ion) concentration (higher P_o) to a zone of high solute concentration (lower P_o) - thus from + to -

2.) As water is drawn into the plant root cells, again in response to osmotic forces across a semi-permeable membrane which will allow the passage of water but will only pass nutrient ions selectively, the solute concentration outside the root remains at a relatively high level

i. Water flow through a plant system functions in a way similar to that in soils and some of the same potentials and gradients are involved here as well, the principal components are:

$$P_{pl} = P_o + P_p + P_g + P_t + P_m$$

where P_{pl} is the total plant potential, and the other potentials are as previously defined - although the processes are somewhat different

1.) Thermal Potential, P_t, is ignored since the plants are considered to be isothermal

2.) Matric Potential, P_m, exists in, on and between plant cells (adsorption and capillarity) but is not important relative to other potentials

3.) Osmotic Potential, again, is a negative (suction) potential.

   a.) Solutes in plant cells decrease the osmotic potential causing a movement from a zone of higher total potential (in the soil water for instance) into the cell (root cell for instance)

   b.) Water similarly moves from cell to cell or from intercellular space into cells within the plant in response to solute concentration and, therefore, osmotic potential differences

   c.) Photosynthesis within the leaf enriches these cells with solutes and the osmotic potential decreases to maintain the suction gradient pulling some water from the roots to the leaf cells and evaporation site within the stomatal openings

4.) As water moves into the cell in response to osmotic potential differences, the internal pressure increases.

a.) This internal pressure buildup causes the cell to inflate

b.) This internal positive pressure resists further water uptake

c.) This is called turgor pressure, P_{tu}

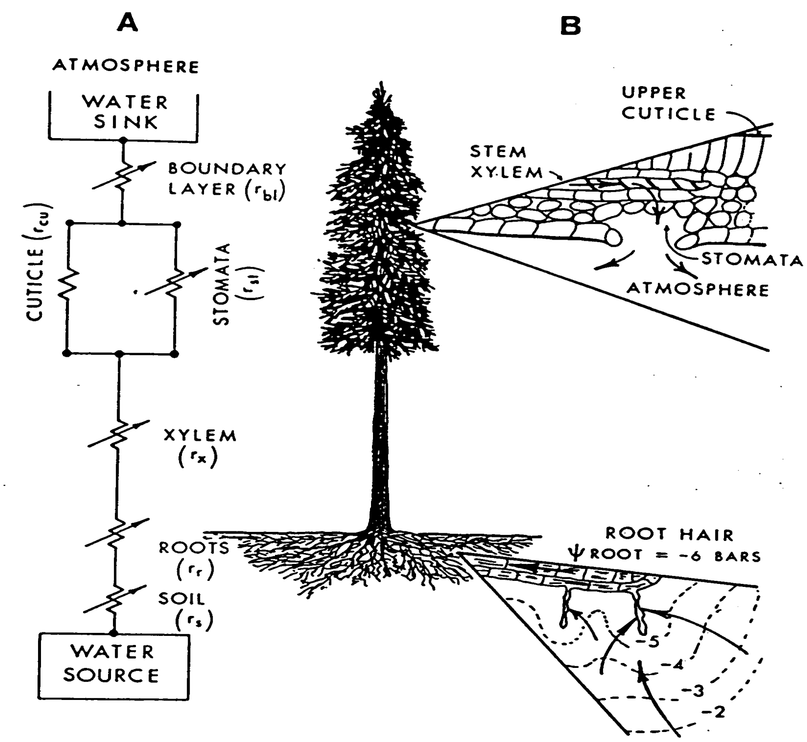
$$P_p = P_{tu}$$

5.) The total cell plant potential, P_{pl}, can be expressed as the difference between these two opposing forces, osmotic pressure, P_o (-), and turgor pressure, P_{tu} (+)

$$P_{pl} = P_{tu} - P_o$$

a.) The turgor pressure in the roots (+) helps to push water up the xylem from below (guttation)

b.) Osmotic suction pressure (-) in the leaves pulls water upward



A representation of soil-plant-atmosphere resistances to water flow (A) and corresponding flow through roots and leaves (B) (adapted from Rose 1966, © Pergamon Books Ltd., by permission). Flow of water can be described by $v = \Delta\psi/r$, analagous to Ohm's Law.

6.) The flow rate through the plant, q in cm^3/sec, is

$$q = -A(dP_{pl} / r_{pl})$$

where A is the cross-sectional area through which the water passes in cm^2, dP_{pl} is the difference in plant water potential, and r_{pl} is the resistance to flow in sec/cm

$$P_{pl} = P_o + P_p + \underline{P}_g + P_t + P_m$$

7.) Transpiration at the top of the plant also helps to maintain the total plant potential gradient by removing water from the stomatal openings thereby lowering the pressure potential

8.) Gravity Potential, P_g is a positive force resisting water movement to the evaporation site in the leaves

   a.) With most vegetation gravity potential does not play a significant role in water movement within the plant

   b.) However, it does become an important force resisting water uptake and transpiration from large trees

   c.) For instance, 0.3 bar / m of tree height must be overcome to move water from the bottom to the top of the tree for

transpiration to occur

j. **In summary:**

In order for water to move up to the site of evaporation, there must be enough negative potential (mainly osmotic pressure) in the leaves coupled with any positive potential in the soil (mainly pressure potential) and in the roots (mainly pressure potential and turgor pressure) to overcome the positive potentials in the leaves (mainly cell turgor pressure, gravity potential, and pressure potential) and the negative potentials in the soil (matric potential) and in the roots (mainly osmotic)

k. **Once the water is in the stomates at the active surface at the top of the crown and energy is supplied to convert the liquid water to vapor (540 to 600 cal/gm), the evapotranspiration process can take place**

1.) Individual water molecules which have freed themselves of the water surface by acquiring kinetic energy (latent heat) must diffuse across a thin boundary layer

- **a.) The boundary layer may be 1 mm thick or less**
- **b.) Water vapor molecules follow the basic laws of diffusion, moving from a region of high concentration and vapor pressure (the water surface) to a region of lower concentration and vapor pressure (in the atmosphere)**

2.) Once this boundary layer is crossed, vapor transport away from the surface (evaporation) goes on via the mass transport convection process

- **a.) Convection upward from the boundary layer helps to maintain the vapor pressure diffusion gradient in the boundary layer**
- **b.) This process is sometimes described empirically for a free water surface by the following:**

$$E_o = N(e_s - e_a) f(u)$$

where E_o is the evaporation from a water body, N is a mass transfer coefficient determined empirically, $(e_s - e_a)$ is the difference in vapor pressure between the surface and the air, and f(u) is a function of wind speed

c.) This simple model may be useful in describing the evaporation of intercepted water but would be inadequate to use with the more complex transpiration process

d.) The rate of evaporation of intercepted water may therefore be several times that of transpirational losses

e.) Indeed, part of the energy going into the evaporation of intercepted water may actually reduce that available for transpiration resulting in a possible soil moisture savings

f.) Therefore, interception may not be a total watershed loss in the true sense

3.) Sensible heat is transferred across the surface - air boundary layer by the process of conduction before the convection process takes over

4.) Remember, when we talked about the convective heat transfer process we said that the rate of convection was directly proportional to the gradients of temperature, vapor pressure, and wind speed

5.) This relationship where the convection rate can be defined as

$$C_v = f\ (dt, de, du\ /\ dx)$$

operates above the active surface

I. When the plant - soil system is added in the transpiration process, additional resistances must be considered which make things much more complicated

1.) The gradient controlling the ET process found in many process models is

$$ET = vpd / R_v$$

where vpd is the difference in vapor pressure or gradient above the surface and R_v includes all the resistances between the soil and the atmosphere above the boundary layer

2.) These resistances include: resistances for the turbulent transfer layer, r_e, and the boundary layer, r_{bl}, the two internal air filled pore sites in the soil, r_s, and in the stomates, r_{st}, and the resistance imparted by the leaf cuticles, r_{cu}, when water takes this more difficult pathway

   a.) The magnitude of these resistances tends to change as environmental conditions vary

   b.) As turbulent transfer increases, the both convection and boundary layer resistances are reduced helping to maintain the air-plant-soil gradient

   c.) As soil moisture varies, the amount of air-filled pore space changes

d.) As the guard cells open and close the stomata in response to water uptake and photosynthesis and respiration, this resistance becomes the most important factor in regulating transpiration