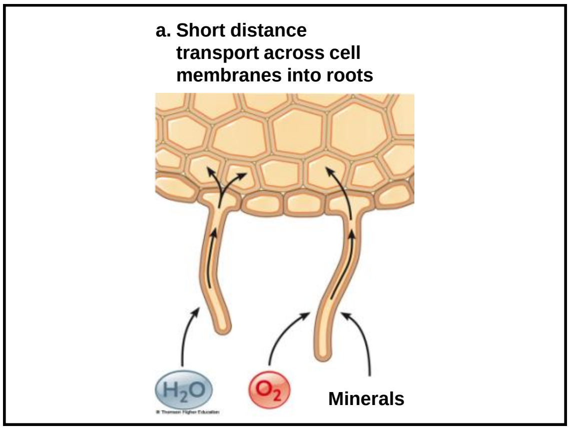
Transport in Plants

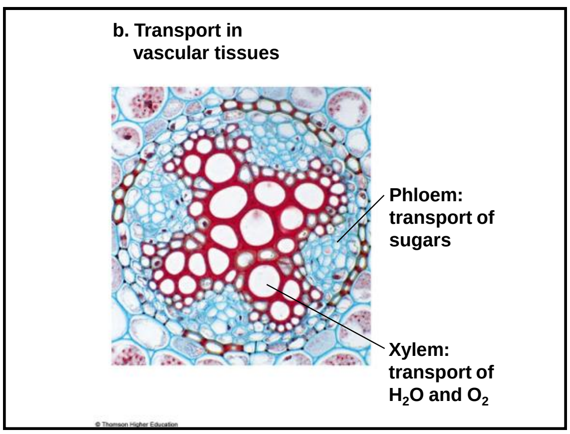
Chapter 32

Redwoods

Plant Material Transport

- Material transport
  - **Short distances** between cells
  - **Long distances** between roots and and shoot parts, such as leaves (xylem and phloem)
- The plant cell wall does not prevent solutes from moving into plant cells
  - ***Plasmodesmata***


a. Short distance transport across cell membranes into roots
H_2O
O_2
Minerals


b. Transport in vascular tissues
Phloem: transport of sugars
Xylem: transport of H_2O and O_2
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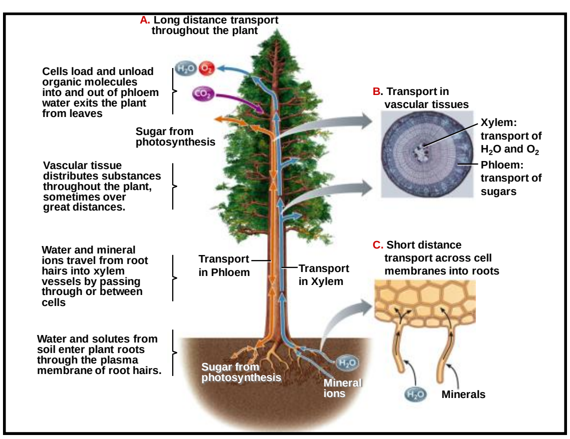
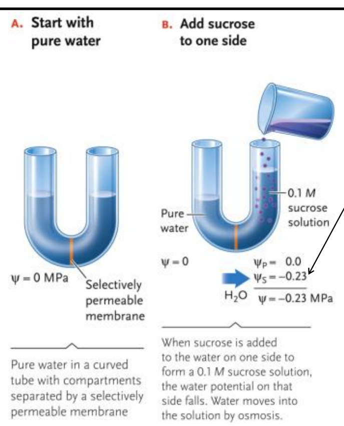

A. Long distance transport throughout the plant
Cells load and unload organic molecules into and out of phloem water exits the plant from leaves
Sugar from photosynthesis
Vascular tissue distributes substances throughout the plant, sometimes over great distances.
Water and mineral ions travel from root hairs into xylem vessels by passing through or between cells
Water and solutes from soil enter plant roots through the plasma membrane of root hairs.
Transport in Phloem
Transport in Xylem
Sugar from photosynthesis
Mineral ions
B. Transport in vascular tissues
Xylem: transport of H_2O and O_2
Phloem: transport of sugars
C. Short distance transport across cell membranes into roots
Minerals

Water Movement in Plants

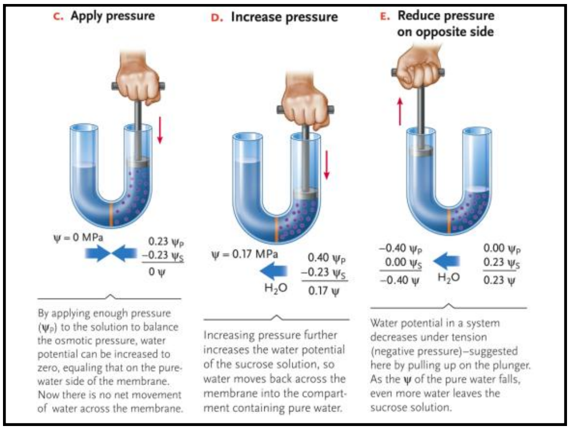
- Movement of water into and through plant cells and tissues is a very important aspect of plant physiology
- **Osmosis**
  - *Passive movement of water across a selectively permeable cell membrane*
  - Driven by water potential (Ψ; MPa)
- **Bulk flow** of water due to pressure differences
  - Example: Xylem sap, a dilute solution of water and ions from roots to leaves

Water Potential (Ψ)

- Water potential (Ψ) is the total of its components
  - Rule of thumb: ***Water moves from high to low water potential***
  - Ψ of pure water is 0 MPa
  - $\Psi = \Psi_s + \Psi_p$
- Presence of **solutes lowers** solute potential (Ψ_s)
- Pressure potential (Ψ_p)
  - Increased pressure **increases** the water potential



***Note the decrease in solute potential when solutes are added.**



Plant Cells and Water Potential

- Central vacuole
  - Tonoplast membrane
  - Contains a dilute solution of sugars, proteins, or other organic molecules, and salts
  - Vacuole maintains turgor pressure
- Aquaporin proteins allow rapid movement of water through hydrophobic membrane core
- Wilting occurs when plants lose more water than they gain (plasmolysis)
  - Low Ψ of dry soil

Transport in Roots

- Water and minerals that enter roots must first travel laterally through the root cortex to the root xylem
- *Roots take up ions by active transport*
- *Water and ions travels to the root xylem by* ***three pathways***

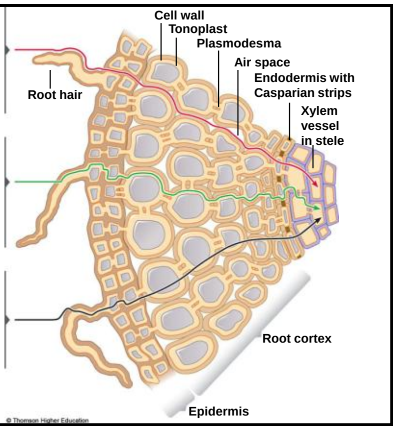
Water in Roots

1) **Apoplastic pathway**: water moves through "non-living" regions
2) **Symplastic pathway**: water passes into and through living cells via plasmodesmata
3) **Transmembrane pathway**: water that enters the cytoplasm moves between living cells by diffusing across cell membranes

In the **apoplastic pathway** (red), water moves through nonliving regions–the continuous network of adjoining cell walls and tissue air spaces. However, when it reaches the **endodermis**, it passes through one layer of living cells.

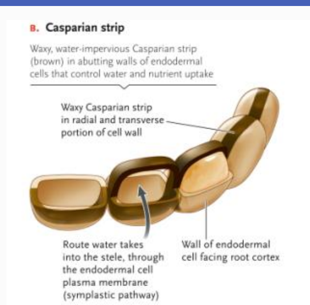
In the **symplastic pathway** (green), water passes into and through living cells. After being taken up into root hairs water diffuses through the cytoplasm and passes from one living cell to the next through plasmo-desmata.

In the **transmembrane pathway** (black), water that enters the cytoplasm moves between living cells by diffusing across cell membranes, including the plasma membrane and perhaps the tonoplast.



Casparian Strip

- Casparian strip in root ***endodermis*** forces apoplastic water to symplast

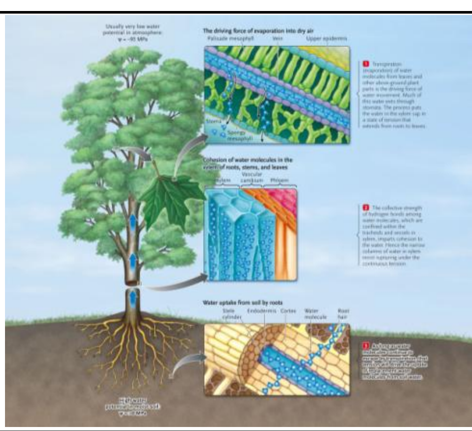


Mineral Active Transport

- Most minerals for growth are more concentrated in root than in soil
  - Active transport into symplast
  - Active transport at Casparian strip across membrane
- Minerals loaded into dead xylem in root stele
  - Transported long distance to other tissues

Transport of Water and Minerals in the Xylem

- How does xylem sap move from roots to stems, and into leaves?
- Transpiration drives the ascent of sap
- **Cohesion**-tension mechanism of water transport
  - **Involves two very important properties of water – cohesion and adhesion**
  - ***Tension***, **negative pressure** gradient, maintained by narrow xylem walls (**wilting** is excess tension)



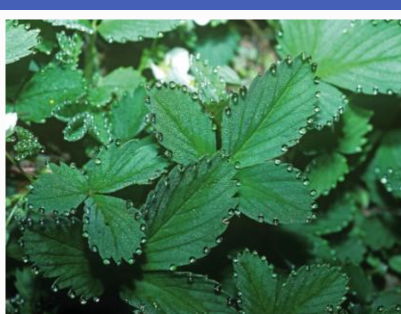
Leaf Anatomy

- Leaves facilitate transpiration
  - **Large volume of air**
    - ~ 2/3 of leaf volume consists of air spaces
  - Thousands to millions of **stomata**, through which water vapor can escape
  - Contains thousands of tiny xylem veins
    - Short cell distances to xylem

Cohesion-Tension in Tallest Trees

- **Transpiration** follows atmospheric evaporation
  - Driving forces: Dryness and radiation
  - Tallest trees (>110m) near physical limit of cohesion
- Root pressure can also occur in moist to wet soils
  - **Moves water up** short distances
- Guttation
  - Water movement under pressure out leaves

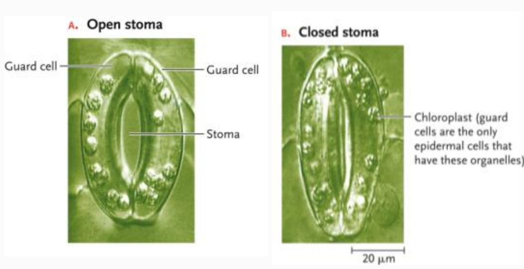
Guttation



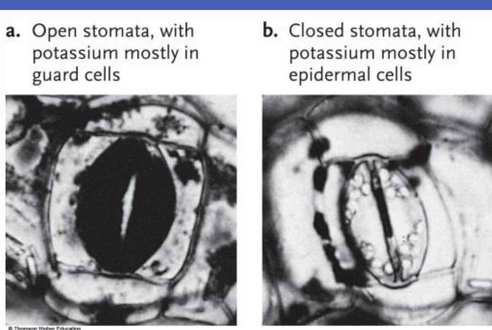
Stomata

- Transpirational losses of water must be regulated to prevent rapid dessication
  - **Cuticle** limits H_2O loss but also prevents CO_2 uptake
  - Water is always lost when **stomata** open for CO_2 (photosynthesis)
- Stomatal opening controlled by symport of H^+/K^+
  - Water follows K^+ by osmosis
  - Turgid stomata open, flaccid closed

Guard Cells and Stomatal Action



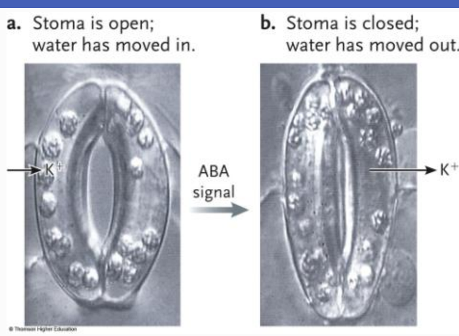
Potassium Accumulation in Stomatal Guard Cells



Physiology of Stomata

- Stomata must balance H_2O loss and CO_2 uptake by responding to many signals, biological clock
- **Stomata open to increase photosynthesis**
  - Increasing light (stimulate blue-light receptors)
  - Decreasing CO_2 concentration in leaf
- **Stomata close under *water stress***
  - Abscisic acid is hormonal signal for closure, synthesized by roots and leaves

Hormonal Control of Stomatal Closing



Arid Adaptations

- **Xerophytes** have adaptations to aridity
  - Thickened cuticle, sunken stomata, water storage in stems
- Crassulacean acid metabolism (CAM) plants have stomata that open at night
  - Include cacti, orchids, and most succulents
  - **Stomata** are **fewer in number** and **follow a reversed schedule**
  - CO_2 fixed at night (low evaporation) into malate
  - CO_2 released from malate during day when stomata closed

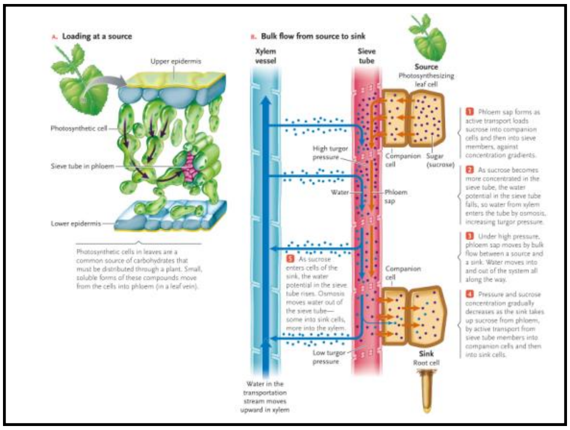
Surviving Water Stress

Transport of Organic Substances in the Phloem

- **Translocation**
  - Long-distance transport of substances via phloem
  - Phloem flows under pressure, moves any direction
- Macromolecules broken down into constituents for transport across cell membranes
  - **Sucrose** is the main form in which sugars are transported through the phloem of most plants
- **Phloem sap** composed of water and organic compounds that move through sieve tubes

Source and Sinks

- Source: Any region of plant where organic substance is loaded into phloem
  - Companion and transfer cells
- Sink: Any region of plant where organic substance is unloaded from phloem and used or stored
- **Pressure flow mechanism (next slide)** moves substance by bulk flow under pressure from sources to sinks
  - Based on water potential gradients


A. Loading at a source
Upper epidermis
Photosynthetic cell
Sieve tube in phloem
Lower epidermis
Photosynthetic cells in leaves are a common source of carbohydrates that must be distributed through a plant. Small, soluble forms of these compounds move from the cells into phloem (in a leaf vein).
B. Bulk flow from source to sink
Xylem vessel
Sieve tube
Source
Photosynthesizing leaf cell
High turgor pressure
Companion cell
Sugar (sucrose)
Water
Phloem sap
Companion cell
Low turgor pressure
Sink
Root cell
Water in the transportation stream moves upward in xylem
1 Phloem sap forms as active transport loads sucrose into companion cells and then into sieve members, against concentration gradients.
2 As sucrose becomes more concentrated in the sieve tube, the water potential in the sieve tube falls, so water from xylem enters the tube by osmosis, increasing turgor pressure.
3 Under high pressure, phloem sap moves by bulk flow between a source and a sink. Water moves into and out of the system all along the way.
4 Pressure and sucrose concentration gradually decreases as the sink takes up sucrose from phloem, by active transport from sieve tube members into companion cells and then into sink cells.
5 As sucrose enters cells of the sink, the water potential in the sieve tube rises. Osmosis moves water out of the sieve tube—some into sink cells, more into the xylem.