Energy is the driving force for the universe

Energy ➡ Physiological Processes ➡ Plant Growth.

Potential energy and Kinetic energy

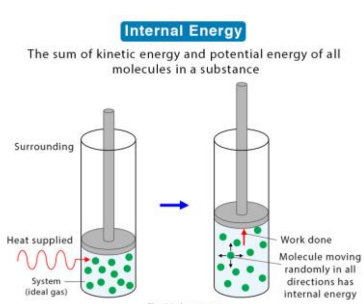
- **Potential energy** is a form of energy that has the potential to do work but is not actively doing work or applying any force on any other objects. Potential energy of an object is found in **its position**, **not its motion**. It is the **energy of position**.

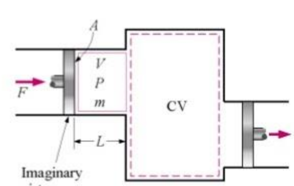
- **Kinetic energy** is the energy of motion. When work is done on an object and it accelerates, it increases the kinetic energy of an object. The most important factors that determine kinetic energy is the motion .

(Kinetic energy is created when potential energy is released)

- **Internal energy** is the sum of potential energy of the system and the system's kinetic energy.

- **Flow energy** is the energy required to push the mass into or out of the control volume. It is also called flow work.



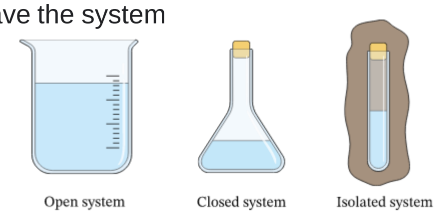


Thermodynamic systems

1. **An open system** does allow both matter and energy to enter or leave the system.

2. **A closed system** does not allow matter to enter or leave, but does allow energy to enter or leave the system .

3. **An Isolated system** does not allow both the matter and the energy to enter or leave the system

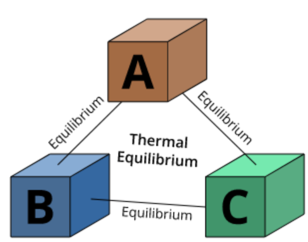


Energy is the driving force for the universe

Energy flow in universe is controlled by the laws of thermodynamics.

Laws of thermodynamics:-

0th low :- The zeroth law of thermodynamics states that if two systems are in thermodynamic equilibrium with a third system, the two original systems are in thermal equilibrium with each other.



Zeroth law of Thermodynamics

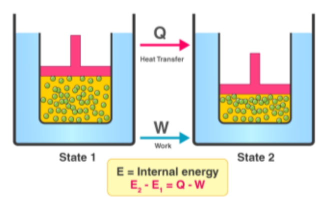
1st law:-The law of conservation of energy states that the total energy of an isolated system is constant; energy can be transformed from one form to another, but cannot be created or destroyed.

"You can't get something for nothing"

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

$$\Delta U = Q - W$$

Change in internal energy | Heat added to the system | Work done by the system



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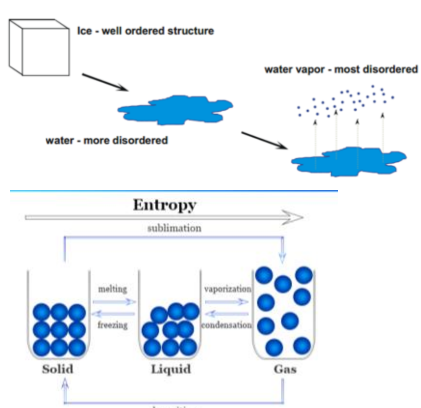
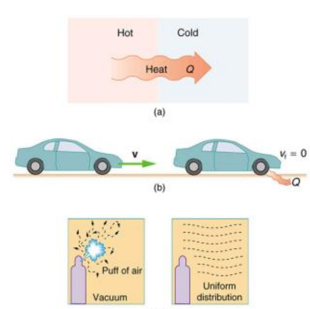
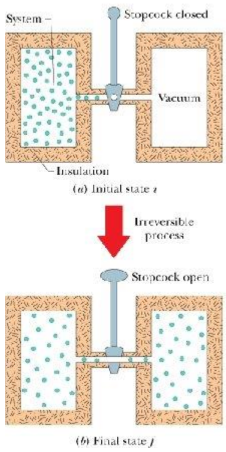
2nd law:-The state of entropy of the entire universe, as a closed isolated system, will always increase over time.

(The disorder in the universe is constantly increasing)





Change in Entropy



The Second Law of Thermodynamics:

If a process occurs in a *closed* system, the entropy of the system increases for irreversible processes and remains constant for reversible processes. It never decreases.

$$\Delta S \geq 0$$

+ΔS indicates that entropy is increasing in the reaction or transformation (it's getting more disordered -- mother nature likes)

-ΔS indicates that entropy is decreasing in the reaction or transformation (it's getting less disordered {more ordered} -- mother nature doesn't like, but it does happen)

3rd law:- All molecular movement stops at a temperature of absolute zero, or 0 Kelvin --- (-273°C).

Any pure crystalline substance at a temperature of absolute zero (0 K) has an entropy of zero (S = 0 J/K. mol).

Free energy (G):- Is defined as the amount of available energy to do work. Or , the energy that can be convert into work at a uniform temperature and pressure throughout a system.

G = Gibbs free energy.

$\Delta G = G_2 - G_1$

Where the ΔG = change in free energy.

G_2 = free energy at the end of a reaction.

G_1 = free energy in the beginning of a reaction.

$\Delta G = \Delta H - T\,\Delta S$

H= <u>enthalpy</u> or <u>heat content</u>.

Enthalpy is the amount of heat <u>released from</u> or <u>absorbed</u> by a chemical reaction at constant pressure.

$+\Delta H$ indicates that heat is being absorbed in the reaction ----- (it gets cold) -------- endothermic.

$-\Delta H$ indicates that heat is being given off in the reaction ------ (it gets hot) ---------- exothermic.

ΔS= entropy.

entropy: a measure of the unavailable energy in a closed thermodynamic system that is also usually considered to be a measure of the system's

T is absolute temperature.

Relative change in free energy (ΔG) determines **<u>spontaneous</u>** and **<u>non-spontaneous</u>** reactions.

I. If **ΔG = (- <u>ve</u>) value**, this means the reaction is spontaneous, and it <u>releases energy</u>.

II. If **ΔG = (+ <u>ve</u>**) **value**, this means the reaction is non-spontaneous, and it <u>requires energy</u>.

III. If **ΔG = 0**, this means that the reaction is at equilibrium status.

Relative change in free energy (ΔG) determines **spontaneous** and **non-spontaneous** reactions.

Exergonic reactions are chemical reactions that release energy in the form of heat. Typically, this energy is released when bonds are broken. **ΔG = - ve (spontaneous)**

Endergonic reactions are a reaction that require energy to be absorbed in order for it to take place. **ΔG = + ve.** For example, chemical reaction that occurs in nature is photosynthesis, or when plants convert sunlight into usable energy. . **ΔG = + ve (non-spontaneous)**

Entropy Example Problem

Calculate the entropy of the surroundings for the following two reactions.

a. $C_2H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4H_2O(g)$

$\Delta H = -2045$ kJ

b. $H_2O(l) \rightarrow H_2O(g)$

$\Delta H = +44$ kJ

Solution

The change in entropy(ΔS) of the surroundings after a chemical reaction at constant pressure and temperature can be expressed by the formula

$\Delta S_{surr} = -\Delta H/T$

Surr. = surroundings

where

ΔS is the change in entropy of the surroundings

$-\Delta H$ is heat of reaction

T = Absolute Temperature in Kelvin

Reaction A

$\Delta S_{surr} = -\Delta H/T$

$\Delta S_{surr} = -(-2045 \text{ kJ})/(25 + 273)$

❖Remember to convert °C to K

$\Delta S_{surr} = 2045 \text{ kJ}/298 \text{ K}$

$\Delta S_{surr} = 6.86 \text{ kJ/K or } 6860 \text{ J/K}$

Note the increase in the surrounding entropy , means the reaction was exothermic.

Reaction B

ΔS surr = $-\Delta H/T$

ΔS surr = -(+44 kJ)/298 K

ΔS surr = -0.15 kJ/K or -150 J/K

This reaction needed energy from the surroundings to proceed and reduced the entropy of the surroundings. (endothermic).

To find out the H for any chemical raction use:-

Enthalpy Formulas

$H = E + PV$

H is enthalpy

E is internal energy of the system

P is pressure

V is volume

What Is the Importance of Enthalpy?

Measuring the change in enthalpy allows us to determine whether a reaction was endothermic (absorbed heat, positive change in enthalpy) or exothermic (released heat, negative change in enthalpy).

Example Change in Enthalpy Calculation

We will use the heat of fusion of ice and heat of vaporization of water to calculate the enthalpy change when ice melts into a liquid and the liquid turns to a vapor.

1. The heat of fusion of ice is 333 J/g (meaning 333 J is absorbed when 1 gram of ice melts).

2. The heat of vaporization of liquid water at 100 °C is 2257 J/g.

Part 1: Calculate the change in enthalpy (ΔH) for these two processes.

$H_2O(s) \rightarrow H_2O(l); \Delta H = ?$

$H_2O(l) \rightarrow H_2O(g); \Delta H = ?$

Part 2: Using the values you calculated, find the number of grams of ice you can melt using 0.800 kJ of heat.

Solution

1. The heats of fusion and vaporization are in joules, so the first thing to do is convert to kilojoules. Using the periodic table, we know that 1 mole of water (H_2O) is 18.02 g. Therefore:

fusion ΔH = 18.02 g x 333 J / 1 g
fusion ΔH = 6.00 x 10^3 J
fusion ΔH = 6.00 kJ

vaporization ΔH = 18.02 g x 2257 J / 1 g
vaporization ΔH = 4.07 x 10^4 J
vaporization ΔH = 40.7 kJ

So, the completed thermochemical reactions are:

$H_2O(s) \rightarrow H_2O(l); \Delta H = +6.00$ kJ
$H_2O(l) \rightarrow H_2O(g); \Delta H = +40.7$ kJ

2. Now we know that:

1 mol $H_2O(s)$ = 18.02 g $H_2O(s)$ ~ 6.00 kJ

Using this conversion factor:

0.800 kJ x 18.02 g ice / **6.00 kJ** = 2.40 g ice melted

Free Energy and Reaction Spontaneity Example Problem

Using the following values for ΔH, ΔS, and T, determine the change in free energy and if the reaction is spontaneous or nonspontaneous.

1- $\Delta H = 40$ kJ, $\Delta S = 300$ J/K, T = 130 K

2- $\Delta H = 40$ kJ, $\Delta S = 300$ J/K, T = 150 K

3- $\Delta H = 40$ kJ, $\Delta S = -300$ J/K, T = 150 K

Solution

The free energy of a system can be used to determine if a reaction is spontaneous or nonspontaneous. Free energy is calculated with the formula

$\Delta G = \Delta H - T\Delta S$

where

ΔG is the change in free energy
ΔH is the change in enthalpy
ΔS is the change in entropy
T is the absolute temperature (Kalvin + room temp.)

- A reaction will be spontaneous if the change in free energy is negative. It will not be spontaneous if the total entropy change is positive.

- Watch your units! ΔH and ΔS must share the same energy units.

System 1

$\Delta G = \Delta H - T\Delta S$

$\Delta G = 40\ kJ - 130\ K \times (300\ J/K \times 1\ kJ/1000\ J)$

$\Delta G = 40\ kJ - 130\ K \times 0.300\ kJ/K$

$\Delta G = 40\ kJ - 39\ kJ$

$\Delta G = \underline{+1}\ kJ$

ΔG is <u>positive</u>, therefore the reaction will <u>not be spontaneous</u>.

System 2

$\Delta G = \Delta H - T\Delta S$

$\Delta G = 40\ kJ - 150\ K \times (300\ J/K \times 1\ kJ/1000\ J)$

$\Delta G = 40\ kJ - 150\ K \times 0.300\ kJ/K$

$\Delta G = 40\ kJ - 45\ kJ$

$\Delta G = \underline{-5}\ kJ$

ΔG is <u>negative</u>, therefore the reaction will <u>be spontaneous</u>.

System 3

$\Delta G = \Delta H - T\Delta S$

$\Delta G = 40\text{ kJ} - 150\text{ K x } (-300\text{ J/K x } 1\text{ kJ/1000 J})$

$\Delta G = 40\text{ kJ} - 150\text{ K x } -0.300\text{ kJ/K}$

$\Delta G = 40\text{ kJ} + 45\text{ kJ}$

$\Delta G = +85\text{ kJ}$

ΔG is positive, therefore the reaction will not be spontaneous.

Q- Given the reaction of diamond converting to graphite. Determine ΔG at 298 K and determine if this reaction is spontaneous or not.

2C (diamond)→2C (graphite)

* ΔH (C(s) diamond) =1.9 kJ/*mol*
* S (C(s) diamond =2.38 J/(*mol K*)
* S (C(s) graphite) =5.74 J/(*mol K*)

ΔG=ΔH−TΔS

* ΔH=2mol C(graphite) × ΔH (graphite)-(2mol C diamond × ΔH C (diamond)

ΔH=2(0)-2(1.9 kJ/mol)=-3.8kJ

* ΔS= 2mol C (graphite)× C (sof graphite) - 2mol C diamond × C (s of diamond)

ΔS=2(5.74 J/(mol K))- 2(2.38 J/(mol K))= + 6.72 J/mol

ΔG=-3.8×10*3 J-298.15(6.72 J/mol K)= **-5.51 kJ** (This reaction is spontaneous)

Principles of Plant Physiology Plant water relations

Water Potential

Definition:-

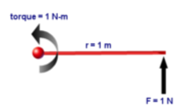
Water potential is a measure of the energy state of water.

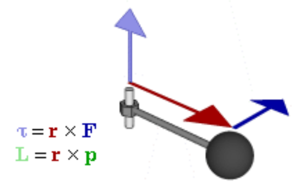
Why water potential important in plant physiology?

Water potential is important concept in plant physiology because it determines the direction and movement of water.

A- Definitions:-

1- Free energy of water :- Energy available to do work (**J** = **N. m**).





2- Chemical potential (μ) :- free energy **(J)** per unit quantity **(mol$_{-1}$);**

μ = J / mol$_{-1}$.

3- Water potential (Ψw) :- Chemical potential of water, compered to **pure water** at the same temperature and pressure; the measure unite of water potential is in **<u>pressure</u>**

* Why the measure unites of **Ψw** are in **<u>pressure</u>**?

Because:-

A- Plant cells are under pressure.

B- Measuring pressure is easy.

4- Derivation of units:- Water potential is officially defined as the chemical potential of water ($J\ mol^{-1}$),When divided by the partial molar volume ($L\ mol^{-1}$).

$J\ mol^{-1} / L\ mol^{-1}$ = J / liter = energy / volume = (weight x distance) /area x distance = force/area = pressure units.

Principles of Plant Physiology Plant water relations

5- Pressure is measured in MPa (mega Pascal's).

1. **1 MPa = 10 bars = 10 atm**.
2. **1 atm. = 760 mm Hg**
3. **760 mm Hg = 14. 7 lb in^{-2}**
4. **14.7 lb in^{-2} = 1.013 bar.**

B- Equation of water potential (should included all the factors that influence the diffusion of water):-

$\Psi w = \Psi p + \Psi s + \Psi m + \Psi g$

Ψw = water potential.
Ψp = pressure potential.
Ψs = solute or osmotic potential.
Ψm = matric potential.
Ψg = gravity potential.

Principles of Plant Physiology Plant water relations

1- Pressure potential (Ψp):- Due to the pressure build up in cell.

Pressure potential could be positive or negative.

Pressure potential (Ψp)

Positive → **Turgid plant cells** → **Is called (Turgor Pressure)**

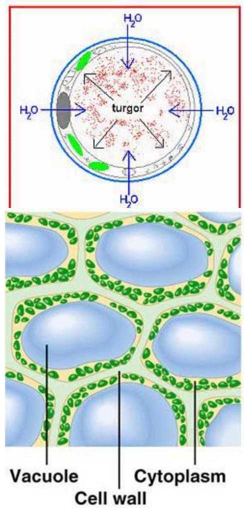
In turgid plant cells it usually has a positive value as the entry of water causes the protoplast to push against the cell wall.

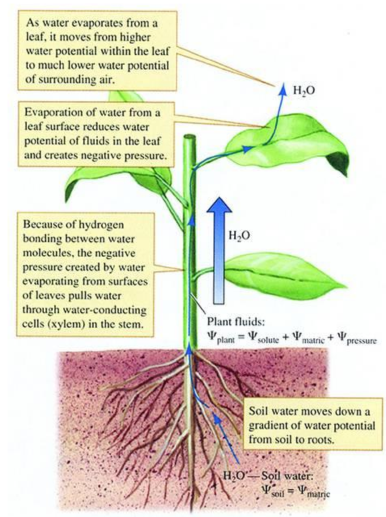
Negative → **Xylem cells** → **Is called (Tension)**

In xylem cells there is a negative pressure potential, or tension, as a result of transpiration. Water at atmospheric pressure has a pressure potential of zero.

B- Negative potential pressure

A- Positive potential pressure





2- Solute or osmotic potential (Ψs):- This is due to dissolved solutes. Solutes always decrease the free energy of water, thus their contribution is always negative.

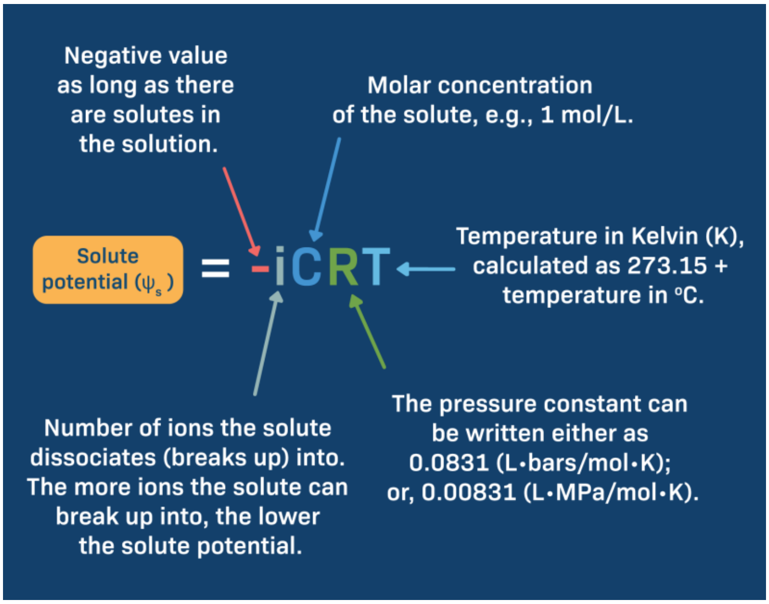
- The solute potential of a solution can be calculated with the van't Hoff equation: **$\Psi s = - miRT$**

Where

- m = molarconcentration
- i = ionization constant (often 1.0);
- R = gas constant (0.0831 liter x bar/mol / deg);
- T = temperature (K).

Or **$\Psi s = - iCRT$**

$\Psi s = -iCRT$



Example :- The molar concentration of a sugar solution in an open beaker has been determined to be 0.4M. Calculate the solute potential in MPa and the water potential at 22 °C.

$\Psi s = -iCRT$

$\Psi s = -(1)(0.4$ moles/liter$)(0.0831$ liter/bars/mole K$)(273+22K)$.

$\Psi s = -(1)(0.4)(0.0831)(295)$bars.

$\Psi s = -9.8058$ bars.

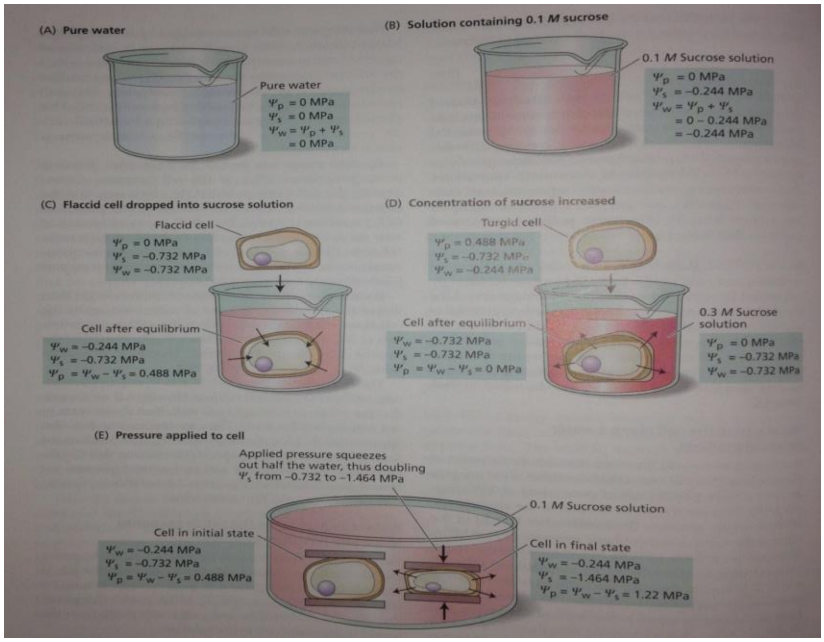
$\Psi s = -10$ bars.

What is the overall water potential?

$\Psi w = \Psi p + \Psi s$

$\Psi w = ?!$

Principles of Plant Physiology **Plant water relations**



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Q. A solution in a beaker has NaCl dissolved in water with a solute potential of -0.5 bars. A flaccid cell is placed in the above beaker with a solute potential of -0.9 bars.

a) What is the pressure potential of the flaccid cell before it was placed in the beaker?
Ψp = 0 bars

b) What is the water potential of the cell before it was placed in the beaker?
Ψw = Ψp + Ψs
X = 0 bars + -0.9 bars
X = -0.9 bars

c) What is the water potential in the beaker containing the sodium chloride?
Ψw = Ψp + Ψs
X = 0 bars + -0.5 bars
X = -0.5 bars

d) How will the water move?
Water will move from solution and enter the cell.

e) Is the cell hypotonic or hypertonic with respect to the outside?
Hypertonic

Q.A. Calculate the water potential of a solution of 0.15 M sucrose. The solution is at standard temperature (21C°)

$\Psi w = \Psi p + \Psi s$
X = 0 bars + [-iCRT]
X = 0 bars + [-(1) (0.15 mol/L) (0.0831 L bars/mol K) (273K)
X = 0 bars + -3.40 bars
Ψw = -3.40 bars

Q. B. If a flaccid cell having a solute potential of -0.69 bars is placed in the above solution, what will be its pressure potential at equilibrium?

Equilibrium means Ψw cell = Ψw solution

$\Psi w = \Psi p + \Psi s$
-3.40 bars = X + -0.69 bars
Ψp = -2.71 bars

Q. If a cell having a molar concentration of glucose at 0.22 M is placed in a solution of pure 20 °C water, what will be its pressure potential at equilibrium?

Equilibrium means Ψw cell = Ψw solution

Solution:
$\Psi w = \Psi p + \Psi s$
X = 0 bars + 0 bars
Ψw = 0 bars

Cell:
$\Psi w = \Psi p + \Psi s$
0 bars = X + [-iCRT]
0 bars = X + [-(1)(0.22 mol/L)(0.0831 Lbar/molK)(293K)]
0 bars = X + -5.36 bars → Ψp = -5.36 bars

Q. What must be the molar concentration of sugar inside a cell for it not to change volume when placed in a beaker of 0.35M NaCl solution at 37°C? The Ψp of the cell is 4.7 bars.

Solution: **For the volume not to change the cell is in equilibrium.**

Ψw = Ψp + Ψs
X = 0 bars + [-iCRT]
X = 0 bars + [-(2)(0.35 mol/L)(0.0831 Lbar/molK)(310K)]
X = 0 bars + -18.03 bars
Ψw = -18.03 bars

Cell:
Ψw = Ψp + Ψs
-18.03 bars = 4.7 bars + Ψs or [-iCRT]
Ψs or -iCRT = -22.73 bars
C = -22.73 bars/[-(1)(0.0831 Lbar/molK)(310K)]
C = 0.88 mol/L

3-Matric potential (Ψm):- it is related to the force of attraction of water for colloidal, charged surfaces.

- It is **negative** because it reduces the ability of water to move.
- In large volumes of water it is very small and usually ignored.
- it can be very important in the soil, especially when referring to the root /soil interface.

4- Gravity (Ψg):- A gravity is usually ignored unless referring to the tops of tall trees.

❖The water potential of pure water is zero. Water potential in intact plant tissue are usually negative

Why negative?!

❖ because of the large quantities of dissolved solutes in cells.

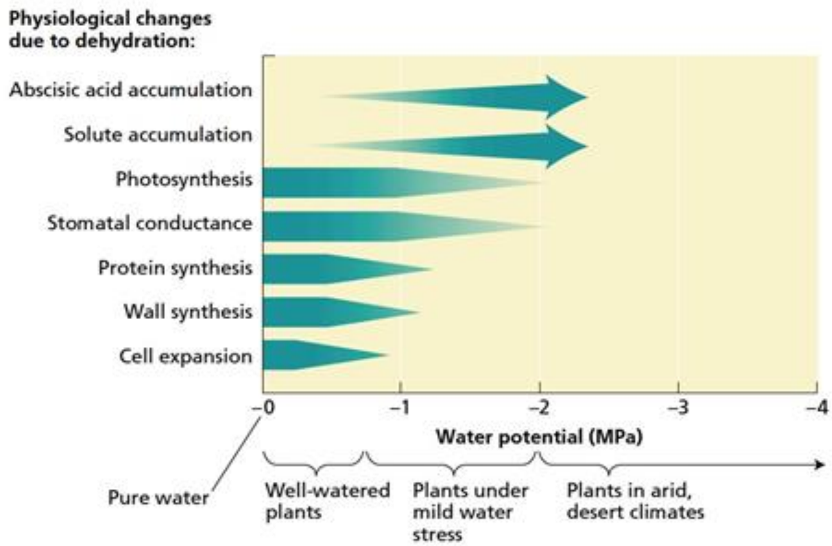
Principles of Plant Physiology Plant water relations

❖The water potential of pure water is zero. Water potential in intact plant tissue are usually negative

Why negative?!

❖ because of the large quantities of dissolved solutes in cells.

The water potential concept helps us evaluate the status of a plant



Types of Solutions.

There are three types of solutions relating to the effects of osmosis on cells.

1- Hypertonic Solution.

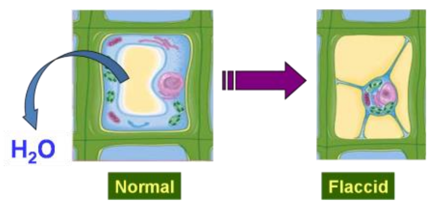
2- Hypotonic Solution.

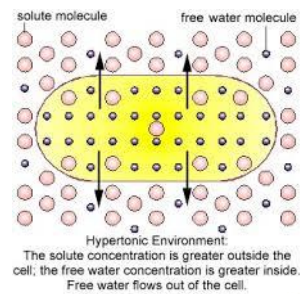
3- Isotonic Solution.

1-Hypertonic Solution:- The **solution** has a **higher solute concentration** than that of the **cell.**

(Plasmolysis)

- The water as a result will leave the cell.
- Plant cells will have a collapsed vacuoles.





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Plasmolysis:- Is the process in which cells lose water in a hypertonic solution.

Types of plasmolysis:-

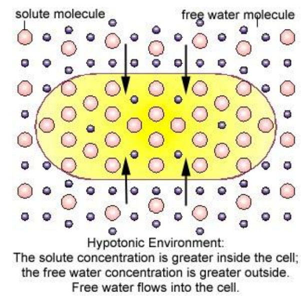
1- Incipient plasmolysis:- The cell shrinks in volume.

2- Evident plasmolysis:- The plasma membrane gets torn completely from the cell wall and goes on contracting.

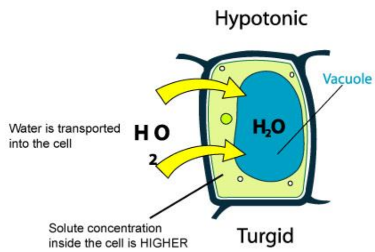
3-Final plasmolysis:- Cytoplasm will be completely free from the cell wall and remains in the center of the cell.

2- Hypotonic Solution:- The **solution** has a **lower solute concentration** than that of **solute** concentration **inside** the **cell.**

(Cytolysis)

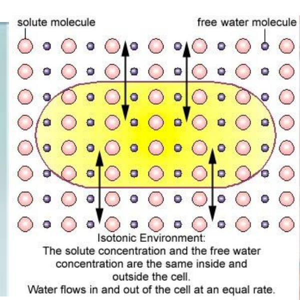


- The water as a result will enter the cell.
- The vacuoles of the plant cell will swell, and the contents of the cell will be pushed against the cell wall.



3- Isotonic Solution:- The concentration of **solutes** is the **same inside** the **cell** as it is **outside** of the **cell.**

- The cell would not lose water, nor will it gain water.



Significance of osmosis to plant:-

1- Maintenance of plant tissues in a state of turgidity where the tissues remain active metabolically.
2- Causes entrance of water into plant as will as transport and distribution of water within plant.
3- Provides a strength and rigidity for the soft plant cells *e.g.* shoot tips.
4- Enhances penetration of root tissues into soil.
5- Facilitate emergence of seedlings (Sprouting) from the soil.

Imbibition:- The uptake of water by substances that do not dissolve in water, so that the process results in swelling of the substance.

Or

A special type of diffusion based on water movement according to the difference in water potential. *e.g.* seed imbibition's, xylem imbibition's.

- Imbibition is one of the causes of water movement inside the plants.

Conditions for imbibition.

1. Presence of difference or gradient in water potential ($\Delta\Psi w$) between imbibed material and surrounding liquid (imbibition material).

2- Presence of attraction between them, *e.g.* rubber imbibes by Ether but dose not imbibes by water. Other plant materials are less imbibed by ether.

Ψw for dry seeds = - 900 bar (or -90Mpa).

When seeds are placed in water, a sharp gradient is generated, and imbibition of water take place.

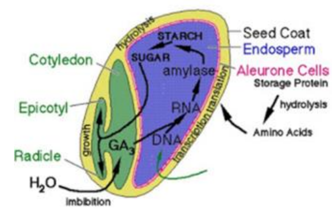
Factors affecting imbibition.

1-Temperature: rate of imbibition increases by increased temperature, but does not affect the amount of imbibed water.

2. Osmotic potential: affects both the rate of imbibition and amount of imbibed water.

- During imbibition pressure is generated, called imbibition pressure or matric potential (Ψm).

- Imbibition have a significant importance in seed germination. No germination takes place without imbibition.



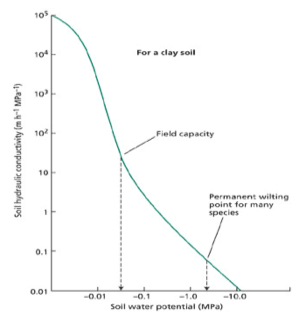
Water absorption and translocation.

Water and soil.

1- Saturated:- Soil before drained. Gravitational water, water that drains and is not tightly bound; Ψ = 0 Mpa.

2- Field capacity:- Soil that holds all the water it can ---- against gravity. Capillary water-water held by capillary action, water at field capacity; Ψ = -0.015 Mpa.

3- Permanent wilting percentage:- Soil moisture content at which plants can't get enough water. mostly, Ψ = -1.5 Mpa.



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Principles of Plant Physiology Plant water relations

1. Between PWP and FC is the water available for a plant to use.

2. Clay holds more water than sand at any →Ψ ; and

3. Clay holds water more tightly.

   Why?

   Smaller particles in clay have a larger total surface and hence, have more charged surfaces that will bind water tightly.

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❖ Soil water potential is a function of osmotic potential (which is usually near zero except in saline soils) and mostly pressure is used to call it matrix potential; this refers to the tension generated because of the attraction of colloidal particles; *i.e.*, adhesion).

❖ Water movement through soil - mostly is due to bulk flow as a result of pressure gradients with some diffusion.

Principles of Plant Physiology Plant water relations

➢ In addition, **diffusion** of water vapor accounts for some water movement.

➢ As water moves into root – less in soil near the root.

- ➢ Results in a **pressure gradient** with respect to neighboring regions of soil.
- ➢ So there is a **reduction** in Ψp near the root and a **higher** Ψp in the neighboring regions of soil.

- Soil pores are water filled and interconnected, water moves to root surface by bulk flow down the pressure gradient.

- As water moves from soil into root the spaces fill with air.

- This **reduces** the flow of water.

- **Permanent wilting point**
- At this point the water potential (Ψw) in soil is so low that plants cannot regain turgor pressure
- There is not enough of a pressure gradient for water to flow to the roots from the soil.

- **This varies with plant species.**
- The rate of water flow depends on:-

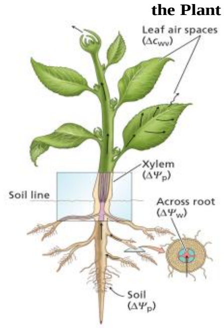
- Size of the pressure gradient.
- Soil hydraulic conductivity (SHC).
    - SHC is the measure of the ease in which water moves through soil.
- SHC varies with water content and type of soil.
  - Sandy soil high SHC.
    - Large spaces between particles.
  - Clay soil low SHC.
    - Very small spaces between particles.

Water Absorption and Translocation.

The plant obtains water from the soil and absorbs it through its root system. Very little amount of absorbed water remain in the plant and used in growth, photosynthesis and other metabolic activities, while the greater amount of water is lost by transpiration.

- **Absorption** means movement of water from soil to root.
- **Translocation** means the movement of food from "source" to "sink".

Main Driving Forces for Water Flow from the Soil Trough the Plant to the Atmosphere



Water potential in soil:
$\Psi_w = \Psi_s + \Psi_p$

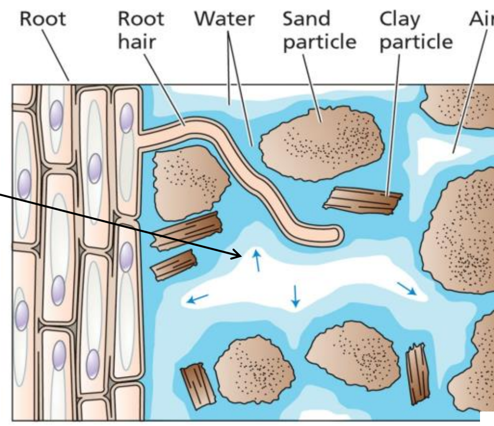
Ψ_s – usually negligible, because solute concentrations are low (-0.02 MPa; soils with salts: -0.2 MPa).

Ψ_p – in wet soils: close to 0
– in dry soils: decreases, becomes negative

Where does the negative pressure in soil water come from?

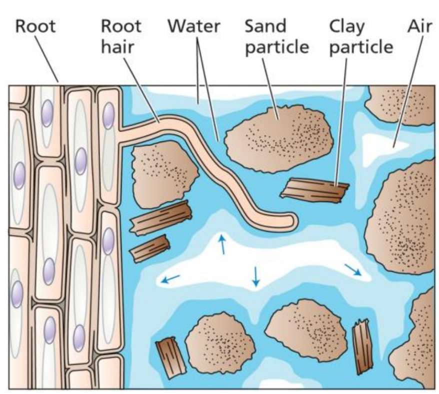
A Negative Hydrostatic Pressure in Soil Water Lowers Soil Water Potential

- root hairs increase plant surface area for water absorption.
- soil is a mixture of particles, water, solutes, air.
- as water is absorbed by plant, soil solution recedes into smaller pockets.
- at air-water interface, this recession causes development of **concave menisci**, thus brings the solution into tension (negative pressure) by surface tension.
- as more water is removed from soil, more acute menisci are formed, resulting in greater tension, i.e. more negative pressure.



A Negative Hydrostatic Pressure in Soil Water Lowers Soil Water Potential.

- Water under these curved surfaces develops a negative pressure:
  $\Psi_p = -2T/r$
- T – surface tension of water (7.28×10^{-8} MPa m)
- r – radius of curvature of air-water interface

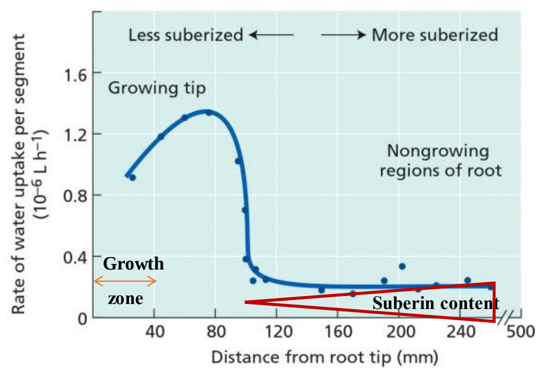


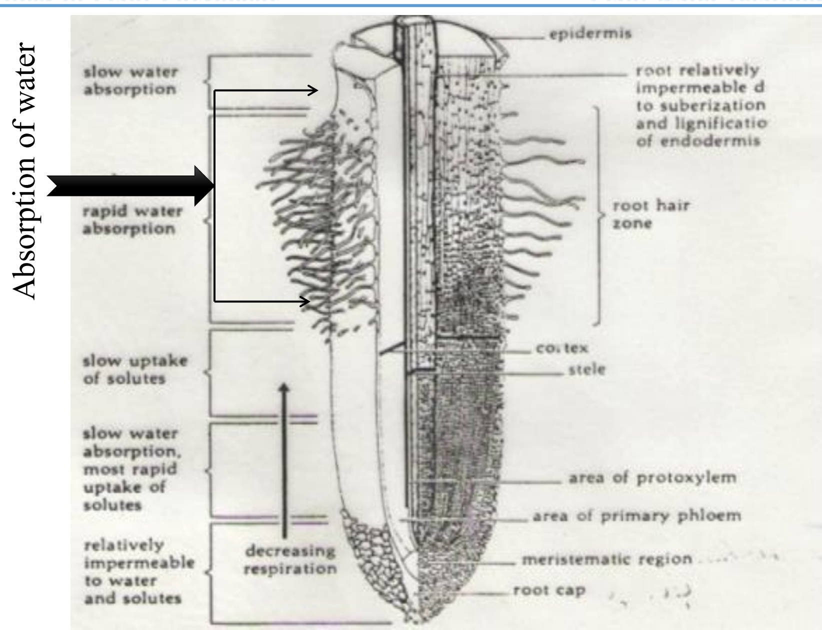
Example:- r = 1 µm (~ size of the largest clay particles) equals Ψp = -0.15 MPa (may reach -1 to -2 MPa in further dried-out soils)

Water Moves in the Root via the Apoplast, Transmembrane, and Symplast Pathways.

- Water moves through soil by **bulk flow.**
- Water enters root most readily near the root tip.
- Although it might seem unpredictably, older root regions must be sealed off if there is water uptake from regions that are actively growing.
- This allows xylem tensions to extend further into the root system, allowing water uptake from distal (further away) regions of the root system.

Suberin is highly hydrophobic, Its main function is to prevent water from penetrating the tissue, In roots suberin is deposited in the radial and transverse cell walls of the endodermal cells. This structure is known as the Casparian stripe



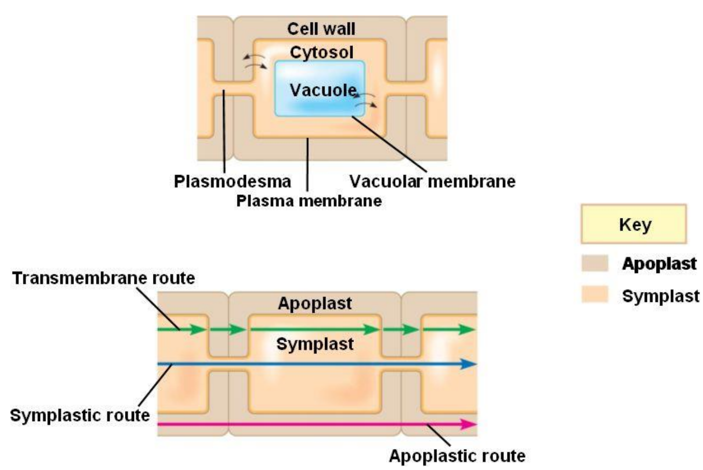


Water Movement in the Plant.

Absorbed water by the root hairs diffuses through the cell walls into the endodermis, which prevents the diffusion due to the presence of suberine layer (an impermeable to water) in **Casparian** strip. Therefore, the water goes into the protoplasm of the endodermis cells, then translocation to the xylem tissues.

Transmembrane route.

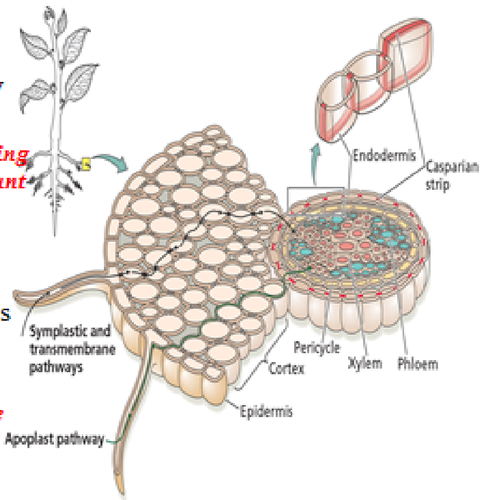
- **Apoplast:**- Movement of water in continuous system between cell walls and intercellular spaces filled with air or water.
- **Symplast**:- Movement of water through a continuous system that connects cell cytoplasm by plasmodesmata and forms a system for water and solute translocation.
- **Transmembrane**:- The water moves from cell-to-cell crossing membranes as it goes.

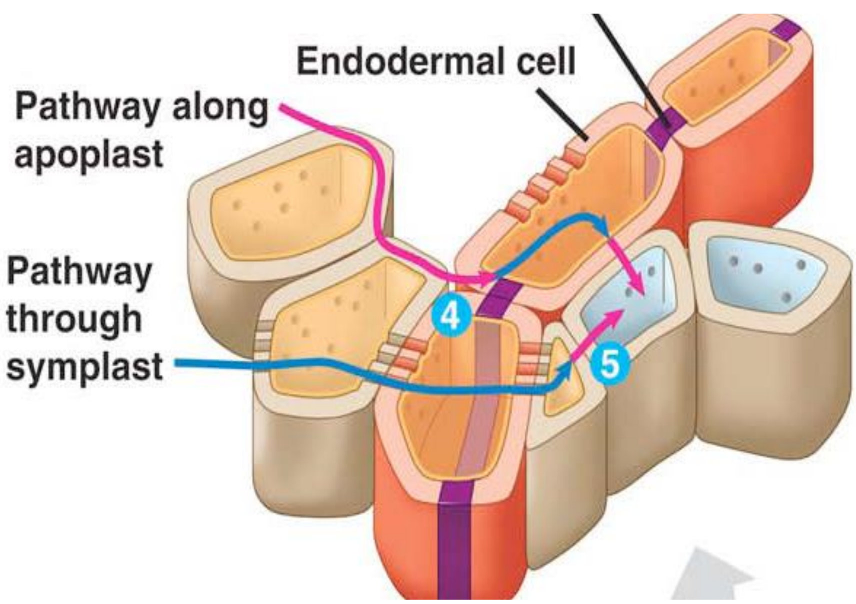


Three Major Pathways of Transport.
The **plasma membrane** and **vacuolar membrane** provide **transmembrane** transport.
The cytoplasmic continuum, connected by plasmodesmata, is the **symplast** route.
The continuum of cell walls plus extracellular spaces provide the **apoplast** route.

Water uptake in the roots.

- *At the endodermis:*
- Water movement through the apoplast pathway is stopped by the Casparian Strip
  - *Band of radial cell walls containing* **suberin** , *a wax-like water-resistant material*
- The casparian strip breaks continuity of the apoplast and forces water and solutes to cross the endodermis through the plasma membrane
  - *So all water movement across the endodermis occurs through the symplast*





Mechanism of Water Transport.

How does water moves up to high plant parts and organ that sometimes reaches more than a 100 meter ?

Water movement to the upper parts must be achieved either by pumping force or by pulling or lifting force (i.e. under tension).

Several theories are available.

1-Water movement through capillary vessels by capillary phenomena.

2-Root pressure theory.

3-Cohesion- tension theory :(Cohesion – Adhesion theory).

1-Water Movement Through Capillary Vessels by Capillary Phenomena Theory.

Movement by such force is not enough to support water movement for more than 1 meter. It is not accepted theory.

2-Root Pressure Theory.

If a stem of herbaceous plant is severed near the soil level, the xylem sap is seen to come out from the cut edge.

This flow of sap is caused by <u>root pressure</u> that develops as a result of metabolic activities.

This phenomenon is not observed when metabolic activities are repressed by :-

1-Respiration inhibitor.

2-lack of oxygen .

3-low temperature.

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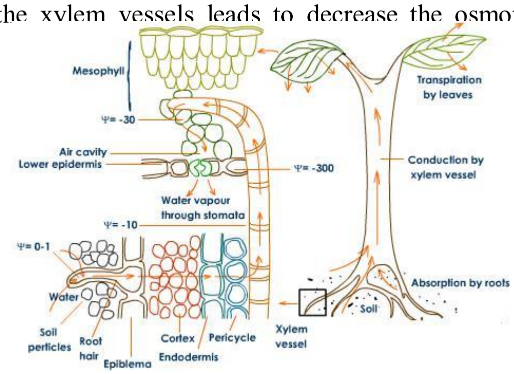
How the root pressure is generated ?

Root pressure is generated as follows:-

- The ions are absorbed and accumulate in the xylem vessels (active absorption).
- Increased ion concentration in the xylem vessels leads to decrease the osmotic potential.
- This will lead finally to water movement towards the xylem vessels by osmotic forces.
- As a result of water entrance, pressure is generated.



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The generated pressure of water it can be seen by naked eyes and measured:-

- If the stem is severed (cut off), the sap will come out or **exudation** to the outside.
- If a manometer is placed on the cut surface, root pressure can be observed and measured.

Usually

- Root pressure occurs when soil water potential is high and transpiration is low.

In some plants: root pressure causes the appearance of **water drops** on leaf edges (**Guttaion**) under **low transpiration** rate conditions (e.g. in humid weather). In such cases the **root pressure** will be **high**, and causes the exit of water drops from special openings or pores at the end of veins called **hydathodes**.

Water transport **cannot be explained** according to this theory for the following reasons:-

- Some plants (for example: conifers) does not show or generate root pressure, nevertheless water moves up in such plants.
- Root pressure is not enough to push the water up to more than **few meters** (max. **2 bars only**, while more than **20 bars** are required for **tall plants**).
- Rate of flow of xylem sap is **less than** the **rate of transpiration**, which means that the xylem sap is **under tension** rather than **pressure**.

3- Cohesion- tension Theory:- (Cohesion – Adhesion Theory).

The force needed for water translocation to the top of a high tree might reach 10-15 bars or even higher. This force is available only as a result of force of evaporation (or transpiration). Under fast transpiration rate condition, transpiration pull is responsible for water movement.

- **Elements of cohesion- tension theory.**

1- **Driving force** (or pulling force): water movement from soil to root stem, then to the leaf and later to stomata and to the air is based (or dependent) on reduction in water potential gradient.

2- **Adhesion force** between water molecules and cell walls of hydrophilic nature by hydrogen bonds.

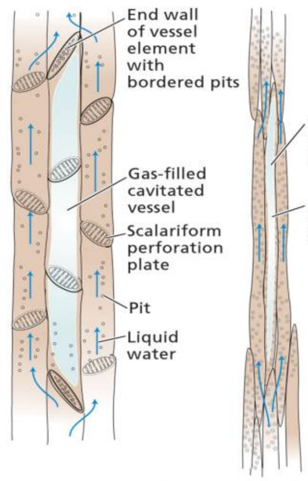
3- **Cohesion force** between water molecules by hydrogen bonds.

The mechanism of water transport according to this theory:-

- Roots can develop positive hydrostatic pressure in their xylem → root pressure.
- However, root pressure is less than 0.1 MPa and disappears when transpiration rate is high → would not be enough to move water up a tall tree.
- Water at top of trees develops large tension = negative hydrostatic pressure (suction).
    - This tension "pulls" water through the xylem
    - This mechanism is called **cohesion-tension theory of sap ascent**
- Requires cohesive properties of water to sustain large tensions in the xylem water columns.

Water transport through xylem

- Such breaks in the water column are not unusual.
- Impact minimized by several means
  - Gas bubbles can not easily pass through the small pores of the ***pit membranes***.
  - Xylem are interconnected, so one gas bubble does not completely stop water flow
- Water can detour blocked point by moving through neighboring, connected vessels.



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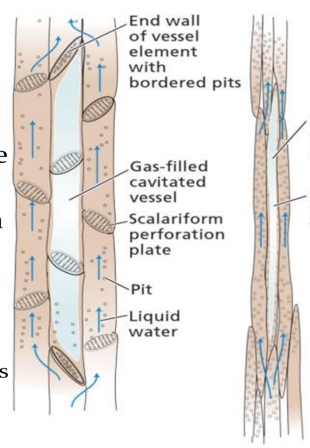
- Gas bubbles can also be eliminated from the xylem.
  - At night, xylem water pressure increases and gases may simply dissolve back into the solution in the xylem.
  - Many plants have secondary growth in which new xylem forms each year. New xylem becomes functional before old xylem stops functioning
    - As a back up to finding a way around gas bubbles.



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Xylem Transport of Water in Trees Faces Physical Challenges Problems:-

1-Water under tension transmits an inward force to walls of xylem → tendency to collapse → wall thickenings

2- As tension in water increases → tendency for air to be pulled in (air seeding) → air bubble will expand (cannot resist tensile forces) → **cavitation/embolism** →continuity of water column breaks.

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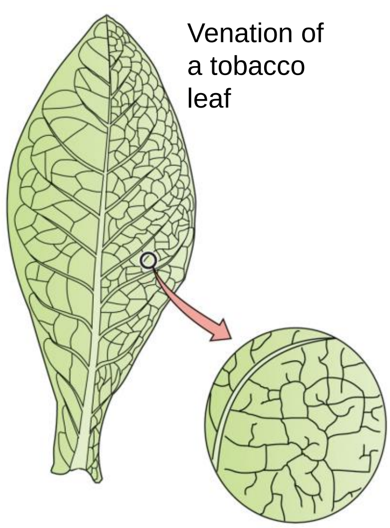
Water Evaporation in the Leaf Generates a Negative Pressure in the Xylem



Venation of a tobacco leaf

- Water transported through vascular bundles into leaves
- venation is very fine: most cells are within 0.5 mm of a minor vein
- negative pressure that causes water to move up through xylem develops at surface of cell walls in leaf (similar to situation in soil)
- cell wall acts like a fine capillary wick soaked with water
- cells within leaf are in contact with atmosphere through intercellular spaces

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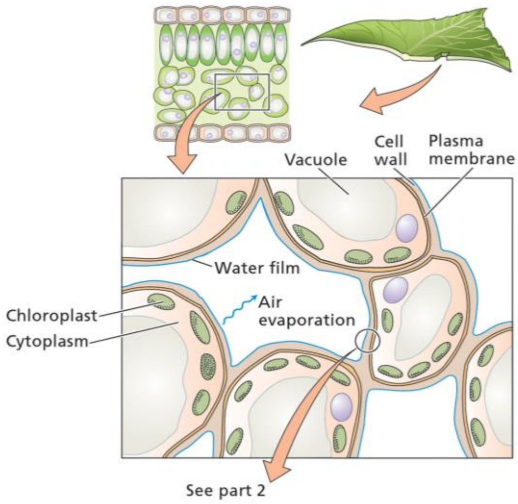
Water Evaporation in the Leaf Generates a Negative Pressure in the Xylem



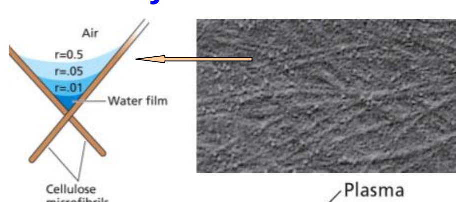
- Water evaporates from a thin film lining these air spaces.

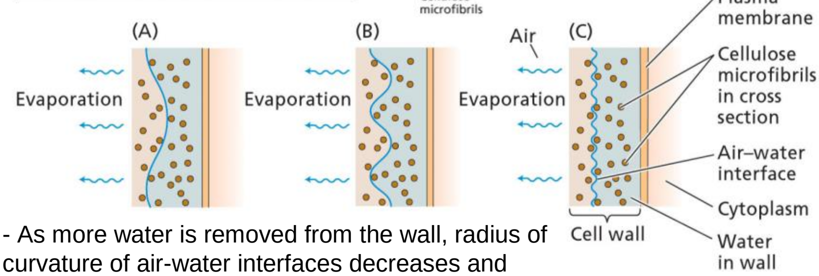
- As water is lost to air, surface of the remaining water is drawn into interstices of the cell wall forming curved air-water interfaces.

- Because of high surface tension of water, curvature of these interfaces induces tension (negative pressure) in the water.

Water Evaporation in the Leaf Generates a Negative Pressure in the Xylem

	Radius of curvature (μm)	Hydrostatic pressure (MPa)
(A)	0.5	−0.3
(B)	0.05	−3
(C)	0.01	−15





- As more water is removed from the wall, radius of curvature of air-water interfaces decreases and pressure of the water becomes more negative.

→ Motive force for xylem transport is generated in the air-water interfaces within the leaf

Note:-

1-Diffusion of water out of the leaf is very fast.

2-Diffusion is much more rapid in a gas than in a liquid.

3-Transpiration from the leaf depends on two factors:-

- ONE: Difference in **water vapor concentration** between leaf air spaces and the atmosphere.
- TWO: The diffusion **resistance** of the pathway from leaf to atmosphere.

The diffusion **resistance of the pathway** from leaf to atmosphere has two components:-

- **Leaf stomata resistance** associated with diffusion through the stomata pore.
- Boundary layer resistance due to a layer of unstirred air next to the leaf surface.

Factors affecting water absorption.

Several factors can affect this process as follows:-

1- **Soil temperature:** the rate of absorption is increased with increased temperature of soil and decreased with its reduction because:-

A-Water viscosity increase with reduction in temp.

B-Permeability of membranes decreased with reduction in temp.

C- Biological activities in general, as well as root growth are reduced with reduction in temperature.

2- **Availability of soil water** between field capacity (FC) and permanent wilting point (PWP).

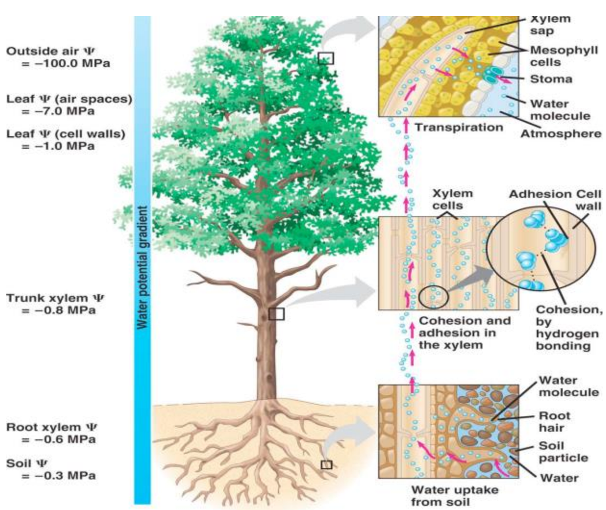
3- **Osmotic potential of soil solution** leads to increase in water potential (Ψw), which subsequently increases the Ψw gradient between soil solution and cell sap, which further leads to increased absorption. In Halophytes (i.e. plants adapted to grow under saline conditions), their Ψs might reach -200 bars, gradient is generated in Ψs between cell sap and water, thus they absorb water as a result of $\Delta \Psi s$.

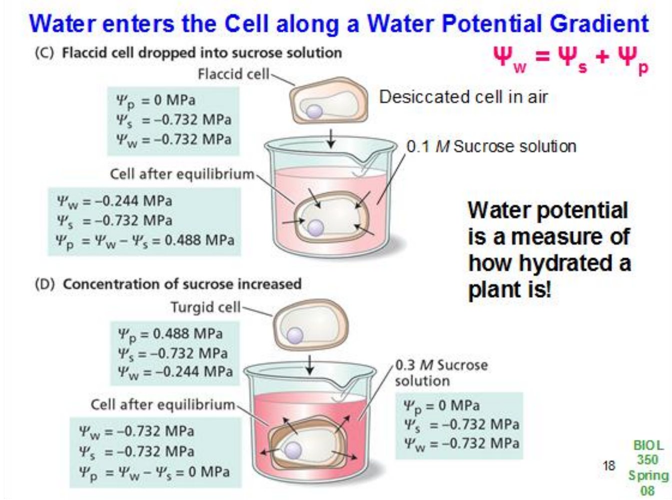
4- Soil aeration:- Good soil aeration leads to a fast water absorption, while bad soil aeration causes reduction in absorption of water through reduction of oxygen availability, and subsequent reduction in metabolic activities such as respiration, reduced ion uptake, and finally reduced water absorption. Similarly, bad aeration causes carbon dioxide accumulation, which increases protoplasm viscosity, which further reduces the permeability of membranes to water, and subsequently reduces water absorption.

5- Rate of transpiration:- high rate of transpiration cause more negative Ψw in the leaves, which increases the transpiration pull (Tn-pull) and cause increased water absorption.

6- Root characteristics:- tap root system may absorb less water than fibrous root system due to increased surface area. Tap root system may go deeper into the soil searching for water to absorb. Absorption of water by areal part is very limited and depends upon.

a.Ψ w of leaf cells.




Water enters the Cell along a Water Potential Gradient
(C) Flaccid cell dropped into sucrose solution
$\Psi_w = \Psi_s + \Psi_p$
Flaccid cell
Ψ_p = 0 MPa
Ψ_s = −0.732 MPa
Ψ_w = −0.732 MPa
Desiccated cell in air
0.1 M Sucrose solution
Cell after equilibrium
Ψ_w = −0.244 MPa
Ψ_s = −0.732 MPa
Ψ_p = $\Psi_w - \Psi_s$ = 0.488 MPa
Water potential is a measure of how hydrated a plant is!
(D) Concentration of sucrose increased
Turgid cell
Ψ_p = 0.488 MPa
Ψ_s = −0.732 MPa
Ψ_w = −0.244 MPa
0.3 M Sucrose solution
Cell after equilibrium
Ψ_w = −0.732 MPa
Ψ_s = −0.732 MPa
Ψ_p = $\Psi_w - \Psi_s$ = 0 MPa
Ψ_p = 0 MPa
Ψ_s = −0.732 MPa
Ψ_w = −0.732 MPa
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