13** **Mechanisms of stomatal opening and closing.**

Many factors effect transpiration



- **Carbon dioxide**
  - Increase in carbon dioxide -> stomata close
  - Decrease in carbon dioxide -> stomata open
- **Light**
  - Increase in light -> stomata open
  - Decrease in light -> stomata close
- **Temperature**
  - Between 10 to 25^{o}C = little effect
  - Higher temperatures -> stomata close

Many factors effect transpiration

- **Water**
  - Decrease in water available (i.e. Water stress/high transpiration) -> stomata close
- **Hormones** i.e. Abscisic acid (ABA)
  - Increase in ABA -> stomata close
- **Biological clock**

Synergistic effects occur

1. **Increase in temperature** → increase in respiration→ increase in carbon dioxide →stomata closing
2. **Increase in water stress** → increase in ABA → stomata close
3. **Increase in light** → increase in photosynthesis → decrease in carbon dioxide → increase in potassium ions → stomata opening → water stress → stomata closing

Stomata respond to all of these environmental factors, and one factor can affect another

Factors effecting the rate of transpiration

- Main effect on rate of transpiration is the opening and closing of stomata
- Other factors include:
  - **Temperature** – transpiration rate doubles for every 10 degree rise. However, evaporation cools the leaf surface → leaf temperature doesn't rise as rapidly as that of surrounding air
  - **Humidity** – increase in humidity → decrease in water loss.
  - **Air currents** – increase in wind → decrease water vapour around the leaf → increased transpiration (but also depends on humidity)

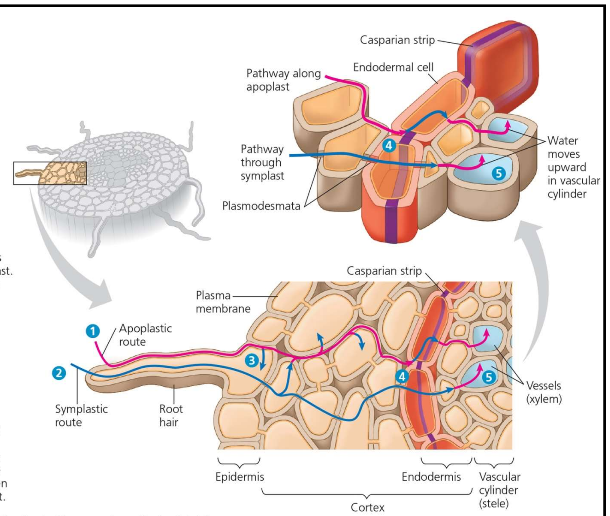
Water Transport

- Water and dissolved substances move into the roots and then into the xylem vessels via the **endodermis**
- Most plants have roots with a very large surface area
  - E.g. 4 month old rye plant has over 10 000 km of roots and many root hairs
- This high surface area means roots have a <u>high absorption ability</u>

Water transport

Water enters the root and travels through it in 3 ways:

1. **Apoplastic** – via the cell walls
2. **Symplastic** – from protoplast (the living contents of a cell surrounded by the plasma membrane) to protoplast via Plasmodesmata
3. **Transcellular** – from cell to cell passing from vacuole to vacuole



1 Apoplastic route. Uptake of soil solution by the hydrophilic walls of root hairs provides access to the apoplast. Water and minerals can then diffuse into the cortex along this matrix of walls and extracellular spaces.

2 Symplastic route. Minerals and water that cross the plasma membranes of root hairs can enter the symplast.

3 Transmembrane route. As soil solution moves along the apoplast, some water and minerals are transported into the protoplasts of cells of the epidermis and cortex and then move inward via the symplast.

4 The endodermis: controlled entry to the vascular cylinder (stele). Within the transverse and radial walls of each endodermal cell is the Casparian strip, a belt of waxy material (purple band) that blocks the passage of water and dissolved minerals. Only minerals already in the symplast or entering that pathway by crossing the plasma membrane of an endodermal cell can detour around the Casparian strip and pass into the vascular cylinder (stele).

5 Transport in the xylem. Endodermal cells and also living cells within the vascular cylinder discharge water and minerals into their walls (apoplast). The xylem vessels then transport the water and minerals by bulk flow upward into the shoot system.

▲ **Figure 36.8 Transport of water and minerals from root hairs to the xylem.**

? *How does the Casparian strip force water and minerals to pass through the plasma membranes of endodermal cells?*

Water transport

- Some trees are 100m or more tall – How can water be lifted this high in such trees?
- Logically there are two possibilities
  1. Pushed from the bottom
  2. Pulled from the top
- **Root pressure** – develops as a result of osmosis of water into the xylem, forcing both water and ions up the xylem

  HOWEVER – this is not responsible for transpiration

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Why?

1. Root pressure is least effective during the day when transpiration is greatest
2. Root pressure never becomes high enough to forces water to top of tall tress
3. Many plants – including conifers develop no root pressure at all
4. Transpiration occurs in cut stems -> pull from the top

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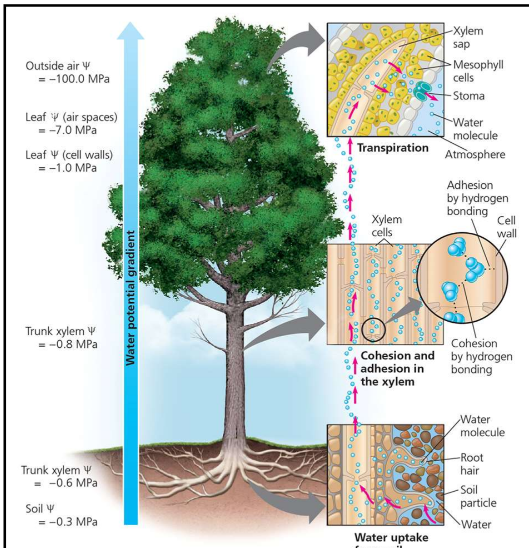
How does this ‘pull’ occur?

- Air has less water than leaf tissue -> water moves from leaf to the air
- **Water is cohesive** – water molecules stick together -> if one molecule goes the whole string does
- **Water adheres to xylem walls** -> counteracts downward pull of gravity

Because of the high cohesive forces between water molecules and adhesion to xylem walls a continuous column of water is pulled up through the xylem - capillary action– **cohesion/adhesion theory**



▲ **Figure 36.11 Ascent of xylem sap.** Hydrogen bonding forms an unbroken chain of water molecules extending from leaves to the soil. The force driving the ascent of xylem sap is a gradient of water potential (ψ). For bulk flow over long distance, the ψ gradient is due mainly to a gradient of the pressure potential (ψ_P). Transpiration results in the ψ_P at the leaf end of the xylem being lower than the ψ_P at the root end. The ψ values shown at the left are a "snapshot". They may vary during daylight, but the direction of the ψ gradient remains the same.

Water potential in the root needs to be lower than that of the soil for water to flow by osmosis from the soil into the root

Transpiration of water vapour from the leaf does this as a continuous stream (or string) of water molecules is lost extending from the leaf to the root

As the root loses water it is replaced from that of the soil

Control of water uptake by the root

•First of all, by the control of transpiration via **opening/closing of stomata**

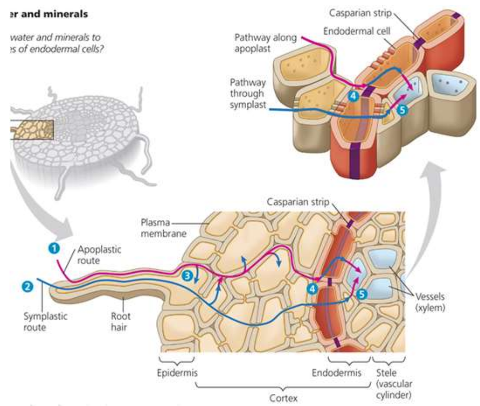
•But also within the endodermis is a water impervious layer = **Casparian strip**

•This occurs in the cell walls that are perpendicular to the root surface

•The Casparian strip is **suberised** (has a fatty substance), thus is water impermeable and therefore forces apoplastic water to cross the plasma membrane of the endodermis

•**Endodermis controls water entry**

•Water can only pass through surfaces parallel to the root surface



Phloem Transport

- Phloem contains **sieve tube members** arranged end to end
- Phloem sap (sugary solution) moves freely from cell to cell
  - Inorganic ions
  - Amino acids
  - Hormones
  - Sucrose
- Phloem transports sugars from where it is produced to where it is stored or consumed = **sugar sink**
- Sugar is produced by photosynthesis or starch breakdown

What organs/structures are sugar sources and sugar sinks?

Source	Sink

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Sap movement is due to the pressure-flow mechanism

- At a sugar source (e.g. Leaves) sugar is loaded into the phloem by **active transport**
- This leads to an increase in solute concentration inside the phloem tube
- **Water** then enters the phloem tube osmotically, leading to an increase in water pressure at the source end of the tube

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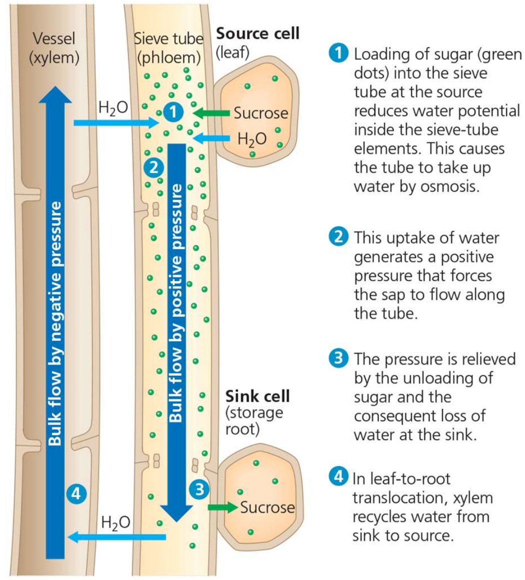
Sap movement is due to the pressure-flow mechanism

- At the sugar sink, sugar exits the phloem
- Then water follows by osmosis, causing a decrease in the hydrostatic water pressure
- The **high water pressure** at the source and **low water pressure** at the sink causes water to flow from source to sink
- **Xylem** transports the water back from the sink to the source



▲ **Figure 36.16** **Bulk flow by positive pressure (pressure flow) in a sieve tube.**

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Phloem loading

- Phloem loading can be apoplastic or symplastic
- **Symplastic** – surcrose from mesophyll cells passes to sieve tube/companion cell complex via plasmodesmata
- **Apoplastic** – sucrose enters apoplast (cell wall) prior to active loading into the sieve tube/ companion cell complex
- The sieve tube/companion cell complex of apoplastic loaders have virtually no plasmodesmatal connections with other cell types of the leaf

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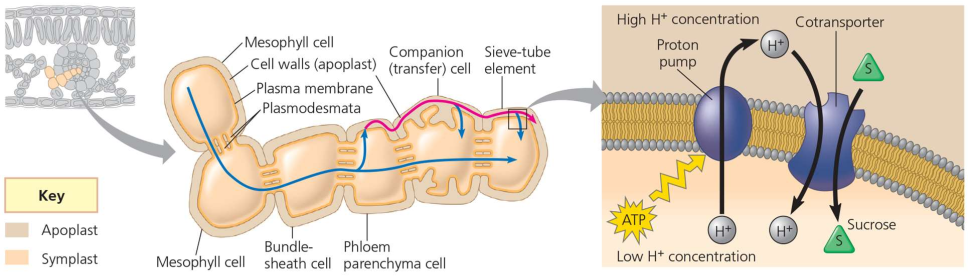
Phloem Loading

Some companion cells have ingrowths to increase surface area



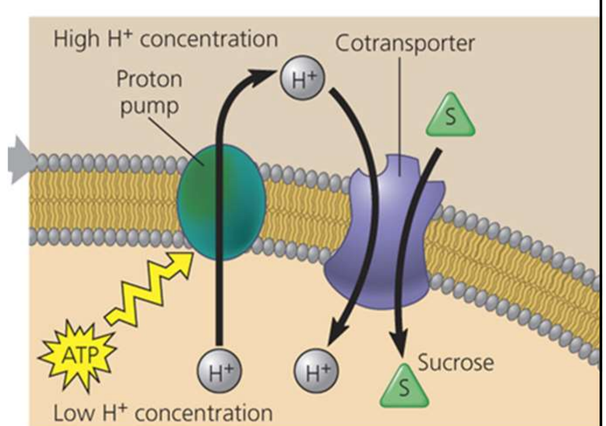
(a) Sucrose manufactured in mesophyll cells can travel via the symplast (blue arrows) to sieve-tube elements. In some species, sucrose exits the symplast near sieve tubes and travels through the apoplast (red arrow). It is then actively accumulated from the apoplast by sieve-tube elements and their companion cells.

(b) A chemiosmotic mechanism is responsible for the active transport of sucrose into companion cells and sieve-tube elements. Proton pumps generate an H^+ gradient, which drives sucrose accumulation with the help of a cotransport protein that couples sucrose transport to the diffusion of H^+ back into the cell.

▲ **Figure 36.15 Loading of sucrose into phloem.**

Apoplastic loading of sucrose is driven by a proton gradient

- Within the cell a proton pump uses energy from hydrolysis of ATP to transport protons across the membrane into the apoplast
- This produces a **proton gradient** with a high concentration of protons in the apoplast and a low concentration in the symplast
- The H+ ions are then coupled to sucrose which can then be transported into the cell via specific carrier molecules in the plasma membrane



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