Chapter 36

Transport in Vascular Plants

PowerPoint Lectures for
Biology*, *Seventh Edition
Neil Campbell and Jane Reece

Lectures by Chris Romero

- Overview: Pathways for Survival
- For vascular plants
  - The evolutionary journey onto land involved the differentiation of the plant body into roots and shoots

- Vascular tissue
  - Transports nutrients throughout a plant; such transport may occur over long distances

Figure 36.1

- Concept 36.1: Physical forces drive the transport of materials in plants over a range of distances
- Transport in vascular plants occurs on three scales
  - Transport of water and solutes by individual cells, such as root hairs
  - Short-distance transport of substances from cell to cell at the levels of tissues and organs
  - Long-distance transport within xylem and phloem at the level of the whole plant

- A variety of physical processes
  - Are involved in the different types of transport

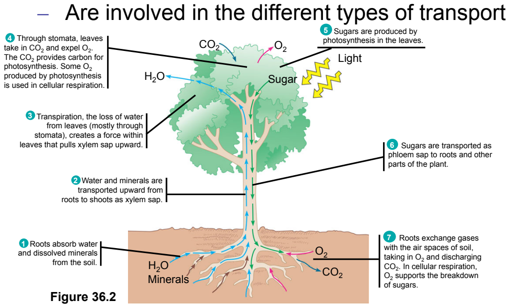


Figure 36.2

Selective Permeability of Membranes: *A Review*

- The selective permeability of a plant cell's plasma membrane
  - Controls the movement of solutes into and out of the cell
- Specific transport proteins
  - Enable plant cells to maintain an internal environment different from their surroundings

The Central Role of Proton Pumps

- Proton pumps in plant cells
  - Create a hydrogen ion gradient that is a form of potential energy that can be harnessed to do work
  - Contribute to a voltage known as a membrane potential

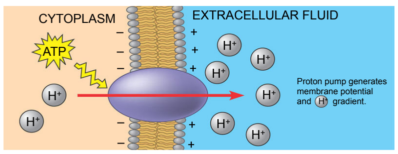
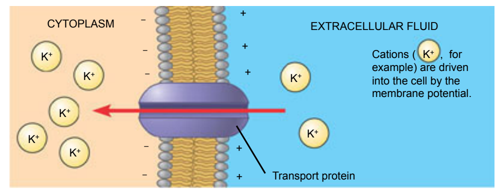


Figure 36.3

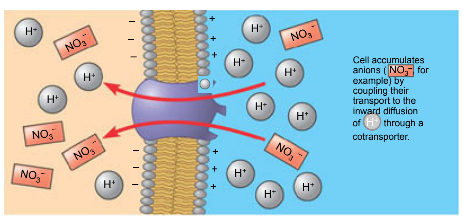
- Plant cells use energy stored in the proton gradient and membrane potential
  - To drive the transport of many different solutes



(a) Membrane potential and cation uptake

Figure 36.4a

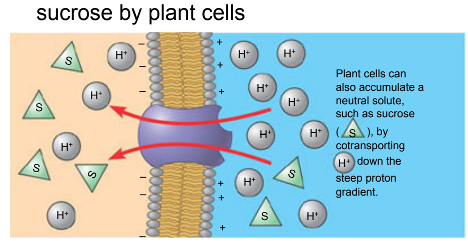
- In the mechanism called cotransport
  - A transport protein couples the passage of one solute to the passage of another



(b) Cotransport of anions

Figure 36.4b

- The "coattail" effect of cotransport
  - Is also responsible for the uptake of the sugar sucrose by plant cells



(c) Contransport of a neutral solute

Figure 36.4c

Effects of Differences in Water Potential

- To survive
  - Plants must balance water uptake and loss
- Osmosis
  - Determines the net uptake or water loss by a cell
  - Is affected by solute concentration and pressure

- Water potential
  - Is a measurement that combines the effects of solute concentration and pressure
  - Determines the direction of movement of water
- Water
  - Flows from regions of high water potential to regions of low water potential

How Solutes and Pressure Affect Water Potential

- Both pressure and solute concentration
  - Affect water potential

- The solute potential of a solution
  - Is proportional to the number of dissolved molecules
- Pressure potential
  - Is the physical pressure on a solution

Quantitative Analysis of Water Potential

- The addition of solutes
  - Reduces water potential

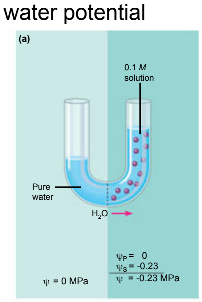


Figure 36.5a

- Application of physical pressure
  - Increases water potential

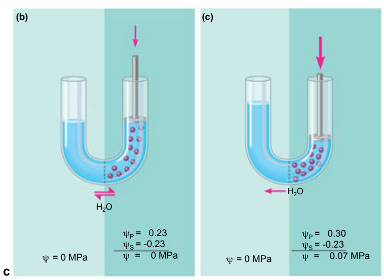


Figure 36.5b, c

- Negative pressure
  - Decreases water potential

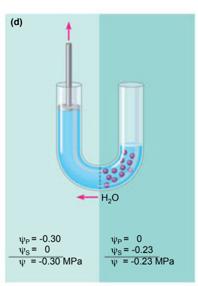


Figure 36.5d

- Water potential
  - Affects uptake and loss of water by plant cells
- If a flaccid cell is placed in an environment with a higher solute concentration
  - The cell will lose water and become plasmolyzed

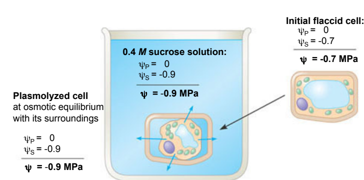


Figure 36.6a

- If the same flaccid cell is placed in a solution with a lower solute concentration
  - The cell will gain water and become turgid

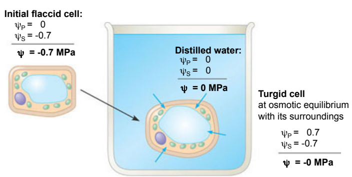


Figure 36.6b

- Turgor loss in plants causes wilting
  - Which can be reversed when the plant is watered

Figure 36.7

Aquaporin Proteins and Water Transport

- Aquaporins
  - Are transport proteins in the cell membrane that allow the passage of water
  - Do not affect water potential

Three Major Compartments of Vacuolated Plant Cells

- Transport is also regulated
  - By the compartmental structure of plant cells

- The plasma membrane
  - Directly controls the traffic of molecules into and out of the protoplast
  - Is a barrier between two major compartments, the cell wall and the cytosol

- The third major compartment in most mature plant cells
  - Is the vacuole, a large organelle that can occupy as much as 90% of more of the protoplast's volume
- The vacuolar membrane
  - Regulates transport between the cytosol and the vacuole

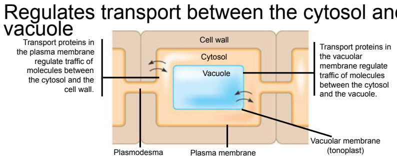
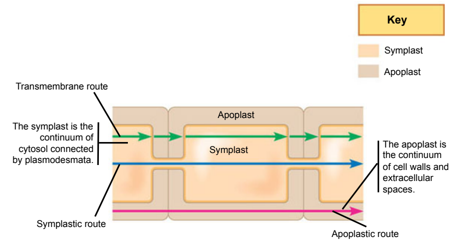


Figure 36.8a

(a) Cell compartments. The cell wall, cytosol, and vacuole are the three main compartments of most mature plant cells.

- In most plant tissues
  - The cell walls and cytosol are continuous from cell to cell
- The cytoplasmic continuum
  - Is called the symplast
- The apoplast
  - Is the continuum of cell walls plus extracellular spaces



(b) Transport routes between cells. At the tissue level, there are three passages: the transmembrane, symplastic, and apoplastic routes. Substances may transfer from one route to another.

Figure 36.8b

Functions of the Symplast and Apoplast in Transport

- Water and minerals can travel through a plant by one of three routes
  - Out of one cell, across a cell wall, and into another cell
  - Via the symplast
  - Along the apoplast

Bulk Flow in Long-Distance Transport

- In bulk flow
  - Movement of fluid in the xylem and phloem is driven by pressure differences at opposite ends of the xylem vessels and sieve tubes

- Concept 36.2: Roots absorb water and minerals from the soil
- Water and mineral salts from the soil
  - Enter the plant through the epidermis of roots and ultimately flow to the shoot system

- Lateral transport of minerals and water in roots

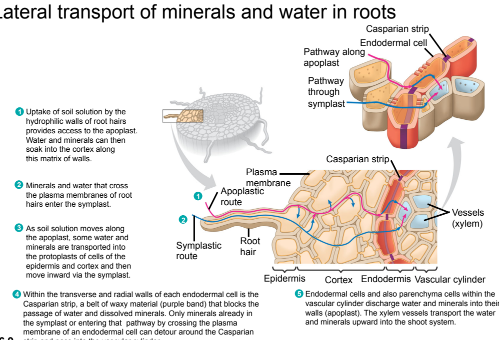


Figure 36.9

The Roles of Root Hairs, Mycorrhizae, and Cortical Cells

- Much of the absorption of water and minerals occurs near root tips, where the epidermis is permeable to water and where root hairs are located
- Root hairs account for much of the surface area of roots

- Most plants form mutually beneficial relationships with fungi, which facilitate the absorption of water and minerals from the soil
- Roots and fungi form mycorrhizae, symbiotic structures consisting of plant roots united with fungal hyphae

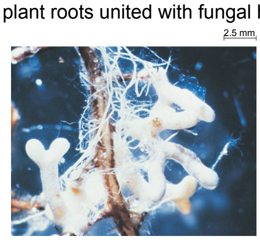


Figure 36.10

- Once soil solution enters the roots
  - The extensive surface area of cortical cell membranes enhances uptake of water and selected minerals

The Endodermis: A Selective Sentry

- The endodermis
  - Is the innermost layer of cells in the root cortex
  - Surrounds the vascular cylinder and functions as the last checkpoint for the selective passage of minerals from the cortex into the vascular tissue

- Water can cross the cortex
  - Via the symplast or apoplast
- The waxy Casparian strip of the endodermal wall
  - Blocks apoplastic transfer of minerals from the cortex to the vascular cylinder

- Concept 36.3: Water and minerals ascend from roots to shoots through the xylem
- Plants lose an enormous amount of water through transpiration, the loss of water vapor from leaves and other aerial parts of the plant
- The transpired water must be replaced by water transported up from the roots

Factors Affecting the Ascent of Xylem Sap

- Xylem sap
  - Rises to heights of more than 100 m in the tallest plants

Pushing Xylem Sap: Root Pressure

- At night, when transpiration is very low
  - Root cells continue pumping mineral ions into the xylem of the vascular cylinder, lowering the water potential
- Water flows in from the root cortex
  - Generating root pressure

- Root pressure sometimes results in guttation, the exudation of water droplets on tips of grass blades or the leaf margins of some small, herbaceous eudicots

Figure 36.11

Pulling Xylem Sap: The Transpiration-Cohesion-Tension Mechanism

- Water is pulled upward by negative pressure in the xylem

Transpirational Pull

- Water vapor in the airspaces of a leaf
  - Diffuses down its water potential gradient and exits the leaf via stomata

- Transpiration produces negative pressure (tension) in the leaf
  - Which exerts a pulling force on water in the xylem, pulling water into the leaf

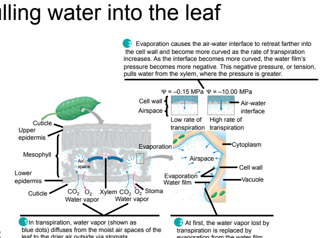


Figure 36.12

Cohesion and Adhesion in the Ascent of Xylem Sap

- The transpirational pull on xylem sap
  - Is transmitted all the way from the leaves to the root tips and even into the soil solution
  - Is facilitated by cohesion and adhesion

- Ascent of xylem sap

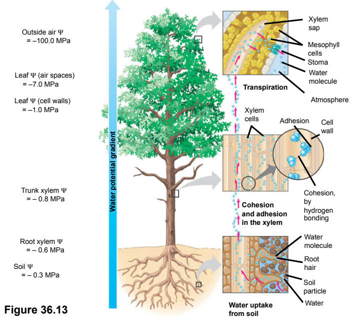


Figure 36.13

Xylem Sap Ascent by Bulk Flow: *A Review*

- The movement of xylem sap against gravity
  - Is maintained by the transpiration-cohesion-tension mechanism

- Concept 36.4: Stomata help regulate the rate of transpiration
- Leaves generally have broad surface areas
  - And high surface-to-volume ratios

- Both of these characteristics
  - Increase photosynthesis
  - Increase water loss through stomata

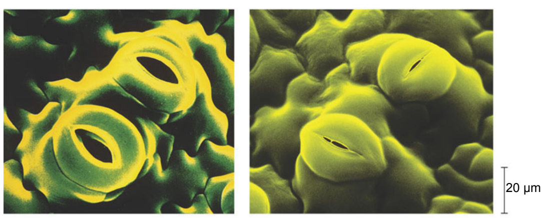


Figure 36.14

Effects of Transpiration on Wilting and Leaf Temperature

- Plants lose a large amount of water by transpiration
- If the lost water is not replaced by absorption through the roots
  - The plant will lose water and wilt

- Transpiration also results in evaporative cooling
  - Which can lower the temperature of a leaf and prevent the denaturation of various enzymes involved in photosynthesis and other metabolic processes

Stomata: Major Pathways for Water Loss

- About 90% of the water a plant loses
  - Escapes through stomata

- Each stoma is flanked by guard cells
  - Which control the diameter of the stoma by changing shape

(a) **Changes in guard cell shape and stomatal opening and closing (surface view).** Guard cells of a typical angiosperm are illustrated in their turgid (stoma open) and flaccid (stoma closed) states. The pair of guard cells buckle outward when turgid. Cellulose microfibrils in the walls resist stretching and compression in the direction parallel to the microfibrils. Thus, the radial orientation of the microfibrils causes the cells to increase in length more than width when turgor increases. The two guard cells are attached at their tips, so the increase in length causes buckling.

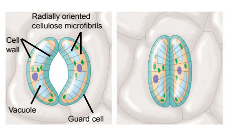


Figure 36.15a

- Changes in turgor pressure that open and close stomata
  - Result primarily from the reversible uptake and loss of potassium ions by the guard cells

(b) **Role of potassium in stomatal opening and closing.** The transport of K^+ (potassium ions, symbolized here as red dots) across the plasma membrane and vacuolar membrane causes the turgor changes of guard cells.

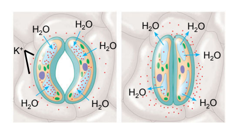


Figure 36.15b

Xerophyte Adaptations That Reduce Transpiration

- Xerophytes
  - Are plants adapted to arid climates
  - Have various leaf modifications that reduce the rate of transpiration

- The stomata of xerophytes
  - Are concentrated on the lower leaf surface
  - Are often located in depressions that shelter the pores from the dry wind

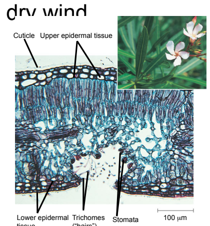


Figure 36.16

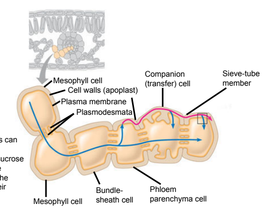
- Concept 36.5: Organic nutrients are translocated through the phloem
- Translocation
  - Is the transport of organic nutrients in the plant

Movement from Sugar Sources to Sugar Sinks

- Phloem sap
  - Is an aqueous solution that is mostly sucrose
  - Travels from a sugar source to a sugar sink

- A sugar source
  - Is a plant organ that is a net producer of sugar, such as mature leaves
- A sugar sink
  - Is an organ that is a net consumer or storer of sugar, such as a tuber or bulb

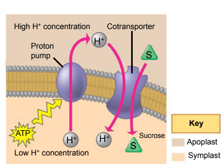
- Sugar must be loaded into sieve-tube members before being exposed to sinks
- In many plant species, sugar moves by symplastic and apoplastic pathways



(a) Sucrose manufactured in mesophyll cells can travel via the symplast (blue arrows) to sieve-tube members. In some species, sucrose exits the symplast (red arrow) near sieve tubes and is actively accumulated from the apoplast by sieve-tube members and their companion cells.

Figure 36.17a

- In many plants
  - Phloem loading requires active transport
- Proton pumping and cotransport of sucrose and H^+
  - Enable the cells to accumulate sucrose



(b) A chemiosmotic mechanism is responsible for the active transport of sucrose into companion cells and sieve-tube members. Proton pumps generate an H^+ gradient, which drives sucrose accumulation with the help of a cotransport protein that couples sucrose transport to the diffusion of H^+ back into the cell.

Figure 36.17b

Pressure Flow: The Mechanism of Translocation in Angiosperms

- In studying angiosperms
  - Researchers have concluded that sap moves through a sieve tube by bulk flow driven by positive pressure

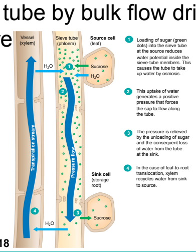
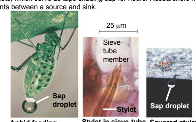


Figure 36.18

- The pressure flow hypothesis explains why phloem sap always flows from source to sink
- Experiments have built a strong case for pressure flow as the mechanism of translocation in angiosperms

EXPERIMENT To test the pressure flow hypothesis,researchers used aphids that feed on phloem sap. An aphid probes with a hypodermic-like mouthpart called a stylet that penetrates a sieve-tube member. As sieve-tube pressure force-feeds aphids, they can be severed from their stylets, which serve as taps exuding sap for hours. Researchers measured the flow and sugar concentration of sap from stylets at different points between a source and sink.



Aphid feeding | Stylet in sieve-tube member | Severed stylet exuding sap

RESULTS The closer the stylet was to a sugar source, the faster the sap flowed and the higher was its sugar concentration.

Figure 36.19 **CONCLUSION** The results of such experiments support the pressure flow hypothesis.