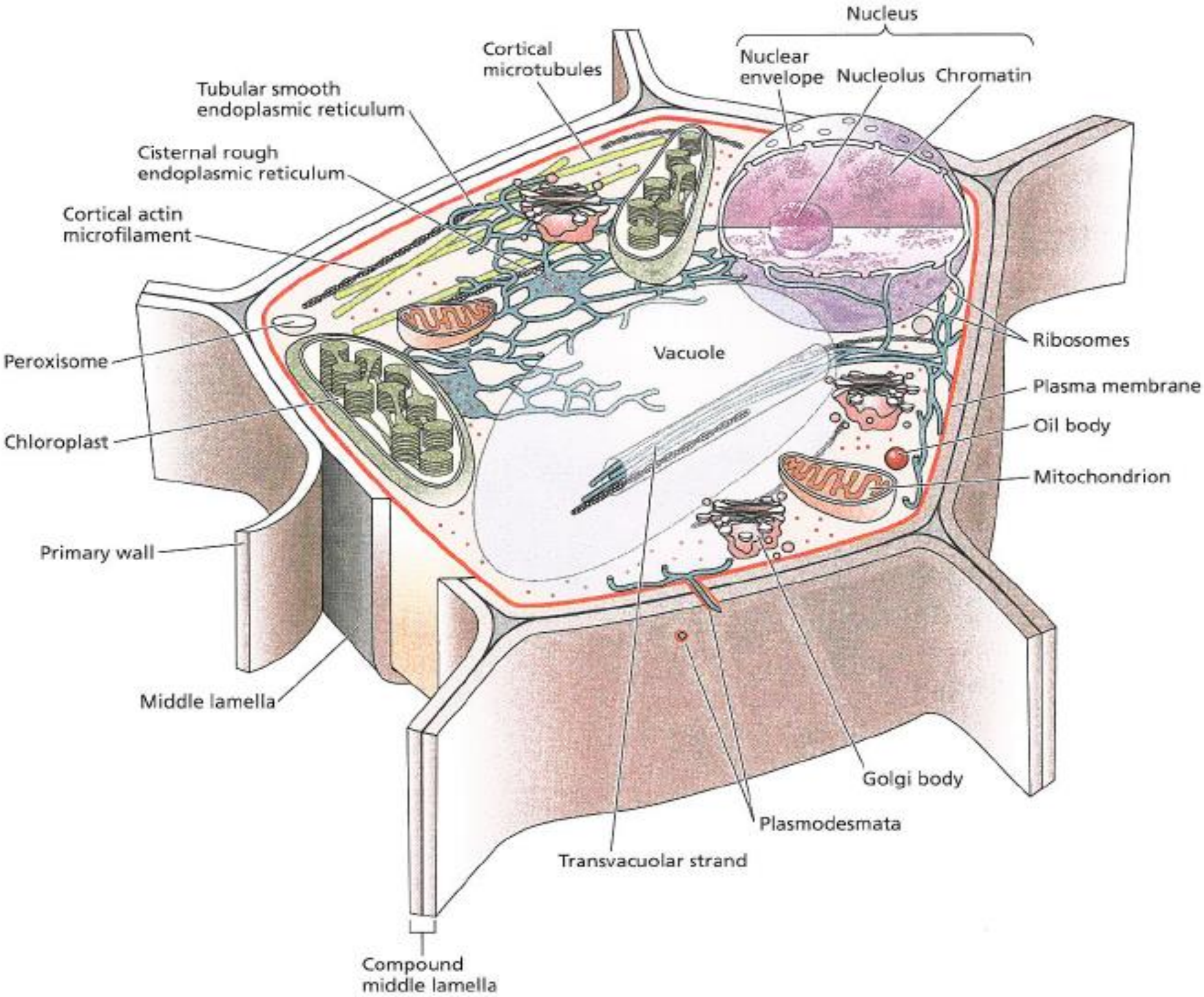
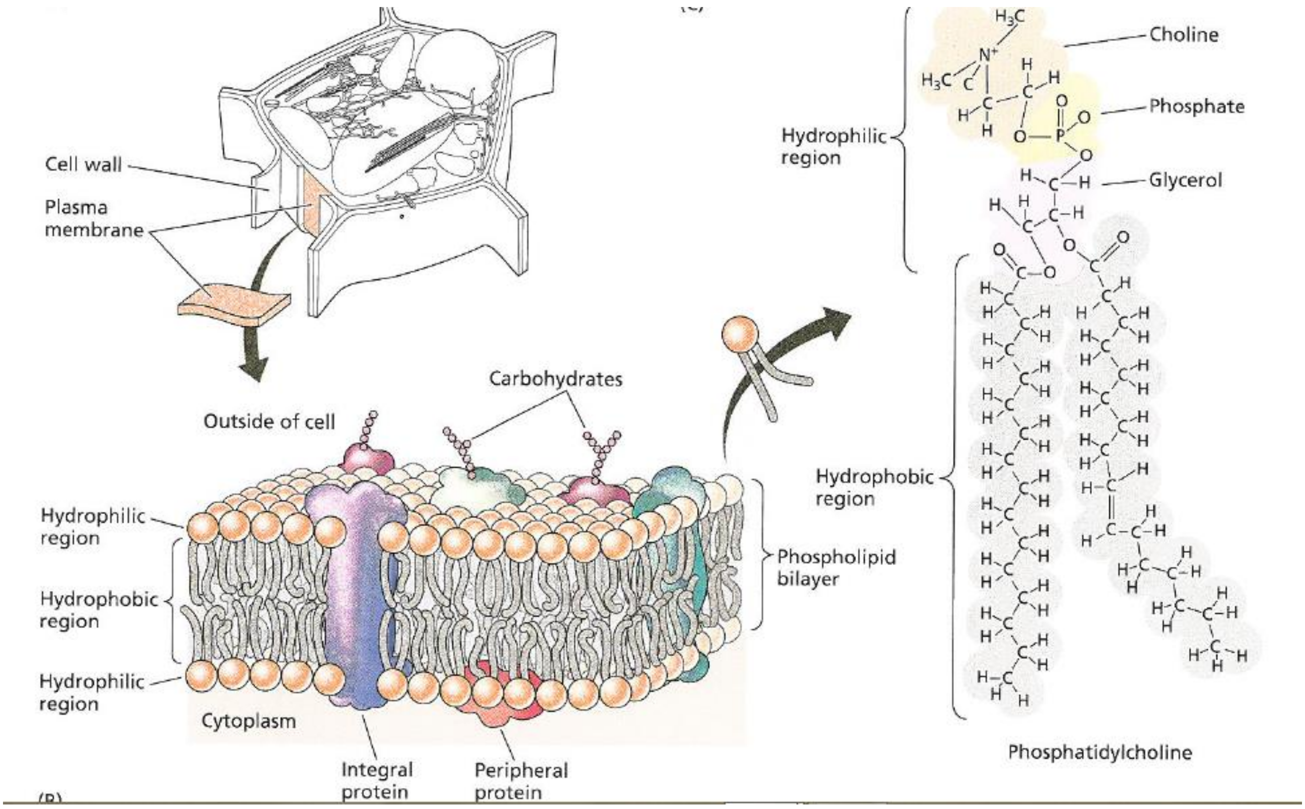
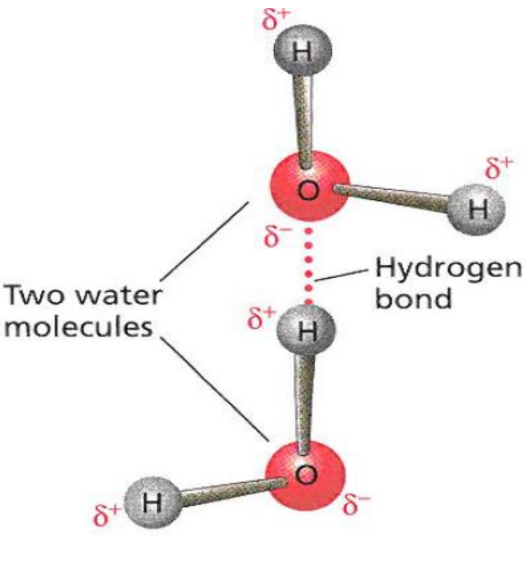
Plant Soil Water Relation

Major difference between plant and animal cell which has a great Influence on their water relations is presence of cell wall in plant cells



The **cell membrane**, also called the **plasma membrane**, is found in all **cells** and separates the interior of the **cell** from the outside environment. The **cell membrane** consists of a lipid bilayer that is semipermeable. The **cell membrane** regulates the transport of materials entering and exiting the **cell**.





WATER

It is the most abundant, yet limiting compound on earth

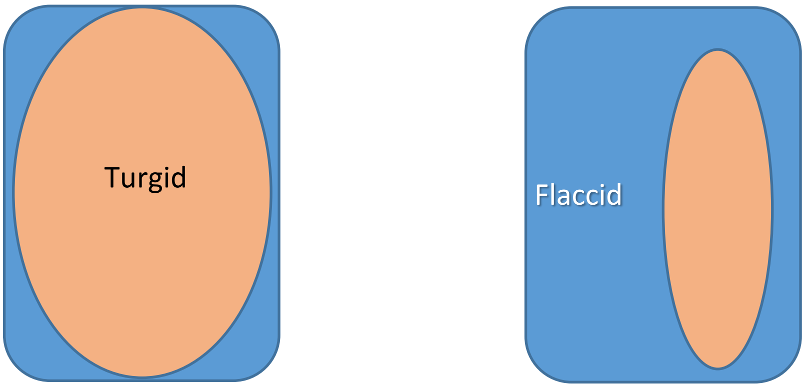
- 97% absorbed through roots is transported and evaporated
- 2% actually remains to supply for growth
- 1% consumed in biochemical reactions

PROPERTIES of Water

- Hydrogen bond
- Polarity (partial –ve and +ve charges, equal in magnitude)
- Excellent solvent (as compared to others), that is why called Universal Solvent (small molecule)
- High specific heat capacity (heat energy to raise the temperature)
- High latent heat of vaporization (liquid to vapour in transpiration)
- Surface tension (energy to increase the surface area of gas-liquid)
- Cohesion (mutual attraction between molecules)
- Adhesion (attraction of water to a solid)
- High tensile strength

WATER POTENTIAL

- Tendency of water to move from an area of high concentration to lower concentration
- Water potential is the sum of the pressure potential and the osmotic (or solute) potential **($\psi_\omega = \psi_p + \psi_s$)**
- A cell generating a positive hydrostatic pressure (turgor pressure) is turgid; one in which it is negative is flaccid
- Water Potential for pure water is Zero and for water with solute (a solution) is negative
- Water moves from high water potential to low water potential (zero to negative)



- The **chemical potential** of water is the amount of free energy (maximum amount of work done) associated with it.

- **Water potential** is defined as the chemical potential of water divided by the volume of a mole of water. It is measured in J m–3 or Pascals (Pa).
- The symbol used for water potential is ψ_ω
- It has two major components, **solute** or **osmotic potential**, ψs, and **pressure potential**, ψp, such that ψω = ψs + ψp.
- The solute or osmotic potential, ψs, is dependent on the solute concentration and the temperature.
- The pressure potential, ψp, is the hydrostatic pressure in excess of atmospheric pressure developed by the cell or tissue.
- Water moves from areas of high water potential to areas of low water potential (i.e. to areas where the solute concentration is higher and therefore the 'water concentration' is lower).
- Water entering a cell will result in an increase in volume. If the cell wall stops that volume increase, the **hydrostatic pressure** will increase. Eventually, the positive hydrostatic pressure equals the negative osmotic potential and the water potential of the cell reduces to zero (i.e. ψω = 0 on both sides of the membrane). At this point there is no net movement of water into or out of the cell

TRANSPIRATION

- Transpiration is the process of water movement through a plant and its evaporation from aerial parts especially from leaves but also from stems and flowers (small fraction)
- Evaporation of water from the leaves through stomata generates a low water potential and results in the movement of water from the soil through the root system and into the xylem
- Water is drawn upwards through the xylem by tension created by transpiration at the leaves
- Root pressure and capillary action also contribute
- Surfaces exposed to the air are generally covered with a layer which resists water loss (epidermal, cuticle, etc.)
- **Stomata** in the leaf surface permit water loss by evaporation from the leaf
- Most transpiration (90–95%) occurs through these pores. The rate of transpiration increases with <u>temperature</u> and with <u>wind speed</u>

- Changing the stomatal aperture varies the rate of water loss in changing environmental conditions

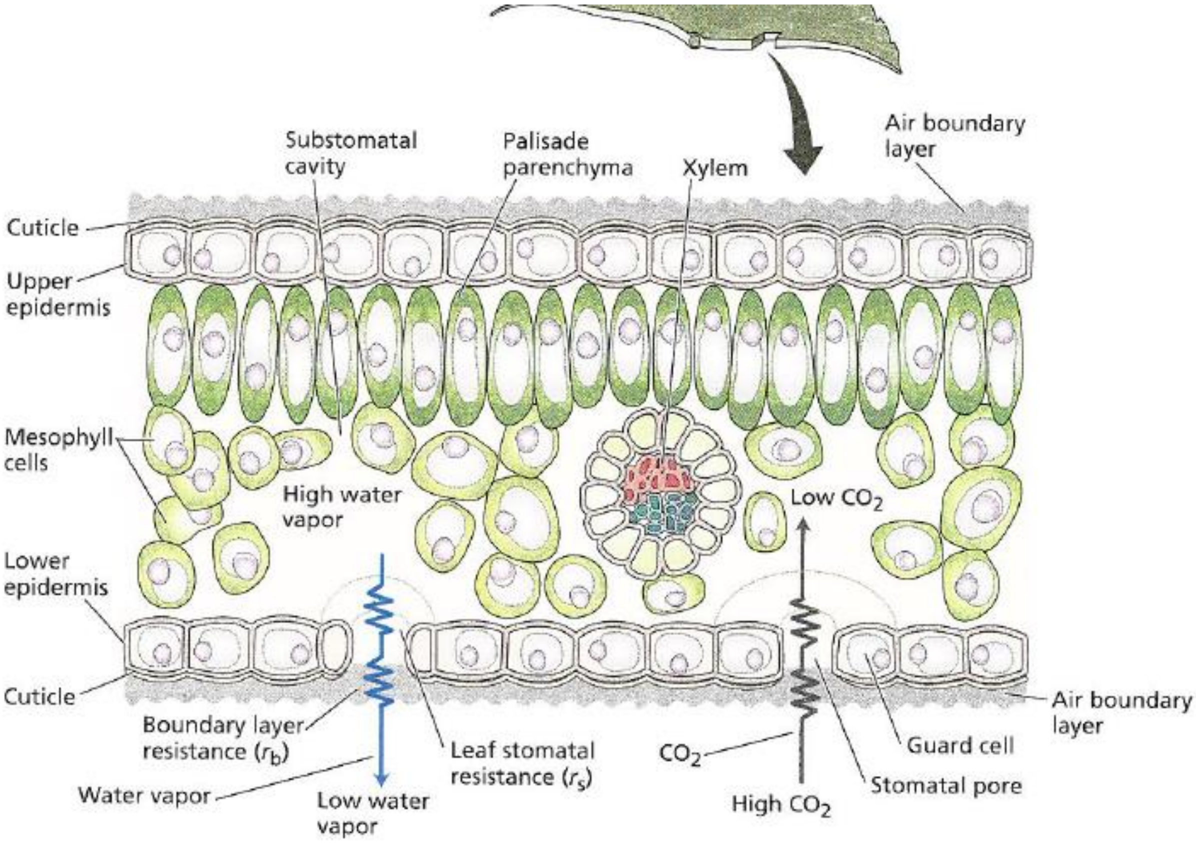


Figure 4.10 Water pathway through the leaf. Water is pulled from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces within the leaf. Water vapor then diffuses through the leaf air space, through the stomatal pore, and across the boundary layer of still air found next to the leaf surface. CO_2 diffuses in the opposite direction along its concentration gradient (low inside, higher outside).

The driving force for transpiration is the difference in water vapor concentration

Transpiration from the leaf depends on two major factors: (1) the **difference in water vapor concentration** between the leaf air spaces and the external bulk air (Δc_{wv}) and (2) the **diffusional resistance** (r) of this pathway. The difference in water vapor concentration is expressed as $c_{wv(leaf)} - c_{wv(air)}$. The water vapor concentration of air ($c_{wv[air]}$) can be readily measured, but that of the leaf ($c_{wv[leaf]}$) is more difficult to assess.

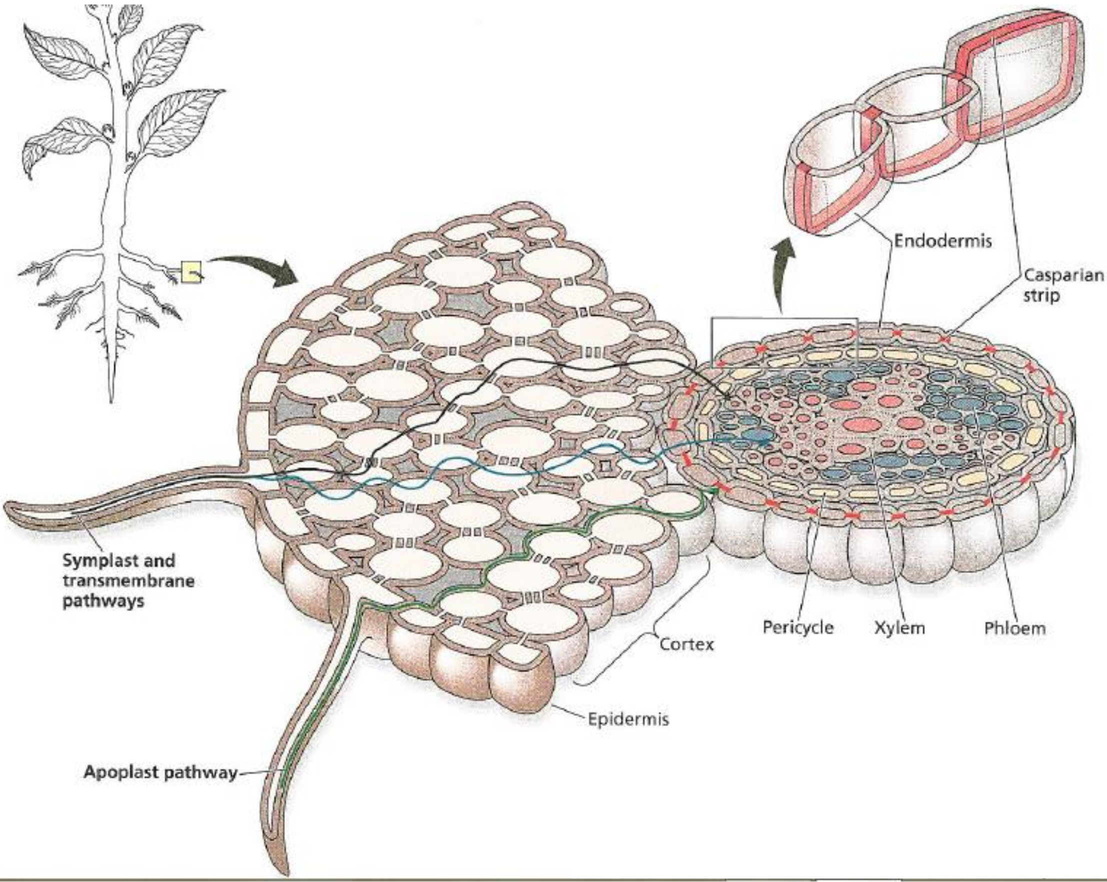
Root pressure is most likely to occur when soil water potentials are high and transpiration rates are low. As transpiration rates increase, water is transported through the plant and lost to the atmosphere so rapidly that a positive pressure resulting from ion uptake never develops in the xylem.

Plants that develop root pressure frequently produce liquid droplets on the edges of their leaves, a phenomenon known as **guttation** (Figure 4.5). Positive xylem pressure causes exudation of xylem sap through specialized pores called *hydathodes* that are associated with vein endings at the leaf margin. The "dewdrops" that can be seen on

WATER TRANSPORT IN ROOTS

- In most plants, water uptake occurs predominantly through **root hairs**, fine, extensions of single epidermal cells that enter the water film on soil particles
- They provide a very large surface area for absorption.

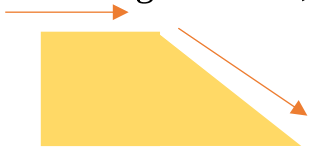
- Mycorrhizal fungi may also fulfil this function
- The internal anatomy of the root is also important. The xylem and endodermis (a water-impermeable cell layer with suberinized cell walls, through which water movement must be symplastic develops some distance behind the root tip.
- Water flows either through the cell wall spaces (the **apoplast**) or through the cell contents (the **symplast**). Water may be taken up from, or lost to, the apoplast by any cell in the pathway.
- Movement of a water molecule across the root involving both pathways is termed **transcellular transport**.
- Water enters the xylem as a result of the low water potential generated by the transpiration stream



DIFFUSION

- It is the net movement of substance (liquid or gas) from an area of higher concentration to lower.
- Water molecules are in constant random motion.
- **Diffusion** occurs when molecules migrate as a result of this motion.

- Molecules will move progressively from regions of high free energy (high concentration) to regions of low free energy (low concentration) down a concentration gradient.
- Diffusion may be considered important over short distances, for instance within a plant cell, but not over long distances, such as from soil to leaf



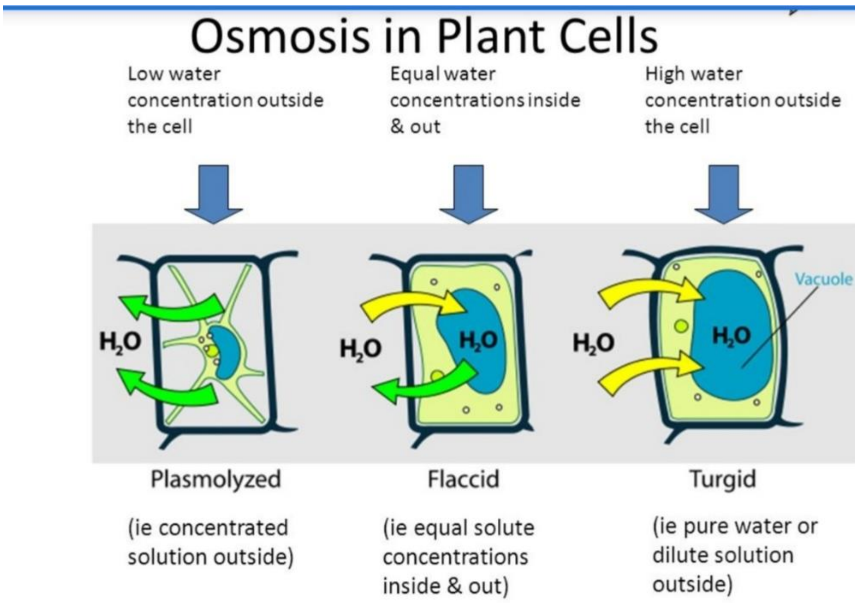
BULK/MASS FLOW

- Movement of water through xylem is largely by **bulk flow** that occurs as a response to a pressure gradient
- Fluid flow through a pipe depends on the <u>pressure gradient</u> between the ends of the pipe, the <u>radius of the pipe</u> and the <u>viscosity of the fluid</u>
- As the radius doubles, the flow rate increases by a factor of 2^4 =16. Therefore, flow in larger pipes can be much faster than in small ones.
- Larger pipes are much more susceptible to **embolism** and **cavitation**, the formation of air bubbles and the break-up of the water column.
- This occurs as the pressure gradient is provided by a tension, a force drawing from above, rather than a pressure below

Embolism: block due to gas bubble   Cavitation: break in the water column

OSMOSIS

Diffusion through a semi/selectively permeable membrane



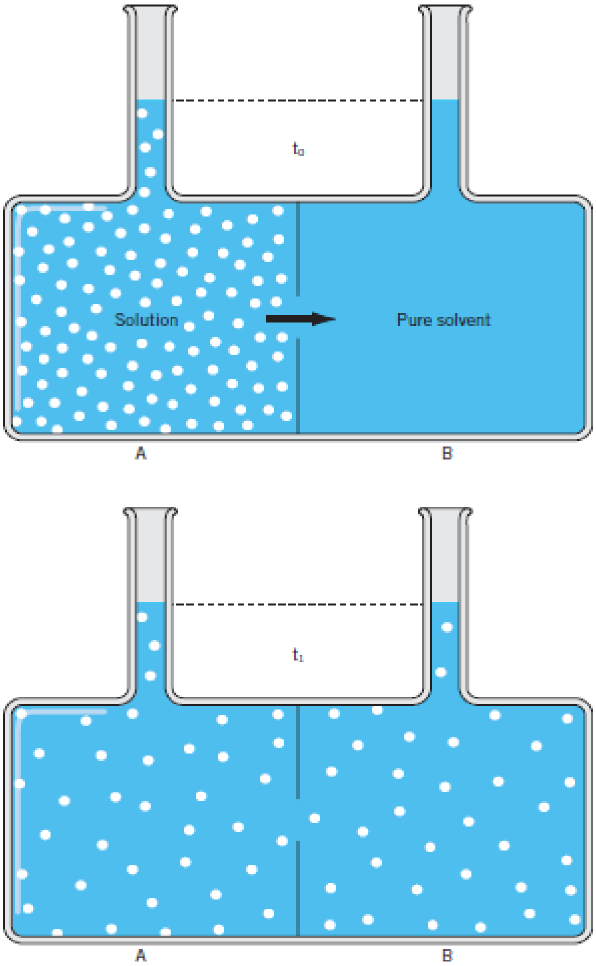


FIGURE 1.4 Diffusion in solutions is usually associated with the directed movement of a solute molecule from a region of high concentration to a region of lower concentration, due to the random thermal motion of the solute

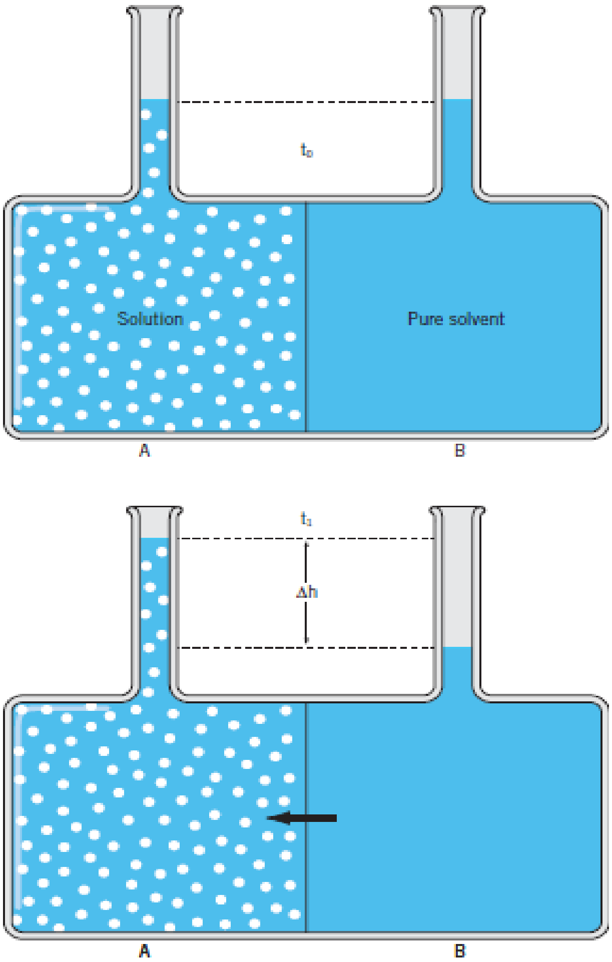


FIGURE 1.5 Osmosis is the directed movement of the solvent molecule (usually water) across a selectively permeable membrane. Chamber A is separated from chamber B by a selectively permeable membrane. The selectively permeable membrane allows the free movement of the solvent (water) molecules between chambers A and B.

TURGIDITY AND PLASMOLYSIS

- A cell in a **hypotonic** solution, i.e. one with a lower solute concentration and therefore a more positive osmotic potential than the cell cytoplasm will take up water, generating a **hydrostatic pressure** (**turgor pressure**) in the cell.
- In such a cell, the cell contents exert a pressure on the cell wall and the cell is turgid.
- A cell in a **hypertonic** solution (i.e. one with a higher solute concentration, and therefore a more negative osmotic potential than the cell cytoplasm) will tend to lose water, until the hydrostatic potential becomes negative.
- At this point, the plasma membrane will pull away from the cell wall and the cell will be **plasmolysed** (**flaccid**).

- The **point of incipient plasmolysis** occurs when the plasma membrane is in contact with the cell wall and just begins to move away from the cell wall, but no hydrostatic (turgor) pressure is generated; at this point, $\psi\omega = \psi s$ as $\psi p = 0$

XYLEM WATER FLOW

- The water-conducting tissue of the plant is the **xylem**. It is made up of **elongated cells** with walls thickened and strengthened by secondary wall deposits.
- Three possible driving forces exist for water flow in the xylem: **root pressure**, **capillary action** and **cohesion-tension** (in which a column of water is drawn up from the soil by forces generated by evaporation at the leaf surface)

ROOT PRESSURE/ ROOT PRESSURE THEORY

- When the stem of a plant is cut, xylem fluid often exudes from the cut. This exudation is driven by root pressure. It occurs where accumulated solutes in the xylem cause the influx of water into the xylem by osmosis. The suberized endodermal layer prevents back-flow of water and a hydrostatic pressure is generated, causing water movement.
- Root pressure is insufficient to explain water movement to the upper leaves of a tall tree and is not observed in all plants. It is therefore unlikely to be the major cause of xylem water flow.

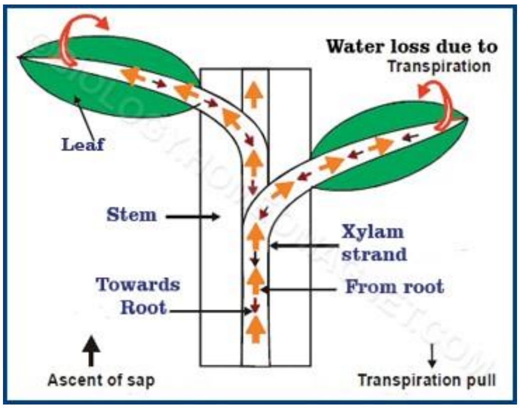
CAPILLARY ACTION

- Capillary action is generated by the adhesive forces between the surface tension in the meniscus of water and the wall of a tube.
- While capillary effects occur, the total rise of water achieved by capillaries of a diameter typical of xylem elements are less than a meter, insufficient to explain water transport to the top of a tall tree

COHESION, ADHESION, TENSION

- Cohesion-tension explains water flow through large plants.
- The driving force is provided at the leaf, where evaporation generates **tension** (negative pressure, or 'suction').
- This is particularly strong where the water surface bridges microscopic gaps, eg. at the junction of two mesophyll cells

- Evaporation from the surface of the leaf causes the water to retreat to microscopic pores in these cell wall junctions, where it adheres to hydrophilic wall components
- Cohesion of the water molecules (surface tension) results in the formation of a concave **meniscus**.
- This is pulled by adhesion and cohesion, of water molecules to the walls and of water molecules to each other, generating a negative pressure.
- The leaf water is in a continuous column running through the xylem to the root.
- The whole water column is therefore under tension and water is drawn upwards from the soil.
- A gas free water column can withstand a tension about 10 times this; however, the presence of dissolved gas greatly reduces this as **embolisms** (gas bubbles) form.
- Damage due to embolism is minimized as the xylem is divided into many small pipes, with interconnections via pits



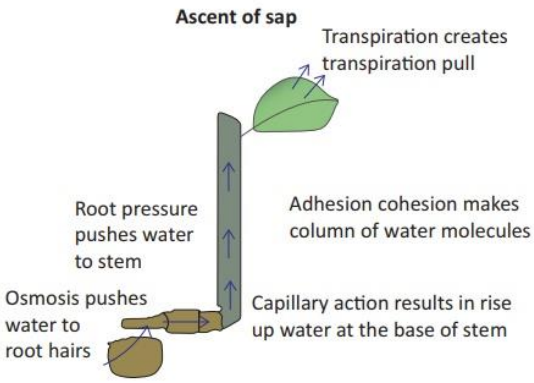
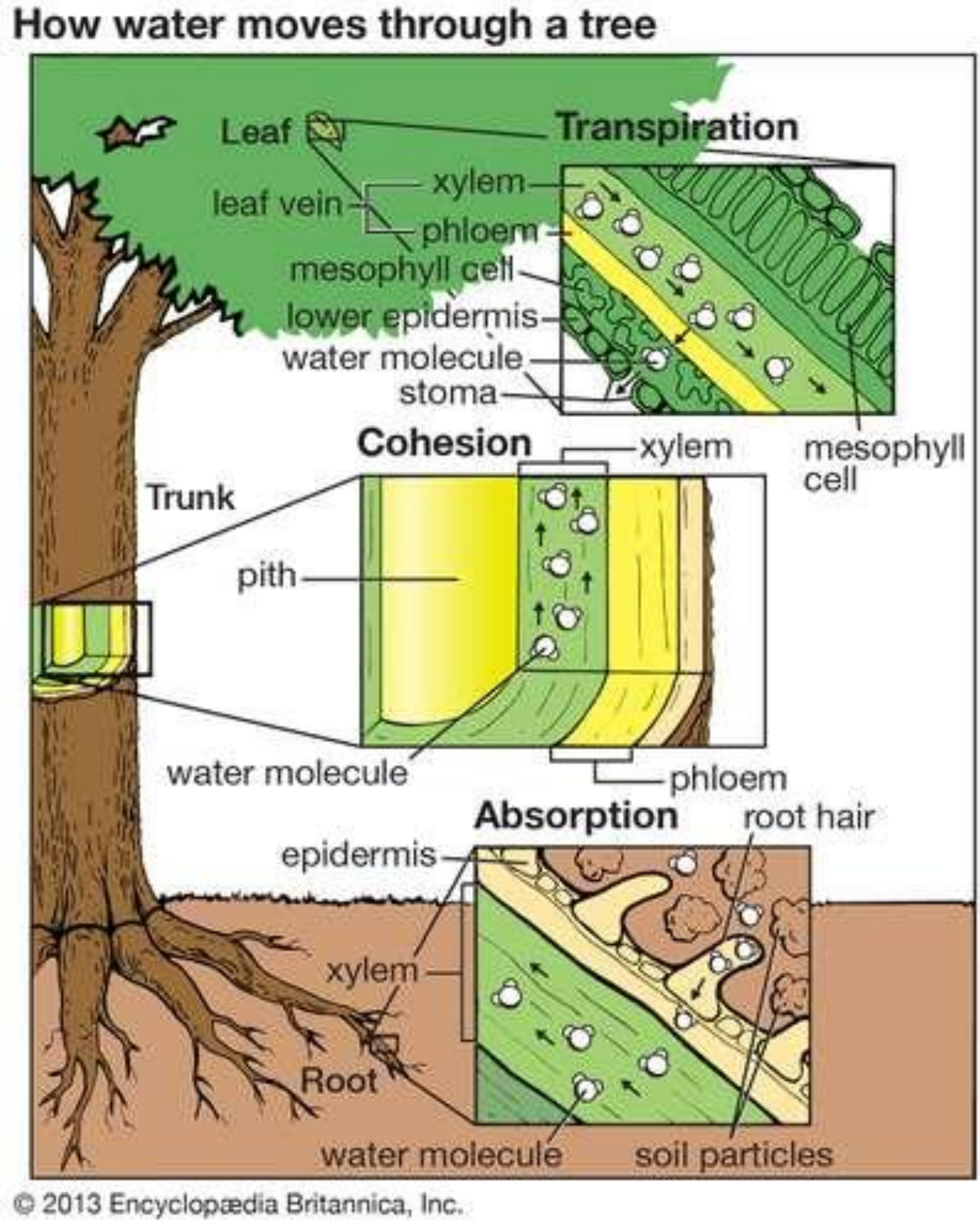


Figure 14.8 Ascent of Sap

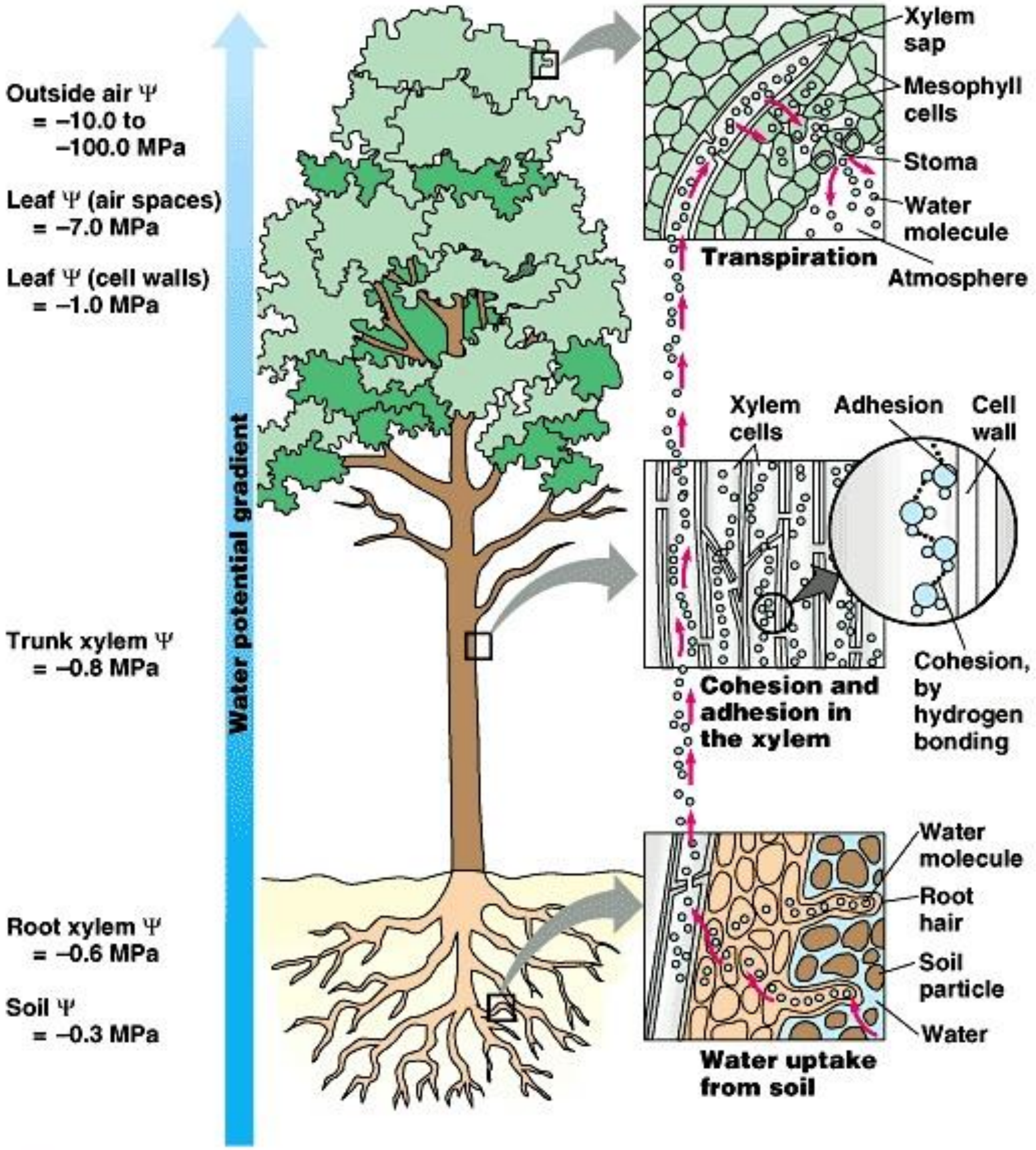
Source: https://www.brainkart.com/article/Ascent-of-Sap-and-its-Events---An-Overview_39732/
https://biology.homeomagnet.com/ascent-of-sap/

ASCENT OF SAP

The **ascent of sap** in the xylem tissue of plants is the upward movement of water and minerals from the root to the crown. Transpiration pull or tension, cohesion property of water, and hydration of the cell walls (i.e., adhesion) are collectively responsible for the **ascent of sap**.



Souurce: https://www.britannica.com/science/transpiration-pull



Source: https://www.bitlanders.com/blogs/how-transpiration-pull-occurs-in-plants/237102

Further Reading:

Fundamentals of Plant Physiology – V.K. Jain (S. Chand Publication)
Introduction to Plant Physiology – William G. Hopkins (John Wiley and Sons, Inc.)
Plant Physiology – Lincoln Taiz & Eduardo Zeiger 6th ed (Sinauer Associates, Inc.)

(The source of figures are the books mentioned above)