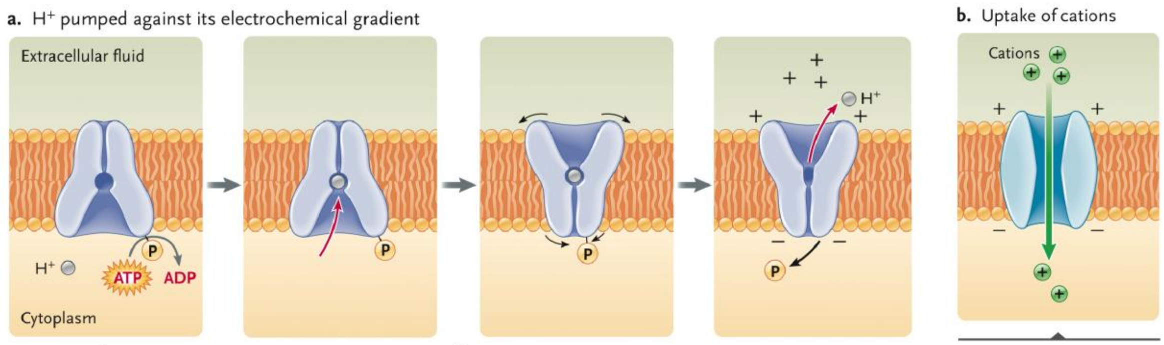
BI 111
Plant Transportation

Passive and Active Mechanisms

- Simple diffusion is the simplest form of passive transport
  - Requires no metabolic energy
  - Substances move down concentration or electrochemical gradient
- Passive Diffusion → the spread of sugars and minerals from more concentrated area to other parts
  - Simple diffusion: adjacent cells
    - Very slow and therefore plant would die using this process
  - Not very efficient over long distances; 1mm in 100 sec



ATP energy pumps hydrogen ions (H^+) out of the cytoplasm, creating an H^+ gradient.

The concentration of H^+ becomes higher outside the membrane than inside. Inward diffusion of H^+ in response to the gradient becomes a source of energy for transporting other ions and neutral molecules such as sugar into the plant cell.

Some cations, such as NH_4^+, enter the cell through selective channel proteins, following the electrochemical gradient created by H^+ pumping.

Active Transport Mechanisms

- Active transport requires metabolic energy in the form of ATP
  - Based on H^+ pumps (proton pump)
  - H^+ gradient maintained through ATP use
  - H^+ diffusion into cell powers uptake of solutes
- Symport
  - Material transported in same direction as movement of H^+ and solute, organic uptake
  - Accumulation of molecules the plant actually wants/needs
- Antiport
  - Material transported in opposite direction to movement of H^+ and solute, Na^+ export
  - Waste products or something the organism do not want in the cell bodies.
  - Metabolically expensive (anabolic)
- Cells generate electrochemical gradient
  - Chemical potential charge
- Positive charge – into their inner body
  - (positive ions e.g. Potassium will be pulled into the channel)
- Have more control for the channel port if ATP or energy is required e.g. antiport

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Diffusion and Osmosis

- Diffusion→ the spontaneous movement of molecules or particles along a concentration gradient
- Osmosis → special case of diffusion
    - Water molecules diffuse across the selectively permeable membrane from an area of high water concentration to a lower water concentration
      (low solute concentration) → (high solute concentration)

Consequences of Gradients

- Hypertonic   Water moves out of cell (from most abundant to less abundant) → cell shrivels
- Hypotonic   water moves into the cell → the cell bursts
- Isotonic   water moves in and out t the same rate
- Moves from the positive to the negative end of the cell
  (water moves from an area of high concentration to low concentration)
- Live in a hypotonic environment (which an animal cell cannot live in)
    - Cell wall and tonoplast is essential for survival in a hypotonic environment
    - Cell wall: like a cage that provide the cell some degree of control
    - Tonoplast: large vaculoes (store sugars and regulating water), creates a physical pressure → offsets the water being pushed in and eventually equals out.
- Increase in mass   → hypotonic
- Decrease in mass   → hypertonic
- Water potential (pure): Ψ=0
    - In open container under normal atmospheric pressure and temperature
- Solute potential: Ψ_s = NEGATIVE
    - Causes water to move across permeable membrane (into cell) from region of high water potential to low
- Pressure potential: Ψ_p
    - Generated by cell walls
    - Increase physical turgor pressure inside cells halts net osmosis across membrane

Clicker Questions

1. Which of the following should you expect to occur in a living plant cell in a living plant
    a. Protons being actively pumped out of the cell (move against the concentration gradient)
2. Turgor pressure is also referred to as
    a. Pressure potential   (offsets the solute potential)
3. What is likely to happen to a plant cell that is placed in pure water?
    a. It becomes turgid   (swells → inflexible)
4. Why do plant cells behave differently to animal cells when placed in a hypotonic solution?
    a. Plant cells have a cell wall → does not burst; animal cells will burst

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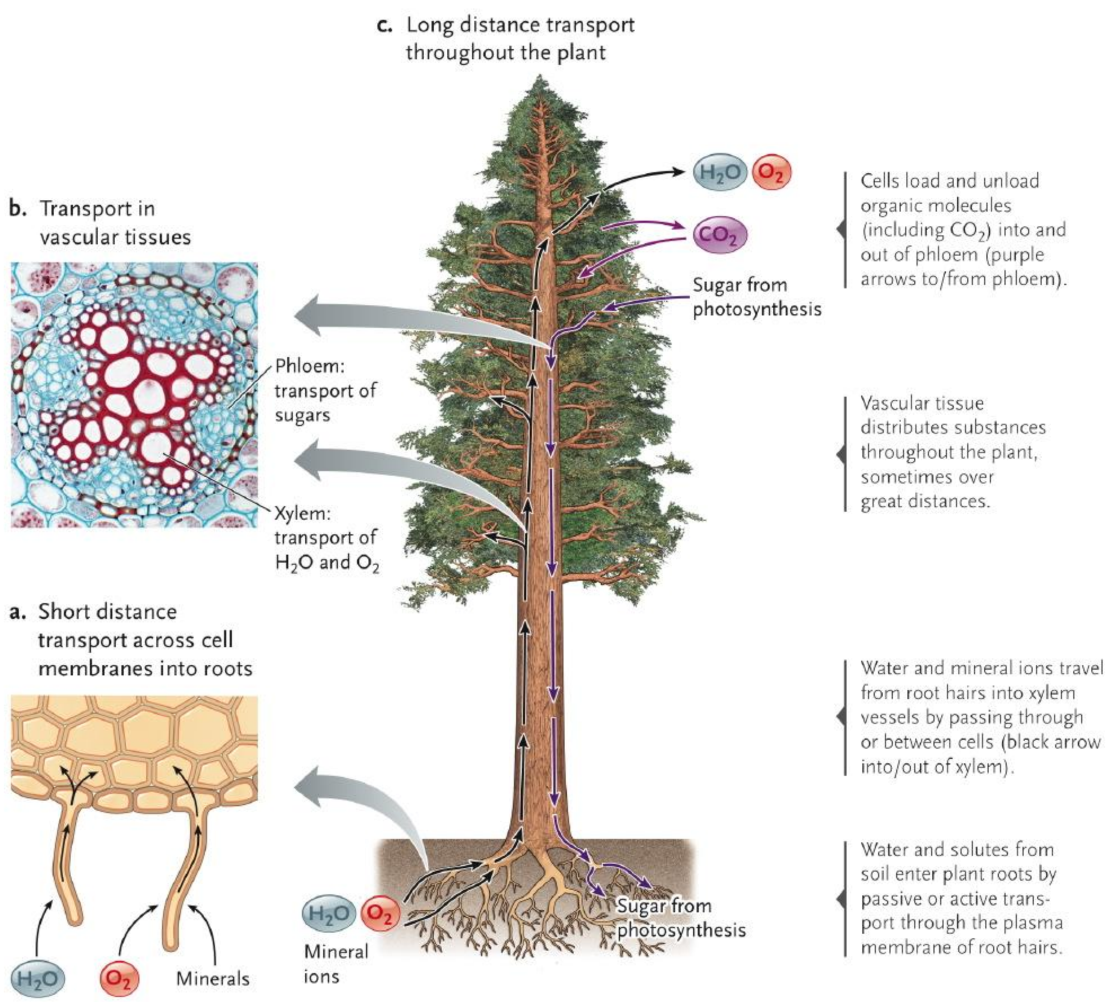
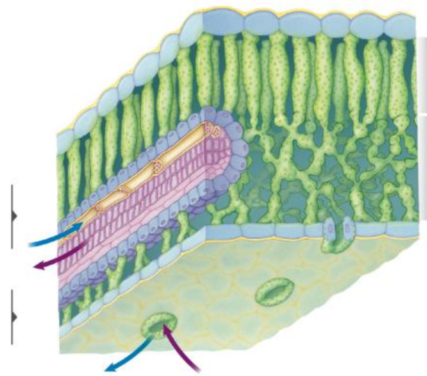
Transport Routes in Plants

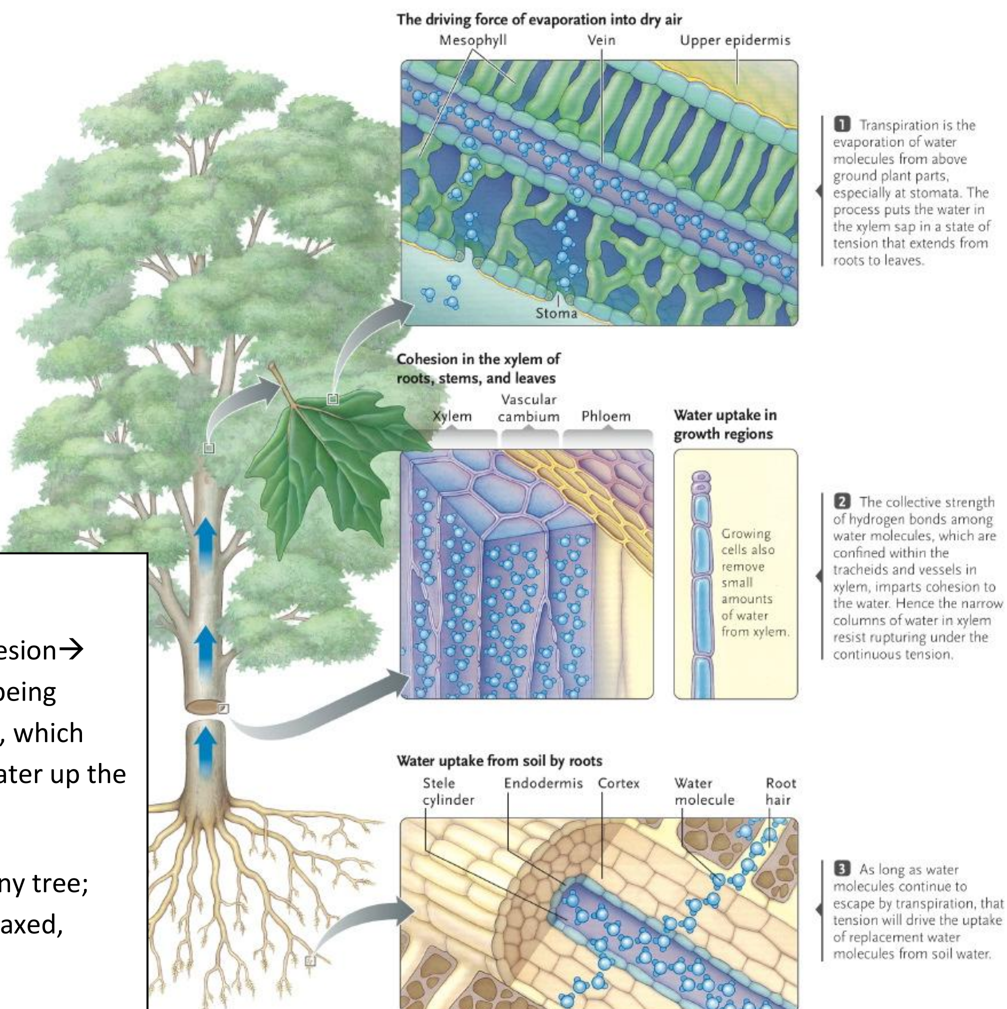
- Water moves by osmosis (high conc → low conc)
- Water forms H-bonds with adjacent water molecules (up to four); H-bonds are weak
- **Cohesion** Water has the ability stick to itself
- Higher profile than alcohol
- **Adhesion** Water has the ability to stick to other things
- **Transpiration**
    - evaporation of water out of plants
        - this is how water moves from the roots to the rest of the plant
        - Most water molecules are lost by transpiration, losing that water helps the plant
        - Greater than water used in growth and metabolism
- **Cohesion-tension mechanism of water transport**
    - Evaporation from mesophyll walls
    - Replacement by cohesion (H-bonded) water in xylem
    - Tension, negative pressure gradient, adhesion of water to xylem walls adds to tension



- spongy mesophyll
  - Inside the plant, where photosynthesis occurs, lots of air spaces between because they need to exchange gases ➔
  - undergo transpiration (open to air)



- Guard cells → outside the plant
- Plasmodesmata → conductivity
- Vascular bundles →xylem and phloem tissues
- Cells losing water
  - Specific water potential
  - The solute to water abundance will change
  - Cell will lose water, water moves from high water potential to low water potential
  - Simple diffusion will occur
  - Xylem full of water (high conc) and low in the surrounding cells (yellow in diagram)
- Water will pull the water molecules throughout the xylem, water molecules are really connected to each other



Transpiration

Adhesion & cohesion→ we see tension being formed in a tree, which helps pull the water up the roots

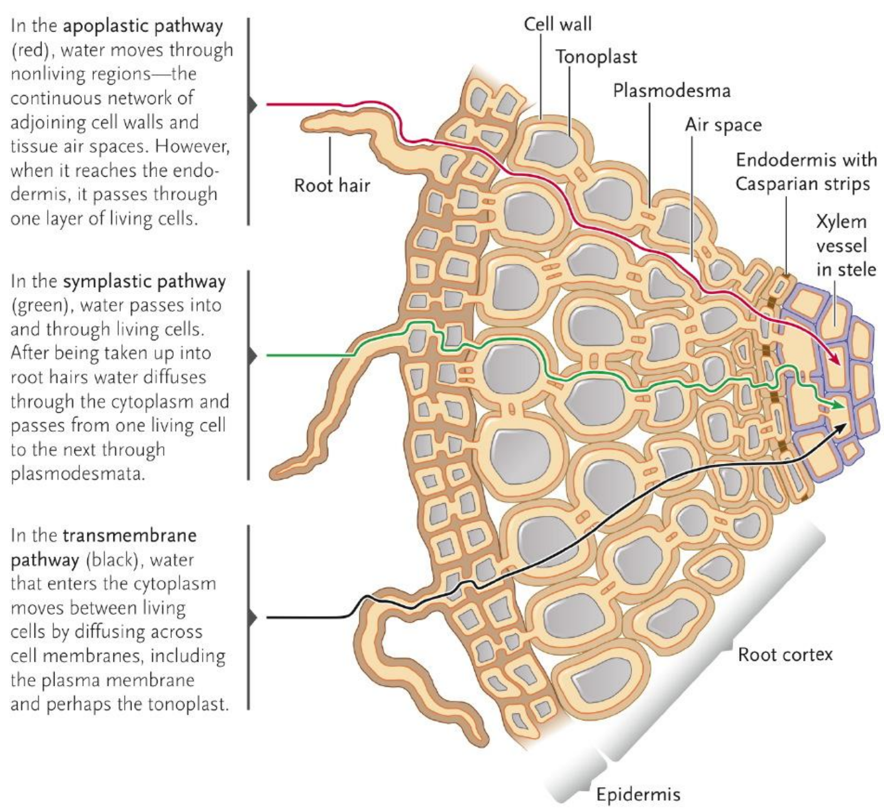
Morning → skinny tree; Night → tree relaxed, bigger

Cohesion-Tension in Tallest Trees

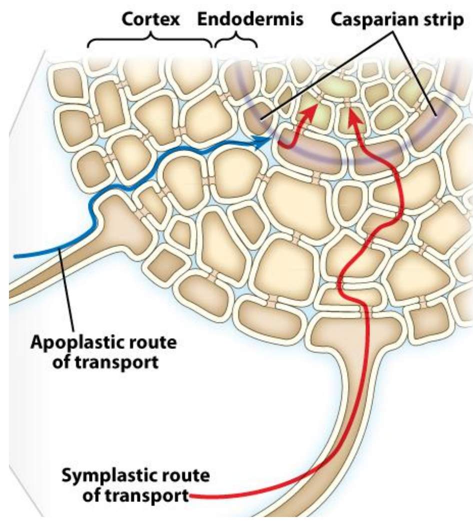
- Tallest trees (>110m) near physical limit of cohesion
- Root pressure → positive pressure in roots that force xylem sap upward
    - Occurs in high humidity or low light
    - Moves water up short distances
- Guttation
    - When root pressure strong enough to force water out of leaf opening
    - Water is pushed up and out of veins

Pathways of Water into Roots

- Apoplastic pathway
    - Water does not cross cell membrane, diffuses through non living regions including cell walls and air spaces
    - has a certain limit, molecules move through dead tissues, have to go through a plasma-membrane, they hit a wall and blocks the intracellular pathway
- Symplastic pathways
    - Water crosses membrane, often uses plasmodesmata, diffuses through cytoplasm
    - More degree of control
- Transmembrane pathway
    - Water crosses plasma membranes and perhaps tonoplasts (vacuolar membrane)



Pathway into Roots



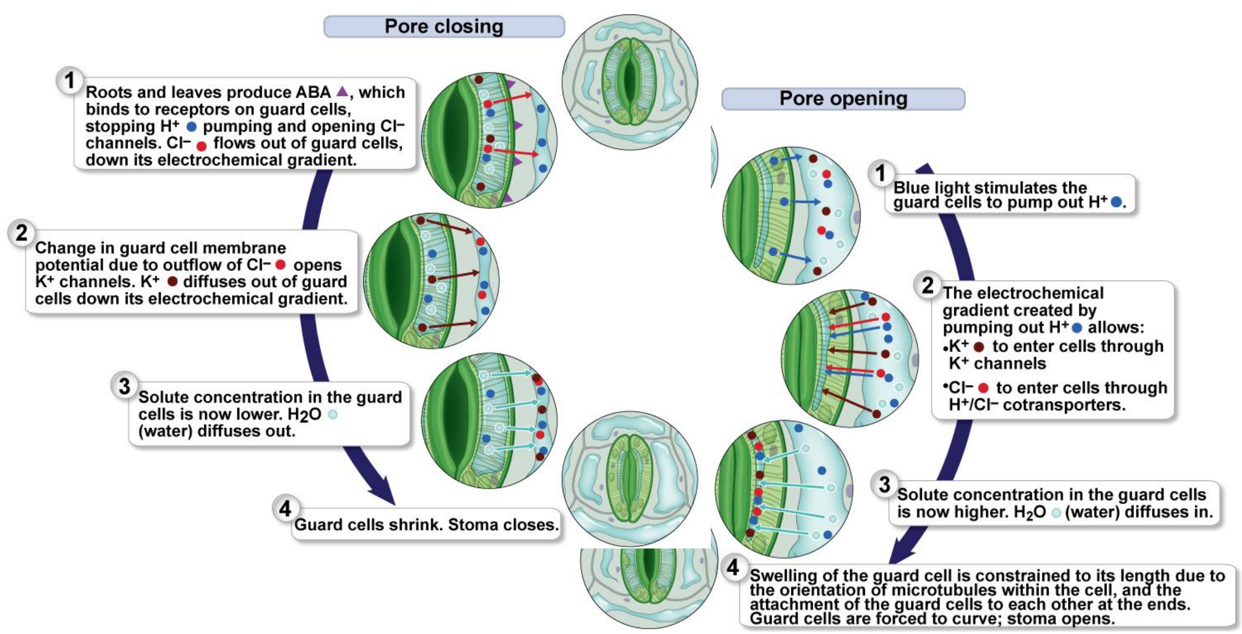
- Casparian strip
  - In root endodermis; forces apoplastic water to symplast
  - Gate keeper
- Active transport of minerals into symplast
- Active transport at Casparian strip across membrane
- Allows cell membranes to regulate solute movement

Stomata

- Transpiration losses of water must be regulated to prevent rapid desiccation
  - Cuticle limits H_2O loss but also prevents CO_2 uptake
  - Water is lost when stomata open for photosynthesis
  - Stomatal opening controlled by symport of H^+/K^+
  - Water follows K^+ by osmosis
  - Turgid → stomata open; flaccid → stomata closed

Guard Cells and Stomatal Action

- Guard Cells
  - Generating an electrical gradient, bringing in ions and molecules by symport
    - Size of concentration increases, water becomes more negative
    - Cell takes in more water and pushes against the cell wall
    - The cell bends in a sausage like shape and opens up the stomata (swells)
  - Only epidermal cells that have chloroplast organelles



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Potassium Accumulation in Stomatal Guard Cells

- Open stomata
  - Potassium mostly in guard cells
- Closed stomata
  - Potassium mostly in epidermal cells

Physiology of stomata

- Stomata must balance water loss and CO_2 uptake by responding to many signals
  → biological clock
- Stomata open to increase photosynthesis
  - Increasing light (blue)
  - Decreasing CO_2 concentration in leaf
- Stomata close under water stress
  - Abscisic acid is hormonal signal for closure, synthesized by roots
  - Mesophyll cells take up abscisic acid from xylem and release it
- Light, heat, and temperature
- Arid adaptations
  - Pathway of photosynthesis

Hormonal control of Stomatal closing

- K^+ enters the guard cells → stomata is open; water has moved in
- ABA signal → K^+ leaves the guard cells → stomata is closed; water has moved out

Arid Adaptation

- Xerophytes have adaptation to hot, dry environments
  - Thickened cuticle, sunken stomata, water storage in stems, modified leaves
- Crassulacean acid metabolism (CAM) plants have stomata that open at night
  - CO_2 fixed at night into malate (night time → low evaporation)
  - CO_2 released from malate during day when stomata is closed
- Pathway of photosynthesis

Clicker

1. ________ bonds are responsible for the cohesion of water molecules?
   a. Hydrogen
2. The best way to visualize water molecules moving through a tree's xylem would be
   a. As a thin cable formed from water molecules connected and to end

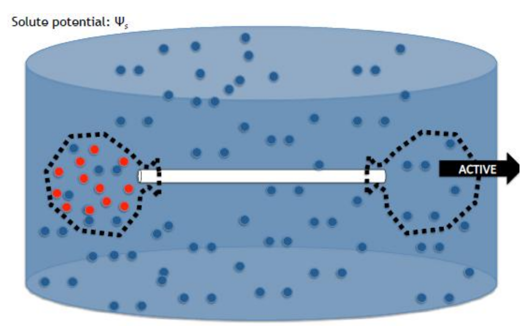
**friend linking arms → like hydrogen bond

Organic Compounds

- Macromolecules broken down into constituents for transport across cell membranes
- Translocation
    - Long-distance transport of substances via phloem (flows under pressure)
    - Phloem sap (water & organic compounds) flow through sieve tubes whose end walls (sieve plates) studded with pores
    - Companion cells (connected via plasmodesmata), or transfer cells load & unload
- Phloem systems movement of water in long distances with lots of pressure

Source and Sinks

- Source → any region of plant where organic substances are loaded into phloem
- Sink → any region of plant where organic substances are unloaded from phloem
- Pressure flow mechanism moves substances by bulk flow under pressure from sources to sinks
    - Based on water potential gradients
- Loading solute into sieve tubes lowers water potential
    - Causes water to move across permeable membrane (into cell) from region of high water potential to low
        - This increases turgor pressure in tube
- Source the modified stem (sugar → to leaves);
  Sink is the rest of the plant

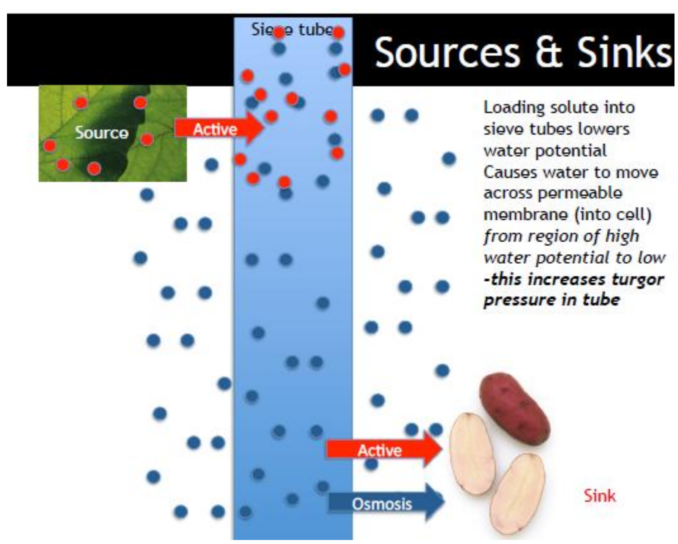


Principle of Bulk Flow

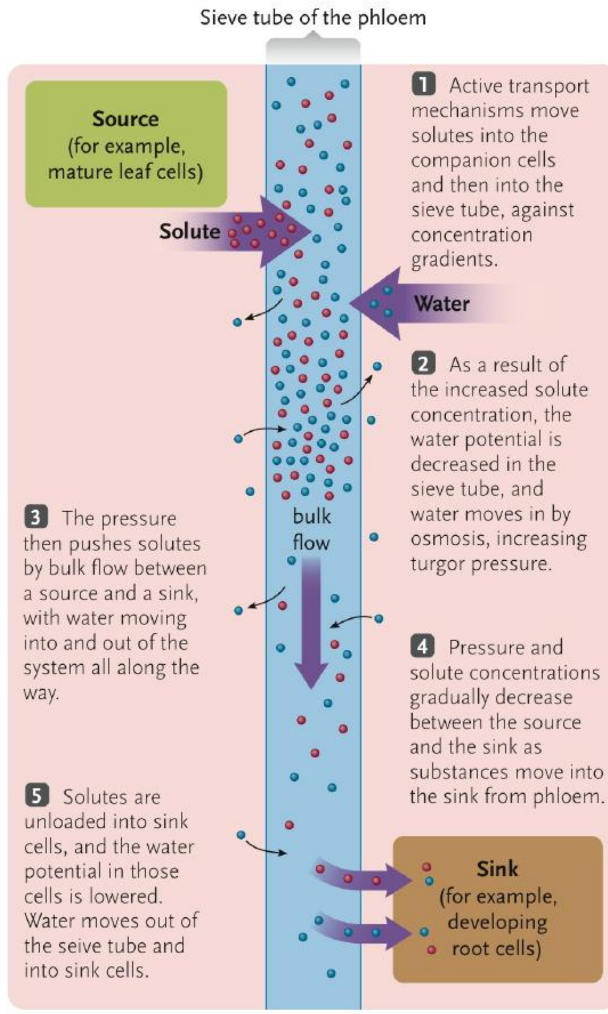
- Plants moving sugars into their systems
- High water potential outside the bag then inside
    - Pressure will build up until the plasma membrane bursts
- Move solutes from high abundance to low abundance (more solute on left than right)

Sources and Sinks

- Sources → sugar molecules move over to the sieve tube
- Sieve tube = phloem
- We move the dissolved molecule/sugars (sources) down the sink
- Actively cross membrane using transport channels active = osmosis
- Create a pressure gradient

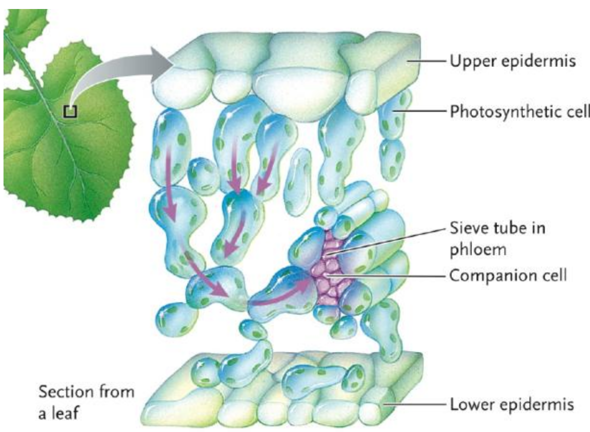


Pressure Flow Mechanism ➔

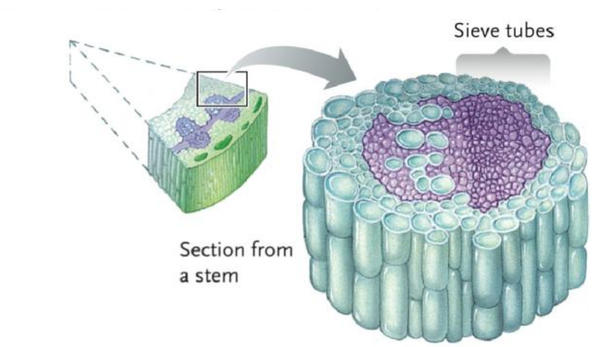


Translocation

loading at a source



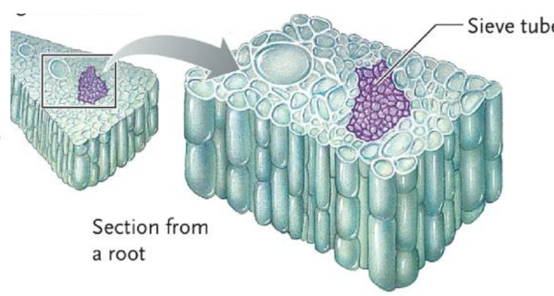
Photosynthetic cells in leaves are a common source of carbohydrates that must be distributed throughout a plant. Small, soluble forms of these compounds move from the cells into phloem (in a leaf vein).



Fluid pressure is greatest inside sieve tubes at the source. It pushes the solute-rich fluid to a sink, which is any region where cells are growing or storing food. There, the pressure is lower because cells are withdrawing solutes from the tubes and water follows the solutes.

← translocation along a distribution path

Unloading at the sink →



Solutes are unloaded from sieve tubes into cells at the sink; water follows. Translocation continues as long as solute concentration gradients and a pressure gradient exist between the source and the sink.

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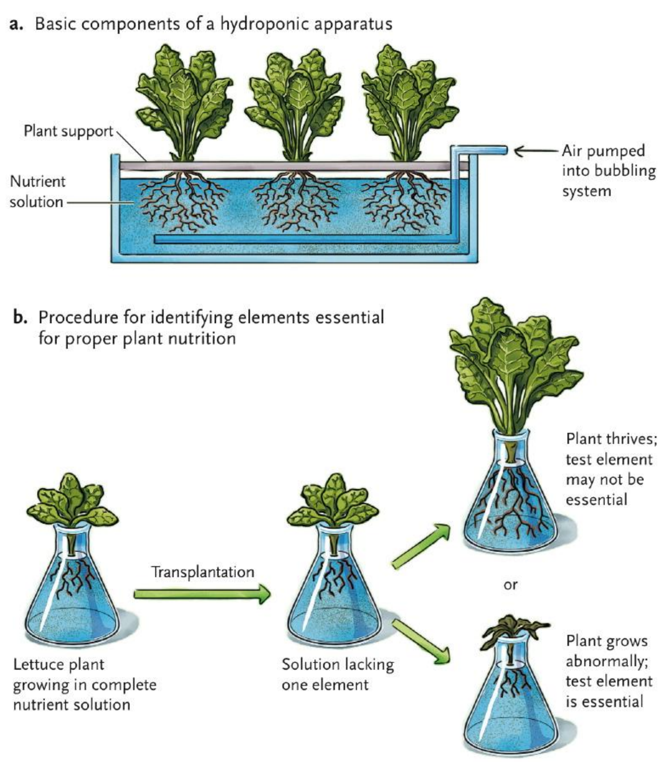
Macronutrients and Micronutrients in Plant Metabolism

- By weight, tissues of most plants are >90% water mechanical advantage
- Most plant's nutrition comes from photosynthesis
    - Made mostly from the air carbon fixation
- Smaller amounts of other nutrients come from soil or water
- Essential elements [plants have 17 elements required for life]
    - Necessary for growth/reproduction
    - Cannot be substituted
    - One or more roles in metabolism
- Macronutrients essential in large quantities
    - C, H, O
        - ~96% of dry mass, come from air and water, not considered minerals
    - N, P, Ca, S, Mg
- Micronutrients essential in trance quantities
    - Hard to exclude (Cl)
    - May be enough in seeds for multiple generations (Ni)
    - Some micronutrients specific to plant types

Nutrient deficiencies

- Different plants have different needs for (or toxicity to) elements
    - Soil determines where and how well plants grow
- Nutrient deficiencies have symptoms with clues to metabolic function
    - Stunted growth, leaf color, dead spots, abnormal stems, chlorosis



Hydroponic culture

- Plants in solutions of water instead of soil to figure out which elements are more sufficient for plants
- Compare growth to one group of plants with all essential elements to another group of plants with nothing
- Macronutrients
    - Elements in large abundance
- Micronutrients
    - Elements in extremely small amounts, but are still needed for plant growth

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Root Systems

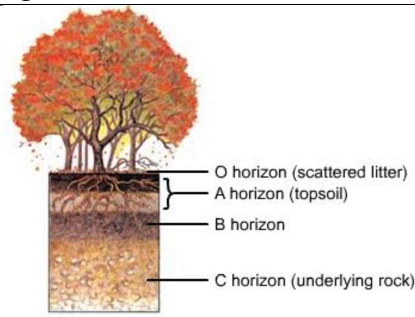
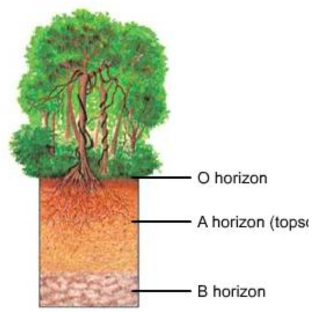
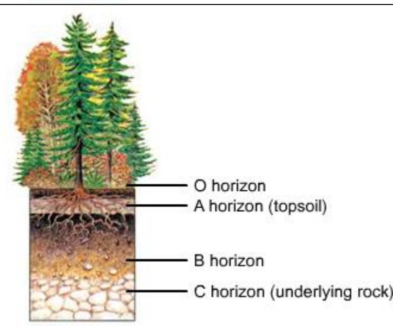
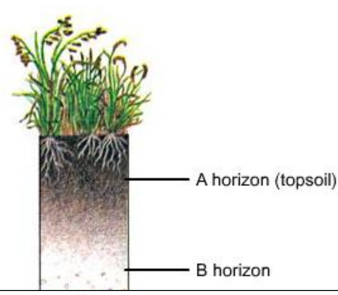
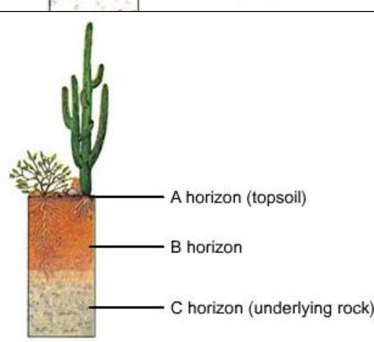
- Extensive root systems are adaptations to limited mineral nutrients
  - Make up 20-50% of total plant mass much larger in total volume
  - Roots grow as long as plant lives
- Roots have mechanisms to increase uptake
  - Root hairs (Large SA:V ratio)
    - Thin, epidermal → lots of surface area to take in ions and minerals
  - Membrane transporters
  - Mycorrhizae → symbiotic associations between fungus and roots of plant
    - Fungi extend their body, with high surface area, they extract **phosphorus** and pass on to the plants, and plants provide them with sugars
- More soil = more surface a plant could take into the body

Soil

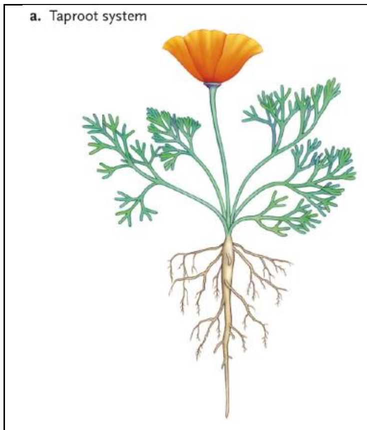
- Soil-mineral particles, compounds, ions, decomposing organics, water, air, organisms
  - Sand, silt, and clay particles
  - Humus → decomposing organics (negative charge)
- Relative amount of soil particles determine soil properties
- As soils develop, tend to take on characteristic vertical profile, with series of layers or horizons with distinct texture and composition
- Formed over long periods of time by new dead material coming on from the surface, decomposed elements

Soil Horizons

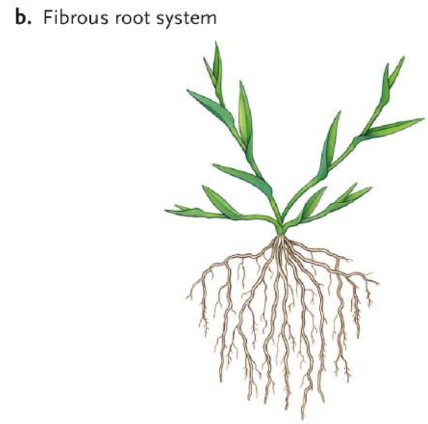
- 0 Horizon → surface material
- A Horizon → Topsoil
  - Has most biological activity and usually most fertile, most roots
  - "most important" most nutrients are found, most roots and bacteria
- B Horizon → Subsoil
  - Accumulates nutrients, woody roots
  - Lots of sources of water; less biological activity
- C Horizon → Parent material
  - No organic material, partially weathered fragments and grains of rock
- Leaching loss or extraction of minerals from a carrier into a liquid (water)
- Amount of leaching is determined by how hot the environment is, and the precipitation of the environment

	Figure	Notes	Temp/Precipitate
Decidous			Temperature: -30⁰C ~ 30⁰C Precipitate: 75 – 150cm rain/year
Rainforest		- All nutrients are in the surface - High concentrations of aluminum and iron (not good for plant)	Temperature: -20⁰C ~ 25⁰C Precipitate: 1000cm rain/year
Coniferous forest		- Higher up North; temperatures are colder - A lot of leaching - Poor/acidic soil - Poor nutrient in the 0 horizon - Poorer nutrients than decidous trees	Temperature: -30⁰C ~ 20⁰C Precipitate: 200cm rain/year
Grasslands		- Less rain than the decidous trees - High calcium carbonate - Great basic nutrient that could serve grasslands (carbon fixation)	Temperature: -30⁰C ~ 20⁰C Precipitate: 30 – 90cm rain/year
Desert		- Hot, dry area - Less water available - Access to water is deeper down the soil; not much water available on surface	Precipitate: Less than 25cm rain/year

Adaptation to resource availability



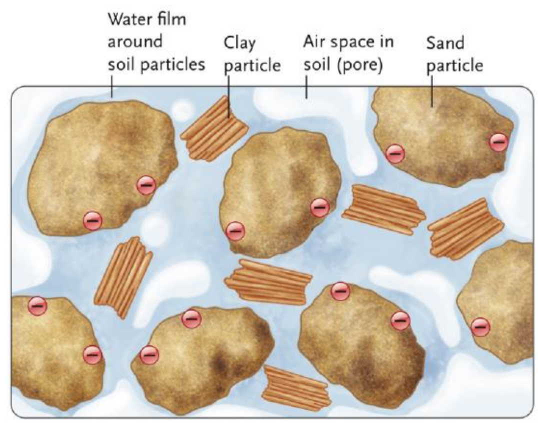
dry areas



monocots

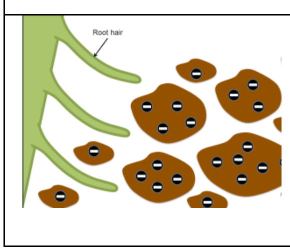
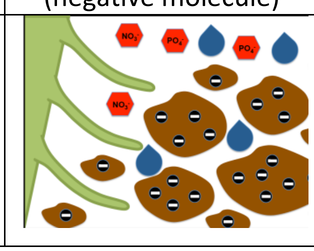
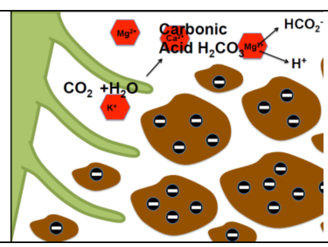
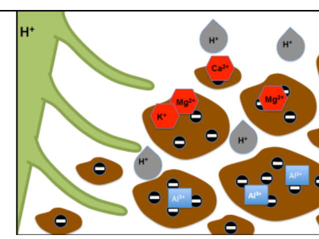
Soil Solutions

- Water molecules have cohesive and adhesive properties
- Soil is a complex mixture of different things
- Negative properties, negative changes
- What type of nutrients takes less time to be absorbed



Ion Exchange

- Both anions and cations
- Both needed by plants
- Anions are washed away/lost
- Attracted to the clay surfaces (anions)
    - Cations get released to the water, where it gets picked up by the plant

Ion Exchange	Anion uptake (negative molecule)	Cation Exchange	
			

Acid Rain

- Rain droplets are acidic (the Hydrogen ions)
- Cause the cations to be released and lost
- Toxicins are picked up by the plant

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Nitrogen Limitations

- Nitrogen (N)
  - Abundant element in air, most limiting to plant
  - Triple bond requires specific enzyme
  - Nitrogen cycle provides soil nitrogen
- Nitrogen fixation incorporates atmospheric N_2 into plant-available compounds
  - Nitrogen-fixing bacteria

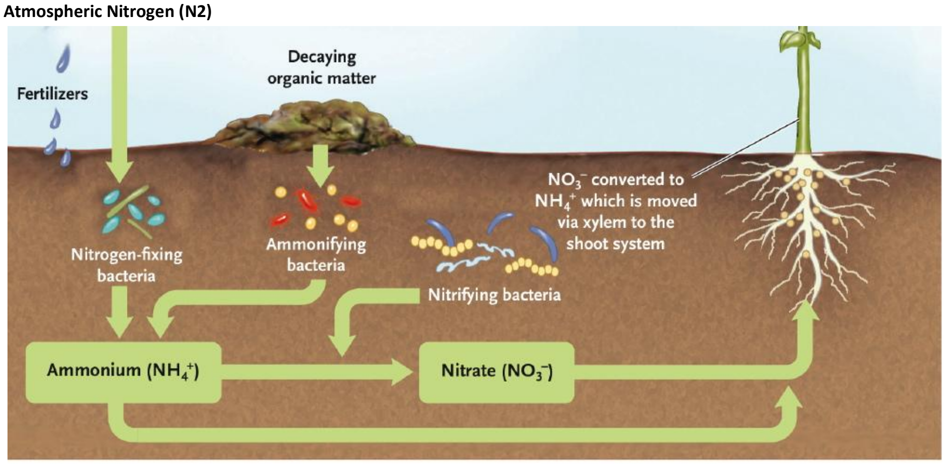
Nitrogen bases in DNA

- Guanine

Nitrogen Cycling

- Bacterial ammonification breaks organic N compounds into NH_4^+ (ammonium)
  - Plants take up NH_4^+, but prefer NO_3^- (nitrate)
- Bacterial nitrification oxidized ammonium to nitrate
  - High rates of nitrification, except in acidic soils
- Plants convert nitrate to ammonium to assimilate Nitrogen into organic compounds

Atmospheric Nitrogen (N2)



Nitrogen Fixation

- Most Nitrogen is fixed by plant symbioses with bacteria
  - Plant provides organic molecules for respiration energy, bacteria provide ammonium
- Legumes form root nodules with *Rhizobium* or *Bradyrhizobium*
  - Bacterial *nod* genes expressed with flavenoid signals from plant
  - Infection thread allows bacterial invasion
  - Bacteroids enclosed in nodule (leghemoglobin and nitrogenase)