Plant Physiology

Unit - I : Plant Water Relations :-

* Importance of water in plants life :-

1) Water is the main constituent of the protoplasm, comprising upto 90-95 % of its total weight. In absence of water, protoplasm becomes inactive & is even killed.
2) Different organic constituents of plants, such as carbohydrates, proteins, nucleic acids & enzymes etc., lose their physical and chemical properties in absence of water.
3) Water participates directly in many metabolic process
4) Water increases the rate of respiration. Seeds respire fast in presence of water.
5) During photosynthesis, water is source of hydrogen atom for reduction of CO_2.
6) Water maintains temperature of plant tissue.
7) Water acts as a good solvent. It forms the medium in which several reactions Take place.
8) Water maintains turgidity of plant cells.
9) Water helps in translocation of solutes, mobility of gametes, dissemination of spores, fruits & seeds and provides support to aquatic plants.
10) The amount of water present in the soil changes the morphology and anatomy of the plants. Accordingly the plants are hydrophytes, mesophyte and xerophytes.
11) Because of all these properties, water has great importance in plant life.

(2)

* Different bio-physico-chemical phenomena

(1) Permeability :—

"The entry of substances into living cells & their exit from the cells depends on the property of the cell membrane known as permeability."

Depending on permeability properties, the membrane may be of following types—

(a) Permeable :— It allows the passage of both solvent & solute molecules.

(b) Semipermeable / selectively permeable :— It allows passage of some substances, but checks the passage of others.

(c) Impermeable :— It does not allow the passage of any substance through it.

In plants, all the three types of membranes are found. The cell-wall is permeable, the plasma membrane is semi-permeable and cuticle is impermeable.

Factors affecting permeability :—

i) Physical agents :- The physical agents like ^high temp., heat, radiations, etc. increase the permeability of plasma membrane.

ii) Chemical agents :- The chemicals like ether, benzene, chloroform, acetone etc., when added to external medium or solution, increase the permeability.

iii) Ageing of cells :- The permeability varies at different ages of cells. In young cells, it is low, but at the time of senescence, it increases.

(2) Diffusion :—

To diffuse means 'to spread' or 'to flow out' 'to extend in all directions', 'to disperse'. Diffusion can be defined as, "Movement of particles of a matter due to their own kinetic energy." The direction of movement of these particles is from the region of their higher concentration to the region of their lower concentration in order to equalize the concentrations of two regions.

The dispersal of good smell of agarbattis in a room, dissolution of sugar in water, dissolution of $KMnO_4$ particles in water, intake of CO_2 & liberation of O_2 in photosynthesis, intake of O_2 and liberation of CO_2 during respiration are all the examples of diffusion.

The movement of molecules depends on the internal kinetic energy. The molecules in the region of higher concentration contain more kinetic energy & that is why they show fast movement. During the movement, all the molecules collide themselves and produce a pressure in the medium called diffusion pressure, which is directly proportional to the concentration & temperature of diffusing molecules.

Factors affecting diffusion :—

i) Temperature :- It is directly proportional to the rate of diffusion. On increasing the temperature, rate of diffusion is increased because of increase in the velocity of these particles.

ii) Concentration of the medium :- It is inversely proportional to the rate of diffusion. On increasing the concentration of the medium, the rate of diffusion is reduced & on decreasing the conc^{n}., it is increased.

Importance of diffusion in plants :-

1) The exchange of O_2 and CO_2 gases in the atmosphere through stomata of leaves takes place by the process of diffusion. O_2 gas participates in respiration, while CO_2 in photosynthesis.
2) Transpiration also takes place by diffusion.
3) Mineral nutrition uptake in plant is takes place by diffusion.
4) The movement of food & mineral nutrition in plant-body takes place by diffusion.

* Diffusion pressure deficit (DPD) or Suction pressure (SP)

- Like gases, solvents and liquids also posses diffusion pressure. The diffusion pressure of a pure solvent is always maximum and when solute particles are added in it, the diffusion pressure of the solution is reduced.
- The difference bet^{n} the diffusion pressure of a solvent and its solution is called diffusion pressure deficit (DPD).
- When a deficiency in diffusion pressure of the sol^{n} is created, it starts absorbing more solvent particles to overcome this deficiency.

(5)

(3) Osmosis :-

"When two solutions of different concentrations are separated by a semipermeable membrane, the diffusion of water or solvent molecules takes place from the solution of lower concentration towards the solution of higher concentration. This process is called as Osmosis." As a result of osmosis, concentration of the two solutions becomes equal.

Actually, the diffusion of solvent molecules takes place across the membrane on both the sides, but it is faster from lower conc. side than the higher conc. side. This is according to the principle of diffusion because the solution of lower conc.n possesses higher conc.n of solvent molecules, whereas the solution of higher concentration possesses comparitively lower concentration of solvent molecules. Thus, it can be said that, osmosis is a type of diffusion through semipermeable membrane.

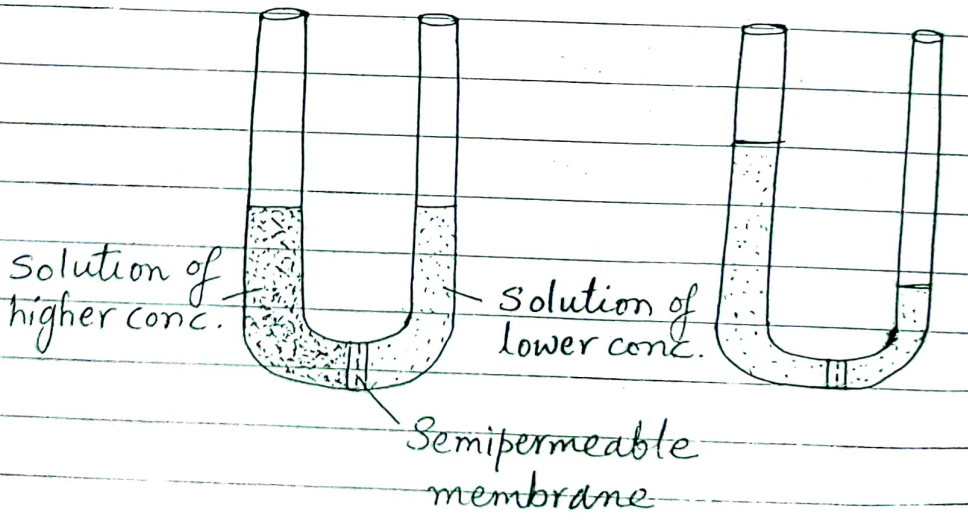


Fig : Demonstration of osmosis.

From biological point of view, the solutions may be of three Types, as follows :-

(a) Hypertonic solution — The sol^{n} whose concentration is more than the conc. of cell-sap is called as hypertonic solution.

(b) Hypotonic solution — The sol^{n} whose concentration is less than the conc. of cell-sap is called as hypotonic solution.

(c) Isotonic solution — The sol^{n} whose concentration is equal to the conc. of cell-sap is called isotonic solution.

Types of Osmosis in plants :-

(1) Endosmosis :- When a plant cell is placed in hypotonic solution, the water molecules move from outer medium into plant cell thro' plasma membrane. This process is called endosmosis.

(2) Exosmosis :- When a plant cell is placed in hypertonic solution, the water molecules move from the cell into outer medium thro' plasma membrane. This process is called exosmosis.

Importance of osmosis to plants :-

1) Entry of water into plant cells from the external environment depends on osmosis.
2) Movement of water from one living cell to another cell occurs due to osmosis.
3) Turgidity of cells is maintained due to osmosis.
4) Variety of movements are related to osmosis.
eg : Opening & closing of stomata & flowers, sleeping movements of most legume plants & nastic movement of Mimosa pudica.

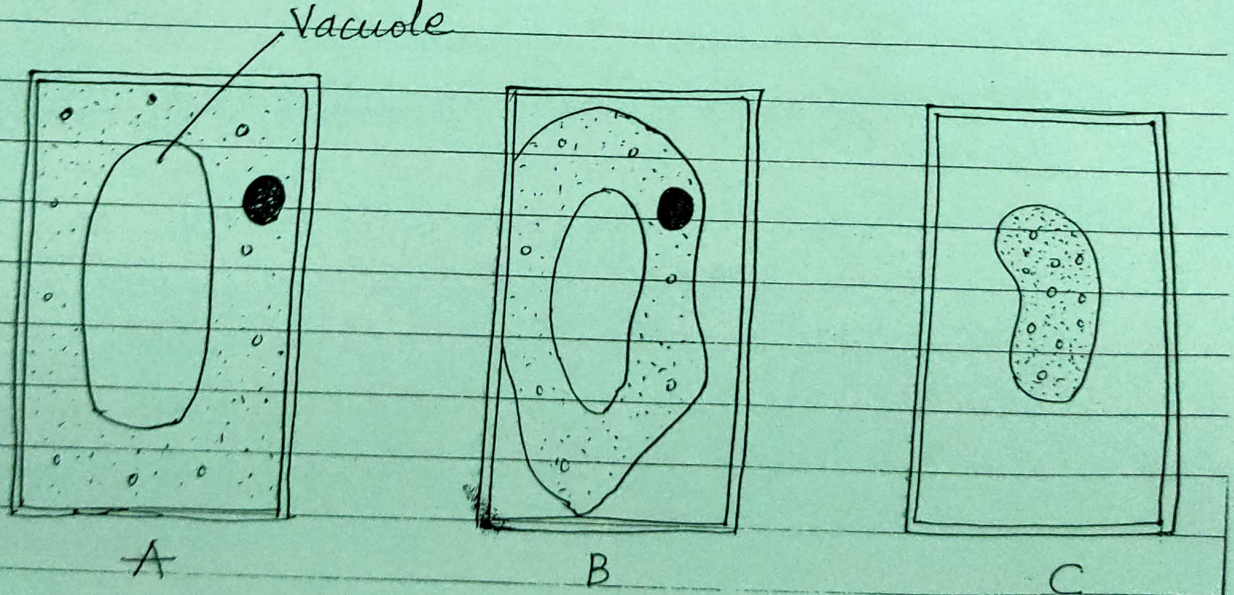
5) The equal distribution of water along different plant organs such as leaves, roots, seeds etc., is largely due to osmosis.

6) An increase in osmotic pressure of cell sap increases resistance of plants to dessication & freezing temp.

7) [illegible]

(4) Plasmolysis :—

"When a plant cell is placed in a hypertonic solution (ie. a solution having high concentration than that of cell sap), exosmosis occurs and water comes out from within the protoplasm. As a result, the protoplasm shrinks & leaves the cell-wall. This shrinking of protoplasm is known as plasmolysis." Since the cell-wall is permeable, the space between protoplasm and cell-wall is filled with the external solution.



Stages in plasmolysis : A – Normal cell
B – Incipient plasmolysis
C – A plasmolysed cell

If a plasmolysed cell is again placed in hypotonic solution (or a solution less concentrated than the cell-sap), water from outside enters the protoplasm or endosmosis occurs. As a result, the protoplasm again comes back to its original position & stretches up with the cell-wall. This process is known as deplasmolysis. The point at which the plasmolysis just starts, is known as incipient plasmolysis.

If a cell is placed in isotonic solution (ie. the solution having ~~same~~ concentration equal to the concentration of cell-sap), neither shrinking nor swelling of protoplasm occurs.

Advantages of plasmolysis. :—

1) Plasmolysis confirms the semi-permeable nature of plasma membrane.
2) Plasmolysis phenomenon is used to find out osmotic pressure of cell-sap.
3) ~~Plasmolysis is also used to protect the jam & jelly from fungal and bacterial infection. Jams and jellies possess high concentration of sugar which plasmolyses the fungal hyphae and bacterial cells & thus, their growth is checked.~~
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(5) Imbibition :—

"The absorption of water by hydrophilic colloids is called as imbibition." Some materials like gum, starch, cellulose, gelatin, agar, protein etc., when placed in water, they absorb it and swell up. This is imbibition.

Imbibition of water increases the volume of imbibant, due to which pressure is created, which is known as imbibitional pressure.

Different types of organic substances have different imbibing capacities. Proteins have a very high imbibing capacity, starch less & cellulose least. That is why proteinaceous pea seeds swell more on imbibition than starchy wheat seeds.

The swelling of dry seeds when placed in water, the swelling of wooden windows, tables, doors, etc. due to moisture during rainy season are the examples of imbibition.

Significance of imbibition :—

1) Imbibition initiates seed-germination.
2) It causes increase in volume of seeds & ultimately bursting of testa or seed coat.
3) During imbibition, heat energy is released, which further increases the activities of cells of living seeds.

✱ Ascent of Sap :—

Introduction :—

The water is absorbed by root hairs of the plant from where it reaches xylem via cortical cells & through xylem, it reaches top of the plant, where it is transpired by leaves and also used for other metabolic activities. By a number of experiments, it has been demonstrated that, xylem is the main water-conducting tissue.

"The upward movement of water from stem base to tree top is called ascent of sap." Sometimes, it covers a height of more than 90 meters against gravitational pull as in case of Australian Eucalyptus & Californian Sequoia.

Various theories have been proposed to explain the mechanism involved in the ascent of sap. Some workers consider that, living cells are actively involved in pumping of water, while others explained the mechanism to be purely physical one & independent of life activity.

Mechanism of Ascent of Sap :—

Transpiration-pull theory :—

This theory was proposed by Dixon & Jolly (1894) and has been supported by various scientists. This theory is also called as Cohesion-tension theory.

In order to understand the theory, it has been divided into following headings :—

(A) What is cohesion ? :— Attraction between the similar molecules is called as cohesion. The water molecules have strong mutual attraction

(cohesion) due to which they can not be easily separated from one-another.

(B) Cohesion-tension theory :- Water forms a continuous column from base of the plant to its top & remains under cohesive tension due to transpiration pull. According to need, water is being pulled up to the top of the tree

(C) Characteristics of cohesion-tension theory :-

i) Water forms a continuous column from the base of the plant to its top.

ii) Water is lost from mesophyll cells due to transpiration because of which a pulling force develops. It pulls these cells under tension.

iii) The tension may cause a break in water column, but due to cohesive property of water molecules, the continuous column is not broken

iv) The tension ~~is transmitted to~~ or transpiration pull is transmitted to the root region to regulate absorption.

(D) Mechanism of ascent of sap :- The loss of water from the surface of leaf mesophyll cells due to transpiration reduces the water amount & causes an increase in the osmotic pressure of these cells. Water from adjacent cells & ultimately from the conducting tissue is pulled to meet this loss of water & as a result, a pull is developed in mesophyll cells & xylem cells of the leaf. Now water present in the xylem ~~vessel~~ cells is placed under tension which is ultimately transmitted to the root through the stem tracheids.

(mesophyll cells)

This downward transmission of tension is because of cohesive properties of continuous water column in the vessels & tracheids from leaves to roots thro' stem. The water column moves upward due to Transpiration pull & simultaneously process of ascent of sap is accomplished.

(12)

★ Transpiration :-

A considerable amount of water absorbed by the roots and carried to the top of the plants is lost by aerial parts either in the form of water vapours or rarely in the form of liquid. "The loss of water from the living tissue of aerial parts of the plant in the form of water vapours is termed as transpiration and in the form of liquid is known as guttation."

Transpiration is a physiological process found in plants. Millions of plants die every year because the transpiration exceeds the amount of water absorbed through roots. But, transpiration is unavoidable. ~~Transpiration~~ It is said that, "Transpiration is a necessary evil." It is vital & unavoidable phenomenon (वरदान) in plants. Transpiration helps in the ascent of sap. It affects the absorption of water and minerals by roots. It maintains suitable temperature of the leaves. It helps in keeping surface of leaf & young stem wet ∴ to protect from sunburning.

Types of Transpiration :-

1) Cuticular transpiration :- The transpiration which occurs thro' cuticle is called cuticular transpiration. Cuticle is a layer of wax-like covering on the epidermis of leaves & herbaceous stem. Though it is meant to check transpiration, it may have some cracks on it ~~it~~ or when it is thin, transpiration occurs. Up to 10-20 % of the total transpiration may take place thro' cuticle.

2) Lenticular transpiration :- The transpiration occuring through lenticels is called lenticular transpiration. Lenticels are the areas in the bark which contains loosely arranged cells. The water vapour loss thro' lenticels is about 0.1% of total loss. It is quite negligible in comparison to total loss by the whole plant.

3) Stomatal transpiration :- The transpiration occuring thro' the stomata is called stomatal transpiration. Stomata are minute pores in epidermis & their opening & closing is controlled by guard cells. Maximum diffusion of water vapour takes place thro' stomata. The ~~root~~ loss of water vapour thro' stomata is about 80 - 90 % of the total loss. Stomata are mostly situated in leaves but also found in herbaceous stems.

Structure of stomata :-

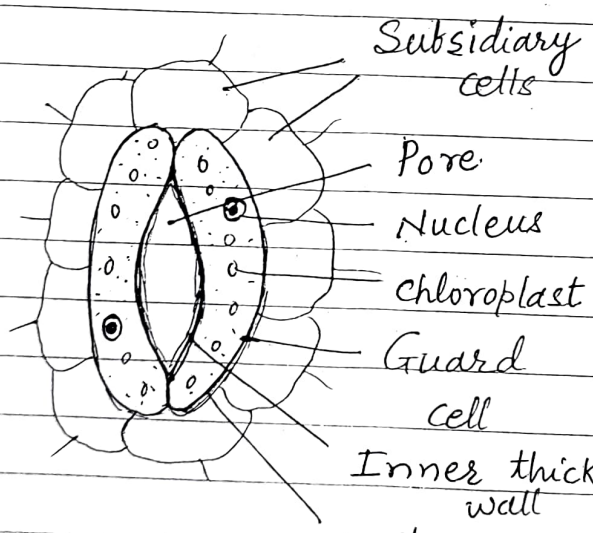

Fig : A stoma

The epidermis of leaves and green stems possesses many small pores called stomata. (Singular : stoma) Each pore is surrounded by two specialized epidermal cells, called guard cells. The guard cells are kidney-shaped in dicotyledons & dumbbell-shaped in members of Graminae family. The pore and guard cells are jointly called stoma. The stoma

opens to the interior into a cavity, called as sub-stomatal cavity.

The inner wall of the guard cells surrounding the pore is thick & inelastic (due to the presence of a secondary layer of cellulose), while the outer wall is thin, elastic & permeable. The guard cells possess a nucleus, cytoplasm & several chloroplasts. The epidermal cells surrounding guard cells are specialized & called subsidiary cells or accessary cells, which support in the movement of guard cells.

* Mechanism of opening & closing of stomata

Microscopic examinations of opened & closed stomata reveal that, open stomata have turgid guard cells, while closed stomata have flaccid guard cells. It was, therefore, concluded that, the opening & closing of stomata depends upon the changes in the turgidity of their guard cells. ie. when the guard cells are turgid, pores are open, but when flaccid, the pores are closed. The size of the pore depends upon the degree of turgidity of guard cells. When turgidity increases, the outer thin walls of the guard cells stretch outward causing outward stretching of their inner wall. The inner wall, being inelastic, becomes concave & as a result, the space surrounding the pore widens & pore opens. Thus, in the opening & closing of stomata, turgor mechanism is involved. Many theories have been proposed to explain how this change in turgidity in guard cells is brought about.

(1) Starch – sugar theory :–

According to Lloyd (1905), Loftfield (1921) & Sayre (1926), the amount of starch in guard cells increases during night & decreases during day time. The insoluble starch present in guard cells is hydrolyzed to into soluble glucose-1-(P) during daytime & soluble glucose-1-(P) is converted into insoluble starch during night. Thus, both are reversible reactions

$$\text{Starch (Insoluble)} + \text{Phosphorylase} \underset{\text{Night pH 4.5-5.0}}{\overset{\text{Day pH 7.5}}{\rightleftharpoons}} \text{Glucose-1-phosphate (Soluble)}$$

Sayre (1926) observed that, stomata opening & closing of stomata depends upon pH of guard cells. Stomata remain opened in neutral or alkaline pH & closed in acidic pH. He proposed that, pH determines interconversion of starch into sugar and vice-versa. The pH of guard cells increases during daytime & decreases during night time. How this change in pH occurs in guard cells was explained by Scarth (1932) & he proposed the theory of starch–sugar interaction. According to him, during daytime, CO_2 liberated due to respiration is utilized by mesophyll cells & guard cells in photosynthesis, which results in the lowering H ion concentration. Whenever, the pH value is high (less acidity), the enzymatic conversion of starch into glucose is favoured. In darkness, CO_2 accumulates in the intercellular spaces & vacuoles & increases the H ion concentration

Light → CO_2 in guard cells decreased → org. acid decreased by decarboxyl. reactions → pH of guard cells raised to 7.0 → Phosphorylase activated → Starch hydrolysed → Soluble Sugars increased

of cell-sap of guard cells & this decrease in pH favours conversion of sugar into starch.

The steps involved in opening & closing of stomata may be summerised as follows :—

Guard cells in light	Guard cells in dark
1) CO_2 is consumed in photosynthesis.	1) CO_2 released from respiration accumulates in the intercellular spaces. There is no photosynthesis.
2) pH rises; ie. guard cells show alkaline reaction.	2) pH falls, ie. guard cells show acidic reaction.
3) An increase in pH favours hydrolysis of starch into sugars.	3) A decrease in pH favours formation of starch from soluble sugars.
4) Sugars increase Osmotic pressure of cell-sap of guard cells.	4) Starch decreases osmotic pressure of cell-sap of guard cells.
5) Water enters in the guard cells due to rise of ~~O.P.~~ osmotic pressure & turgor pressure & volume of cells increase.	5) Water moves out of guard cells and osmotic pressure, turgor pressure and volume of cells decrease.
6) Guard cells become turgid & change their shape.	6) Guard cells become flaccid due to loss of water & change their shape.
7) As a result, stomata opens.	7) As a result, stomata close.

(17)

(2) K^+ pump theory :-

This theory was proposed by Levitt (1974) to explain the mechanism of opening and closing of stomata. According to this theory, potassium ions (K^+) have been found to play a critical role. The opening and closing of stomata are the result of an active transport of potassium ions into guard cells & out of them. The adjacent epidermal cells or subsidiary cells act as ion storage cells for guard cells.

The exact biochemical steps are not known. One possibility is that, during day time, starch is metabolised to malic acid & then light triggers the excretion of malic acid from chloroplasts into the cytoplasm of guard cells. The malic acid is then converted into malate ion and proton (H^+) by enzyme phosphoenol pyruvic acid carboxylase (PEPC). The protons produced are used for ionic balance. ie. protons (H^+) are given out from guard cells in exchange of K^+ ions & some Cl^- ions are also imported in guard cells. Malate then becomes potassium malate, which is transported into vacuoles. The increased conc^n. of potassium malate in the cell increases osmotic pressure & water enters into guard cells. This increases turgor pressure of guard cells & makes them turgid. Due to this, the stomata get opened.

Noggle & Fritz (1976) have summerised the sequence of events which occur during light-induced stomatal opening as follows :-

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Light → Malic acid production → Dissociation into hydrogen & malate ions →

→ Influx of K^+ & efflux of H^+ → Transport of potassium malate into the vacuoles →

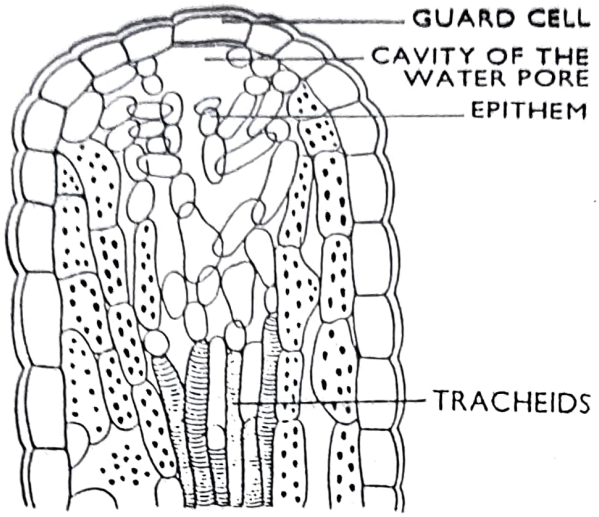
→ Osmotic entrance of water into guard cells → Increase of Turgor pressure

↓

Stomata open.

* Guttation

- In some plants such as tomato, strawberry etc., watery drops coze out from the uninjured margins of the leaves where a main vein ends. This is called as guttation.
- Usually it takes place early in the morning when the rate of water absorption is high and transpiration is very low.
- The watery drops consist of water in which many inorganic and organic substances are dissolved.
- After the drops have dried, the salts and organic substances etc. remain in the form of a residue on the margins of the leaves.
- The phenomenon of guttation is associated with the presence of special types of stomata at the margins of the leaves which are called as water stomata or hydathodes.
- Each hydathode consists of a water pore which remains permanently open. Below this there is a small cavity of a loose tissue called as epithem.
- The epithem is in close association with the ends of vascular elements of veins as shown in following figure.
- Under higher root pressure the water is given to the epithem by the xylem of the veins.
- From epithem the water is released into the cavity and when cavity is completely filled with the watery sol", the water begins to ooze out in the form of watery drops through the water pore.



Vertical section of a leaf through a hydathode.

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* Antitranspirants.

- Those substances which reduce the rate of transpiration in plants are called plant antitranspirants.
- An antitranspirant (AT) applied to transpiring plant surfaces to reduce transpiration water losses and conserves water in plant.
- Anti-transpirants are liquids that you spray on your plants to shield them from moisture loss. once the product is sprayed on plants the spray dries and forms transparent coating without interfering the plant growth, osmosis or photosynthesis.
- The examples of antitranspirants are phenyl-mercury acetate, Abscisic acid and aspirin. There are some colourless plastics, silicone oils and low viscocity waxes when sprayed on leaves, form a thin film which is impermeable to water but not to CO_2 or O_2.
- CO_2 is also known to act as antitranspirant. An increase in CO_2 concentration in atmosphere from usual 0.03% to about 0.05% causes partial closure of stomata.
  In very high concentration, however, it may cause complete stomatal closure and thus retard photosynthesis too.
- Use of CO_2 as antitranspirant is economical and practically used in greenhouses.

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* Water Absorption

The absorption of water in different types of plants is performed by some of their special organs. ie. in lower plants, water is absorbed by their all cells, in aquatic plants by the cells of external surface of different organs and in higher plants by the well developed root system. Roots possess several unicellular root hairs which play an important role in absorption of water

* Mechanism of water absorption

According to Renner (1912 and 1915), the mechanism of water absorption is of following two types.

① Active absorption :-
- When roots are involved actively in absorption of water and water absorbing forces in plants are developed primarily in roots, such type of absorption is called active absorption.
- It requires energy which is released during respiration. It is found in those plants where transpiration is less and water is present in sufficient amounts.

It is of two types:-

ⓐ Osmotic absorption

- In this type of absorption the roots act like a osmometer and water is absorbed according to osmotic gradient (Atkins, 1961 and Priestley, 1922)

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- ~~Soil~~ According to active osmotic absorption theory, soil is made up of irregularly arranged soil particles. The soil particles are having air spaces which contain capillary water.
- The root hairs remain spread in this water. The root hairs contain vacuole which remains filled with mineral salts, sugar and organic acids.
The cell wall of root hair is permeable which allows entry and exit of the liquids in the cell.
- plasma membrane of root is semipermeable in nature and it allows only the diffusion of water and important dissolved salts through it into the cytoplasm.
- The cell-wall of root hair is being hydrophilic in nature first absorbs soil water through imbibition.
- The cytoplasm of root hair is usually concentrated than the capillary water of soil. The OP of cell sap of root is also greater than the OP of capillary water of soil.
- Thus the DPD (Diffusion pressure deficit) and SP (suction pressure) becomes more in root hairs resulting in osmotic diffusion or endoosmosis of water and its dissolved substances into the root hair.
- After a definite time, the cells of root hairs become turgid and their OP, DPD and SP are reduced and TP is increased due to continuous absorption of water into the root hair.
- Due to this the cytoplasm of root hair becomes thin and its OP, DPD and SP are reduced in comparison to the cytoplasm of its adjacent cell (first cortex cell) resulting in osmotic water and its dissolved subs-

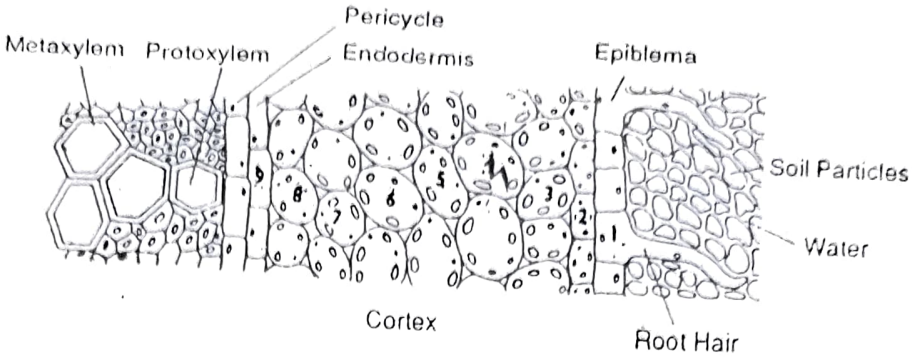

Fig 3.7: Osmotic active absorption.

tances from root hair into the first cortex cell.
- Now the OP, DPD and SP of this first cortex cell are also reduced and TP is increased and similarly the osmotic diffusion of water and its dissolved substances from first cortex cell to second adjacent cell takes place because the second cortex cell possesses greater OP, DPD and SP than the first cortex cell.
- This process continues till the water reaches pericycle through all cortex cells and endodermal cells. The endodermis possesses passage cells which are thin walled and diffuses water into the cells of pericycle and ultimately into xylem vessels.
- As the water diffuses from root hair to first cortex cell, the cytoplasm of root hair cell again becomes concentrated and its OP, DPD and SP are also increased resulting again in osmotic diffusion of capillary water of soil into the root hair.
- This phenomenon continues for long time and thus osmotic active absorption takes

→ Pathway of Water in Root

The pathway of water in root cells is as follows,

Root hair → Epidermal cell → various cortical cells → Endodermal cell (passage cell) → cells of pericycle → xylem cells → xylem duct → upward movement of water.

Root pressure :-

When the water enters from the turgid pericycle cells into xylem vessels, a pressure is created in the xylem of roots due to which the water rises to a certain height in the xylem. This pressure is called root pressure.

- Actually the root pressure is a type of hydrostatic pressure which is produced in the cell-sap of xylem vessels.

(b) Non-osmotic Active Absorption

- According to Thimann (1951) and Kramer (1959) the water absorption is an active process which takes place against the osmotic gradient.
- It means that sometimes the water absorption also takes place when the osmotic pressure of soil water is greater than that of OP of cytoplasm of root hair.
- This is against osmosis and such type of water absorption is called non-osmotic absorption.
- It requires ATP which is produced during respiration of root cells.

water absorption continued

[2] Passive Absorption

- It takes place mainly due to transpiration.
- In passive absorption, the roots remain inactive and the water absorbing forces are first produced in the cells of leaves.
- When DPD increases in the cells of leaves due to transpiration, the water diffuses from the xylem cells of leaves to all mesophyll cells.
- When the rate of transpiration is high, a tension is created in the water column of xylem which increases the DPD of water.
- This tension is like negative pressure and it moves from leaves to roots.
- In this way the absorption of water through the roots takes place.

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① Capillary water: water held in the micropores of the soil that composes the soil soil.

★ Plant Movements :

Everywhere in our daily life, movements of living objects are observed. The animals show noticeable movements, plants do not show noticeable movements, because the movements of higher plants are chiefly in the form of bending, twisting, elongation of certain plant parts, etc. Some of the lower plants show characteristic noticeable motility.

Plant movements occur in response to certain stimuli & depend on irritability and sensitivity of protoplasm. Stimulus is defined as "change in the external environment which affects living organism". Irritability is defined as "quality of protoplasm because of which it shows response to external stimuli". Stimuli may be gravitational, thermal or chemical or they may be that of light, touch & shock.

Plant movements are classified as -

(A) Autonomic movements / Spontaneous movements.

(B) Induced / Paratonic movements.

(A) Autonomic / Spontaneous movements :-

The plant movements which occur due to the internal stimuli are called autonomic movements / spontaneous movements.

Ex :- Streaming of protoplasm, chromosomal movements during cell division, motility of the zoospores & gametes of many plants, etc.

(B) Induced / Paratonic movements :—

The plant movements which occur due to external stimuli are called induced / paratonic movements.

∴ Paratonic movements are of three Types, viz: (1) Tactic movements, (2) Tropic movements & (3) Nastic movements.

(1) Tactic movements :— These are locomotion (Translocation) movements. These movements occur in response to external stimuli and their direction is controlled by the direction of the stimulus. Depending on the type of stimulus, tactic movements are of ~~four~~ 3 Types, as follows :-

(a) Phototactic — The tactic movements in response to light are called phototactic movements.

eg. : The movement of chloroplasts in palisade cells in response to light stimulus.

(b) Chemotactic — The tactic movements in response to chemical ~~as~~ are called chemotactic movements.

eg. : The movement of spermatozoids towards egg in response to chemotactic attraction.

(c) Thermotactic — The ~~mov~~ tactic movements in response to temperature ~~as~~ are called thermo-~~tactic~~ tactic movements.

eg. : Movement of algae like Chlamydomonas.

(2) Tropic movements :—

These movements are growth & curvature movements which occur in response to external stimuli. They occur in one direction due

to differences in rates of growth on two sides of the moving organ, which results in curvature.

Depending on the type of stimulus, tropic movements are of five types, as follows :-

i) Phototropic movements :- The tropic movements in response to light are called as phototropic movements. These are curvature movements that take place when plant is provided with artificial or natural light only from one direction.

eg. a) The flowers of Helianthus annus (Sunflower) move keeping their faces towards Sun.

b) In Arachis hypogea (groundnut), ovary stalk is positively Phototropic till ovary is unfertilized, but after the ovary is fertilized, it becomes negatively phototropic & bends towards soil & moves the ovary inside the soil

ii) Chemotropic movements :- The tropic movements in response to chemicals are called as chemotropic movements.

eg. : The pollen tube, in many cases, moves through the style towards ovary due to a chemical stimulus.

iii) Geotropic movements :- The tropic movements in response to gravitational stimulus are called geotropic movement.

eg. : Positive geotropism in primary roots & negative geotropism in shoots.

iv) Hydrotropic movements : The tropic movements in response to water stimulus are called as

hydrotropic movements.
eg: Roots are positively hydrotropic.

v) Thigmotropic movements :- The tropic movements in response to the stimulus of touch are called as thigmotropic movements.
eg: The stem tendrils of the members of Cucurbitaceae when come in contact with any solid object, they grow fast & encircle around it & help the plant to climb up.

(3) Nastic movements :-

These movements ~~are which the movement~~ are unrelated and direction of the stimulus is not fixed & it is diffused. ~~The examples of~~ Such movements are mostly observed in leaves and petals, etc.

Depending upon the Types of stimulus, nastic movements are of following Three types —
(i) Photonastic - Nastic movements due to light.
eg: The flowers of Oxalis & Portulaca open in day & close at night.
(ii) Thermonastic - Nastic movements in response to temperature.
eg: The flowers of Crocus & Tulip open in warm normal temperature, but close in cool temperature.
(iii) Seismonastic - Nastic movements in (touch) response to mechanical shocks such as blows, shaking, ~~etc or~~, pressure etc.
eg: Leaflets of Mimosa pudica (touch me not plant) get closed ~~on touching~~ & hang down on touching.

Tropic Movements

1- **Phototropism**: phototropic or curvature movements that take place when plant is provided with artificial or natural light only from one direction. If curvature movement is toward the source of light it is known as positive phototropism and if away from the source of light is known as negative phototropism. Leaves of some plants can keep themselves perpendicular to the source of light and diaphototropic. One example of phototropic movement is the leaves of Neptunia oleracea which keeping their faces towards sun keep on moving throughout the day turning from east to west. The flowers of Helianthus annuus (sun flower) also move the same way always keeping their faces towards sun. Ovary stalk of Arachis hypogea shows different type of phototropic movements during different phases of its life. It is positively phototropic when the ovary is unfertilized; if it becomes negatively phototropic with the result that it bends towards soil and moves the ovary inside the soil. The dispersal of spores in pilobolus (a fungus) occurs when the sporangiophores have moved towards light.

The phototropic movements are thought to be controlled by growth regulatory substances which collect on the side away from the light to increase its growth and result in curvature.

In the laboratory, phototropism can be demonstrated by keeping a potted plant inside a box with a small opening only on one side to provide light. After sometime it will be found that stem has bent towards the opening through which the light is coming.

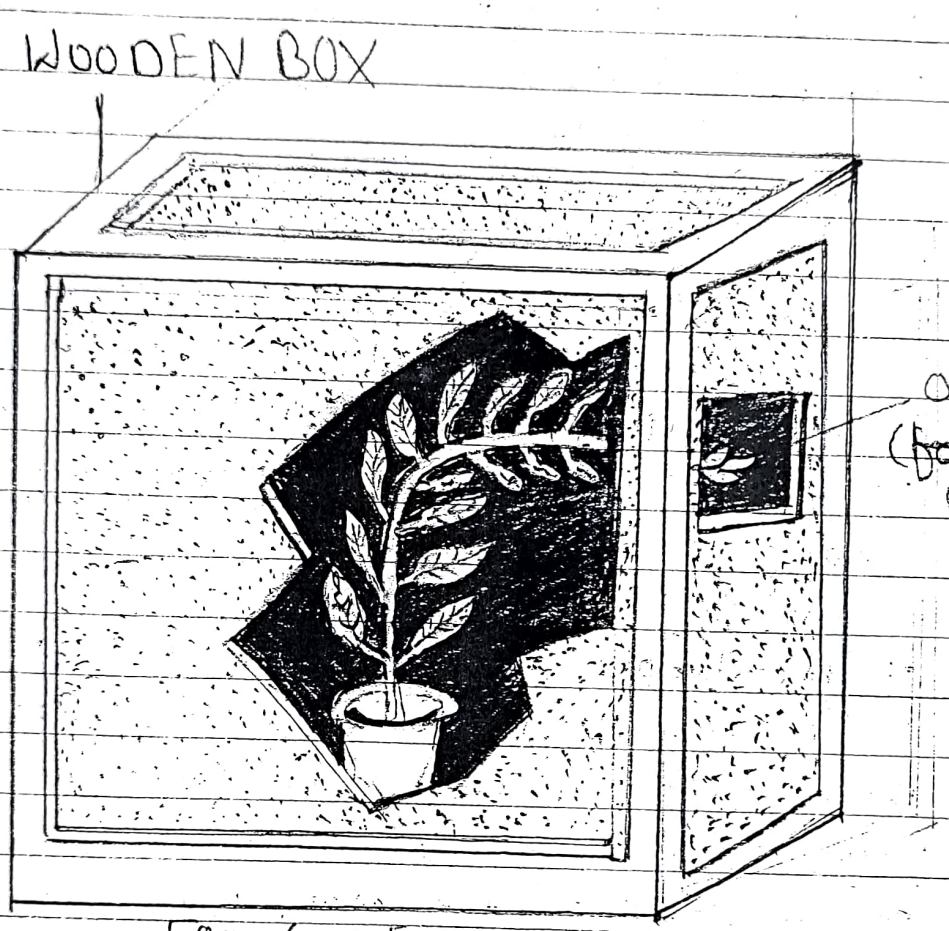

Fig. 6.19. Experiment to show phototropism

2- Geotropism: Geotropism is the movement caused in responce to gravitational stimulus. positive geotropism is observed in the primary roots of many plants and negative geotropism in their shoots. The secondary branches of roots and stems are diageotropic or plagiogeotropic or apogeotropic as they grow laterally at an angle to the gravitational stimulus. The flower stalk of poppy flower shows different responce to gravitational

stimulus during different phases of its life. It is positively geotropic and keeps the unopened bud hanging down but as the bud opens and changes into flower, it becomes negatively geotropic with the result that the direction of the stalk changes and flower grows upwards. The change in the direction occurs due to unequal growth on the two sides of the stalk. Depending on the contour, the rhizome of many plants also grows horizontally in the soil due to some reason.

The geotropism can be demonstrated in the laboratory with the help of an instrument known as klinostat which when fixed on it can keep a potted plant rotating with a definite speed. If two klinostat are taken with potted plants kept in horizontal positions and one is rotated while keeping the other one fixed and stationary, after some time it will be found that the shoot of the plant kept on the fixed klinostat bend upwards showing negative geotropism and root bends downwards showing positive geotropism. While both the roots and shoots of the plant fixed on the rotating klinostat do not show any bending because the gravitation stimulus in this case is not unilateral as it affects all the sides of the rotating organs equally.

Charles Darwin's experiment showed that if the shoot and root tips are cut off, there is no response to gravitational stimulus and the region of perception of the stimulus (the tip) is different from the region of response (the zone

of cell elongation). To explain the reason of the curvature and bending of the roots and shoots, various theories have been put forward by Vernon, Nemec, Haberlandt etc, in the part but the most convincing evidences are for the hormone theory proposed by Cholodny, Dolk, Bennet, Clark, Ball, etc.

According to this theory, the hormones synthesized in the apical meristem uniformely distributed flow towards mature regions due to gravitational force when the plant is upright, but when it is kept in horizontal position, the concentration of flowing hormone becomes more on low side due to gravitational force and less on the other side. This unequal concentration of hormones on the two sides of the organ concerned results in an unequal growth rate of two sides affecting the tendency of the organ.

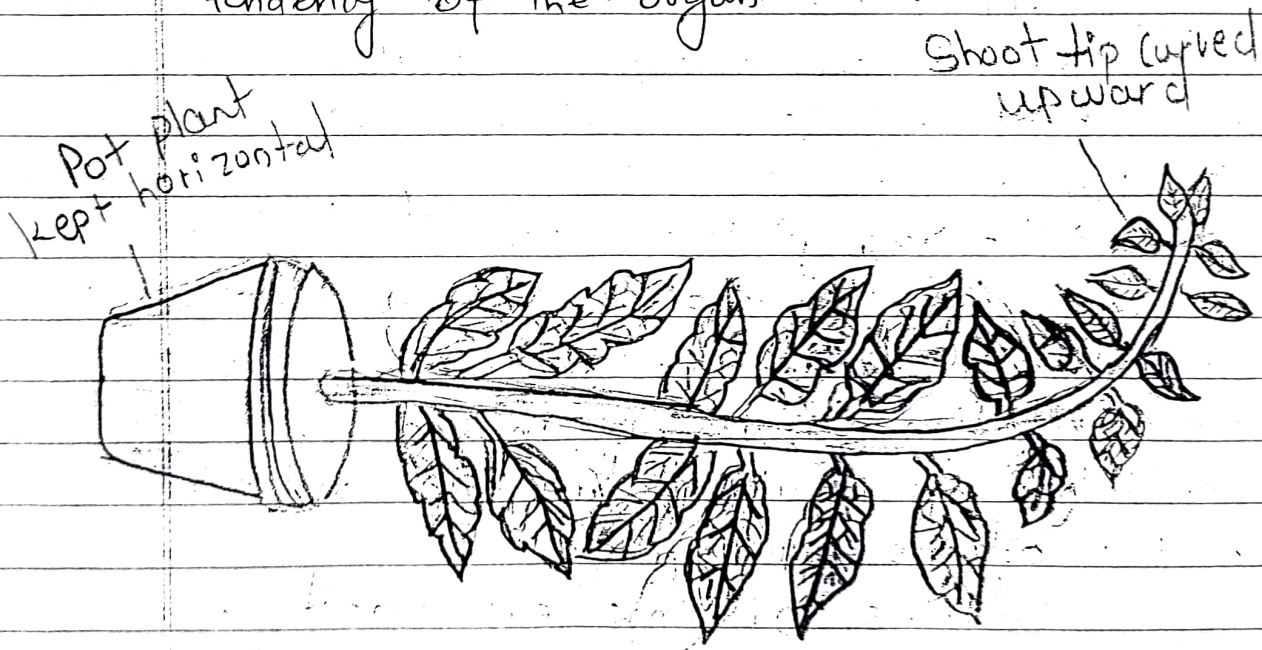

Fig: Experiment to Show geotropic Curvature

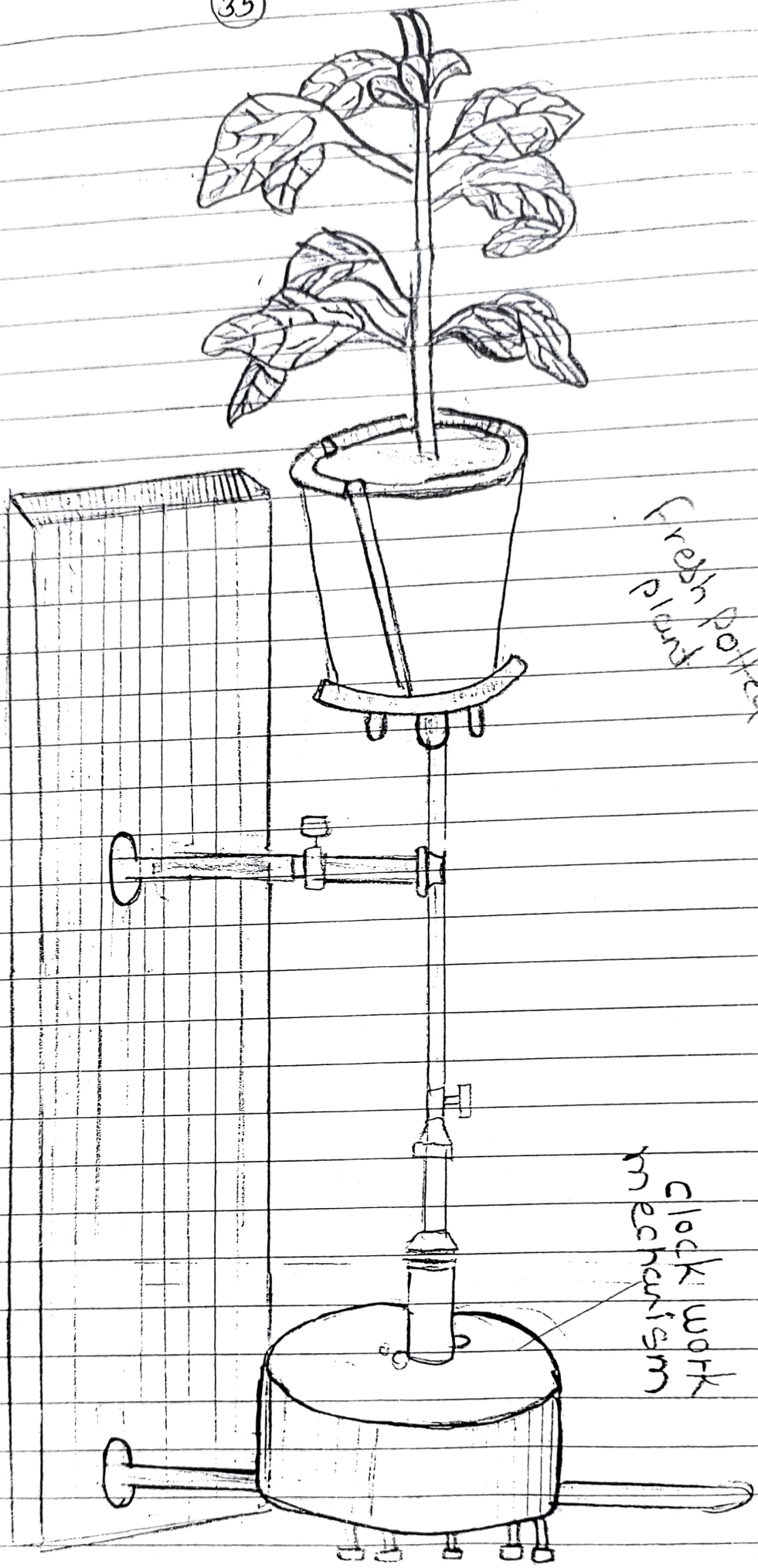

Fig. : Klinostat

3. Hydrotropism :-

This is the reaction of plant organs induced by an unilateral change in the concentration of water vapour. The rhizoids of some liverworts and the roots of higher plants are for the most part positively hydrotropic. Sporangiophores of lower fungi and stipes of fructification of higher fungi as well as some seedling shoots are negatively hydrotropic.

See on Page 38 / Experimental demonstration

4. Chemotropism :-

This is caused by an unequal distribution of certain chemical substances in the environment of the plant. Such substances include carbonates of ammonium, potassium, sodium and lithium as well as sulphates of ammonia and potassium which induce only positive curvatures. Many acids, almost all chlorides, sulphates and nitrates (except potassium sulphates and potassium ureate) which induce negative curvatures. Sodium tartrate, potassium nitrate and potassium ureate which induce either positive or negative curvature depending on the concentration used. Glucose, lactose, sucrose, calcium carbonate and magnesium carbonate which exert no chemotropic response and asparagine, urea, ammonium oxalate and some dyes yield indefinite results.

The chemotropic influence has been detected in zoospores of saprolegnia fungal hyphae, moss spermatozoids, pollen-tubes of higher plants as well as shoots and root of seedlings.

In case of the root, chemotropism is due to differential changes produced in the emulsoids of the protoplasm on the

two sides of the stimulated organ.

fig: Chemotropic Movement

5. Geotropism :-

The bending movement of plant organs in response to gravitational force is called geotropism. Since gravitational force is an external stimulus, this geotropic movement is said to be a paratonic movement. This bending movement is stabilized in the plant organs, so that it is a growth movement.

The roots have a tendency to grow towards the soil. Such movement of roots towards the soil is called positive geotropism. On the other hand shoots tend to grow away from the soil against the force of gravity. Such growth movement is negative geotropism.

The geotropism can be distinguished into three types based on direction of curvature. they are orthogeotropism

If the organ bends vertically upward or downward in response to gravity, the geotropic movement is called orthogeotropism. In plants, primary root grows vertically downwards, this movement is called positive orthogeotropism. main stem grows vertically upwards. so movement is called negative orthogeotropism

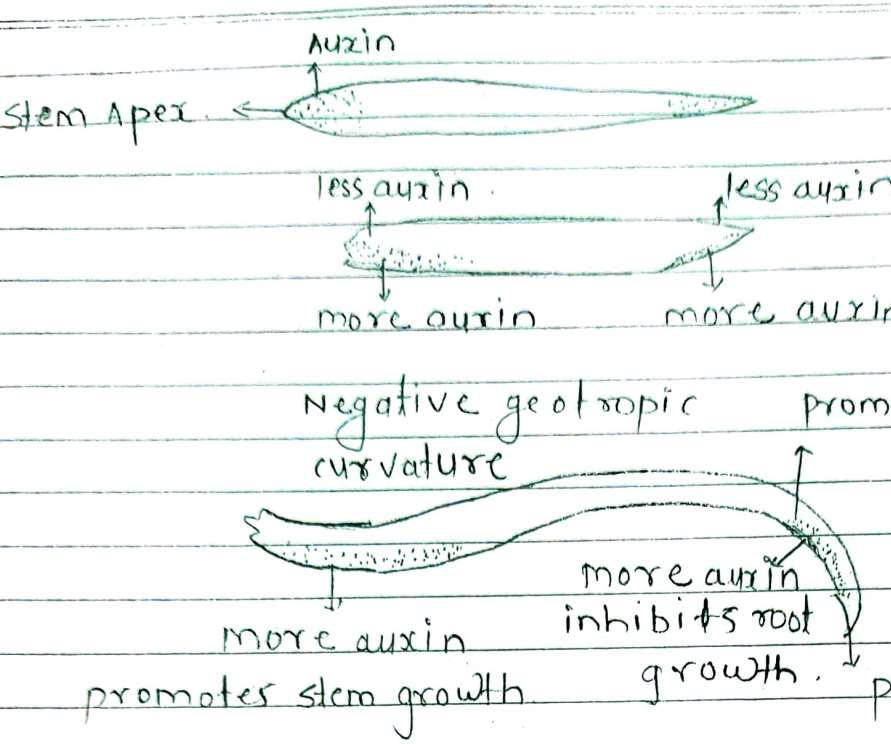

fig: An Interaction of gravitational force & auxin leading to geotropic curvature in root & stem tips

* Hydrotropism :-

The bending movement of plant parts in response to water stimulus is called hydrotropism. The curvature is caused by growth and hence it is a growth movement. water is an external stimulus, hydrotropism is a paratonic movement. Normally, roots grow towards water. so, they are positively hydrotropic.

positive hydrotropism can be demonstrated with germinating seedlings. It involves following steps:

1) freshly sprouted seedlings are allowed to grow on an inclined wire gauge.

2) The seedlings are covered with moist saw dust.

3) The wire guage is kept on a support in such a way that its lower surface remains to air

4) The seedlings are observed after few days to visualize the movement of roots.
5) The radicles a first grow downwards and come out of the wire gauge due to the force of gravity.
6) then they bend towards the moist saw dust (positive hydrotropism) and reenter the saw dust through another hole of wire gauge.

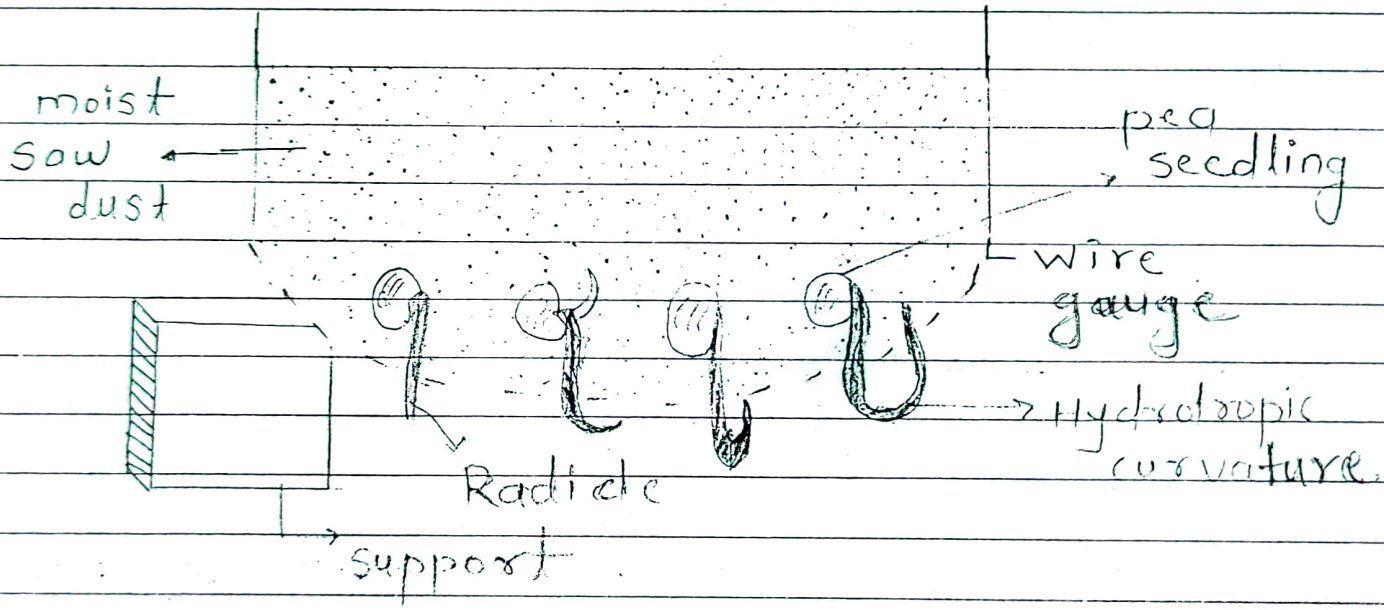

fig: Demonstration of Hydrotropism

[2] Paratonic movements
(Induced movements)

- The movements arising from some external stimulus are called induced or paratonic movements.
- The stimulus may be unidirectional or diffused.

Nastic movements

- These are paratonic variation movements which are brought about by certain external stimuli ie. light, temp. and touch.
- Nastic movements are brought about by stimuli which are not directional but diffused (widely spread) means in these movements the direction of the stimulus is not fixed, but it is diffused.
- Depending upon the nature of external stimuli ie. light, temp., length of day and night, touch the nastic movements are of following types,

(a) Photonastic :-

The nastic movements which are brought about by the stimulation of light are called photonastic movements.

For Ex:- the flowers of oxalis open in a day and close at night in response to light.

(b) Thermonastic movements :-
The nastic movements which are brought about by the stimulation of temp. are called thermonastic movements.
For ex. : The flowers of crocus open in a warm temp. but close in cool temps.

(c) Nyctinastic movements (sleep movements) :-
In many plants the leaves and flowers acquire a particular but different position during day and at night. such movements are called as nyctinastic movements or sleep movements.
- ~~If~~ The diurnal (daily) change in day and night causes such movements.
- In oxalis, the three leaflets are spread out almost in a horizontal position during the day but at night, the leaflets fold together and droop down.

...ments which occur in response ...are called as **thermonastic movements.**

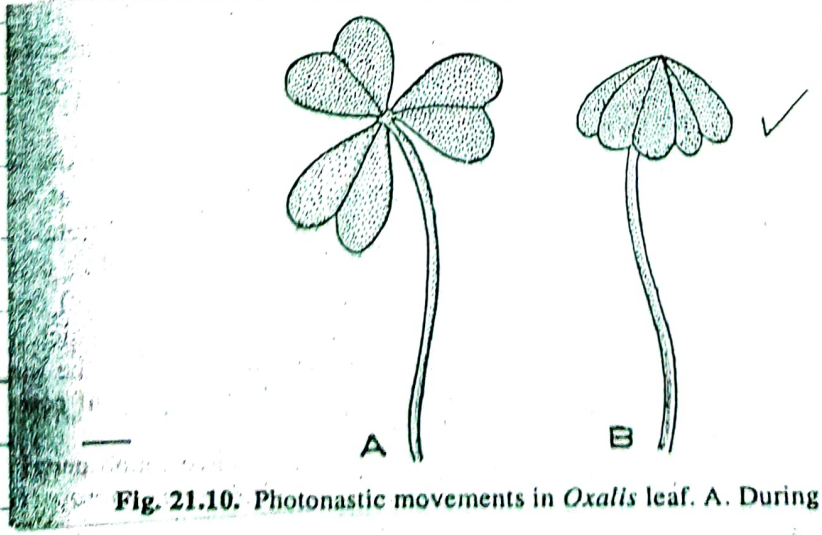

Fig. 21.10. Photonastic movements in *Oxalis* leaf. A. During day; B. During night.

(2) Seismonastic movements :-

- These movements are best exhibited by sensitive plant ~~pi~~ (Mimosa pudica) and occur in response to a touch or shock stimulus.
- In this plant the leaves are bipinnately compound with a swollen pulvinus at the bases of each leaf and similar but smaller pulvinules at the bases of each leaflet or pinna.
- If a terminal pinnule of a leaflet is touched or given a shock treatment, the stimulus passes downward to the pulvinule and all the pinnules of that leaflet get successively closed in pairs.
- Now the stimulus passes to the other pinnae or leaflets so that their pinnules also close down and finally it reaches the pulvinus resulting in drooping of whole of the leaf and whole of this process is completed just in few seconds.

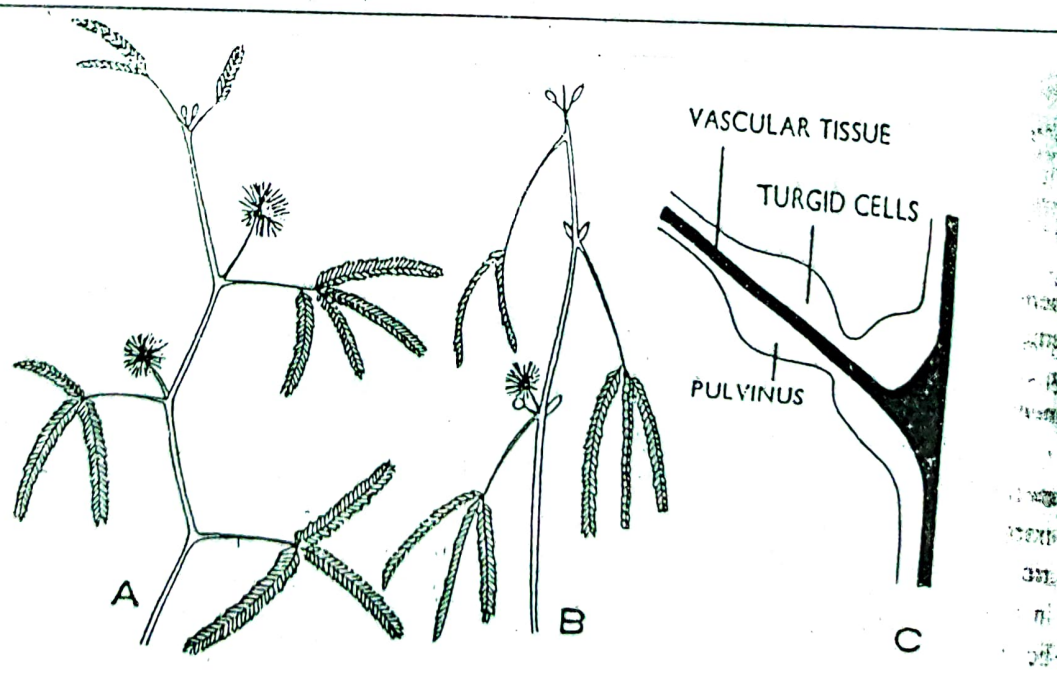

Fig. 21.11. Seismonastic movements in *Mimosa pudica* A. Unstimulated leaf ; B. Stimulated leaf ; C. Diagrammatic section of the pulvinus.

- The pulvinus contains a number of specialised large thin walled parenchymatous cells called motor cells which undergo reversible changes in turgor in response to the stimulus.
- When stimulus reaches the pulvinus, the osmotic pressure of motor cells is decreased. consequently, water is released from them into intercellular spaces and they suddenly collapse, resulting in drooping down of the leaflets and the leaf.
- After the lapse of sometime, the leaf recovers from the shock or touch stimulus, the turgor of motor cells is restored and the leaflets and the leaf come in their normal erect position.

(e) Thigmonastic movements.

- The movements are found in the leaves of Drosera (sundew) and result in response to the touch stimulus of the insects.
- In Drosera, as soon as an insect sits on the leaf, the tentacles curve inward to trap the insect.
- These parts of the leaves come to their normal position after the insect has been digested.