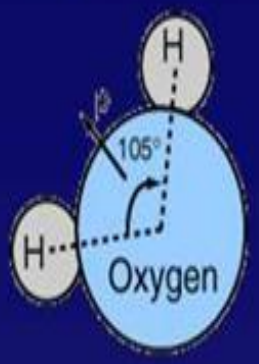
# PLANT WATER RELATION

# WATER




- All plant life requires water in large amount
- Present through out the plant body
- 80% is water & more than 90% in fresh weight
- Dormant seeds & buds – 10%

# AVAILABILITY OF WATER

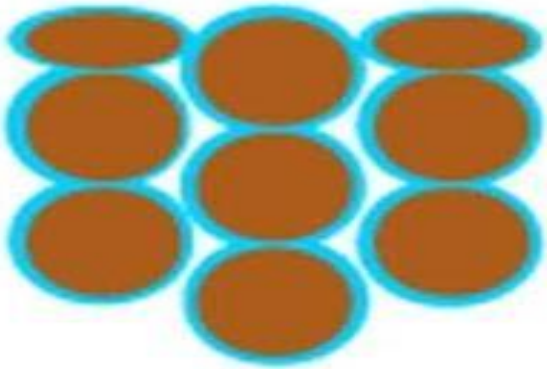
**1. Gravitational (free) water- Water percolates deep, due to the gravity, in the soil, is called 'gravitational water'. This is not available to plants for absorption.(too deep)**

**2.Hygroscopic water- Fine soil particles imbibe/ adsorb water and hold it. This is called 'hygroscopic water'. Roots cannot absorb it.**

**3. Combined water – Water present in the form of hydrated oxides of silicon, aluminum, etc., is called 'combined water'. It is also not available to plants for absorption.**

**4. Capillary water- Some amount of water is held in pores present between the neighbouring soil particles, due to capillarity. This is called Capillary water. ONLY CAPILLARY WATER is avilable for absorption.**

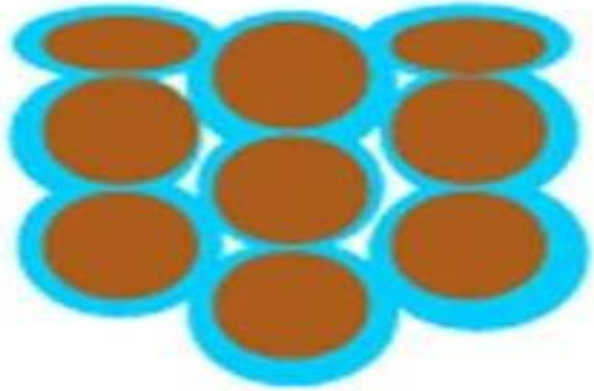
## Hygroscopic water



Remaining water adheres to soil particles and is unavailable to plants

Wilting point ⟶

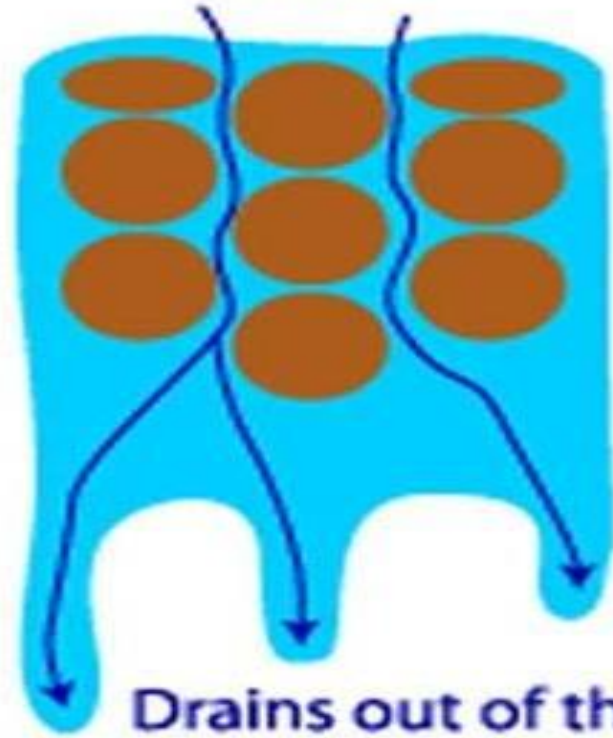
## Capillary water



Water held in micropores

Available water- plant roots **can** absorb this

## Gravitational water



Drains out of the root zone

⟵ Field capacity

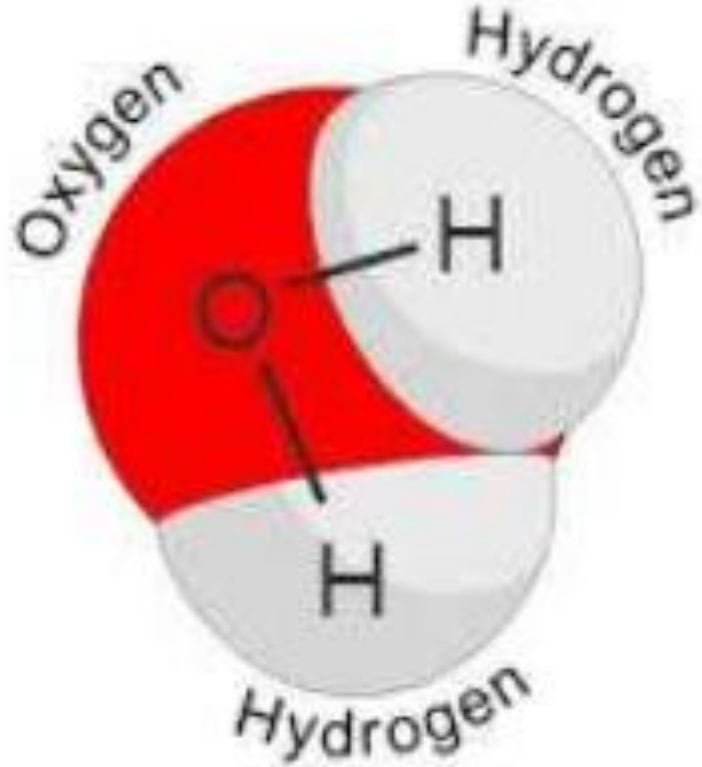
# Available water for plant growth

# *Properties of water*

-It is in the liquid form at room temperature
- is the best solvent for most of the solutes.
-It is inert inorganic compound with neutral pH when in pure form.
-water is best transporting medium for dissolved minerals and food molecules.
-It is best aqueous medium for all biochemical reactions occurring in the cells.
-It is an essential raw material for photosynthesis.
-Water has high specific heat, high heat of vaporization and high heat of fusion.
-it acts as thermal buffer.

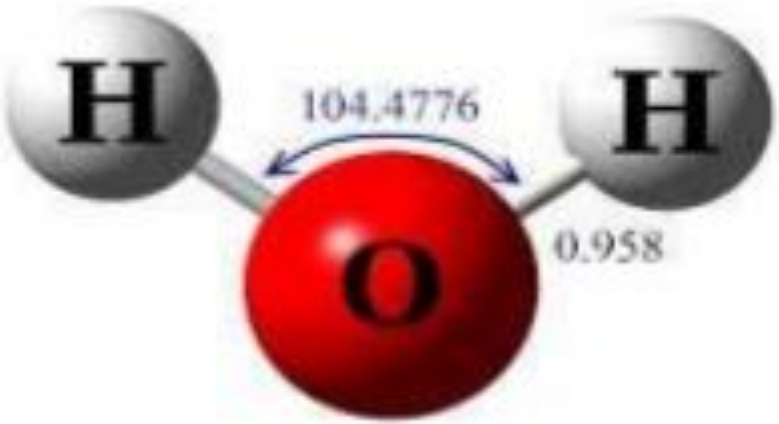
# Structure of Water

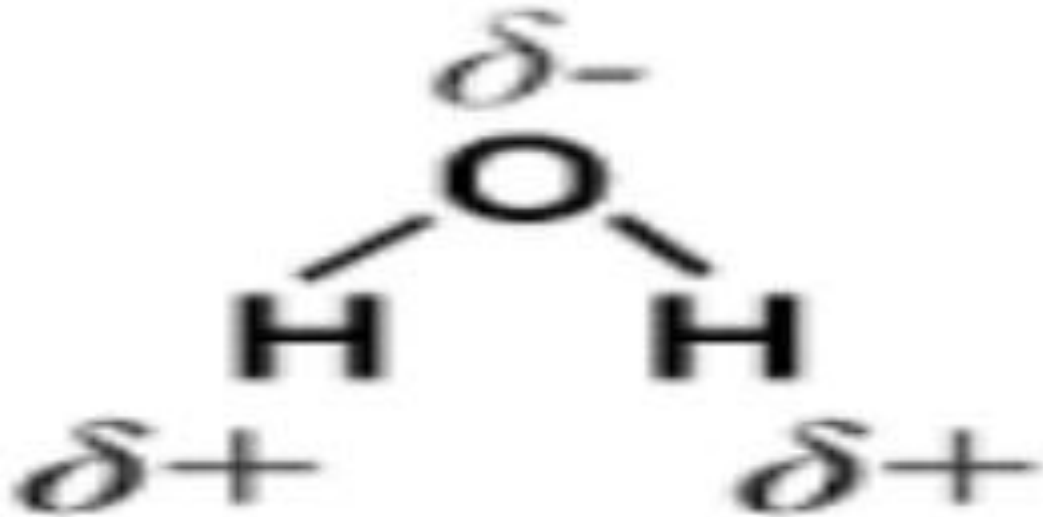
Chemical formula H2O: one molecule of water has two hydrogen atoms covalently bonded to a single oxygen atom.




**Water Chemical Symbol:**

$H_2O$



# Polarity

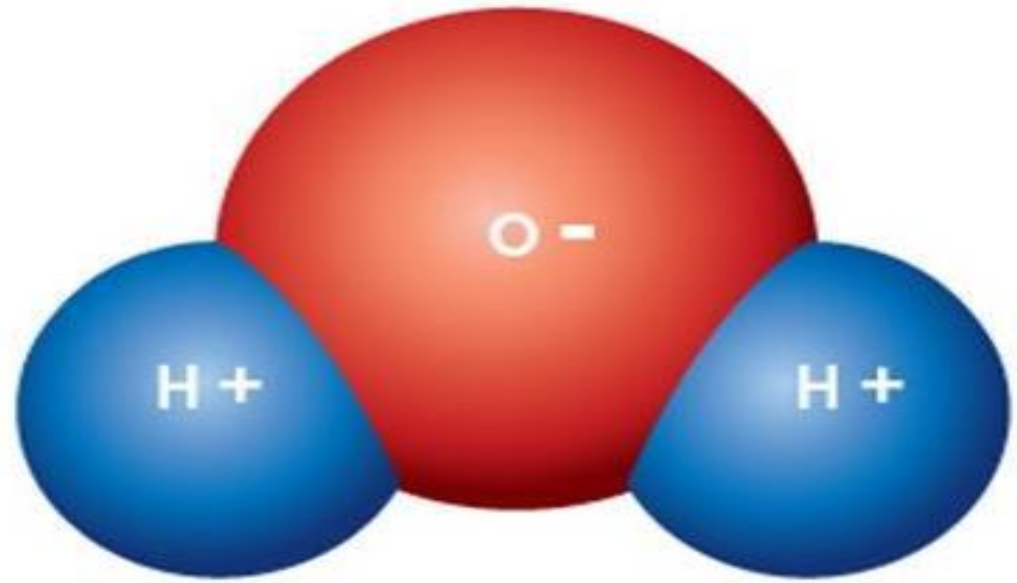
Water is polar because

-of the angles of its chemical bonds,

-the oxygen atom is on one end of the molecule,

-the hydrogen atoms are on the other,

-with 8 protons in its nucleus, an oxygen atom has a much stronger attraction for electrons than the hydrogen atom with a single proton.



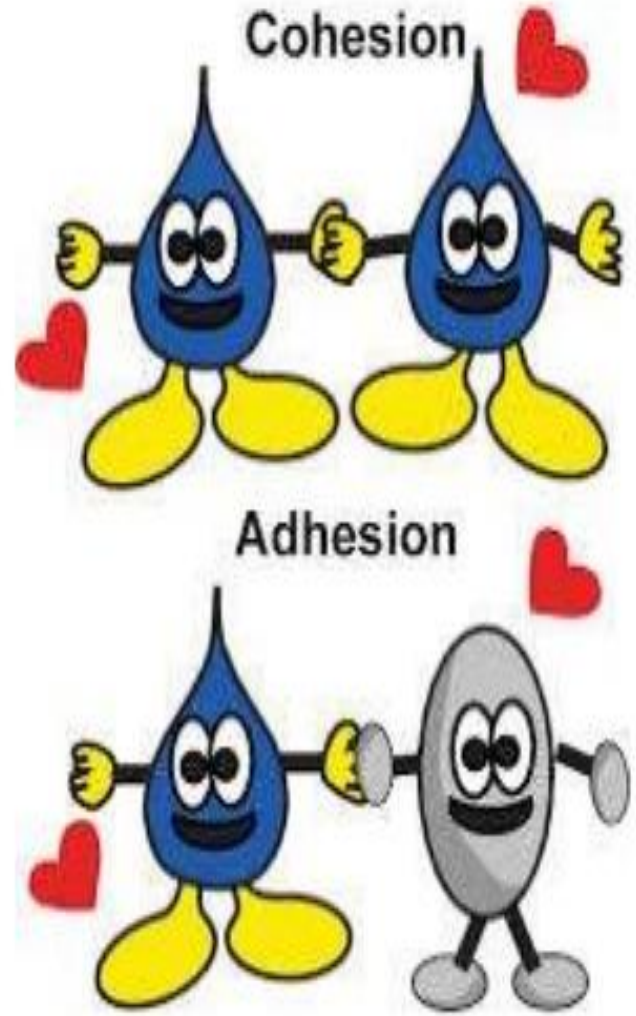
# Elixir of Life

- Special properties of water
  1. cohesion & adhesion
     - surface tension, capillary action
  2. good solvent
     - many molecules dissolve in $H_2O$
     - hydrophilic vs. hydrophobic
  3. lower density as a solid
     - ice floats!
  4. high specific heat
     - water stores heat
  5. high heat of vaporization
     - heats & cools slowly


# Cell Water related terminologies

**Cohesion:** water molecules stick together, a process known as cohesion.

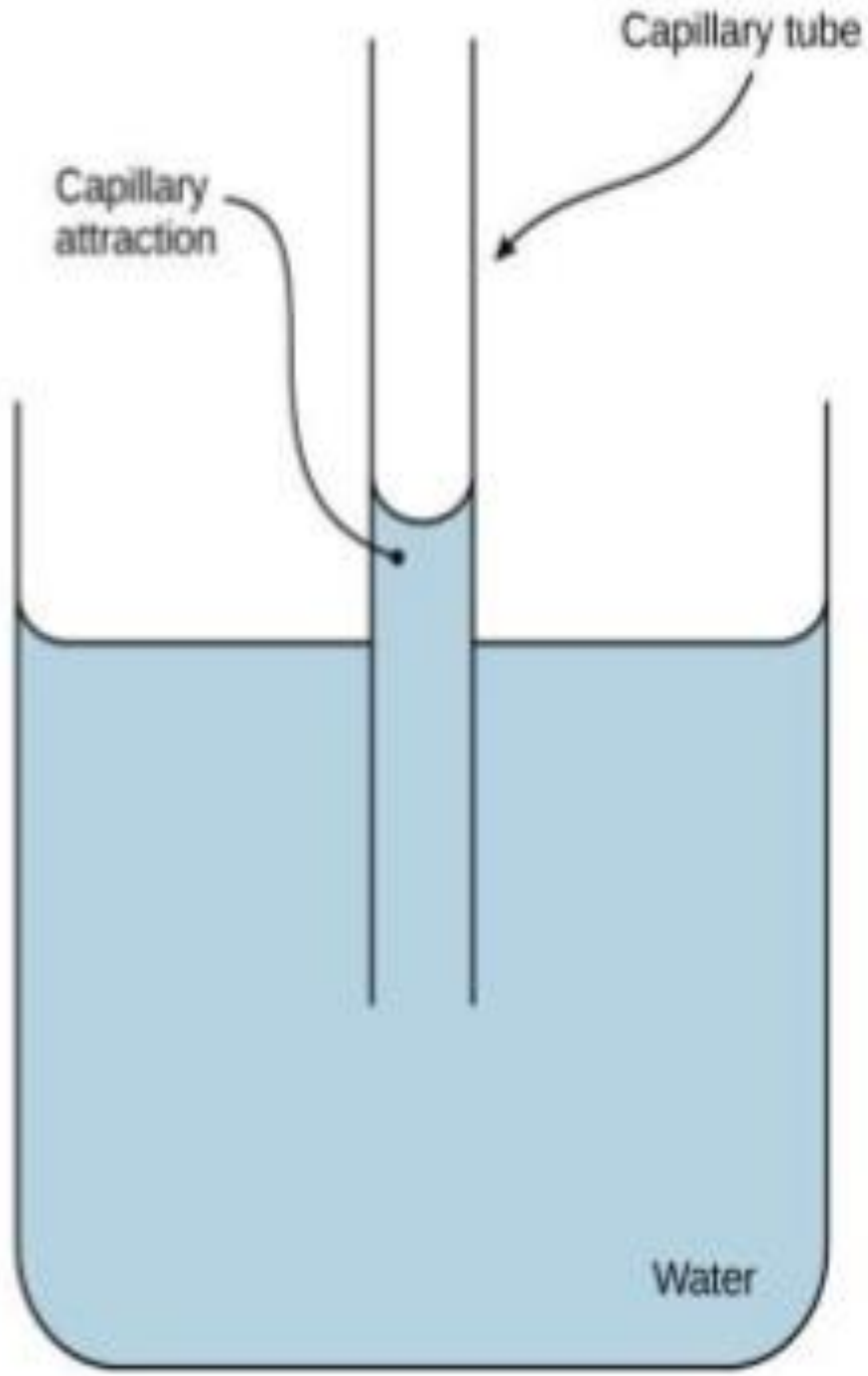
**Adhesion:** When water molecules form hydrogen bonds with other molecules.

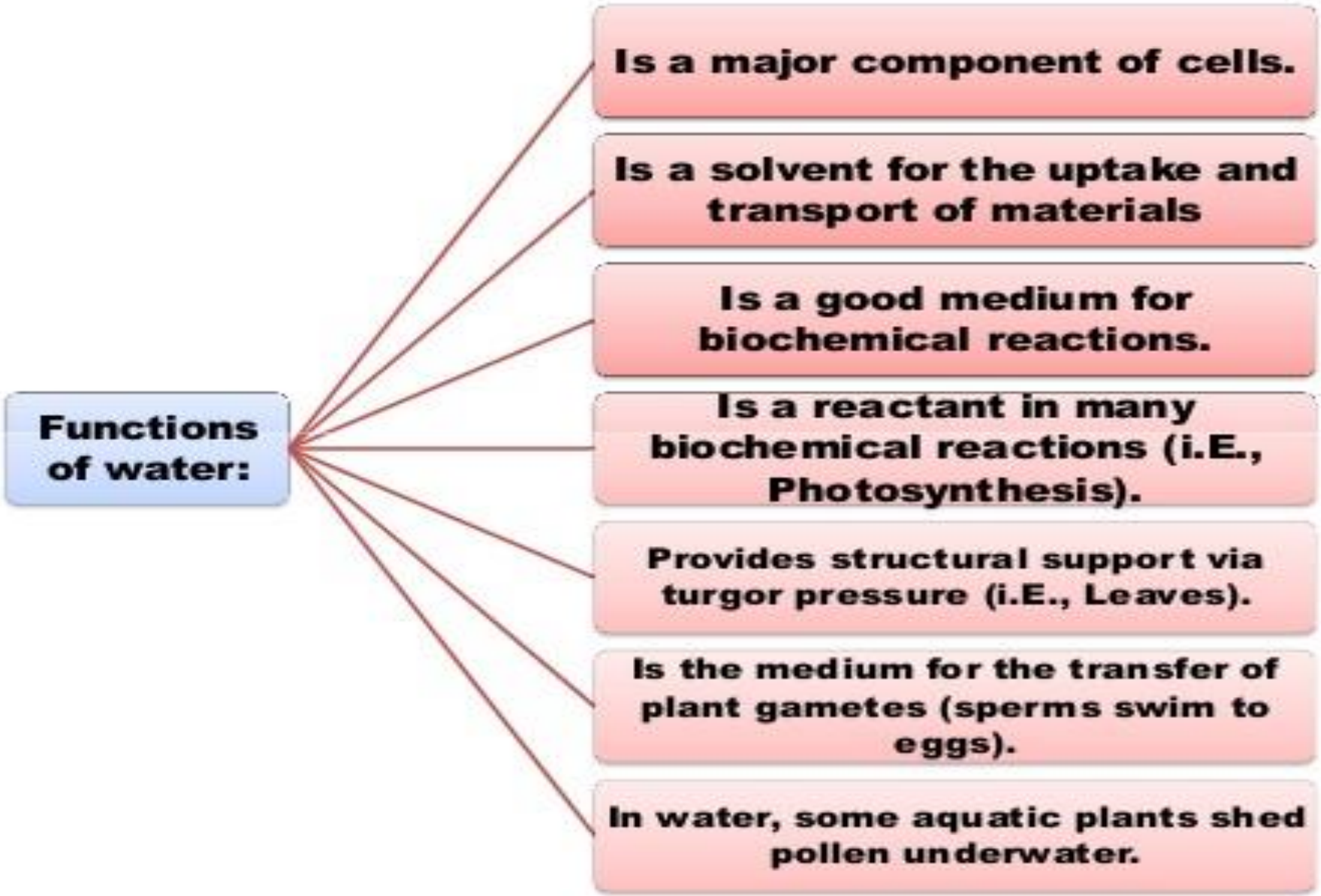


# Capillary action:

The tendency of water to move up a narrow tube against the force of gravity.

E.g. vascular plants, such as trees.




Functions of water:
Is a major component of cells.
Is a solvent for the uptake and transport of materials
Is a good medium for biochemical reactions.
Is a reactant in many biochemical reactions (i.E., Photosynthesis).
Provides structural support via turgor pressure (i.E., Leaves).
Is the medium for the transfer of plant gametes (sperms swim to eggs).
In water, some aquatic plants shed pollen underwater.

# ROOT

Root is the main organ of water and mineral absorption.

Terestrial plants –absorb water in the form of liquid from the soil

Epiphytic plants – (orchids) absorb water vapours from air with the help of epiphytic roots having special tissue called velamen

# STRUCTURE OF ROOT

Typical root is divisible into four different

regions.

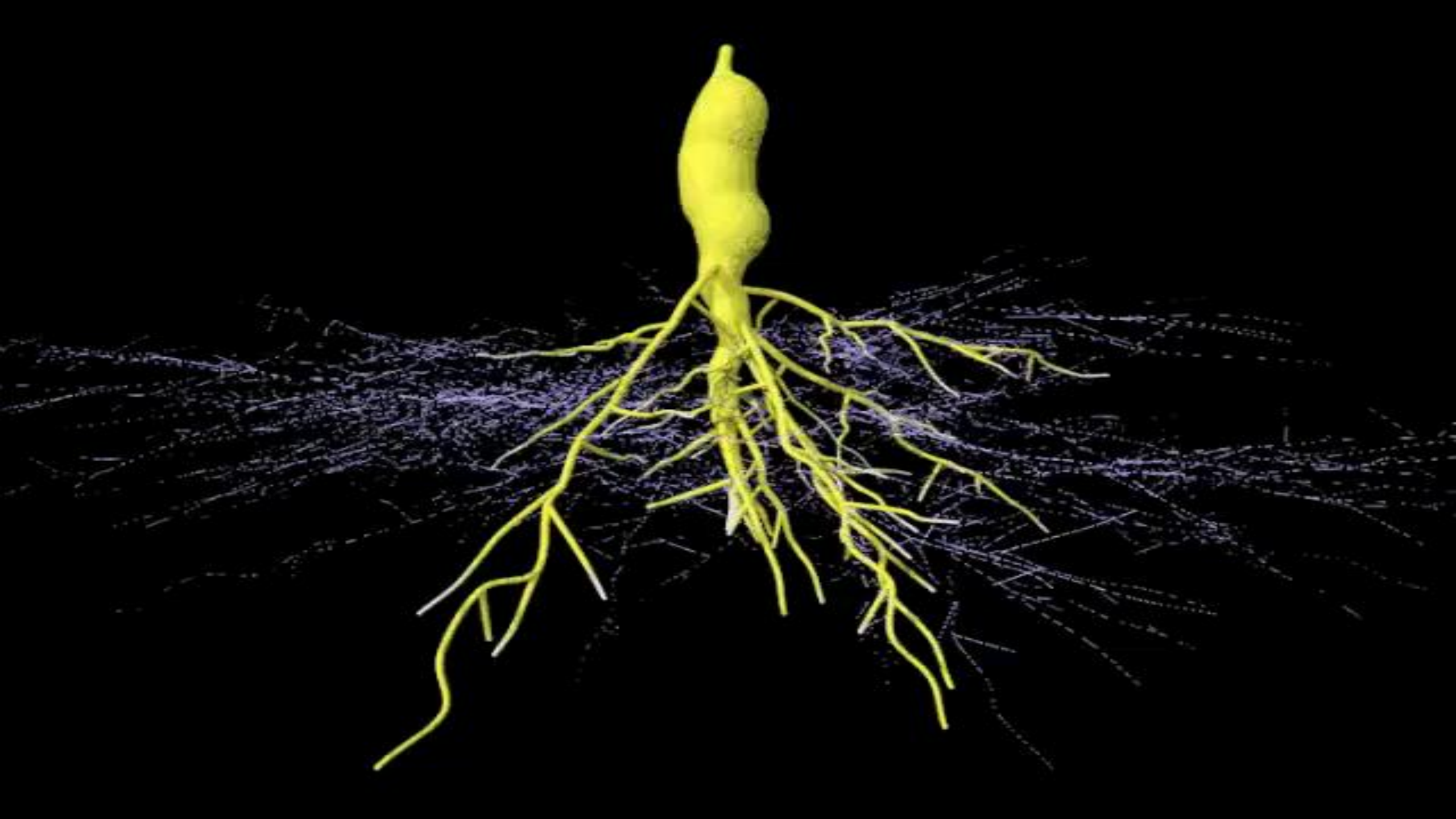
Root cap

Zone of cell division

Zone of Elongation

Zone of Absorption

Zone of Maturatio



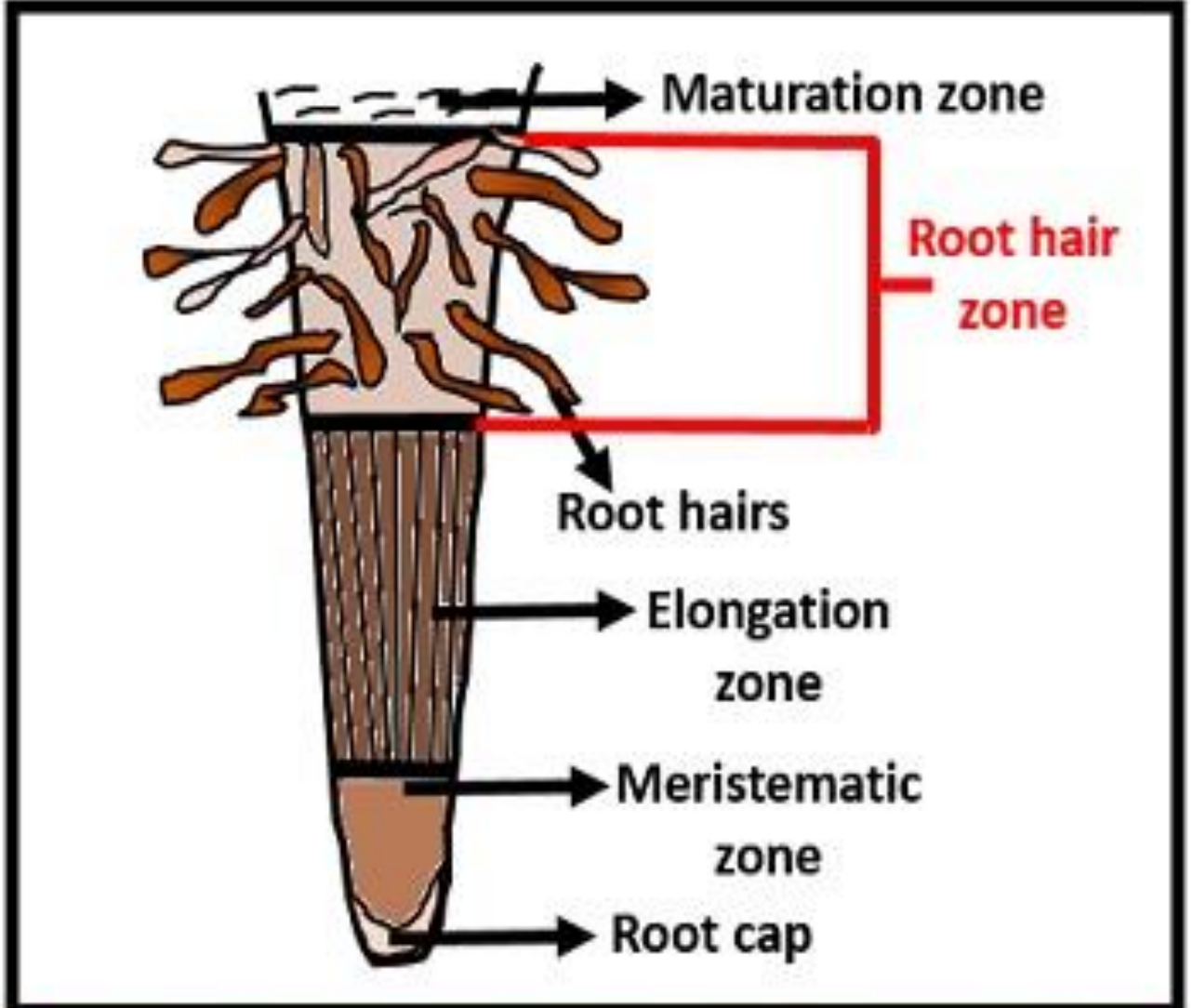
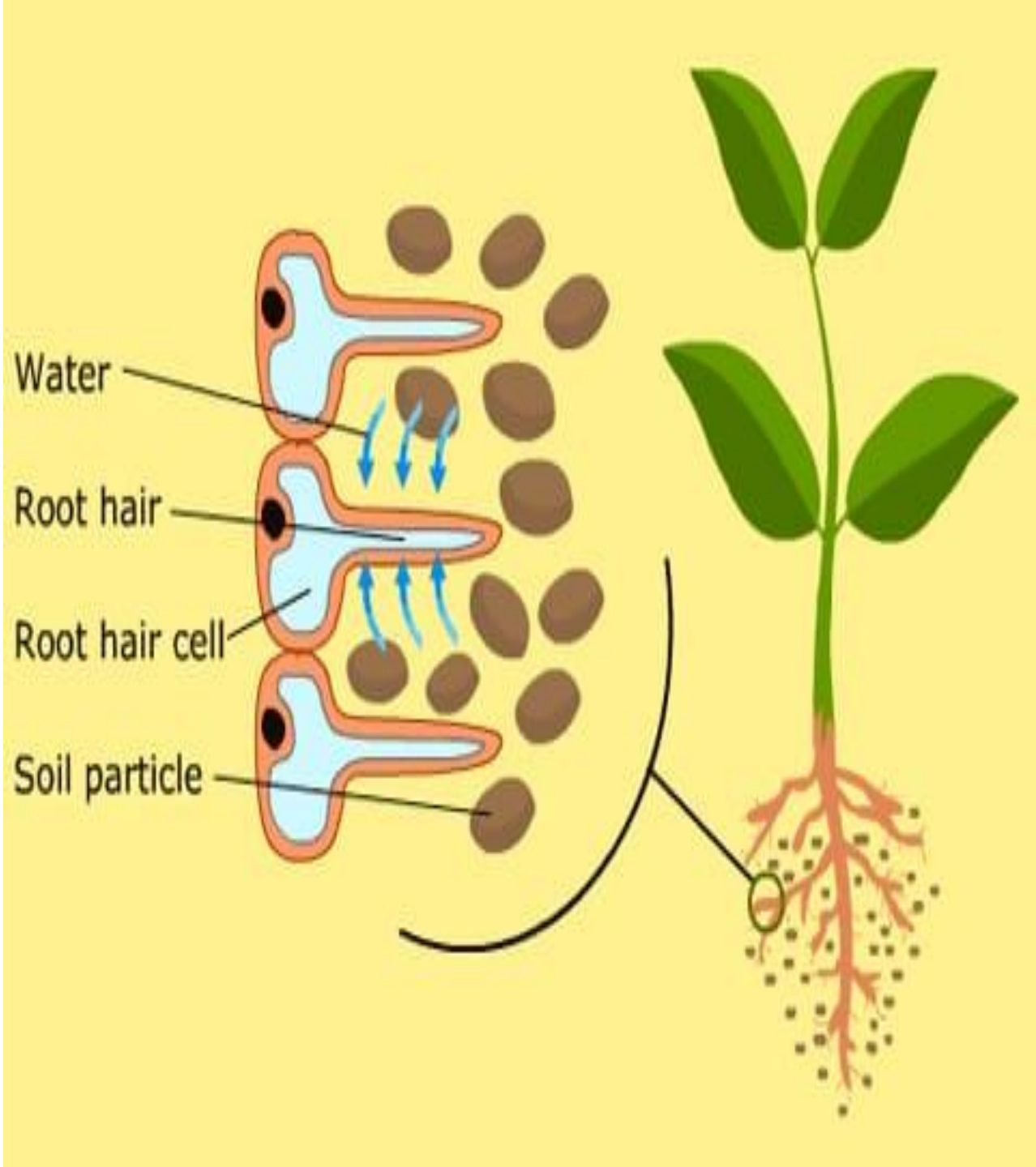
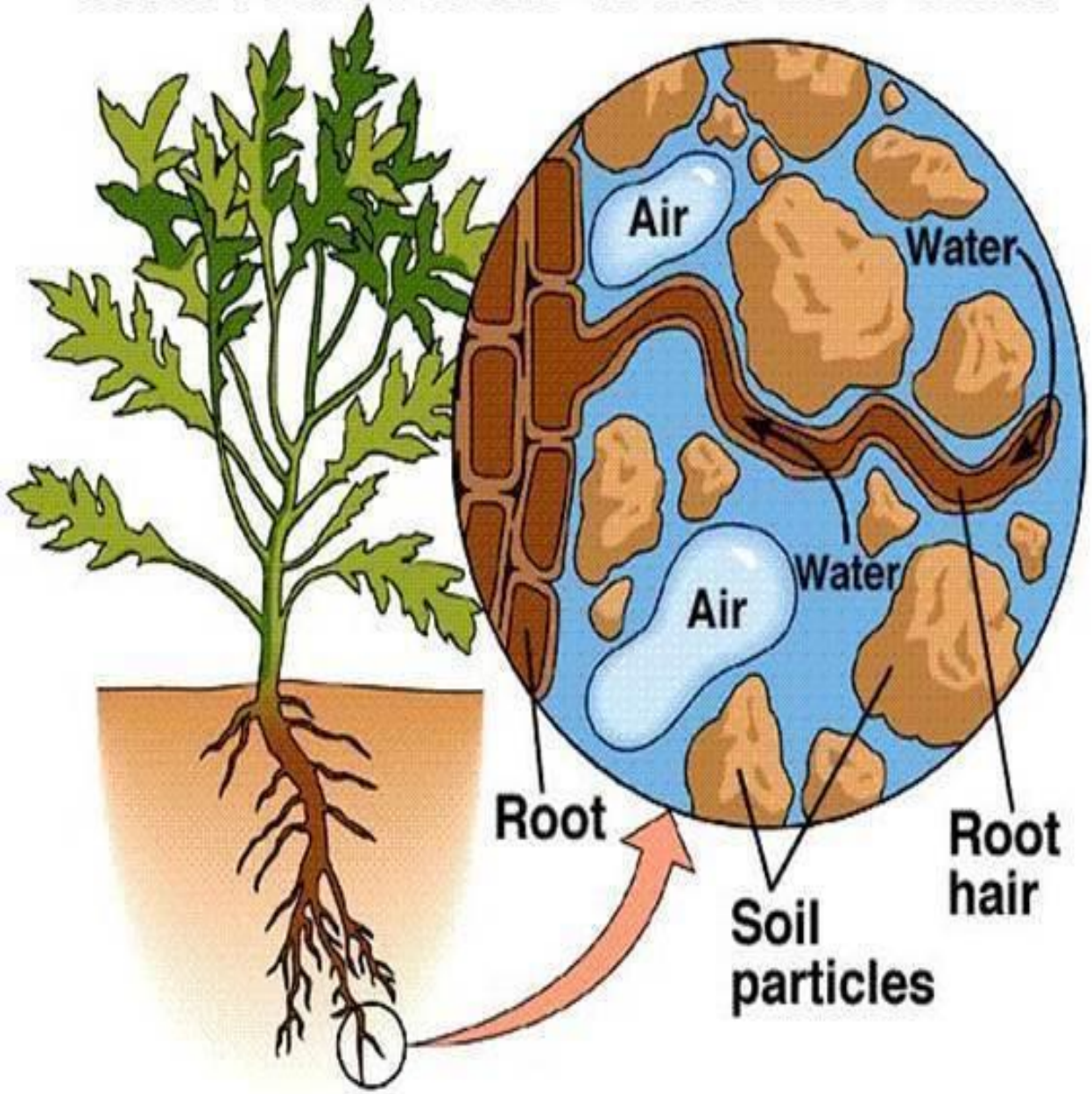
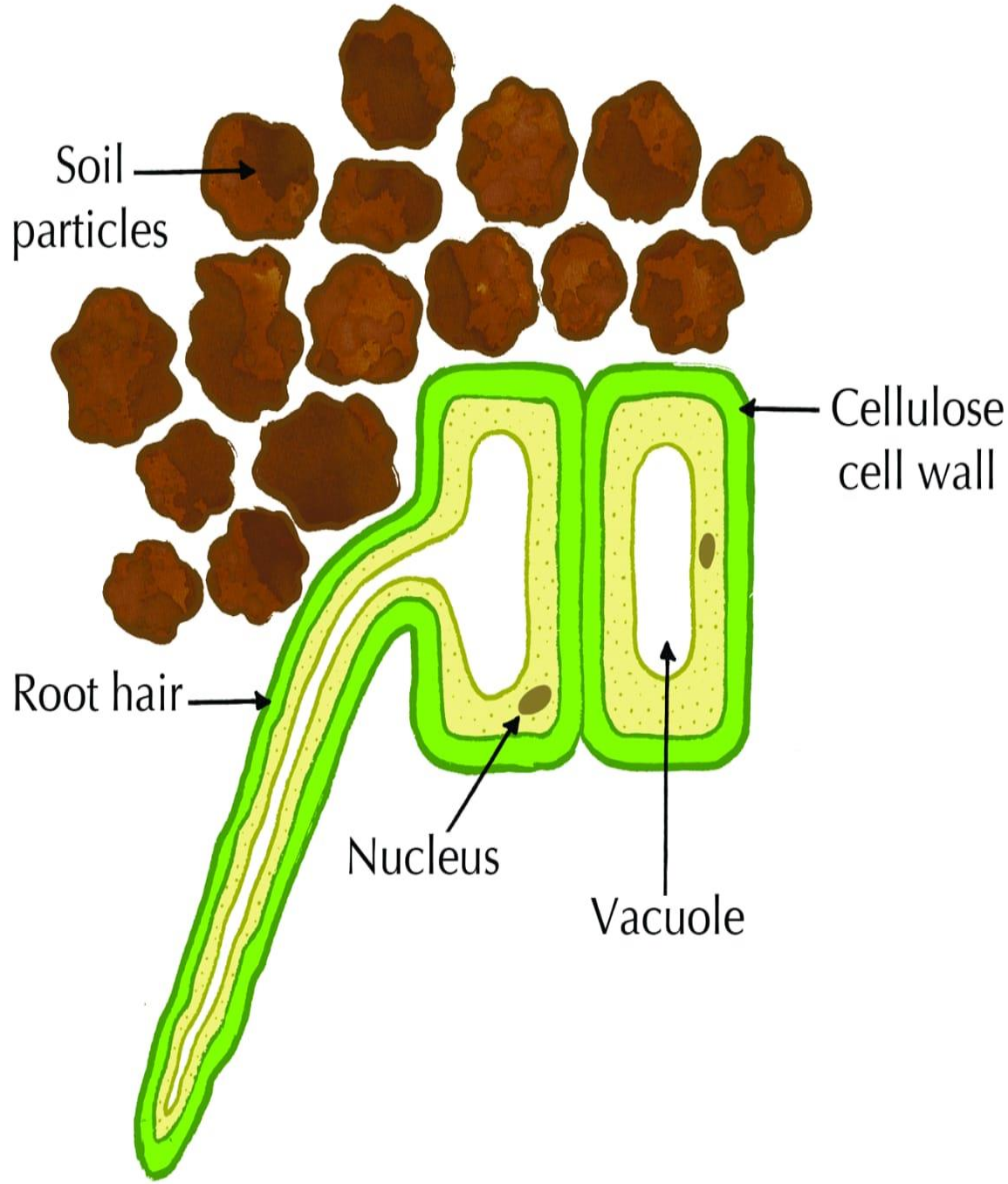



**DIAGRAM SHOWING ROOT HAIR ZONE: REGION OF WATER ABSORPTION**



# Root Hairs Absorb Water and Nutrients from the Soil



# STRUCTURE OF ROOT HAIRS

-presnt at the zone of absorption

-epidermal cells (epiblema cells) form unicellular hair like extensions called root hairs.

## Structure of root hair :

-Root hair is cytoplasmic extension (prolongation) of epiblema cell.

-Each root hair may be approximately 1 to 10mm long and tube like structure.
-It is colourless,unbranched, short-lived (ephemeral) and very delicate.

-It has a large central vacuole surrounded by thin film of cytoplasm, plasma membrane and thin

cell wall, which is two layered.

- Outer layer is composed of pectin and inner layer is made up

of cellulose.

- Cell wall is freely permeable but plasma membrane is selectively permeable

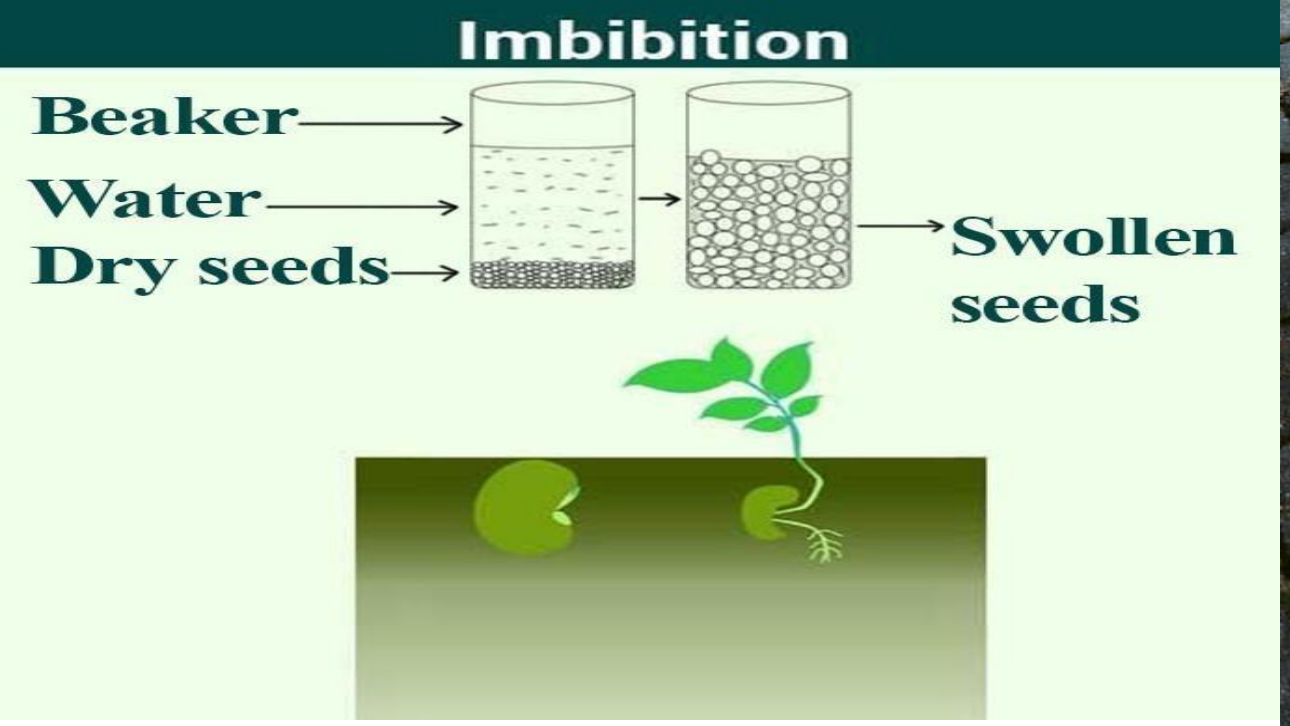
1. Plants absorb water from the *rhizosphere* (the microenvironment surrounding the root)

2. Root hair absorbs water by employing three physical processes that occur sequentially- *imbibition*, *diffusion* and *osmosis*.

The rhizosphere is the zone of soil surrounding a plant root where the biology and chemistry of the soil are influenced by the root. As plant roots grow through soil they mostly release water soluble compounds such as amino acids, sugars and organic acids that supply food for the microorganisms.

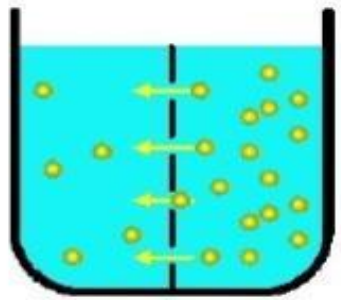
# *IMBIBITION*

1. Imbibition is swelling up of hydrophillic colloids due to adsorption of water.
2. Substance that adsorbs water / liquid, is called as *imbibant*
3. And water/ liquid, that gets imbibed is called as *imbibate*.
4. The root hair cell wall is made up of pectic compounds and cellulose which are *hydrophillic colloids*. During Imbibition, water molecules get tightly adsorbed without the formation of solution. Imbibition continues till the equilibrium is reached. In other words, water moves *along the concentration gradient*.

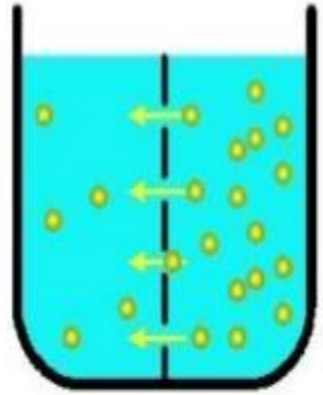

Imbibition
Beaker
Water
Dry seeds
Swollen seeds

# Diffusion

- Diffusion is the *net* movement of ions or molecules from a region where they are in **higher** concentration to a region where they are in **lower** concentration i.e. *down a concentration gradient*



Diffusion



**LOW** concentration

**HIGH** concentration

A difference in concentration between 2 areas is called a **CONCENTRATION GRADIENT**.

# Factors affecting rates of diffusion

| Rate of diffusion | Effect |
| --- | --- |
| Temperature | Increase temp increase rate of diffusion |
| Size of particles | Decrease molecule size increase rate of diffusion |
| Thickness of barrier | Cell membrane in plant and animals are about the same<br>Increase thicker cell wall decrease rate of diffusion |
| Concentration gradient | Increase concentration gradient increase rate of diffusion |
| Total surface area of cell membrane | Increase in surface area increase rate of diffusion<br><br>E.g. root hair cells microvillus in ileum |

-Diffusion results in the diffusion pressure (D. P.) which is directly proportional to the number of diffusing particles.
-Diffusion pressure of pure solvent (pure water) is always more than the diffusion pressure of solvent in a solution.
-The difference in the diffusion pressures of pure solvent and the solvent in a solution is called *Diffusion Pressure Deficit (DPD)* or Suction Pressure (SP).
The term was coined by *B.S. Meyer (1938).*
-Now a days, term water potential is used for DPD.
- the term DPD is actually the thirst of a cell with which it absorbs water from the surroundings.
-Water arro diffusion wall has more diffusion pressure than cell sap.
- Due to this, water moves in the cell by diffusion.

## *Facilitated diffusion :*

The passive absorption of solutes when mediated by a carrier, is called Facilitated diffusion.

- Particles that are lipid soluble can easily diffuse through lipoproteinous cell membrane.

-The diffusion of hydrophilic solutes has to be facilitated because their diffusion across the membrane is difficult.

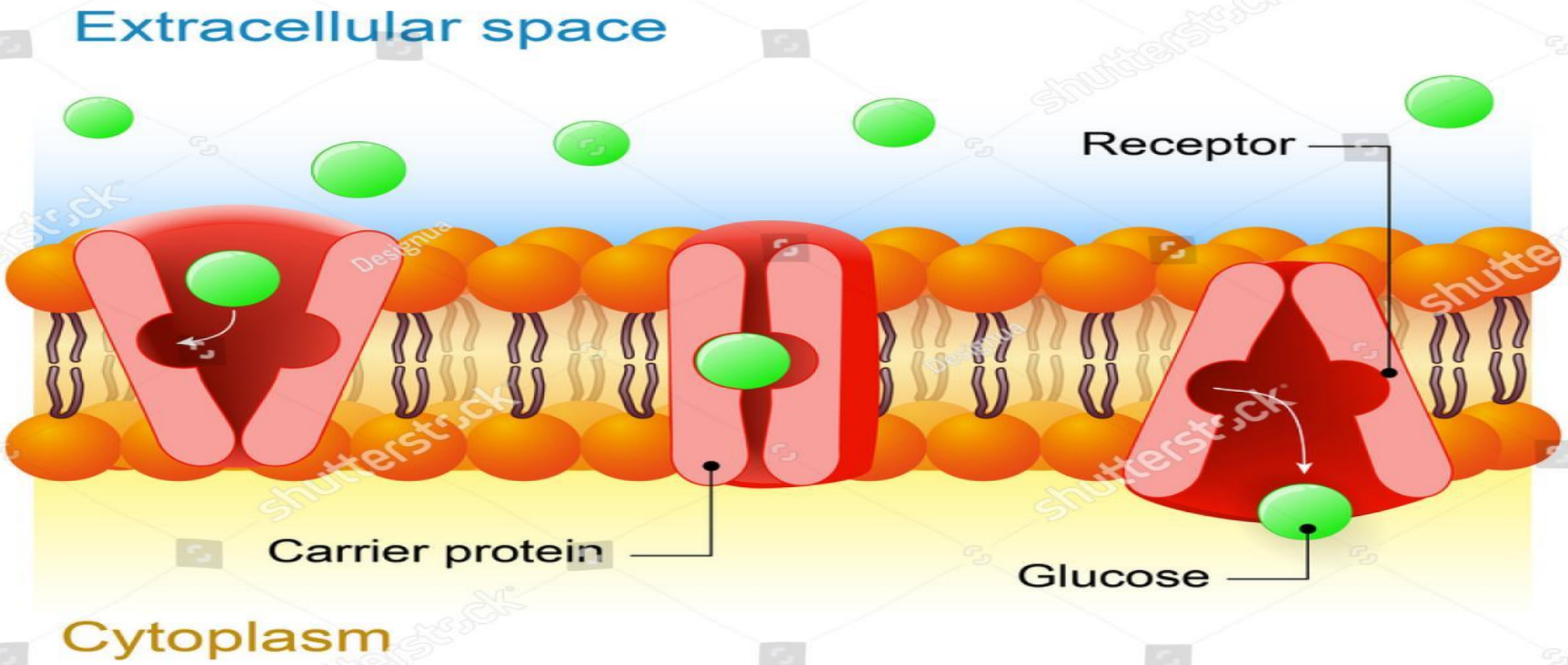
Membrane proteins provide such sites for facilitated diffusion.

-These proteins are aquaporins (8)and ion-channels.

-These proteins help move substances across membranes without the expenditure of energy.

-Concentration gradient must be present for the molecules to be diffused through facilitated diffusion.

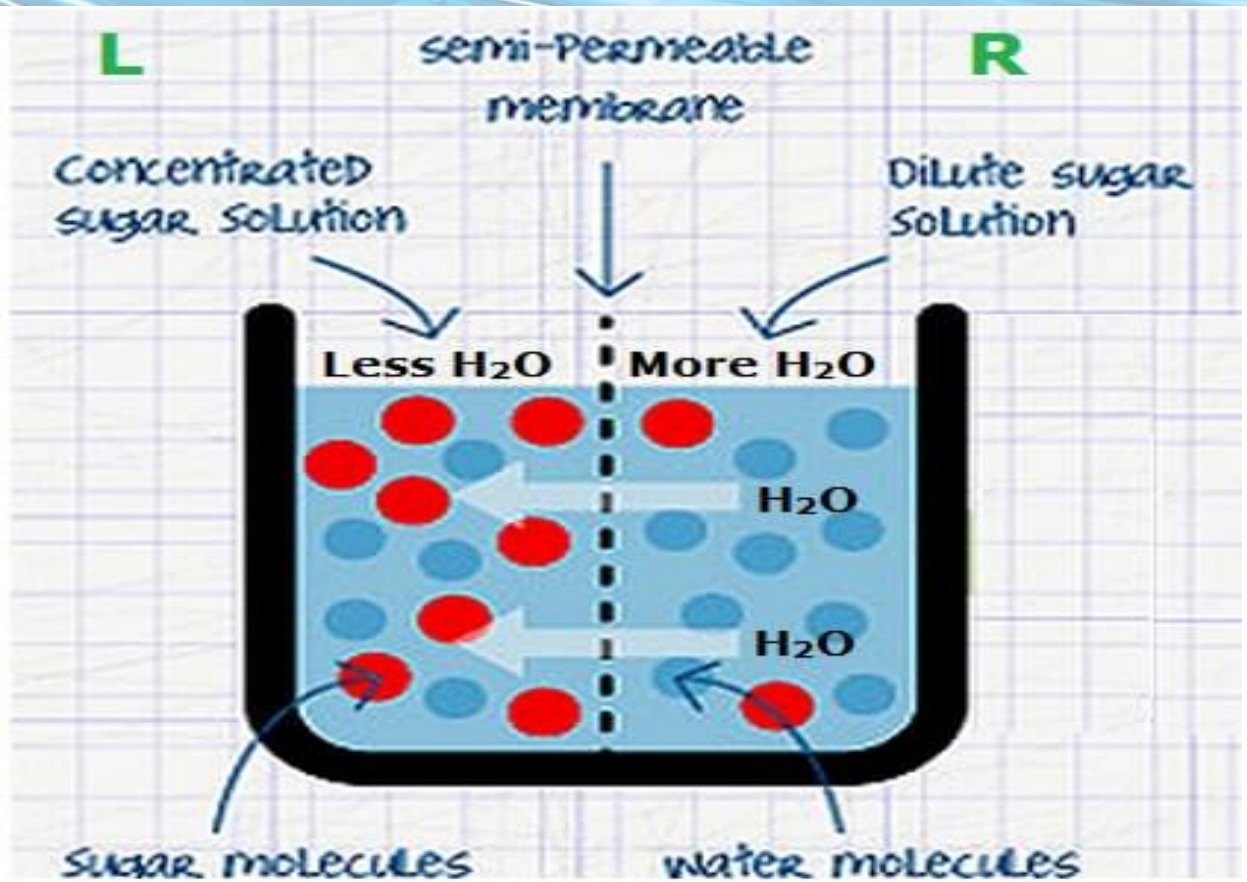
# FACILITATED DIFFUSION

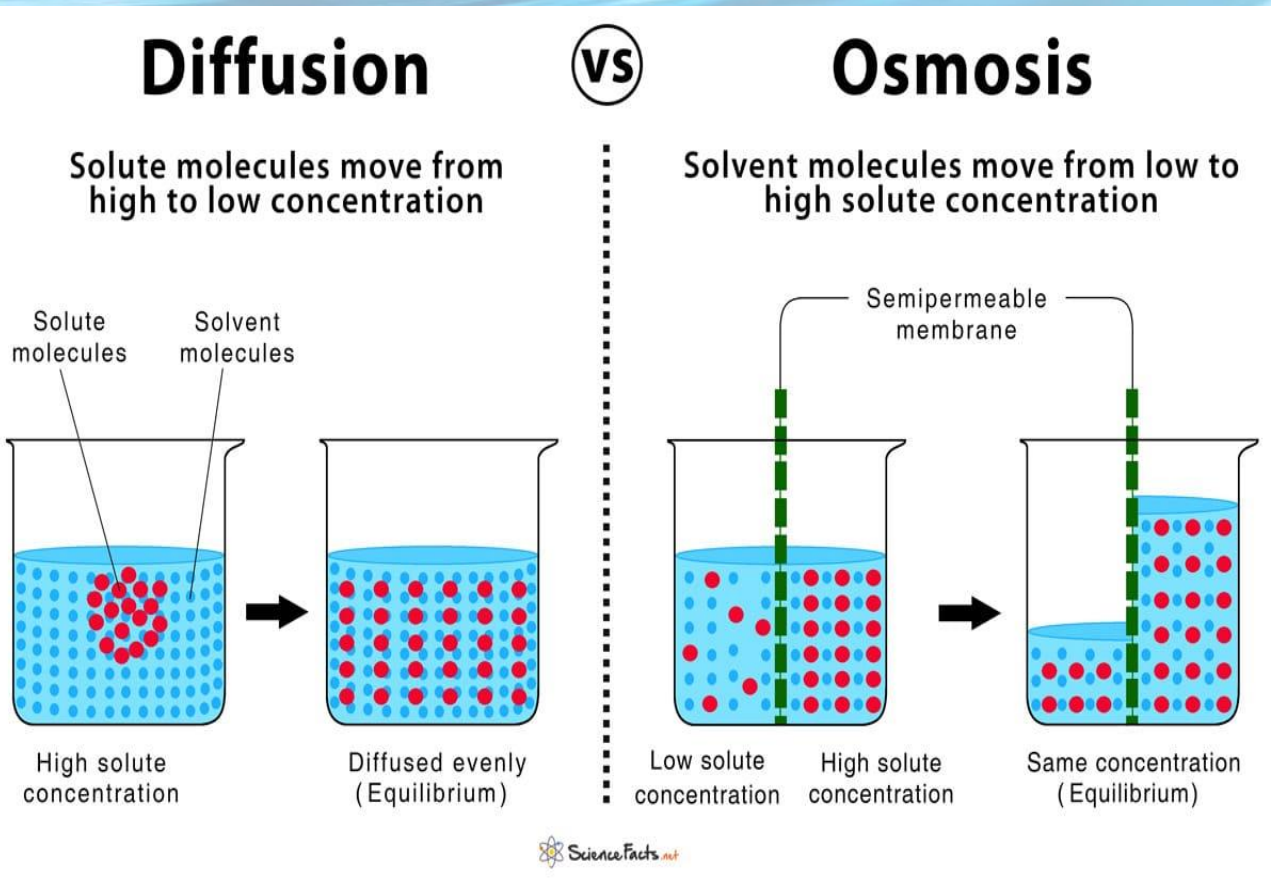


# Osmosis

*n., from Greek ὠσμός (ōsmós), meaning "push"*

**In biology, the net movement of water molecules through the cell membrane from an area of higher to an area of lower water potential**

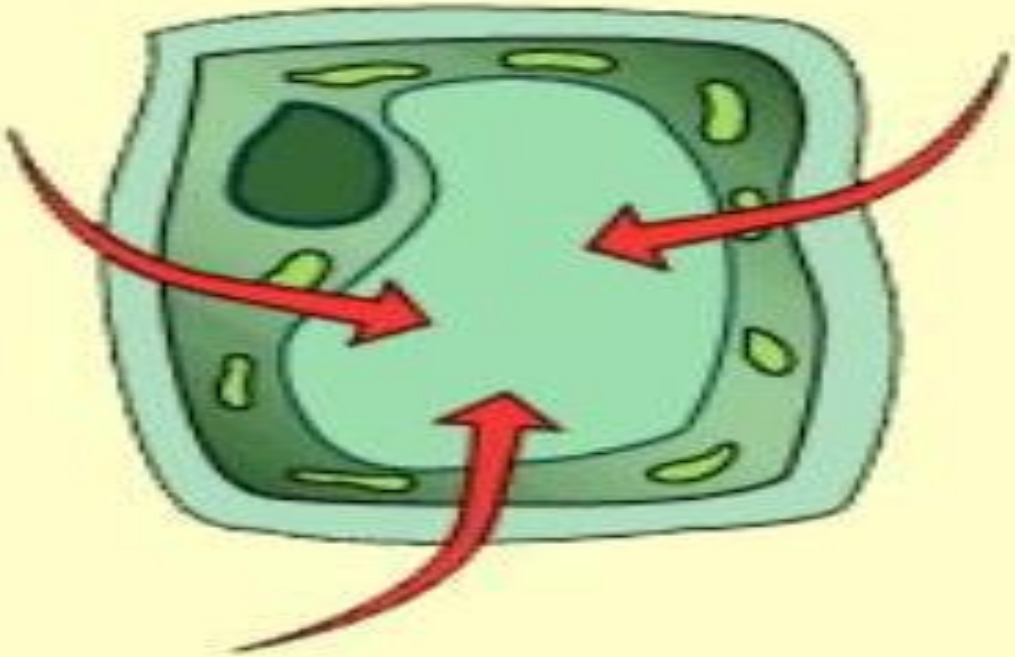


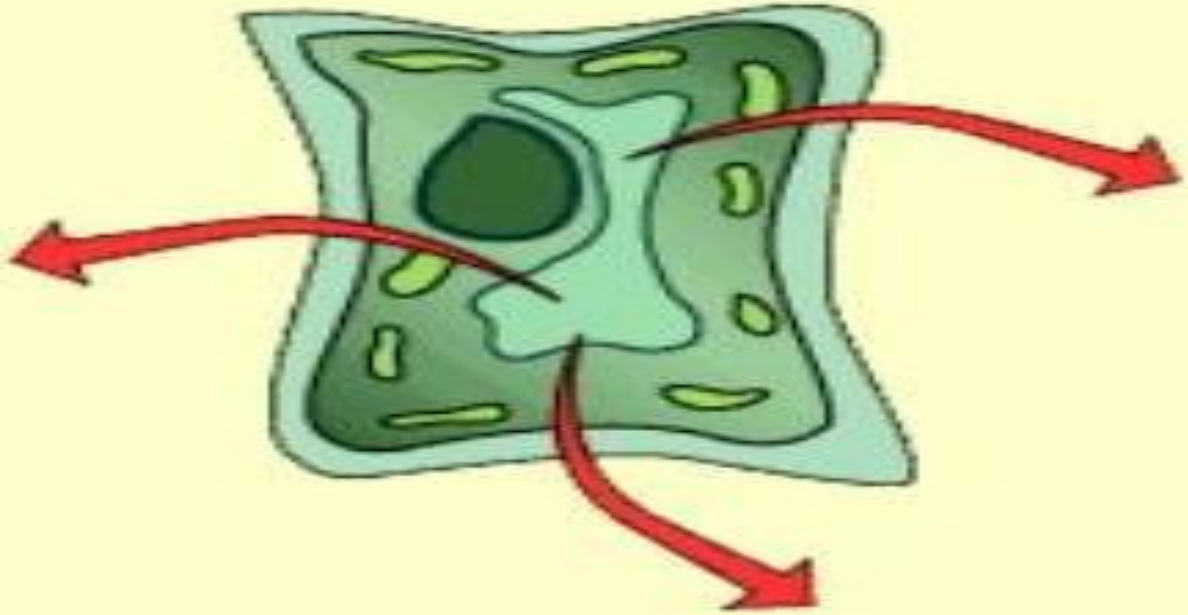
# Osmosis is of two types

**Endo-osmosis :** It is the migration of the solvent into the cell. It causes turgidity of cell i.e. Cytoplasm becomes turgid.qq

**Exo-osmosis :** It is the migration of solvent from the cell outside. It causes flaccidity of cell



TURGID CELL:
water enters by osmosis,
vacuole swells and
pushes against cell wall



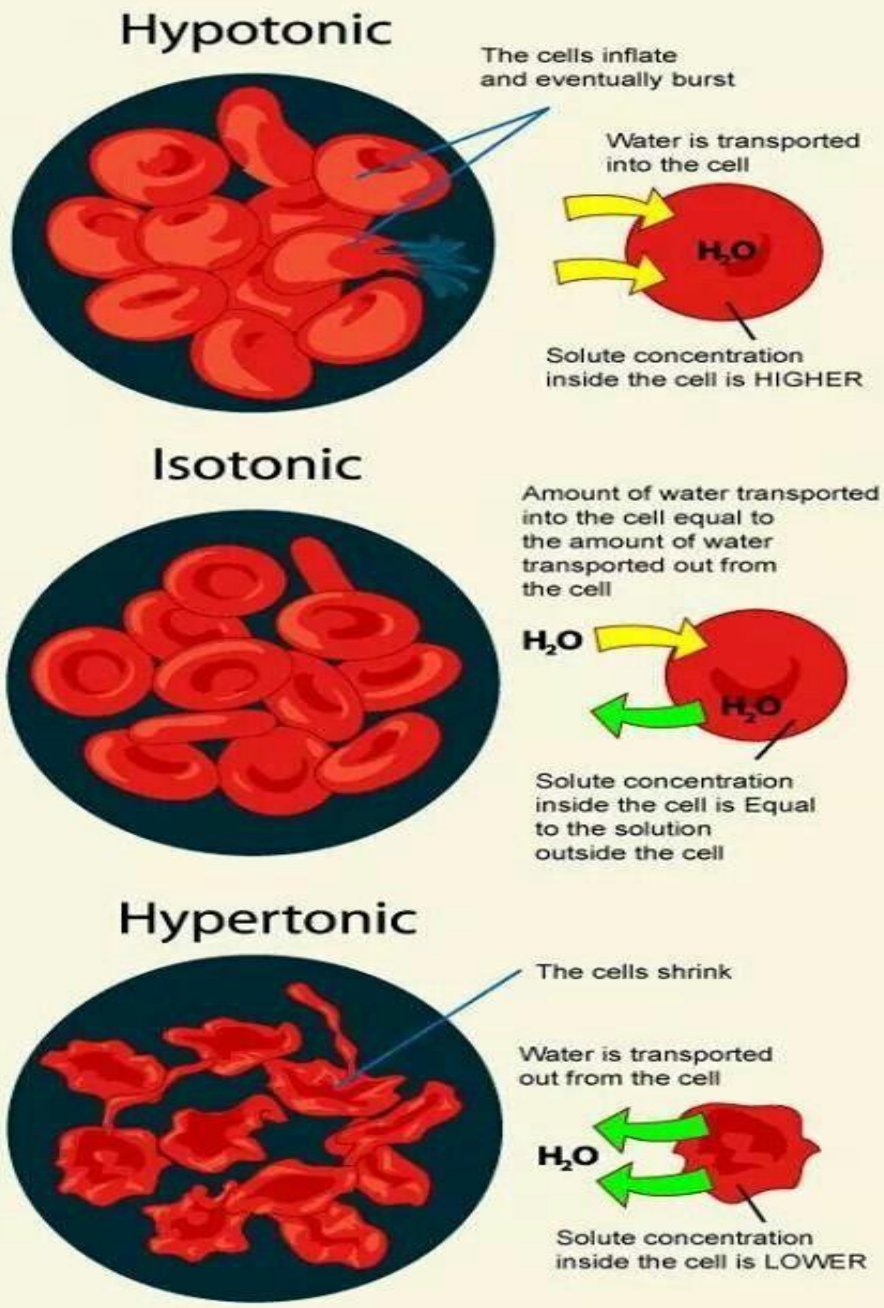
FLACCID CELL:
water lost from cell,
vacuole shrinks,
cell loses shape

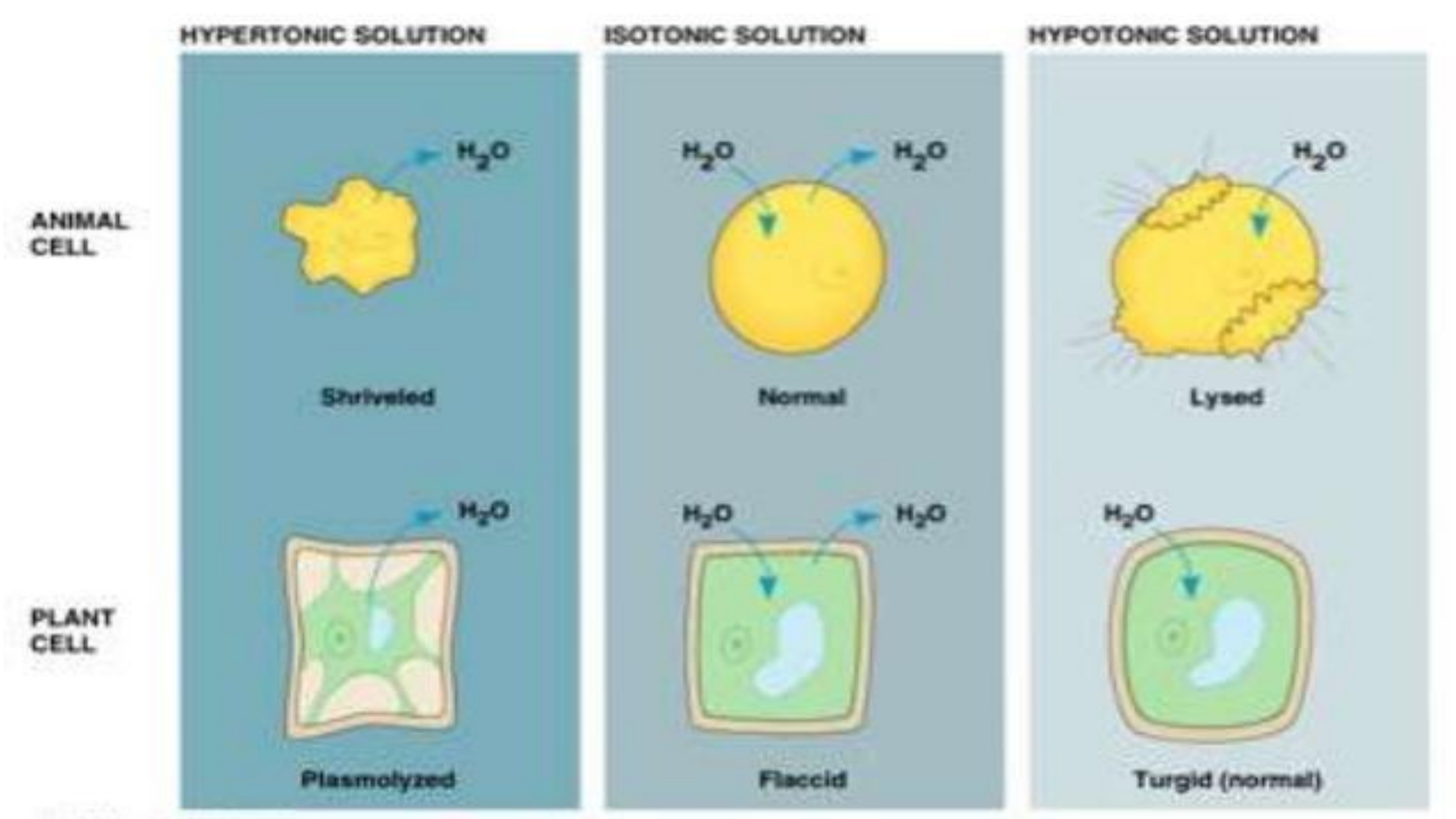
Three types of solutions are recognized viz,

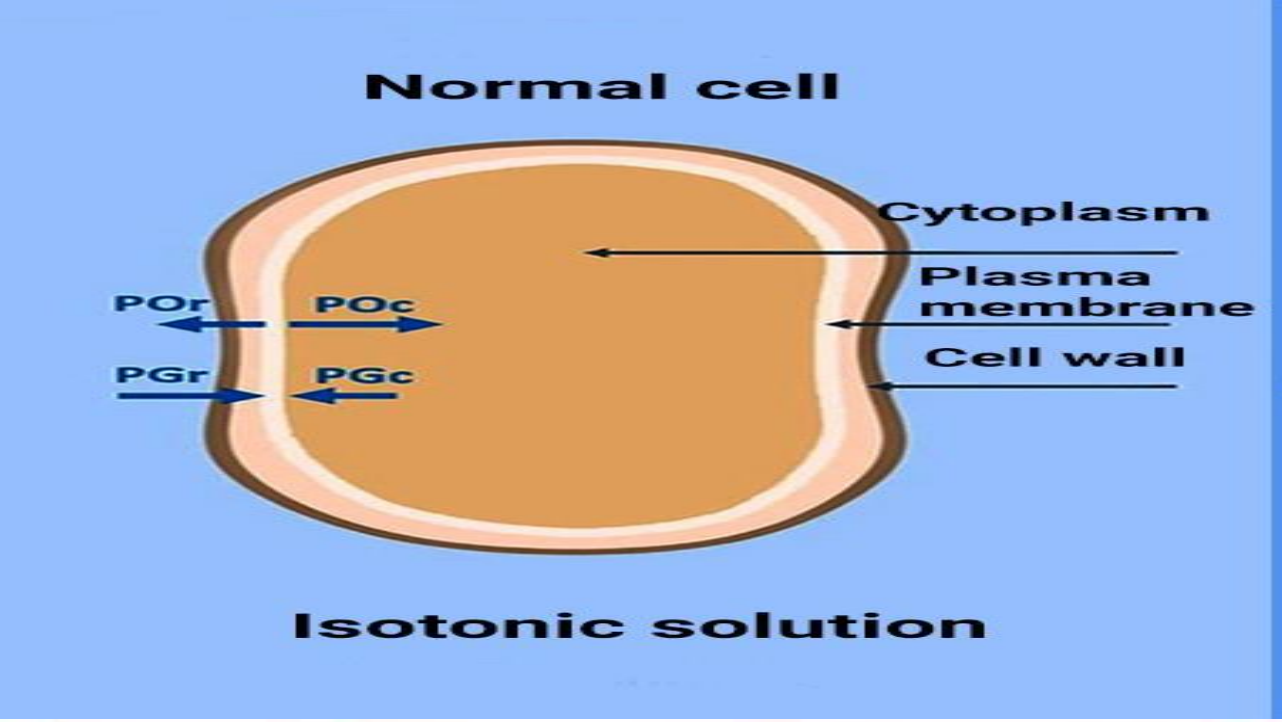
i. *Hypotonic* (weak solution or strong solvent) having low osmotic concentration.

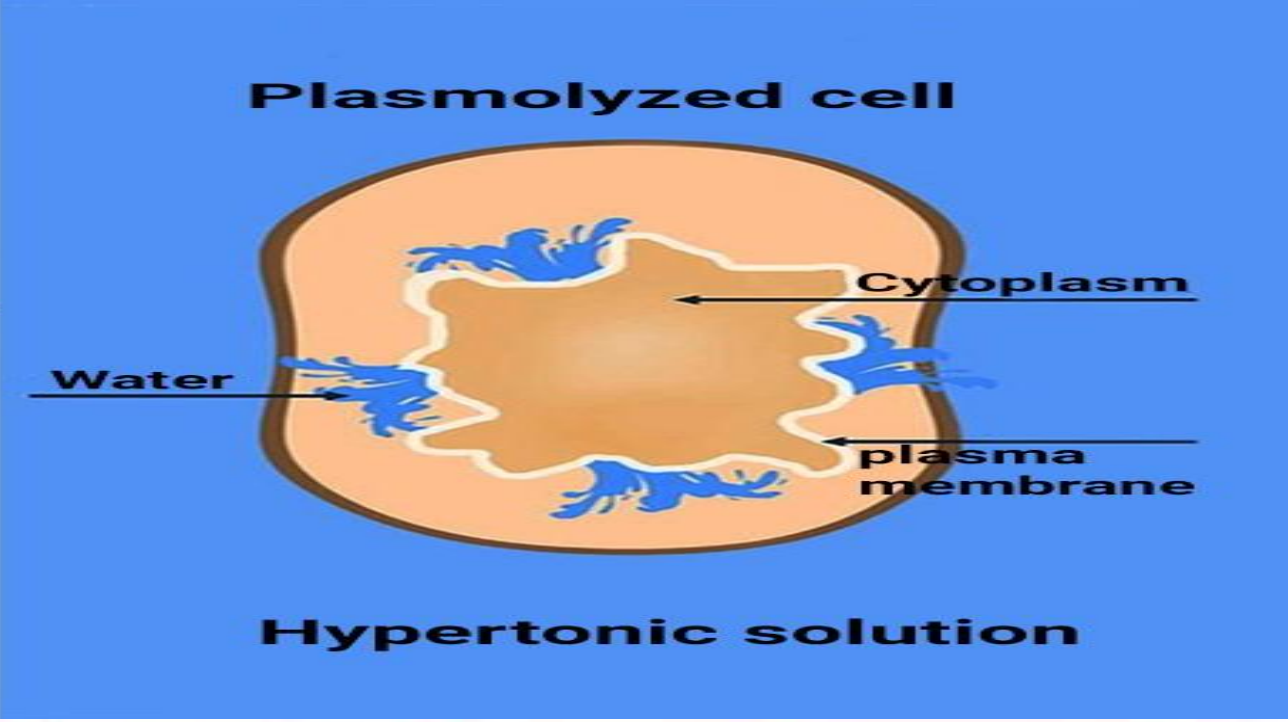
ii. *Isotonic* having such a concentration of solution where there is neither gain nor loss of water in an osmotic system. In other words, concentration outside and inside the cell is same

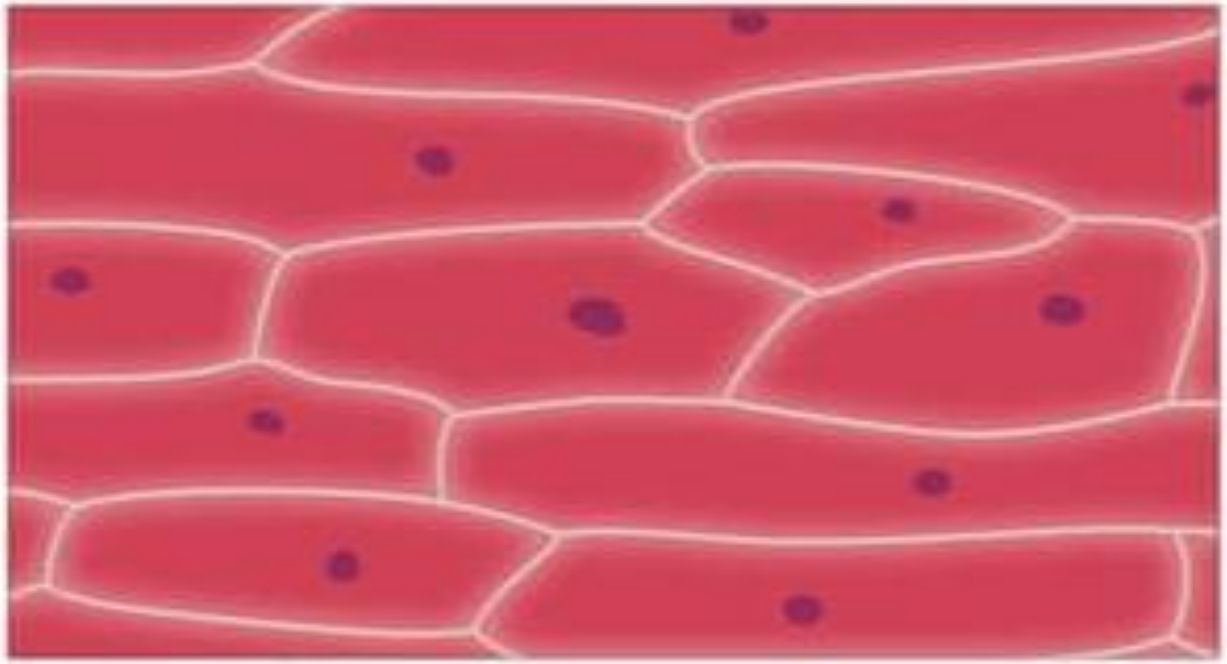
iii. *Hypertonic* (strong solution or weak solvent) having high osmoticconcentration.

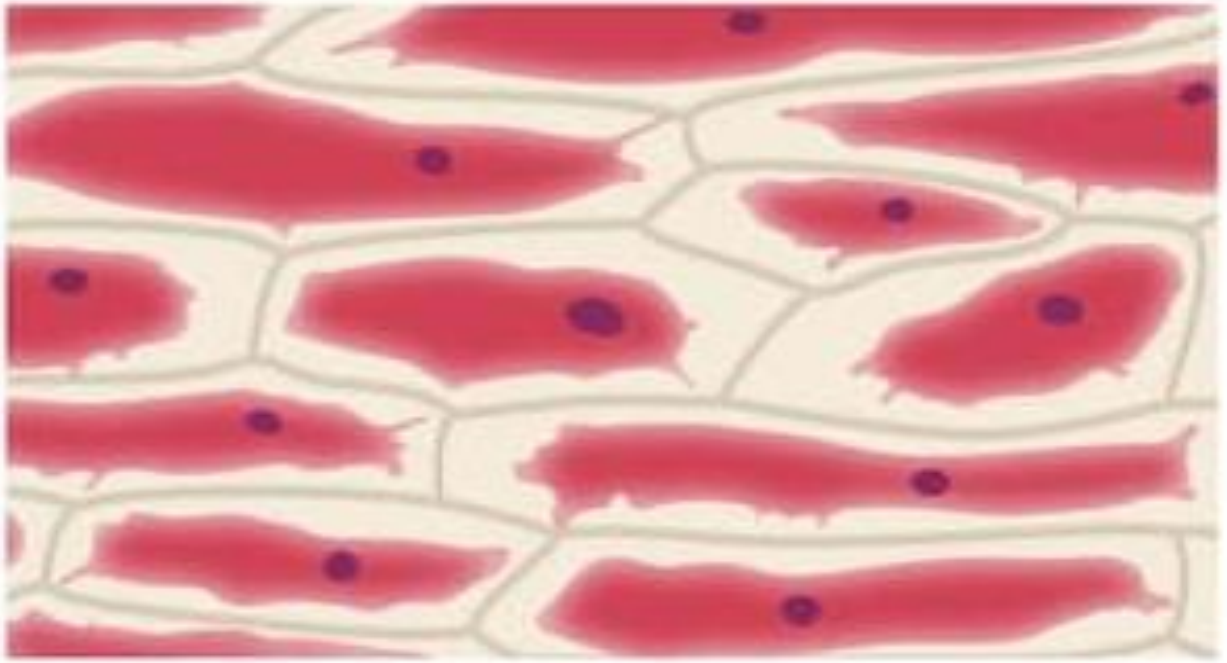



HYPERTONIC SOLUTION
ISOTONIC SOLUTION
HYPOTONIC SOLUTION
ANIMAL CELL
PLANT CELL
$H_2O$
Shriveled
Normal
Lysed
Plasmolyzed
Flaccid
Turgid (normal)


Normal cell
Cytoplasm
Plasma membrane
Cell wall
POr
POc
PGr
PGc
Isotonic solution


Plasmolyzed cell
Cytoplasm
Water
plasma membrane
Hypertonic solution





## *Importance of T. P. :*

-It keeps cells and

organelles stretched. –provides support to

the non-woody tissues –essential for cell

enlargement during growth –maintains shape of cell and –facilitates opening and closing of stoma.

## *Improtance of Osmosis :*

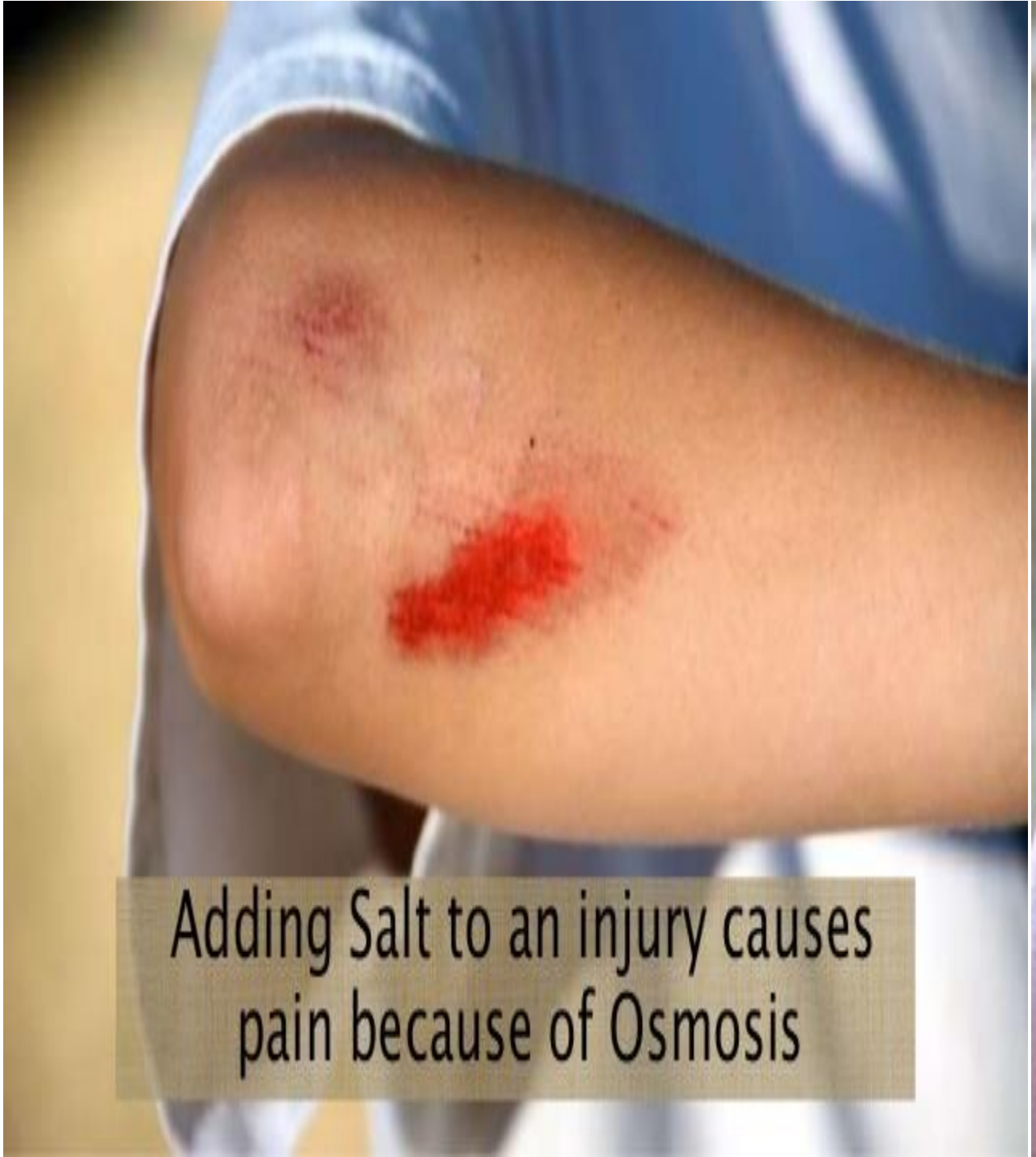
It is responsible for absorption of water into root

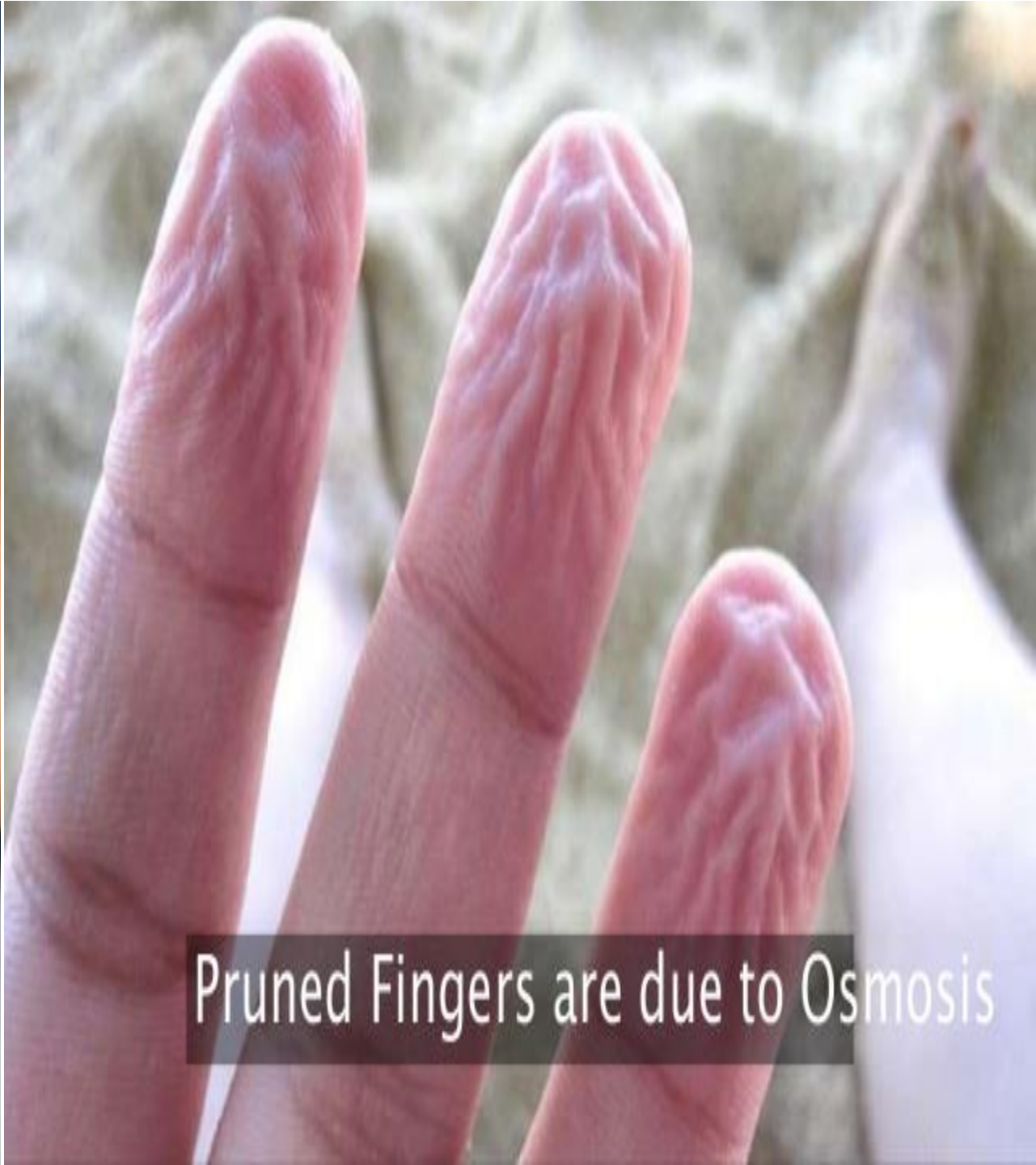
-maintains turgidity of cell

-facilitates cell to cell movement of water.

-offers resistance to drought, frost, etc

- helps in the drooping of leaflets and leaves in vicinity of “touch me”


Adding Salt to an injury causes
pain because of Osmosis


Pruned Fingers are due to Osmosis

## *Water Potential (ψ):*

According to the principle of thermodynamics, every component of a system is having a definite amount of free energy which is used to do work.

- Osmotic movement of water is on the basis of free energy.
-Free energy per molecule in a chemical system, is called its chemical potential.
-Chemical potential of water is called water potential.
- It is represented by Greek letter psi (ψ).
-Water potential of protoplasm is equal but opposite in sign to DPD It has negative value.
-The unit of measurement is in bars/ pascals/ atmospheres

# Water Potential

- Physical property of water that determines the direction that water will flow.
- In the world of water potential 0 is high!
  - Usually a negative number
  - Occasionally a positive number
- Determined by the solute concentration and pressure

# Water Potential Principles

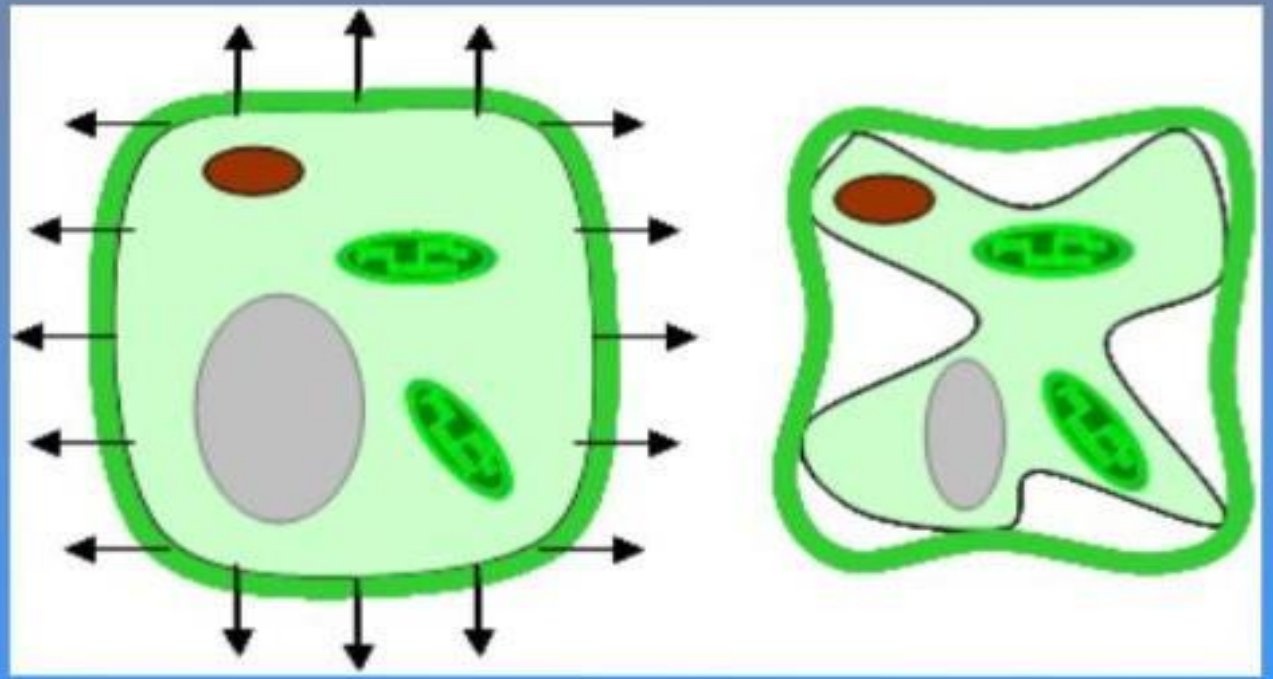
- Water always moves from high water potential to low water potential
- Water potential is a tendency of water to move from high free energy to lower free energy
- Distilled water in an open beaker has a water potential of 0 (zero)

# Water Potential Principles

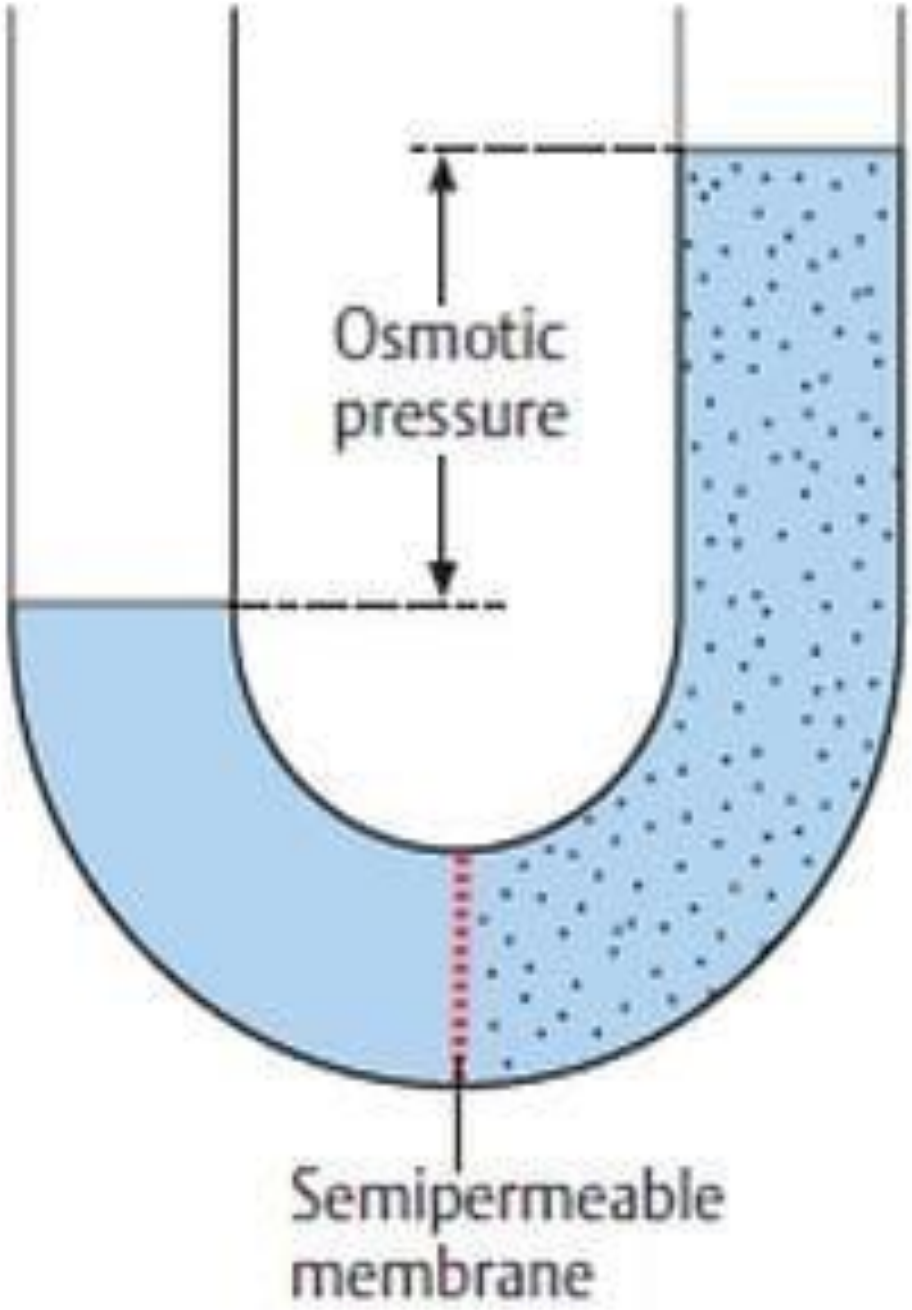
- Addition of solute decreases water potential
- Addition of pressure increases water potential
- In cells, water moves by osmosis to areas where water potential is lower.
  - A hypertonic solution has lower water potential
  - A hypotonic solution has higher water potential

# Pressure Potential

- Turgid cell (left) have a high positive pressure potential (the water presses out on the cell wall, and the wall presses back on the water with an equal but opposite force).
- Cells that are flaccid or plasmolysed (right) have a pressure potential of zero.
- We assume a pressure potential of zero when measuring water potential in our experiment.



Osmotic pressure is a pressure of the solution, which is required in opposite direction,so as to stop the entry of solvent molecules into the cell.
Osmotic pressure of a solution is equivalant to the pressure which must be exerted upon it to prevent flow of solvent across a semipermeable membrane.
Thus D. P. D. = O. P. – T. P.
( ∴ T. P. = W. P.)
∴D. P. D. = O. P. – W. P.
In a flaccid cell, T. P. Is zero ∴ DPD = OP
In a turgid cell, DPD is zero ∴ TP = OP



T. P. Is the pressure exerted by turgid cell sap on to the cell membrane and cell wall. In a fully turgid cell, DPD is zero.
- Cell wall being thick
and rigid, exerts a counter pressure on the cell sap. This is called Wall pressure (W. P.).
In a fully turgid cell, T. P. = W. P. But operating in opposite direction.

-Water potential of pure water is higest and value always zero.
-Addition of any solute in it, decreases its psi (ψ) value. Therefore, any solution has negative value.
-Water always flows from less negative potential to more negative water potential (i.e. From high water potential area to low water potential area).
-Difference between water potential of the adjacent cells decides movement of water through plasmodesmata across the cells.

# Water potential

**Water Potential, Ψ*** , describes the likelihood water will diffuse in or out of a cell. Based on two factors:

$$\Psi = \Psi_s + \Psi_p$$

- **Solute potential ($\psi_s$)**
  - Proportional to number of dissolved solutes
  - Osmotic potential
  - $\psi_s = 0$ in pure water
  - $\psi_s = -0.23$ in 0.1M solution of sugar
  - Addition of solutes lowers the ψ

- **Pressure Potential ($\psi_p$)**
  - Physical pressure on a solution
  - Can be + or –
  - Water in xylem is often negative
  - Water in cell is often positive
  - Additional pressure raises the ψ

# FACTORS AFFECTING WATER ABSORPTION

- Capillary water
- Temperature 20 to 30°C is best
- Solute soil concentration is inversely proportional
- Poor aeration –less absorption
- Transpiration rate is directly proportional to absorption rate

# PATHWAYS OF WATER MOVEMENT

**ROOT HAIRS → XYLEM**

**IMBIBITION – DIFFUSION – OSMOSIS**

**Water enters cell**

↓

**Cell becomes turgid /DPD Decreases**

↓

**Next cell DPD high- pulls water-becomes turgid**

↓

**Suction pull**

Root hair cells

cortex

inner cortex

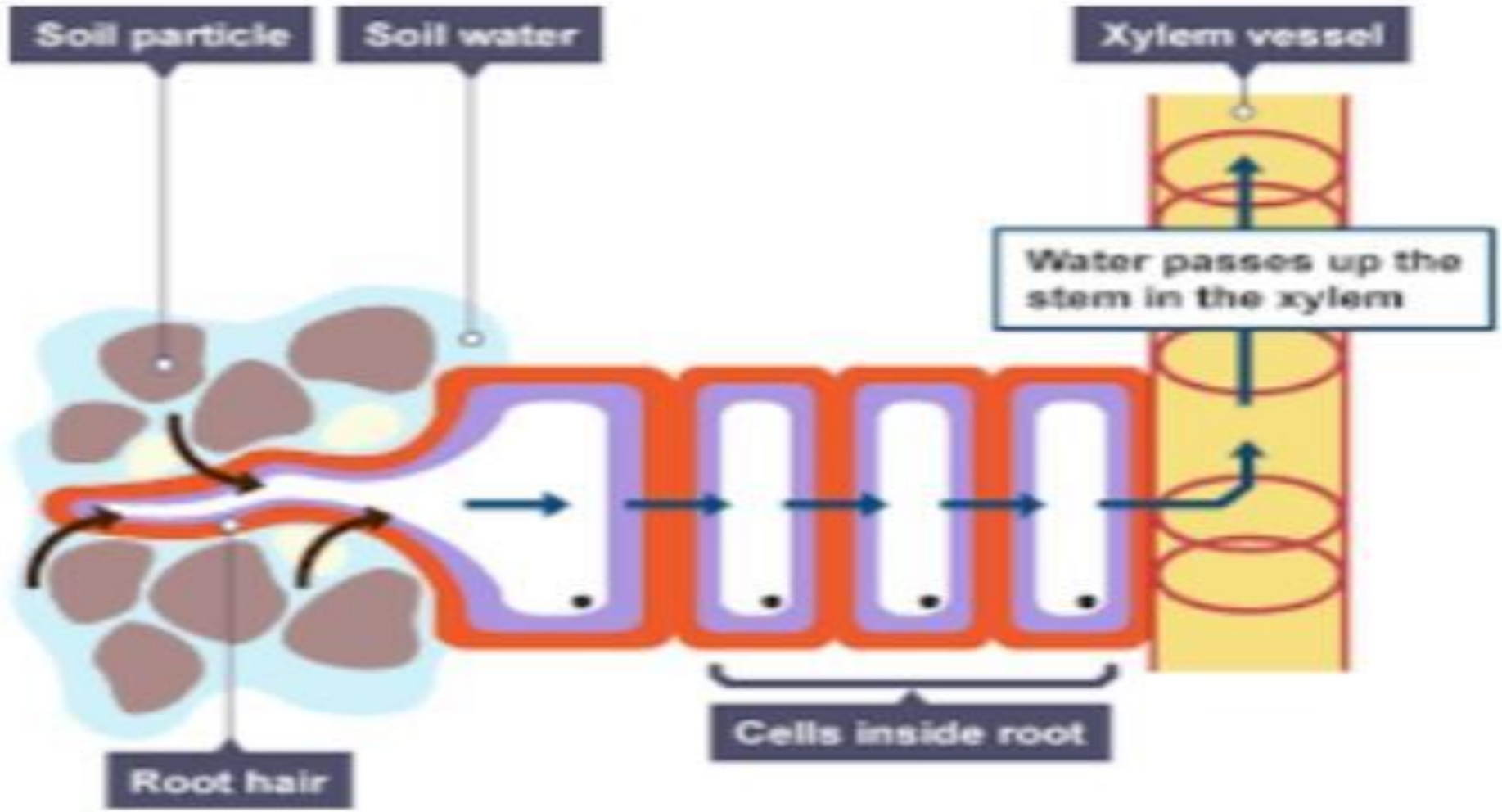
endodermis

passage cells

pericycle

protoxylem

metaxylem



# WATER PATHWAY

## APOPLAST

**Non living**

**intercellular space**

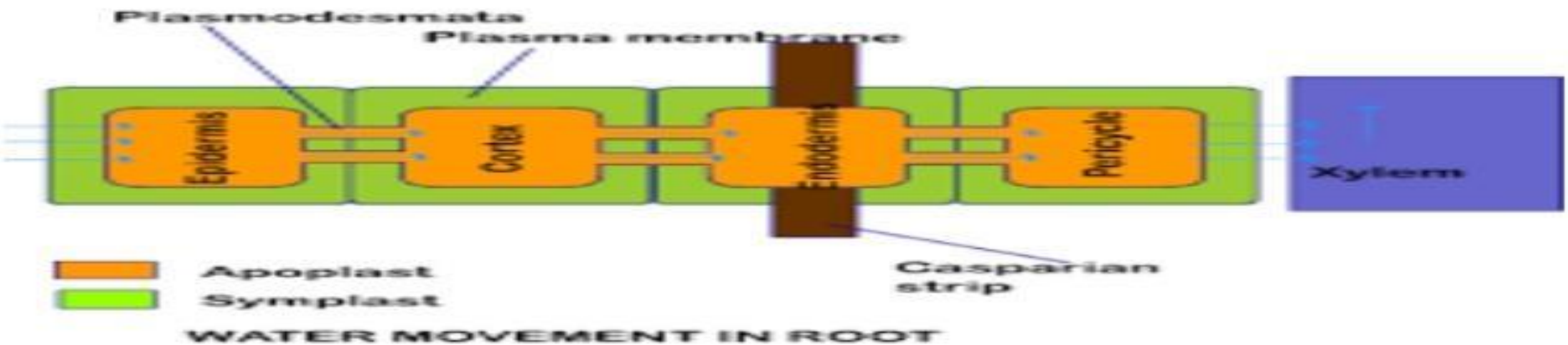
**cell wall**

## SYMPLAST

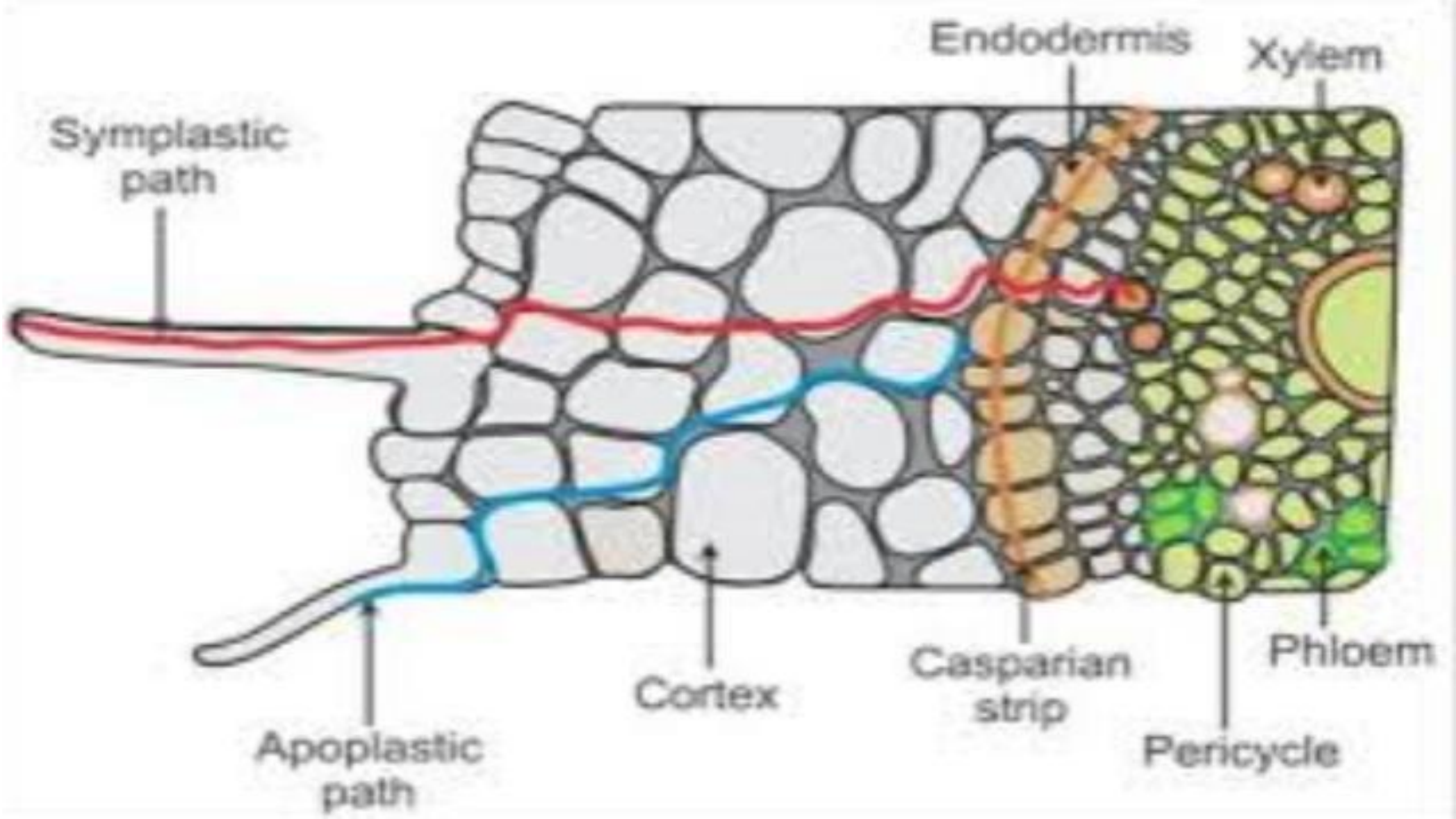
**Living cells**

**transmembrane**

**plasmodsmata**




WATER MOVEMENT IN ROOT


Endodermis
Xylem
Symplastic path
Cortex
Casparian strip
Phloem
Pericycle
Apoplastic path

# APOPLAST VERSUS SYMPLAST

| APOPLAST | SYMPLAST |
| --- | --- |
| Apoplast refers to the nonprotoplasmic components of a plant, including the cell walls and the intracellular spaces | Symplast refers to the continuous network of protoplasts of a plant, which are interconnected by plasmodesmata |
| Consists of nonprotoplasmic parts such as cell walls and intracellular spaces | Consists of protoplast |
| Composed of nonliving parts of a plant | Composed of living parts of a plant |
| Water movement occurs by passive diffusion | Water movement occurs by osmosis |
| Shows less resistance to the water movement | Shows some resistance to the water movement |
| Water movement is rapid | Water movement is slower |
| Metabolic rate of the cells in the root cortex does not affect the movement of water | Metabolic rate of the cells in the root cortex highly affects the movement of water |
| With the secondary growth of the root, most of the water moves by this route | Beyond the cortex, water moves through the symplastic route |

# PASSIVE ABSORPTION

This mechanism is carried out without utilisation of metabolic energy.Here only the root act as an organ of absorption or passage .Hence, sometimes it is called water absorption 'through roots', rather 'by' roots.

It occurs in rapidly transpiring plants during daytime, because of opening of stomata and the atmospheric conditions. The force for absorption of water is created at the leaf end i.e., the transpiration pull.

- In passive absorption the driving force is transpiration pull and DPD gradient
- Rapid transpiration creates a tension in the xylem vessel due to negative water potential. This tension is transmitted to xylem in the roots. Consequently water is pulled upwards.
- Rapid transpiration creates a tension in the xylem vessel due to negative water potential. This tension is transmitted to xylem in the roots. Consequently water is pulled upwards
- There is no expenditure of energy (ATP) as water moves in accordance to the concentration gradient
- The rate of respiration is not affected. .
- About 98% of the total water absorbed
- Occurs during day time when transpiration is in progress. It stops at night when transpiration stops.

# Passive absorption

- The intake of water by plants due to transpiration pull is called passive absorption.
- The water is absorbed due to transpiration activity in the top of the plants.
- The root hair cell has no role in absorption. It function as an absorptive surface.
- Water is absorbed through roots.
- Transpiration increase the concentration of cell sap and DPD in the leaves.
- As result water from the xylem vessels move into the mesophyll cells of leaves.
- The water in the xylem vessels is in the from of a column.
- Hence there is pulling up of water column.
- This result in a tension in the root hair cells.
- The water moves through apoplastic pathway, symplast pathway and transmembrane pathway.
- It is now largely greatest amount of water is pulled up by passive absorption.

# Active Absorption

It is absorption of water by roots with the help of metabolic energy generated by the root respiration. The force for water absorption originates from the cells of root due to root respiration. As the root cells actively take part in the process so it is called **Active absorption**.

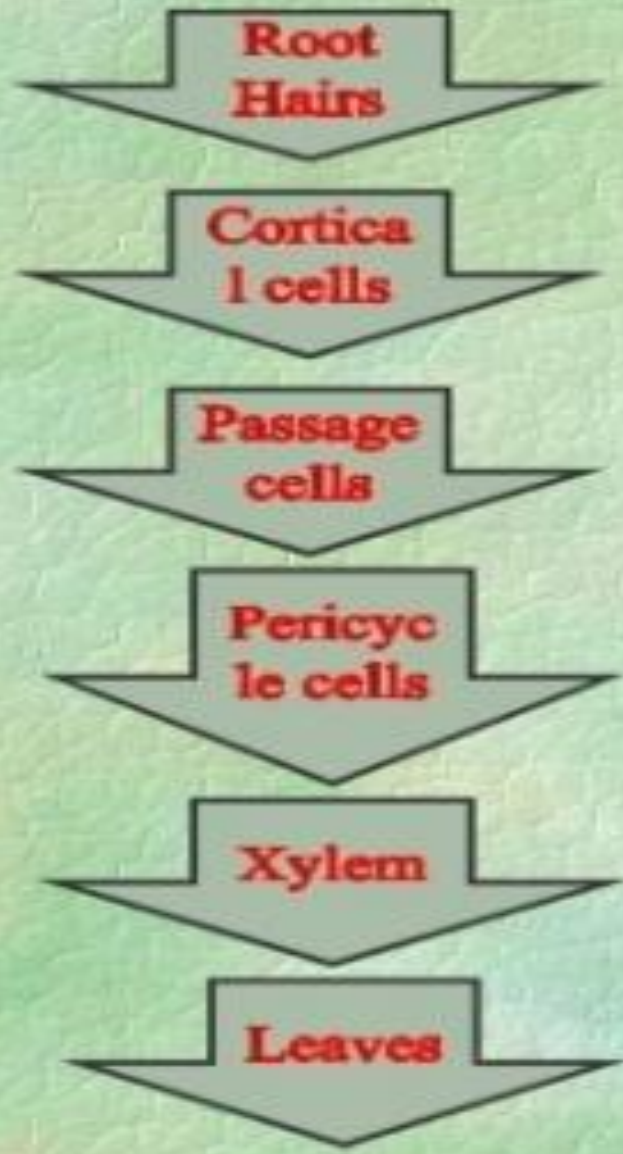
According to Renner, active absorption takes place in low transpiring and well-watered plants and 4% of total water absorption is carried out in this process. The active absorption is explained by two theories which are, **Active osmotic water absorption** and **Active non-osmotic water absorption**.

# 1.Active absorption

Proposed by Atkins (1916) & Priestly (1922)

- Active osmotic absorption.
- Active non osmotic absorption.

- Active absorption – the absorption of water by the plant with the use of energy is known as active absorption. in this process, the root cell play active role in the absorption of water.
- Intake of water by the plants with the use of energy is called active absorption.
- The water is absorbed by the activity of root hair cells.
- The water is absorbed by the operation of osmotic forces by the use of energy.
- In osmotic active absorption, the water move from hypotonic solution to hypertonic solution.



# I. Active Osmotic Absorption

- The intake of water by the root hairs by the operation of osmotic forces is called **osmotic active absorption.**
- Water is absorbed by the activity of root cells.
- Osmotic pressure, root pressure, turgor pressure and DPD play the main role.
- The water move from hypotonic solution to hypertonic solution.
- The root hair cells suck the soil water and the xylem vessel pumps the water upwards.

# Difference between active and passive absorption

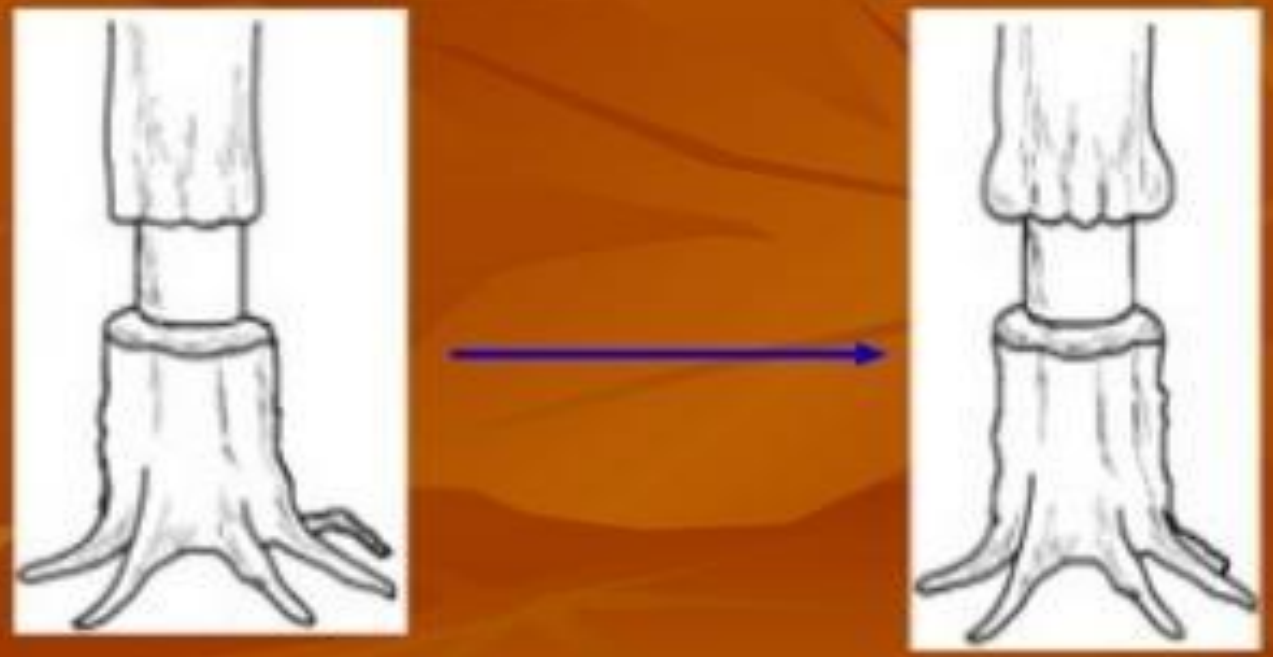
| s.no. | Active absorption | Passive absorption |
|---|---|---|
| 1 | Energy is required. | Energy is not required. |
| 2 | The forces are created by osmotic concentration. | Created by transpiration pull |
| 3 | Absorption is due to activity of root hair cell. | Absorption is due to the activity of the leaves. |
| 4 | root hair cells have high DPD,compared to soil solution. | The mesophyll cell have high DPD compared to xylem vessels. |
| 5 | Rate of absorption depend on DPD. | Rate of absorption depend on transpiration. |
| 6 | Absorbed through symplast pathway and transmembrane pathway. | Water passes through apoplast pathway,symplast pathway and transmembrane pathway. |
| 7 | It is correlated with respiration for energy. | It is correlated with transpiration. |
| 8 | The rate of absorbtion is slow. | The rate of absorbtion is high. |

# ASCENT OF SAP

- The transport of water with dissolved minerals from root to other aerial parts like stem and leaves, against the gravity, is called translocation or ascent of sap.
- Translocation of water occurs through the lumen of conducting elements of xylem tracheids and vessels, in all vascular plants.
- Ringing experiment has proved that xylem is the path of ascent of sap.

## 3. To show the role of phloem: Bark Ringing Experiment

| Method | Result |
| --- | --- |
| a) Choose a healthy small branch of a tree.<br>b) By using a knife, remove a complete ring or bark, about 2 cm length.<br>c) Leave it for one month. | The tissue above the ring swell up, whereas the one below the ring withers. |



# ROOT PRESSURE

- Soil solution hypotonic
- Water potential lower in root hairs so water enters by osmosis
- Water potential becomesless negative
- Adjacent cells of cortex now have more negative water potential so water enters them
- This continues till water gets to xylem
- The potential gradient built up is called roots pressure

**ROOT PRESSURE**

**A positive hydrostsatic pressure developed in the living root cells due to absorption of water.**

**ROOT PRESSURE THEORY [ J. Pristley]**

- the activity of living cells of root is responsible for translocation of water
- When a stem of potted plant is cut few inches above the soil by a sharp knife, xylem sap is seen flowing out/ oozing out through the cut end.
- This exudation at the cut end of stem is a good proof for the existence of root pressure.
-As water absorption by roots is constant and continous process, a hydrostatic pressure is developed in the living cells of cortex of root. This is termed as root pressure by Stephen. Hales.

# Root Pressure Theory

In, 1956 Stocking defined root pressure as “Pressure developing in tracheary elements of xylem as a result of metabolic activities of roots”.
Experiment:

If a well watered plant is cut near its base, the xylem sap is seen to flow out through cut end with a pressure. This pressure is actually the hydrostatic pressure developed in the root system called root pressure.

# Root Pressure

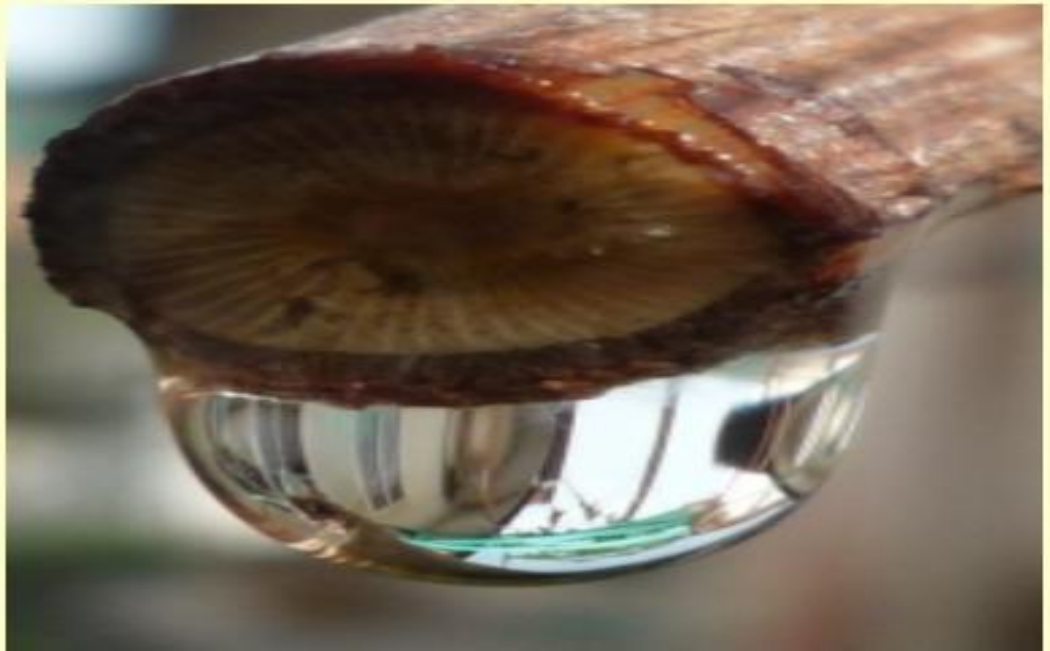
- Rate of transpiration is low
- Roots still collecting minerals
- Water is forced from higher pressure in roots to lower pressure in leaves

# Root Pressure: Evidence

1. Cut stumps of plants exude water from their cut ends

2. In certain conditions some leaves exude water from their leaves = guttation

3. Pressures recorded by mercury manometers attached to the cut stumps could push water in the xylem up to 30m



-It is due to root pressure water along with dissolved minerals is not only forced into xylem but it is also conducted upwards against the gravity.

- Root pressure seems to be largely an osmotic phenomenon and its development is an active process.

-The value of root pressure is +1 to +2 bars which is enough to pump water to a height of 10 to 20 meters.

- The factors like

oxygen, moisture, temperature of soil, salt contents, etc. influence the root pressure

## Objections/ limitations of root pressure theory:

i. It is not applicable to plants taller than 20 meters.

ii. Ascent of sap can also occur even in the absence of root system.

iii. Root pressure value is almost nearly zero in taller gymnosperm trees.

iv. In actively transpiring plants, no root pressure is developed.

v. Xylem sap under normal condition is under tension i.e. it shows negative hydrostatic pressure or high osmotic pressure.

thus root pressure is not the sole mechanism explaining the ascent of sap in all plants of varying heights.

Removal of roots cause transient drop in transpiration.

A tension/negative pressure is found in rapidly transpiring plants.

Root pressure is seen in favourable periods (Spring/rainy) When xylem sap is hypertonic & transpiration rate is low & in summers, when water requirements are high root pressure is almost nil.

Kramer, (1969): Amount of sap exuded by root pressure is only 4% of total transpiration of intact plant.

# Capillarity theory (physical force theory):

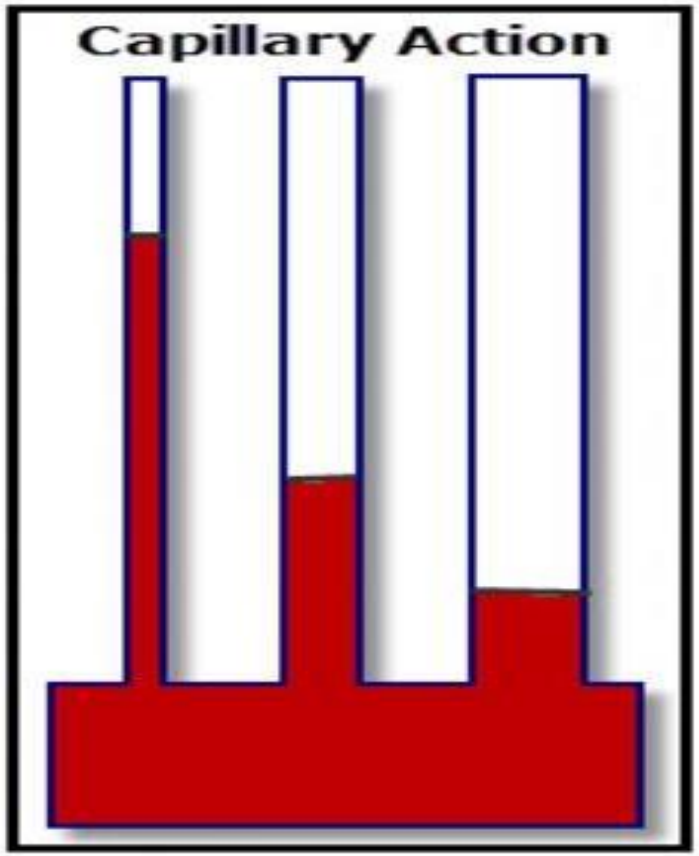

-Physical forces and dead cells are responsible for ascent of sap.

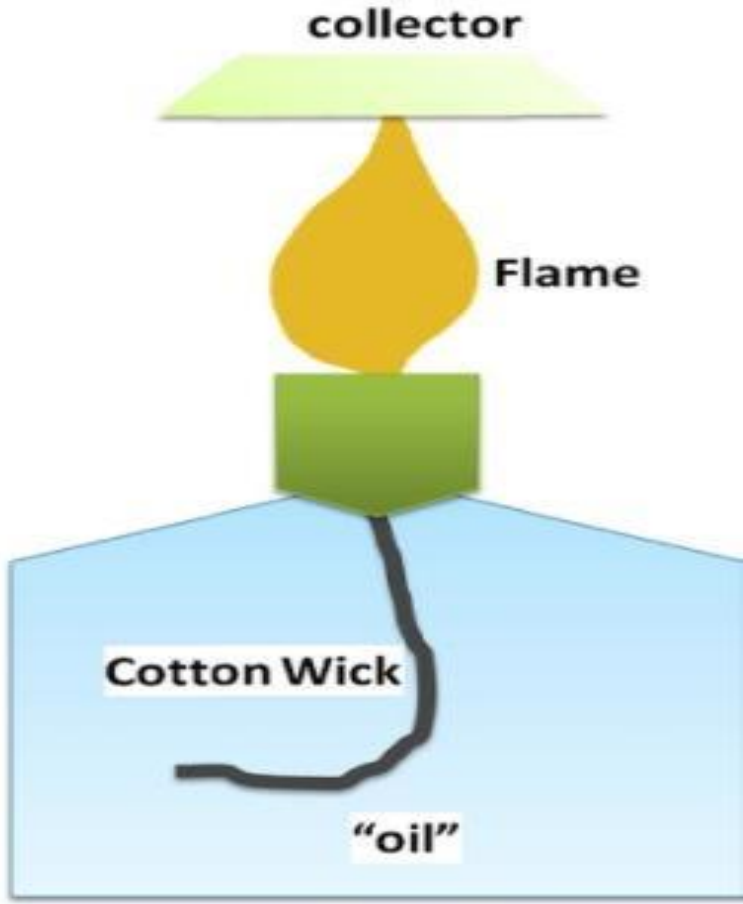
[ Boehm (1863).]

-Wick dipped in an oil lamp, shows capillarity due to which oil is raised upwards.

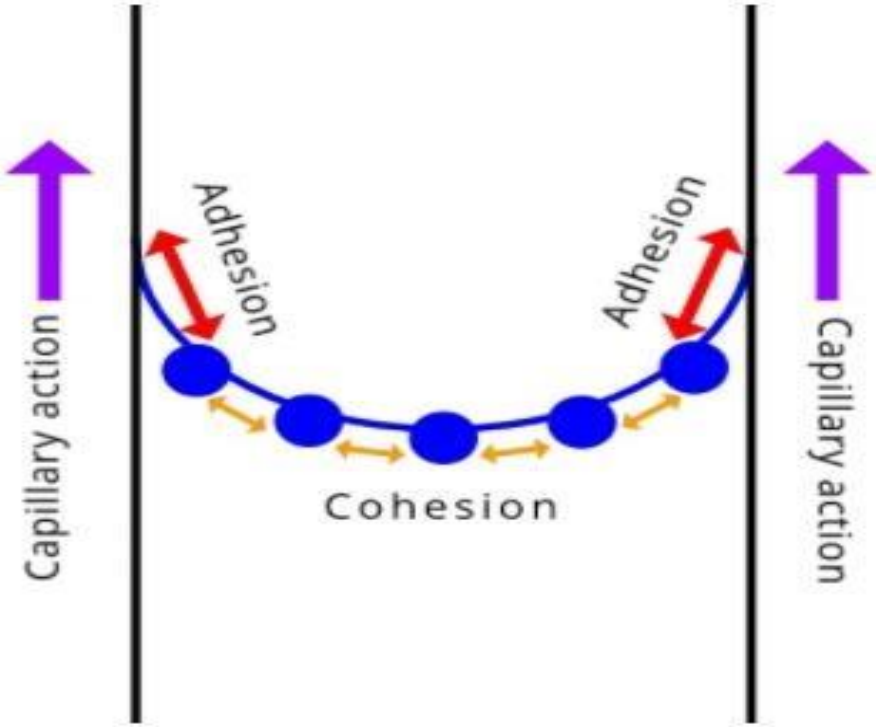
-The conduction of water in a straw dipped in water, is raised to a certain height because of capillarity.

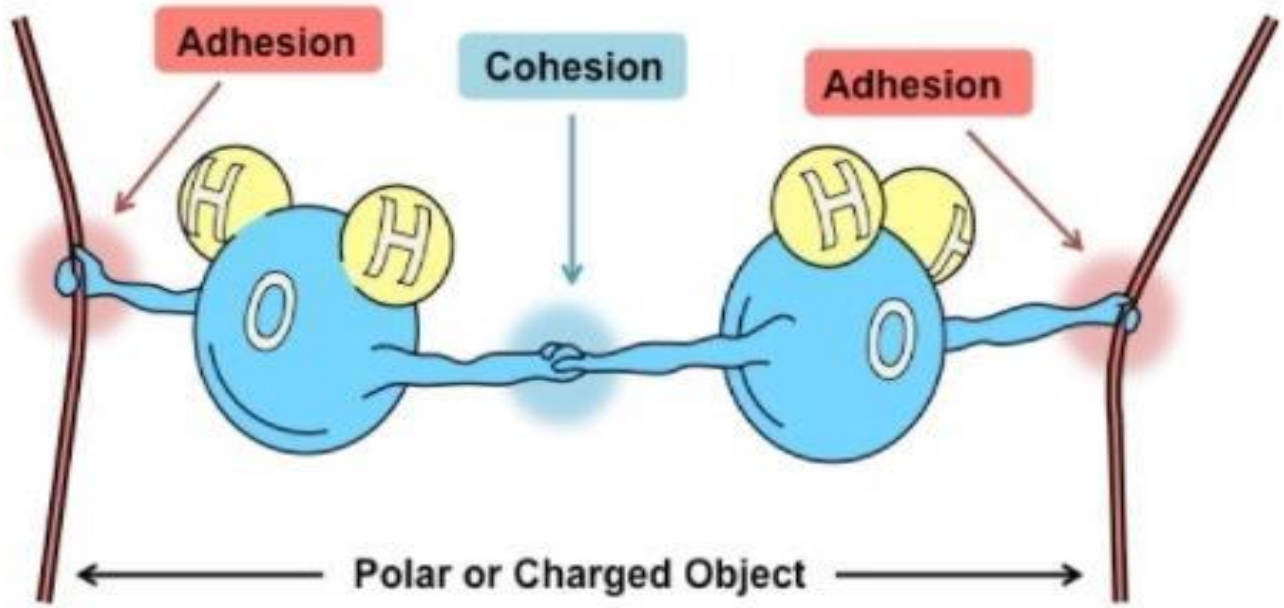
- The height to which water is raised depends on the diameter of the straw



- Capilarity is because of surface tension and forces of cohesion (attraction between like molecules) and adhesion (attraction between unlike molecules).
-Xylem vessel/ tracheid with its lumen is comparable with straw.
- Water column exist because of combined cohesive and adhesive forces of water and xylem wall due to capillarity.
- It is because of capillarity
water is raised or conducted upwards against the gravity to few centimeters only.



## Objections/ Limitations of capillarity theory:

i. Capillary tube (xylem) must be continously and completely hollow from one end to the other end but tracheids in the xylem show closed end-walls.

ii. The lower end of capillary tube i.e. xylem must be in direct contact with soil water.

However, there exists a barrier of root cortex between xylem and soil water.

iii. Narrower the capillary tube, greater is the height to which water column is raised.

Thus, taller trees should show xylem vessels with very narrow bore (diameter). but, in nature the tall trees show xylem vessels having wider bore.

Hence, capillarity can not be the sole mechanism to explain ascent of sap in all the plants of varying heights.

## Cohesion- tension theory (Transpiration pull theory) :

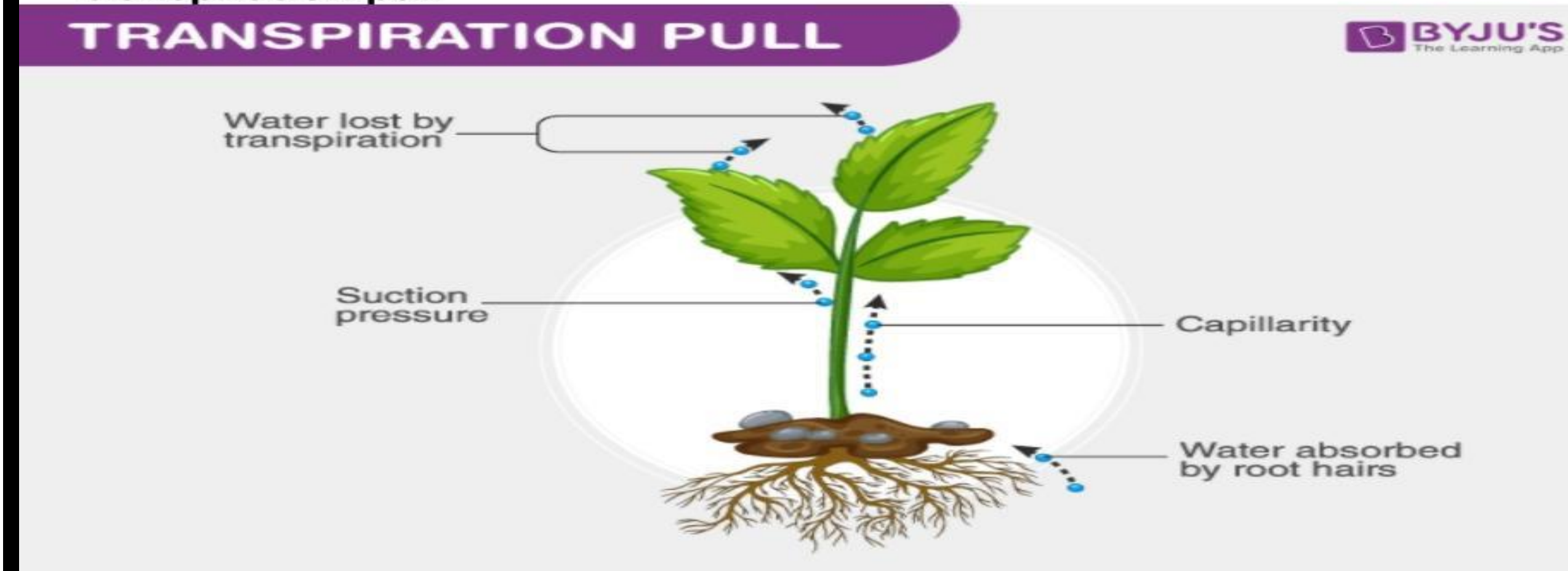
**-[ Dixon and Jolly (1894)]**

**- widely accepted theory explaining ascent of sap in plants.**

**- two principles.**

**Cohesion and adhesion**

**transpiration pull**



- A strong force of attraction between water molecules, is called cohesive force.
- a strong force of attraction between water molecules and lignified wall of lumen of xylem vessel, is called adhesive force.
-Due to combined cohesive and adhesive forces a continious water column is developed in the xylem right from root upto the tip of the topmost leaf in the plant.
-Transpiration pull : The transpiration pull developed in the leaf vessel is transmitted down to root and thus accounts for the ascent of sap.
-Excess water is lost in the form of vapour, through the stomata found on leaf.
-This water loss increases D. P. D. of mesophyll cells.
-so cells withdraw water ultimately from xylem in the leaf.
- due to continous transpiration, a gradient of suction pressure (i.e. D. P. D.) is developed right from guard cells up to the xylem in the leaf.
- This create a tension (called negative pull or transpiration pull) in the xylem.
-thus water column is pulled out of xylem, upwards passively against the gravity leading to the ascent of sap

# Cohesion Tension/Cohesion Transpiration Pull Theory

## Dixon & Jolly (1894)

a. Continuous Water Column.
b. Withdrawl of water due to DPD deficit b/w atmosphere & inner surface of leaves.
c. Development of tension/transpiration pull
d. Cohesion or tensile strength of water.
e. Ascent of Sap

## Objections/ Limitations of transpiration pull theory:

i. For transpiration pull to operate, water column should be unbroken and continous.

However, due to temperature fluctuations during day and night, gas bubbles may enter in water column breaking the continuity.

ii. This mechanism assumes that tracheids are more efficient than the vessels, as their end walls support water column. but, vessels are more evolved than tracheids and are more efficient.

iii. If plant is smeared with vaseline in order to stop transpiration, even then ascent of sap occurs.

iv. Ascent of sap also occurs in deciduous plants that have shed all of their leaves. pointers to the fact that besides physical forces, activity of living cells seems to be necessary for lifting the water

column up

## Transport of mineral ions :

-Soil serves as main source for minerals.

-Minerals constitute most commonly occuring solid, crystalline inorganic materials obtained from earth's crust.

-Minerals play an important role in the day to day life of plant.

-Minerals are absorbed by plants in the ionic (disolved) form,mainly through roots and then transport

-An estimate of plant ash supports that minerals are absorbed by plants from soil

and surroundings


# Macro/Micro Nutrients

- Macro
  - Nitrogen
  - Phosphorus
  - Potassium
  - Magnesium
  - Calcium
  - Sulfur
- Micro
  - Boron
  - Copper
  - Chlorine
  - Manganese
  - Molybdenum
  - Nickel
  - Zinc
  - Iron

- Absorption of minerals is independent of that of water.
-Absorbed mineral ions are pulled in upward direction along with xylem sap because of transpiration pull.
-Cells uptake them actively
- Soil would not be the only source for mineral uptake.
-Mineral ions can be remobilized within the parts of the plant. Older parts (like leaves in deciduous plants) export their ions to younger leaves before the fall.
-Ions are like phosphorus, sulphur, nitrogen and potassium are remobilized but the ions from structural components like calcium is not remobilized

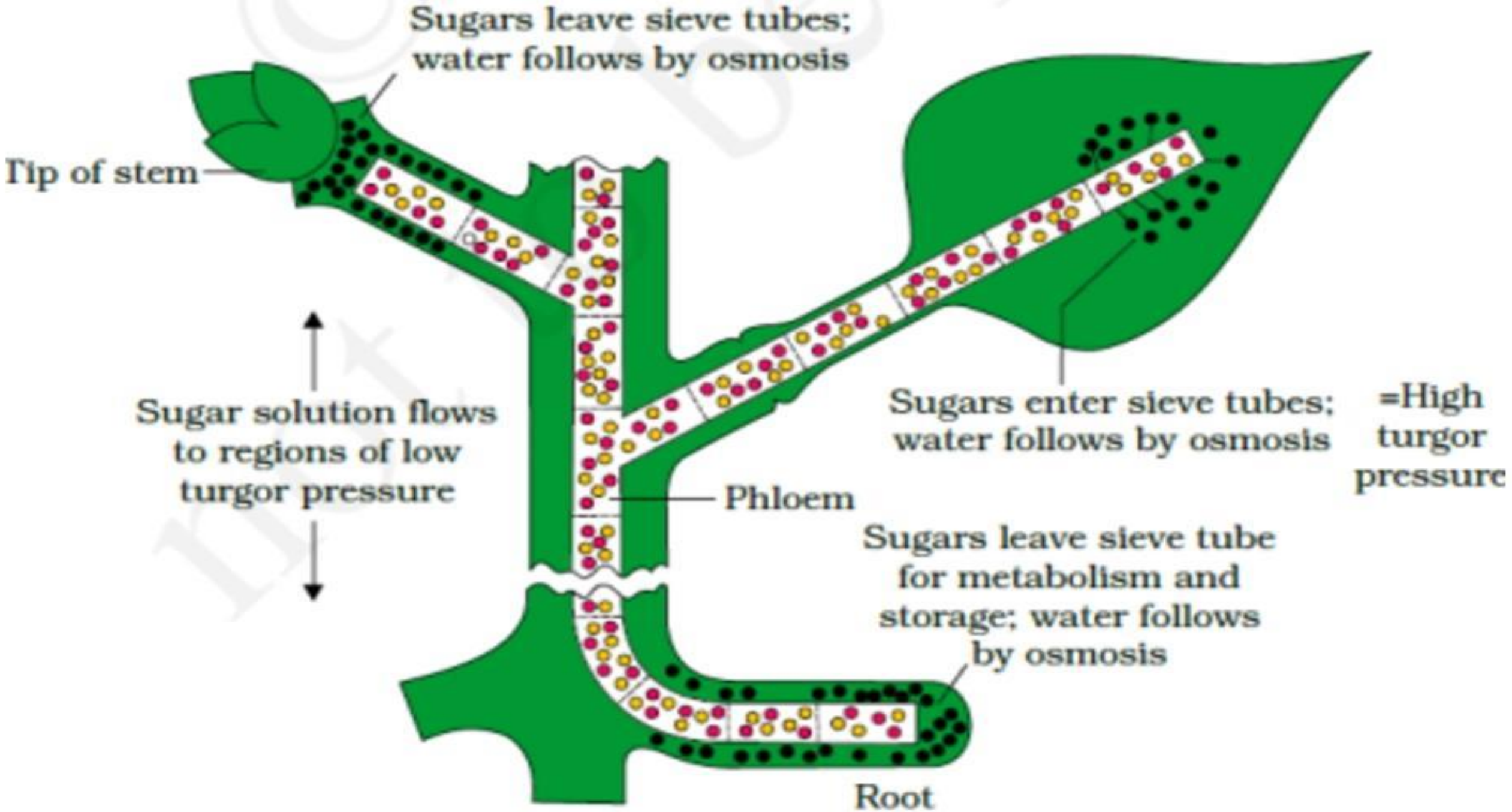
- Mineral ions are needed in the areas of the plant viz. apical, lateral, young leaves, developing flowers, fruits, seeds and storage organs.

-A belief earlier that xylem transports inorganic and phloem transports organic molecules.

However, it is not correct because some exchange of materials also occurs between xylem and phloem

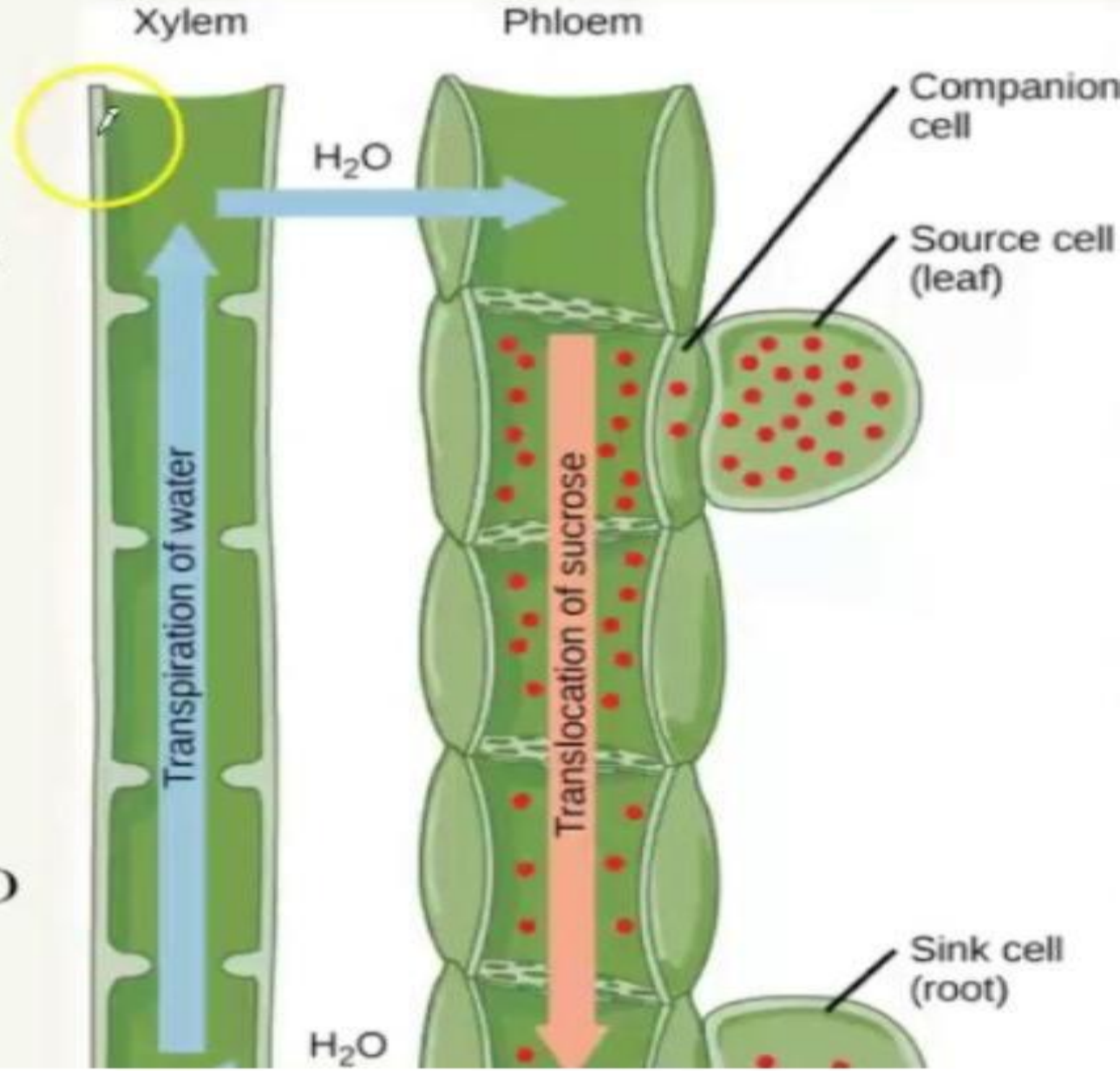
## Transport of food

- All the plant parts require continous supply of food for nutrition and developement.
- Chloroplasts are confined to green cells of leaves where food is synthesized.
-The non-green parts like root and stem must received food from leaves.
-The part where food is synthesized is called source and while part where it is utilized, is called sink.
-Food has to travel from source to sink.
- This movement of food from one part to the other part, is called translocation of food.


Sugars leave sieve tubes; water follows by osmosis
Tip of stem
Sugar solution flows to regions of low turgor pressure
Phloem
Sugars enter sieve tubes; water follows by osmosis
=High turgor pressure
Sugars leave sieve tube for metabolism and storage; water follows by osmosis
Root

# Mechanism for translocation (extra)

- **Mass flow** hypothesis
  - Sucrose is loaded at the source. Lowers water potential.
  - Water moves in from xylem, builds up pressure for mass flow.
  - Sucrose translocation to the sink.



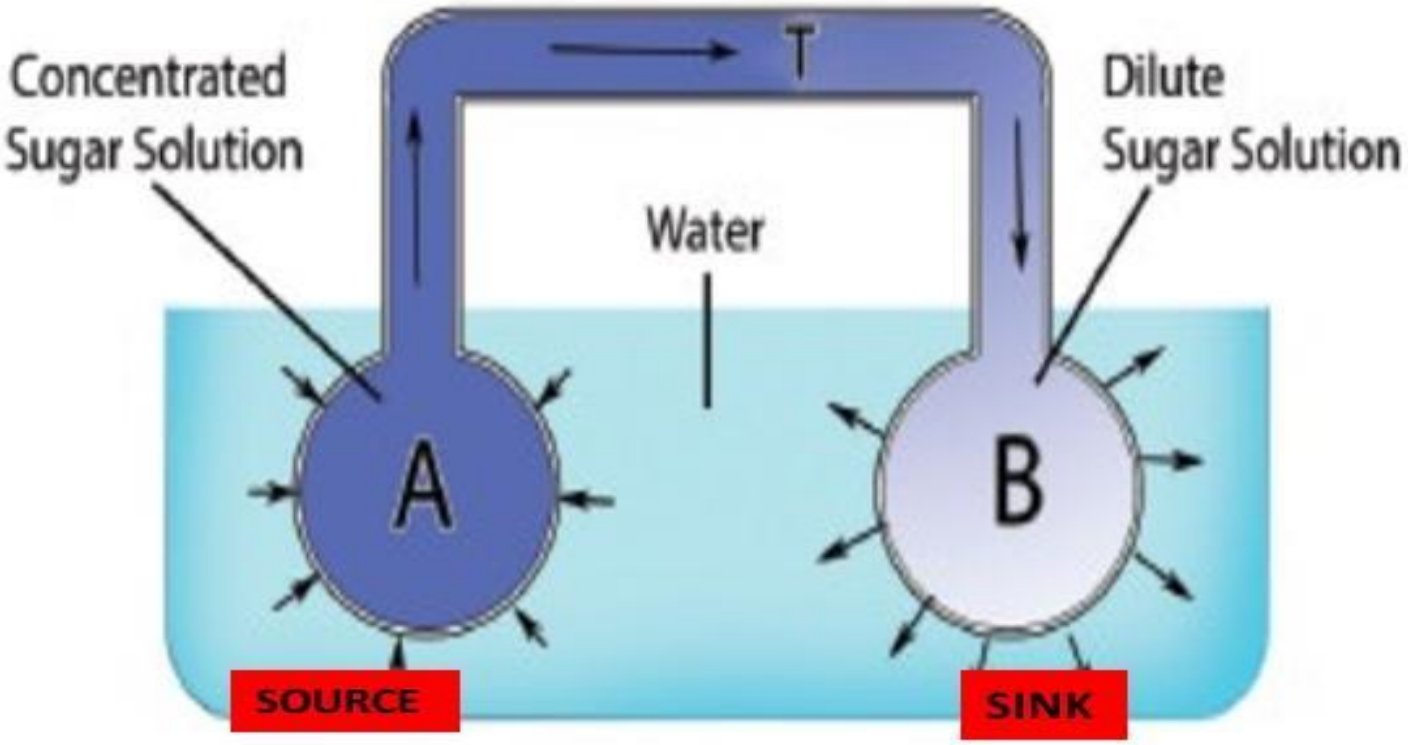
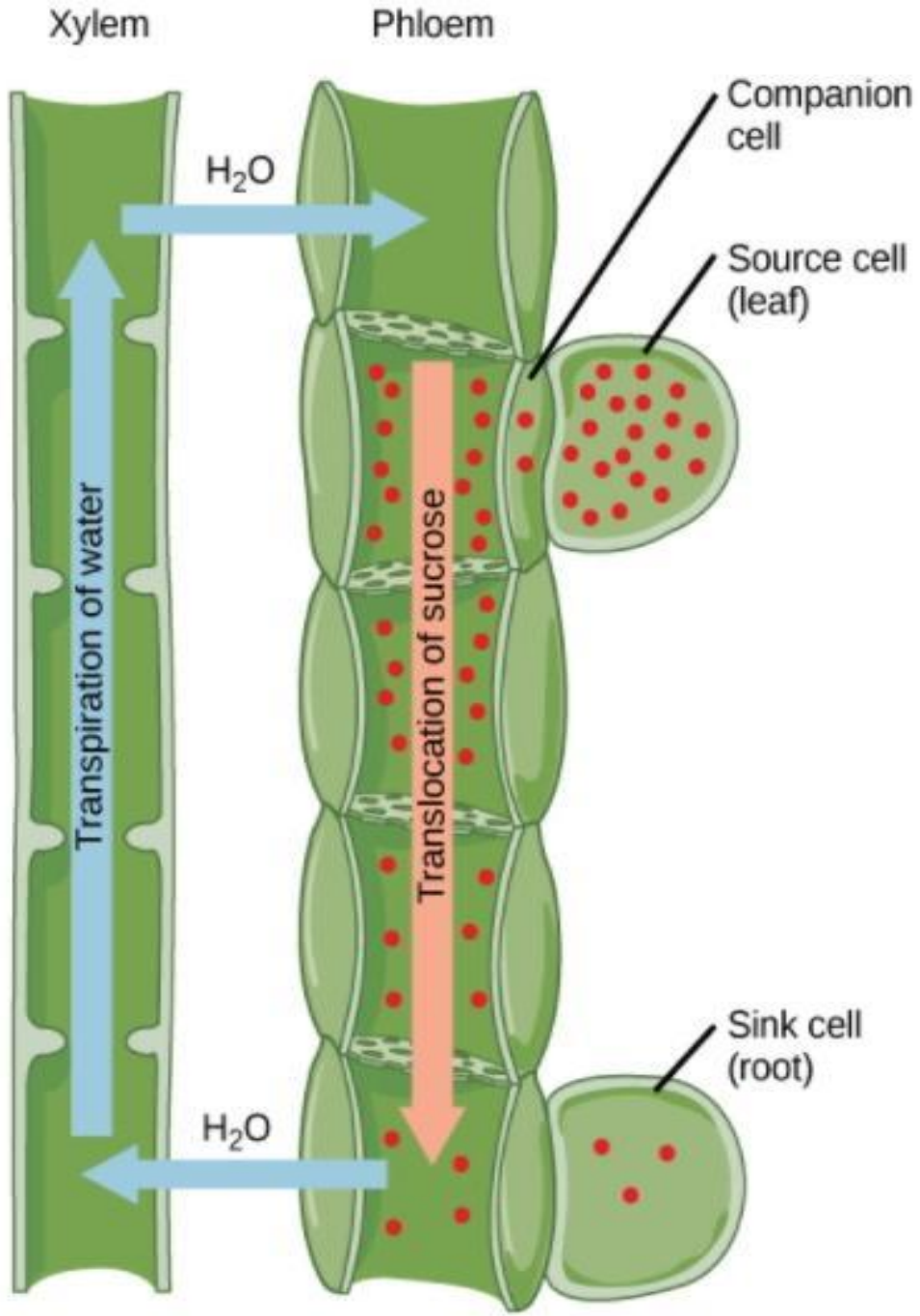
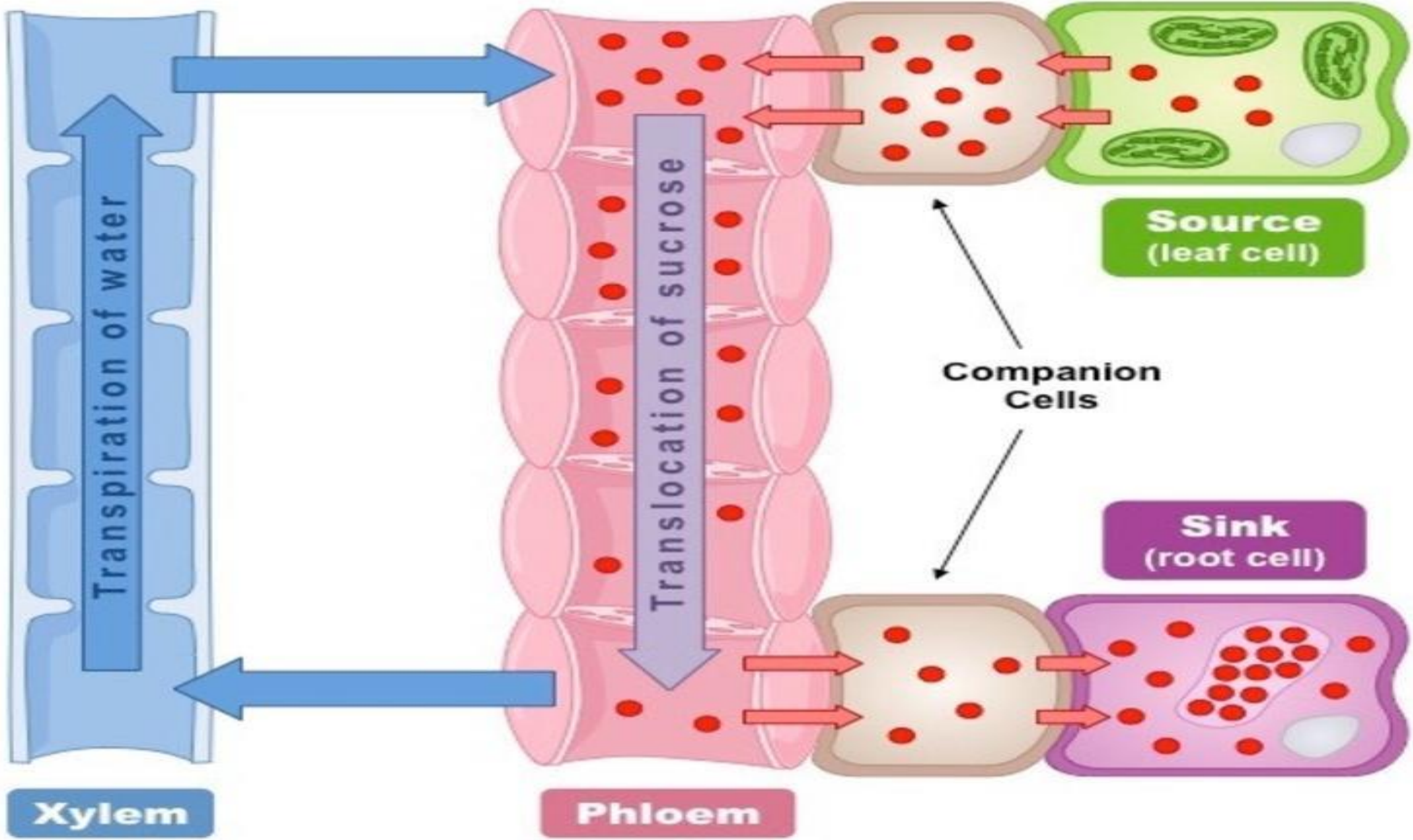



Figure 11.22: A model demonstrating the Mass flow hyphothesis

MUNCH




Transpiration of water
Translocation of sucrose
Source
(leaf cell)
Companion
Cells
Sink
(root cell)
Xylem
Phloem

## Path of translocation :

- Food is to be translocated to longer distances in higher plants. Hence plants must have adequate channels for the transport of food.

Sieve tubes and vessels [PHLOEM]are structurally ideally suited for longitudinal (vertical) translocation.

-The horizontal (lateral) translocation occurs from phloem to pith or phloem to cortex via medullary rays in the stem.

Food is always translocated in the form of sucrose (soluble form) and always along the concentration gradient from source to sink.

## Vertical translocation :

- In vertical (longitudinal) transport, food is translocated in downward direction from leaves (source) to stem and root (sink).
- It also occurs in upward direction during germination of seed, bulbils, corm, etc.
- Upward translocation also occurs from leaves to growing point of stem, to developing flowers and fruits situated near the ends of the branches of stem

## Lateral translocation :

- It occurs in the root and stem.
- When food is translocated from phloem to pith, it is called radial translocation.
- And from phloem to cortex, it is called tangential translocation

The transport of food through phloem is bidirectional.

Phloem sap contains mainly water and food in the form of sucrose.

- Sugars, amino acids and hormones are also transported through phloem

# Mechanism of sugar transport through phloem :

**The most convincing theory is Munch's pressure flow theory or mass flow hypothesis.**

**-Ernst Munch proposed that photosynthetic cell synthesizes glucose. Hence, its osmotic concentration increases.**

**- Due to endo-osmosis water is absorbed from surrounding cells and the cell becomes turgid.**

**-Due to increase in turgor pressure, sugar from photosynthetic cell is forced into the sieve tube of the vein. This is called loading of Vein.**

- At the sink end, root cell utilizes sugar and also polymerizes excess sugar into the starch.
- Its osmotic concentration is lowered.
-Exo-osmosis occurs, Water in the root cell is lost to surrounding cells, thereby decreasing the turgidity of cell.
- Turgor pressure is lowered.
Hence, a turgor pressure gradient is developed from sieve tube in the leaf to the root cell.
- food is translocated along the concentration gradient, passively. This is Vein unloading.
- At the sink end sugar is used and excess water exudes into the xylem.

Main objection to this theory is that this
- does not explain bidirectional transport of food.
-Munch, pressure flow is purely a physical process

# Transpiration :

5% of the total water is utilised for cell expansion and plant growth.

-95% water which is then lost into the atmosphere, through its aerial parts.

-1% of surplus water is lost in the form of liquid

- 99% of surplus water, is lost in the form of vapour.

## GUTTATION

- The loss of water in the form of liquid is called guttation.

- It occurs through special structures called water stomata or hydathodes.

# HYDATHODES

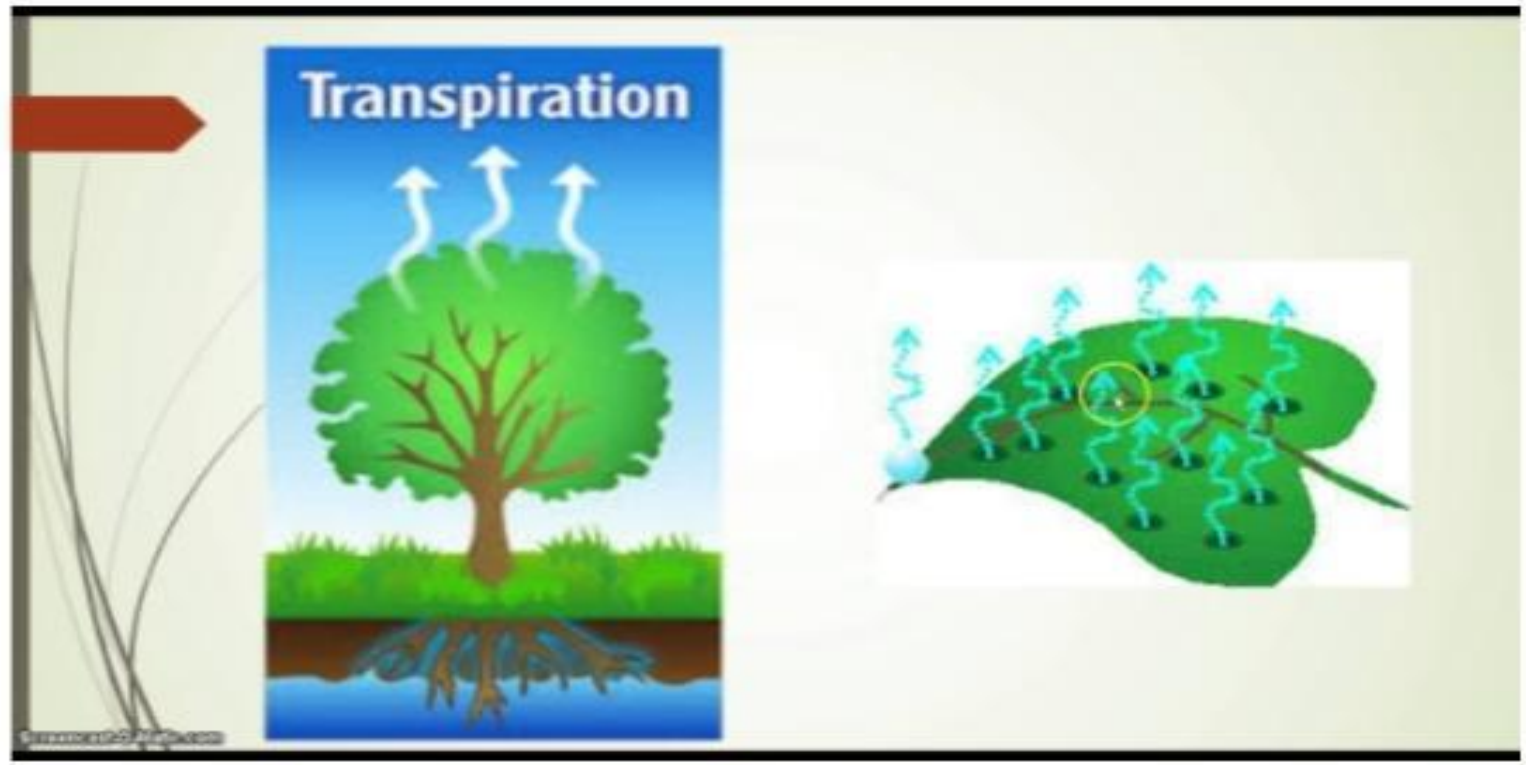
- A **hydathode** is a type of secretory tissue in leaves, usually of Angiosperms, that secretes water through pores in the epidermis or margin of leaves, typically at the tip of a marginal tooth or serration.
- They probably evolved from modified stomata. It is involved in guttation, where water is released from the top in order to transport the nutrients in the water from the roots to the leaves. Hydathodes are connected to the plant vascular system by a vascular bundle.

# TRANSPIRATION

-The loss of water in the form of vapour is called transpiration that occurs through leaves, stem, flowers and fruits.

-Most of the transpiration occurs through the leaves (called foliar transpiration).

- The actual water loss during transpiration occurs through three main sites - cuticle, stomata and lenticels.

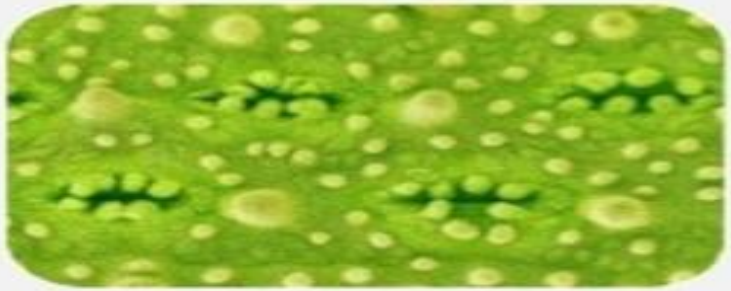


# THREE TYPES of TRANSPIRATION

## cuticular, stomatal and lenticular

## Types of transpiration

- On the basis of the passages through which plants give out water in the form of vapor transpiration is of three types:



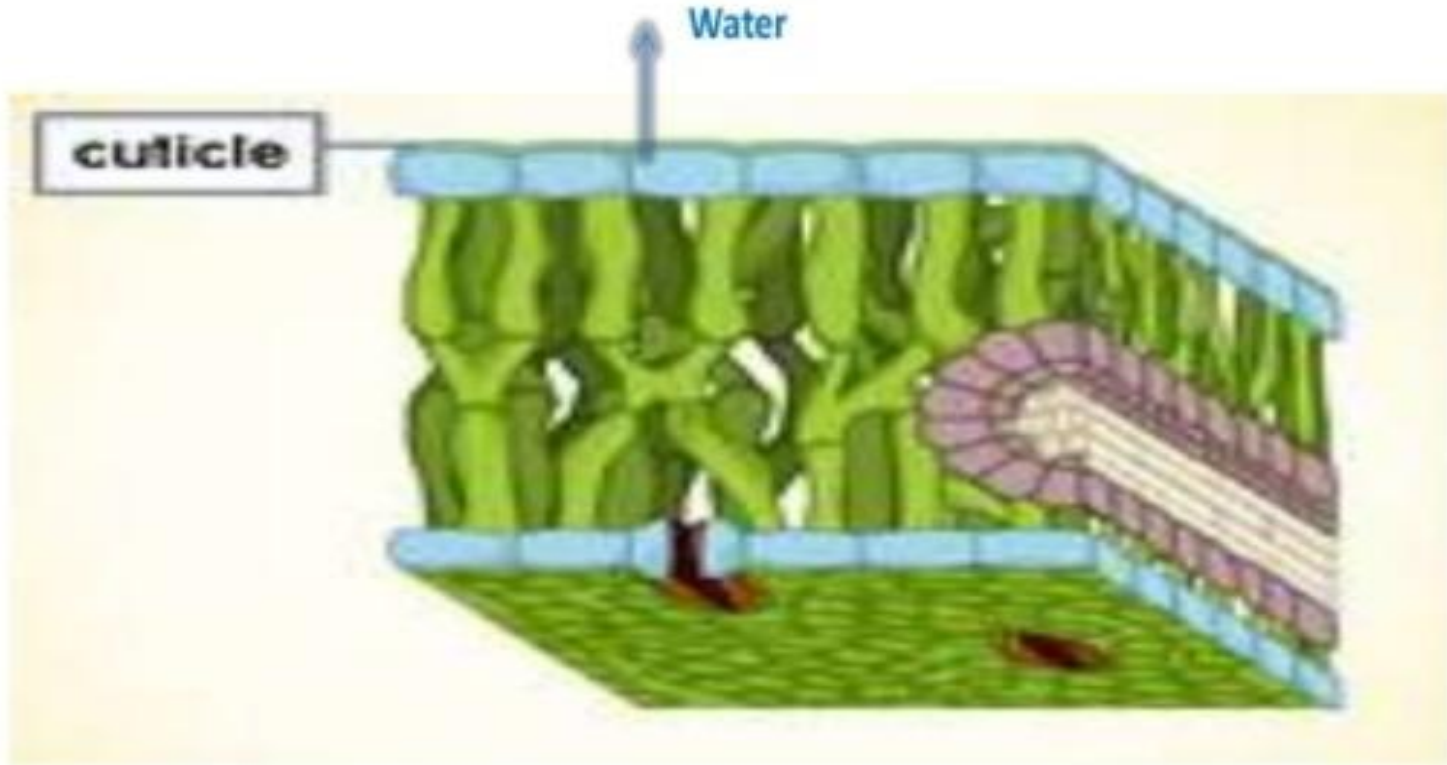
Stomatal transpiration

Cuticular transpiration

Lenticular transpiration

# Types of Transpiration

**1. Cuticular Transpiration:** the loss of water through the cuticle is known as Cuticular transpiration.




Cross section of leaf

**i. Cuticular transpiration:**

Cuticle is a layer of waxy substance- cutin, on outer surface of epidermal cells of leaves and

-rate is inversely proportional to thickness of cuticle

stem.

- contributes 8-10%

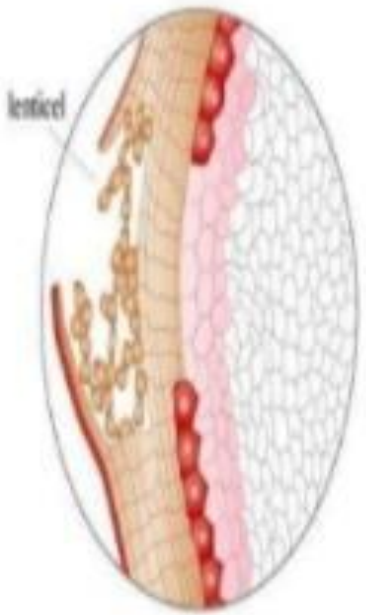
-occurs throughout the day its

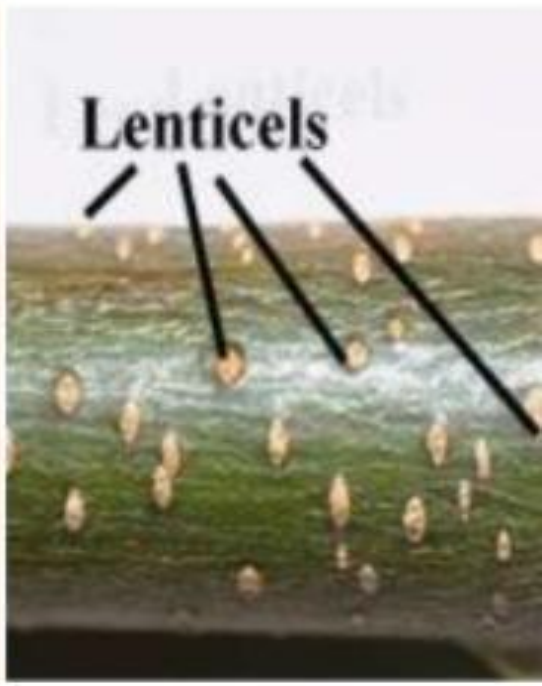
# Types of Transpiration

## ii. Lenticular transpiration:

- Lenticels are small raised structures composed of loosely arranged complementary cells.
- Each lenticel is a porous tissue consisting of cells with large intercellular spaces in the periderm of the secondarily thickened organs and the bark of woody stems and roots of dicotyledonous flowering plants.
-Lenticels are present in bark of old stem and pericarp of woody fruits [absent in leaves]
- contributes 0.1-1.0% of total transpiration.
-Rate of is very slow.
-occurs throughout the day.

**2. Lenticular Transpiration:** Loss of water in the form of water vapour taking place through the lenticels present in woody stem and fruits.



## iii. Stomatal transpiration:

-Stomata are minute apertures formed of two guard cells and accessory cells.

- They are located in the epidermis of young stem and leaves.

-more number of stomata on the lower surface.

Depending upon distribution of stomata on leaves are of three types namely

-epistomatic- on upper epidermis (Hydrophytes-e.g. Lotus)

- hypostomatic- on lower epidermis (Xerophytes- e.g. Nerium)

- amphistomatic- on both surfaces

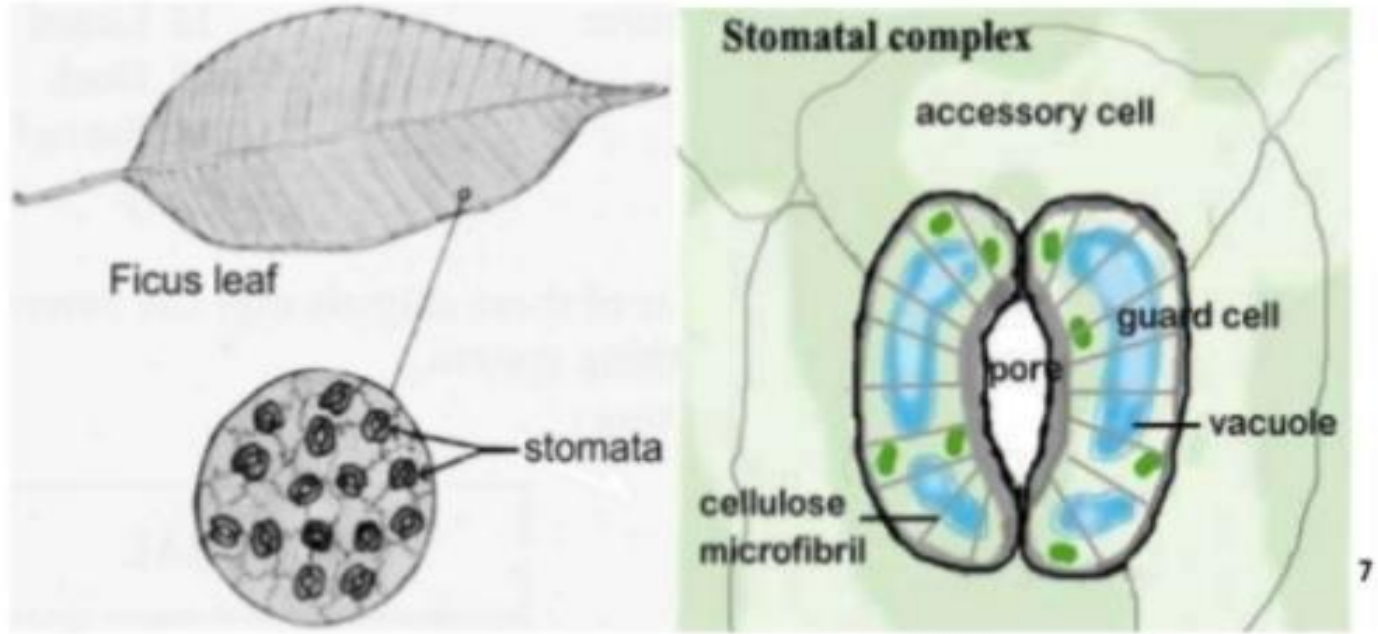
- (Mesophytes- e.g. Grass).

Stomatal transpiration occurs only during daytime. (Exception: Desert plants).

- 90 to 93% of total transpiration occurs through stomata, during day time.

# Types of Transpiration

**3. Stomatal Transpiration:** Stomata are minute pores confined to epidermis of green shoot and leaves.



# STRUCTURE OF STOMATA

Stomatal apparatus consists of

-two guard cells

- stoma

-accessory cells.

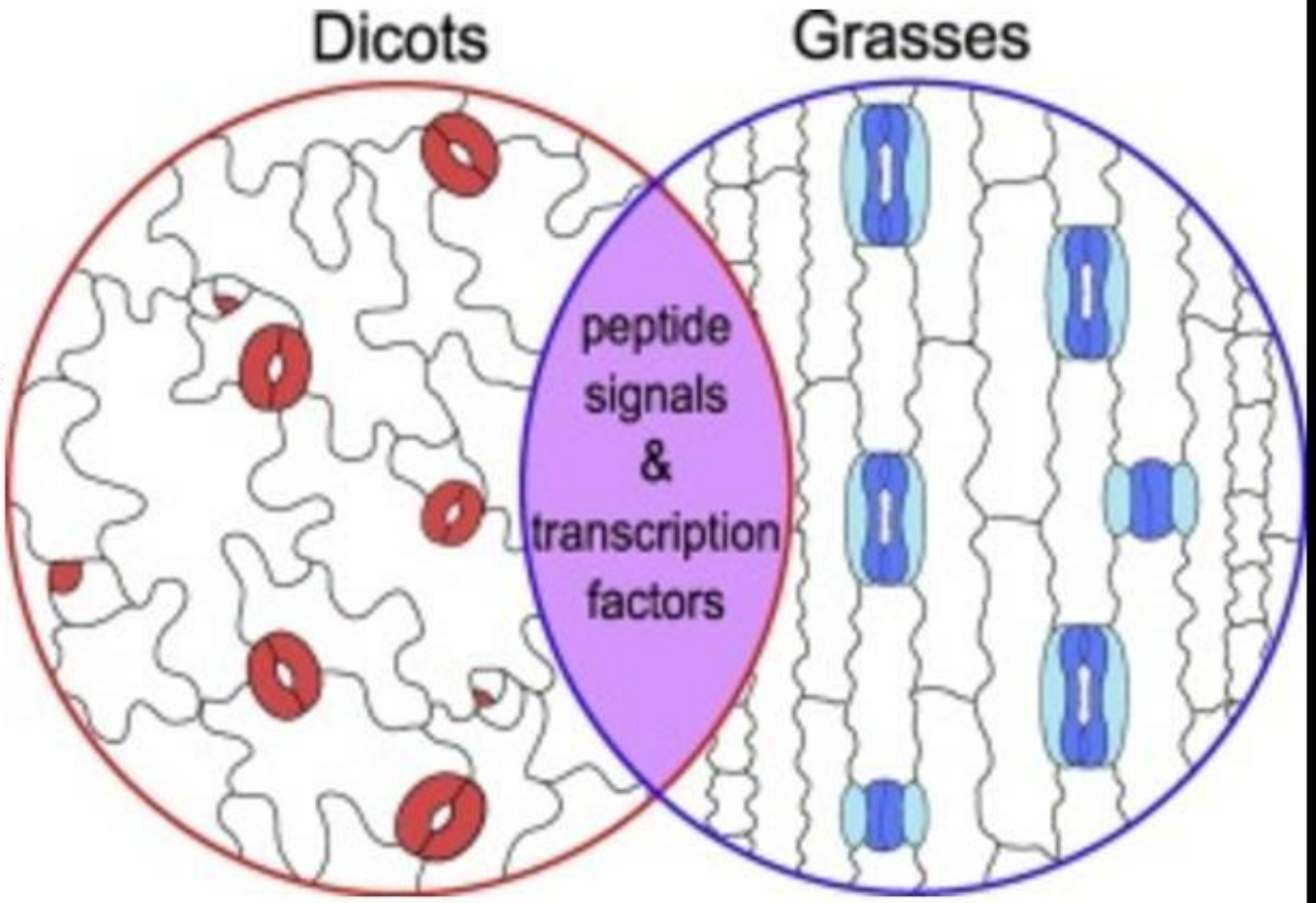
-Stomata are minute, elliptical pores bounded by two kidney/ dumbbell shaped guard cells. Guard cell is a type of epidermal tissue which may be called as modified, epidermal parenchyma cell.

-They are

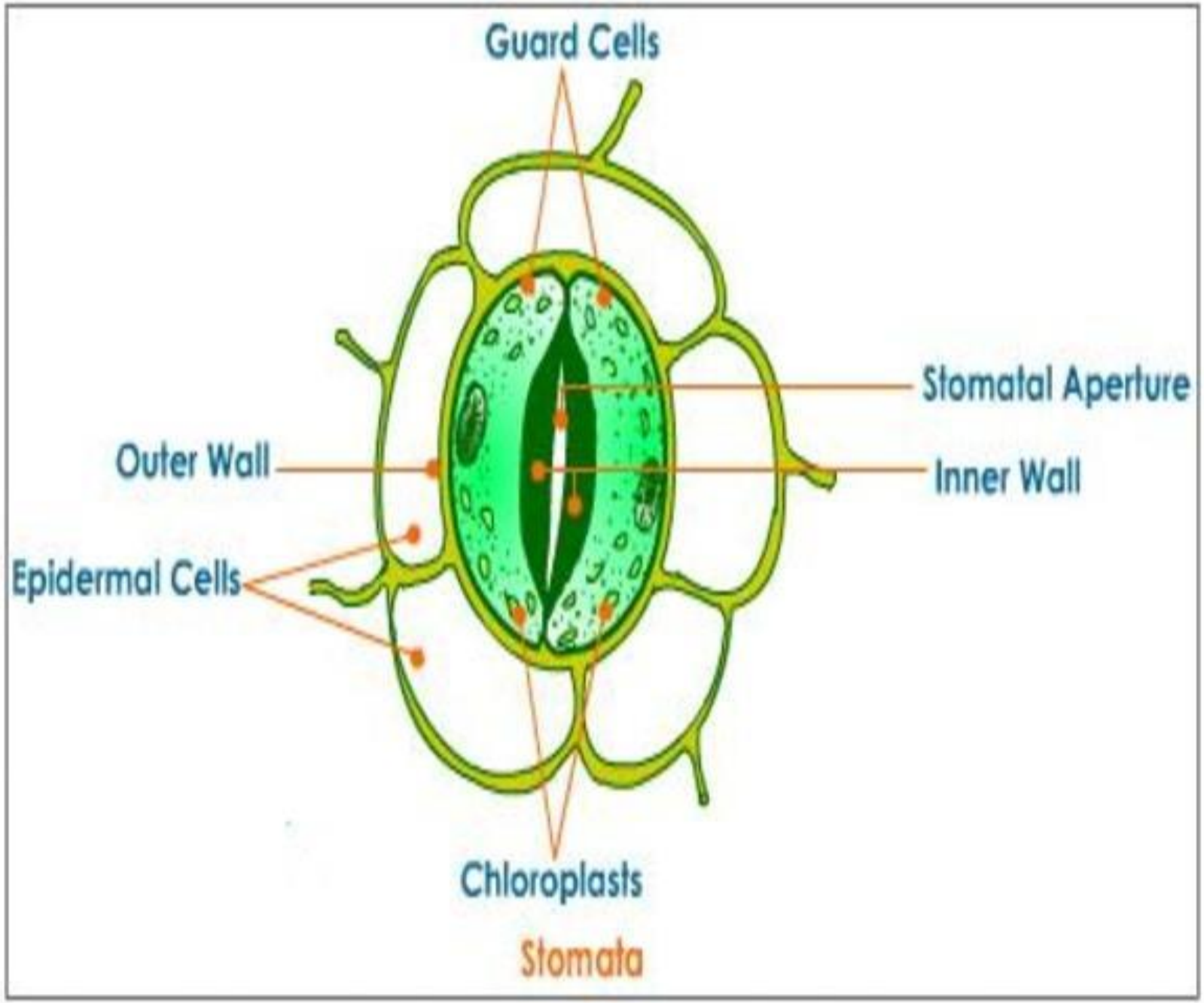
-kidney shaped-dicotyledons

-dumbbell shaped-monocotyledons

In Cyperus, both kidney- and dumbbell-shaped guard cells are present.

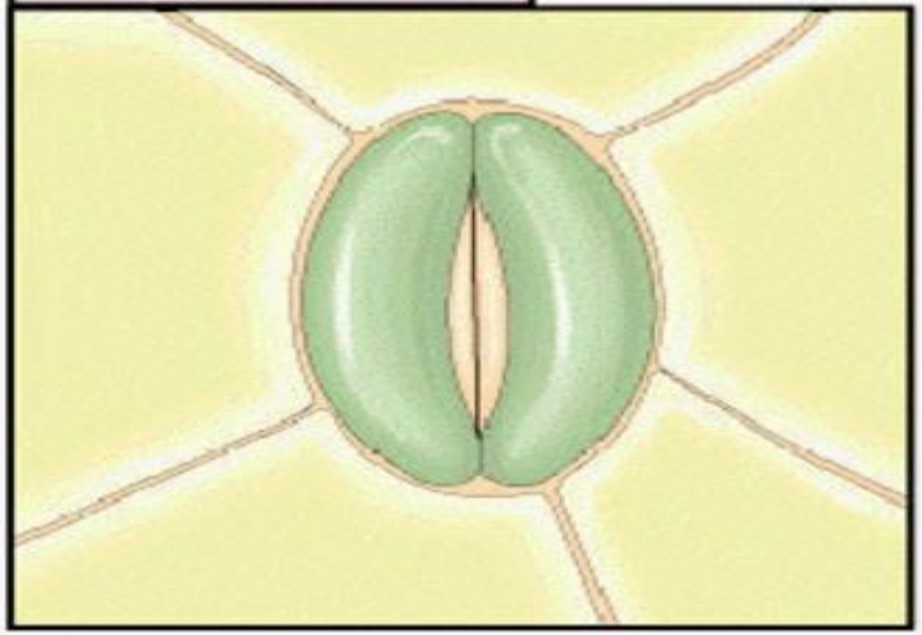


- Guard cells are living, nucleated cells with
unevenly thick walls
- Inner wall is thick and inelastic
-Outer lateral wall is thin and elastic.
- Guard cells contain few chloroplasts which are capable of poor photosynthesis.
- Guard cells can
change their size and form
- due to which stoma
opens (widens) or closes (narrows).
- Stoma is an elliptical pore formed due to specific arrangement of guard cells.
- It is through the stoma transpiration takes place.
-Accessory cells : These are specialized epidermal cells surrounding the guard cells.
-Their number is variable and are the reservoirs of K+ ions.
- are also called subsidiary
cells



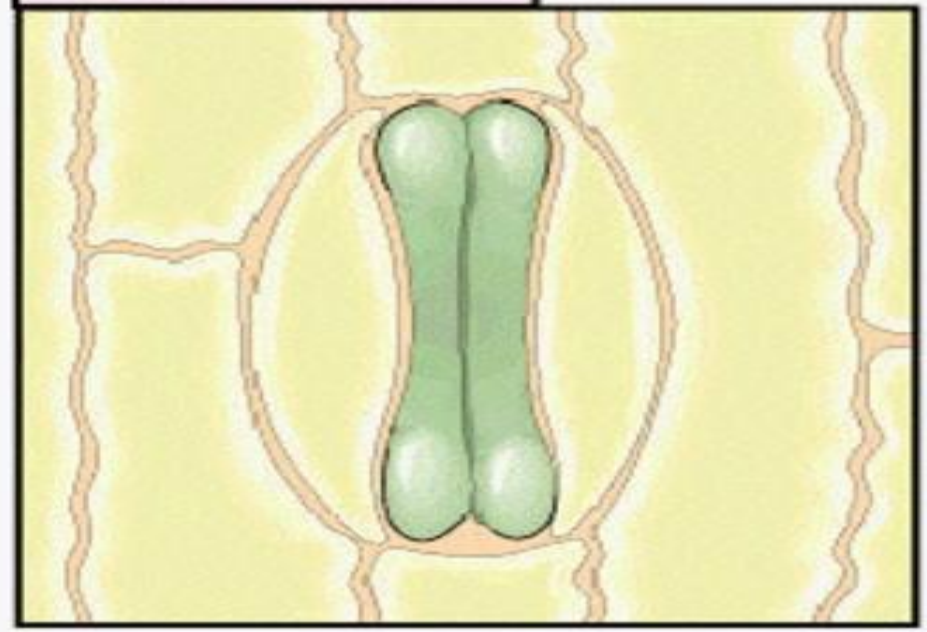
## Dicots and some monocots

Closed



## Certain monocots (grass)

Closed



# Opening and Closing of Stoma :

**Opening and closing of stoma is controlled**

**-by turgor of guard cells.**

**Day time- guard cells become turgid due to endosmosis.**

**-turgor pressure is exerted on the thin walls of guard cells.**

**-lateral walls are stretched out.**

**- inner thick walls are**

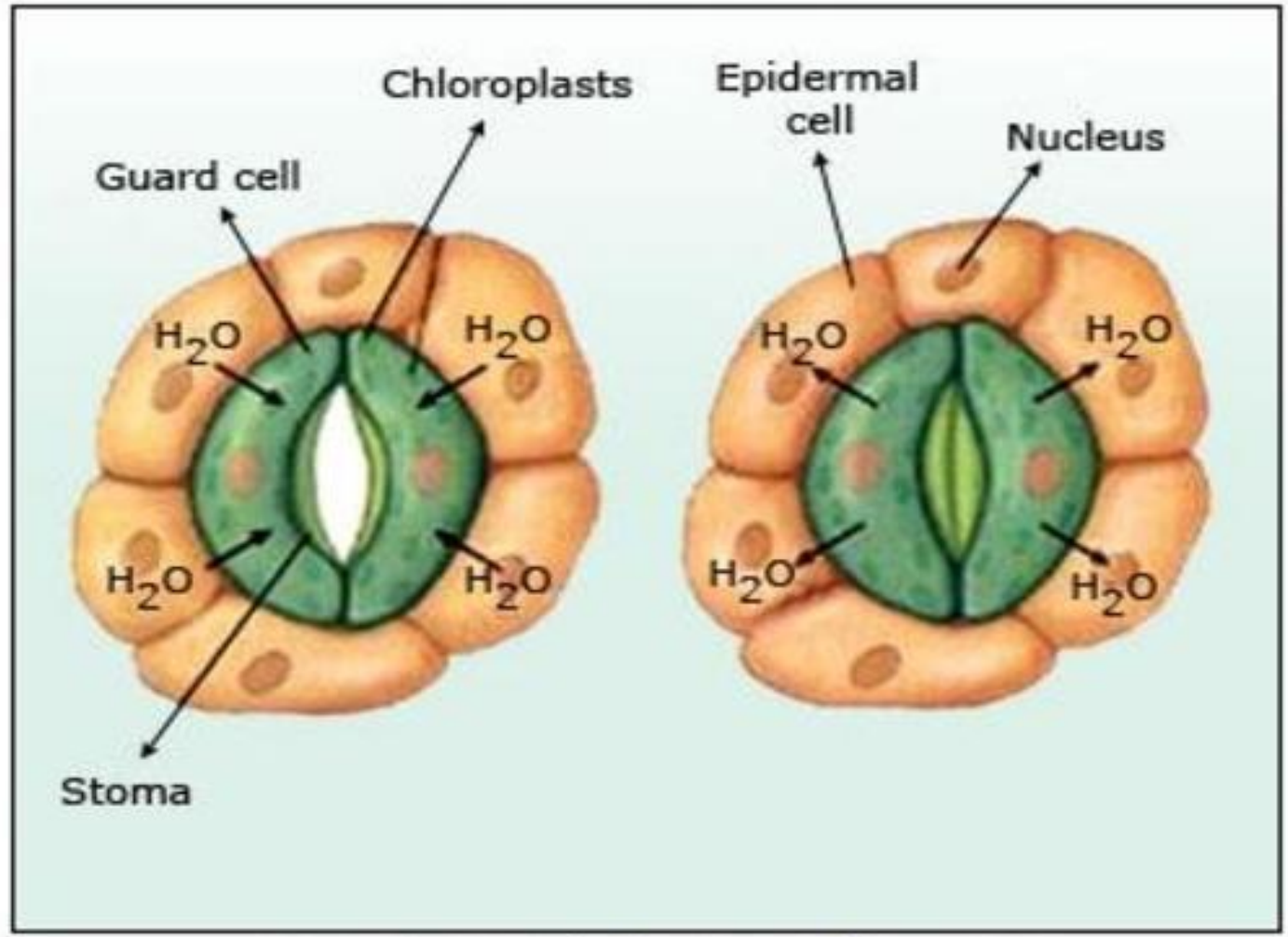
**pulled apart**

**-the stoma opens**

**During night time**

**- guard cells become flaccid due to exosmosis.**

**- Flaccidity closes the stoma almost completely.**




Opening and Closing of Stoma

## Starch-Sugar Inter-Conversion Theory (Steward 1964)

During Day

- enzyme phosphorylase converts starch to sugar
-this increasing osmotic potential of guard cells closing entry of water
- there by guard
cells are stretched and stoma widens.

At Night

-Reverse reaction brings about
the closure of stoma.

Sugar — Phosphorylase — Starch

(Stoma opens) --- (Stoma closes)

(DAY) NIGHT

# STARCH | SUGAR HYPOTHESIS

**In Light:**

Photosynyhesis

↓

Decreased $CO_2$ concentration

↓

Increased pH

↓

Conversion of starch to sugar

↓

Increased Cell Sap Concentration

↓

Endosmosis of water

↓

Increased turgor pressure

↓

Stomata Open

**In Dark:**

No Photosynyhesis

↓

Increased $CO_2$ concentration

↓

Decreased pH

↓

Conversion of sugar to starch

↓

Decreased Cell Sap Concentration

↓

Exosmosis of water

↓

Decreased turgor pressure

↓

Stomata Close

## Theory of Proton Transport (Levitt-1974)

-stomatal movement occurs due to transport of protons H+ and K+ ions.

During Daytime

- starch is converted into malic acid.
-Malic acid dissociates to form Malate and protons.
- Protons are transported to subsidiary cells and K+ ions are imported from them.
-Potassium malate is formed that increases osmolarity and causes endosmosis.
- Uptake of K+ ions is always accompanied with $Cl^-$ ions.

At Night

-uptake of K+and Cl-ions is prevented by abscissic acid
- this changes the permeability of guard cells.
-thus guard cells become hypotonic and so become flaccid

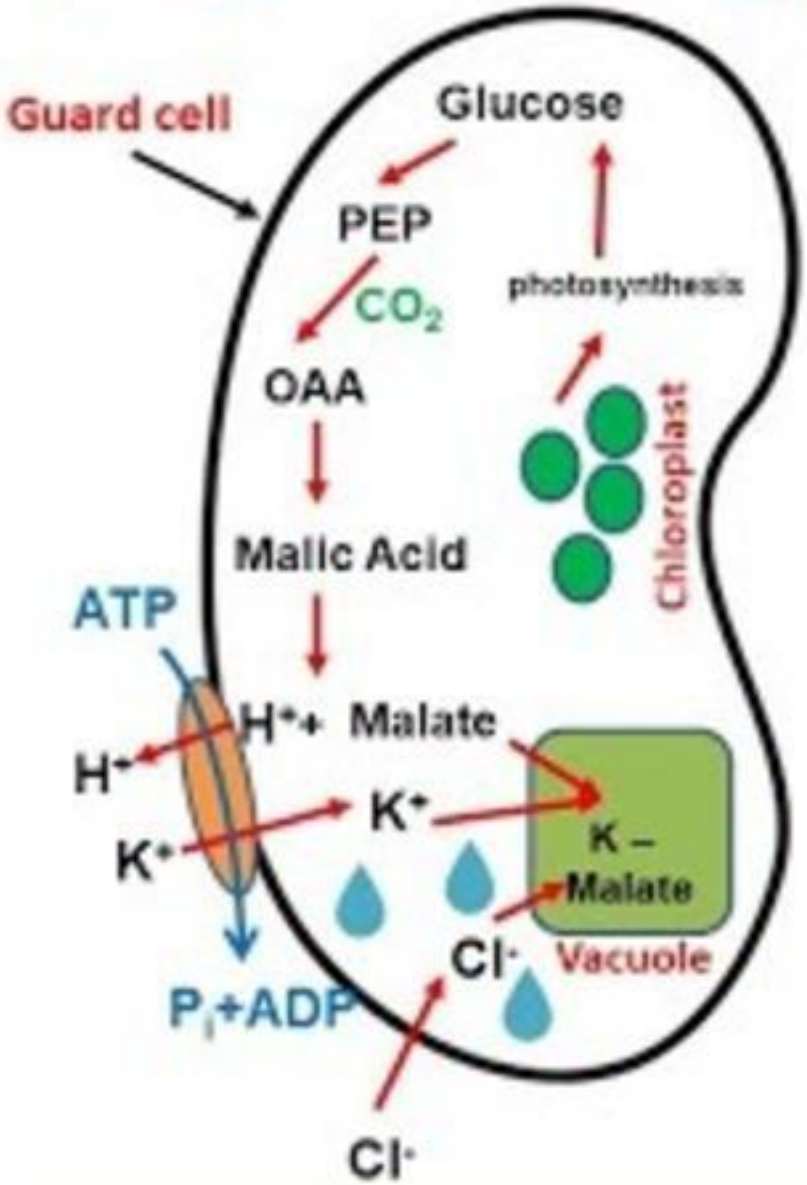
# Opening of Stomata

Day time

PEP – Phosphoenol Pyruvate

OAA -- Oxalo Acetic acid

Hydrogen potassium ion exchange pump




Increased ionic concentration ($K^+$ & $Cl^-$)

↓

Rise in osmotic pressure

↓

Water Potential decreases in Guard cell

↓

Water enters GC from Subsidiary cells

↓

GC becomes turgid


Active $K^+$ transport or potassium pump theory Levitt

## Significance of Transpiration :

## Advantages:

i. It removes excess of water.
ii. It helps in the passive absorption of water and minerals from soil.
iii. It helps in the ascent of sap.
iv. As stomata are open,gaseous exchange required for photosynthesis and respiration, is facilitated.
v. It maintains turgor of the cells.
vi. Transpiration helps in reducing the temperature of leaf and in imparting cooling effect.

## Disadvantages:

-Excessive transpiration leads to wilting and injury in the plant.
- It may also lead to the death of the plant.


WHY TRANSPIRATION IS KNOWN AS NECESSARY EVIL?

## Transpiration is 'A necessary evil' :

-For stomatal transpiration to occur, stoma must remain open, during day time.

-When stomata are open then only the gaseous exhange needed for respiration and photosynthesis, will take place but with loss of water.

- If stomatal transpiration stops, it will directly affect productivity of plant through the loss of photosynthetic and respiratory activity.

Hence for productivity, stomata must remain Open

So transpiration can not be avoided. Hence, Curtis (1926) regarded transpiration as 'a necessary evil'