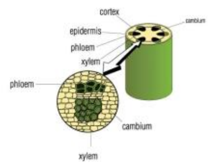
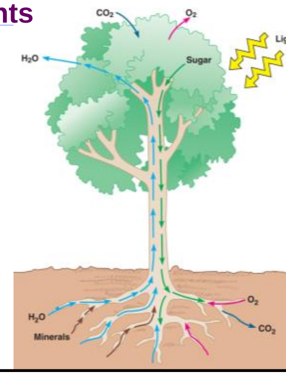
Transport and Transpiration in Multicellular Plants



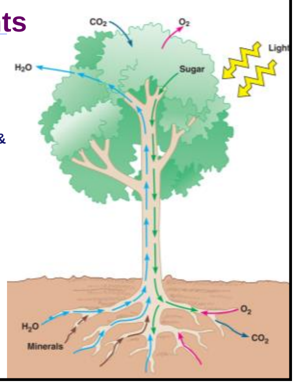
Transport in plants

- H_2O & minerals
- Sugars
- Gas exchange



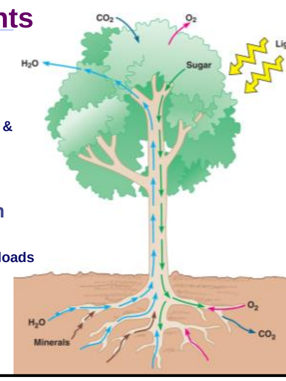
Transport in plants

- H_2O & minerals
  - transport in xylem
  - transpiration
    - evaporation, adhesion & cohesion
    - negative pressure
- Sugars
- Gas exchange



Transport in plants

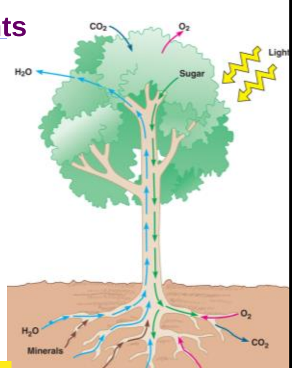
- H_2O & minerals
  - transport in xylem
  - transpiration
    - evaporation, adhesion & cohesion
    - negative pressure
- Sugars
  - transport in phloem
  - bulk flow
    - Calvin cycle in leaves loads sucrose into phloem
    - positive pressure
- Gas exchange



Transport in plants

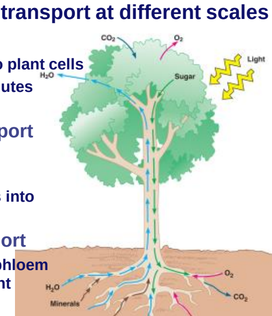
- H_2O & minerals
  - transport in xylem
  - transpiration
- Sugars
  - transport in phloem
  - bulk flow
- Gas exchange
  - photosynthesis
    - CO_2 in; O_2 out
    - stomates
  - respiration
    - O_2 in; CO_2 out
    - roots exchange gases within air spaces in soil

Why does over-watering kill a plant?



Transport in plants

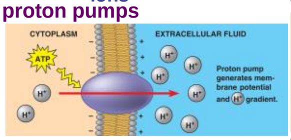
- Physical forces drive transport at different scales
  - cellular
    - from environment into plant cells
    - transport of H_2O & solutes into root hairs
  - short-distance transport
    - from cell to cell
    - loading of sugar from photosynthetic leaves into phloem sieve tubes
  - long-distance transport
    - transport in xylem & phloem throughout whole plant

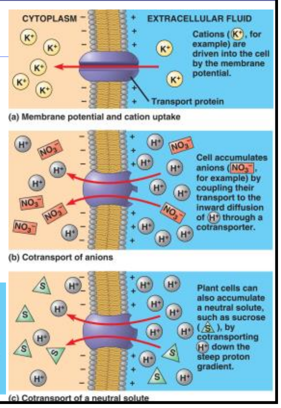


Cellular transport

- Active transport
  - solutes are moved into plant cells via active transport
  - central role of proton pumps
  - Cotransport with H+ ions

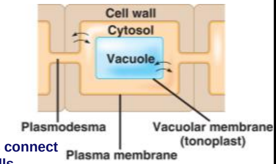
proton pumps

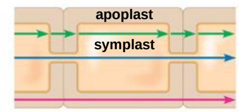




Short distance (cell-to-cell) transport

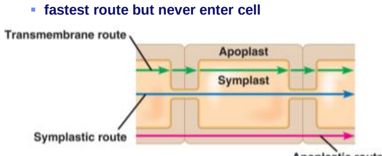
- Compartmentalized plant cells
  - cell wall
  - cell membrane
    - cytosol
  - vacuole
- Movement from cell to cell
  - move through cytosol
    - plasmodesmata junctions connect cytosol of neighboring cells
    - symplast
  - move through cell wall
    - continuum of cell wall connecting cell to cell
    - apoplast





Routes from cell to cell

- Moving water & solutes between cells
  - transmembrane route
    - repeated crossing of plasma membranes
    - slowest route but offers more control
  - symplast route
    - move from cell to cell within cytosol
  - apoplast route
    - move through connected cell wall without crossing cell membrane
    - fastest route but never enter cell

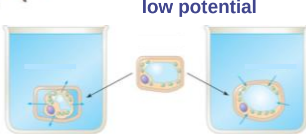


Long distance transport

- Bulk flow
  - movement of fluid driven by pressure
    - flow in xylem tracheids & vessels
      - negative pressure
      - transpiration creates negative pressure pulling xylem sap upwards from roots
    - flow in phloem sieve tubes
      - positive pressure
      - loading of sugar from photosynthetic leaf cells generates high positive pressure pushing phloem sap through tube

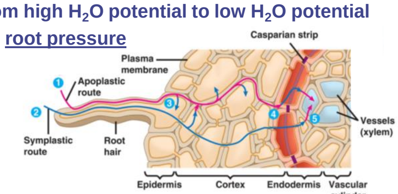
Movement of water in plants

- Water relations in plant cells is based on water potential
  - osmosis through aquaporins
    - transport proteins
  - water flows from high potential to low potential

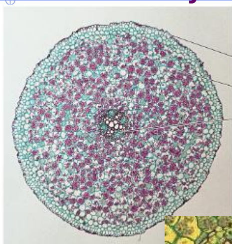


Water & mineral uptake by roots

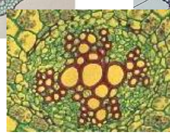
- Mineral uptake by root hairs
  - dilute solution in soil
  - active transport pumps
    - this concentrates solutes (~100x) in root cells
- Water uptake by root hairs
  - flow from high H_2O potential to low H_2O potential
  - creates root pressure

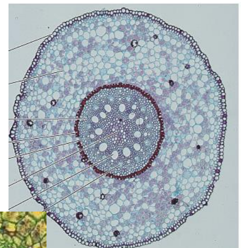


Root anatomy

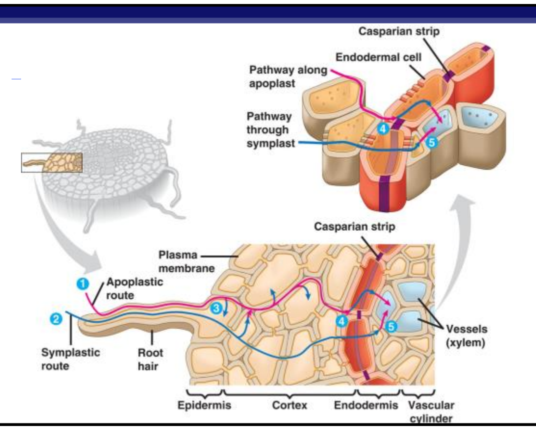


dicot



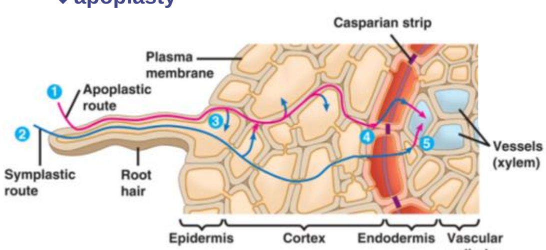


monocot



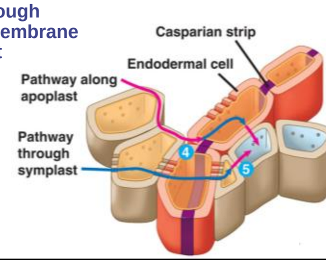
Route water takes through root

- Water uptake by root hairs
  - a lot of flow can be through cell wall route
  - apoplasty



Controlling the route of water in root

- Endodermis
  - cell layer surrounding vascular cylinder of root
  - lined with impervious Casparian strip
  - forces fluid through selective cell membrane & into symplast
    - filtered & forced into xylem vessels

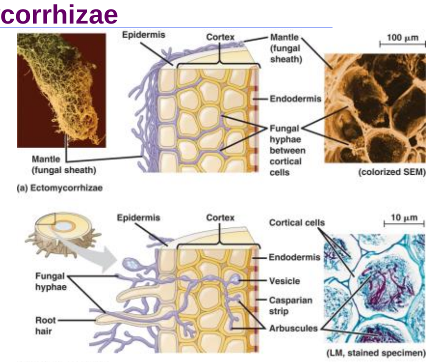


Mycorrhizae increase absorption

- Symbiotic relationship between fungi & plant
  - symbiotic fungi greatly increases surface area for absorption of water & minerals (phosphates)
  - increases volume of soil reached by plant
  - increases transport to host plant

2.5 mm

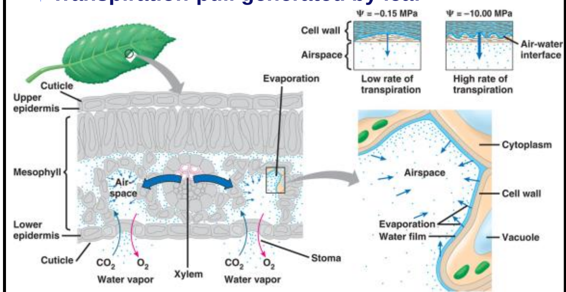
Mycorrhizae



May apples and Mycorrhizae

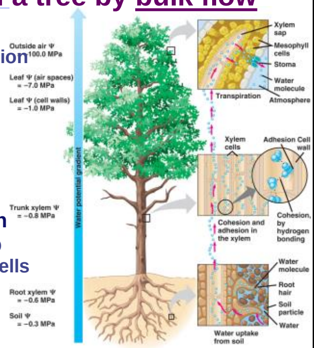
Ascent of xylem “sap”

Transpiration pull generated by leaf



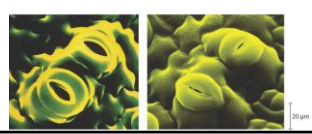
Rise of water in a tree by bulk flow

- Transpiration pull
  - adhesion & cohesion
    - H bonding
  - brings water & minerals to shoot
- Water potential
  - high in soil → low in leaves
- Root pressure push
  - due to flow of H_2O from soil to root cells
  - upward push of xylem sap

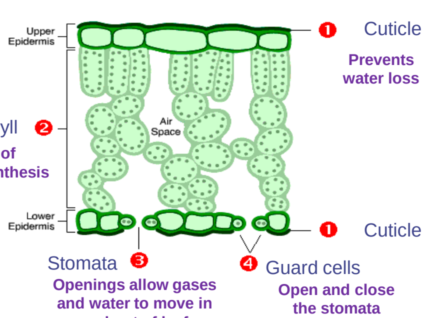


Control of transpiration

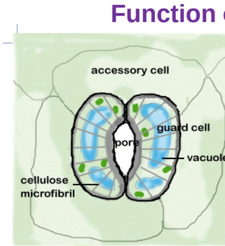
- Stomate function
  - always a compromise between photosynthesis & transpiration
    - leaf may transpire more than its weight in water in a day…this loss must be balanced with plant’s need for CO_2 for photosynthesis
      - a corn plant transpires 125 L of water in a growing season



Stomatal transpiration



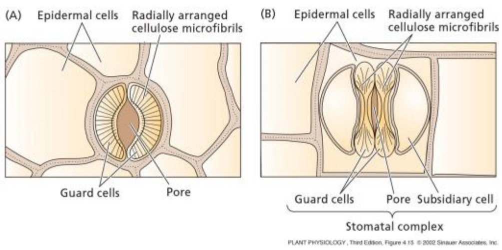
Function of Guard Cells



How do the guard cells react to the availability of water?

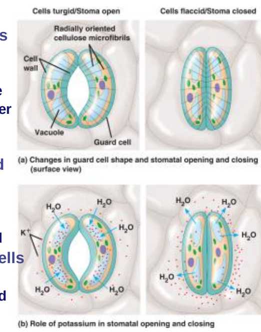
- Dry – guard cells CLOSE
- lots of H_2O – guard cells OPEN

Characteristics of guard cells



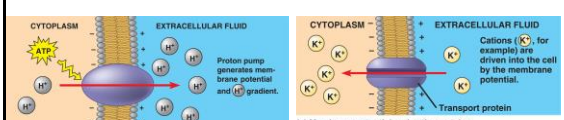
Regulation of stomates

- Microfibril mechanism
  - guard cells attached at tips
  - microfibrils in cell walls
    - elongate causing cells to arch open = open stomate
    - shorten = close when water is lost
- Ion mechanism
  - uptake of K^+ ions by guard cells
    - proton pumps
    - water enters by osmosis
    - guard cells become turgid
  - loss of K^+ ions by guard cells
    - water leaves by osmosis
    - guard cells become flaccid
- Abscisic acid can also close stomates



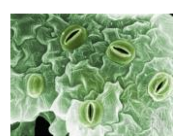
Regulation of stomates

- Other cues
  - light trigger
    - blue-light receptor in plasma membrane of guard cells triggers ATP-powered proton pumps causing K^+ uptake
      - stomates open
  - depletion of CO_2
    - CO_2 is depleted during photosynthesis (Calvin cycle)
  - circadian rhythm = internal "clock"
    - automatic 24-hour cycle



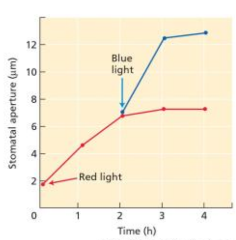
Stomatal Control

- Stomates fill with water to open and empty of water (become flaccid) to close
- Overall, stomata import solutes when they need to open
  - Higher solute concentration = lower water potential = more negative = water flows in
  - The opposite is true for closing
- Several factors influence these openings and closings…



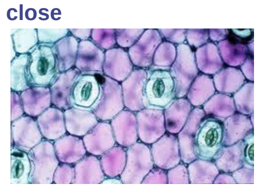
Light

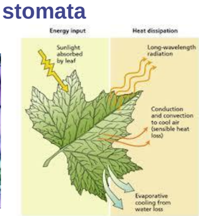
- Stomata of most plant open in the day and close at night
  - CAM plants are the opposite (desert adaptation)
- Stomata opening are sensitive to red light and blue light
  - Blue light is more effective--stimulates opening by blue-light receptor zeaxanthin.
  - Allows stomata to be open in light that is conducive to photosynthesis



Temperature

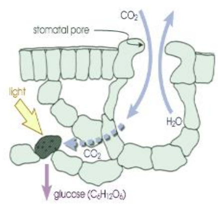
- Stomatal aperture increases with temperature
  - 20- 30℃ is optimal—too hot means too much evaporation and the plant can wither, so stomata close





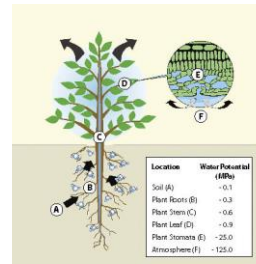
CO_2

- Low CO_2 concentration promotes stomatal opening
  - Necessary so enough CO_2 is available for photosynthesis
- High CO_2 concentration inhibits stomatal opening
  - CO_2 acidifies the guard cell



Water content

- Stomata open when the leaf contains enough water. When there is a water shortage, they close.
  - Helps prevent wilting from over transpiration



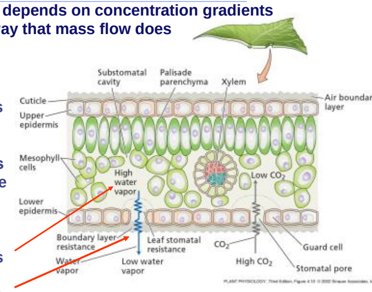
Hormones

- Cytokinins (CTKs) stimulate stomatal opening
- Abscisic Acic (ABA) stimulates stomatal closing
- Both affect overall solute concentration in the guard cells, causing water to move in or out

Transpiration Rates

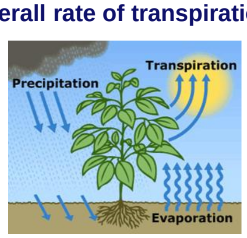
- Transpiration depends on concentration gradients in the same way that mass flow does

The driving force of transpiration is the "vapor pressure gradient." This is the difference in vapor pressure between the internal spaces in the leaf and the atmosphere around the leaf



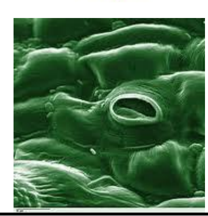
Factors affecting rate of transpiration

- Many factors affect this water vapor concentration gradient
- Affect overall rate of transpiration



Light

- Plants transpire more rapidly in the light than in the dark.
- Light stimulates the opening of the stomata
- Light also increases temperature of leaf

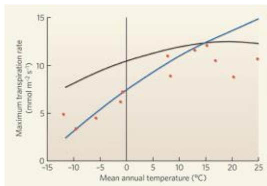


Temperature

- Plants transpire more rapidly at higher temperatures because water evaporates more rapidly as the temperature rises.

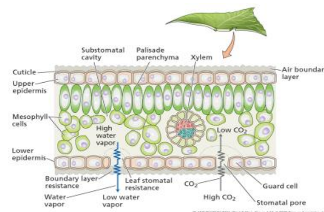
Humidity

- When the surrounding air is dry, diffusion of water out of the leaf goes on more rapidly.



Wind

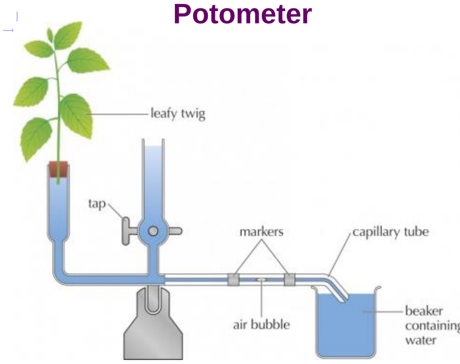
- When a breeze is present, the humid air is carried away and replaced by drier air



Soil Water

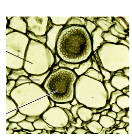
- A plant cannot continue to transpire rapidly if its water loss is not made up by replacement from the soil.
- If absorption of water by the roots is < the rate of transpiration…
  - loss of turgor occurs
  - stomata close.
  - Reduces the rate of transpiration.
  - If this extends to the rest of the leaf and stem, the plant wilts.

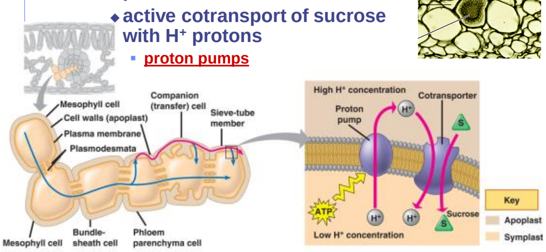
Potometer



Translocation via phloem

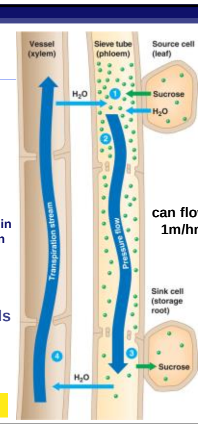
- Loading of sucrose into phloem
  - flow through symplast via plasmodesmata
  - active cotransport of sucrose with H^+ protons
    - proton pumps





Pressure flow in sieve tubes

- Water potential gradient
  - "source to sink" flow
    - direction of transport in phloem is variable
    - Can be simultaneously up and down in different tubes, but only one direction in any given tube
  - sucrose flows into phloem sieve tube
  - water flows in from xylem vessels
    - increase in pressure due to increase in H_2O causes flow



What plant structures are sources & sinks?

Maple sugaring

Putting it all together

- Obtaining raw materials
  - sunlight
    - leaves = solar collectors
  - CO_2
    - stomates = gas exchange
  - H_2O
    - uptake from roots
  - nutrients
    - uptake from roots

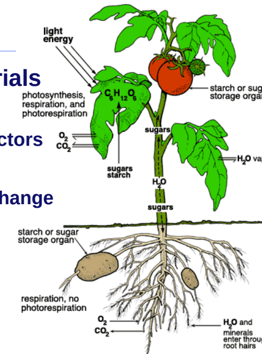
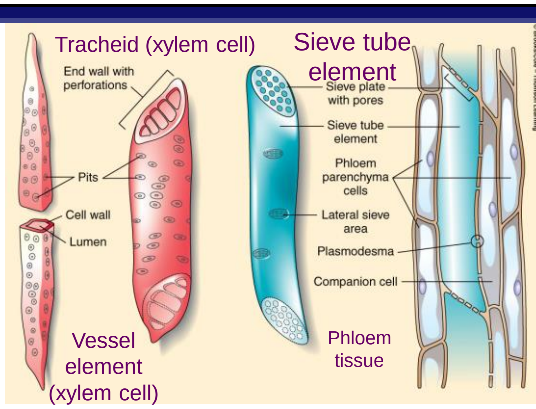


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.

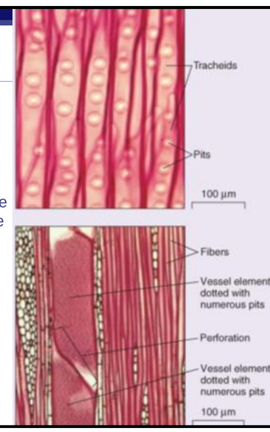


Tracheid

Lignified walls provide structure to withstand negative pressure of transpiration

Vessel element

*Vessel elements have holes between them to allow unimpeded flow



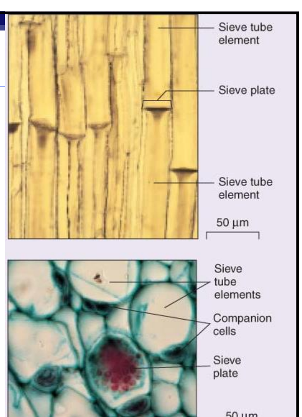
Sieve tube element

*Sieve plates maintain positive pressure in tube elements

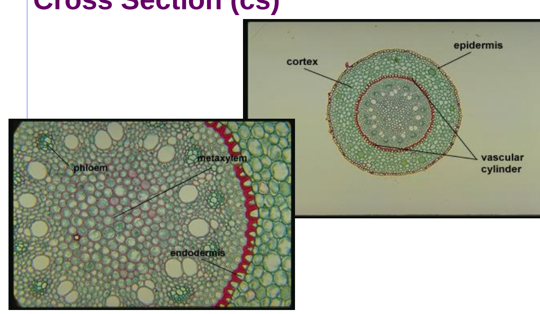
*Thin cytoplasm, no nuclei in sieve tubes

Companion cell

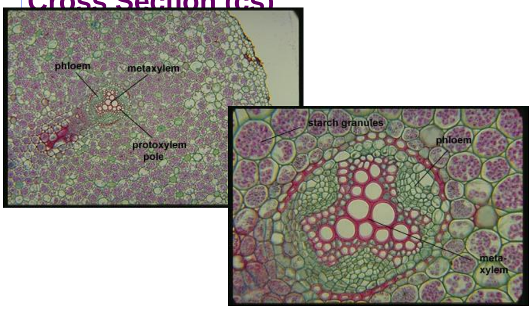
Site of active loading of phloem—H+ pumped into apoplast, flow back into companion cell cotransporting sucrose



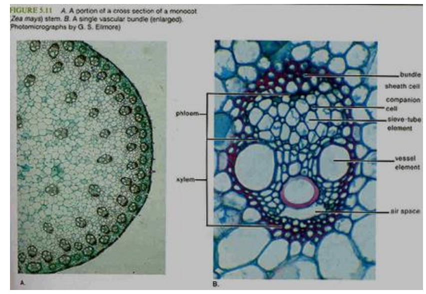
Monocot Root Cross Section (cs)



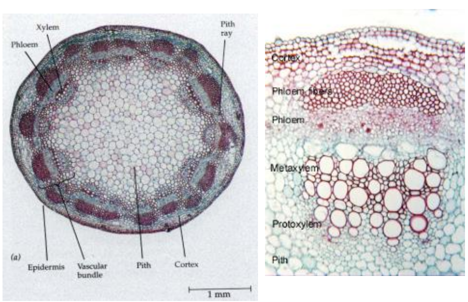
Dicot Root Cross Section (cs)



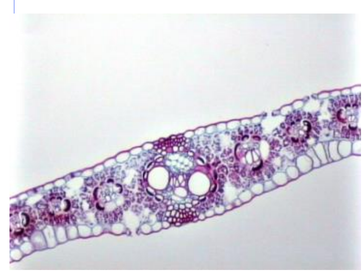
Monocot Stem



Dicot Stem

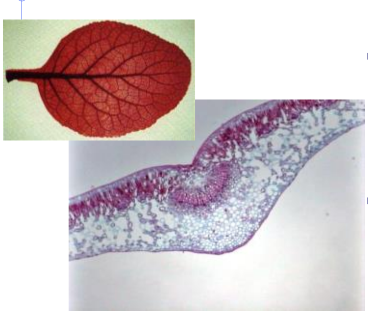


Monocot Leaf



- Midrib shows vascular tissue: Can you ID?
- Leaves have parallel veins (visible here)
- Do you see the stomata?

Dicot Leaf



- These leaves have a more obvious mid-rib (central vein)
- Veins are perpendicular to the central vein.

Any Questions??