Plant and water relationships

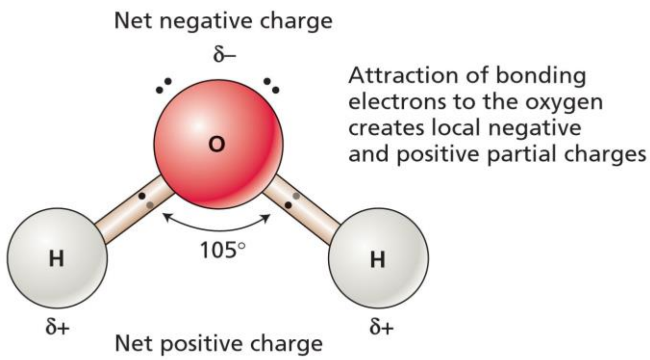
The Importance of Water in Plant Life.

- Water is the most abundant and best solvent known.
- Helps in movement of molecules within the cell.
- Influences structure of proteins, nucleic acids, polysaccharides etc.
- Forms environment in which most biochemical reactions of the cell occur.
- Directly participates in chemical reactions.
- Builds up hydrostatic pressures - turgor pressure - within the cell due to cell wall.
- Turgor pressure is important for cell enlargement, gas exchange, transport processes, rigidity and stability of non-lignified plant tissue.

Properties of Water.

Water is a polar molecule.

The Water Molecule



Because oxygen is more electronegative than hydrogen, it tends to attract the electrons of the covalent bond → polar molecule

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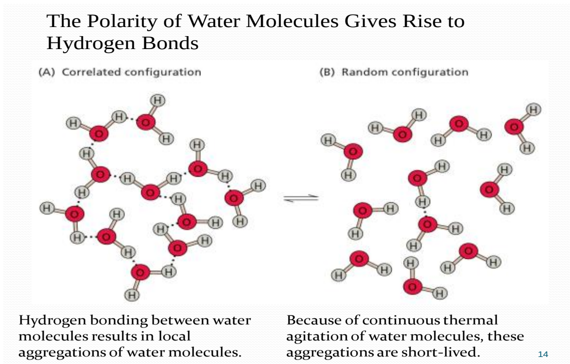
This electron distribution gives the central part of the water molecule a partial negative charge. The terminal hydrogen atoms thus have a partial positive charge. These partial charges of course mean that the hydrogen ends of one water molecule are attracted to the central oxygen portions of a neighboring water molecule. This kind of attraction is called **hydrogen bonding.**



Water is an excellent polar solvent.

The polarity of the water molecule gives it the ability to dissolve polar molecules as well as less-polar molecules. In fact, among known liquids, water dissolves the widest range of chemical solutes. This makes water a medium for chemical transport and exchange. For plants, water dissolves soil minerals and carries them up the plant in the transpiration stream in the xylem; photosynthesis produces carbohydrates which are dissolved in water and carried from the leaf to the rest of the plant in the translocation stream in the phloem. Solubility in water causes phospholipids to orient themselves into membrane bilayers, and causes amino acid R-groups to twist in space to bring about protein conformation.

Water is reactive.

Not only does water dissolve solutes, it serves as a medium for chemical reactions, and can react chemically with solutes. Groups of reactions in plant cells are named "hydrolysis" or "dehydration" reactions because of this chemical participation by water. Water is a reactant in photosynthesis ($CO_2 + H_2O + \text{light} \rightarrow O_2 + CH_2O$) and a product of respiration ($CH_2O + O_2 \rightarrow CO_2 + H_2O + \text{energy}$).

Water has high specific heat.

The polarity of water and the resulting hydrogen bonding among water molecules means that it takes much heat (one calorie) to raise the temperature of 1 ml of water just 1°C. The hydrogen bonding has to be given a lot of energy to get them to vibrate and generate the temperature change. This property of water is called specific heat. It means that this liquid can absorb much heat from the various chemical reactions occurs in cells without temperature change; it is a heat buffer. It helps maintain an even plant body temperature.

Water has a high latent heat of vaporization.

Among liquids, water has the highest latent heat of vaporization (44 kJ mol-1) which is also known as heat of fusion. This means that when water goes from liquid to gas it takes a lot of energy. This property can obviously be traced directly to hydrogen bonding again. As the highest energy molecules in the liquid achieve what it takes to move away as a gas, their energy is removed from the liquid and it gets cooler. We sometimes refer to this as evaporative cooling. This is a critical property in maintaining the temperature of dark green leaves essentially "parked" in sunshine. The water evaporating out of the stomata in the epidermis carries away the excess heat. The water is replaced by the transpiration stream in the xylem.

Water demonstrates adhesion and cohesion.

The partial polarity of the water molecule makes it attractive to polar and less-polar surfaces. Water adheres to and climbs up materials like glass (forming a meniscus). The fact that water molecules attract each other makes them cohesive. These two properties allow water to climb up small-diameter tubes and remain in an unbroken fluid column; this is called capillarity. The column of water will climb inside the small tube to a height determined by:

$$\text{Rise in m} = 14.9 \cdot 10\text{-}6 \text{ m2 (radius in m)}^{-1}$$

Obviously water will climb higher in tubes of smaller radius that those of larger radius. In addition to capillary climb, the water is pulled through the xylem by evaporation. This evaporative pull is the major force in movement to the top of tall trees. This is accomplished by capillary movement of water away from the xylem along tiny intercellular spaces. The water bathing the mesophyll cells occupies even smaller spaces among the cellulose and hemicellulose polymers of the cell wall. These are in the range of 10-8m in radius. The evaporative pull is achieved in large part by capillarity of the very tiny cell wall spaces.

The cohesion of water molecules to each other relative to the much less polar N_2 and O_2 of air or other surfaces leads to the property called **surface tension**.

Water has high tensile strength.

The cohesive property of water keeps the column of water in the xylem unbroken all the way up to the top of a tree. A failure to do this would produce cavitations in the xylem and this would stop all flow of water up the tree in that column of xylem elements.

Water is not compressible.

While gases can be compressed into smaller and smaller spaces, liquid water is not so compressible. Thus compression of water into a space surrounded by a cell wall produces **turgor pressure**. This form of hydraulic pressure is critical for cell growth, for the opening and closing of stomata, flow processes in translocation in the phloem, exchange of materials within and between cell compartments, and for the rigidity and support for herbaceous (not supported by lignin in wood) plants. Turgor keeps petals and leaves extended into the air and prevent wilting.

Water is commonly available.

Because of the water cycle, rainfall and ground water are linked through the transpiration and evaporation from plants. Water is a free medium for cell and body enlargement. Vacuole water provides up to 90% of the volume of a cell. Perhaps 5% more is found in the water of the cytosol. This very high water content of plant cells makes plants excellent "diet food."

Water can be limiting to growth.

While water is often commonly available, water can be insufficient during important times in the life of a plant. A drought is common in late summer and can reduce the yield of crop plants quite significantly. Because plants need water for photosynthesis, for evaporative cooling, and a host of other uses, they can run through a staggering amount of water. On a warm, dry, sunny day a plant can lose 100% of its water content in one hour! This all has to be replaced from the soil at these rates to keep up with the water demand.

Membranes.

Permeability is different among membranes, and could be classified into three types according to permeability as follows:-

1. Impermeable membranes:- includes those that do not allow any particles to pass through them. e.g. glass.
2. Differentially permeable:- such as cellophane, where the membranes may allow some substances to pass, but not the others according to the size of molecules.
3. Semi permeable membranes:- these membranes are the most important in plant since most of the membranes inside the cells are of this kind e.g. plasmalema and tonoplast. They are selective for molecules that pass through them.
   Permeability is a characteristic of the membrane, but not of the substances that passes through it.

Water Transport Processes.

Water Movement:- There are two major ways to move molecules:-

A. Bulk (or Mass) Flow.

This is the mass movement of molecules in response to a pressure gradient. The molecules move from hi → low pressure, following a pressure gradient. A good example would be a faucet. When you turn a faucet on, water comes out. This occurs because the water in the tap is under pressure relative to the air outside the faucet. Some molecular movements rely on bulk flow which requires a mechanism to generate the pressure gradient. For example, animals have evolved a pump (i.e., heart) that is designed for the bulk flow of molecules through the circulatory system.

B. Diffusion.

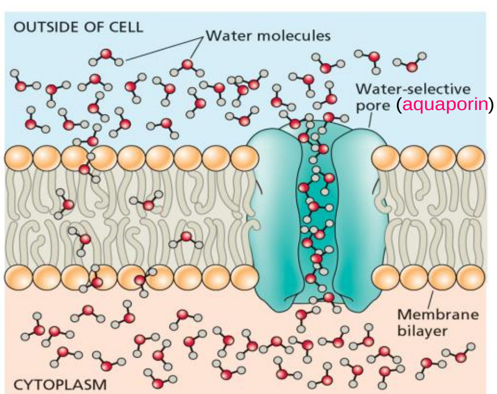
The net, random movement of individual molecules from one area to another. The molecules move from [hi] → [low], following a concentration gradient. Another way of stating this is that the molecules move from an area of high free energy (higher concentration) to one of low free energy (lower concentration).

Aquaporins in all living cell are a serious proteins which located in plasmatic membrane or tonoplast, and play an important role in water transmembrane transport because they have less resistance to water and speed up water transport across the membrane. About 80% of water entrance is controlled by aquaporins.

C. Osmosis.

This is a specialized case of diffusion; it represents the diffusion of a solvent (typically water) across a membrane.

Diffusion of Water through the Plasma Membrane



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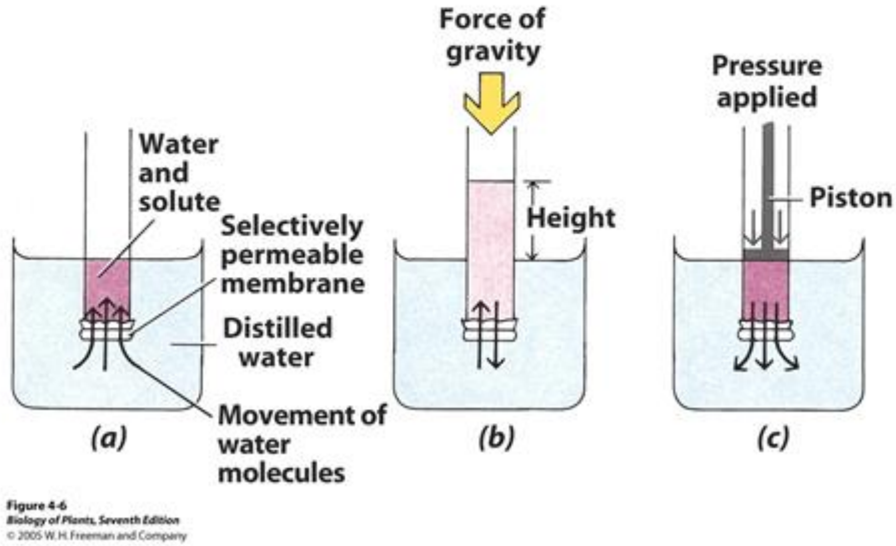

D. Dialysis.

Another specialized case of diffusion; it is the diffusion of solute across a semi-permeable membrane. Example – consider a cell containing a sugar dissolved in water. If water (the solvent) moves out of the cell into the surroundings it moves osmotically; if the sugar (solute) moves into the surroundings, it is an example of dialysis.

Water flow is a passive process, i.e. water moves in response to physical forces, toward regions of low water potential or low free energy. There are no metabolic pumps (driven by ATP hydrolysis) that push water from one place to another (if water is the only substance being transported). When solutes are transported, water transported may be coupled, i.e. water is moved against a water potential gradient.

Factors influencing the rate of diffusion.

Several factors influence the rate of diffusion. These include:-

A. Concentration Gradient: - As previously stated, solutes move from an area of high concentration to one of lower concentration; in other words, in response to a concentration gradient (ΔC). Although this is true for most solutes, it is NOT important for water. The concentration of water (55.2 - 55.5 mol L^{-1}) is nearly constant under all conditions (i.e., MW = 18 g/mol, and 1000 g/liter; thus, 1000/18 = 55.5 mol/L).

B. Molecular Speed:- According to kinetic theory, particles like atoms and molecules are in always in motion at temperatures above absolute zero (0 K = -273ºC). The take-home-lesson is that molecular movement is:-

1. directly proportional to temperature; and
2. Indirectly related to molecular weight (heavier particles move more slowly than lighter, smaller ones). At room temperature, the average velocity of a molecule is fast - about 2 km/sec (=3997 mph!).

C. Temperature: - Increases the rate of molecular movement, therefore, increases the rate of diffusion.

D. Pressure: - increases pressure of molecules, therefore, increase the rate of diffusion.

E. Solute effect on the chemical potential of the solvent: - Solute particles decrease the free energy of a solvent. The critical factor is the number of particles, not charge or particle size. Essentially solvent molecules, such as water in a biological system, move from a region of greater mole fraction to a region where it has a lower mole fraction. The mole fraction of solvent = # solvent molecules/ total (# solvent molecules + # solute molecules). This is particularly important in the movement of water. Water moves from an area of higher mole fraction or higher energy to an area of lower mole fraction or lower energy.