CONDUCTION SYSTEMS IN PLANTS: XYLEM
Two systems are required by photosynthesis

1) **xylem**, to supply water and mineral nutrients

Stomata allow CO₂ entry and H₂O exit

H₂O diffuses out because humidity inside leaf is 99-100%; outside, 30-90% (usually)

Xylem cells (tracheids, vessels) resupply water

2) **phloem**, to distribute photosynthate to nourish non-photosynthetic cells and supply material for storage
Anatomy of vascular bundles in young dicot leaf and stem
Leaf: small veins with single vascular bundles connect to midrib, often with several vascular bundles; midrib connects to petiole.

Stem: several discrete vascular bundles around periphery of stem, surrounded by parenchyma.
Xylem (top, adaxial): thick cell walls (lignin), no cytoplasm (tracheids, vessels), also fibers, parenchymal cells

Phloem (bottom, abaxial): small cells, dense cytoplasm (sieve tubes, companion cells), also fibers, parenchymal cells
Connection between vascular bundles in midrib and stem gives continuity between xylem, phloem without connecting xylem to phloem
Anatomy of vascular bundles in young root
xylem

phloem
Xylem and transpiration water flow
Tracheids

Long, spindle-shaped cells
Develop from normal cell with primary wall
Add secondary wall (with lignin) inside primary wall
   --helix, rings, sheets with pits
Pits allow water flow between adjacent tracheids (through primary wall)
Protoplasts dissolve (loses all cytoplasm, organelles),
   leaving water-filled tubes, connected by pits

Vessels

Vessel elements (large cells) in line produce heavy secondary cell wall
Cells dissolve end walls together with protoplast to form water-filled tube \( \geq 1 \text{ m long} \)
How water flows through the plant

Generally, water is pulled into the root, up the stem, into the leaf, into the air.
Sequence of events, showing the pull:

• water vapor diffuses from leaf inter-cellular space through stomata, boundary layer, to bulk air; air in inter-cellular space loses relative humidity
• water evaporates from mesophyll cell walls to re-saturate air space; cell walls become drier
• water moves to cell walls from xylem by capillary action (depends on adhesion of water to cellulose fibers of wall, etc.)
• when water leaves the xylem (tracheid or vessel), the decrease in volume pulls cell walls inward (water adheres to the cell walls); resistance of walls to deformation causes tension in water; tension pulls water up through xylem
• tension in root xylem pulls water in from root cells; root cell cytoplasm becomes more concentrated; water flows into root cells from cell walls; cell walls become drier
• water moves from soil (between particles) to root by capillary action
Compare water flow up a tree with flow up a tube connected to a vacuum pump: what is the difference in these two systems?
Water rises due to difference in pressure (tension) 
component of water potential
For **pump**, pressure at bottom = 1 atm (= 1 bar = 0.1
MPa = 10^6 dynes/cm^2 = 15 lbs/in^2), at top = 0:
difference of 1 atm raises water 10 m
For **tree**, pressure differential must be 10 atm (actually,
20 atm to overcome friction (due to viscosity and
small channels) as well as gravitational potential);
since pressure at bottom = 1 atm, pressure at top = -
19; negative pressure is **tension**

How is tension in water possible?

Requires "cohesion" and "adhesion": water molecules
stick together and to the sides of the tracheids and
vessels
H-bonds represent cohesive and adhesive force

![Diagram of H-bonds](attachment:diagram.png)
Why is vacuum pump limited to a pressure of 0?

Gas (air, water vapor) will not form H-bonds, will not carry tension
If there are bubbles in the channel, the tension is released and the height limited to 10 m

How does the plant keep air from entering xylem?

Border parenchyma, endodermis have no air spaces between cells

Note that bubbles can form spontaneously when gas comes out of solution at low pressure (high tension), freezing, high temperature
Pits (with primary wall) are too small to allow bubbles to pass through: this isolates bubbles that form in xylem to individual tracheids and vessels
Bubbles resorbed (especially when humidity is high and tension low)
New xylem can be formed, which is already filled with water