Lecture 1
Water & Plant Relation

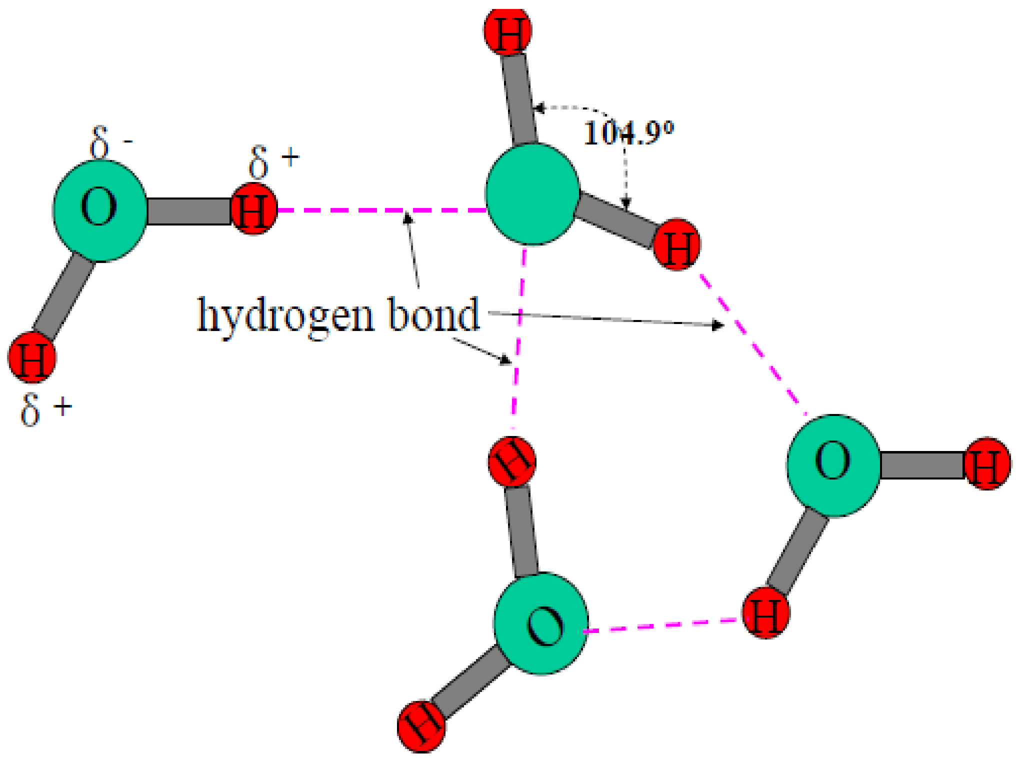
The Role of Water in Plant Life:

1. Component of protoplasm, Water comprise 85-95% of vegetables, 35-75% of wood, 5-15% of seed. 500g of water /g of organic matter made.
2. Substrate for plant metabolism.
3. Solvents for plant absorption and transportation.
4. Keeping plant in shape (extension).
5. Balance plant temperature.
6. Plant movements are the result of water moving into and out of those parts (*i.e.,* stomatal opening, flower opening).

Physical and chemical properties of water

- **Water is Polar**: The water molecule has a positively-charged (hydrogen side) and negatively-charged side (oxygen).

- **Hydrogen Bonds**: It is a weak bond that forms between a hydrogen atom that is covalently bonded to an electronegative atom (oxygen).



Water molecule

- ***A. Water is a liquid at physiological temperatures*** **(between 0-100 °C)**: Water has a high boiling point and a high melting point when compared to other similar-sized molecules such as ammonia, carbon dioxide, hydrogen sulfide.

- ***B. Water has a high heat of vaporization:*** it takes a lot of energy (44 kJ mol^{-1}) to convert water from a liquid to a gas; or stated another way*, Water resists evaporation.* This property is responsible for water's use in **evaporative cooling** systems.

- ***C. Water has a high specific heat (heat capacity)***:

It takes a lot of energy (4.184 J g^{-1} C^{-1}, or 1 cal = 4.184 J) to raise the temperature of water (because it requires a lot of energy to break/make hydrogen bonds).

- ***D. Water has a high heat of fusion***: It takes a lot of energy to convert water from a solid to a liquid, or put another way*, water resists freezing*. Conversely, a lot of energy (6 kJ mol^{-1}) must be released by water to freeze.

- ***E. Water has a high surface tension***: It takes a lot of energy to break through the surface of water, because water molecules at the surface are attracted (cohesion) to others within the liquid much more than they are to air.

  (1) Water rises up a thin tube (capillary action).

  (2) Raindrops are round (the molecules at the surface attract one another).

- ***F. Water is a universal solvent***: Water dissolves more different kinds of molecules than any other solvent. Hydrophilic (water-loving) molecules dissolve readily in water (likes dissolve likes), hydrophobic (water-fearing) ones do not.

- ***H. Water has high tensile strength and incompressibility***: water is good for hydraulic systems because when it is squeezed it does not compress and produces positive pressures (hydrostatic pressures). This pressure provides the driving force for cell growth and other plant movements.

- ***I. Water is transparent to light***: This is important because chloroplasts (inside a cell) are obviously surrounded by water. If water were opaque, plants couldn't photosynthesize.

- ***J. Water is chemically inert***: It does not react unless it is enzymatically designed to do so.

- ***K. Water dissociates into protons and hydroxide ions***: This serves as the basis for the pH system.

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Mechanisms of water movement

The actual movement is the result of two processes: diffusion and bulk flow.

A membrane is the thickness of a phospholipid bilayer. This would be largely a diffusion movement subject to Fick's Law. The membrane also possesses integral proteins; the one involved with water transport is called an aquaporin. The aquaporin protein serves as a water-filled pipe across the membrane.

- **A. Diffusion**:

The net, random movement of individual molecules from one area to another. The molecules move from [hi] → [low], following a concentration gradient. from an area of high free energy (higher concentration) to one of low free energy (lower concentration). The net movement stops when a dynamic equilibrium is achieved. so diffusion is passive movement of any material from an area of higher concentration to an area of lower concentration. For a cell: The rate of movement in diffusion is shown by Fick's Law:

$$J_s = -D_s \bullet \Delta C_s / \Delta x$$

J_s is the rate of movement or flux density usually measured as the moles of substances crossing a square meter of area per second.

- D_s is the diffusion coefficient indicating how easily substances moves through the medium. If the medium is air, then the coefficient is high and movement is rapid. In liquid, the coefficient is low and movement is slow by comparison.
- The negative sign indicates that the movement is from the area of high to the area of low concentration.
- ΔC_s is the concentration difference between the area of high and area of low concentration.
- Δx is the distance between the areas of high and low concentration.

Factors influencing the rate of diffusion

- ***1. Concentration Gradient***: solutes move from an area of high concentration to one of lower concentration; in other words, in response to a concentration gradient (ΔC).
- **2. *Molecular Speed***: It related to molecular weight (heavier particles move more slowly than lighter, smaller ones).
- ***3. Temperature:*** Directly proportional to temperature
- ***4. Pressure***: increases in pressure, therefore, increase the rate of diffusion

- ***5. The mole fraction***

Solute particles decrease the free energy of a solvent. The critical factor is the number of particles, not charge or particle size. Water move from a region of greater mole fraction to a region of lower mole fraction.

The mole fraction of solvent = # solvent molecules/ total (# solvent molecules + # solute molecules).

Diffusion works only over short distances

If we think about sucrose, the transport form of photosynthate in plants, moving in a plant by diffusion, the distance must be very short.

For sucrose the Ds is $0.5 \times 10^{-9} m^2 s^{-1}$, the diameter of a cell is 50 µm (= 50×10^{-6}m)...

Some algebra applied to Fick's law gives us:

$t = x^2 \times Ds^{-1}$

Now we plug in the values above:

$t = (50 \times 10^{-6} m)^2 \times (0.5 \times 10^{-9} m^2 s^{-1})^{-1} = 5$ seconds

So diffusion can explain a rate of movement for a sucrose molecule across a cell.

But diffusion will fail to explain movement when the distance gets larger:

imagine sucrose made in the tip of a sugar cane leaf diffusing to the base of that leaf. That distance is about 1 meter. When you plug 1 meter in for the distance in the formula above, the time calculates out to 63.42 years. So diffusion is too slow to explain how sucrose gets out of a sugar cane leaf.

- **B. Osmosis**: This is a specialized case of diffusion; it represents the diffusion of a solvent (typically water) across a membrane.
- **C. Dialysis**: Another specialized case of diffusion; it is the diffusion of solute across a semi-permeable membrane.
- **D. 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. Bulk flow subject to Poiseuille's Equation
- ***Bulk flow explains long-distance water movement***

Bulk flow is the movement of a substance under influence of pressure from an area of greater pressure to an area of lesser pressure. Rather than individual molecules moving on the basis of their own kinetic energy, large volumes of molecules move together in bulk. The rate of bulk flow is shown in the Poiseuille Equation:

$$\text{Flow} = \pi r^4 (8\eta)^{-1} \bullet \Delta\Psi p \, \Delta x^{-1}$$

$\pi = 3.14$

r= radius of the pipe

η (poise)= fluid viscosity

Ψ (psi)= potential

Ψ_p= pressure potential

P= pressure

x= distance

- The rate of flow is proportional to the fourth power of the radius (r) of the pipe (channel, etc.). Increasing the pipe radius by a factor of two will increase the flow rate by a factor of 16.
- The rate of flow is inversely proportional to 8 times the viscosity of the fluid (8η).
- The rate of flow is directly related to the pressure difference between the ends of the pipe.
- You should notice that the solute concentration has no effect on bulk flow.
- Bulk flow work in phloem and xylem as these are basically pipes.