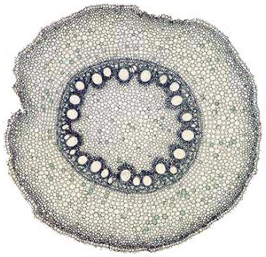
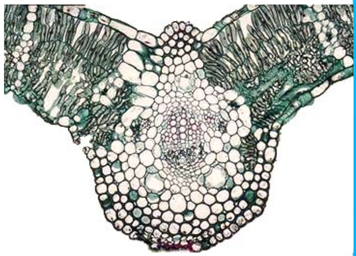
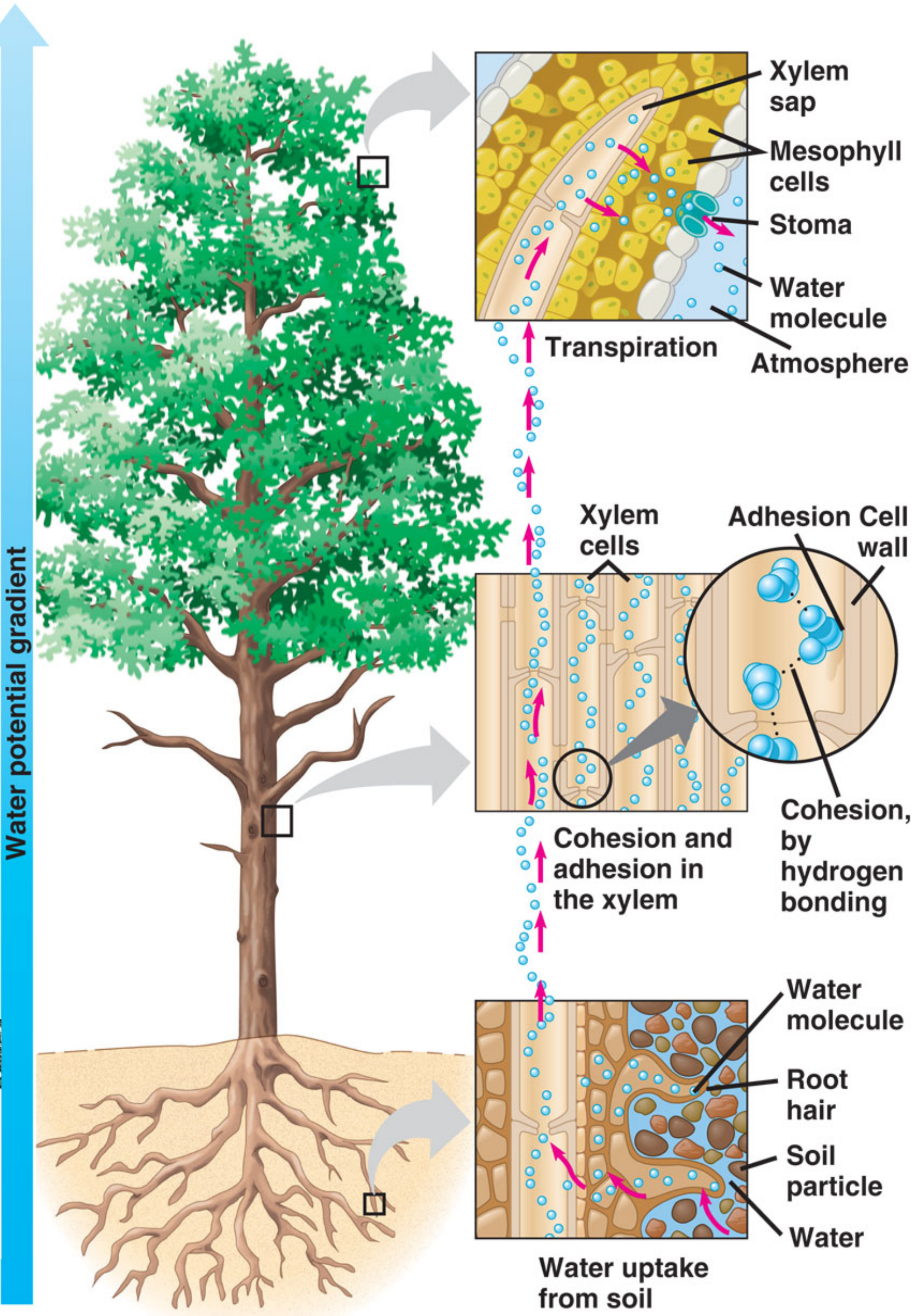
# Plant Anatomy & Transport

## Chapter 35 & 36

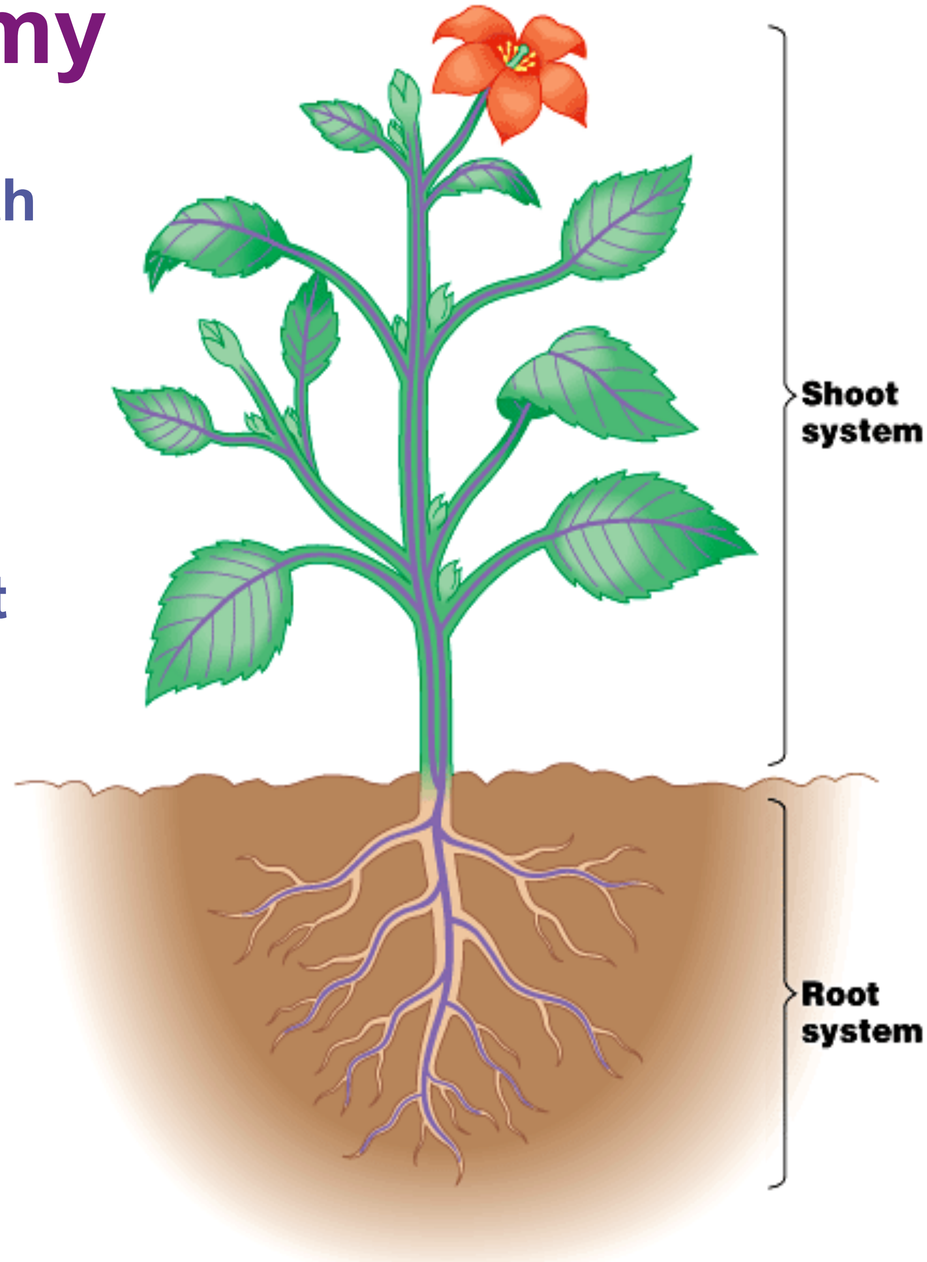






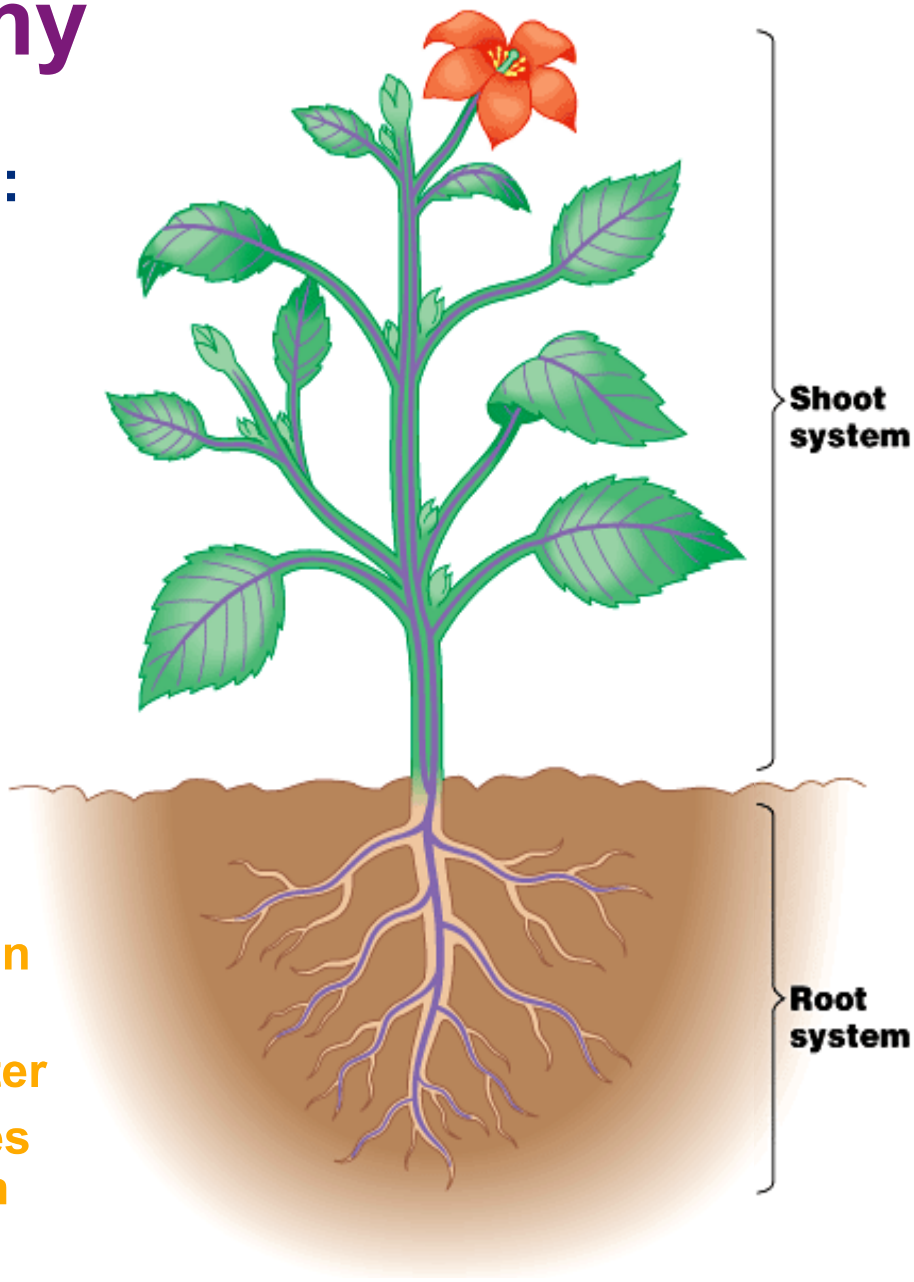
# Basic plant anatomy

- **Tissue** = group of cells with a common function and/or structure
- **Organ** = several types of tissues that together carry out particular functions for an organisms
- **Plants draw resources from two environments:**
  1. Water and minerals from below ground
  2. $CO_2$ and light from above ground



# Basic plant anatomy

- Plants have 3 basic organs:
  1. Roots
  2. Stems
  3. Leaves
- These organs form a ROOT SYSTEM & a SHOOT SYSTEM
- ROOTS
  - Multicellular organ with various functions:
    1. Anchors a vascular plant in the soil
    2. Absorbs minerals and water
    3. Often stores carbohydrates as a way of storing carbon and energy

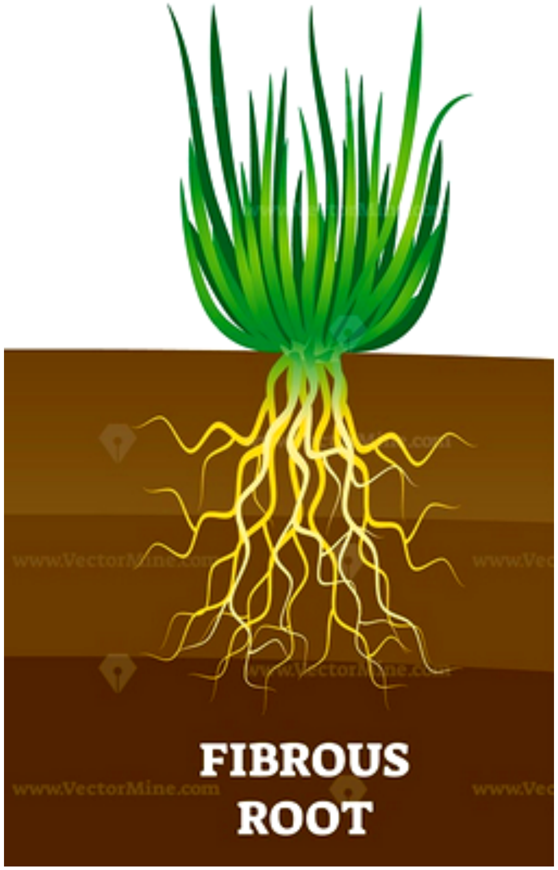


# Plants Exhibit Various Adaptations

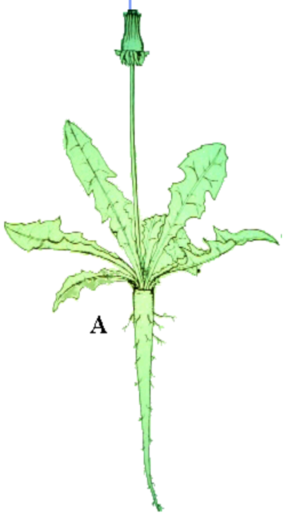
- Remember what you need to evolve via Natural Selection
  1. Variation must exist in a given characteristic across organisms in a population.
  2. The variation in this characteristic must be inheritable (it must be controlled by the alleles of genes the organism inherits)
  3. Because some more beneficial variations help organisms better survive and reproduce in a particular environment, differential reproductive success causes the alleles for certain variations to get passed down to the next generation proportionally more often than alleles for less advantageous variations.

# Different Root Structures Have Evolved as Adaptations in Different Environments

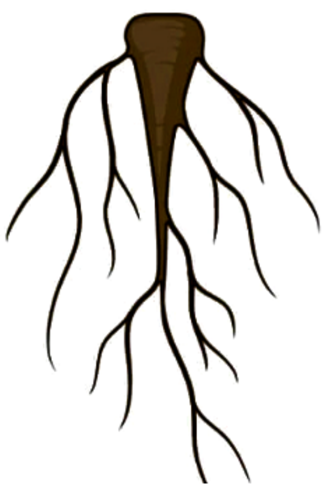
- **Fibrous Root System**
  - Fibrous roots (1)
    - A mat of thin roots spreading out below the soil surface with no root functioning as the main one
      - Many small roots grow out from stem
      - Each small root forms its own lateral roots
        - Roots spread in many directions (but stay in the shallower soil, allowing the plant to absorb rain water easily and quickly.
        - Benefit to ecosystem: help prevent soil erosion (loss)production

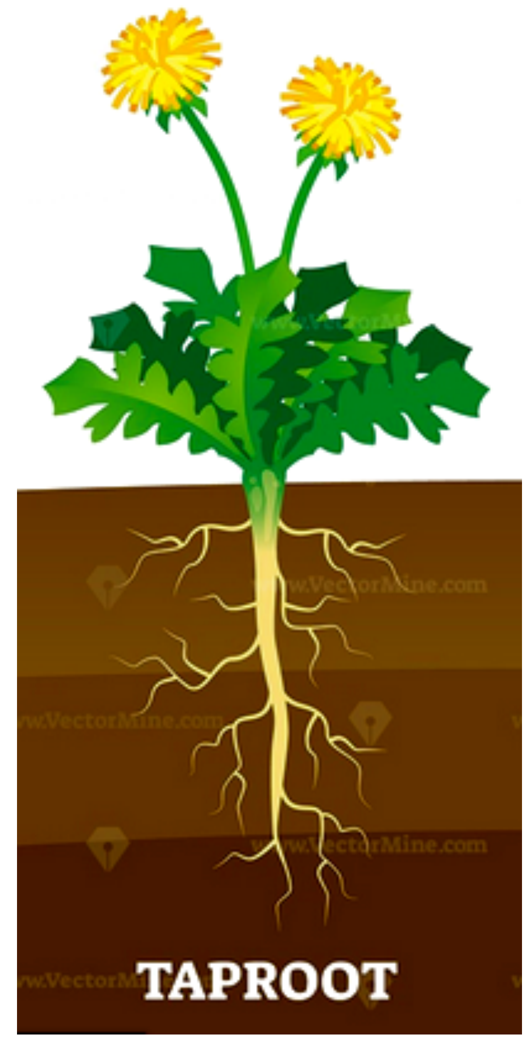


# Different Root Structures Have Evolved as Adaptations in Different Environments




- **Taproot system**
  - Tap roots (2)
    - Consists of 1 large vertical root with many small lateral or branch roots
  - Root penetrates soil deeply
    - Root can reach for water deep in ground
    - Root anchos plant against strong winds
    - Taproot may store sugars and starches for later use during flower and fruit production

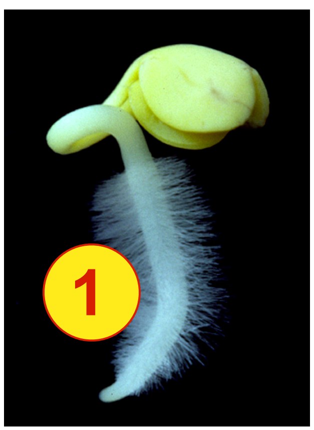


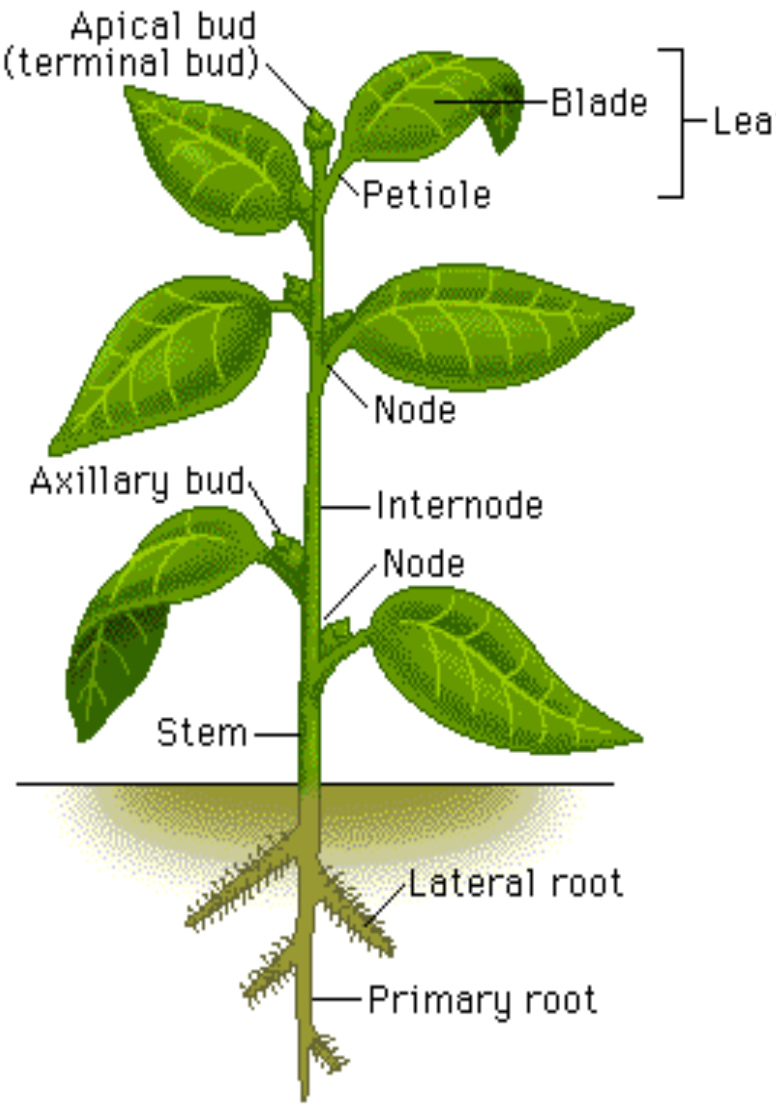


# Roots Hairs Increase a Root Cell's Surface Area for Mineral and Water Absorption

- Most absorption of water and minerals occur near the tip of roots
- Root tips have root hairs (1)
  - Thin tubular cytoplasmic extensions of root epidermal (outermost dermal) cells

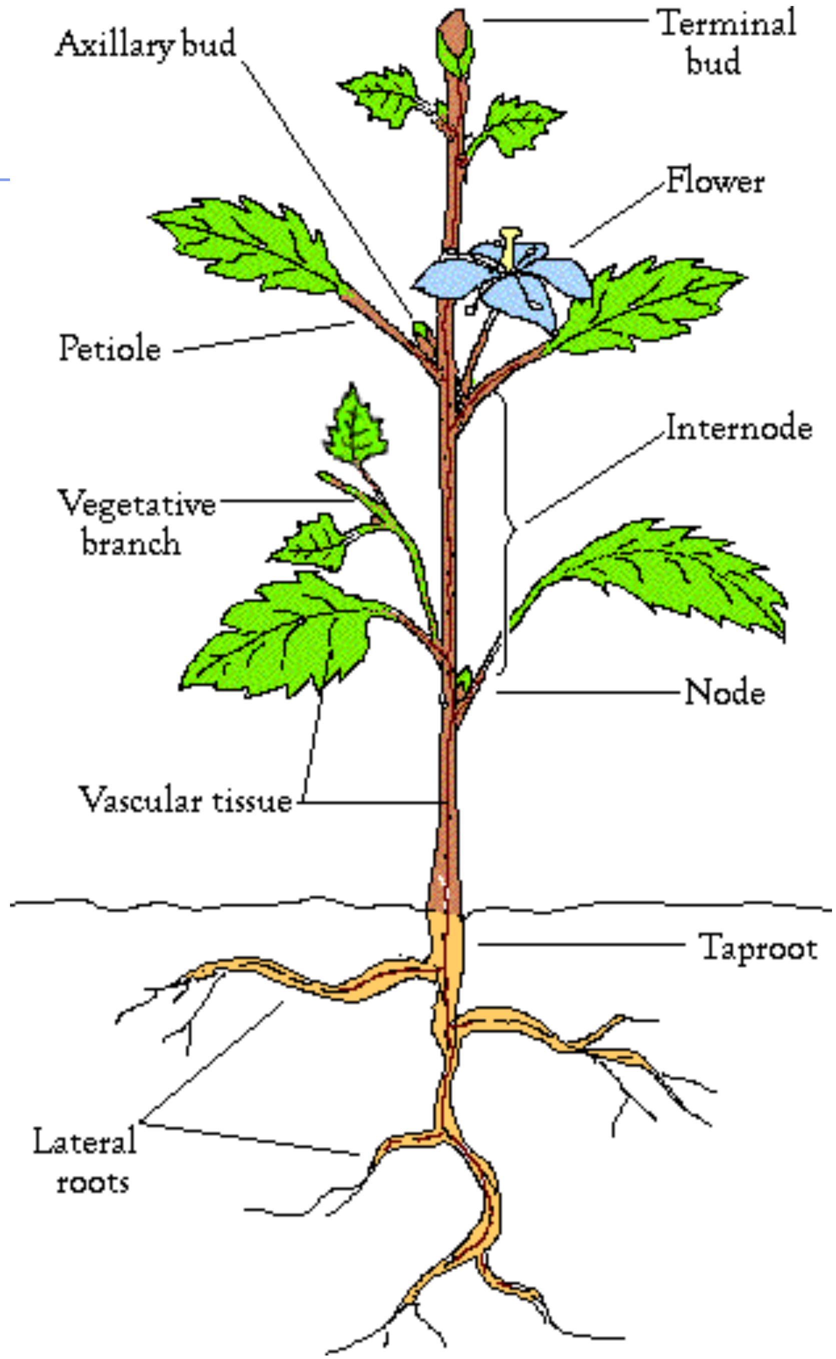
    (root hairs are not a multi-cellular organ like lateral roots are)
  - increase absorptive surface area *(increase the cells surface to volume ratio)*
    - Some plant have modified roots as well that provide more support or anchorage, store water and nutrients, or allow for better absorption o oxygen in water-logged soil



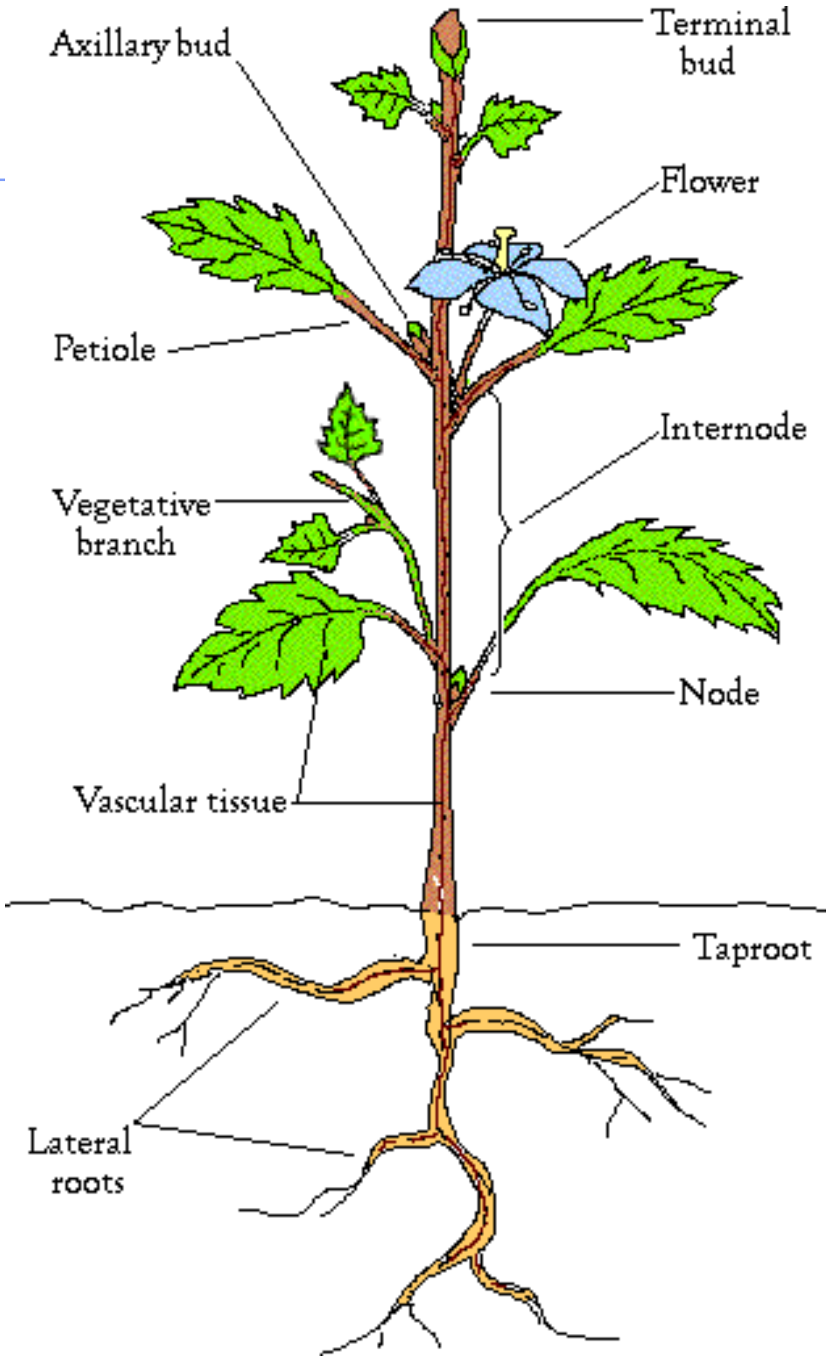
# Shoots

- **SHOOTS (stem & leaves)**
  - A stem is an organ consisting of an alternating system of nodes and internodes
    - **Nodes** = the points at which leaves are attached
    - **Internodes** = the stem segments between nodes



# Shoots

- **BUDS**
  - In the upper angle between the leaf and stem is an axillary bud
    - A structure that can form a lateral shoot, a.k.a. a branch
      - Usually dormant in young shoots
  - Elongation of shoots occur near shoot tip which contains an apical or terminal bud
    - Contains developing leaves and a compact series of nodes and internodes
  - Flower buds form flowers



# Apical dominance

- Apical dominance = the inhibition of axillary buds by apical buds
  - Due to the signal molecules (hormones) secreted by apical bud cells that travel down the plant shoot inhibiting cell division in axillary buds.
    - Apical Dominance is an adaptation that increases the plant's exposure to light
      - If light becomes more intense on the side of a plant or if an animal eats the end of the shoot (and the apical bud), axillary buds break dormancy and start growing into a new lateral shoot or branch

# Modified shoots

## stolons (strawberries)

- horizontal shoots that grow along the surface (allow plants to reproduce asexually from nodes)

## rhizome (ginger)

- horizontal shoots that grow below the surface with vertical shoots emerging from axillary buds


## tuber (potato)

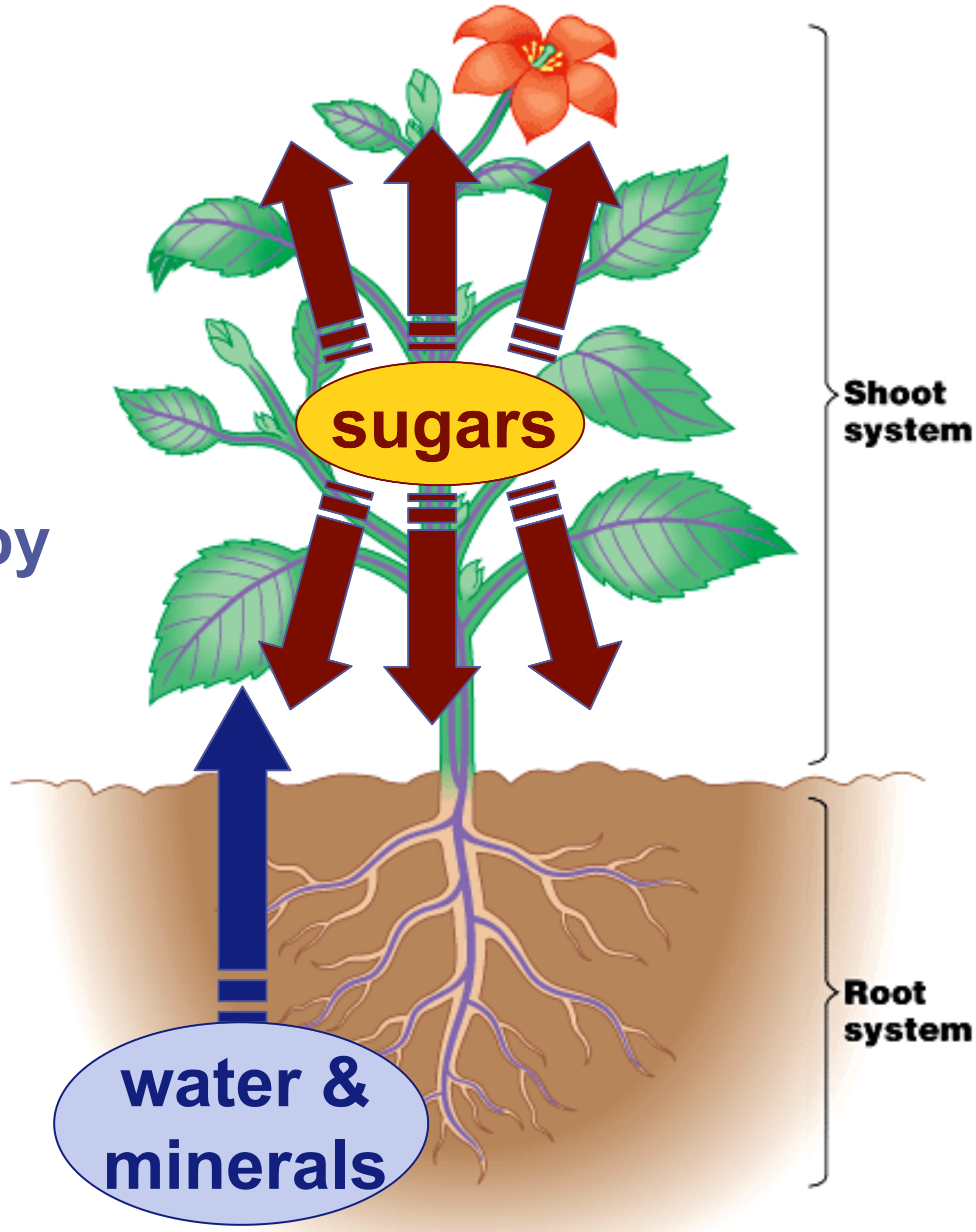
- eyes are clusters of axillary buds

## bulb (onion)

- underground shoots of mainly bases of leaves that sore food

# Shoots & Roots are Interdependent systems

- Both systems depend on each other
  - roots depend on sugars produced by photosynthetic leaves
  - shoots depend on water & minerals absorbed from the soil by roots

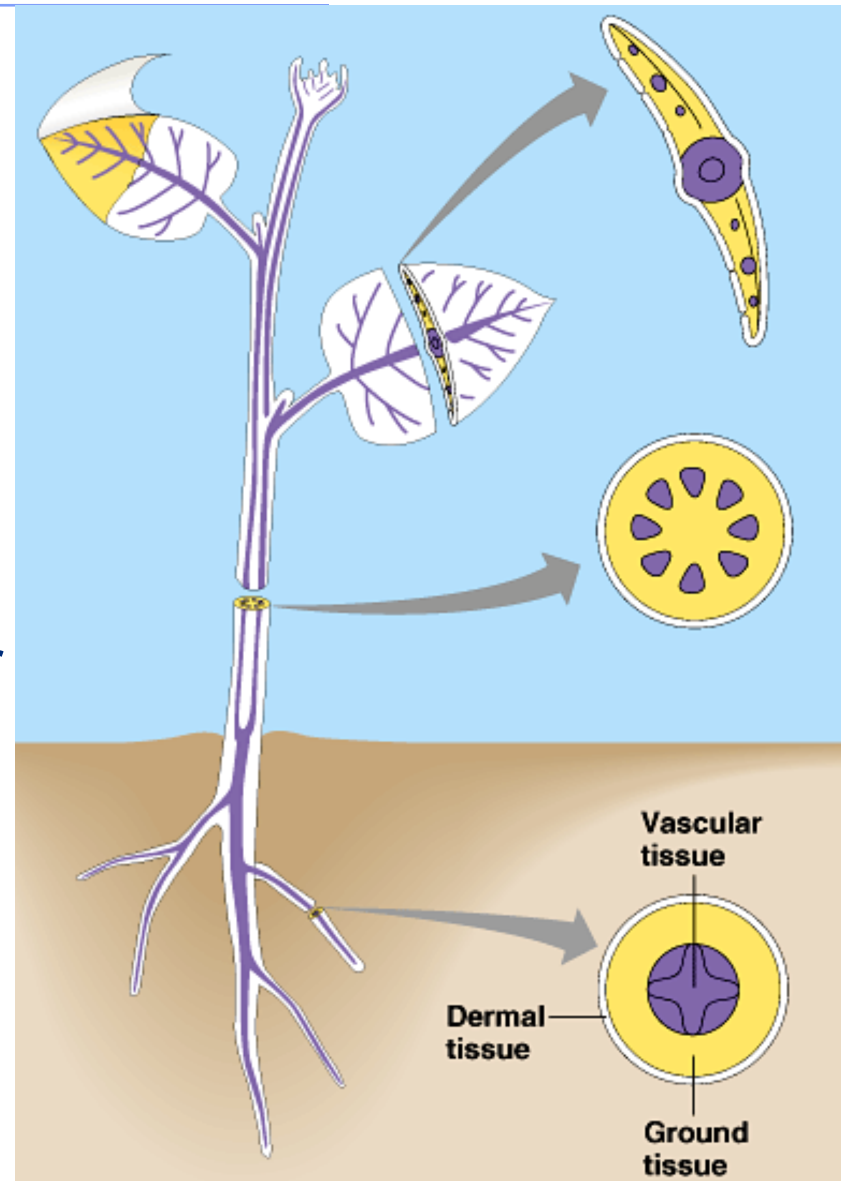


# Plant TISSUES of plant organs

## 1. Dermal tissue system

- Outer protective covering
- epidermis ("skin" of plant)
  - single layer of tightly packed cells that protects plant and prevents water loss
    - Trichomes = cytoplasmic extension of an epidermal cell or a multicellular outgrowth of shoot epidermis that reduce water loss by reflecting excess sunlight, keeps plant warm by trapping air, function in defense by forming barrier to herbivores or by secreting toxins etc…

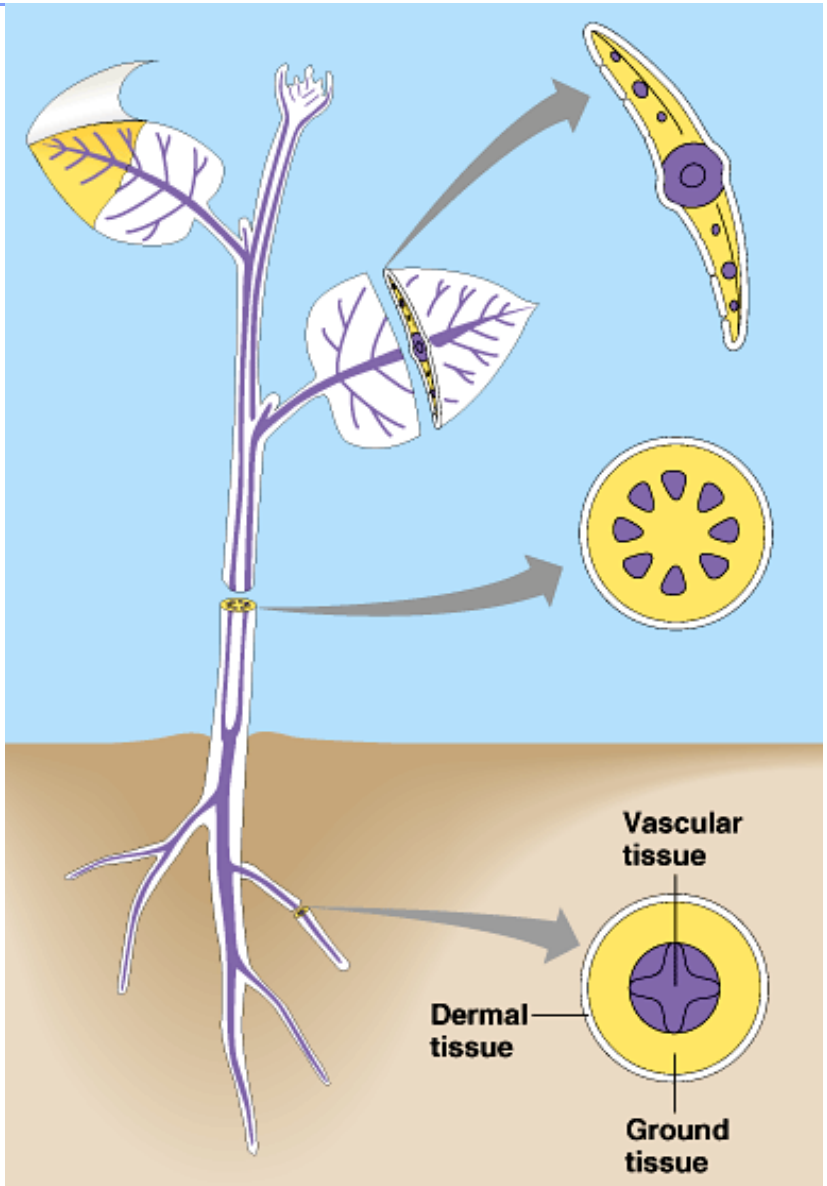
- Cuticle = waxy coating on plants prevents water loss



# Plant TISSUES of plant organs

## 2. Vascular tissue system

- Long distance transport system in shoots & roots
  - xylem
    - Conducts water and minerals upward from roots into shoots
  - Phloem
    - Transports sugars from photosynthesis
- Stele = (Greek for "pillar') vascular tissue of root or stems
  - Vascular cylinder of xylem and phloem in roots
  - Vascular bundles = separate strands containing xylem and phloem *(aka: VEINS)*



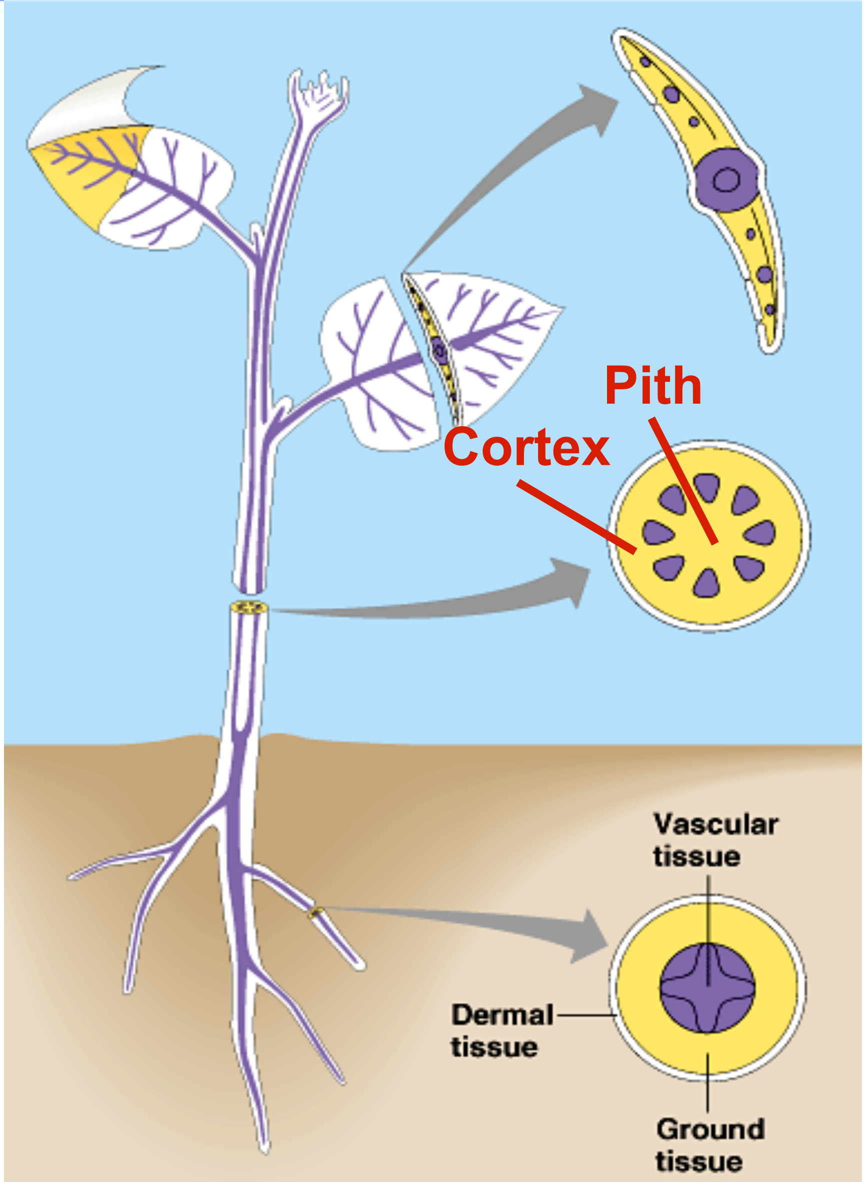
# Plant TISSUES of plant organs

## 3. Ground tissue system

- **Pith** = ground tissue internal to vascular tissue
- **Cortex** = ground tissue external to vascular tissue

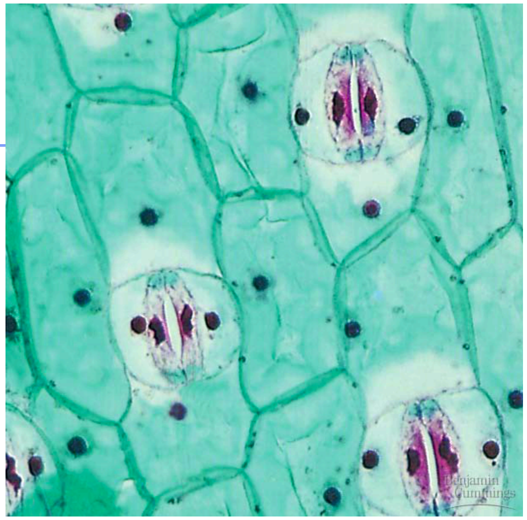
◆ bulk of plant tissue

- Includes....
  - The photosynthetic **mesophyll cells**
  - Cells for **storage**

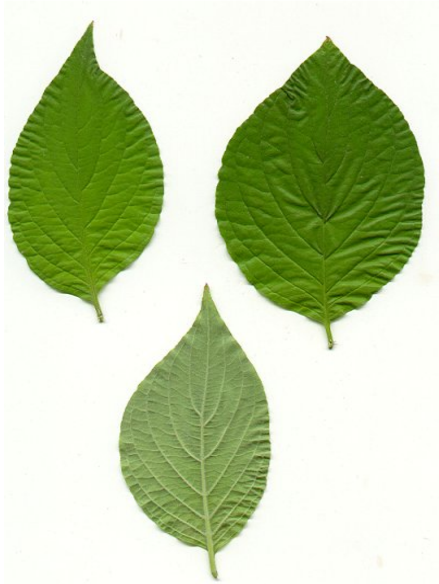


# Leaves

- **Function**
  - Main organs for photosynthesis
    - energy production
  - Allow for gas exchange
  - Allow for Transpiration
    - Though too much water loss is bad, some water loss is necessary in order for the plant to be able to carry minerals up from the soil



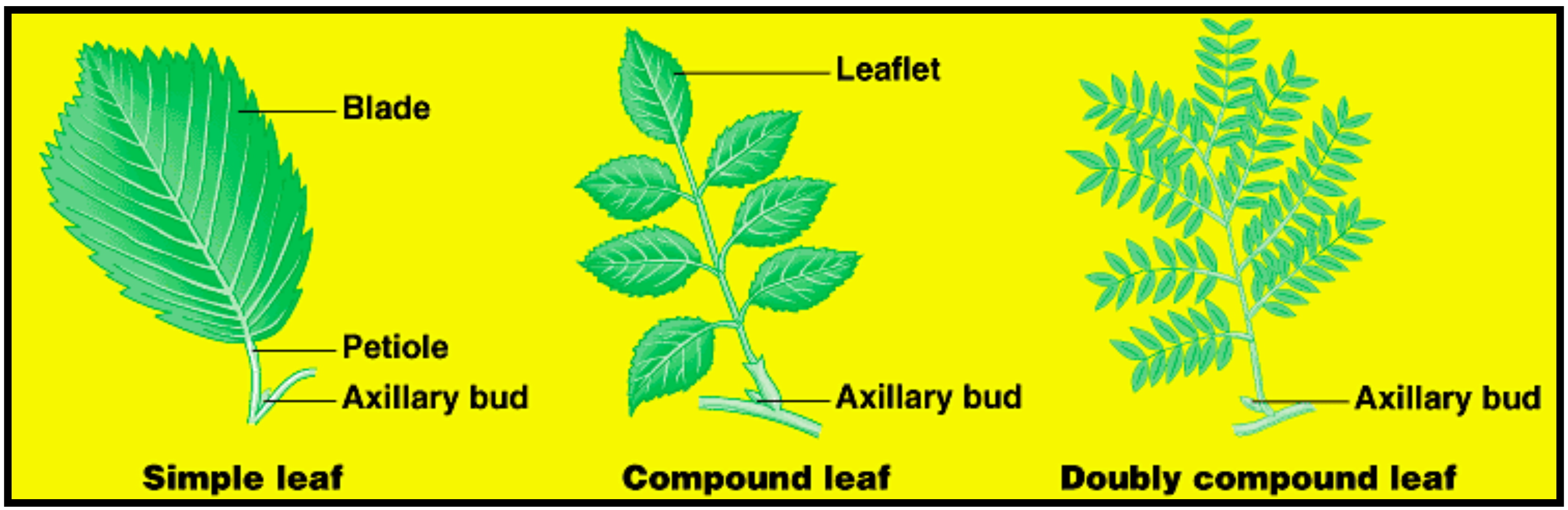
- **Structure**
  - Flattened blade
  - Petiole = stalk that joins the leaf to the stem at a node
    - Many monocots lack petioles and the base of the leaf forms a sheath that envelops the stem



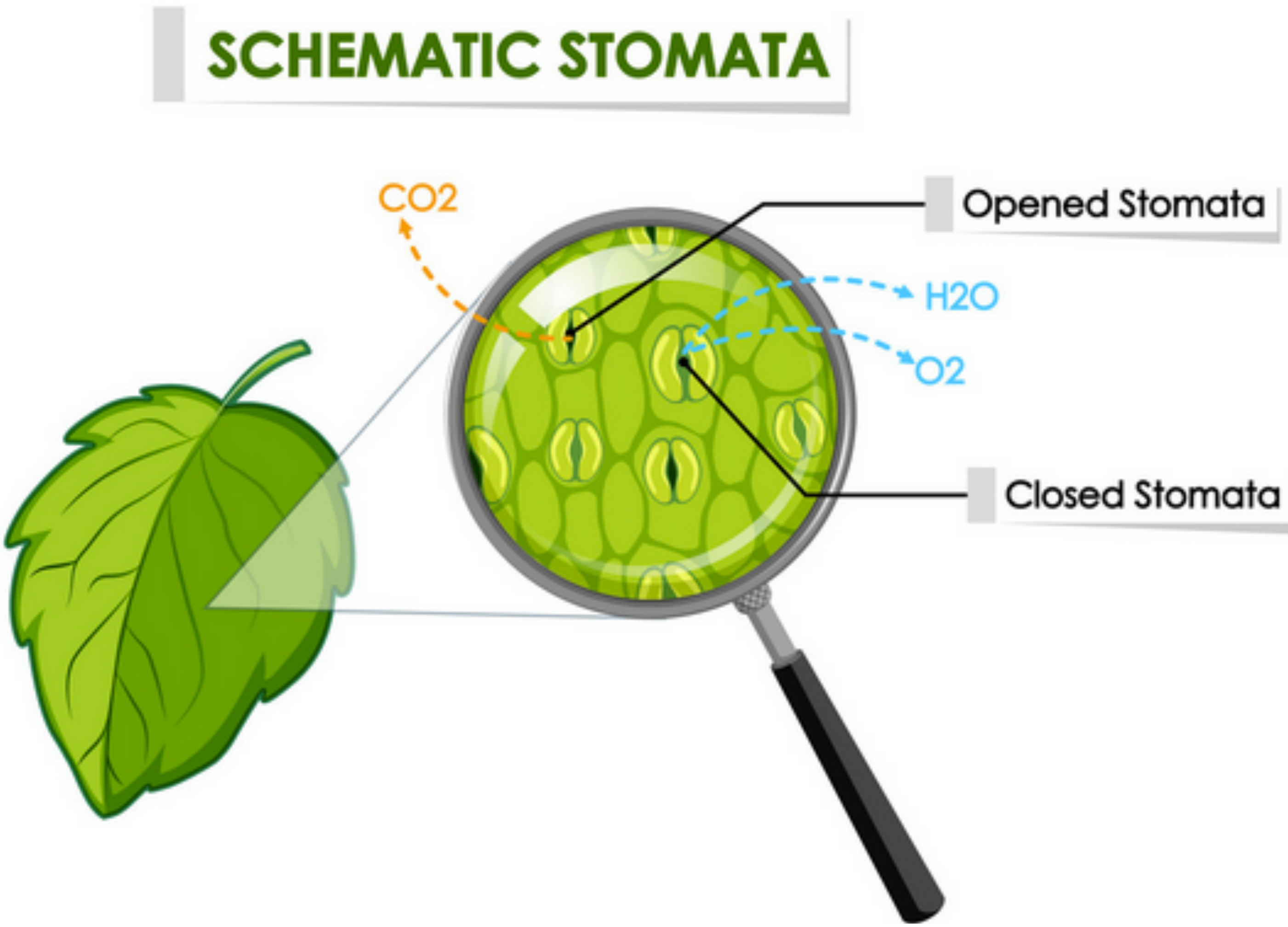
# Leave Morphology

- Leaves can be simple or compound
  - Simple leaves
    - Single undivided blade
  - Compound leaves
    - Blade consists of multiple leaflets
    - Each leaflet is missing any axillary bud at its base
      - Allows leaves to withstand strong wind with less tearing
      - Confines pathogens to a leaflet
  - Double Compound leaves
    - Each leaflet is itself divided into smaller leaflets

AP



**Stomata are structures in the epidermis of tree leaves and needles where carbon dioxide, oxygen, and water are exchanged between between plants and the air.**



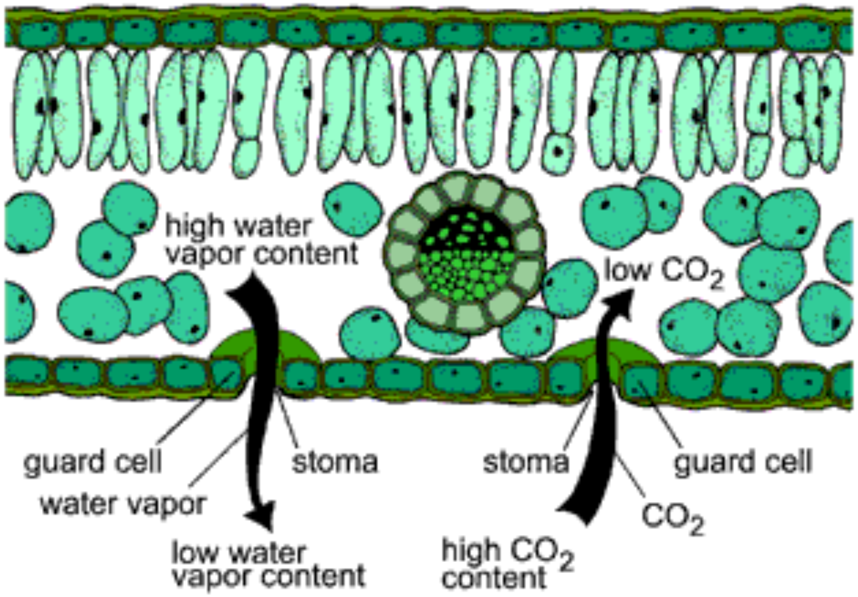
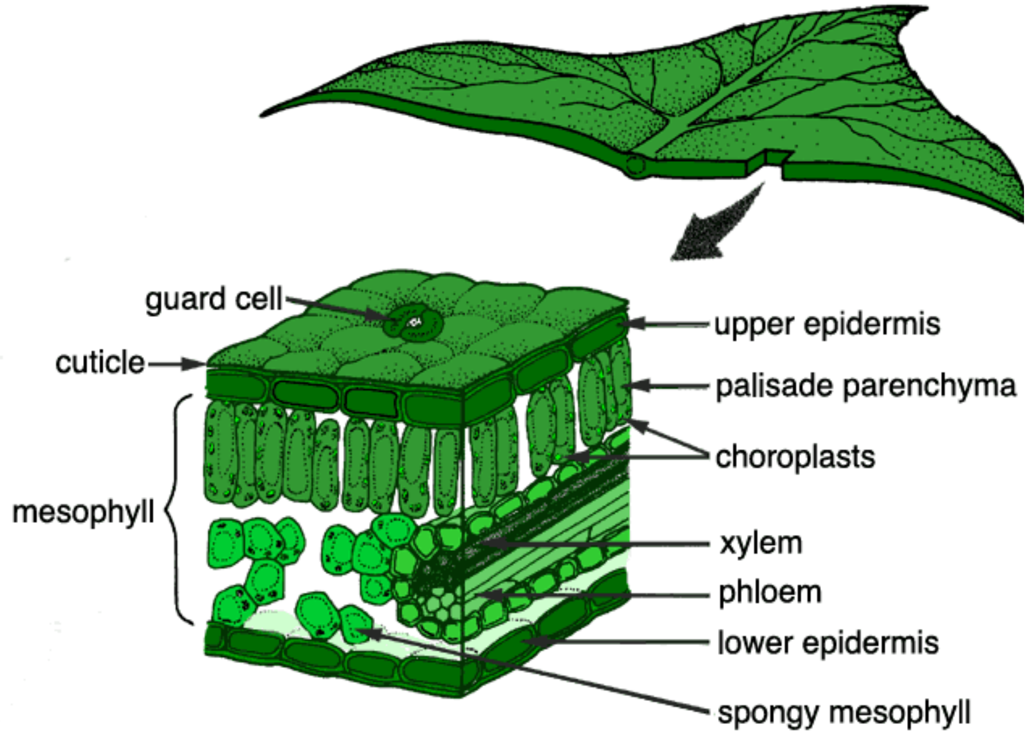
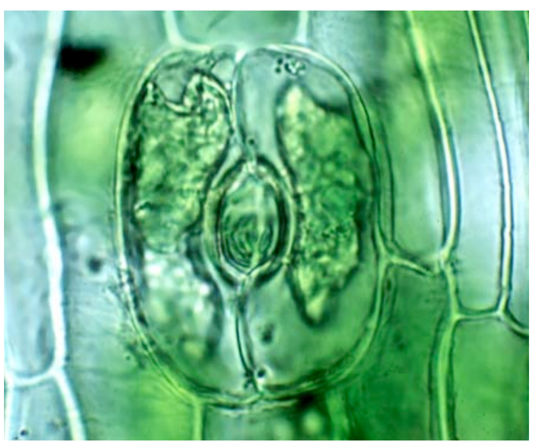
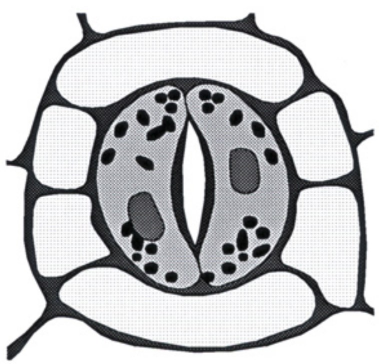
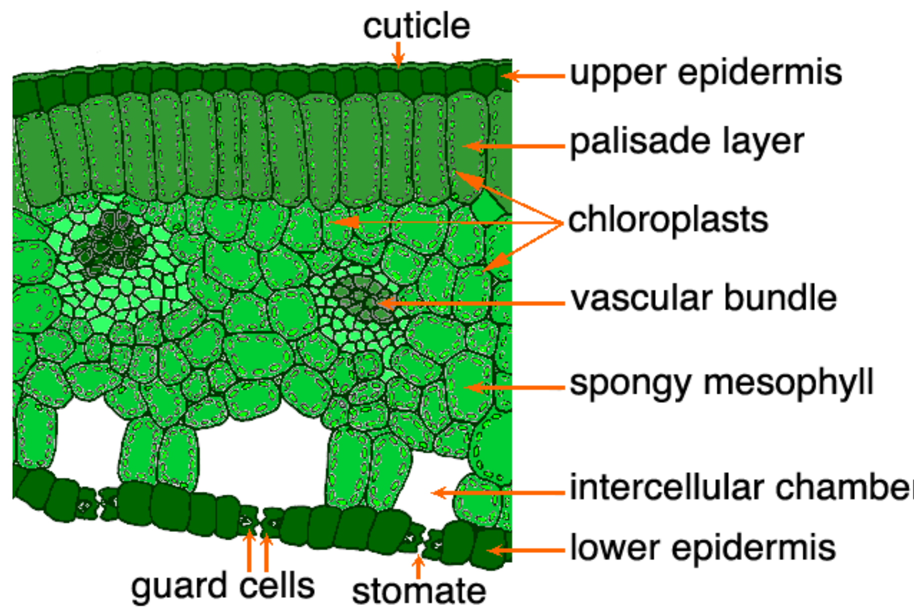



**Figure 25.** Stomata open to allow carbon dioxide ($CO_2$) to enter a leaf and water vapor to leave.







# Modified leaves

## tendrils (peas)

-allow plant to cling to a support

## spines (cacti)

-protection and an adaptation to prevent water loss

## succulent leaves

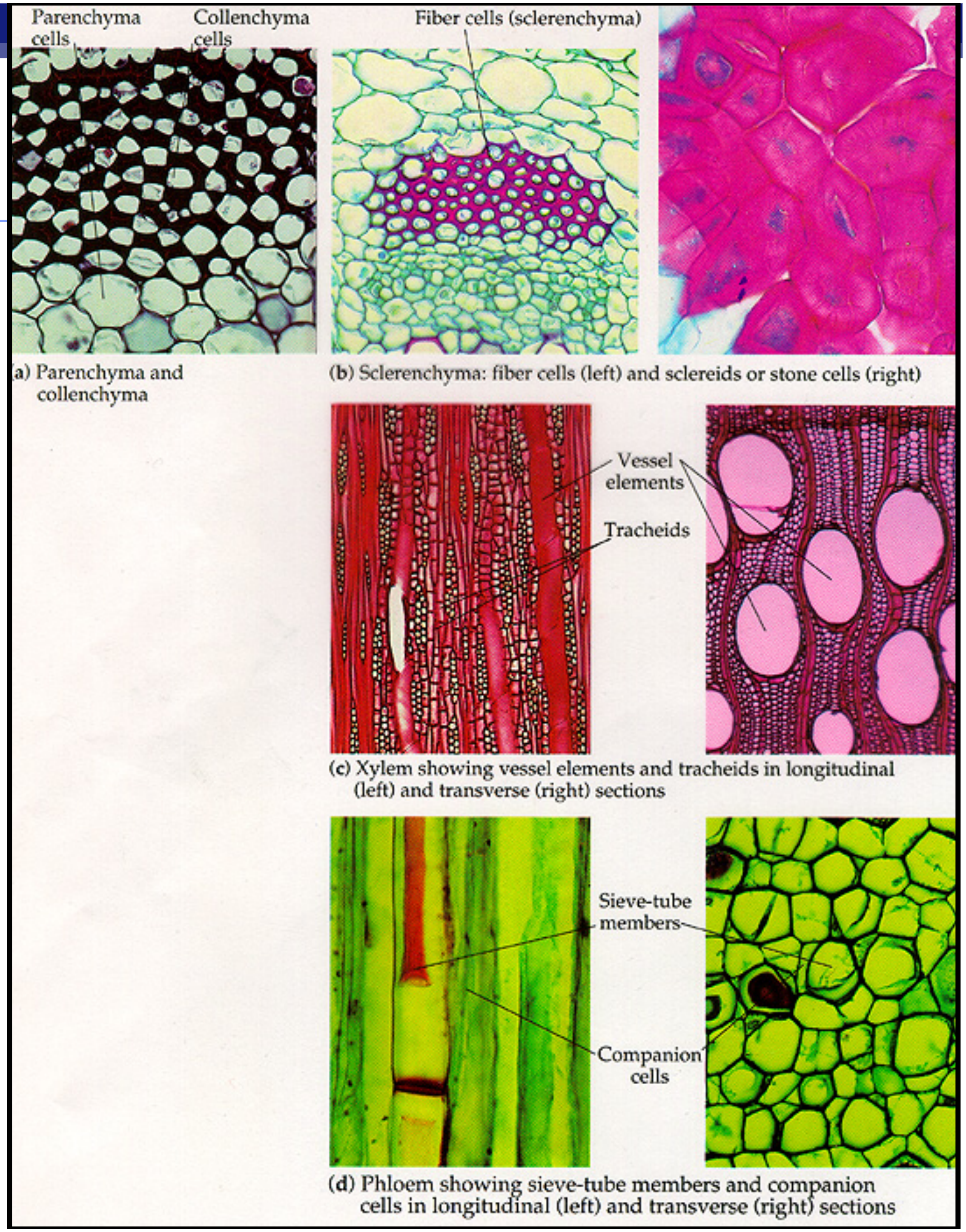
- adapted to store water

## colored leaves (poinsetta)

-brightly colored leaves surround flowers to attract pollinators

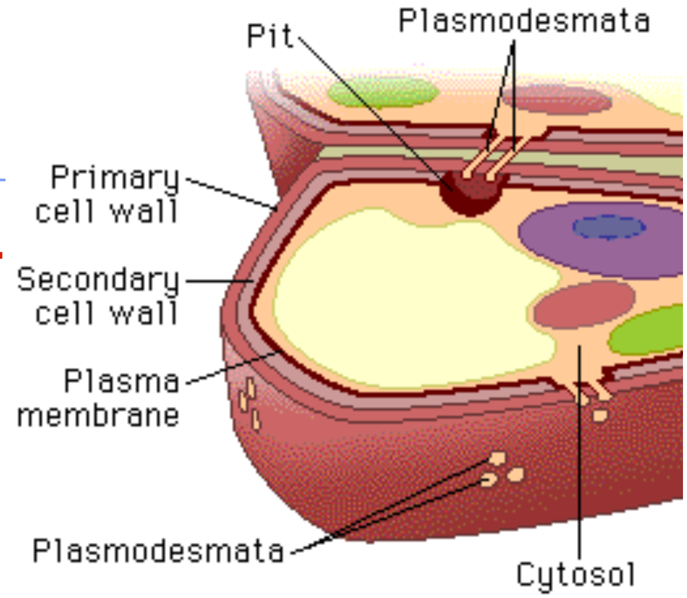
# Plant CELL types

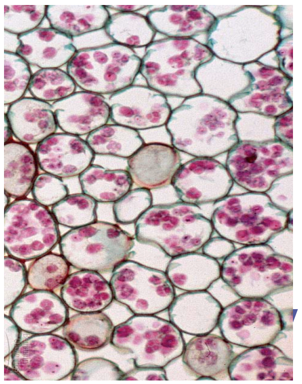
1. Parenchyma
2. Collenchyma
3. Sclerenchyma
4. Water-conducting cells of the Xylem
5. Sugar-conducting cells of the Phloem



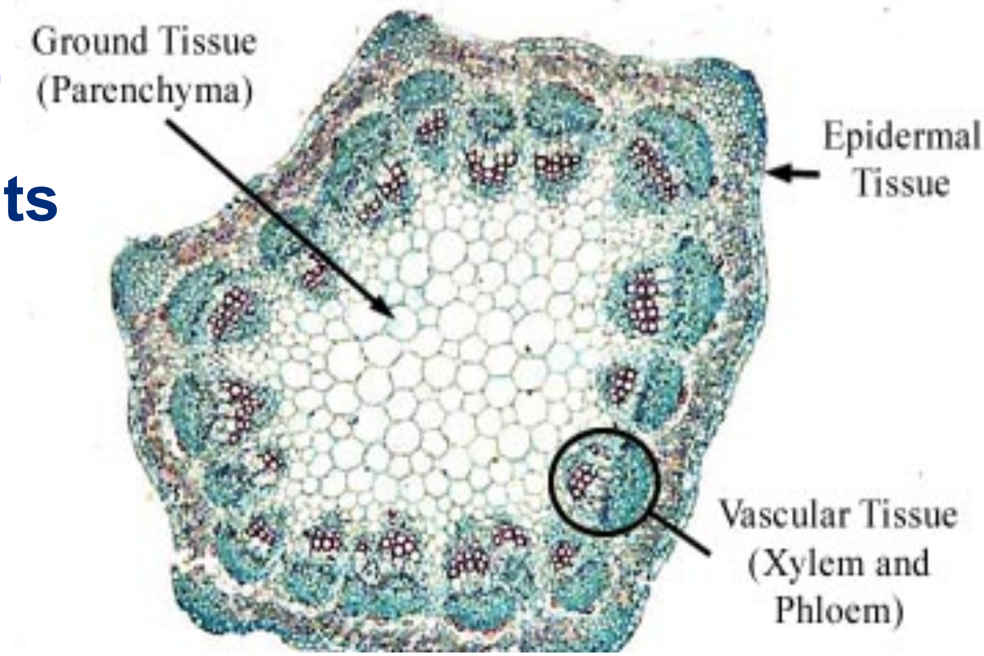
# Parenchyma

- Parenchyma cells are unspecialized
  - Primary cell walls are thin, flexible
  - Lack secondary walls
- carry out many metabolic functions
  - "typical" plant cells = least specialized
  - photosynthetic cells
  - storage cells
  - tissue of leaves, stem, fruit, storage roots
- all other cell types in plants develop from parenchyma



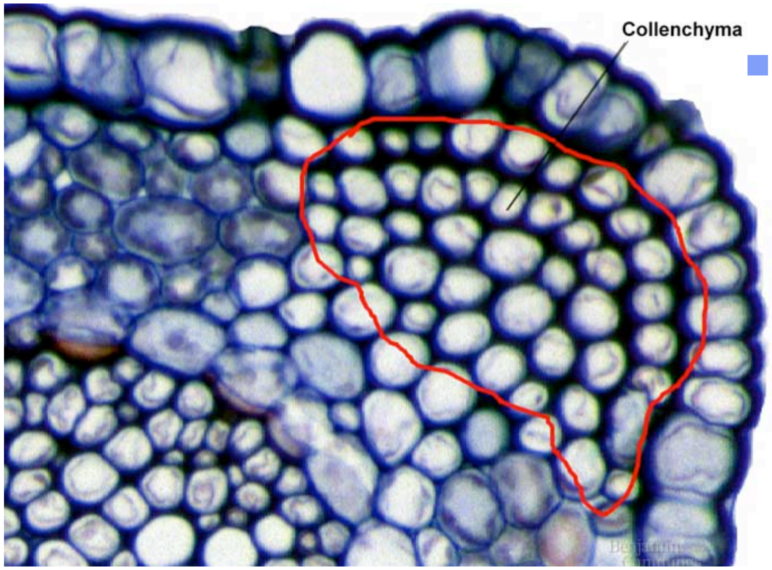



Stem cross-section showing tissue systems.

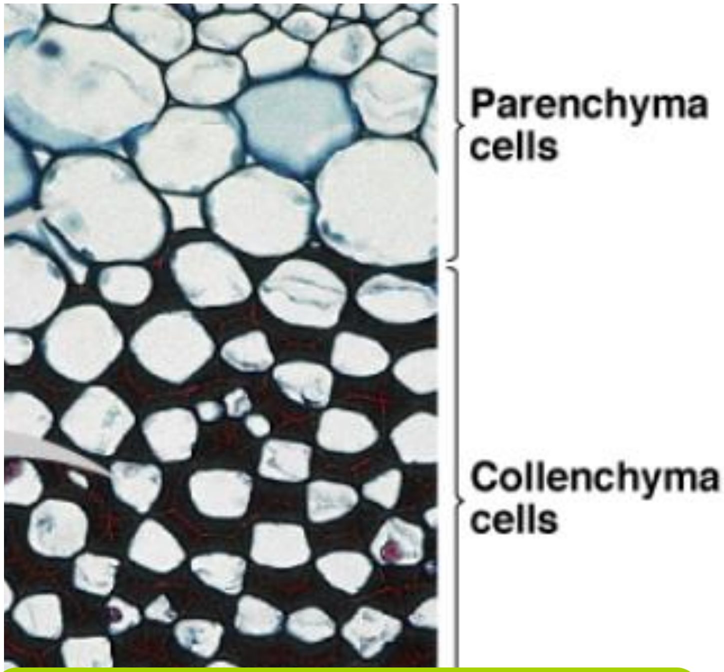


# Collenchyma

- **Collenchyma cells have thicker primary walls & provide support to young parts of plant shoots**
  - Lack secondary cell walls
  - Unevenly thickened primary walls
  - Cell walls lack hardening agent lignin
    - Can elongate to help support without restraining growth



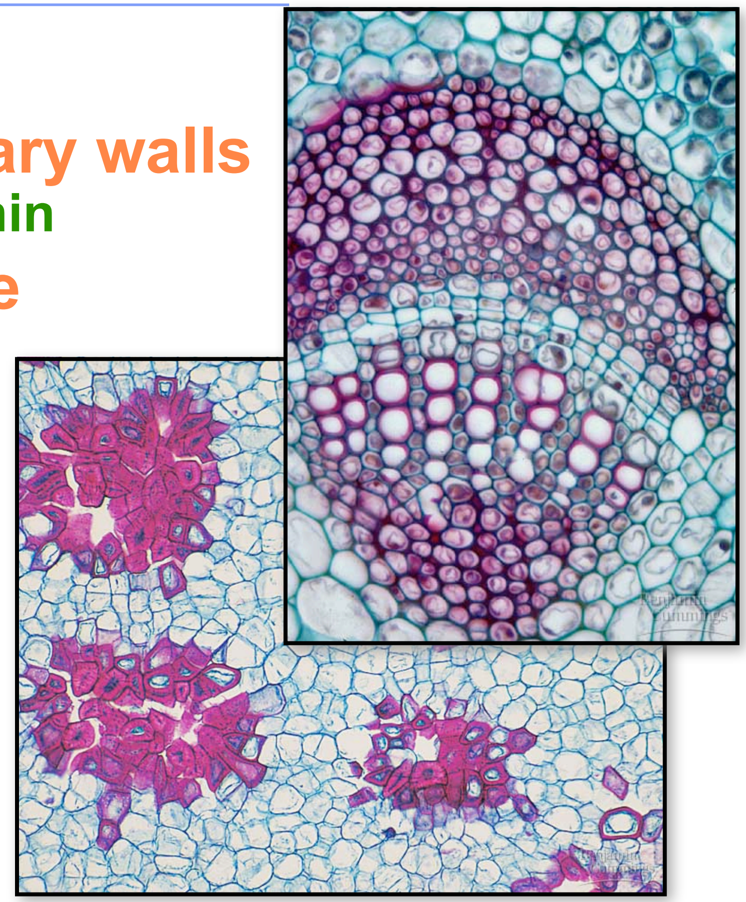

- remain alive in maturity




the strings in celery stalks are collenchyma

# Sclerenchyma

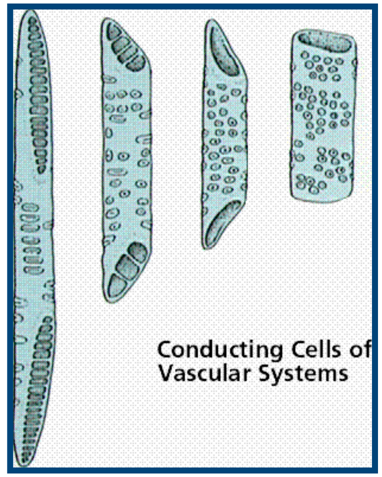
- Cells for support
  - very thick, “woody” secondary walls
    - Cell wall strengthened with lignin
  - rigid cells that can’t elongate
    - Occurs in tissues that have stopped growing
    - Dead at functional maturity (missing protoplast)
- Two types of Sclerenchyma
  - fibers
    - Rope-like threads
      - Ex: hemp
  - sclereids
    - Shorter with very thick lignified secondary walls
      - Ex: Give nutshells & seed coats hardness
      - Ex: grittiness in pears



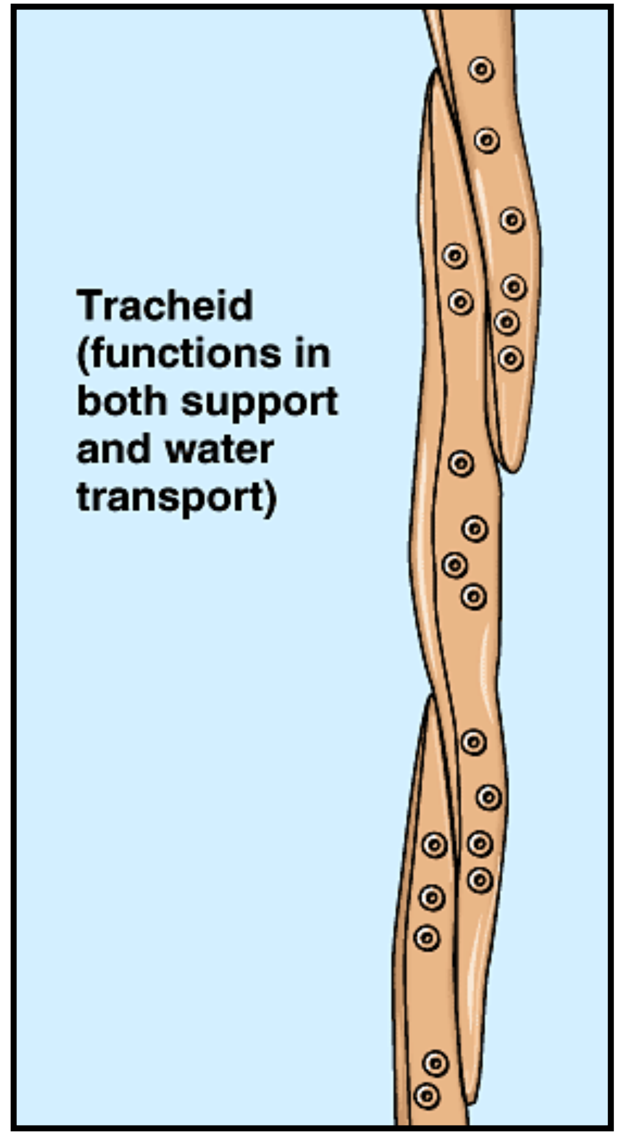
# Xylem's water conducting cells

## Two types:

- Tracheids
- Vessel Elements

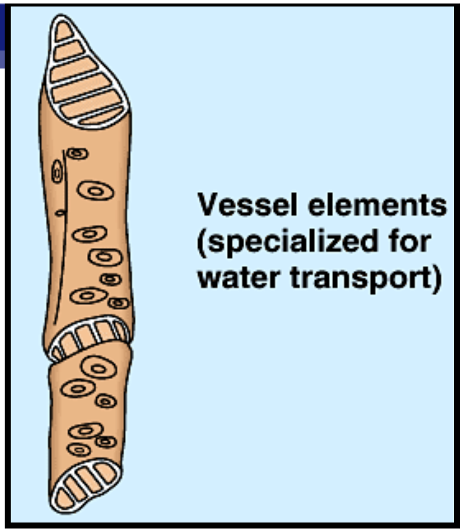


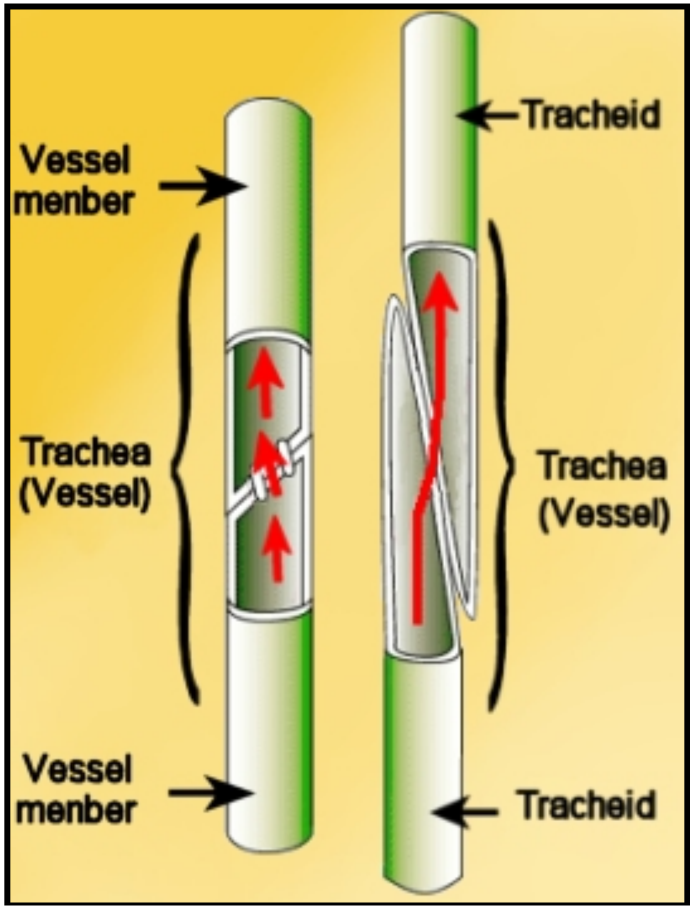

1. **Tracheids**
   - Elongated and tapered tubular cells
     - Dead at functional maturity
   - Secondary walls fortified with lignin providing support and preventing collapse
   - In Xylem of almost all vascular plants
     - Chief water-conducting element in gymnosperms and lower vascular plants, also found in Angiosperm xylem.
   - Contains pits but no perforations



# Xylem's water conducting cells

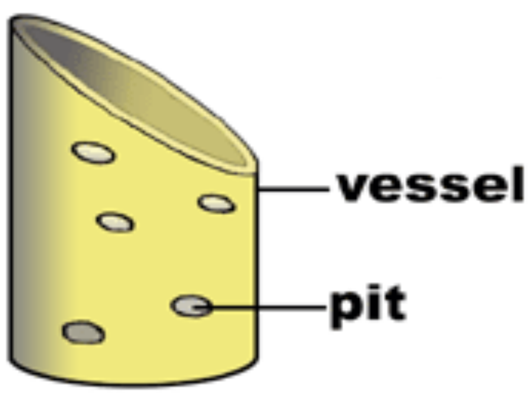
2. **Vessel elements**
   - Elongated tubular cells
     - Wider, shorter, thinner walled than tracheids
     - Dead at functional maturity
   - Aligned end-to-end forming <u>Vessels</u>
   - End walls of vessel elements have <u>perforated plates</u>
     - Allows water to flow freely through the vessels in the xylem
   - <u>Chief water-conducting element in angiosperm xylem.</u>
     - Found additionally to tracheids in angiosperms (a few gymnosperms and seedless vascular plants)
   - Contains pits and perforations

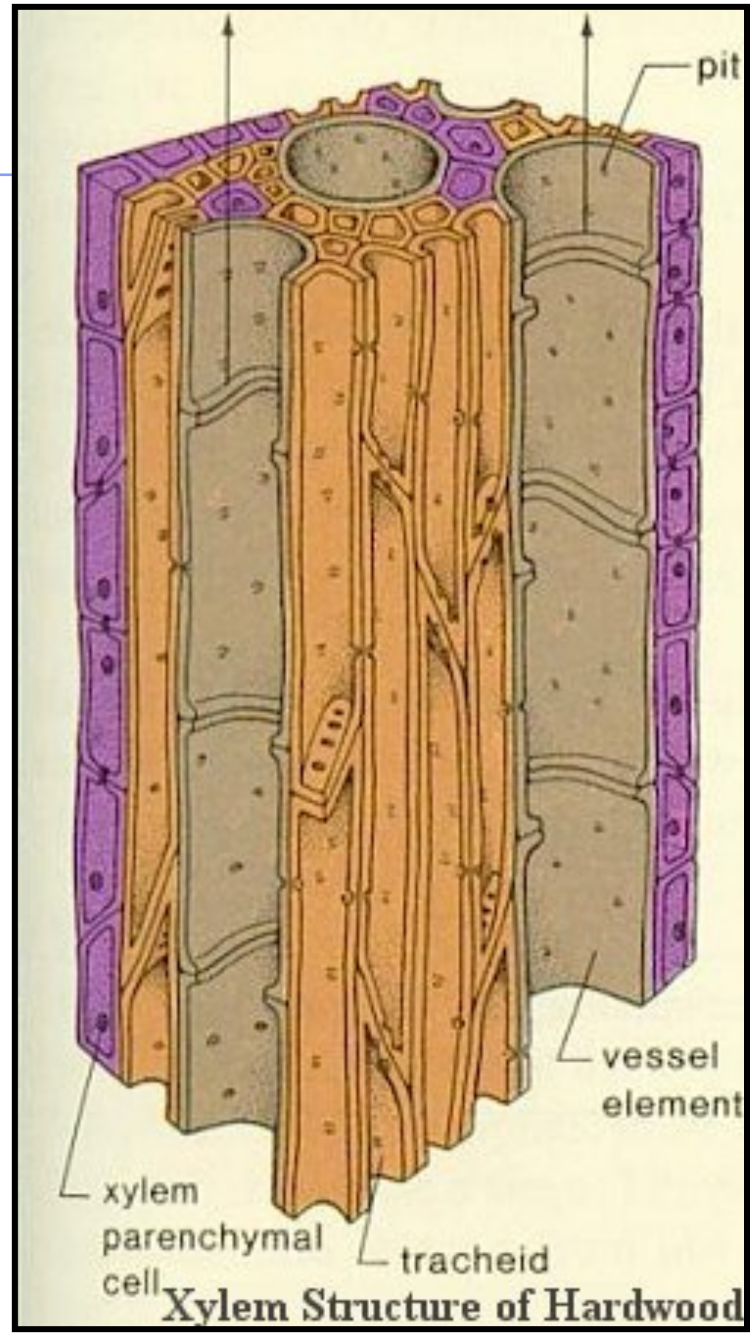


# Xylem cell pits

- Secondary walls of both these cells are interrupted by pits
  - PIT = thinner regions where only primary walls are present
    - Pits allow water to migrate out of these cells laterally

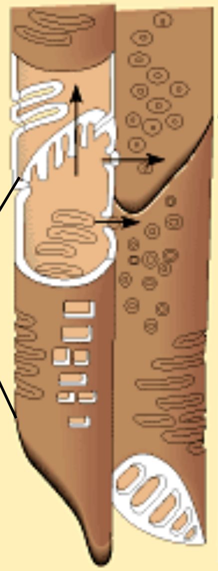


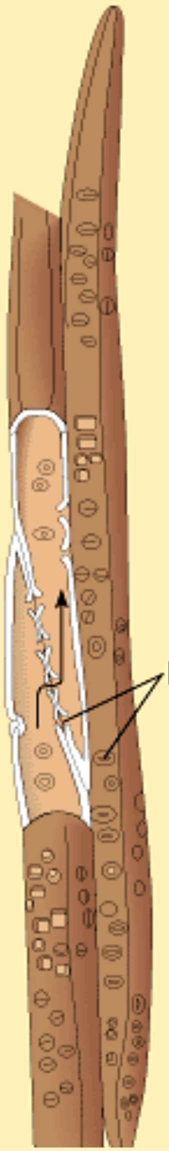



# Vascular tissue

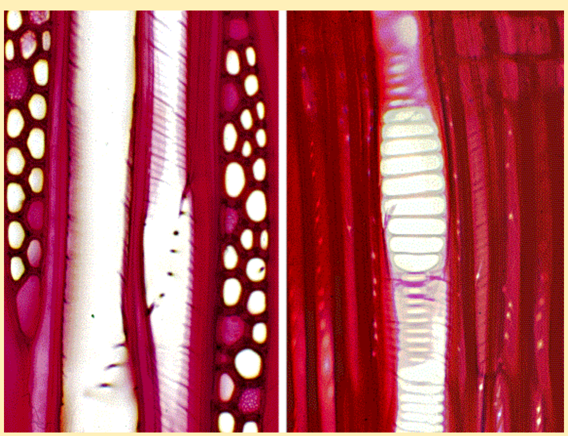
vessel elements

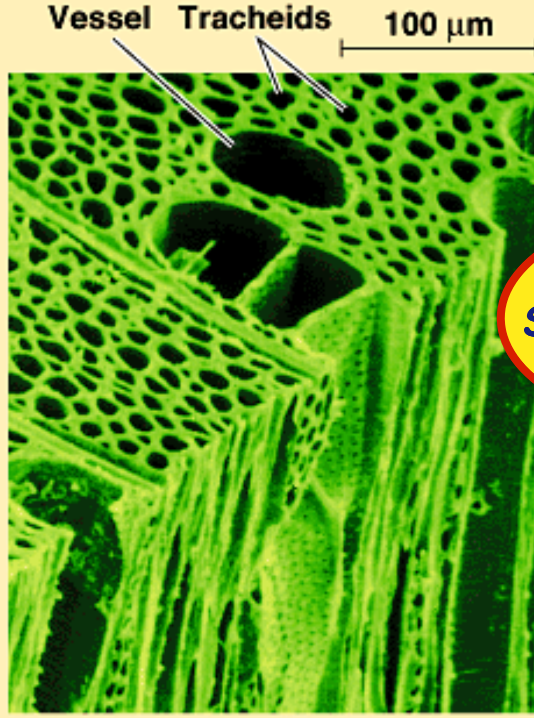
- Xylem
  - move water & minerals up from roots
  - dead cells at functional maturity
    - Only lignified cell walls remain
    - need empty pipes to efficiently move $H_2O$
      - Water moves by transpirational pull



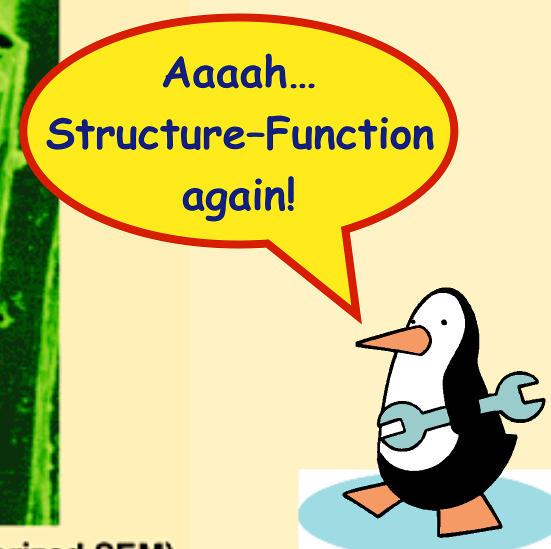

(b) Vessel elements with partially perforated end walls






(c) Tracheids and vessels (colorized SEM)

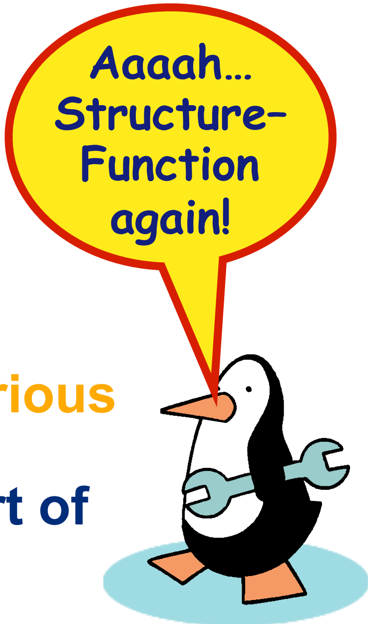
dead cells



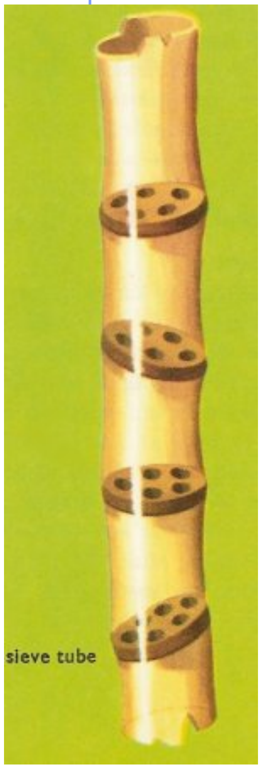

tracheids

# Sugar-conducting cell of the Phloem

- Unlike Xylem, phloem cells are **living cells** at functional maturity
  - They have a cell membrane & cytoplasm
    - Soooo…. They can control of diffusion




- Cells

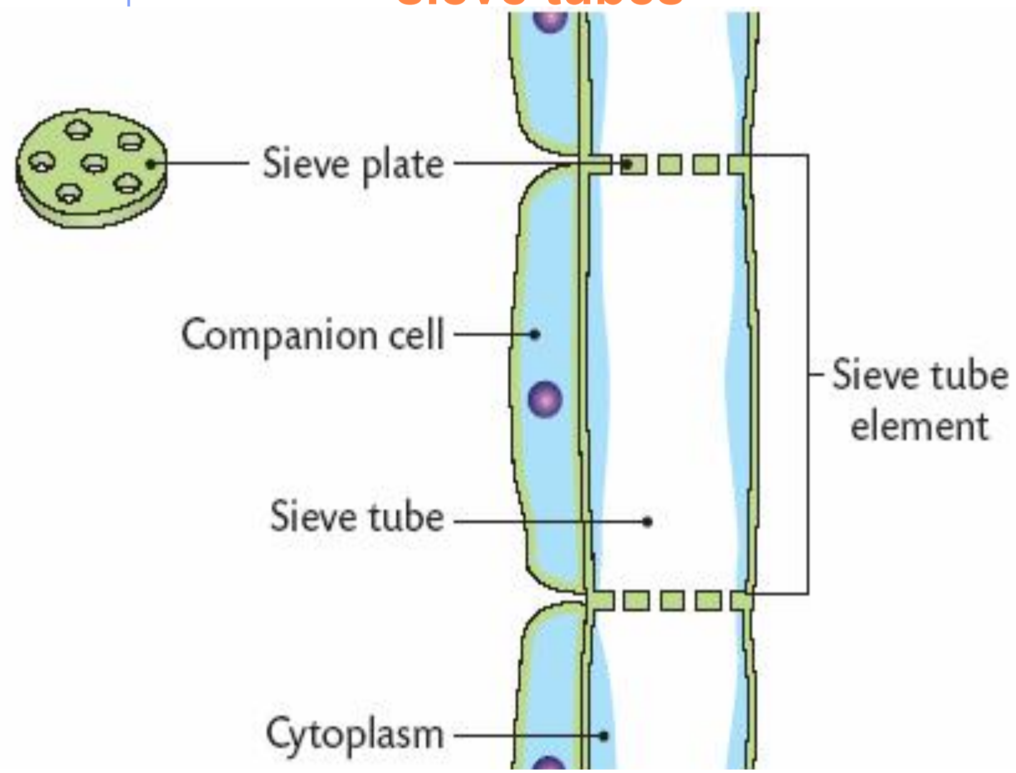


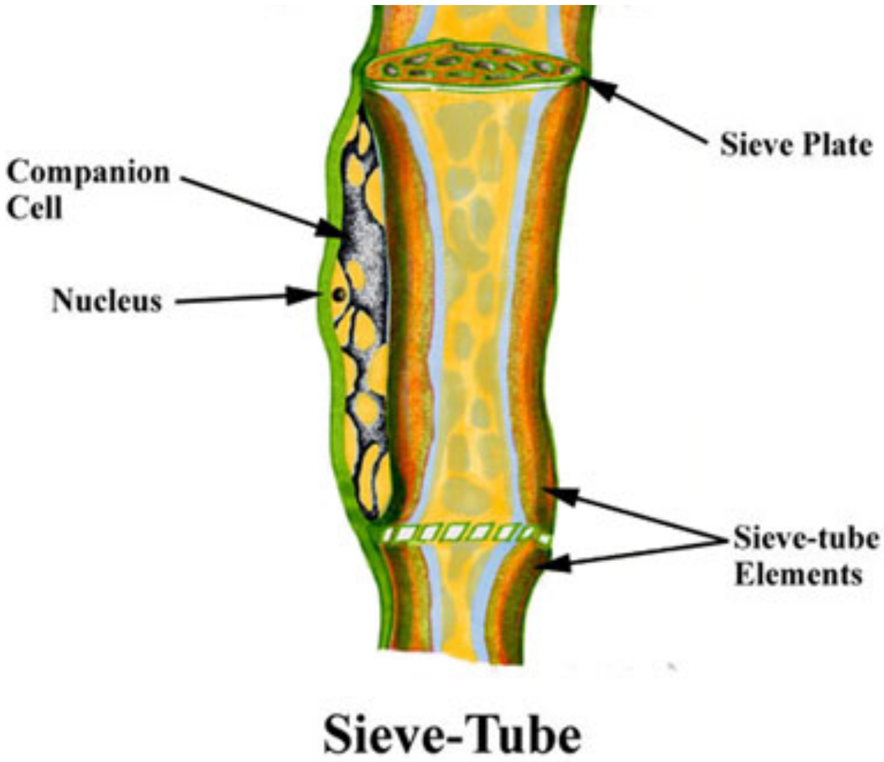

**Sugar Conducting cells**

- loose their nucleus, ribosomes, vacuole & various cytoskeletal elements
  - more room for easier specialized transport of liquid nutrients (sucrose)
- **Sieve cells**
  - Long narrow cell
    - In seedless vascular plants and gymnosperms
- **Sieve tubes**
    - Sugar conducting cells in angiosperms
  - Contain Sieve plates as end walls: have pores to facilitate flow of fluid between cells

# Additional cells of the Phloem

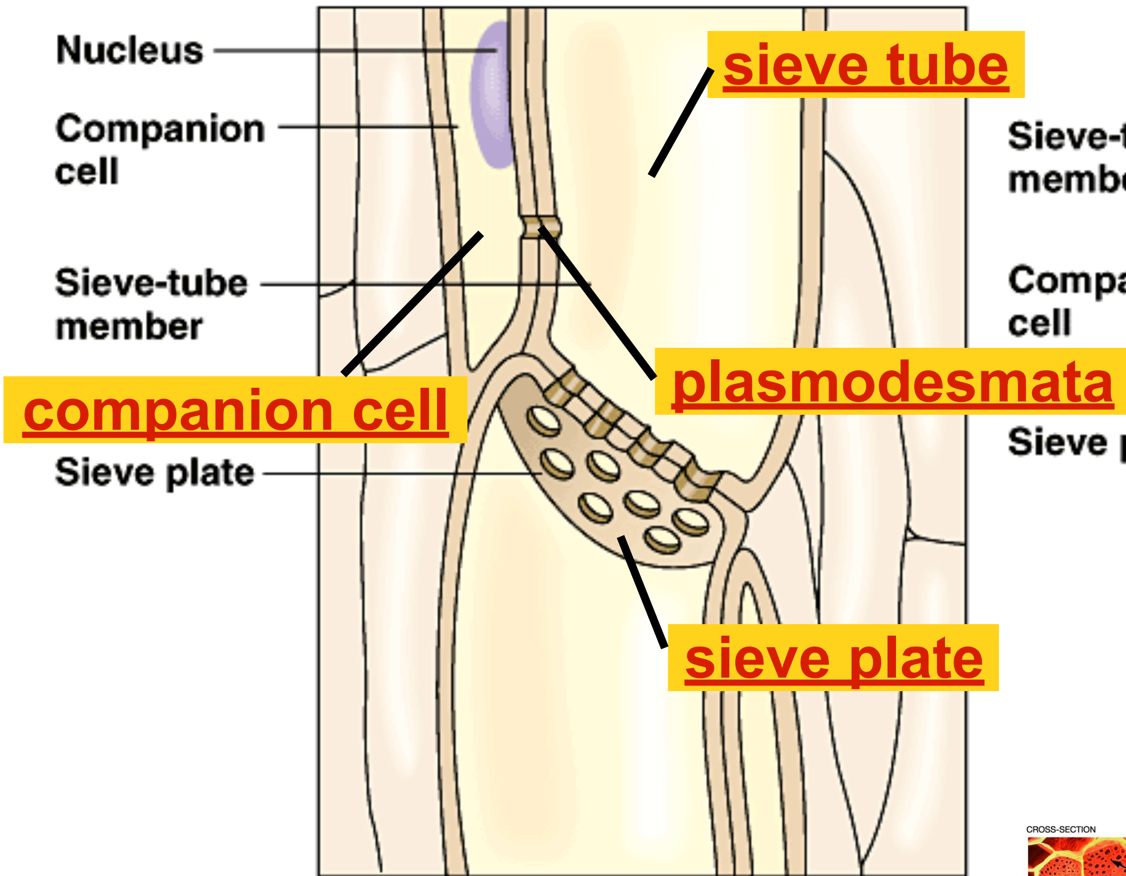
- **Companion cells**
  - Non-conducting cells alongside sieve tube element
  - Nucleated cells connected to the sieve-tube through plasmodesmata
    - Nucleus and ribosomes of companion cells also serve sieve tubes



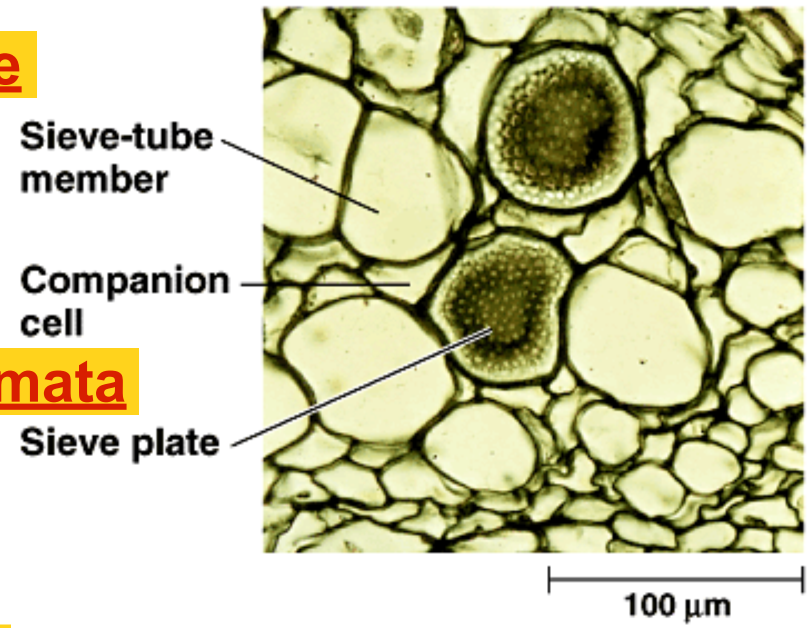



# Phloem: food-conducting cells

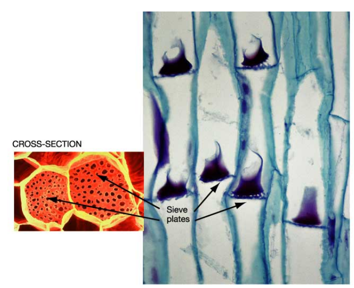
- carry sugars & nutrients throughout plant




(a) Longitudinal view



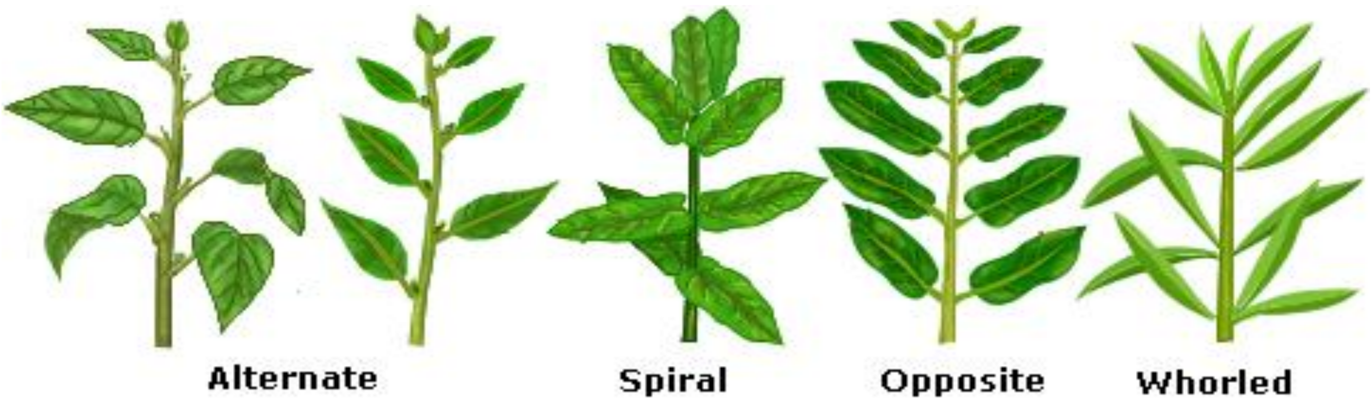

(b) Transverse section (LM)




living cells

# Shoot architecture and light capture

- Stems serve to support leaves and allow for the transport of water and nutrients.
  - Larger leaves found in rain forests
  - Smallest leaves are often in dry or very cold environments
    - Water is scarce
    - Evaporative water loss a bigger problem




- Phylotaxy is very important for light capture
  - Phylotaxy = arrangement of leaves
    - One leave per node = alternate or spiral
    - Two leaves per node = opposite (most angiosperms)
    - More leaves per node = whorled
    - Plants reduce self-shading to increase light capture!

# Shoot architecture and light capture

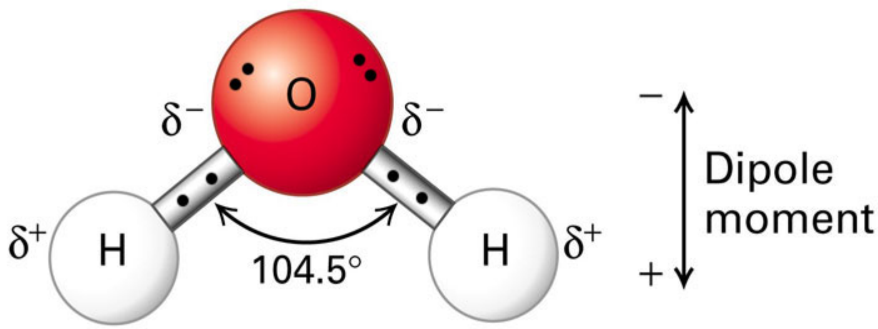
- If leaves are in too much shade, cellular respiration occurs more than photosynthesis.
  - <u>Self-pruning</u>
    - Non-productive leaves or branches may undergo programmed cell death and be shed
- <u>Leaf orientation</u> affects light capture as well.
  - Horizontal leaves are more effective than vertical leaves
  - However, in environments with intense light that may damage tissue, vertical leaves receive less direct light so can be better
- Finally, <u>branching</u> (bud growth and stem elongation) help a plant capture light and $CO_2$

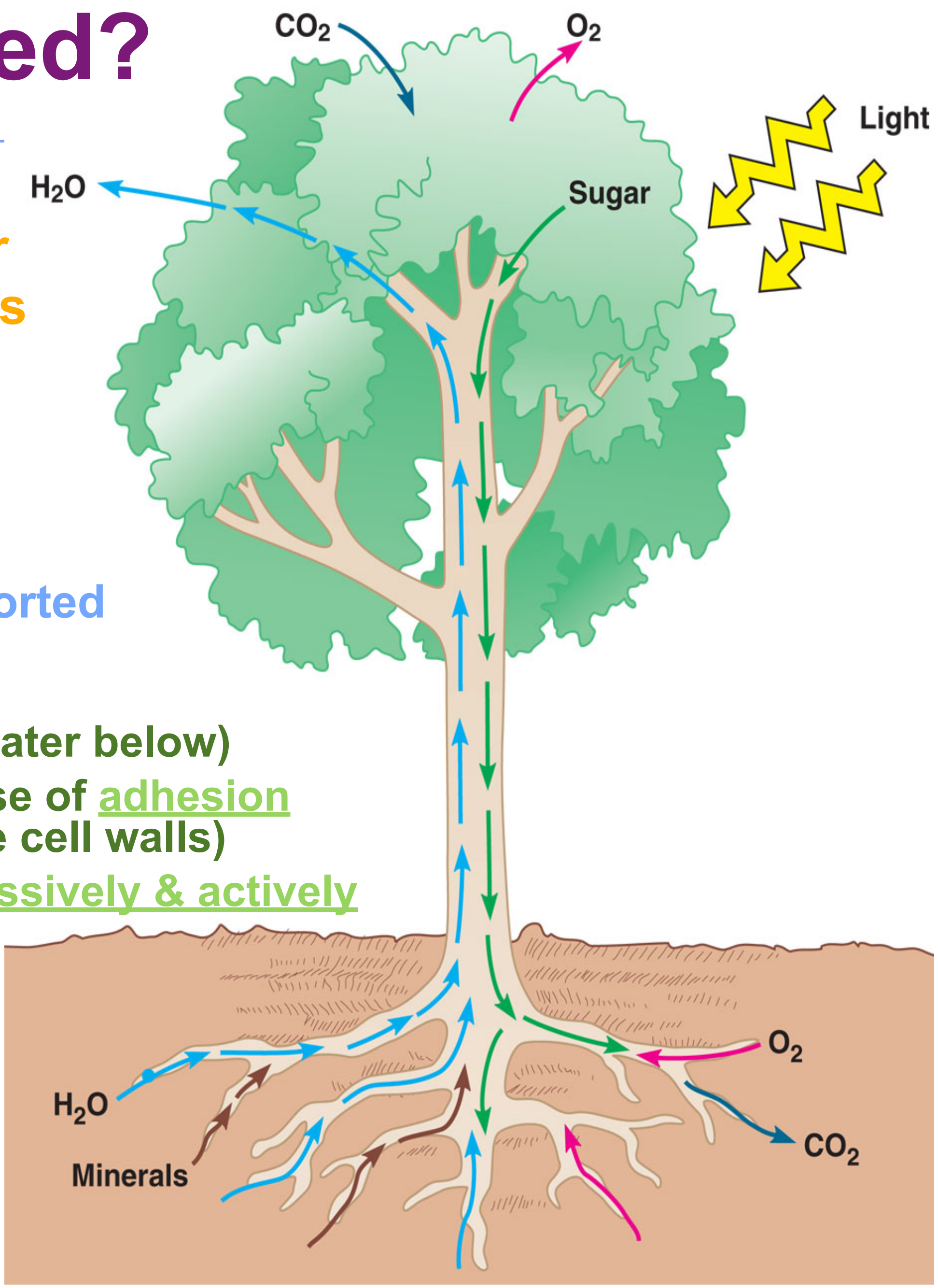


**Natural Selection has optimized shoot architecture that optimizes light absorption in the niche plants occupy**

# What is transported?

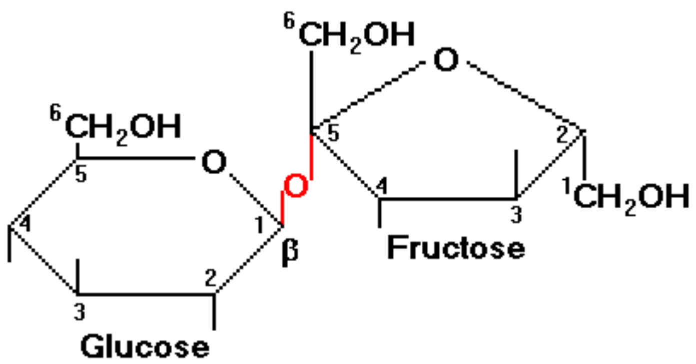
- $H_2O$ & minerals
  - Transpiration = loss of water mostly through leaf stomates
    - Causes negative pressure
      - water from inside xylem moves to fill vacuum
  - Water diffuses into roots
    - Water & Minerals are transported in xylem as xylem sap
      - Water rises by cohesion (water above tugging on water below)
      - Water doesn't drop because of adhesion (water sticking to cellulose cell walls)
      - Minerals are brought in passively & actively

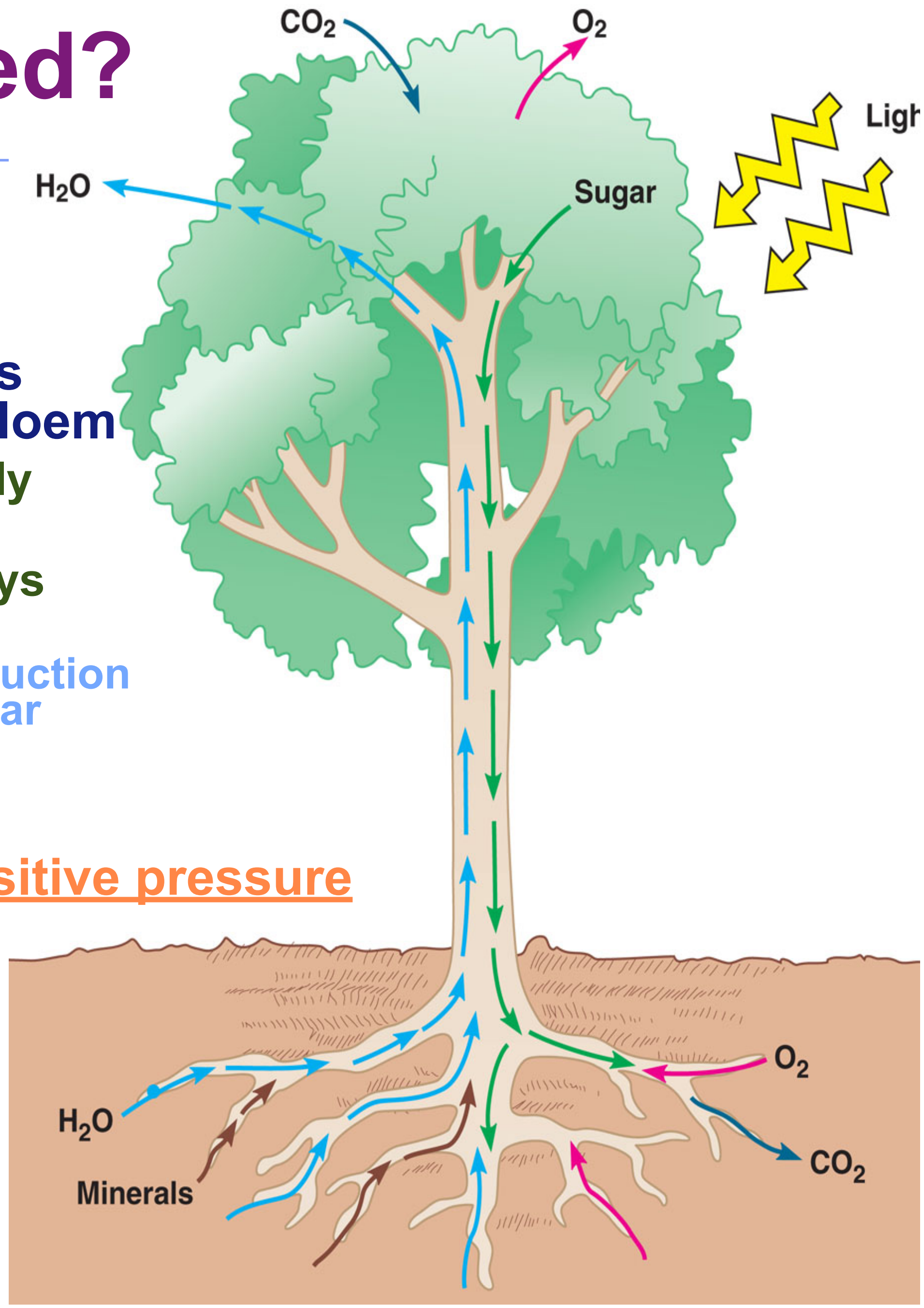


# What is transported?

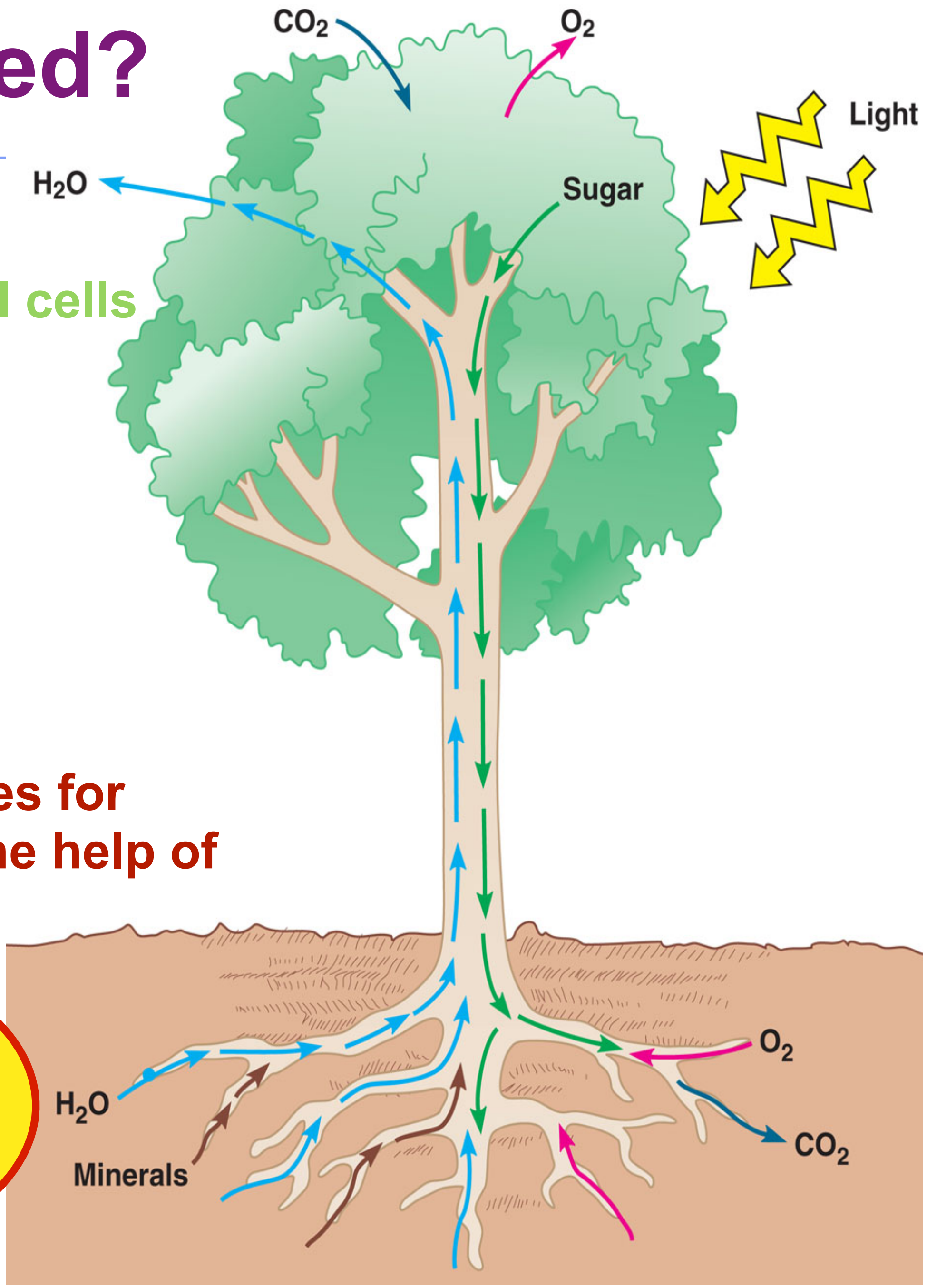
- Sugars
  - Transported in phloem
    - Calvin cycle in leaves loads sugary phloem sap into phloem
      - Transported sugar is mainly sucrose
      - Phloem sap flows both ways between roots and shoots
        - From sites of sugar production or release to sites of sugar storage or consumption
  - Moved by bulk flow
    - Movement results form positive pressure



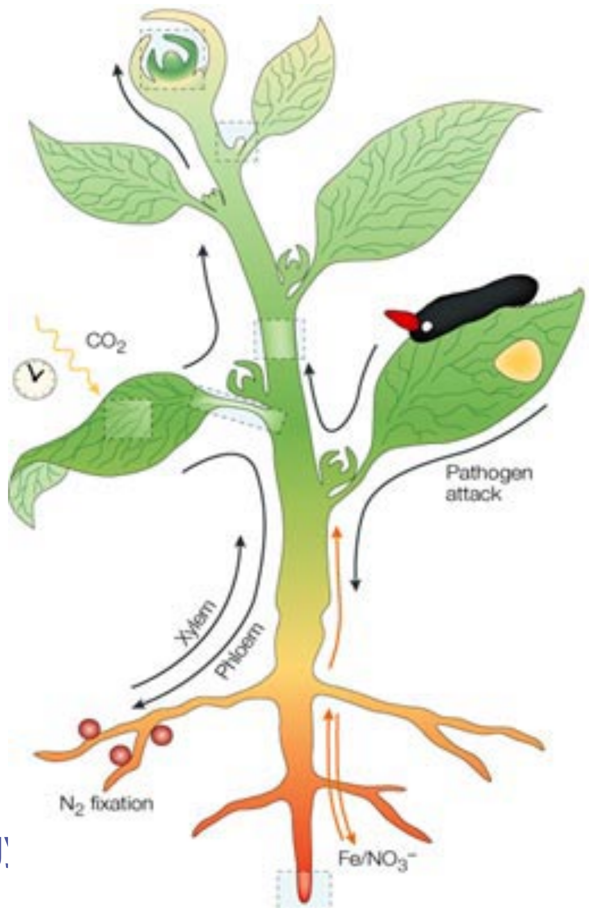
# What is transported?

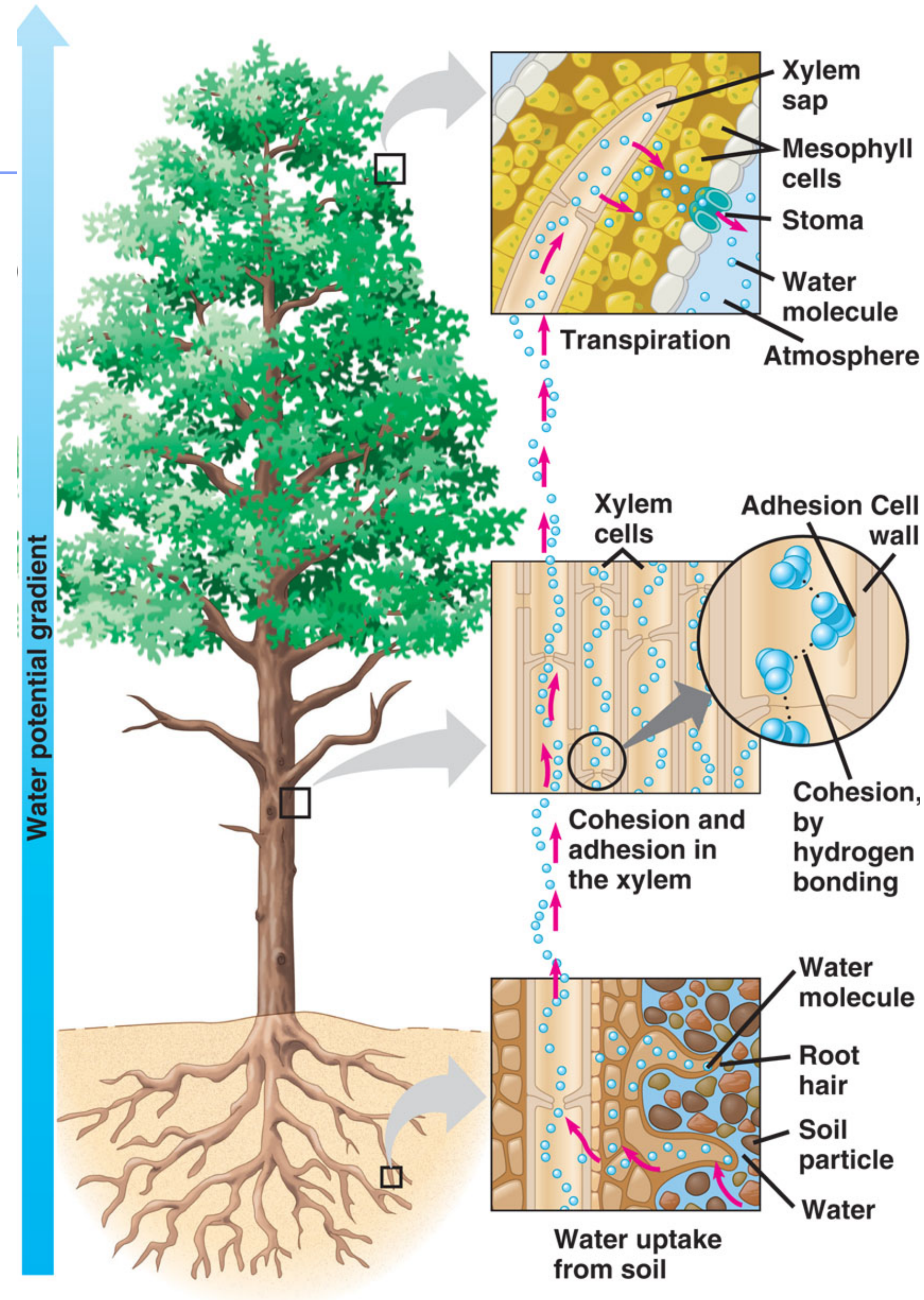
- Gas exchange
  - Photosynthesis in mesophyll cells
    - $CO_2$ in; $O_2$ out
    - Gas exchange possible through stomates
  - Respiration in ALL cells
    - $O_2$ in; $CO_2$ out
    - Roots also exchange gases for cellular respiration with the help of air spaces in soil

# Three Basic Transport Mechanisms in Plants

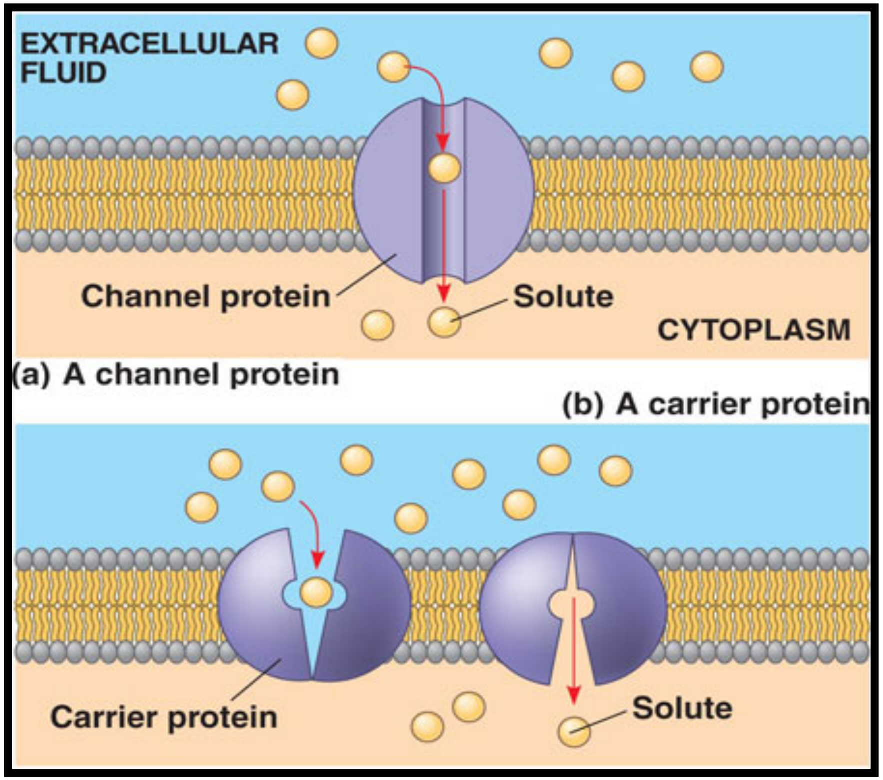
1. Diffusion
2. Active Transport
3. Bulk Flow



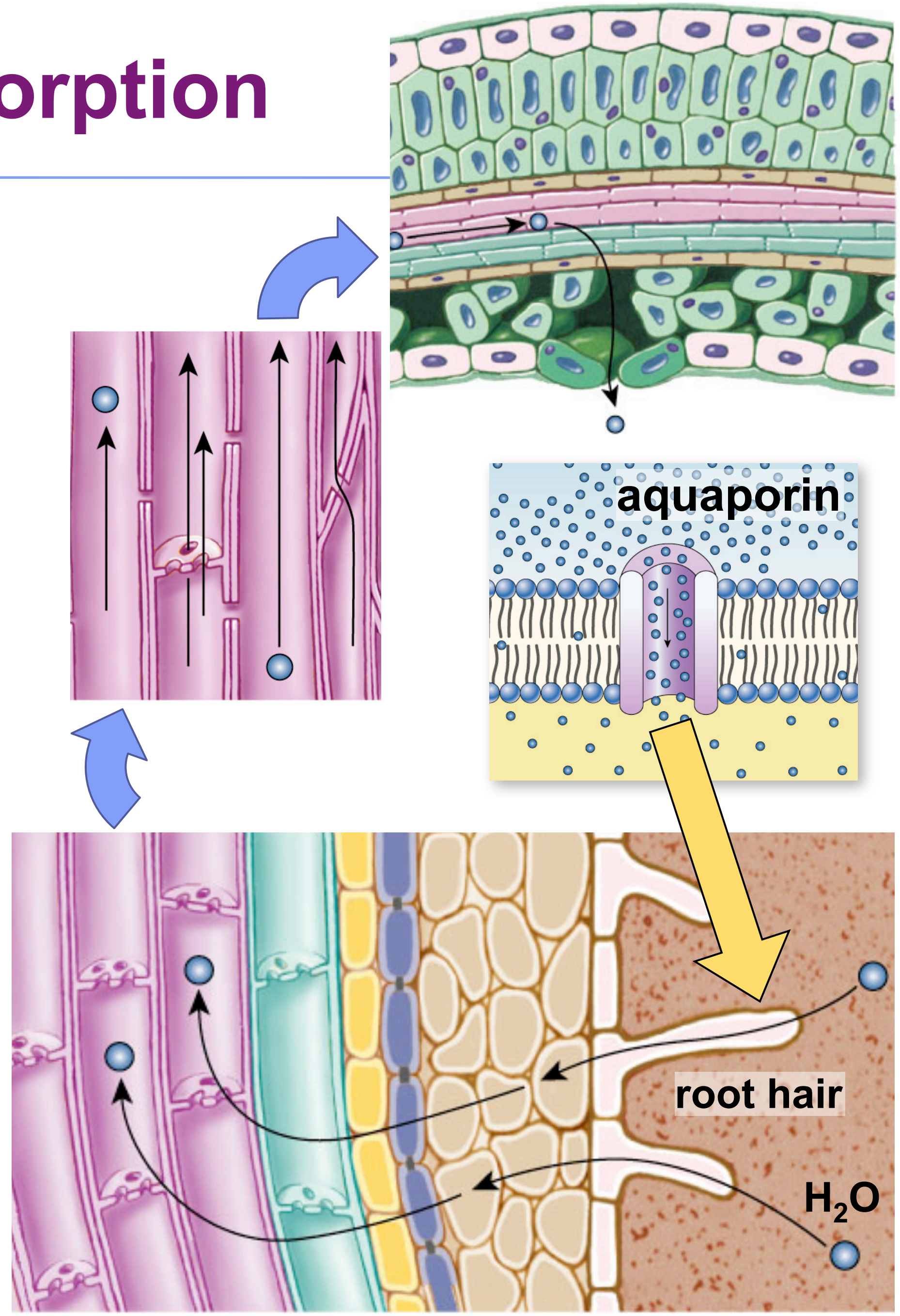
# Selective permeability of the plasma membrane controls the movement of substances into and out of the cell

- Passive Transport
  - Diffusion of solutes down their electrochemical gradient
    1. Solutes move down chemical concentration gradients
    2. Solutes move down their electrical gradient
       - *Voltage = charge difference across the membrane*
  - Does NOT involve the use of metabolic energy
    - Simple Diffusion = does not involve transport protein at all. *Just diffusion across plasma membrane.*
    - Facilitated Diffusion = involves a transmembrane protein that assists in passage of solute
      - Carrier Proteins
      - Channel Proteins
        - Ex: Aquaporins



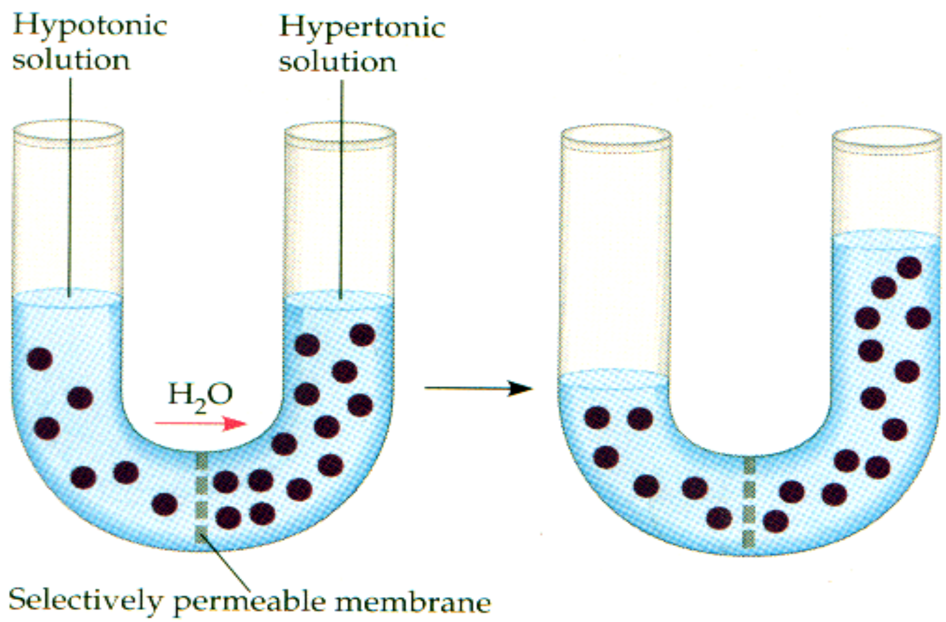
# Water & mineral absorption

- In **plants**, water absorption from soil involves **osmosis**
  - **Aquaporins** *(in root hairs)* facilitate water diffusion & increase the **RATE** of water's diffusion



# Osmosis & Water Potential

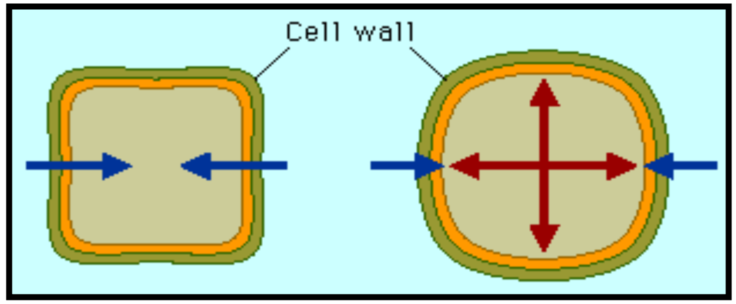
- **Animal cells**
  - Water moves from solution with lower solute concentration to solution with higher solute concentration




- **Plant cells**
  - Must also take into account the cell wall pushing back against expanding protoplast *(protoplast = living part of the cell)*
- **Water potential = incorporates the effects of both solute concentration and physical pressure** $\Psi$ *(Units: Pressure)*
  - Water potential determines the direction of water movement
    - FREE water moves from areas of higher water potential to regions of lower water potential!!!!!

# Water Potential

- Water potential refers to water's potential energy
  - Water is able to perform work as it moves from a region with higher to lower water potential
    - Ex: Expand the cell wall




- Water potential depends on pressure and solute concentration

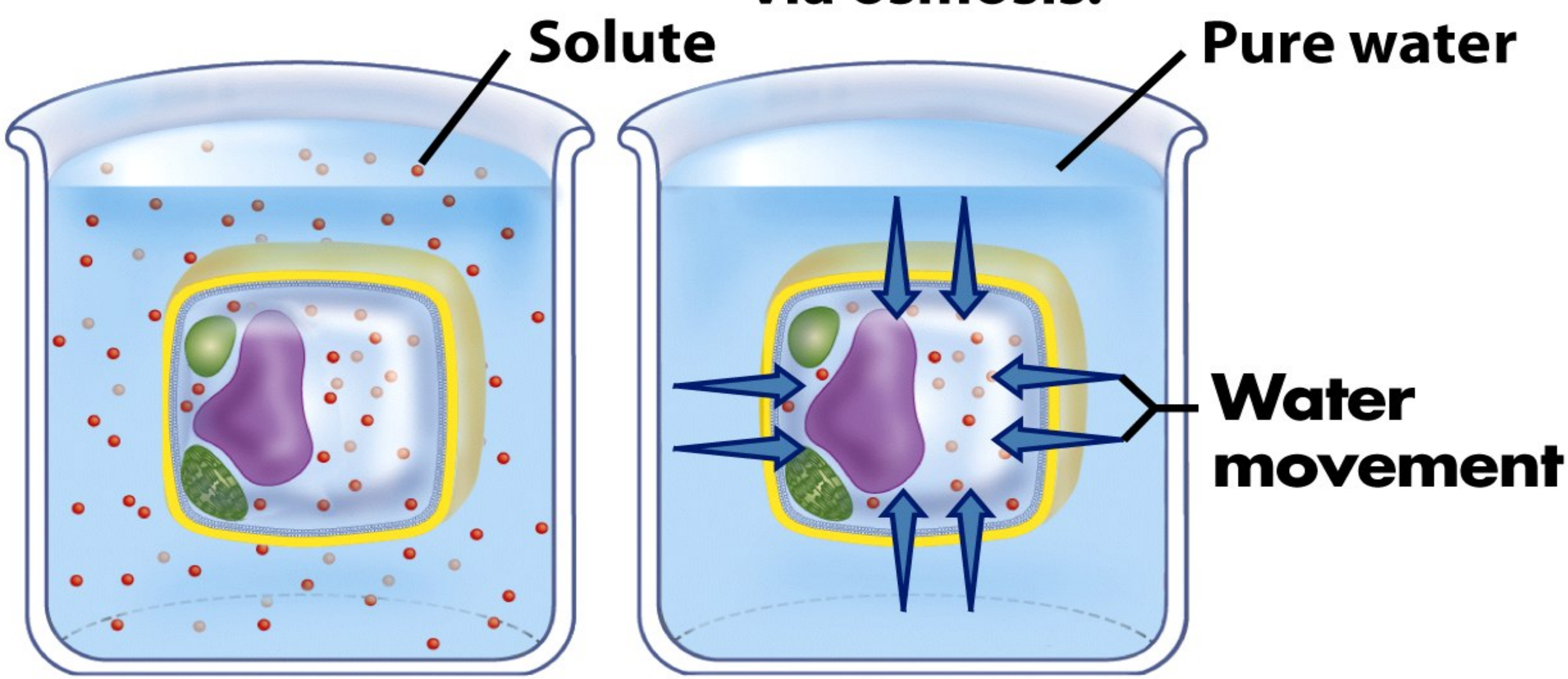
$$\Psi = \Psi_s + \Psi_p$$

1. Solute / Osmotic Potential of a Solution $\Psi_s$
   - Proportional to solution's molarity *(M = mol/L)*
     - Pure water has a osmotic potential of 0 !!!
   - Adding solutes lowers water potential making it NEGATIVE
2. Pressure Potential of a Solution $\Psi_p$
   - Physical pressure on the solution
     - Can be POSITIVE or NEGATIVE

**Solute potential is the tendency of water to move by osmosis.**

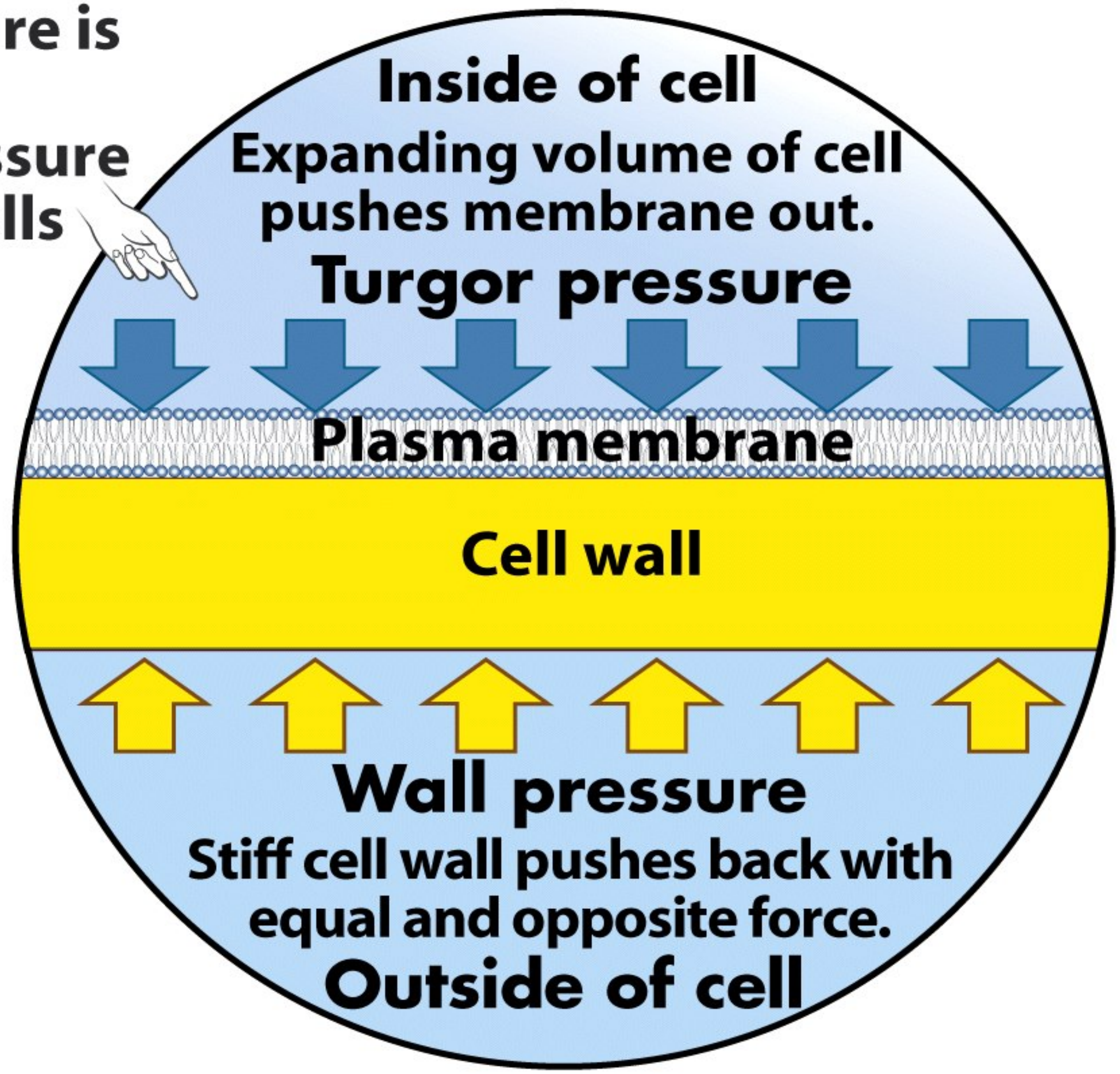
**Solute potential inside cell and in surrounding solution is the same. No net movement of water.**

**Cell is placed in pure water. Its solute potential is low relative to its surroundings. Water moves into cell via osmosis.**



## Pressure potential is the tendency of water to move in response to pressure.

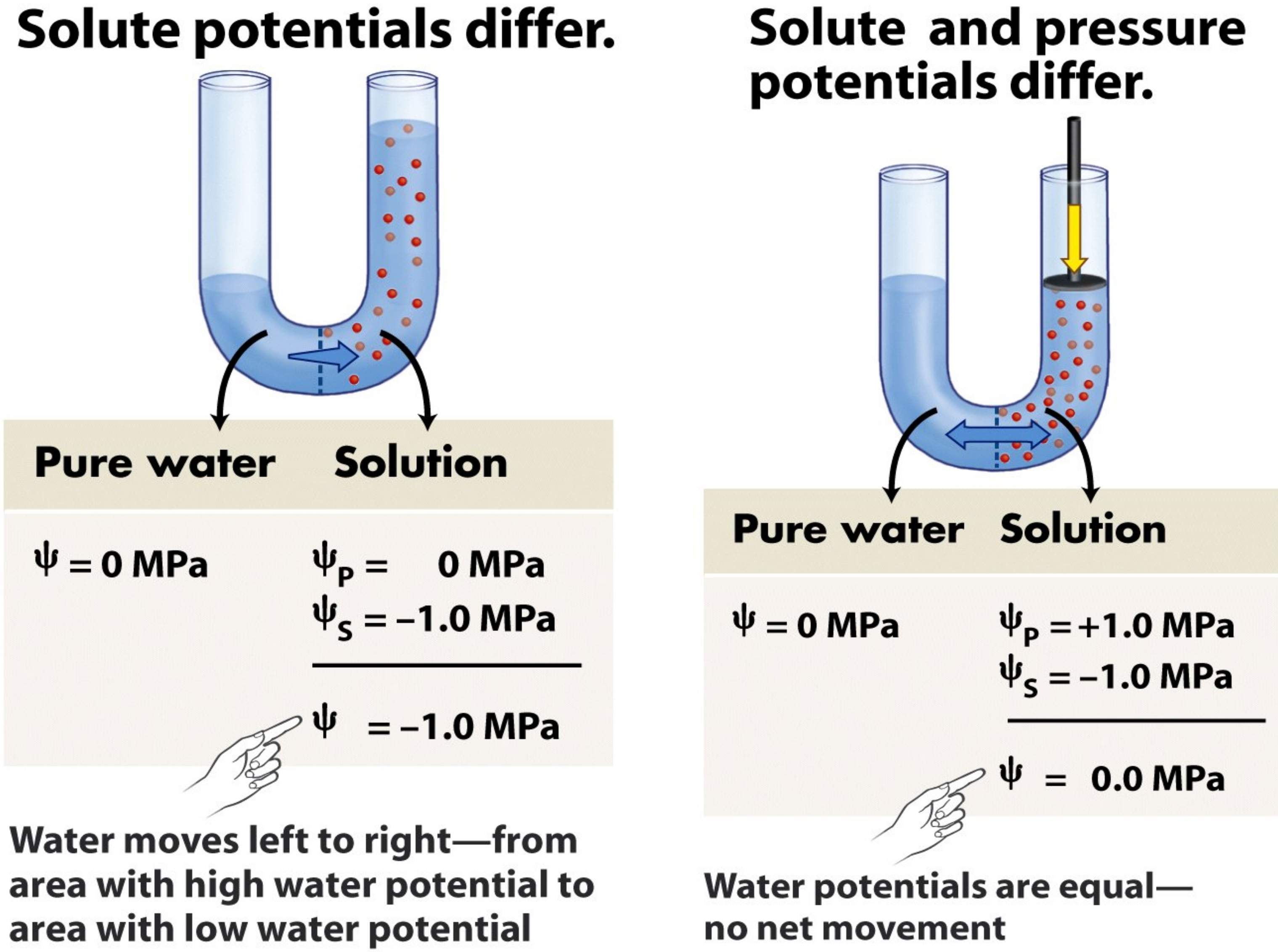
**Turgor pressure is an important source of pressure on water in cells**



# Water Potential

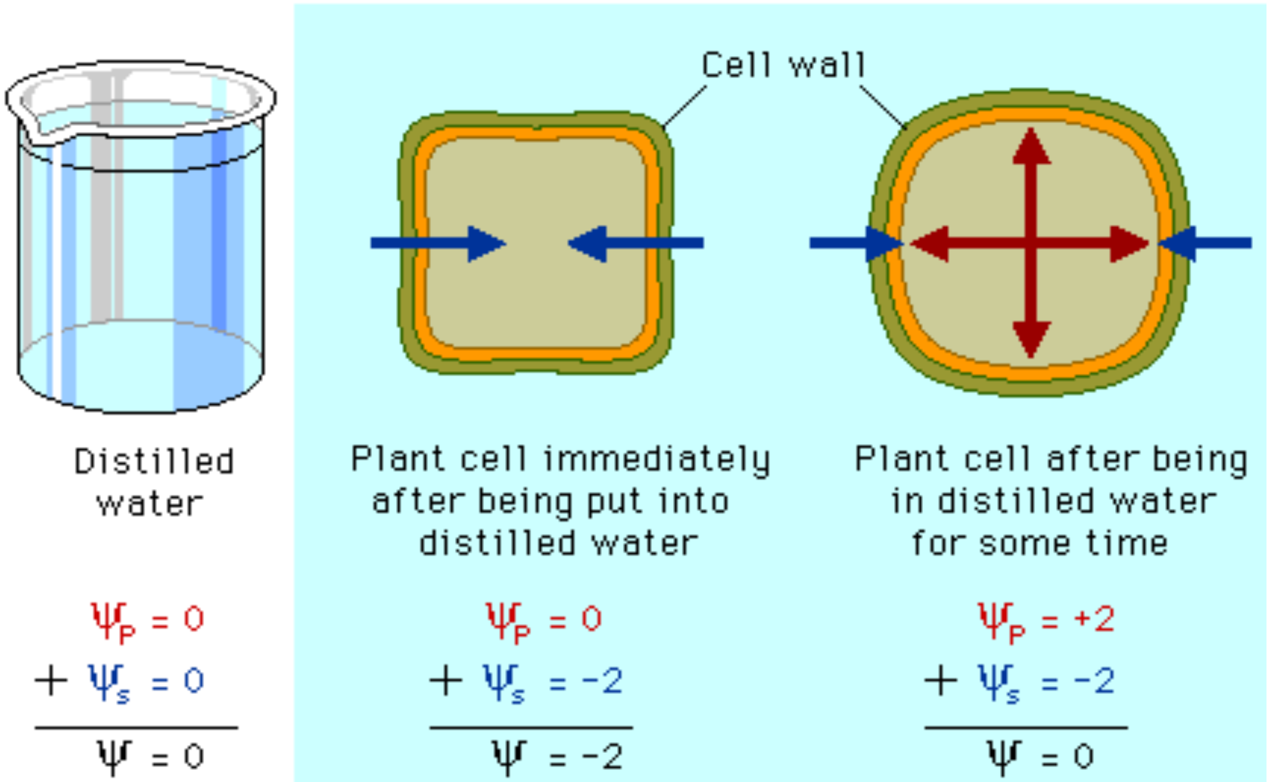
**The pascal (Pa) is the SI unit of pressure defined as one newton per square meter ($N/m^2$).**

***Other units of pressure include standard atmosphere (atm), pounds per square inch (psi), Bar (bar)***



# Water Potential & the movement of water

**Water moves from an area of <u>high water potential</u> to an area of <u>lower water potential</u>**




**Outside 0, inside -2**
**Water moves inward!**

**Outside 0, inside 0**
**No net water movement!**

# Calculating Solute/Osmotic Potential

$$\Psi = \Psi_P + \Psi_S$$

$$\Psi_S = -iCRT$$

- $i$ = The number of particles the molecule will make in water (*sucrose or glucose = 1; NaCl = 2*)
- $C$ = Molar concentration (*usually provided in the problem*)
- $R$ = Pressure constant = 0.0831 liter bars/mole K
- $T$ = Temperature in Kelvin = 273 + °C

***If there are no units in the prompt, your units for water potential will be bars because the R constant in your Appendix B is 0.0831 liters bars/moles K.***

***For problems in megapascals, R is 0.00831 liters megapascals /moles K. R in this case is 10 times smaller because 1 MPa = 10 bars.***

# Tips To Remember Regarding Osmosis & Water Potential

$$\Psi = \Psi_P + \Psi_S$$

$$\Psi_S = -iCRT$$

- $i$ = The number of particles the molecule will make in water (*sucrose or glucose* = 1; *NaCl* = 2)
- $C$ = Molar concentration (*usually provided in the problem*)
- $R$ = Pressure constant = 0.0831 liter bars/mole K
- $T$ = Temperature in Kelvin = 273 + °C

- **In the absence of pressure pushing on the water, water tries to diffuse from areas of higher free water concentration (LOWER TOTAL SOLUTE CONCENTRATION) to areas of lower free water concentration (HIGHER TOTAL SOLUTE CONCENTRATION)**
  - ➡ **Most solute molecules (with their covalently bonded atoms) do not dissociate in water so in solutions where the solute is a molecule i = 1**
  - ➡ **Ionic compounds (metal ions that are ionically bonded to nonmetal ions) do dissociate in water so their i = 2 (ex: NaCl) or i = 3 ($CaF_2$) etc... depending on how many ions separate when the compound enters water**
- **Temperature must be in Kelvin & pressure in bars!**
- **Always show all units when plugging numbers into formulas!**
- **Remember, the unit M (molar) is the same as mol/L**

# Tips To Remember Regarding Osmosis & Water Potential

$$\Psi = \Psi_P + \Psi_S$$

$$\Psi_S = -iCRT$$

- Water diffuses (osmosis occurs) from area of high water potential Ψ to area of low water potential Ψ
  - ★ Ψ of solution 1 > Ψ of solution 2
- Osmosis (the net diffusion of water) stops when WATER POTENTIALS (not necessarily solute concentration) of two fluids or regions within a fluid are EQUAL!!!
  - ★ Ψ of solution 1 = Ψ of solution 2
- $\Psi = \Psi_S + \Psi_P$
  - ➡ $\Psi_S$ is 0 (0 bar) in pure water (water with NO solutes)
  - ➡ $\Psi_S$ only become more and more negative as solute concentration increases ($\Psi_S$ can NEVER be positive)
  - ➡ $\Psi_P$ is 0 (0 bar) in an animal cell (no cell wall), in an open-aired beaker, or a flaccid plant cell (no pressure exerted on the cytoplasm by the cell wall)
  - ➡ $\Psi_P$ is a positive when positive pressure is added to a solution (by an external device on a solution in a beaker or when the turgid plant's cell wall is pushing on the cytoplasm)
  - ➡ $\Psi_P$ is a negative when negative pressure (suction) is experienced by a solution

# Now It's Your Turn to Try a Few Problems

$$\Psi = \Psi_P + \Psi_S$$

$$\Psi_S = -iCRT$$

- *i* = The number of particles the molecule will make in water (*sucrose or glucose* = 1; *NaCl* = 2)
- *C* = Molar concentration (*usually provided in the problem*)
- *R* = Pressure constant = 0.0831 liter bars/mole K
- *T* = Temperature in Kelvin = 273 + °C

➡ **What is the Solute Potential of a 1.0M sugar solution at 20C (assuming standard atmospheric conditions)?**

1. $\Psi_S = -iCRT$
2. $\Psi_S = -(1)\left(1.0\ \frac{mol}{L}\right)\left(0.0831\ \frac{L * bars}{mol * K}\right)(293\ K)$
3. $\Psi_S = -24.4$ bars

# Now It's Your Turn to Try a Few Problems

$$\Psi = \Psi_P + \Psi_S$$

$$\Psi_S = -iCRT$$

- *i* = The number of particles the molecule will make in water (*sucrose or glucose* = 1; *NaCl* = 2)
- *C* = Molar concentration (*usually provided in the problem*)
- *R* = Pressure constant = 0.0831 liter bars/mole K
- *T* = Temperature in Kelvin = 273 + °C

➡ **The solute potential in a plant cell is -7.25 bars and the pressure potential is 0 bars. What is the water potential of the plant cell?**

➡ **If this plant cell is transferred to a beaker with a 0.5M NaCl salt solution at 12C, will osmosis occur and in what direction?**

# Now It's Your Turn to Try a Few Problems

$$\Psi = \Psi_P + \Psi_S$$

$$\Psi_S = -iCRT$$

- *i* = The number of particles the molecule will make in water (*sucrose or glucose = 1; NaCl = 2*)
- *C* = Molar concentration (*usually provided in the problem*)
- *R* = Pressure constant = 0.0831 liter bars/mole K
- *T* = Temperature in Kelvin = 273 + °C

➡ **The solute potential in a flaccid plant cell is -7.25 bars. What is the water potential of the plant cell?**

1. $\Psi_{plant} = \Psi_S + \Psi_P$
2. $\Psi_{plant}$ = -7.25 bars + 0 bars
3. $\Psi_{plant}$ = - 7.25 bars

➡ **If this plant cell is transferred to a beaker with a 0.5M NaCl salt solution at 12C, will osmosis occur and in what direction?**

1. $\Psi_{beaker} = \Psi_S + \Psi_P$
2. $\Psi_{beaker} = \Psi_S$ + 0 bars
3. $\Psi_{S\ beaker}$ = - iCRT
4. $\Psi_{S\ beaker} = -(2)\left(0.5\ \frac{mol}{L}\right)\left(0.0831\ \frac{L * bars}{mol * K}\right)(285\ K)$ = - 23.684 bars
5. $\Psi_{beaker}$ = - 23.684 + 0 bars = - 23.68 bars
6. $\Psi_{plant} > \Psi_{beaker}$ since - 7.25 bars > - 23.68 bars so water will diffuse out of the plant cell and into the beaker (plant cell may plasmolyze).

# Now It's Your Turn to Try a Few Problems

$$\Psi = \Psi_P + \Psi_S$$
$$\Psi_S = -iCRT$$

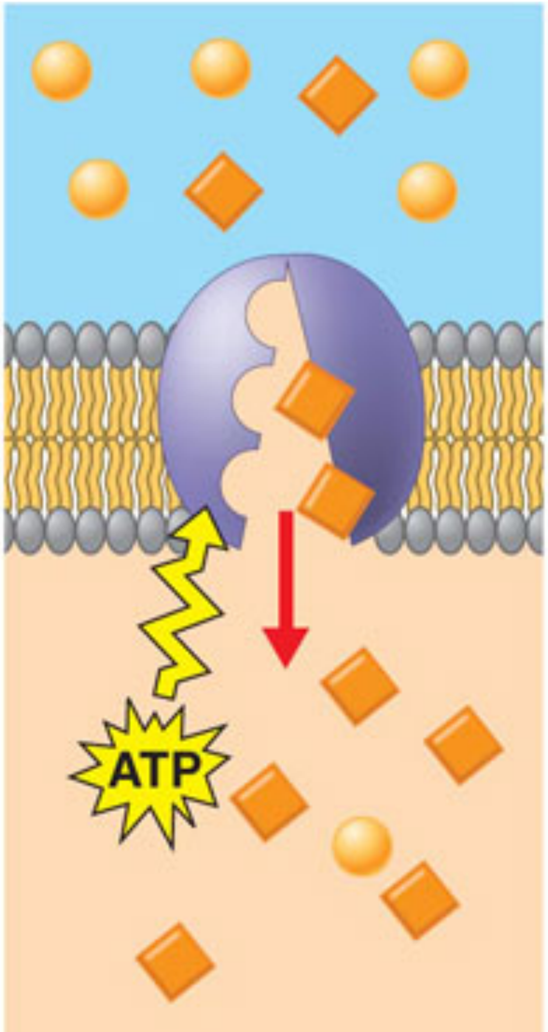
- $i$ = The number of particles the molecule will make in water (*sucrose or glucose = 1; NaCl = 2*)
- $C$ = Molar concentration (*usually provided in the problem*)
- $R$ = Pressure constant = 0.0831 liter bars/mole K
- $T$ = Temperature in Kelvin = 273 + °C

➡ **At 23C, a yeast cell containing 0.75M sucrose is in equilibrium with its surrounding solution, which contains 0.45M sucrose. What is cell's pressure potential?** ***(Remember, yeast cells are single-celled fungal cells and so have cell walls made of chitin)***

1. At **EQUILIBRIUM**: $\Psi_{surrounding} = \Psi_{yeast\ cell}$
2. $\Psi = \Psi_S + \Psi_P$ so at **EQUILIBRIUM**:
   $\Psi_{S\ surrounding} + \Psi_{P\ surrounding} = \Psi_{S\ yeast\ cell} + \Psi_{P\ yeast\ cell}$
3. $\Psi_{S\ surrounding} = -iCRT$
4. $\Psi_{S\ surrounding} = -(1)\left(0.45\ \frac{mol}{L}\right)\left(0.0831\ \frac{L^*\ bars}{mol\ ^*\ K}\right)(296\ K) = -11.069\ bars$
5. $\Psi_{P\ surrounding} = 0\ bars$
6. $\Psi_{S\ yeast} = -iCRT$
7. $\Psi_{S\ yeast} = -(1)\left(0.75\ \frac{mol}{L}\right)\left(0.0831\ \frac{L^*\ bars}{mol\ ^*\ K}\right)(296\ K) = -18.448\ bars$
8. $\Psi_{P\ yeast} = ?\ bars$
9. $\Psi_{S\ surrounding} + \Psi_{P\ surrounding} = \Psi_{S\ yeast\ cell} + \Psi_{P\ yeast\ cell}$
10. $-11.069\ bars + 0\ bars = -18.448\ bars + \Psi_{P\ yeast\ cell}$
11. $\Psi_{P\ yeast\ cell} = +7.38\ bars$

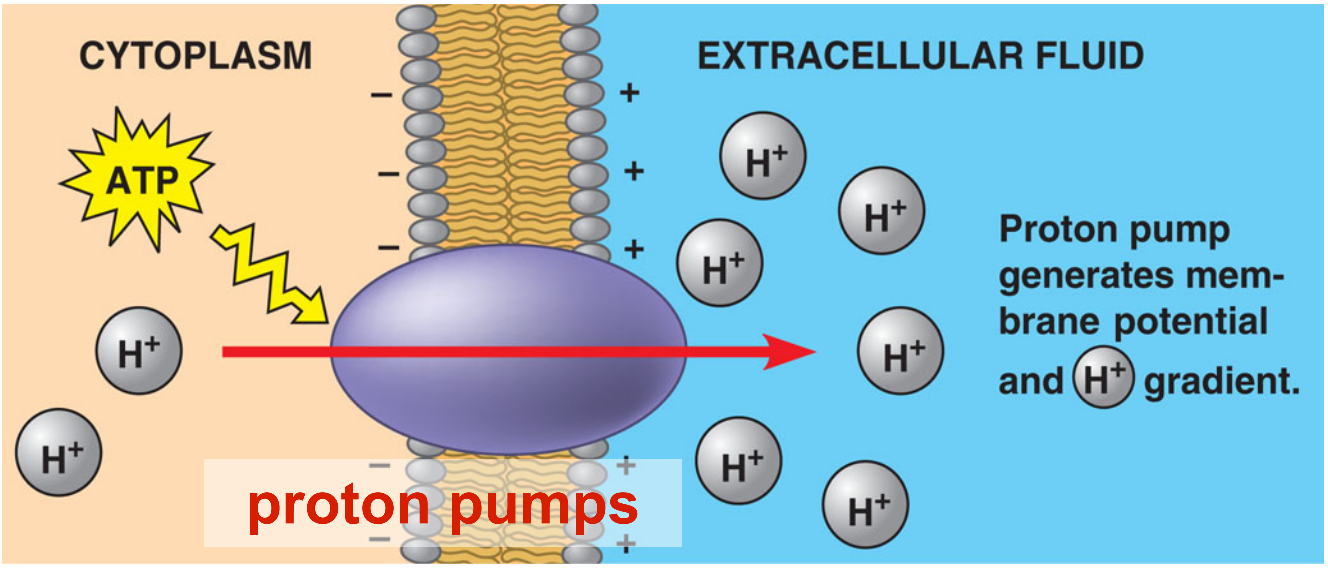
# Active transport

- Pumping solutes across the membrane against their electochemical gradients
  - Requires metabolic energy!
    - ATP
- Transport Proteins
  - Carrier Proteins (Active or Passive Transport)
    - Selectively bind solutes, change shape, and carry the solute to the opposite side of the membrane
  - Channel Proteins (Passive Transport)
    - Provides a selective channel through which specific solutes can travel to opposite side of the membrane
      - May be gated, opening and closing in response to a specific stimulus
        1. *Pressure*
        2. *Chemicals*
        3. *Voltage*



# Mineral Absorption in Plant Roots

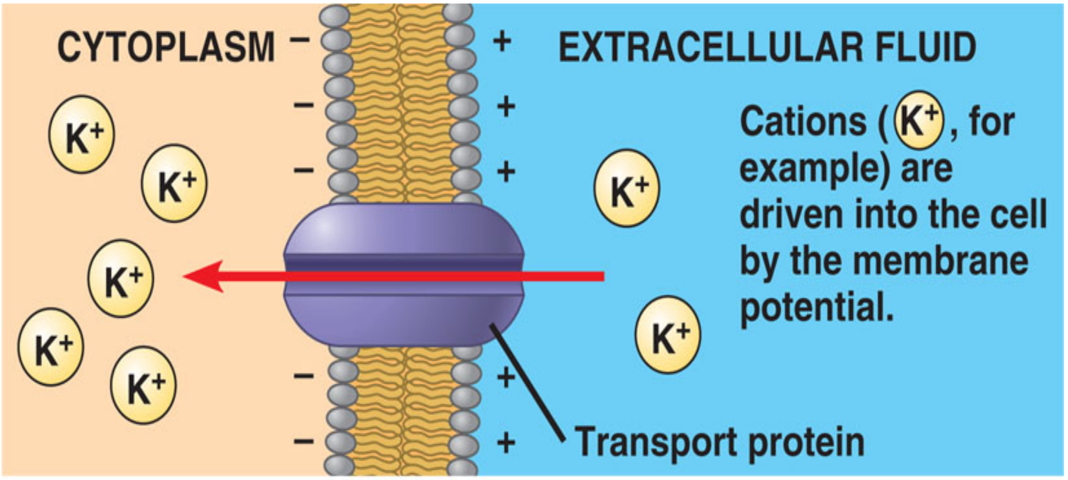
- Mostly by active transport
  - Most important transport protein in plant plasma membrane = Proton pump
    - Uses energy from ATP to pump hydrogen ions (H+) out of cell.
      - Results in a proton gradient with a higher H+ concentration outside the cell than inside
        - *Represents stored potential energy.*



# Mineral Absorption in Plant Roots

- **Proton pumps provide energy for solute transport.**
  - Proton pumps pump H+ out
    1. Produce an $H^+$ chemical gradient
    2. Produce a charge separation or voltage called a membrane potential.
       - *These two forms of potential energy can be used to drive in/ transport into the root hair cells solutes.*

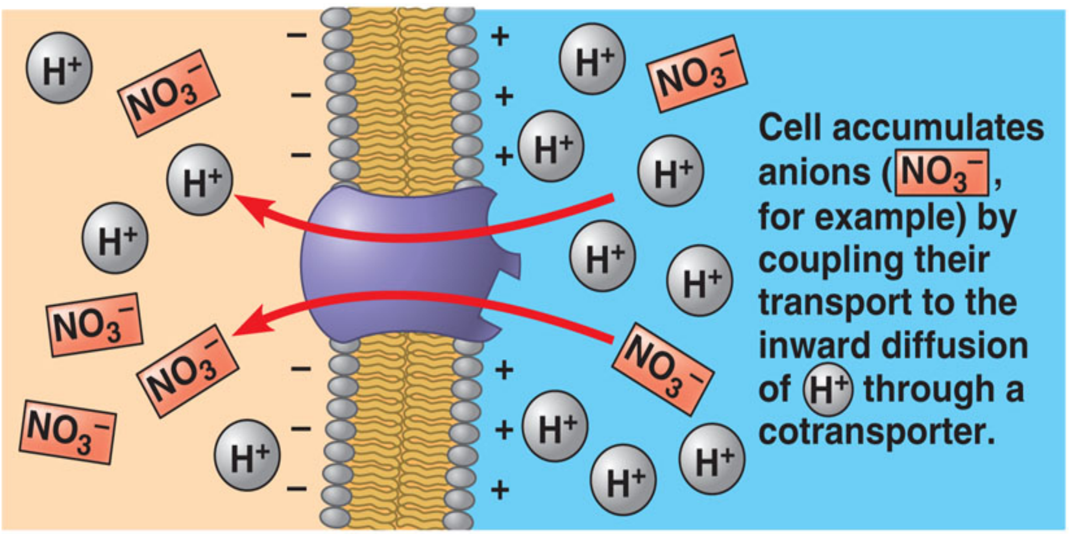
- **Cation Uptake**
  - Charge difference across plasma membrane drives cation uptake
    - *Negative charge inside cell causes K+ to enter root cells*



(a) Membrane potential and cation uptake

# Mineral Absorption in Plant Roots

- **Co-transport of negative and neutral solutes**
  - a transport protein couples the downhill passage of one solute (H+) to the uphill passage of another ($NO_3^-$) against its concentration gradient.
    - The "coattail" effect of co-transport is also responsible for the uptake of the sugar sucrose by plant cells from the phloem.
  - This role of proton pumps in transport is an application of chemiosmosis.

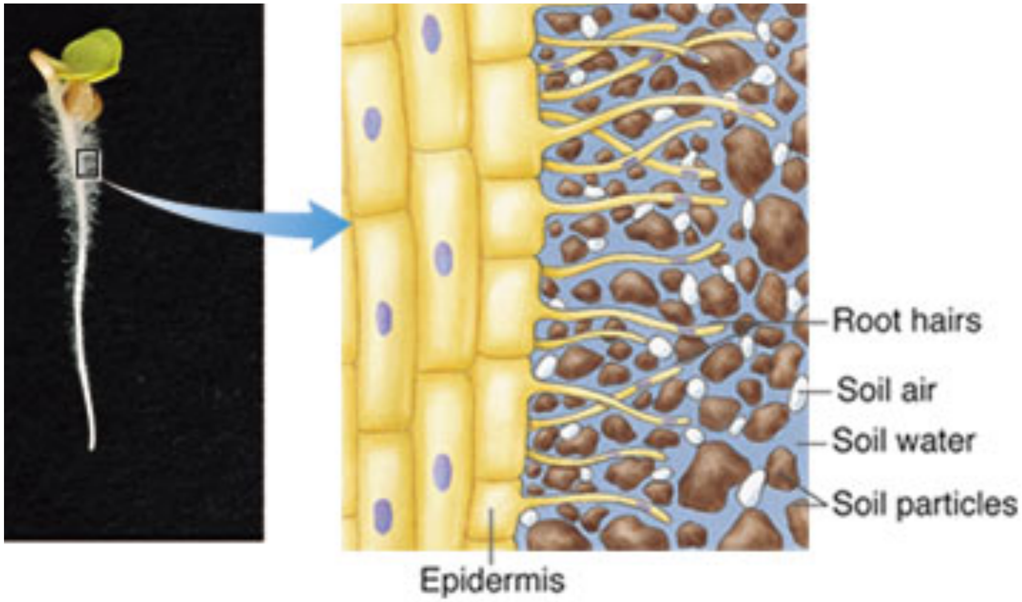


(b) Cotransport of anions

# Absorption of water & minerals occurs at root tips

- **Absorption is a surface area phenomenon**
  - The more surface area there is, the more absorption there will be.

- **Root hairs - extensions of the root epidermal cells to increase surface area**
  - Plasma membranes have aquaporins, proton pumps, proteins, proteins etc..

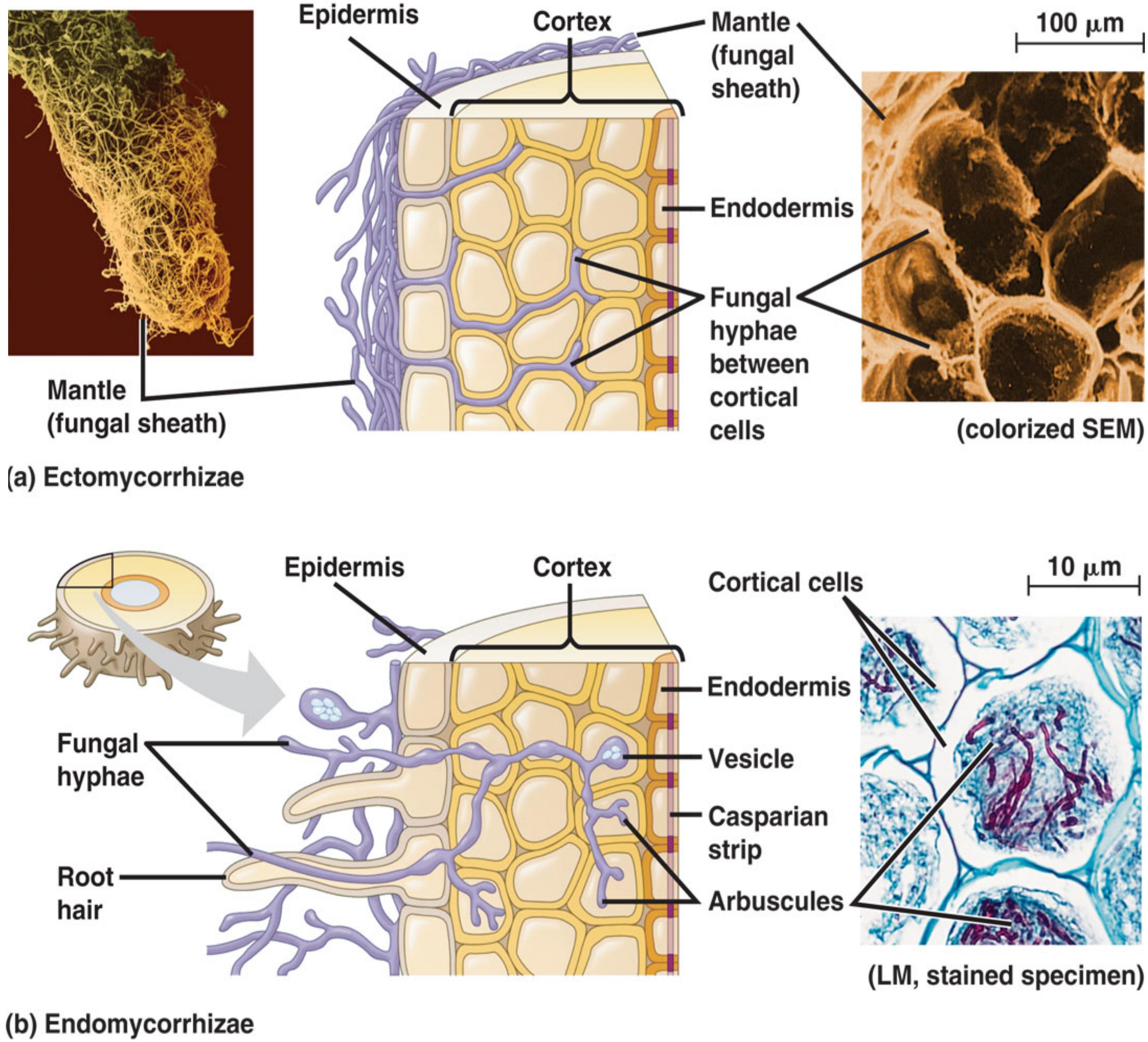



- **Mycorrhizae - fungal associations with roots that greatly increase surface area**
  - Up to 3 m of hyphae can extend from each cm of root
  - Ancient association - association seen in oldest terrestrial plant fossils

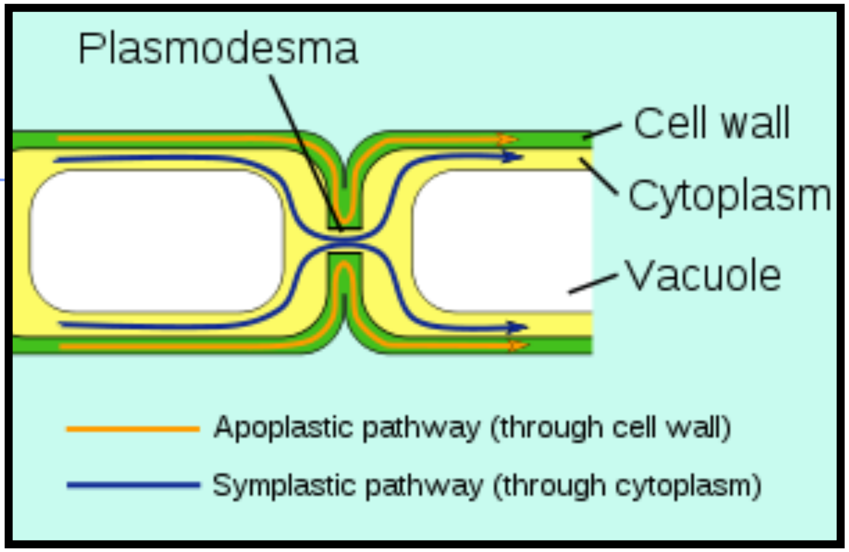
# Two types of Mycorrhizae

## Symbiotic relationship between fungi & plant

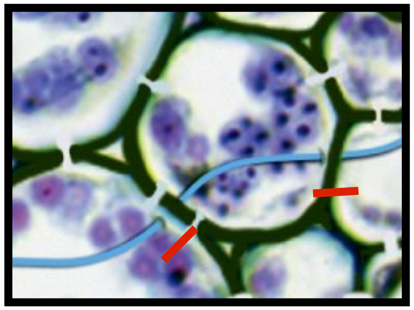
- symbiotic fungi greatly increases surface area for absorption of water & minerals
- increases volume of soil reached by plant
- increases transport to host plant



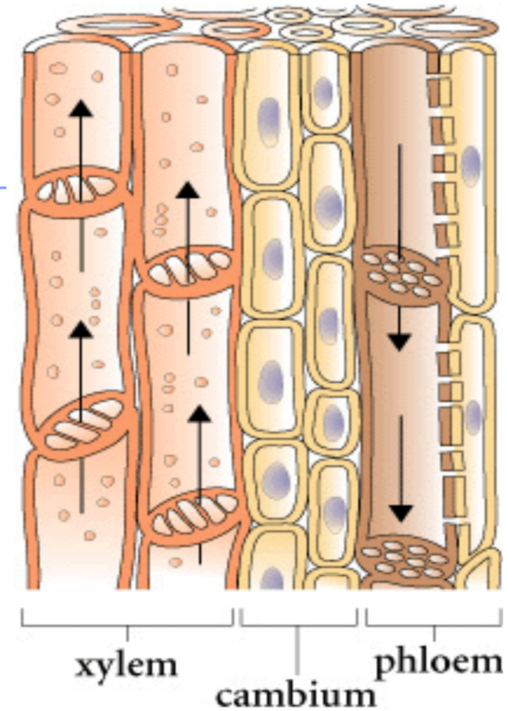
# The three types of short distance transport




1. **Apoplastic Route**
   - **Water and solutes move along the continuum of cell walls and extracellular space**
     - **Apoplast** = the continuum formed y cell walls, extracellular spaces, and dead interiors of tracheids and vessels.
2. **Symplastic Route**
   - **Water and solutes move along the continuum of cytosol within a plant tissue**
   - **Solutes must cross plasma membrane only once this way**
     - **Symplast** = the continuum formed by the cytosol of cells connected through cytoplasmic channels called plasmodesmata
3. **Transmembrane Route**
   - **Water and solutes move out of one cell, across the cell wall, and into the neighboring cell and on**
   - **Solutes must cross multiple cell walls this way**



# Long-Distance Transport in plants

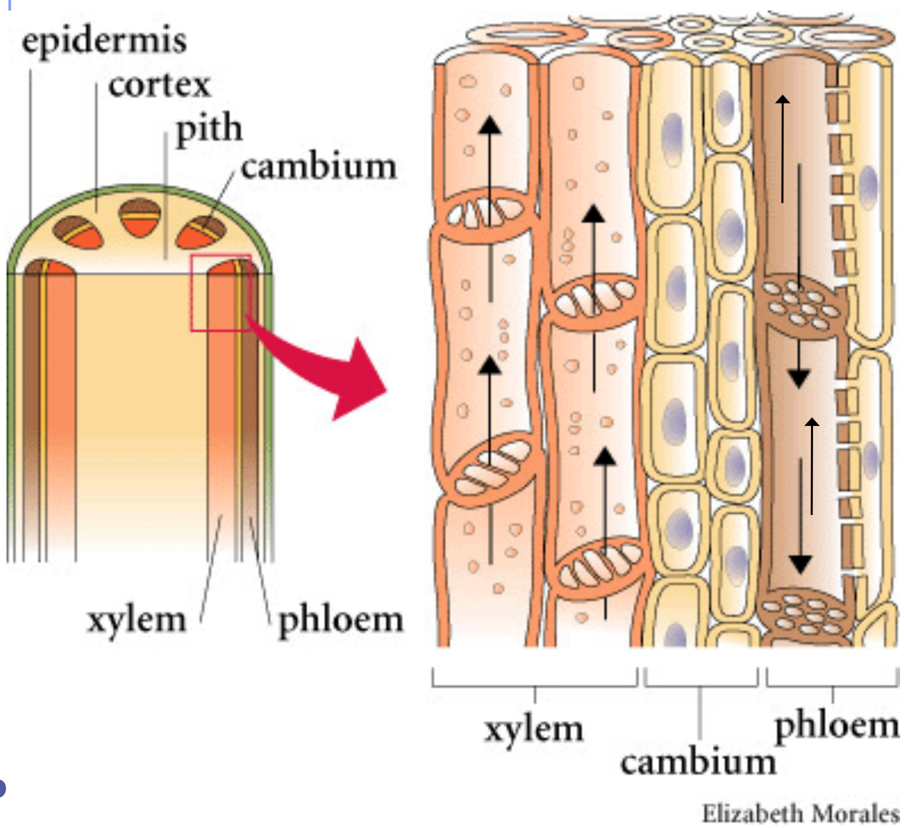


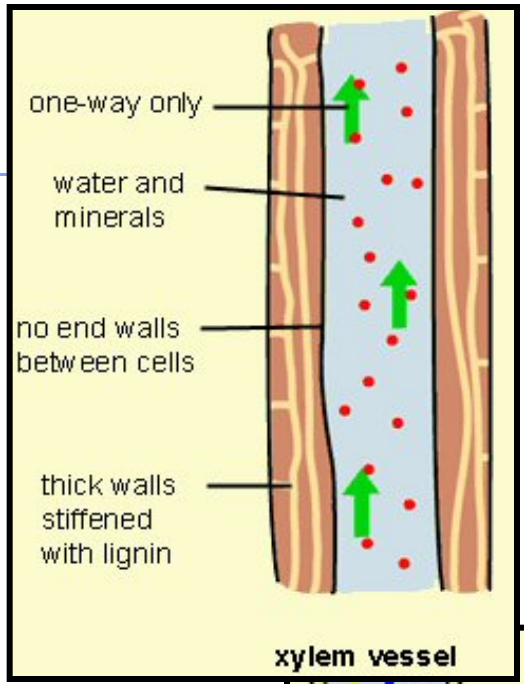

- Diffusion is too slow to function in over long distances
  - Long distance transport occurs through Bulk Flow
    - Xylem moves water and minerals up the shoot
      - Mature tracheids and vessel elements are dead cells with no cytoplasm
      - End plates (remaining cell walls) of vessel elements are perforated so liquid can pass from cell to cell
    - Phloem moves dissolved sugars
      - Sieve tube elements are living but devoid of (missing) many internal organelles
      - Porous sieve plates (cell walls) connect sieve-tube elements and allow sugar to pass from one cell to the next
    - These characteristics of the cells involved in making xylem allows for efficient bulk flow!

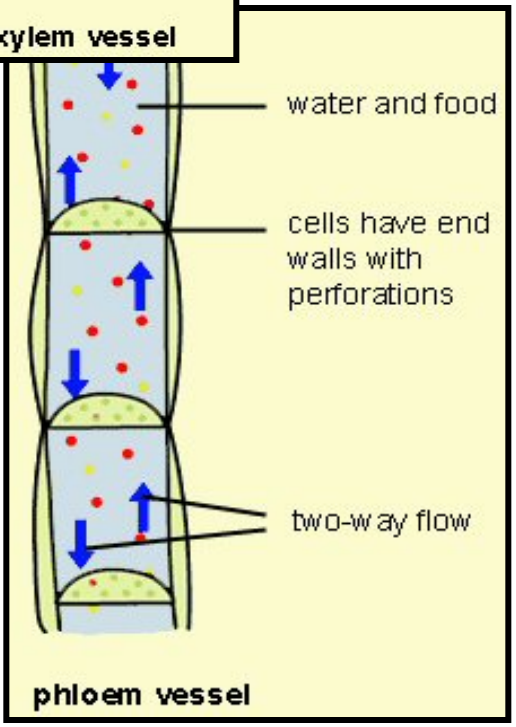
# Direction of Transport

**Xylem:** One way flow of water and minerals

**Phloem:** Two way flow of sugars




AP

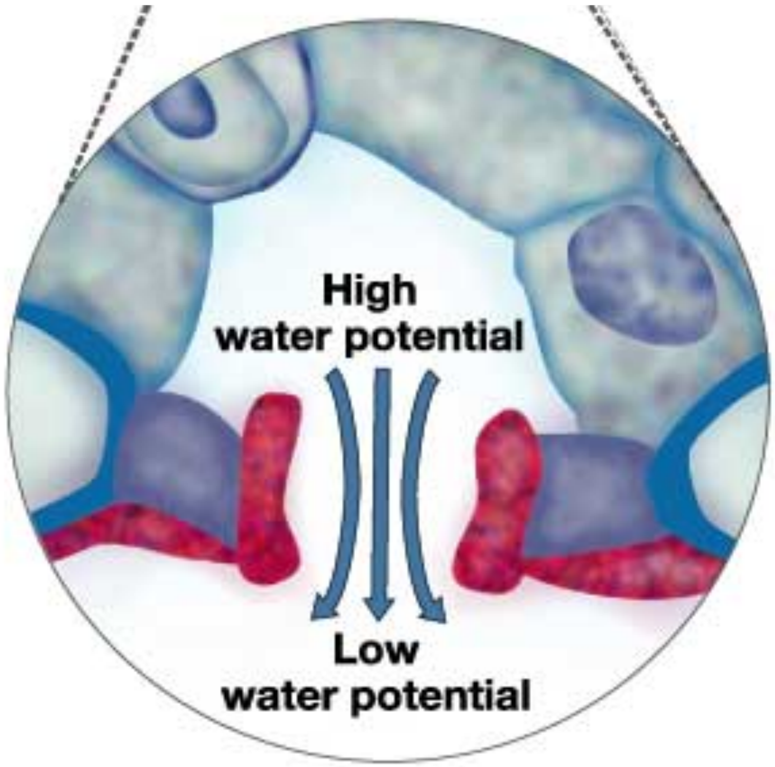
# Ascent of xylem sap

Water and certain minerals pass from outer root hair cells to inner cells via transport proteins in plasma membranes or plasmodesmata connecting cell cytoplasms, the liquid solution eventually reaching the vascular tissue (xylem) deeper in the root.

- From here, bulk flow transports xylem sap through the plant veins to the leaves:
  - Much faster than diffusion or active transport
  - 15 to 45 m / hr
- Moving xylem involves:
  1. Root Pressure
  2. Transpirational Pull

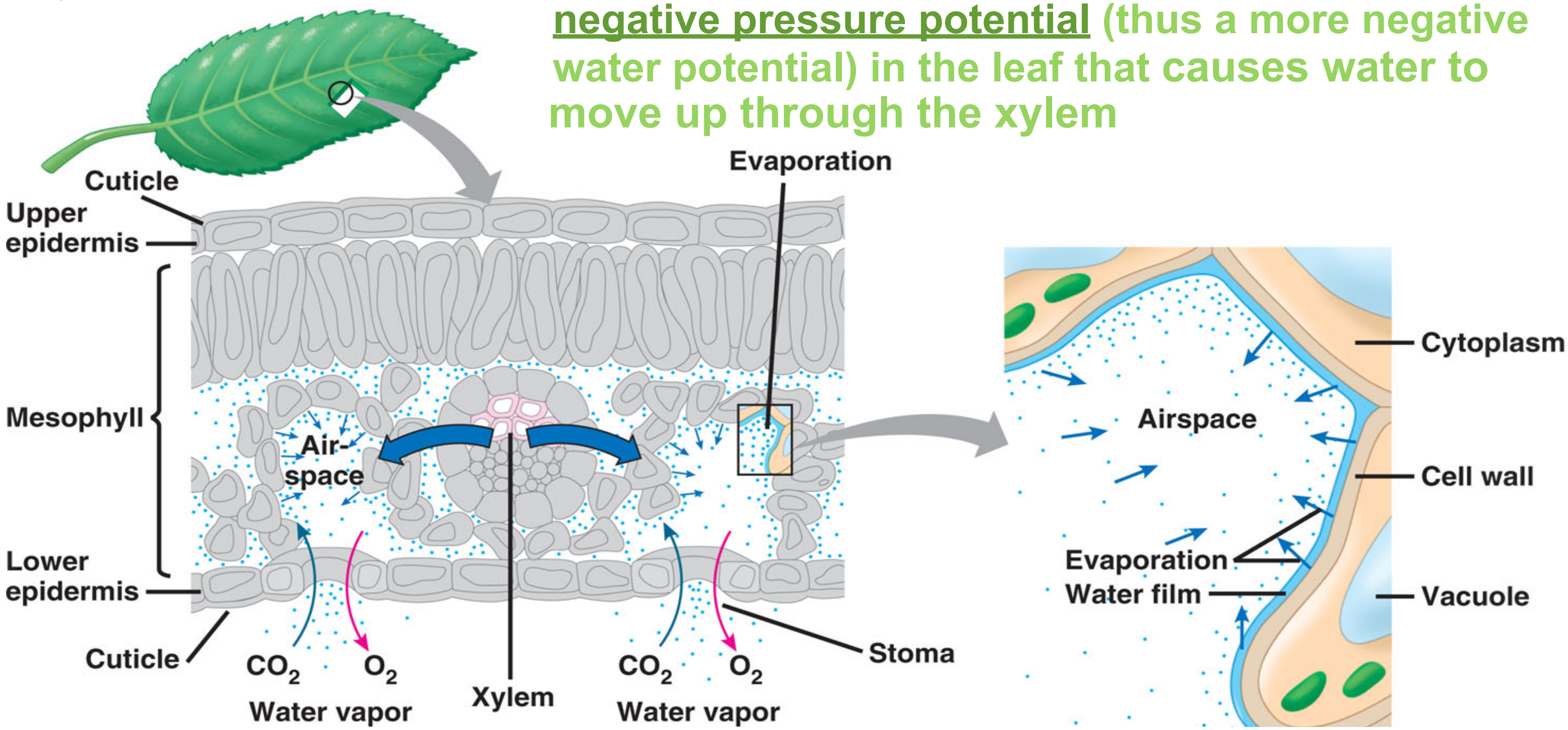
## Transpirational Pull: The major mechanism of moving water and minerals, using negative pressure

- A.k.a. Transpiration-Cohesion-Tension Mechanism
  - Uses negative pressure to pull Xylem Sap up the Plant
- Stomata open up during the day to let $CO_2$ in for photosynthesis and inadvertently let $H_2O$ (in gas form) escape that was located in the leaf air space.



# Transpirational Pull: The major mechanism using negative pressure

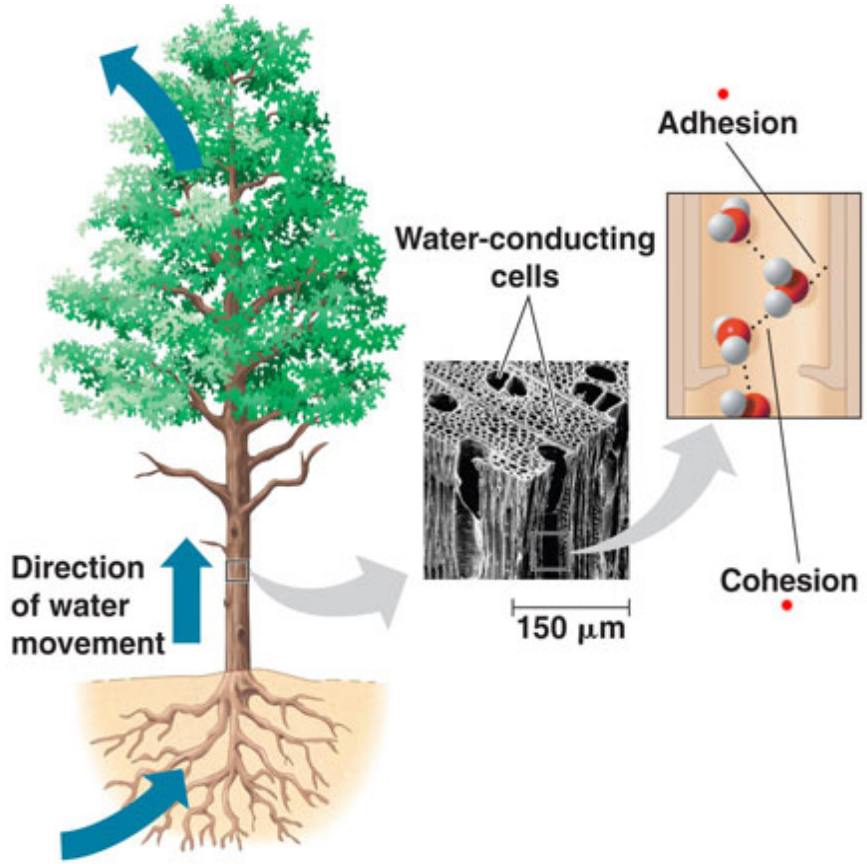
- The water that was in the leaf air space (as a gas) is replaced by new waters that enters the leaf air space in the leaf space by evaporation of the layer of water that clings to the cell walls of leaf cells
- Water has strong cohesive properties
  - *As the water leaves the cell surface, it is replaced by water in the xylem.*
    - Transpiration from the surface of mesophyll cell walls creates negative pressure potential (thus a more negative water potential) in the leaf that causes water to move up through the xylem



## Transpirational Pull: The major mechanism using negative pressure

Transpiration thus causes a tension (pulling) on the water in the xylem by water leaving the xylem and moving into the leaf - water is gently pulled toward the direction of water loss

1. Water from water film evaporates
2. Waterfront in cell walls of mesophyll cells retreats into cell wall
3. High surface tension of water causes negative pressure potential in water in cell walls
4. Water molecules in xylem are pulled towards cell wall area to reduce tension



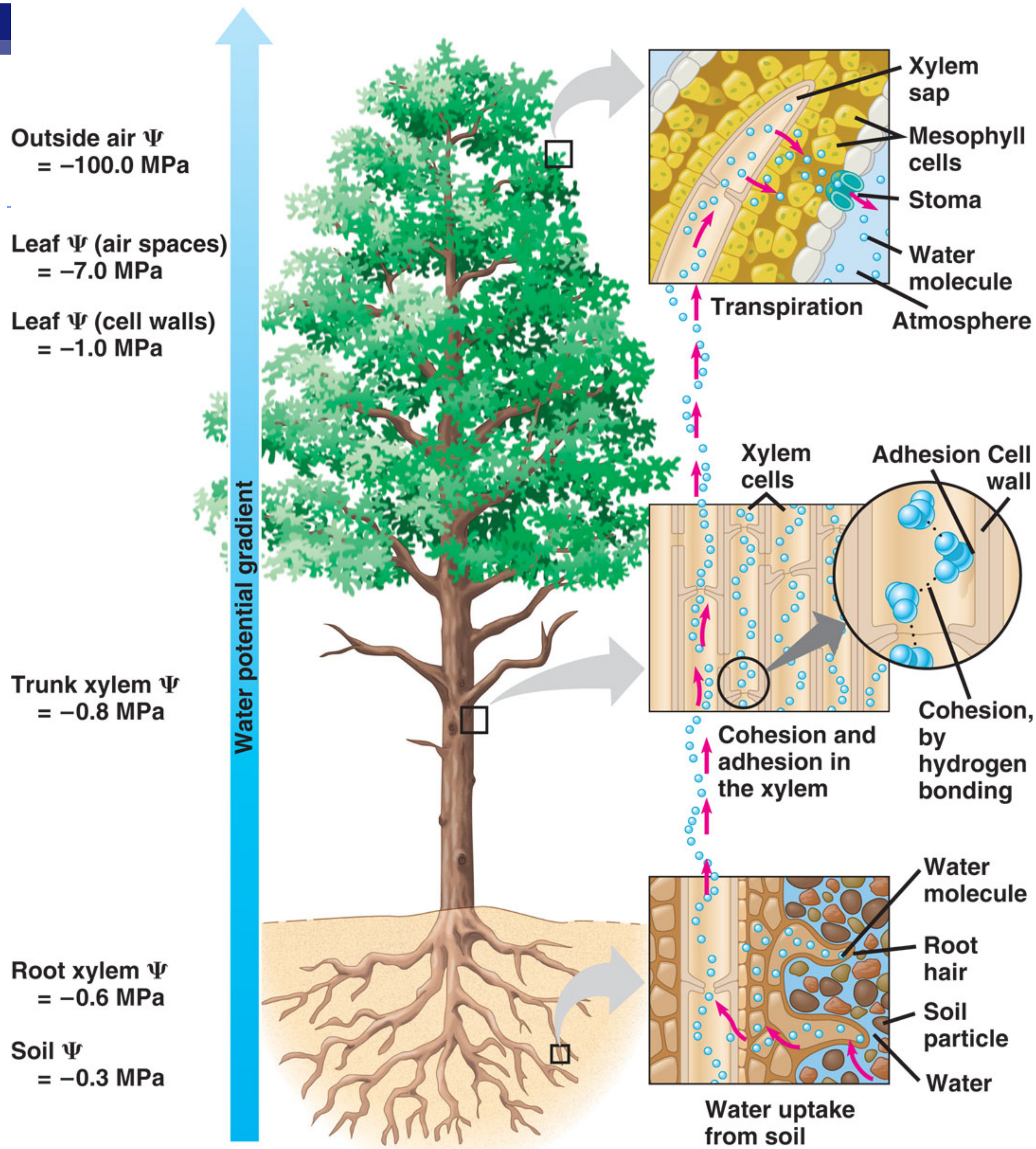

- The cohesion of water is strong enough then to transmit this pulling force all the way down to the roots
- Adhesion of water to the cell wall also aids in resisting gravity

1. Negative pressure potential lowers water potential in leaves

2. Water moves from areas of higher water potential to areas of lower water potential

3. Water potential is highest in the soil and much lower at the air-water interface in the leaves, being the lowest (usually) in the air outside the leaf.

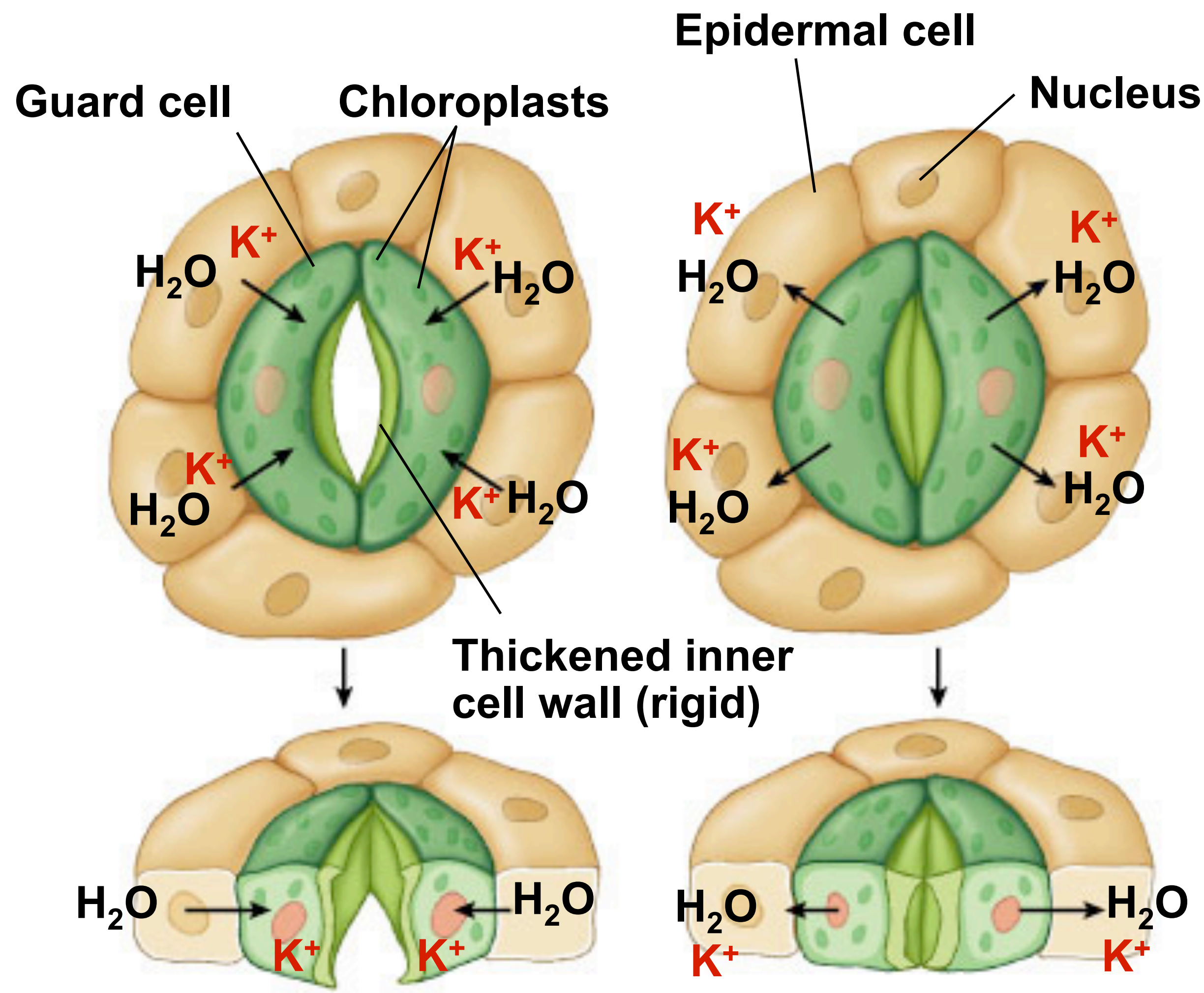
4. More negative water potential of leaves provides causes the osmosis of water (and thus xylem sap) upward



# Controlling Stomates regulates transpiration

## Opening Stomata:

- Uptake of $K^+$ ions by guard cells
  - Involves proton pumps
    - Stimulation of the blue-light receptors activates an ATP-powered proton pump on the plasma membrane of guard cells
    - creation of proton gradient that is used to force the uptake of K+ into guard cells
  - Water potential, therefore, decreases inside guard cell too
    - water from neighboring cells and between cells enters by osmosis
  - As a result, guard cells become turgid




Stoma open

water moves into guard cells

Stoma closed

water moves out of guard cells

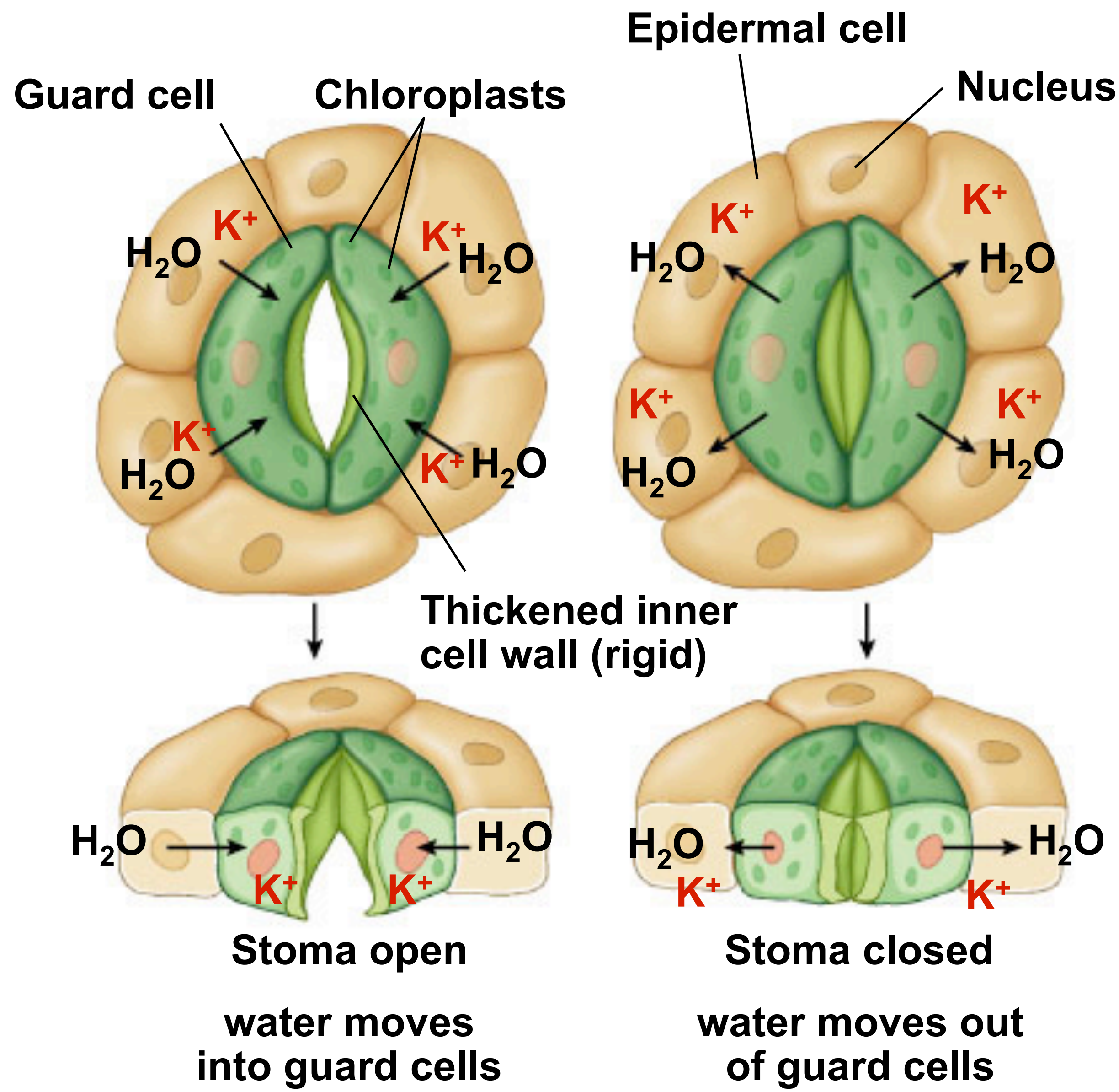
# Controlling Stomates regulates transpiration

- <u>Closing Stomata:</u>
  - Loss of $K^+$ ions from guard cells

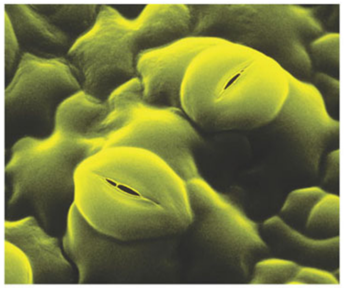
The passive transport of K+ out of the guard cell and K+ getting pumped actively into the central vacuole raises the water potential in the guard cell cytoplasm.

  - Water from guard cells cells leaves cell by <u>osmosis</u>
  - Guard cells become <u>flacid</u>

- Aquaporins in guard cell plasma membranes allow rapid entry or loss of water molecules.
  - Recall that guard cells can also become flaccid by the direct loss off too much water by evaporation that speeds up guard cell close during the hottest time of the day



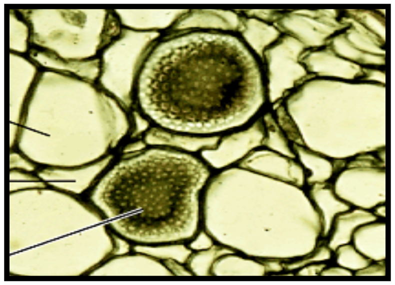
# Control of transpiration



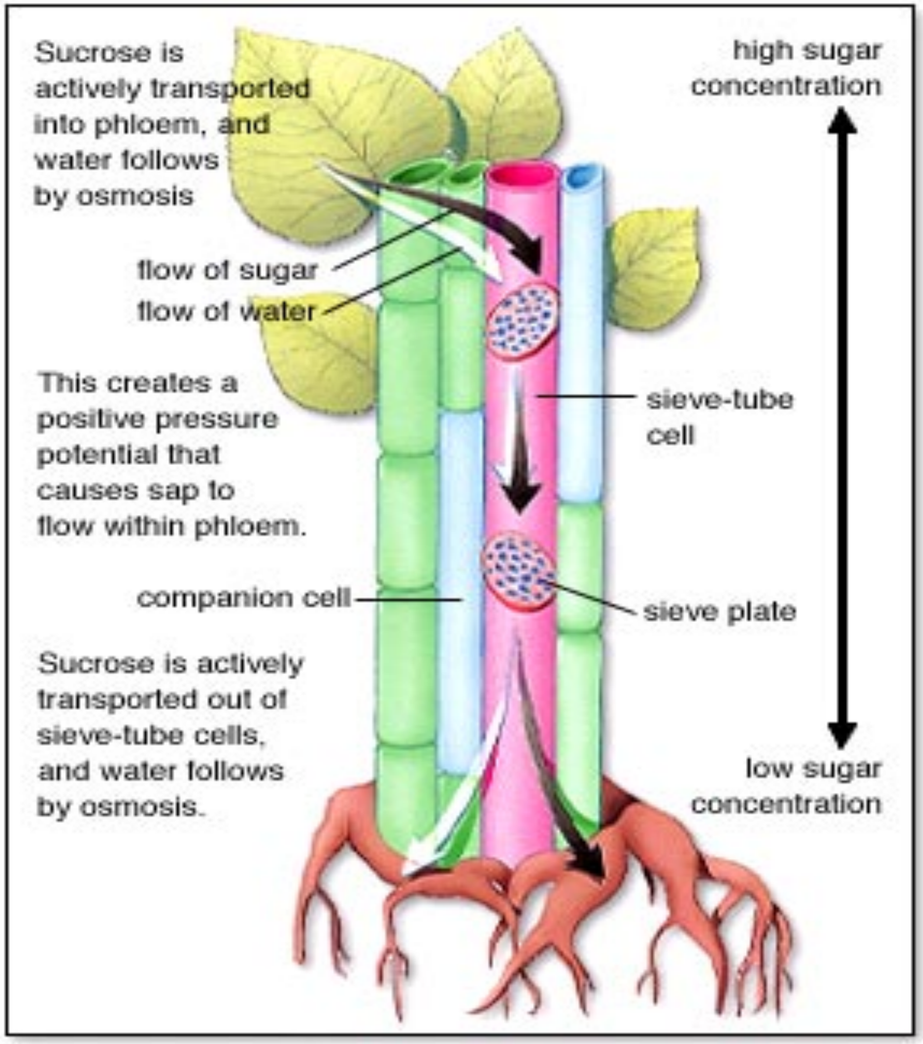
- **Balancing stomate function**
  - there is always a compromise between photosynthesis & transpiration
    - leaf may transpire more than its weight in water in a day…this loss must be balanced with plant's need for $CO_2$ for photosynthesis
  - Three cues contribute to stomatal opening at dawn:
    1. Light
       - Blue-light receptors in guard cell plasma membrane
    2. $CO_2$ depletion
    3. Internal "clock" in guard cells
       - Circadian Rhythms: cycles with intervals of approximately 24 hours


  - Environmental stresses like droughts and hormone abscisic acid signals stomata to close to reduce wilting.

# Transport of dissolved sugars in phloem

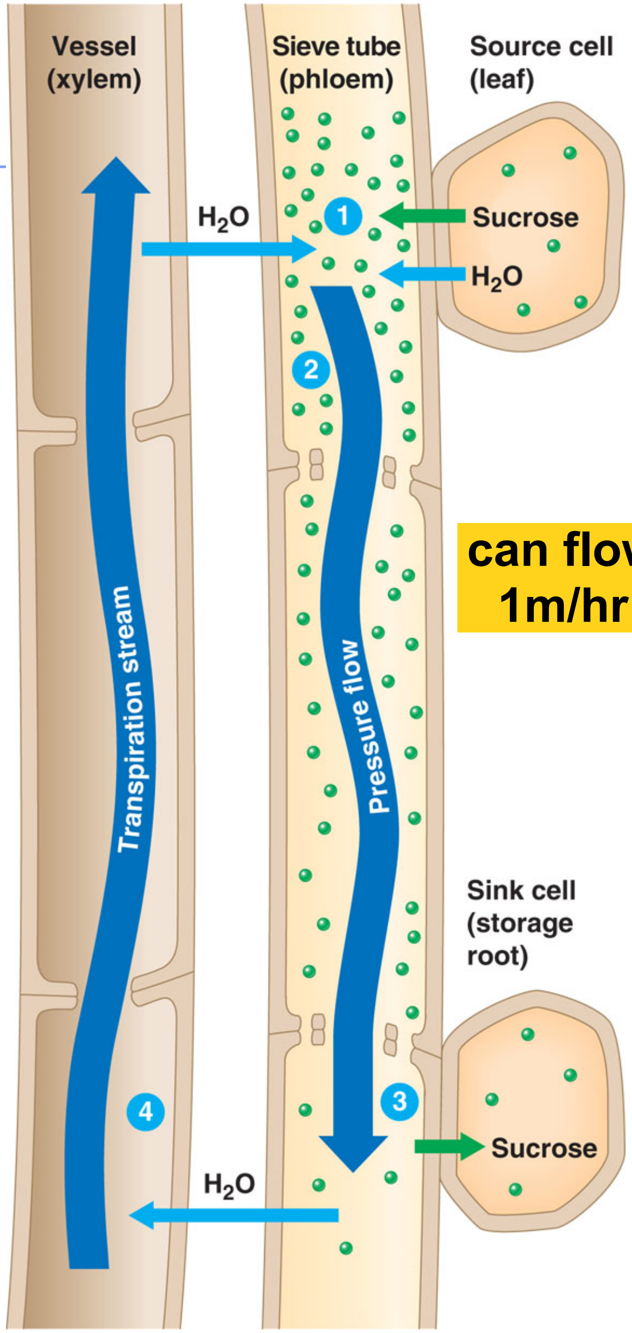


- Dissolved sugars in phloem = phloem sap
  - Most prevalent sugar is sucrose
  - May also contain amino acids, hormones, and minerals
- The transport of the product of photosynthesis in the phloem is called Translocation



# Mass flow hypothesis

- In contrast to the unidirectional movement of xylem sap, phloem sap moves from sites of sugar production to sites of sugar use or storage
  - Sugar Source = plant organ that is a net producer of sugar
    1. Cell doing photosynthesis
    2. Cell breaking down stored starch
       - Ex: Full grown leaf or tuber in early spring
  - Sugar Sink = plant organ that is a net consumer or depository of sugar
    - Ex: Growing roots or leaves, forming fruits, tuber in late summer
  - What is a sink or source may change depending on season
- Flow is from "source to sink"
  - direction of transport in phloem is dependent on plant's needs




can flow 1m/hr

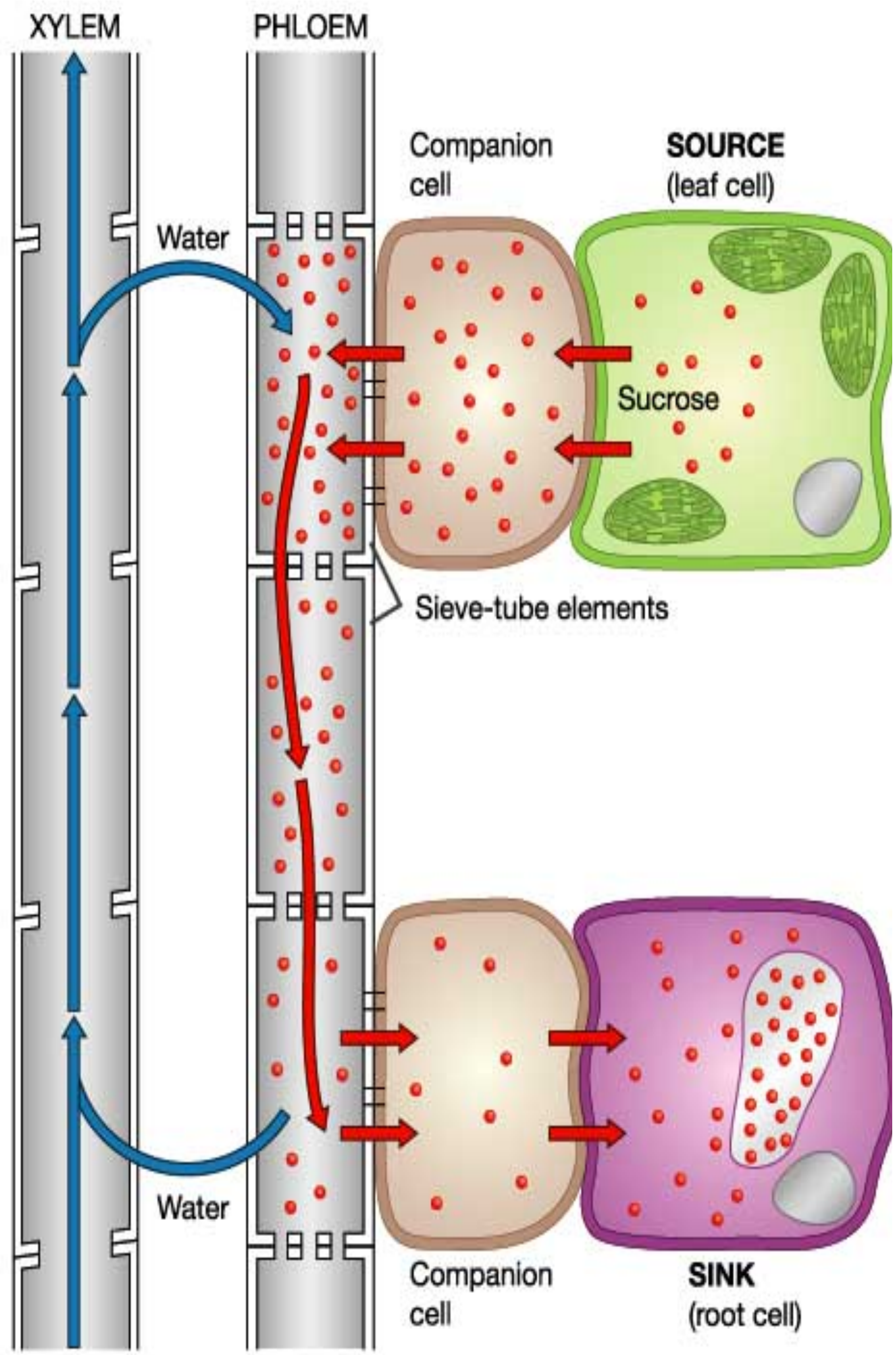
# Starting Translocation

## 1. Phloem loading

- May involve active transport of sucrose into companion cells that are connected through plasmodesmata to phloem cells
  - Proton pumps and secondary active transport (cotransport) pumps sucrose secreted from mesophyll cells into companion and phloem cells.
    - Sucrose becomes more concentrated in phloem & companion cells than in photosynthetic cells
      - Therefore, Water Potentia in phloem decreases

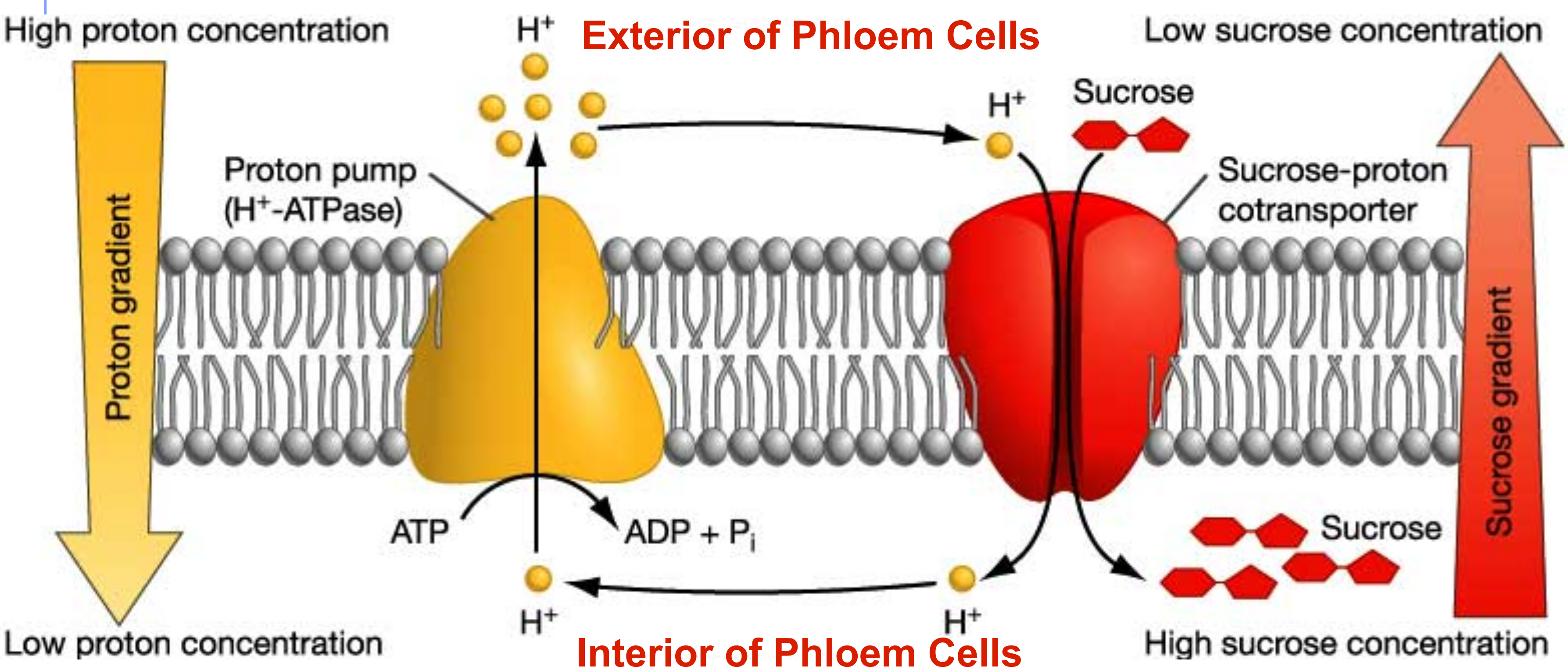
## 2. Water flows into phloem as a consequence from next door xyler

- volume of sugar solution then increases due to the increase in $H_2O$ causing positive pressure tha pushes the sugar solution down through the phloem.



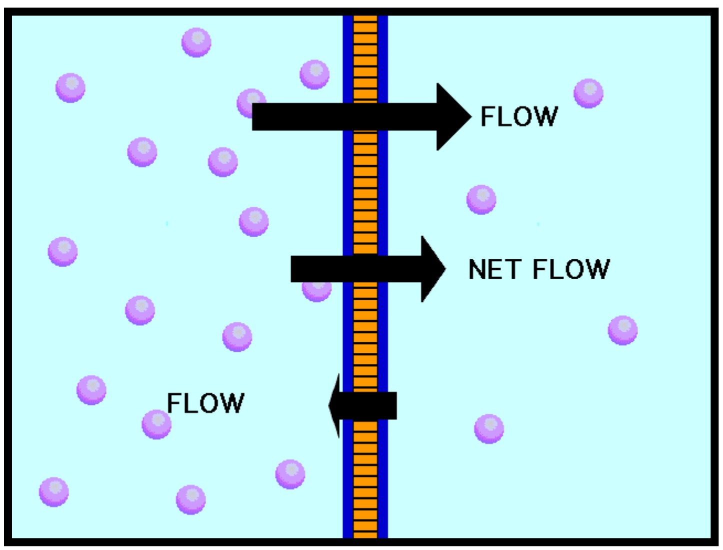
# The sugar co-transporter

- A secondary active transport system is responsible for the active transport of sugar into companion cells and, thus, sieve-tube elements (phloem cells) connected by plasmodesmata
  - Sucrose transport against its concentration gradient is coupled to $H^+$ diffusion down its concentration gradient

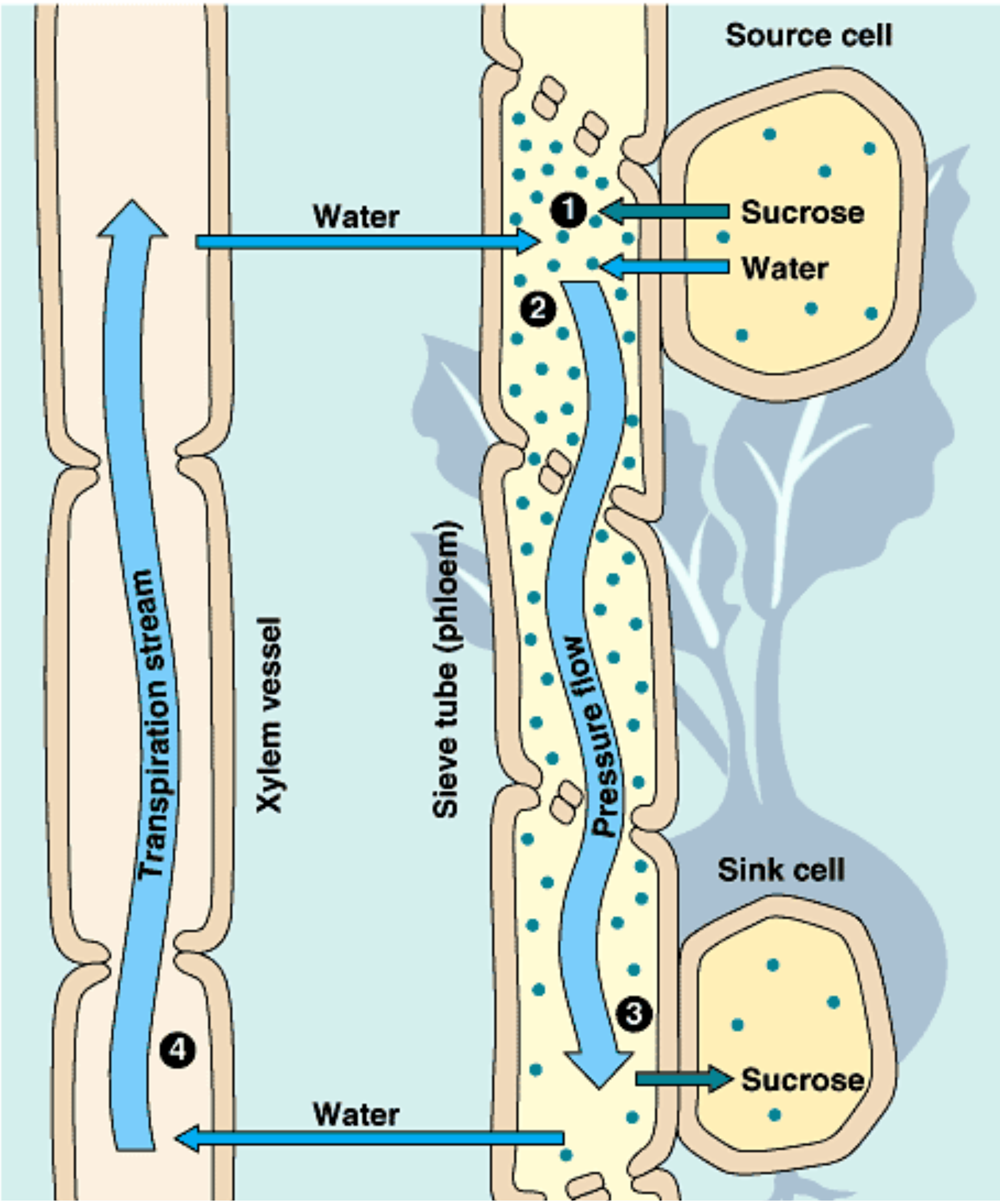


# Transport of dissolved sugars in phloem

- **At the site of the Sugar Sink**
  - Sinks consume sugar during growth, anabolic processes, or metabolism of cells
    - Free sugar in sink cells is always lower than in sieve tube
      - Sugar concentration gradient causes sugar to diffuse (facilitative diffusion) from phloem into sink tissues




# Bulk Flow by Positive Pressure




- Phloem sap moves through sieve tube by positive pressure called pressure flow
  - Pressure is built at the source end and reduced at the sink end
    1. Sugar loaded into sieve tube
    2. Water potential is reduced
    3. Water uptake by osmosis
    4. Water uptake generates positive pressure
    5. Sap is forced to flow along tube
    6. Pressure relieved by unloading of sugar and loss of water as a result
    7. Water is recycled from sink back to source through xylem

Plants can undergo self-thinning

- Remove sinks like aborting flowers or seeds if there aren’t enough sources to support all these sinks

# Experimentation

- **Testing pressure flow hypothesis**
  - using aphids to measure sap flow & sugar concentration along plant stem
    - The closer their stylet is to a sugar source, the higher the droplets sugar concentration



Severed stylet exuding sap

# Maple sugaring

collecting phloem to make syrup out of