Transport in Plants

11

INTRODUCTION :

Stephan hales (1727) is known as ***'Father of plant physiology'.***

Plant physiology is a branch of science which deals with the study of all biological activities of plants. Usually most of the plants absorb water and minerals from land. Water has specific importance for plants. 80-90% part of plant is made up of water. The water relations of plants can be explained by following activities.

DIFFUSION :

The movement of molecules of gases, Liquid solid from the region of higher concentration to the region of lower concentration is called diffusion.

Process of Diffusion is based on kinetic energy of molecules. The molecules move from the higher concentration to lower concentration due to kinetic energy until an equilibrium is obtained.

Ex: Diffusion of copper sulphate particles in water, Diffusion of Ammonia in air.

Diffusion pressure :

The potential ability of a substance to diffuse from an area of its greater concentration to an area of its lower concentration is called diffusion pressure. It is maximum in pure water.

Factor affecting the rate of diffusion :

(1) Temperature : Rate of diffusion is directly proportional to temperature. If temperature increases than the rate of diffusion is increased.

Rate of diffusion $\propto$ Temperature.

(2) Density : The rate of diffusion is inversely proportional to the square root of the density of the diffusing substance.

$D \alpha \frac{1}{\sqrt{d}}$ d = Density

Rate of Diffusion is maximum in Gases.

Gases > Liquid > Solid

(3) Diffusion pressure gradient (DPG) :

DPG =

$$\frac{\text{Differences between diffusion pressure at two places}}{\text{Distance of diffusion}}$$

$$= \frac{DP_1 - DP_2}{D}$$

(4) Pressure : Rate of Diffusion $\propto$ Pressure.

Significance of Diffusion :

1. The exchange of gases (O_2 & CO_2) takes place through diffusion.
2. Passive absorption of ions of mineral substances in plants.
3. Evaporation of water from intercellular spaces during transpiration through diffusion.
4. Distribution of hormones in plants through diffusion.
5. Osmosis is a special type of diffusion.

Facilitated diffusion :

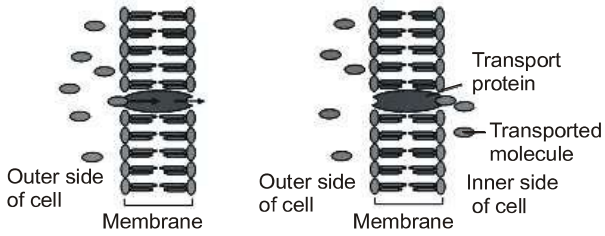


Fig : Facilitated diffusion

Lipid soluble substances diffuse faster through the membrane. But hydrophilic solutes, difficult to pass through the membrane. Their movement has to be facilitated.

Some special proteins are helpful in the movement of substances across membranes without expenditure of ATP energy.

For this purpose membranes contain quaporins and ion channels. Some carrier proteins allow transport only if two types of moleules move together. It is called **cotransport**. It is of three types

(A) When a molecule moves across a membrane independent to other molecules, the process in called **uniport**.

(B) Antiport : Both molecules move in opposite directions.

(C) Symport : Both molecules cross the membrane in the same direction.

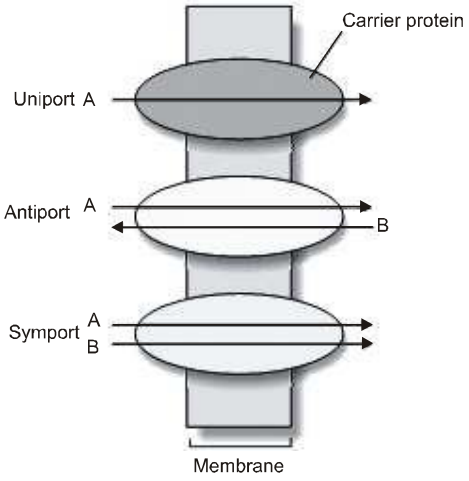


Fig : Facilitated diffusion

Active Transport :

Active transport uses energy to pump molecules against a concentration gradient. Active transport is carried out by membrane-proteins. Hence different proteins in the membrane play a major role in both active as well as passive transport. Pumps are proteins that use energy to carry substances across the cell membrane. These pumps can transport substances from a low concentration to a high concentration ('uphill' transport). Transport rate reaches a maximum when all the protein transporters are being used or are saturated. Like enzymes the carrier protein is very specific in what it carries across the membrane. These proteins are sensitive to inhibitors that react with protein side chains.

Comparison of Different Transport Processes :

Following table gives a comparison of the different transport mechanisms. Proteins in the membrane are responsible for facilitated diffusion and active transport and hence show common characterstics of being highly selective; they are liable to saturate, respond to inhibitors and are under hormonal regulation. But diffusion whether facilitated or not take place only along a gradient and do not use energy.

Comparison of Different Transport Mechanisms			
Property	Simple Diffusion	Facilitated Transport	Active Transport
Requires special membrane proteins	No	Yes	Yes
Highly selective	No	Yes	Yes
Transport saturates	No	Yes	Yes
Uphill transport	No	No	Yes
Requires ATP energy	No	No	Yes

Permeability :

Exchange of different substances from plasma membrane is called permeability. On the basis of permeability, membranes are of four types.

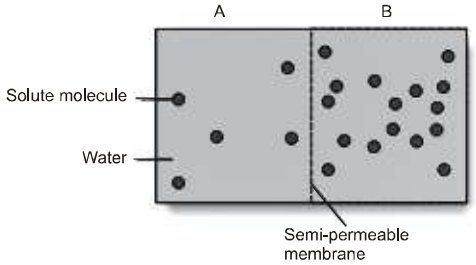
(1) Permeable membrane : It is permeable for the both solute and solvent **Ex: cellulosic cell wall.**

(2) Impermeable membranes : They inhibit the diffusion of both solute & solvent particles through them. **Ex: cutinised or suberised cell walls.**

(3) Semi-permeable membrane : It is impermeable for solute and permeable for solvent **Ex: Copper ferrocyanide membrane, Cellophane.**

(4) Selectively permeable membrane or differential permeable membrane : This membrane is permeable for some solute along with solvents. **Ex: Plasma membrane** is permeable for Alcohol, Ether, water, gases, but impermeable for phospholipids, polysaccharides and protein.

Osmosis :



When two solution of different concentration are separated by means of semipermeable membrane, the diffusion of solvent from a region of high chemical potential to a region of low chemical potential is called **osmosis**.

Osmosis was discovered by **Nollet** (1748). **Dutrochet** (1827) gave detail description of osmosis.

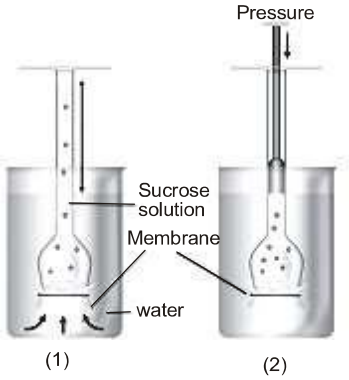


Fig : A demonstration of osmosis. A thistle funnel is filled with sucrose solution and kept inverted in a beaker containing water. (1) water will diffuse across the membrane (as shown by arrows) to raise the level of the solution in the funnel (2) pressure can be applied as shown to stop the water movement into the funnel.

Types of osmosis :

(1) Endosmosis : Intake of water molecules into the cell sap through osmosis, is called endomosis. **Ex: If dry regins are dipped in water for sometime, they swell up due to endomosis.**

(2) Exosmosis : Exit of water molecules from cell is called exosmosis. **Ex: If fresh grapes are dipped in hypertonic solution (like strong sugar solution) they show shrinkage after some time due to exosmosis.**

Osmotic pressure (OP) :

The pressure needed to prevent the passage of water into the solution through semipermeable membrane is called osmotic pressure.

Osmotic pressure of pure water is zero.

Osmotic pressure is measured by **osmometer** which was firstly made by **pfeffer.**

Osmotic pressure increases due to increase in temperature

O.P. $\propto$ Temperature.

Thus osmotic pressure is only potential pressure. At present time the term **osmotic potential ($\Psi\pi$) or solute potential (Ψs)** is used instead of osmotic pressure, solute potential is equal to the osmotic pressure but its sign is negative. $\Psi_s = -\pi$

Significance of osmosis :

1. Root hairs absorb water from soil through osmosis.
2. Exchange of soluble substances & water from one cell to another cell by osmosis.
3. Osmosis cause turgidity in plants which is helpful to maintain the definite shape of leaves, stem & flowers.

   It also provides mechanical support to the plant.
4. Opening and closing of stomata, germination of seeds, dehiscence of sporangium. seismonasty in Mimosa pudica occurs due to osmosis.
5. The resistance of plants to drought and frost increases with increase in osmotic pressure of their cells.

Turgor pressure (TP) and wall pressure (WP) :

The pressure created by cytoplasm upon the cell wall due to intake of water, is called **turgor pressure (TP)**

The pressure created by cell wall upon the cytoplasm is called **wall pressure (WP).** Usually TP & WP are equal and opposite in direction.

Turgor pressure in flaccid cell is zero.

Turgor pressure is maximum in turgid cell and equal to the osmotic pressure (OP).

At present time turgor pressure is known as pressure Potential which is denoted by Ψ_p. Its value is positive.

Diffusion Pressure Deficit (DPD) :

The amount by which the diffusion pressure of a solution is lower than that of its solvent is called DPD. It is also called **Suction pressure (SP).**

The term DPD was given by **B.S. Mayer (1938)**.

Osmosis occurs from a region of lower DPD (SP) to region of higher DPD (SP).

Usually DPD		**=**	**OP – TP**
	if WP	=	TP
Than DPD or	SP	=	OP – WP
In flaccid cell	TP	=	0
	DPD	=	OP – O = OP
In turgid cell	OP	=	TP
	DPD	=	OP – TP = O
	DPD	=	O

On full turgidity of cell DPD will be zero. So water does not enter in cell.

In plasmolysed cell DPD is maximum because TP is negative.

Water potential :

The difference between the free energy of water molecules in pure water and the energy of water in any system is called water potential.

Movement of water occurs from region of higher water potential to region of lower water potential.

Tayler & Slatyer gave the term water potential.

Water potential of pure water is maximum and zero.

Water potential is denoted by **Psi (Ψ)** letter. It is measured in **Bar**.

Water potential (Ψ) of protoplasm is equal to DPD but opposite in sign.

Component of water potential :

Water potential = Matric potential + Osmotic or Solute potential + Pressure potential

$\Psi_W = \Psi_m + \Psi_s + \Psi_P$

$\Psi_W = \Psi_s + \Psi_P$ **Ψ_m is not counted**

Ψ_W = **–Ve**

Ψ_s = **–Ve**

Ψ_P = **+Ve**

(i) Matric potential (Ψ_m) : It is used for the surface to which molecules of water are adsorbed. During osmosis Ψ_m is not significant.

(ii) Solute potential (Ψ_s) : It denotes the concentration of the solutes in a solution. It reduce water potential. Ψ_s is always negative.

(iii) Pressure potential (Ψ_p) : Plant cell is elastic and it exerts a pressure on the cellular contents. The pressure potential is usually positive and operates in plant cells as turgor pressure (TP) or wall pressure (WP).

(A) In case of fully Turgid cell :

When a plant cell is Turgid, its solute potential and pressure potential equal & opposite in sign. So its water potential will be zero. Example if solute potential = –5 bar and pressure potential = +5 bars than water potential will be zero.

$\Psi_W = \Psi_S + \Psi_P$

$\Psi_W = -5 + 5$

$\Psi_W = 0$

(B) In case of flaccid cell :

When a plant cell is flaccid than its turgor pressure will be zero means its pressure potential will be zero. Its solute potential is –5 bar than

$\Psi_W = \Psi_S + \Psi_P$

$\Psi_W = -5 + 0$ bar

$\Psi_W = -5$ bar

(C) In plasmolysed cell :

Because pressure potential is (Ψ_p) is negative So water potential will be more negative.

if $\Psi_s = -10$ bar and $\Psi_p = -5$ bar than.

$\Psi_W = \Psi_s + \Psi_P$

$\Psi_W = -10 + (-5)$ bar

$\Psi_W = -15$ bar

Types of solution :

(1) Hypertonic solution : If the concentration of solution is higher than protoplasm, it is called hypertonic solution. It show exomosis or plasmolysis.

(2) Hypotonic solution : If the concentration of solution is less than protoplasm, it is called hypotonic solution. It shows endosmosis.

(3) Isotonic solution : If the concentration of a specific solution and the protoplasm is same, it is called as isotonic solution. Cell or tissue will remain as such in isotonic solution.

Plasmolysis :

If the plant cell is placed in a hypertonic solution water comes out from the cell sap into the outer solution due to exosmosis and the protoplast becomes reduced. So cell wall contracts which result in reduction in cell size. This first stage of plasmolysis is called **limiting plasmolysis.** Further loss of water from cell causes contraction of protoplast which withdraws from corner of cell. This stage is called as **incipient plasmolysis** ultimately the protoplasm separates from the cell wall and assumes a spherical form This process is known as **evident plasmolysis.**

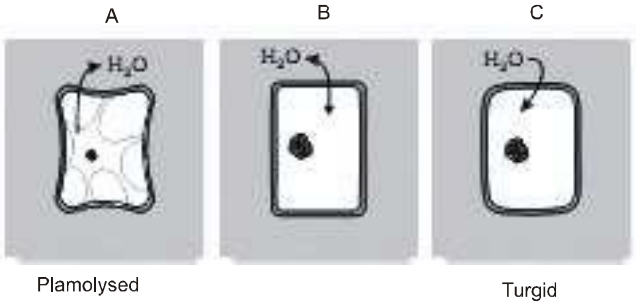


Fig Plant cell plasmolysis

Deplasmolysis :

When a plasmolyzed cell is placed in water or hypotonic solution endosmosis takes place and cell become turgid and protoplasm again assumes its normal shape and position. This process is called as deplasmolysis.

Significance of plasmolysis :

(1) Plasmolysis can be used to detect dead cell and living cell.

(2) Plasmolysis is utilized in salting of meat and fishes and addition of concentrate sugar solution in jams and jellies to check the growth of fungi and bacteria which becomes plasmolysed in concentrate solution.

(3) Common salt kills weeds by plasmolysis.

(4) Osmotic pressure of a cell can be known by plasmolysis.

Imbibition :

It is a physical process in which adsorption of water by hydrophillic protoplasmic substances and cell wall constituents specially polysaccharides and proteins with out forming a solution**. Ex:** Wooden doors absorb water and swell up in rainy season and seeds of pea and gram when placed in water swell up due to imbibition.

Effects of imbibition :

1. **Swelling :** Volume of substances increase due to imbibition but the total volume is less than sum of both volume.

   Imbibant + Water = Swelling

   15 + 85 always less than 100

2. **Liberation of Heat :** Usually water molecules are situated on the surface of the imbibant they loose some of their kinetic energy due to imbibition which appear as heat in system, that is called **Heat of wetting**.

3. **Imbibition pressure (I.P.) :** It is a maximum pressure that is produced after complete absorption of pure water by imbibants. DPD = IP – TP

   The magnitude of this pressure is very significant. for example when dried wooden piece is inserted in to rock, due to swelling of wood enough pressure is created and cracks appear in rock.

Significance :

1. Young cells abosrb water through imbibition.
2. Absorption of water during seed germination through Imbibition.
3. Bursting of seed coat during seed germination due to imbibition.
4. Wood absorbs water and swell up in rainy season.

ABSORPTION OF WATER BY PLANTS

* Water is an excellent solvent and essential for the physiological processes and helps in up take and distribution of nutrients and solutes for growth and development of plants.
* Water participates in many vital activities of the plants. All the organic and inorganic material are translocated only through the water. The cells of the plant remains in turgid condition due to water. It helps in the growth of the plant. Water is essential for germination of seeds. All the enzyme action only takes place in the presence of water. Plant movements is due to the turgidity of the cells. Translocation of nutrients and chemical reaction of plants take place in aqueous solution.

FORMS OF WATER

Water is mainly obtained through rain. Some of the water goes into the water reservoirs. This is called **run off water**. Rest of the water enter into the land. Water present in soil is following types $\rightarrow$

(a) Gravitational water :-

Form of water, which reaches at the soil water table due to the gravitational force after the rainfall. This form is **not available** to plants but available by mechanical methods or by tubewell irrigation. Some plants can absorbed this water – **Calotropis, Prosopis, Capparis, etc.**

(b) Hygroscopic water :-

Thin film of water is tightly held by the soil particles is called hygroscopic water. This water is also **not available** to the plants.

Ψw of hygroscopic water is highly negative or very low.

(c) Chemically combined water :-

The amount of water present in the chemical compounds, which are present in the particles of soil. This is **not available** to the plants. ..... 24 H_2O, ... 7 H_2O

(d) Capillary water :-

Water exists between soil particles in small capillary pores is called **capillary water**. It is **the most available form to the plants. Plants only absorb this form of water.**

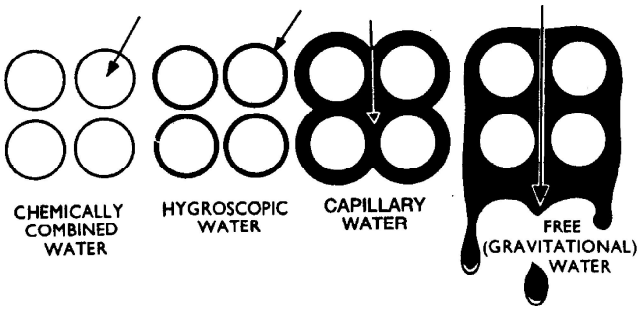
(e) Atmospheric humidity :-

This is water vapour present in air, which can be absorbed by hanging roots of the epiphytes due to presence of velamen tissue.

Holard: It is the **total amount of water presents in the soil. Holard = Chresard + Echard**

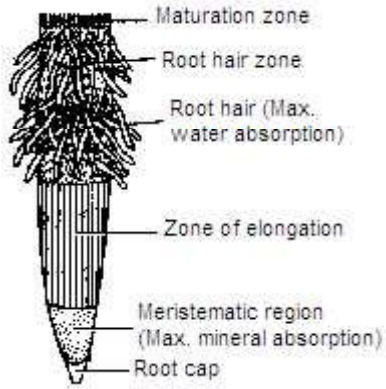
Chresard : This is the **water available** to the plants.

Echard : This **water is not available** to the plants



ORGAN FOR WATER ABSORPTION

Water is absorbed by either the whole surface or by the rhizoids in lower plants but in pteridophytes and spermatophytes absorption of water takes place through the root.



Root has the following four distinct regions :-

[i] Root cap region **[ii] Meristematic region**

[iii] Elongation region **[iv] Root hair region**

[v] Maturation region

The maximum absorption of water takes place from **root hair region**. These root hairs increases the absorption area of root.

* Transplanted plants can not grow easily as root hairs are damaged.

* Osmotic pressure of cell sap is greater than that of osmotic pressure of soil solution. The osmotic pressure of cell sap is about 3 atm.

PATH OF WATER ABSORPTION

Soil solution → Root hairs → Epiblema/Epidermis → cortex → Cortex → Endodermis (passage cells) → Pericycle cells → Protoxylem → Metaxylem.

* The water situated in the soil is to be reach up to the xylem of root. Root hairs remains in the contact of water. First of all water is easily adsorbed on **pectin wall of root hairs**, then water entered into the epidermis of root hairs. From here water reaches up to the endodermis through the cortex. The wall of endodermis are suberised. But cells lie in front of the protoxylem are thin walled known as **passage cells**. These cell transfer water to the xylem. From here water reached to the xylem from endodermal cells through the thin walled pericycle cells.

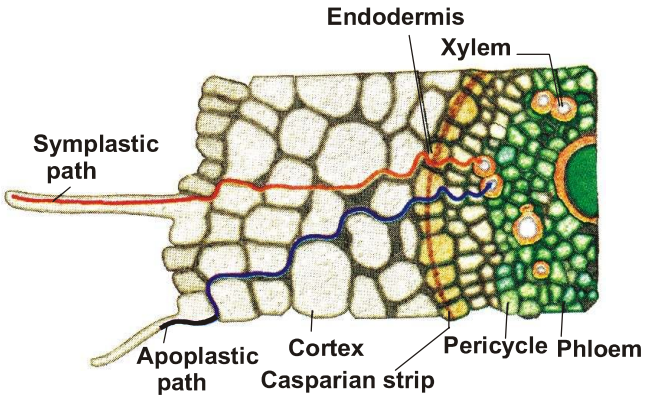


Fig:-Water and ion absorption and movement in roots by symplastic and apoplastic pathways

(a) Symplast :-

A sustainable **living path** is known as symplast. This is the living passage. The movement of water from cell to cell through plasmodesmata is called **symplastic path** in plant. This movement of water through cell membrane is also called as **transmembrane pathway.**

(b) Apoplast :-

This is the **non living path** in plants .Watered cell wall, intercellular space and xylem cavity associate together to form apoplast.

* Term **"apoplast"** & **"symplast"** given by **Munch**

* The path of water from root hair to cortex, may be apoplastic or symplastic. Casparian strips blocks the apoplast, thus water must passes through passasge cells via symplast.

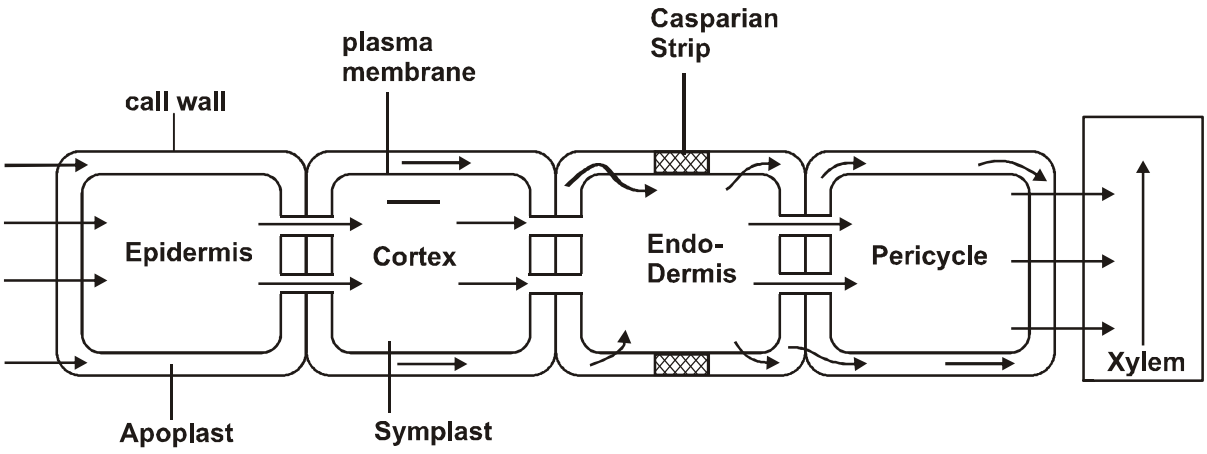


Fig:- Pathways of water movement inside the root

MECHANISM OF WATER ABSORPTION

Water is absorbed by two different ways :-

(1) Active water absorption

(2) Passive water absorption.

Mechanism

Term active & passive absorption was proposed by **Renner.**

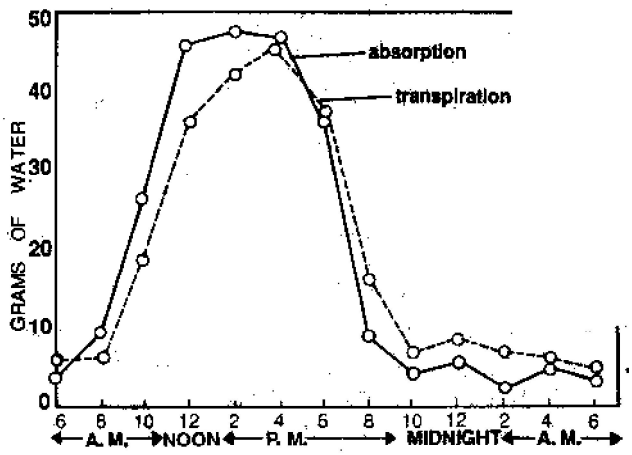
1. **Active absorption of water** → Acco. to this method water is absorbed due to the activity of roots or by expenditure of ATPs.

I. **Osmotic active** → This is given by **Atkins** & **Priestley**. Acco. to this method water is absorbed due to the osmotic activity of roots in order to O.P. & D.P.D. **No direct ATP are consumed** in this method.

II. **Non osmotic Active** → Proposed by **Thieman, Bennet-Clark**. According to this method absorption of water occurs **against the osmotic concentration** by direct investment/**expenditure of metabolic energy** in the form of ATPs. Generally this process present in **Halophytes.**

* Only 4% of total absorbed water is taken by this process.

2. **Passive absorption of water** → According to this method forces for the absorption of water originates in **aerial parts** by rapid transpiration & roots remain as passive organ. According to **Kramer** water absorption in plants is followed by transpiration. **About 96% of water is absorbed by passive method**. Due to rapid transpiration, D.P.D. of leaf cells ⍋ result in suction force, which suck the water from roots.



Factors affecting water absorption :

[1] Available soil water :-

* **Plant absorbs capillary water,** which is present in soil. Absorption of water depends on the amount of capillary water present in the soil. Absorption increases by increasing amount of capillary water.

* If, water is present in higher amount in the soil then such type of soil is called "**Water logged soil**". This soil is **physiologically dry** and lack oxygen. Because of this anaerobic respiration takes place in roots, and alcohol is formed. Roots can be degenerate due to form alcohol. (**Dry soil** is physically dry.)

[2] Soil temperature :-

* Soil temperature affects the following mechanisms:-

[i] Low temperature decreases the permeability of cell membrane.

[ii] It is essential for the activity of enzymes for the formation of root hairs.

[iii] At low temperature viscosity of capillary water is increased.

* Generally, normal absorption of water take place at temperature of soil between 20 - 35^0C.

* Increasing or decreasing soil temperature, lower down the rate of absorption of water.

Cold soil is as **physiologically dry.**

[3] Soil Air :-

* Absorption of water proceeds more rapidly in well aerated soil.

Deficiency of oxygen in soil causes improper respiration in roots.

* **Poorly aerated soil** is **physiologically dry.**

[4] Soil Concentration :

* The rate of the absorption is inversely proportional to the concentration of minerals present in soil.

$$\text{Water Absorption} \propto \frac{1}{\text{concentration of soil minerals}}$$

* Water absorption is only take place in appropriate soil solution. If the concentration of soil minerals is high, it decreases the rate of absorption. Therefore **saline soil** is **physiologically dry**. Halophytes can grown only in this soil.

[5] Transpiration :-

* According to **Kramer** the rate of water absorption is directly proportional to the rate of transpiration. The rate of absorption increases due to increase in the transpiration. Because passive water absorption increases due to transpiration.

OTHER METHODS OF WATER ABSORPTION

(a) By mycorrhiza :-

* The root hairs are not developed in some of **conifer** plants thus water is absorbed with the help of mycorrhizal association.

* These fungus myecilium absorb water and minerals and transfers to the roots.

These fungus myecilium obtain their food from the roots.

(b) By Velamen :-

* Velamens are **found in epiphytes** such as **Orchids.**

* Absorption of water vapour of air takes place in these plants through the hanging roots. These roots have specialised tissue on the **out side of their cortex** is called **velamen**.

(C) By Hygroscopic hairs :-

* Hairs are arises from the aerial parts of the epiphytic plants which absorbs atmospheric moisture are called **hygroscopic hairs**.

ASCENT OF SAP

Upward movement of absorbed water against the gravitational force upto top parts of plants is called as ascent of sap.

* **Xylem is water conducting tissue in plants.**

Evidence for this : Experiments which that xylem is water conducting tissue of the plants :

(i) **Girdling or ringing exp. : Malpighi, Hartig** and **Stephen hales.**

(ii**) Experiment on Balsam** plant - By using eosin dye and found that xylem is water conducting tissue.

(iii) **Blockage experiments** By **Dixon -** Xylem was blocked by using wax.

* **Mechanism :-** Various theories are given to explain the mechanism of ascent of sap.

(A) Vital force theories : According to these theories living cells involved in ascent of sap.

(1) Westermaier (1883) :- According to him ascent of sap is due to the activity of **xylem parenchyma cells.**

(2) Godlewski's theory (1884) :- According to him the ascent of sap is due to rhythemic change of osmotic pressure of **xylem parenchyma** & **medullary cells.**

This theory is also known as **'Relay pump theory' or Clambering hypothesis.**

(3) Pulsation theory :- By **Sir J.C. Bose** – According to this theory ascent of sap is due to the **pulsatory activity of the inner most layer of cortex.**

Bose explains his theory with help of galvanometer or **electric probe**.

Objection :-

According to **Strasburger** ascent of sap is continue after the living cells of xylem killed by poison **picric acid**

It means ascent of sap is through the non living elements of xylem i.e. **vessels** & **tracheids.**

(B) Root pressure theory : By **Priestley**.

According to it, a positive pressure is develop into xylem sap, due to turgidity or activity of root cells (cortical cells), is called **root pressure**, which pushed water upwards is xylem.

* Term **root pressure** & phenomenon was discovered by **Stephen Hales**.

Objection :-

(i) Root pressure is absent in woody plants like Gymnosperms.

(ii) When root pressure is high, during night, then ascent of sap is low.

(C) Physical force theories :

(1) Capillary force theory :- By **Boehm** – According to this **vessels** & **trachieds** acts as capillaries & ascent of sap takes place due to **capillary force.**

(2) Imbibition force theory :- By **Unger** & **Von Sachs**– According to it ascent of sap is due to the **imbibition force of xylem wall.**

(3) Chain theory :- By **Jamin** – According to it a chain of alternate layers of water and air are formed in xylem. When layer of air is expands than water will move upwards.

(4) Transpiration pull & cohesion force theory :- By **Dixon** & **Jolly.**

Most accepted or universally accepted theory of ascent of sap.

According to it 3 components are involved in ascent of sap.

(a) Cohesion : Mutual **attraction between the water molecule** is known as cohesion, which form a continuous water column in xylem elements.

(b) Adhesion : Attraction between xylem walls & water molecules is called **adhesion force**, which helps in maintainance of water coloumn of xylem.

(c) Transpiration Pull : A tension or negative pressure develops in xylem, due to rapid transpiration in leaves (because of high DPD), this creates a transpiration pull, which is responsible for the pulling up of water column in xylem. So ascent of sap is constitutive effect of cohesion, adhesion & transpiration pull.

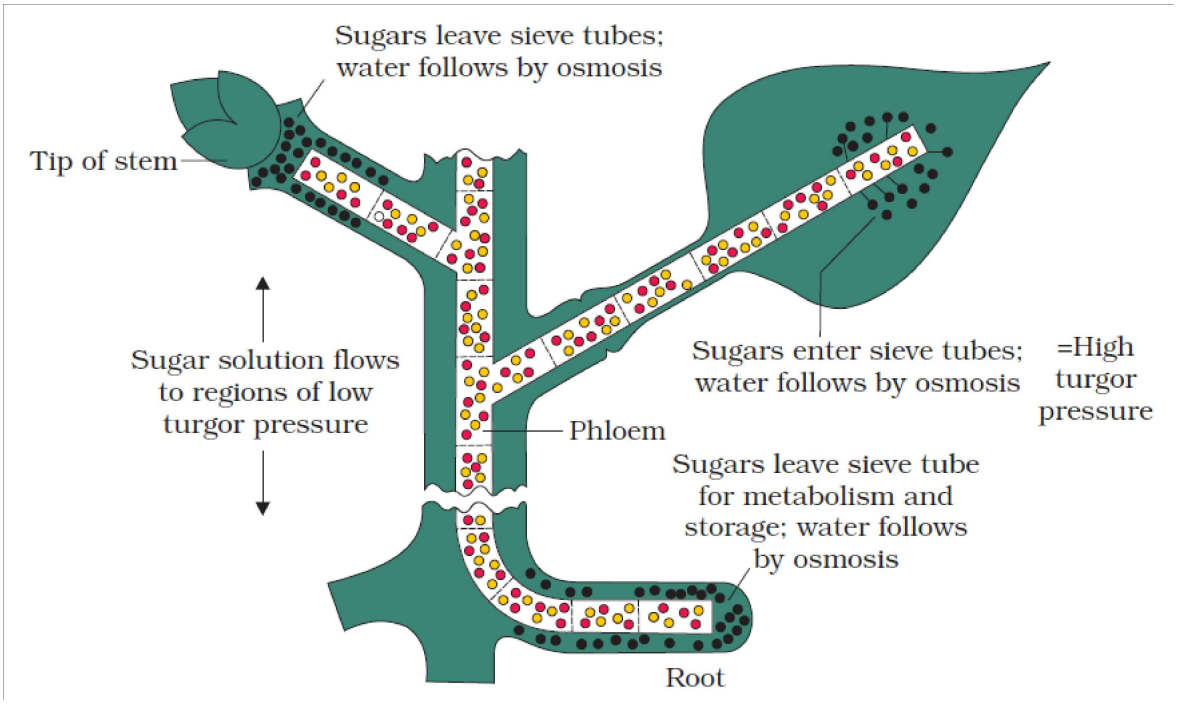


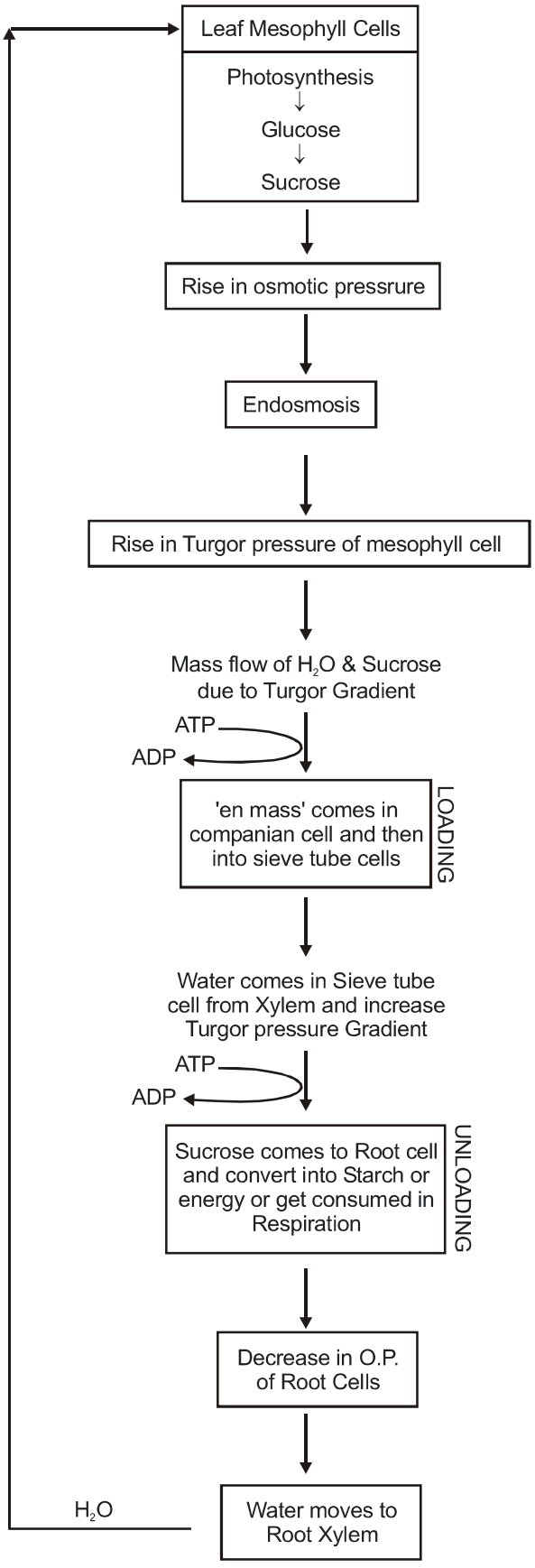
Fig. : Diagrammatic presentation of mechanism of translocation

FOOD TRNASLOCATION IN PLANTS

* Food/organic material conduction in plants mainly occurs by phloem. (Proved by Girdling experiment).
* Food conduction occurs in between **source** and **sink**. Source is net exporter while sink is net importer.
* Generally green photosynthetic plant parts acts as **source** like leaves while non photosynthetic parts like root, shoot, fruits acts as **sink**.
* Food conduction may be in any required direction unlike the water conduction which is a unidirectional process.
* Translocation of food mainly occurs in the form of **sucrose** or it is non-reducing sugar and chemically inert in pathway of conduction.
* Pressure flow/mass flow hypothesis of food/sucrose translocation – Given by E. Munch (1930). this is the most accepted theory of food conduction in plants.

  According to it food translocation occurs in between source and sink in order of turgor pressure gradient i.e. high T.P to low T.P.

* **phloem loading/sucrose loading at source** → It is an active process helped by carrier molecules. At source due to phloem loading concentration of sieve cells increase, results in increase in osmotic pressure and water will moves from nearby xylem into sieve cells results in **increase in turgor pressure** (T.P) and increase in water potential (Ψw).It establish a higher T.P. at source and in sieve tubes. Sucrose moves from source in sieve tubes towards sink from high T.P/'High $\psi\omega$ to towards the low T.P/low Ψw.
* **Phloem unloading/sucrose unloading at sink** → It is an active process helped by carrier molecules. At sink sucrose is unloaded results in decrease in osmotic pressure (O.P), it results in exit of water into near by xylem leads to decrease in Turgor pressure (T.P.) and water potential (Ψw) of phloem. In sink cells the unloaded sucrose is either changed into starch (as starch not change O.P) or consumed, to maintain low O.P and continuous unloading.
* This mechanism was experimentally demonstrated by **Bimodel** exp. of **Munch in 1930**.
* According to evidences of modern research phloem conduction is an active process and it required metabolic energy in phloem cells.



Sucrose translocation in plants

TRANSPIRATION

Loss of water in form of vapour , from the aerial parts(organs) of living plants is known as Transpiration.

* Only few percentage [1-2%] of absorbed water is used by the plants, while remaining [98-99%] of water lost atmosphere.

"Transpiration is an essential evil"- by Curtis

"Tranpiration is an unavoidable evil"-by Steward.

* The minimum transpiration is found in succulent xerophytes & no transpiration in submerged hydrophytes.
* **Maximum transpiration is found in mesophytes.**

TYPES OF TRANSPIRATION

Transpiration is of the following three types :-

[i] Stomatal transpiration :-

* Transpiration takes place through the stomata which are present on the leaves of the plants and delicate organs, is called **stomatal transpiration**. The maximum amount of water is lost by this transpiration. about **80% to 90% transpiration is occurs through the stomata.**
* Stomata are absent in algae, fungi and submerged aquatic plants.

Foliar transpiration : Total transpiration takes place through the leaves is called as **foliar** transpiration.

Foliar transpiration = Stomatal + Cuticular, from the leaves.

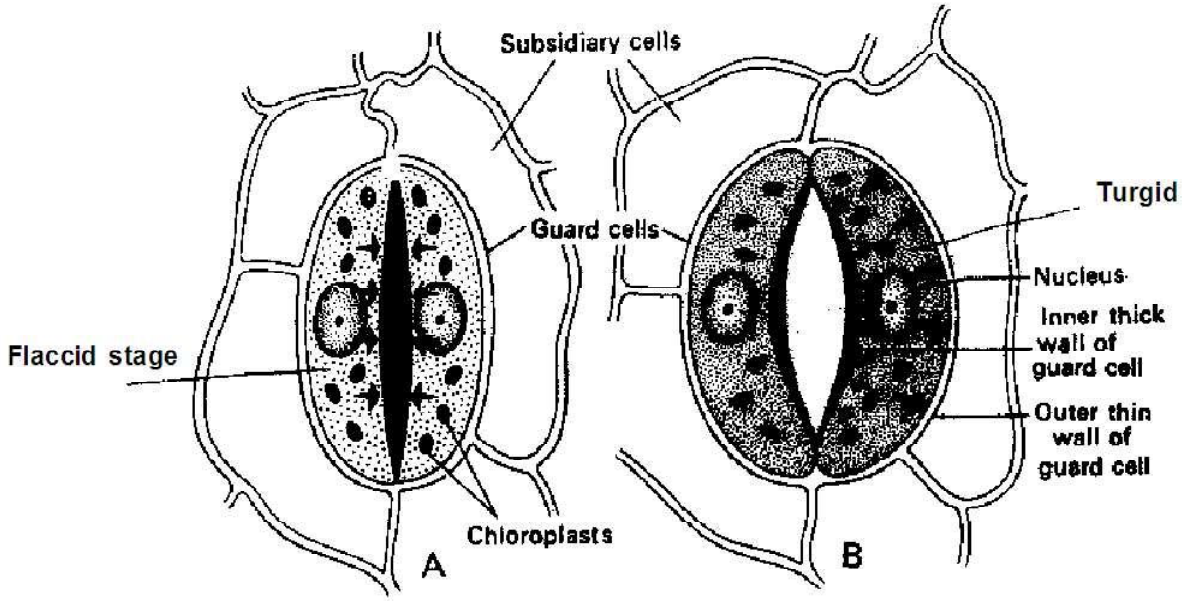
[ii] Cuticular Transpiration :-

Loss of water through the cuticle which present on the herbaceous stem and leaves. Cuticle is a wax like thin layer present on epidermis. About **9% transpiration** is cuticular.

[iii] Lenticular Transpiration :-

* Minute pore like structure found on the stem of some woody plants and epidermis of some fruits called **lenticels**. Some amount of water is lost by lenticels is known as lenticular transpirartion. However it is approximately **0.1%** to **1%** of the total water lost.

STRUCTURE OF STOMATA



The cell wall boardering the stomatal pore is thicker than that of next to the surrounding cells – (A) Aperture closed (B) Aperture open

* Stomata are found on the aerial delicate organs and outer surface of the leaves in the form of minute pores. Stomatal pore is surrounded by two specialised epidermal cells called as **guard cell**. They are kidney shaped. The number of guard cells are two.
* **The structure of guard cells in monocots (Gramineae) is dumbel shaped**
* Guard cells are epidermal cells. But due to presence of chloroplast they are different from that of epidermal cells.
* The **outer wall of the guard cells is thin and elastic, while inner wall is thick and non elastic.**
* Guard cells are surrounded by some specialized epidermal cells called **subsidiary cells or accessory cells**.
* Stomata are found on both upper and lower surface. Stomata attached with air chambers and forms a cavity is called **sub-stomatal-cavity.**
* In xerophytic plants position of stomata is deep in the surface of the leaf. Stomata are present in this position are called **sunken stomata.**

TYPES OF STOMATA

(A) Based on distribution :

(1) **Apple and Mulberry type** → When the stomata present on the lower (Dorsal/abaxial) surface of the leaf e.g.- **Oxalis, Peach, Nausturtium, Morus** etc.

(2) **Potato type** → When stomata present mainly on the lower surface but some stomata are present on the upper surface (Adaxialy) also. e.g.- **Tomato, Brinjal, Cabbage, Pea** etc.

(3) **Oat type** → When stomata are almost equally distributed on both surface of the leaf. e.g. Monocots

(4) **Water lily type** → When stomata present only on the upper surface of the leaf. (Aquatic plants with floating leaves)

(5) **Potamogeton type** → The stomata in this type are either absent or rudimentary or functionless. e.g. Submerged hydrophytes.

* **Leaves**
  - Hypostomatic → Stomata on lower surface
  - Epistomatic → Stomata on upper surface
  - Amphistomatic → Stomata on both surfaces

(B) Based on time of opening & closing ⇒ **By Loftfield**

(1) **Alfa-alfa type** → Stomata are opened in day and closed in night.

Ex. – Mesophytes as **Pea, Bean, Radish, Grapes, Apple** etc.

(2) **Potato type** → Stomata always open except evening time.

Ex. – Onion, Potato, Cabbage, Banana etc.

(3) **Equisetum type** → Always opened stomata. Amphibious plants.

(4) **Barley type** → Stomata always closed except few hours in day time. **Wheat, Maize** etc.

(5) **Scotoactive opening** → Stomata closed in day and opened in night.

Ex- Succulents - **Opuntia**.

(C) Stomata based on structure and number of accessory cells :

(1) **Anomocytic** → Subsidiary cells - 5 or 6 and same in structure.

Ex. – Family – **Ranunculaceae.**

(2) **Anisocytic** → Subsidiary cells - 3 and one cell smaller than two.

Ex. – **Cruciferae**

(3) **Paracytic** → Subsidiary cells - 2 and parallel to guard cells.

Ex. – **Rubiaceae**

(4) **Diacytic** → Longitudinally situated and 2 accessory cells.

Ex. – **Caryophyllaceae.**

Stomata in Gymnosperms :

(i) **Syndetochielic** – When subsidiary cells & guard cells originate from single cell.

(ii) **Haplochielic** – Both cells arises from separate cells.

MECHANISM OF OPENING AND CLOSING OF STOMATA OR STOMATAL MOVEMENT AND MECHANISM OF TRANSPIRATION

Stomata generally open during the day & closed during the night with few exceptions. The important theories of stomatal movements are as follows –

(1) **Photosynthesis in guard cell hypothesis :**

This theory was proposed by ***Schwendener*** & ***Von mohl***. According to this theory guard cell chloroplast perform photosynthesis during the day time. This produce sugars in guard cell which increases the O.P. of GC, compared to adjacent epidermal cells (subsidiary cells). Water enters in guard cells form subsidiary cells by endosmosis, due to this guard cells become turgid & stomata will open.

Objections –

(i) In CAM plants stomata open during dark/night

(ii) Chloroplast of guard cells are non–functional (inactive) photosynthetically.

(2) **Starch $\rightleftharpoons$ Sugar interconversion theory :**

* This theory was proposed by **Sayre** (1926). First of all Lloyd stated that amount of sugar in GC is increases during the day time & starch in night.
* Detail study of this change was done by **Sayre** & given **starch hydrolysis theory**. Acco. to **Sayre**, starch converts in to sugars during day time when pH of guard cell is high. Sugar changes in to starch during night at low pH in guard cells (Supported by **Scarth**). ***Sayre*** clarified that CO_2 reacts with water during night. Due to accumulation of H_2CO_3, pH in guard cell is decreases.
* **Hanes** – Stated that this change takes place by phosphorylase enzyme.
* **Yin** & **Tung** reported the presence of phosphorylase enzyme in guard cells.

$$\text{Starch} + ip \underset{\text{Night pH-4.5-5}}{\overset{\text{day pH 7.5}}{\rightleftharpoons}} \underset{\text{Phosphorylase}}{} \text{Glucose–1,P}$$

⇒ conc. of GC increased → Entry of H_2O in GC

↓

GC - Turgid → Stomata open.

Stewards modification –

Acco. to Steward (1964) appreciable change in O.P. of GC is possible after the conversion of glucose–1 P into Glucose & ip (inorganic phosphate)

Steward gave stomatal mechanism as following

(i) Glucose–1,P $\xrightarrow{\text{Mutase}}$ Glucose–6P

(ii) Glucose–6,P $\xrightarrow{\text{Phosphatase}}$ [Glucose + ip]

$\Downarrow$

[osmotic entry of H_2O] $\Leftarrow$ [Conc. of GC increased]

$\Downarrow$

[GC-Turgid] $\rightarrow$ [Somata open] $\rightarrow$ Cooling effect.

(iii) Glucose + ATP $\xrightarrow{\text{Hexokinase}}$ Glucose–1,P$\rightarrow$ Starch $\rightarrow$ Stomata closed

Objections –

(i) Starch is absent in GC of some monocots like onion.

(ii) Formation of organic acids is observed during stomatal opening.

(3) **Active $K^+ \rightleftharpoons H^+$ exchange theory** or **active proton transport mechanism –**

* Given by **Levitt** (1973-74). This is modern & most accepted theory for stomatal movement.

* First of all **Fujino** observed that influx of K^+ ions in guard cells during stomatal opening. (Supported by Fisher & Hsiao). Detail study of this phenomenon was done by **Levitt**, who proposed this theory. Acco. to him stomata opens by following mechanism-

(i) Carbohydrates $\xrightarrow{\text{Enzymes}}$ PEP + CO_2

$\xrightarrow[\text{Carboxylase}]{\text{PEP}}$ OAA

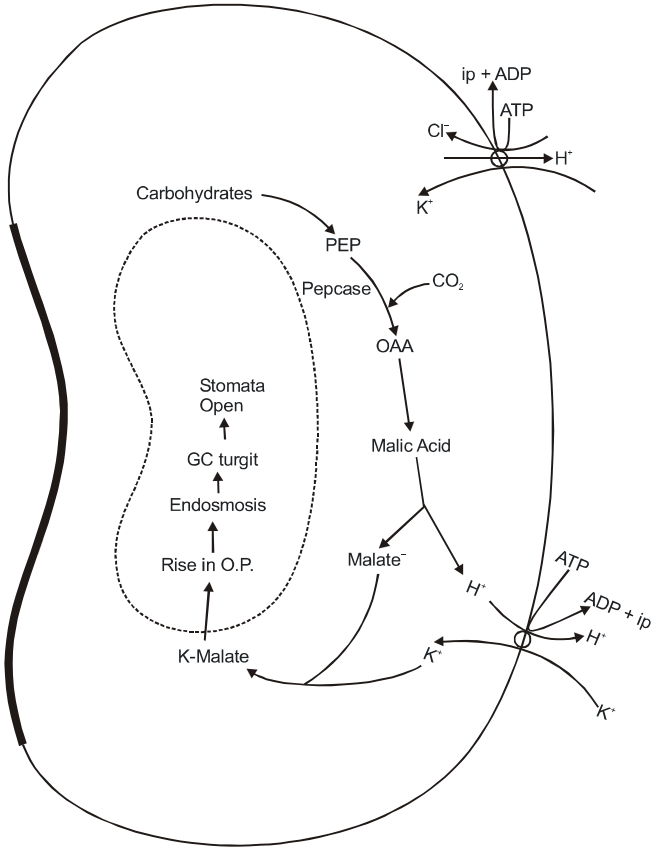
(ii) O.A.A. $\longrightarrow$ **Malic Acid** $\rightarrow$ **$H^+ \rightleftharpoons K^+$** / ATP / **$Malate^-$**

(iii) Malate+$K^+ \longrightarrow$ **K–malate** $\rightarrow$

[Conc. of GC increased] $\Rightarrow$ [Entry of H_2O in GC]

$\Downarrow$

.Cooling$\leftarrow$ [Somata open] $\leftarrow$ [GC-Turgid]



K^+—H^+ Ion Exchange Theory

* **Closing of stomata :-** Plant hormone ABA–acts on guard cells, which interfere the exchange of $K^+ \rightleftharpoons H^+$ ions in guard cells, results in reverse of rxn. of opening of stomata, hence stomata closed. pH of guard cells is decrease during night, which favours stomatal closing.

(4) **Ca–ABA second messenger model** –

Given by **Desilva** & **Cowan** (1985) this is modern explaination of stomatal closing only.

* **Ramdas & Raghvandra** Suggested that ATPs for stomatal movement comes from cyclic ETS.

* **Bowlings :** Malate switch hypothesis.

Raschke : K^+ ions in guard cells comes from subsidiary cells.

* Stomata opens during the night in succulent plants and closed during the day. This nature of stomata in opuntia is called **scotoactive stomata**.

* In CAM plants organic acid is formed during night which broken down during day & Co_2 is liberated which is used in photosynthesis.

Factors affecting stomatal opening and closing :

[1] Light :-

In most of the plants stomata open during the day except succulent xerophytic plants and close during the dark. Opening of stomata completes in the presence of blue and red light.**Blue light is most effective** and causing stomatal opening.

[2] Temperature :-

Loft Field show temperature quotient of opening of stomata is **$[Q_{10}] = 2$**

[3] CO_2 concentration :-

* Stomata opens at low concentration of CO_2 while closed at high concentration of CO_2.
* CO_2 is antitranspiran gas.

[4] Growth Hormones :-

* **Cytokinin hormone induce opening of stomata.** It increase the influx of K^+ ions and stimulate the stomata for opening.
* While **ABA** stimulate the stomata for closing. This hormone **oppose the induction effect of cytokinin.**
* ABA effects the permeability of the guard cells. It prevent the out flux of H^+ ions and increase the out flux of K^+ ions. Because of this pH of the guard cells decreased.

  Cl^- ions also plays important role in stomatal movement.

  Above mentioned effects also found in high amount of CO_2.
* ABA is formed due to high water stress in chloroplast of leaves.

[5] Atmospheric humidity :-

Stomata opens for long duration and more widen in the presence of humid atmosphere, while stomata remains closed in dry atmosphere or partial opening at higher atm. humidity transpiration will be stop but stomata remain completly open.

Factors affecting the rate of transpiration :-

Factors effecting the rate of transpiration are divided into two types :-

[A] External factors (Environmental factor)

[B] Internal Factors

[A] External factors :-

[1] Atmospheric humidity : $T_r \propto \frac{1}{\text{Relative humidity}}$

* This is the most important factor. The rate of transpiration is higher in low atmospheric humidity while at higher atmospheric humidity, the atmosphere is moistened, resulting decreasing of rate of transpiration.
* Therefore, the rate of transpiration is high during the summer and low in rainy season.

[2] Temperature :- $T_r \propto$ Temperature

* The value of $\mathbf{Q_{10}}$ for transpiration is **2**. It means by increasing 10^0C temperature, the rate of transpiration is approximately double. (By Loftfield)
* Water vapour holding capacity of air increased at high temperature, resulting the rate of transpiration increased.
* On contrary vapour holding capacity of air decreased at low temperature so that the rate of transpiration is decreased.

[3] Light :-

* Light stimulates, transpiration by heating effect on leaf.
* **Action spectrum** of transpiration is **blue** and **red**.
* Rate of transpiration is **faster in blue light** than that of red light. Because stomata are completely opened as their full capacity in the blue light.

[4] Wind velocity :- $T_r \propto$ Wind velocity

* Transpiration is less in constant air but if wind velocity is high the rate of transpiration is also high, because wind removes humid air (saturated air) around the stomata.
* Transpiration increases in the beginning at high wind velocity [30 - 35 km./hour] But latter on it cause closure of stomata due to mechanical effect and transpiration decrease.

[5] Atmospheric Pressure :-

* The speed of the air increase at low atmospheric pressure, due to this rate of the diffusion increase which increase the rate of transpiration.
* The rate of transpiration is found maximum at high range of hills.
* By carrying a plant from Kota, to hill station, rate of transpiration increased.

Transpiration ratio (TR) : Moles of H_2O transpired/ moles of CO_2 assimilated

* Ratio of the loss of water to the photosynthetic CO_2 fixation is called TR.
* TR is low for C_4 plants (200-350) while high for C_3 plants (500-1000). It means C_4 conserve water with efficient photosynthesis.
* CAM plants passes minimum TR (50-100)

[6] Anti transpirants :-

Chemical substances which reduce the rate of transpiration are known as **antitranspirants.** Anti transpirants are as follows :-

Phenyl Mercuric Acetate [PMA], Aspirin, (Salicylic acid), Abscisic Acid [ABA], Oxi - ethylene, Silicon oil, CO_2 and low viscous wax

PMA closed the stomata for more than two weeks partially.

* Antitranspirants are used in dry farming.

[B] INTERNAL FACTORS :-

These factors are concerned with structure of plants. These are of following types :-

[1] Transpiring area :-

Pruning increase the rate of transpiration per leaf but overall reduce the transpiration.

[2] Anatomical characteristics of leaf and leaf orientation :

Several structures of leaf effect the transpiration as follows :-

Stomatal characteristics :-

Transpiration is effected by the structure of stomata, position of stomata, distance between the stomata, number of stomata per unit area and activity of the stomata.

By Salisbury – Stomatal Index (SI) $= \frac{S}{E+S}$

SI = Stomatal index S = No. of stomata/unit area

E = No. of epidermal cells in same unit area.

[3] Water status of Leaves

[4] Root - Shoot Ratio :-

* The rate of transpiration decreases with decrease in root - shoot ratio.
* The rate of transpiration increases with increase root - shoot ratio.

The following characteristics are found in leaf to reduce the transpiration.

(i) Leaves modify in spines.

(ii) Leaves transformed into needle e.g. **Pinus**.

(iii) Folding and unfolding of leaves by bulliform cells.e.g. **Amophilla, Poa** etc.

(iv) Small size of the leaves.

(v) Presence of thick waxy layer on leaves.

e.g. **banyan tree**.

Significance of transpiration :

[1] In regulation of temperature :

Cooling effect on the surface of leaves is produced by the process of transpiration, due to which temperature remains constant in plants.

The plants are protected from the burning of heat due to transpiration. Evaporation of water produces cooling effect.

[2] Translocation of minerals in plant body :

* Mass flow of water is found during the passive absorption of water. Hence it is assumed that minerals enter the roots through the water.

[3] In ascent of sap

[4] In water absorption

[5] Distribution of absorbed salts

[6] Gaseous exchange

[7] Control of hydrological cycle.

GUTTATION

Loss of water from the uninjured part or margin of leaves of the plant in the form of water droplets is called as guttation.

* The term "**Guttation**" was coined by **Burgerstein**.
* Exuded liquid of guttation along with water contains some **organic and inorganic (dissolved)** substances. It means it is not pure water.
* Normally, guttation process is found in herbacious plants like **grasses, tomats, balsum, Naustertium, Colocasia, Sexifraga** and in some of the plants of **Cucurbitaceae** family.
* Guttation occurs from the margins of the leaves through the special pore (always open) like structure are called **hydathodes** or **water stomata.**
* Generally guttation occurs during mid night or early morning.
* Parenchymatous and loose tissue are lie beneath the hydathode, which are known as **epithem** or **transfer tissues**.
* The process of guttation take place due to **root pressure**, develope in cortex cells of root.

BLEEDING

Fast flowing of liquid from the injured or cut parts of the plants is called bleeding or exudation.

* This process takes place due to high **root pressure**.
* Sugar is obtained from the Sugar mapple by this process.
* The highest bleeding is found in **Caryota urens** (Toddy palm) (about 50 liter per day).
* Bleeding is important in economic biology, because **Opium, Latex of rubber** is obtained by this.

WILTING

* Droping of soft parts of the plants due to loss of turgidity in their cells is called wilting. Wilting is caused due to high rate of transpiration during mid-day or deficiency of water in soil and also in prolonged drought condition.
* Wilting may be temporary or permanent.
* **Incipient wilting :** This is the starting of wilting without any external symptom is called incipient wilting.

SPECIAL POINTS

* The main reason of osmotic pressure for stomata is **potassium chloride or potassium malate.**
* **Porometer** is used to find out the area of stomata on the leaf.
* Transpiration measuring instrument is called **potometer**. The rate of absorption of water is measured through this instrument. In potometer **rate of water absorption is proportional to the rate transpiration.**
* **Cobalt-chloride test :** This method is used for the comparision of transpiration at both the surface of the leaves. It is first of all shown by **Stall**.
* Stomata covers 1-2% of total leaf area. Size of stomata is 10-40 μ (length) $\times$ 3 - 12 μ (width).
* The photophosphorylation process in the guard cells is a energy metabolic process, not CO_2 - metabolic process. (Cyclic photophosphorylation)
* The rate of transpiration of C_4 plants is less as compared to C_3 plants. In CAM plants minimum transpiration occurs.
* Manometer is used to measure root pressure.
* **Distribution of Stomata on leaf surfaces :**

Plant Type	**Stomata no. / mm^2**	
Dicots	**Upper epidermis**	**Lower epidermis**
Sunflower	120	175
Alfa-alfa	169	188
Geranium	29	179
Monocots		
Wheat	50	40
Barley	70	85
Onion	175	175