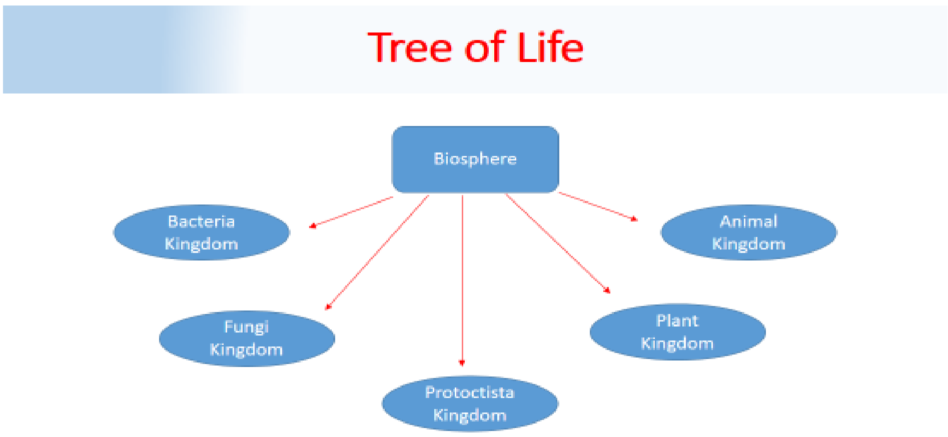
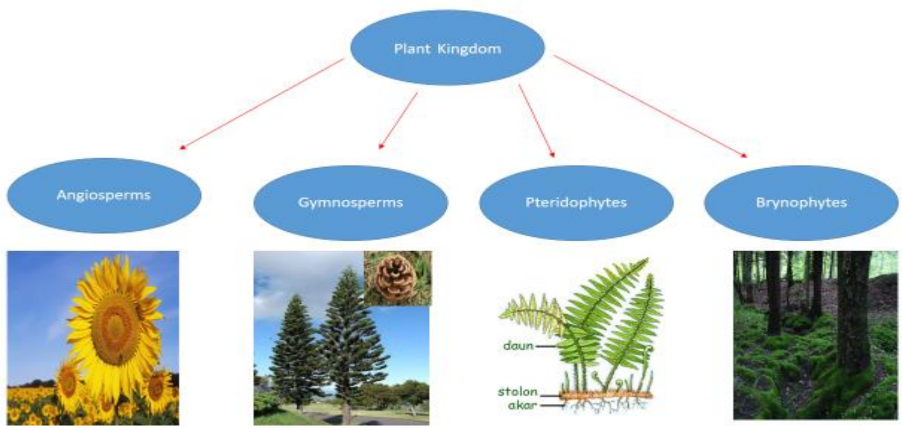
Lecture - 1

Introduction to Plant Physiology

1. The Tree of Life

According to the fossil record, the most primitive organisms known- the bacteria and the cyanobacteria date back over 3 billion years, the first land plants & insects over 400 million years, the first birds and mammals over 180 million years. The living things classified into five kingdoms as shown in the diagram. The kingdoms can be subdivided into smaller groups called phyla (singular phylum). For some kingdoms, only one phylum is given as an example but for others there are several. The Plant Kingdom includes the angiosperms (flowering plants), gymnosperms (cone-bearing plants, fens and bryophytes (mosses &liverworts). Recent classification systems suggest that Fungi Kingdom these organisms, in addition to the red algae and green algae, should be classified in the Plant Kingdom.





2. What is the Plant?

A plant:

A. Is multicellular

B. Is non-motile:- not capable of independent movement

C. Has eukaryotic cells:- cells have distinct membrane-bound organelles, including a nucleus with chromosomes.

D. Has cell walls comprised of cellulose

E. Is autotrophic:- capable of sustaining itself through conversion of inorganic substances to organic material

F. Exhibits alternation of generations - has a distinctive diploid (sporophyte- the diploid (2*n*) spore-producing phase of the life cycle of an organism exhibiting Alternation of Generations) and haploid (gametophyte the haploid gamete-producing phase of the life cycle of an organism that exhibits Alternation of Generation) phase.

3. What is Plant Physiology?

A. Definitions (numerous) - Plant physiology is the study of

1. How plants work

2. The functions and processes occurring in plants

3. The vital processes occurring in plants

4. Physiological functions characteristic of plants

B. In real meaning, plant physiology is a study of the plant way of life, which include various aspects of the plant lifestyle and survival including metabolism, water relations, mineral nutrition, development, movement irritability (response to the environment), organization, growth, and transport processes.

C. Plant physiology is a lab science.

D. Plant physiology is an experimental science.

E. Plant physiology relies heavily on chemistry and physics.

The field of plant physiology is concerned with the functional and mechanistic aspects of plants or, essentially, how the plant works at the molecular level. This course will focus on plant molecular biology (plant transformations and biotechnology), water relations (osmosis, water uptake, endodermal structure, xylem transport, mechanisms of stomata action, transpiration), plant growth regulation (hormones and photo morphogenesis), ion and sucrose (phloem) transport, and those biochemical processes that are unique to plants, photosynthesis, photorespiration, and N2 fixation. Environmental (stress) physiology, development, differentiation, endogenous rhythms, flowering, and secondary metabolites will be covered only briefly.

History of Plant physiology

Plant Physiology actually began from the time of Stephens Hales (1677-1761). He was the first who devise experimental methods with his knowledge of (physics & statistics to find out the movement of sap through the plant body, rate of transpiration, loss of weight due to transpiration.

He was the first who showed that leaves make use of air to form a part of body substance and it is the most active region of growth. Priestley (1733-1804) investigated the composition of different kind of air, found that green plants grown in atmosphere rich in CO_2 produced in course of several days a large quantity of O_2.

Ingenhousz in 1279 reported that green plants exposed to light for few hours absorb CO_2 unfit for respiration and proved that at night plants vitiate the air by their respiration. Early work were carried out by different scientists established the following initial stages in the process that CO_2, is absorbed and O_2, is liberated therefore the process of photosynthesis have been elucidated. Also the importance of N was indicated in plant life.

Plant Structure and Function:-

Angiosperms (Flowering plants) are the most diverse group of plants known (over 275.000 named species and thought to be at least that many more unknown to science). Within the Angiosperms, there are two plant groups, the **Monocots** and the **Dicots**. The distinction between these two groups is not always clear, but some general trends are outlined below:

	Monocot	Dicot
Leaf Venation	Parallel	Net
Vascular bundles	Scattered	Ring
Habit	Herbaceous	Herbaceous+Woody
Roots	Fibrous	Taproot
Growth	Primary only	Primary and secondary
Example	Grass, palm, Wheat	Oak, Rosses, Sunflower

A plant has two organ systems:

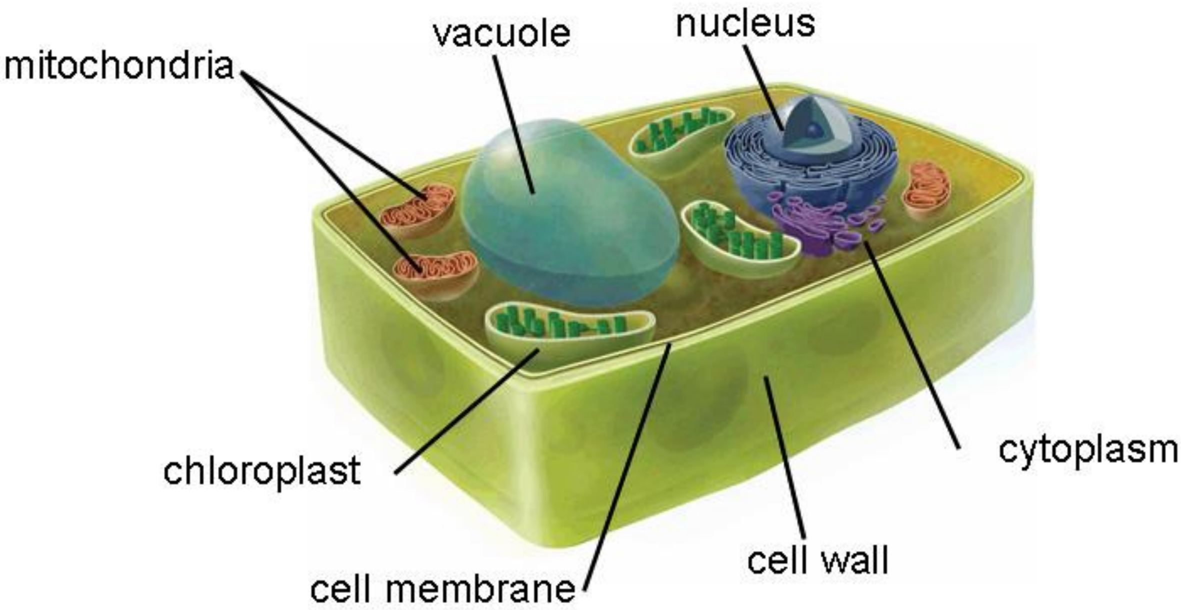
1. Shoot system; includes the organs such as leaves, buds, stems, flowers (if the plant has any), and fruits (if the plant has any).

2. Root system; includes those parts of the plant below ground, such as the roots, tubers, and rhizomes.

Lecture 2

Plant Cell

Cells are the foundation of plants. Like the bones in the body, the cell wall provides the framework for the plant. The walls of the cells actually create the structure of the plant. The understanding of cells will form the base of our understanding of Botany then plant physiology.



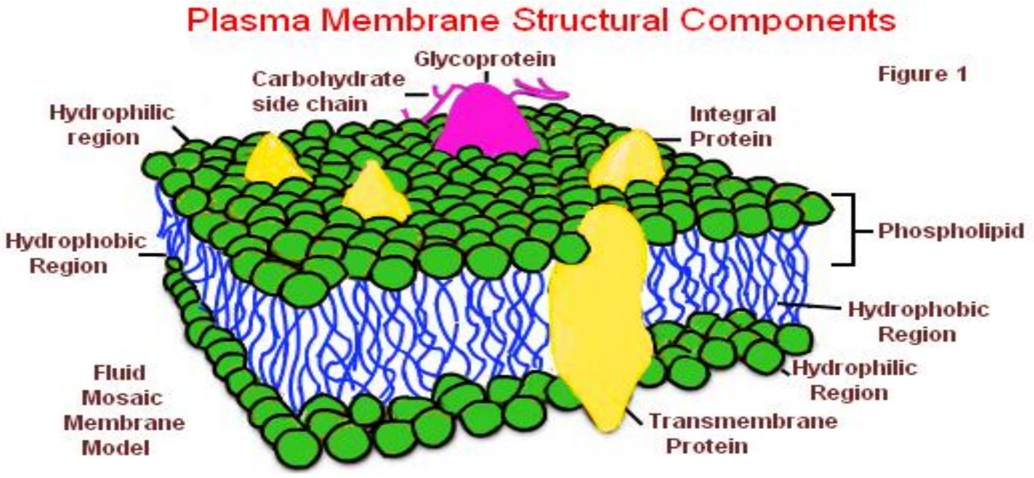
1. Plasma or Cell membrane

Cell boundary; selectively permeable; bilayer of phospholipids with inserted protein. Phospholipids are unique molecules they are amphipathic, meaning that they have both hydrophilic and hydrophobic regions. As a result plant phospholipids usually have a higher degree of unsaturation than animals. Hydrophobic interactions between the tail regions of the phospholipids hold the membrane together.

The function of the membrane is to:

Regulate traffic.

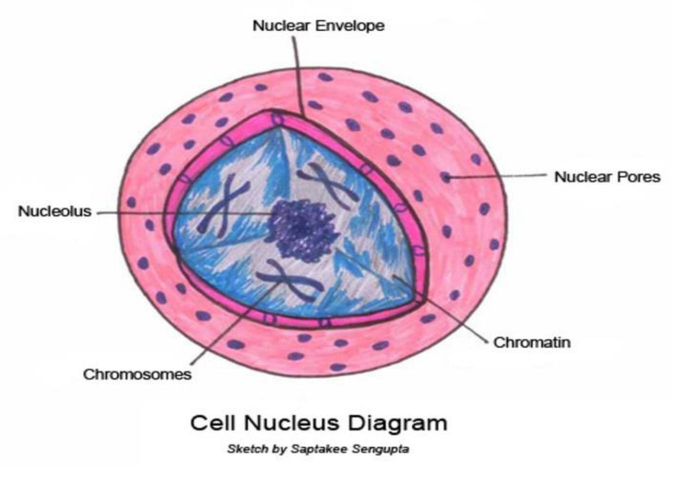
- Separate the internal from external environment.
- Serve as a platform on which some reactions can occur
- Participate in some reactions (i.e., the membrane components are important intermediates or enzymes).
- Provide some structural integrity for the cell



2. Nucleus

The cell "brain", surrounded by a double membrane (two phospholipid bilayers) - the nuclear membrane.

Have pores. The structure of the pores is complex comprised of a more than 100 proteins.



3. Cytoplasm/Cytosol

The cytosol is the gel-like matrix within the cell in which the other structures are embedded. The cytoplasm refers to the cell materials inside the membrane.

4. Mitochondria

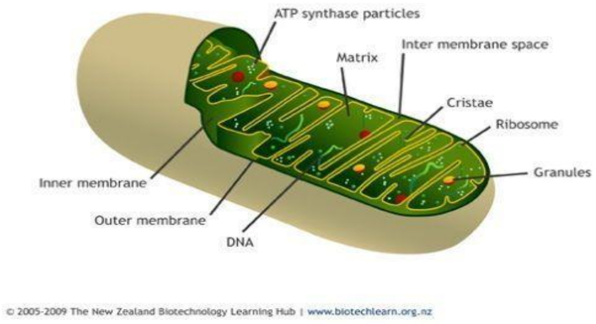
These organelles, like the nucleus and plastids, are double-membrane bound.

They have their own ribosomes and DNA (a circular loop like prokaryotic cells).

Mitochondria are found in all eukaryotic cells.

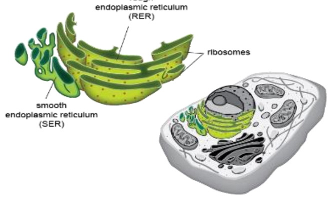
They are the sites of cellular respiration- process by which energy is released from fuels such as sugar.

Mitochondria is the power plan of the cell. A popular misconception is that "plants have chloroplasts, animals have mitochondria. Plant cells, at least green plant cells (ie., leaf cells), have both. Root cells only have mitochondria. The inner membrane differs from the plasma membrane in that it has higher protein content (70 %) and unique phospholipids (i.e., cardiolipin)



5. Ribosome

Sites of protein synthesis (translation).



6. Endoplasmic reticulum

A series of membranous tubes and sacs (cisternae) that run throughout the cell.

Rough ER has ribosomes while smooth ER lacks ribosomes and is tubular.

The ER has several functions including:

- Synthesis of lipids and membranes (smooth ER);
- Serving as a site for the synthesis of proteins by the ribosomes (rough ER)
- Transport (a type of cell 'highway systemy, and
- Support

7. Peroxisomes

Membrane sac containing enzymes for metabolizing waste products from photosynthesis, fats and amino acids.

8. Golgi apparatus

The Golgi is active in synthesizing many cell components, especially carbohydrates and is involved in tagging proteins with carbohydrates and other side chains for sorting them to their final destination.

9. Microtubules

Hollow tubes made of a mix of alpha and beta tubulin, which are globular proteins. The tubes are about 25 *m*m in diameter.

Microtubules are involved in the cell cytoskeleton (for support), cell movements. and cell division.

10. Microfilaments

Protein strands. Solid. Made from G-actin. Involved with the cell cytoskeleton.

Main function is support. They are about 7 nm in diameter.

11. Others

Organelles Unique to Plants

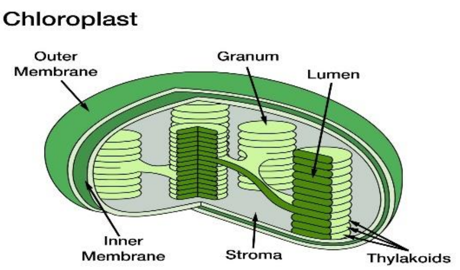
1. Plastids

Plastids are double membrane-bound organelles in plants.

They contain their own DNA and ribosomes.

They contain pigments used for photosynthesis

They are semi- autonomous and reproduce by fission similar to the division process in prokaryotes.



2. Vacuoles

This is the large, central cavity containing fluid, called cell sap, found in plant cells.

The vacuole is surrounded by a membrane (tonoplast).

The vacuole is penetrated by strands of cytoplasm.

The tonoplast and plasma membrane have different properties such as thickness (tonoplast thicker) so every plant cell has a large, well-developed vacuole that makes up to 90 % or more of the cell volume.

Important roles of the vacuoles are:

- Energetically efficient means to increase surface to volume ratio in the dendritic growth from since 90 % of the cell volume is vacuole, therefore 90% of the cell is water which is relatively cheap in metabolic terms.
- Water storage: - Probably a minor role: mostly in succulent plants.
- Waste disposal: The vacuole can be considered the cell cesspool. It contains many secondary metabolites.

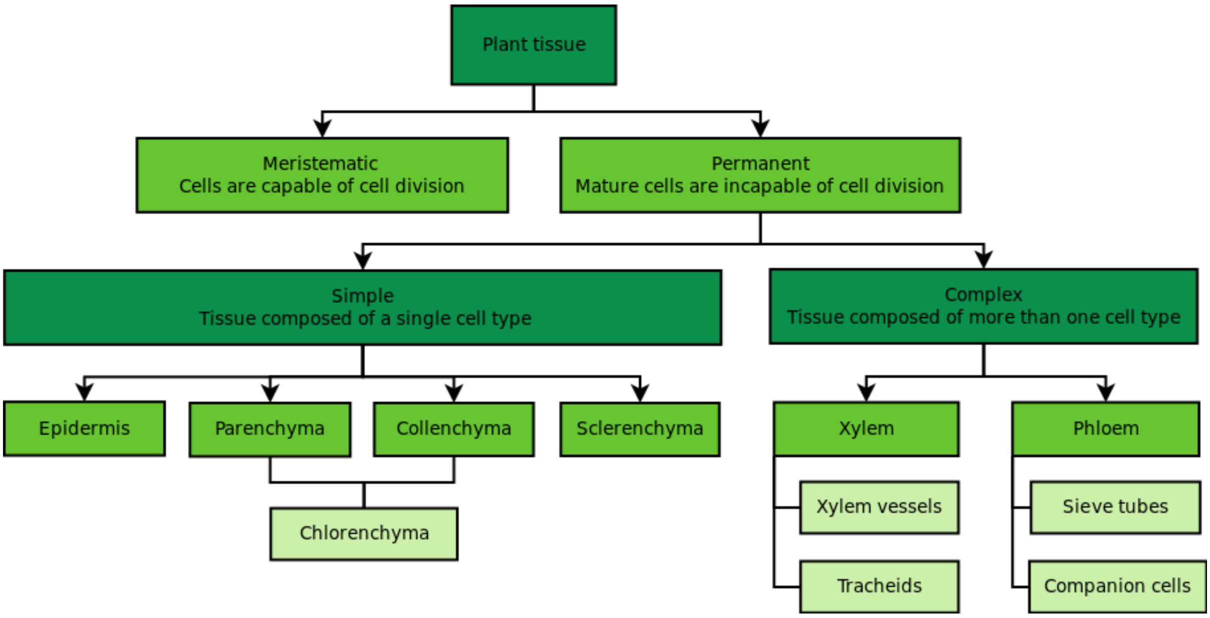
Organelle	Function
Cell Wall	Supports and protects the cell
Nucleus	Stores heredity information in DNA; Synthesis RNA & Ribosomes
Mitochondrion	Transfers energy from organic compounds to ATP
Vacuole	Stores enzymes & waste products
Plastids	Stores food or pigments; one type (Chloroplast) transfers energy form light to organic compounds
Ribosome	Organizes the synthesis of proteins
Endoplasmic reticulum (ER)	Prepares proteins for export(Rough ER); synthesis steroids, regulates Calcium level, breaks down toxic substances (Smooth ER)
Golgi Apparatus	Process & Packages substances produced by the cell
Microfilaments& Microtubules	Contribute to the support. Movement, and division of cell

Plant Tissues

A mature vascular plant, eg., a tobacco plant, contains several differentiated cell types.

These are grouped together in tissues.

Some tissues contain only one type of cell. Some consist of several.



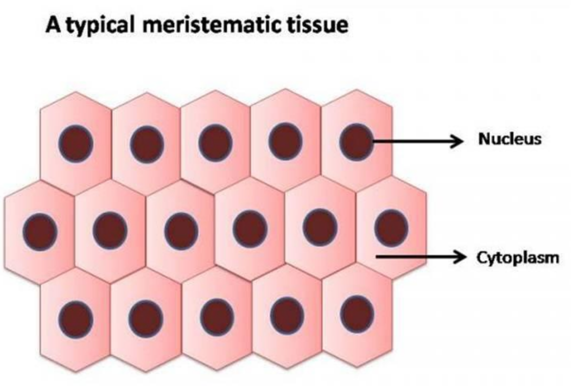
1. Meristematic

The main function of meristematic tissue is mitosis. The cells are small, Meristematic thin-walled, with no central vacuole and no specialized features.

Meristematic tissue is located in; the apical meristems at the growing points of roots and stems.

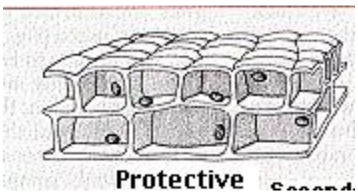
The secondary meristems (lateral buds) at the nodes of stems (where branching occurs, and in some plants; A ring of meristematic tissue, called the cambium that is found within the mature stem.

The cells produced in the meristems soon become differentiated into one or another of several types.



2. Protective

Protective tissue covers the surface of leaves and the living Protective cells of roots and stems. Its cells are flattened with their top and bottom surfaces parallel. The upper and lower epidermis of the leaf are examples of protective tissue



3. Parenchyma

The cells of parenchyma are large, thin-walled, and usually have a large central vacuole. They are often partially separated from each other.

They are usually stuffed with plastids. In areas not exposed to light, colorless plastids predominate and food storage is the main function.

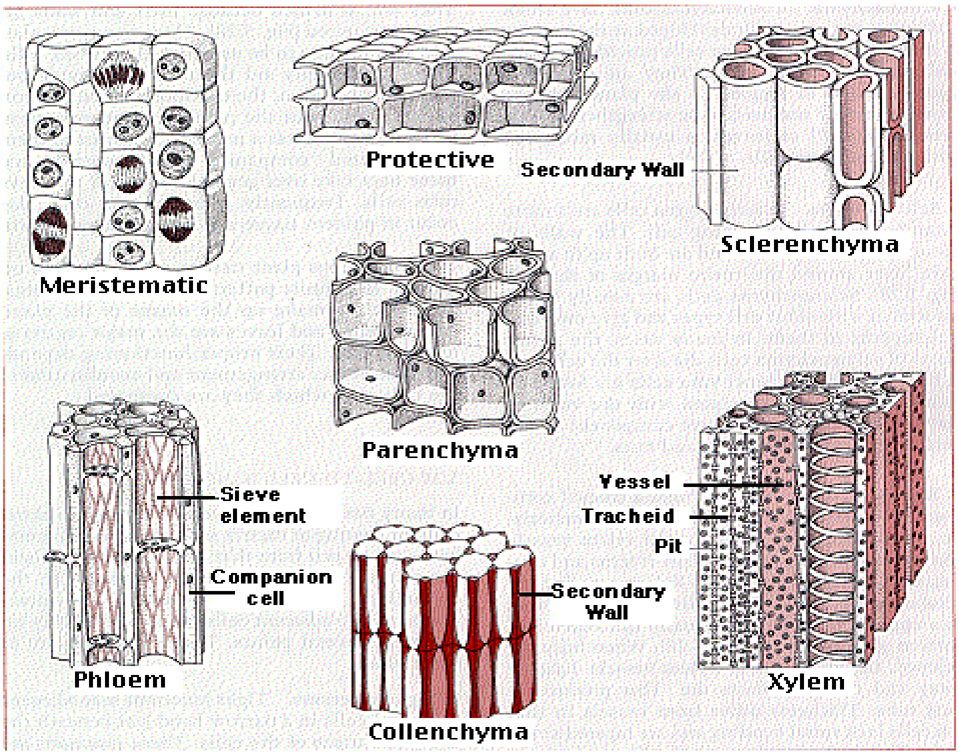
The cells of the white potato are parenchyma cells. Where Parenchyma light is present, e.g., in leaves, chloroplasts predominate and photosynthesis is the main function

4. Sclerenchyma

The walls of these cells are very thick and built up in a uniform layer around the entire margin of the cell. Often, the protoplasts die after the cell wall is fully formed.

Sclerenchyma cells are usually found Sclerenchyma associated with other cells types and give them mechanical support.

Sclerenchyma is found in stems and also in leaf veins. Sclerenchyma also makes up the hard outer covering of seeds and nuts.



5.Collenchyma

Collenchyma cells have thick walls that are especially thick at their corners.

These cells provide mechanical support for the plant. They are most often found in areas that are growing rapidly and need to be strengthened. The petiole ("'stalk") of leaves is usually reinforced with collenchyma.

6.Xylem

Xylem conducts water and dissolved minerals from the roots to all the other parts of the plant. In angiosperms, most of the water travels in the xylem vessels.

These are thick-walled tubes that can extend vertically through several feet of xylem tissue.

Their diameter may be as large as 0.7 mm.

Their walls are thickened with secondary deposits of cellulose and are usually further strengthened by impregnation with lignin.

The secondary walls of Xylem vessels are deposited in spirals and rings and are usually perforated by pits.

Xylem vessels arise from individual cylindrical cells oriented end to end.

At maturity the end walls of these cells dissolve away and the cytoplasmic contents die.

The result is the xylem vessel, a continuous non-living duct.

The vessels carry water and some dissolved solutes, such as inorganic ions, up the plant.

Xylem also contains tracheids.

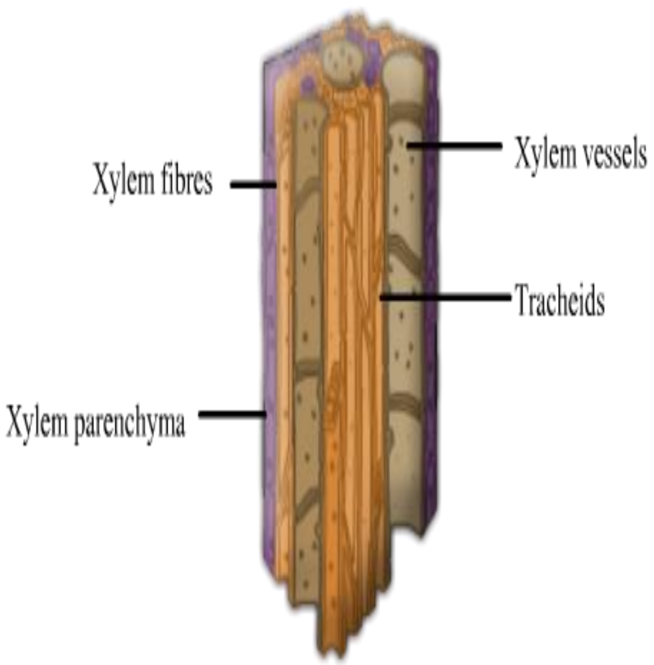
These are individual cells tapered at each end so the tapered at each end of one cell overlaps that of the adjacent cell.

Their walls are perforated so that water can flow from one tracheid to the next.

The xylem of ferns and conifers contains only tracheids.

In woody plants, the older xylem ceases to participate in water transport and simply serves to give strength to the trunk.

Wood is xylem. When counting the annual rings of a tree, one is counting rings of xylem.

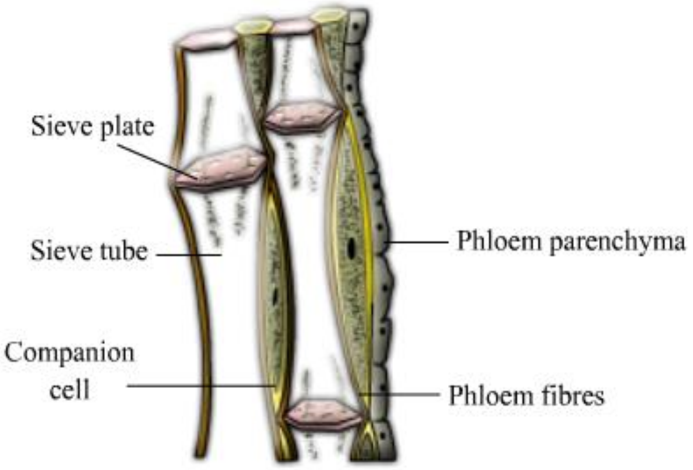


Xylem

7. Phloem

The main components of phloem are

- Sieve elements and
- Companion cells.



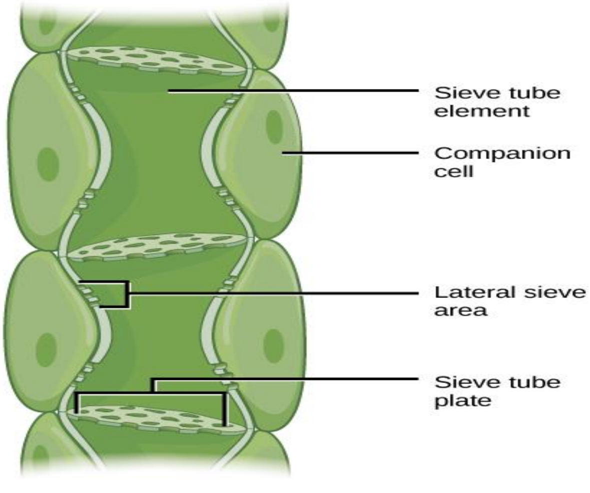
Sieve elements are so-named because their end walls are perforated.

This allows cytoplasmic connections between vertically-stacked cells.

The result is a sieve tube that conducts the products of photosynthesis, sugars and amino acids from the place where they are manufactured (a "source"), eg. leaves, to the places where they are consumed or stored; such as(roots, growing tips of stems and leaves, flowers, fruits, tubers, corms, etc.

Sieve elements have no nucleus and only a sparse collection of other organelles.

They depend on the adjacent companion cells for many functions.



PARENCHYMA VS COLLENCHYMA VS SCLERENCHYMA

Parenchyma cells are found in every soft part of the plant	Collenchyma cells are found in petiole, leaves and young stems	Sclerenchyma is found in the mature parts of the plant
Unspecialized cells	Specialized cells	Specialized cells
Consists of a thin cell wall	Consists of an unequally thin cell wall	Consists of a thick and rigid cell wall
Cell wall is made up of cellulose	Cell wall is made up of cellulose and pectin	Cell wall is made up of waterproofing lignin
Intercellular space is present between cells	No or little intercellular space is present between cells	No intercellular space is present between cells
Consists of living cells at maturity	Consists of living cells at maturity	Consists of dead cells at maturity
Photosynthesis, storage of food, gas exchange and floating of aqueous plants are the major functions	Providing mechanical support to the plant, resisting bending and stretching by the wind are the major functions	Providing mechanical support, protection and transportation of water and nutrients are the major functions

Plant Water Relations

1- Importance of Water:

Physiologically active plant tissues have up to 95 % of water while in the inactive and dry seed grains the water content is about 10 %, water importance can be summarized as

- Water is a major component of cells
- Water is a solvent for the uptake and transport of materials
- Water is a good medium for biochemical reactions
- Water is a reactant in many biochemical reactions (i.e., photosynthesis)
- It provides structural support via turgor pressure (i.e., leaves)
- Water is the medium for the transfer of plant gametes (sperms swim to eggs in water, some aquatic plants shed pollen underwater)
- Plant movements are the result of water moving into and out of those parts (i.e., diumal movements, stomatal opening, flower opening)
- Cell elongation and growth
- Water has directed the evolution of all organisms.

2. Diffusion

It is the movement of molecules or ions of a solute or a solvent from the region of its higher concentration to that of its lower concentration, the net movement stops when a dynamic equilibrium is achieved.

The molecules move from [hi] to [low], following a concentration gradient.

The molecules move from an area of high free energy (higher concentration) to one of low free energy (lower concentration).

At equilibrium the molecules continue to move randomly, back and forth from one side of the partition to the other.

This purely physical phenomenon of diffusion is of top interest to the living cells because they have high percentages of water and are always surrounded by some kind of watery medium.

Minerals & food dissolves in water may move into or in between cells by diffusion so hardly there is any physiological process which dose not involves diffusion in other words diffusion is the basic phenomenon of **osmosis & imbibition**.

Factors Affecting Diffusion

A number of external & internal factors control the rate of diffusion in any plant some of the important factors are summarized below

- **Diffusion gradient**: - the rate of diffusion of any substance is directly proportional to difference in concentration of its molecules or ions in the two regions, and inversely proportional to the distance between these two regions, so the difference in diffusion pressure determines the rate direction of diffusion.
- **Temperature:** -Temperature greatly influences the rate of diffusion due to its direct proportional; that meant raising temperature will increase the diffusion of molecules or ions of a substance.
- **Density**: - Concentration of diffusing particles and the density of the liquid or gas through which the diffusion occurs markedly affect the rate of diffusion.

3. Imbibition

It is defined as the absorption of water by colloidal materials, the entry of water invariably results in swelling a colloidal particle (eg, the swelling of plant seeds) when dry seeds are sown in moist soil the cellulose of the cell walls, the starch, & the protein particles imbibe considerable volume of water; while as germination begins osmosis phenomenon comes to play.

The greatest degree of swelling is displayed by protein substances then starch particles then finally the cellulose swells the least.

Imbibition in plants is a characteristic of hydrophilic colloids so the amount of water imbibed when no other factor is involved depends on the cohesive force of the colloidal particle.

Water is not the only liquid that may be imbibed.

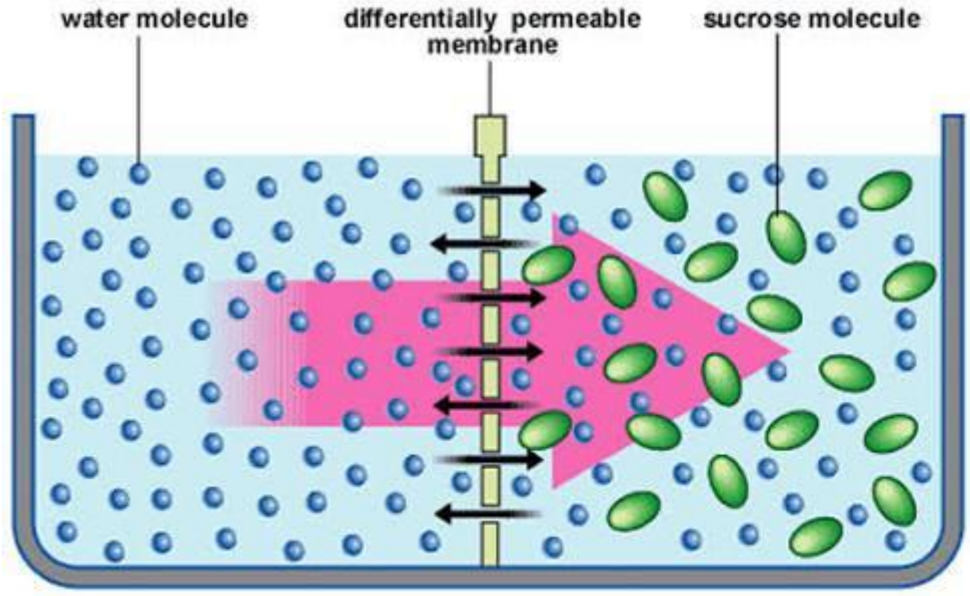
Organic Solvents are freely imbibed by several substances, imbibition of a-liquid by a-solid can occur only if there is an-infinity (similarity) between the two; so living protoplasm and cell walls are able to imbibe several kinds of liquids but under natural conditions water is the only liquid imbibed.

4.Osmosis

Osmosis is a specialized case of diffusion; it represents the diffusion of a solvent (typically water) across a membrane.

For osmosis to occur there must be:

- A selectively permeable membrane between two water solutions, or between a water solution and pure water.
- The concentration of solute in the two solutions must be unequal; i.e there must be more solute on one side of the membrane than on the other side.
- The membrane must be impermeable to the solute, but permeable to water.



Every living cell is bounded by plasma-membrane which, through this membrane the various materials used in metabolism (e.g, CO, H20, Salts, Sugar, amino acids, fatty acids, etc..) enter and leave out of the cell through it depending upon permeability.

The plasma membrane which allows the passage of the solvent but only some of the solutes (and not others) is actually a differential permeable membrane it is different from semi-permeable membrane which allow only the passage of the solvent but not the solute.

On the other hand, the cell wall present on the outer side of the plasma membranes is permeable that means it allows the passage of solvent as well as solutes.

Importance of Osmosiss

Following are the important processes resulting due to osmosis in plants:

1. Root-hairs absorb water from the soil by the process of osmosis.

2. From the root-hairs cell to cell osmosis takes place until cortical cells of the root become saturated with water, similar cell to cell osmosis takes place through-out the plant body.

3. The osmotic pressure generated in the root cortex responsible for forcing the water into the xylem vessels and possibly upwards through them at least to some height.

4. The living cells surrounding xylem draw water from it by this process and so do the mesophyll cells of the leaf at the upper end of xylem, prior to transpiration.

5. Osmosis makes the cells turgid which gives the required rigidity to the young soft parts of the plant body.

6. Various movements such as opening& closing stomata bursting of fruits are due to osmosis.

7. By Plasmolysis which is an osmotic phenomenon it is possible to determine osmotic pressure

Osmotic Pressure

It is the hydrostatic pressure produced by the difference of concentration between the sides of a surface such as a semi-permeable membrane in other words it's the pressure that is needed to ensure the process of osmosis.

5- Turgidity

As water absorbed by a cell and resulting in its accumulation in the vacuole a certain pressure is exerted on the surrounding protoplasm and the cell wall.

A cell thus charged with water with its wall in a state of tension is said to be turgid and the condition is designated as Turgidity or turgor.

It is clear now that in a fully turgid cell two pressures are involved

1. Outward pressure exerted on the cell wall is called **the turgor pressure.**

2. Inward pressure exerted on cell content is called **wall pressure**.

Normally these two pressures counter-balance each other.

So when the plant cell is placed in water, it will swell but will not burst or break.

Due to the negative osmotic potential of the cell sap, water moves into the cell and causes the plasma membrane to press against the cell wall.

This pressure responsible for pressing the plasma membrane against cell wall is called **turgor pressure.**

5. **Plasmolysis**

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

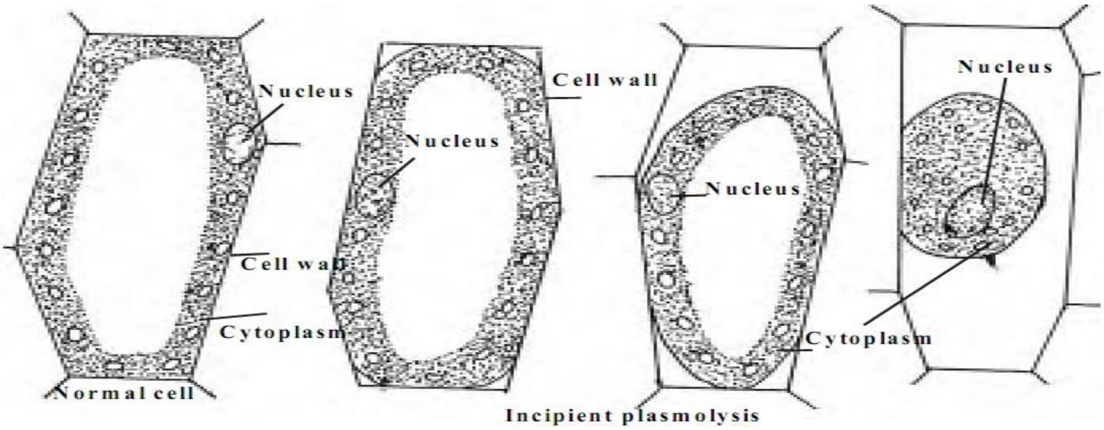
Since cell wall is permeable, salt solution enters the cell through the cell wall but its further inward diffusion beyond the plasma-membrane is checked as the latter is differentially permeable and would-not allow salt to cross it, instead water from the interior of the cell moves out beyond the plasma membrane due to the greater concentration of water molecules inside the cell as compared to the concentration of water molecules in salt solution.

The cytoplasm, which has so far been held in position against the cell wall due to the turgor pressure, now shrinks away from the cell wall and thus a space is formed between the plasma membrane and the cell wall.

This space filled with salt solution, now in much dilute form as compared to its initial concentration.

Such shrinkage of the protoplast of plant cells through loss of water is called plasmolysis which can be defined as:

the shrinking in volume of the protoplasm of a cell and the separation of the protoplasm from the cell wall due to loss of water via osmosis.



When plasmolysis is allowed to go on for considerable period of time the cell dies and disorganizes because the dead plasma-membrane is freely permeable.

On the other hand, if a slightly plasmolyzed cell is placed in water, it regains its water content and the original turgid form this phenomenon is called deplasmolysis.

A specific solution may be **Isotonic** (if the concentration of both the solution and the protoplasm is the same), or **hypertonic** (if the concentration of the solution is higher than that of the protoplasm) or **hypotonic** (if the concentration of the solution is lower than that of the protoplasm)

Colloidal System in Plants

- Protoplasm is present in a colloidal condition and various physiological processes are performed by the colloidal nature of the cell contents.
- Most soils also contain materials in colloidal state.
- The colloids play an important part in the physiology of plants.
- Colloids and colloidal systems are essential to life.
- They function in everybody cell, in the blood, and in all body fluids, especially the intercellular fluids.

Colloidal chemistry deals with both organic and inorganic substances affected by two conditions:

a. Size of particles.

b. Particle dispersion in a medium.

Together, the particles and the medium are called a **colloidal system**.

Water Absorption

Water makes up most of the mass of plant cells, each cell contains a large water- filled vacuole, in such cells the cytoplasm makes up only 5 to 10 % of the cell volume, the remainder is vacuole.

Water typically constitutes 80 to 95 % of the mass of growing tissues.

The Soil Water:

Thought the soil particles lie close to each other yet some angular spaces is always present there, all such spaces in soil called pore space , which comprises 40-60 % of total soil volume that remains fill of water or gases in various situations.

Plant Available Water (PAW):

Following rainfall, or irrigation, all the pores in soil will be filled with water this is the saturation water content (SWC).

With time the water in the largest pores will drain to depth due to gravitational forces.

In coarser (large particle) textured, sandy and loamy soils this drainage will take place in less than a day and will, therefore, be unavailable to plants.

Fine-textured, clayey soils, however, may be somewhat poorly drained and all pores may remain filled with water for several days.

In these cases, some of the SWC may be available for evapotranspiration and would need to be considered in calculations of soil water balances and irrigation scheduling.

Poorly drained soils, however, are less suitable for irrigation.

They are difficult to manage and may be waterlogged (saturated with or full of water) for times that can cause damage to plants for reasons of anaerobic root environments.

With time, some of the saturation water content will drain to depth and an amount will be retained to be available for use by plants.

This is known as **Field Capacity (FC)** and is a store of water that can meet the plant demands for several days.

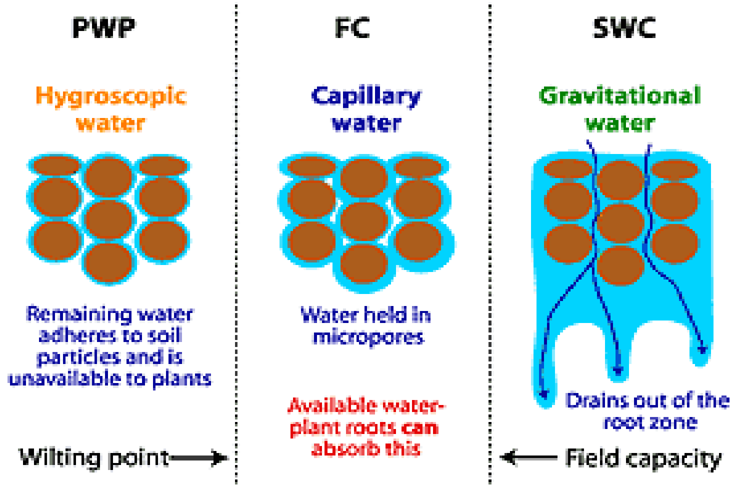
The amount of water at FC varies with the porosity of the soil and is greatest in fine textured soils and least in coarse textured sandy soils.

As the soil dries out due to Evapotranspiration the water remaining is held at increasingly greater suctions and is less available to plants.

At a suction of 1500kPa water is tightly held in very fine pores and is no longer available to plants; this is defined as **Permanent wilting Point (PWP).**

Between the extremes of FC and PWP the water is available to plants and is known as **Plant Available Water (PAW).**

In other words, Plant available water is the amount of water held in a soil between the limits of **Field Capacity** and **Permanent Wilting Point**.



Available water for plant growth

However, this only the water near to Field Capacity may be Readily available water.

This is particularly for fine textured, clayey soils because a high proportion of **Plant Available Water** is held in small pores and as thin films and plants need to do more work to extract this fraction of water from soils.

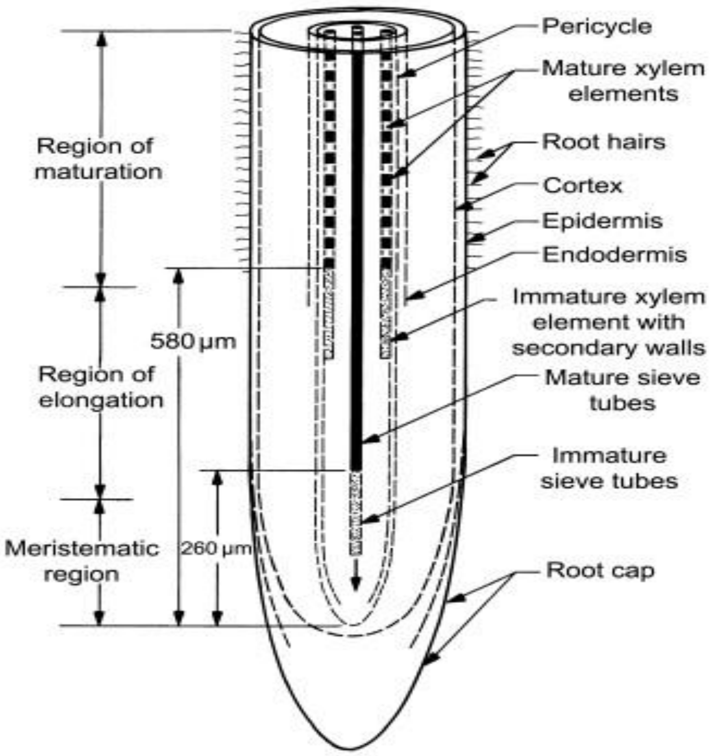
Not all PAW is equally available to plants.

As soils dry out-and PAW approaches PWP, plants will come under water- stress and wilt.

Organ of Water Absorption

Roots have four regions:

1. The root cap
2. The meristematic region,
3. The region of cell elongation
4. The region of differentiation and maturation.



The root cap is composed of loosely arranged cells and is usually well defined.

Because it has no direct connection with the vascular system, it probably has no role in absorption.

The meristematic region typically consists of numerous small, compactly arranged, thin-walled cells almost filled with cytoplasm.

Relatively little water or salt is absorbed through this region, largely because of the high resistance and the lack of a conducting system.

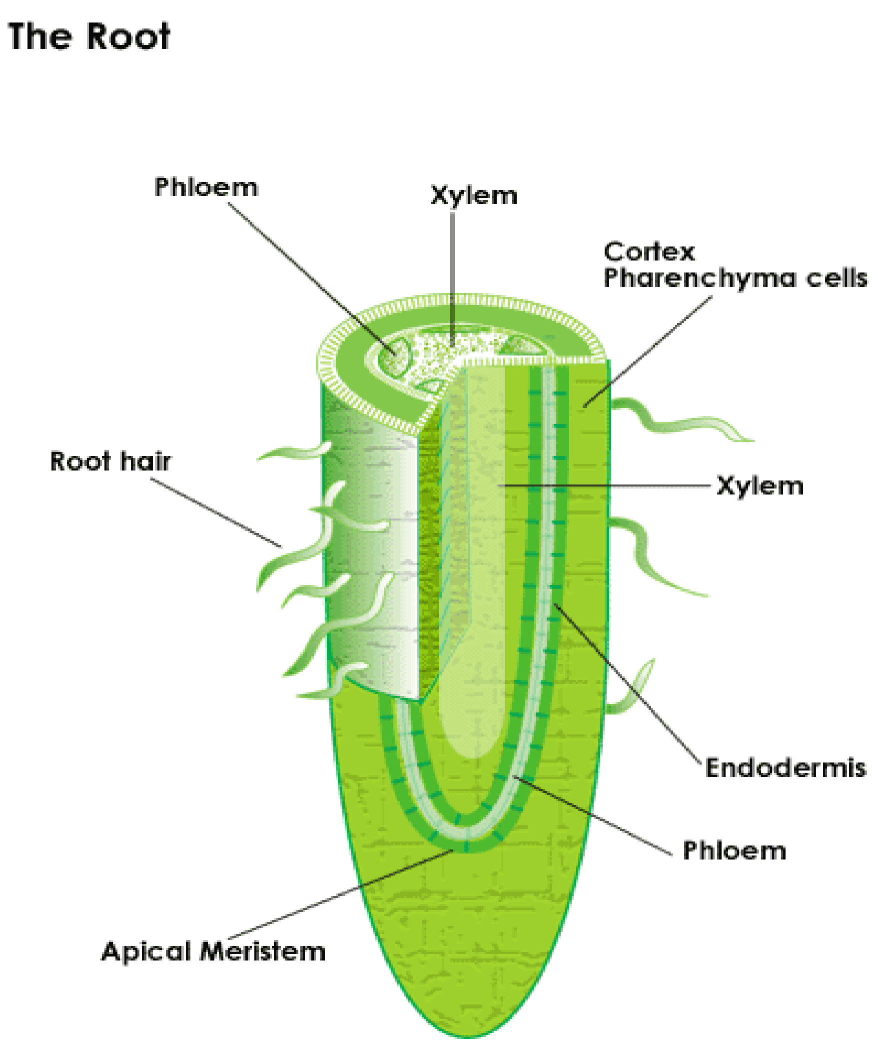
Usually there is a zone of rapid cell elongation and expansion a few tenths of a millimetre behind the root apex.

Typically sieve tubes of the phloem differentiate before the xylem elements, as the newly enlarged, thin-walled cells at the base of the zone of enlargement cease to elongate, they become differentiated into the epidermis, cortex and stele, which constitute the primary structures of roots.

Root hairs appear when the epidermis differentiates.

The epidermis has specialized cells that are root hair cells.

The distance from the tip at which the various tissues differentiate and mature depends on the kind of root and the rate of growth.

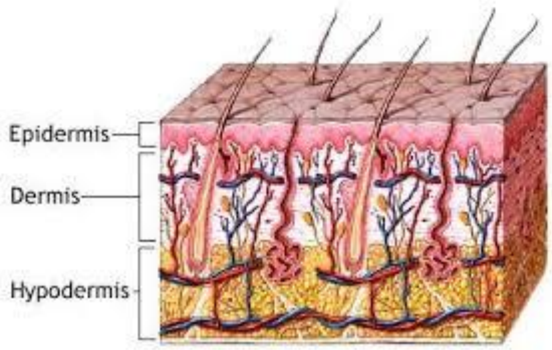


The epidermis is usually composed of relatively thin-walled, elongated cells that form a compact layer covering the exterior of young roots.

Water enters the root most readily in the apical part of the root that includes the root hair zone.

More mature regions of the root often have an outer layer of protective tissue, called hypodermis, which contains hydrophobic materials in its walls and is relatively impermeable to water.

The intimate contact between the soil and the root surface is easily ruptured (Broke) when the soil is disturbed.



It is for this reason that newly transplanted seedlings and plants need to be protected from water loss for the first few days after transplantation. Thereafter, new root growth into the soil re-establishes soil-root contact, and the plant can better withstand water stress.

Let's consider how water moves within the root, and the factors that determine the rate of water uptake into the root.

Water moves in the root via Apoplast & Symplast Pathways

In the soil, water is transported predominantly (mainly) by bulk flow.

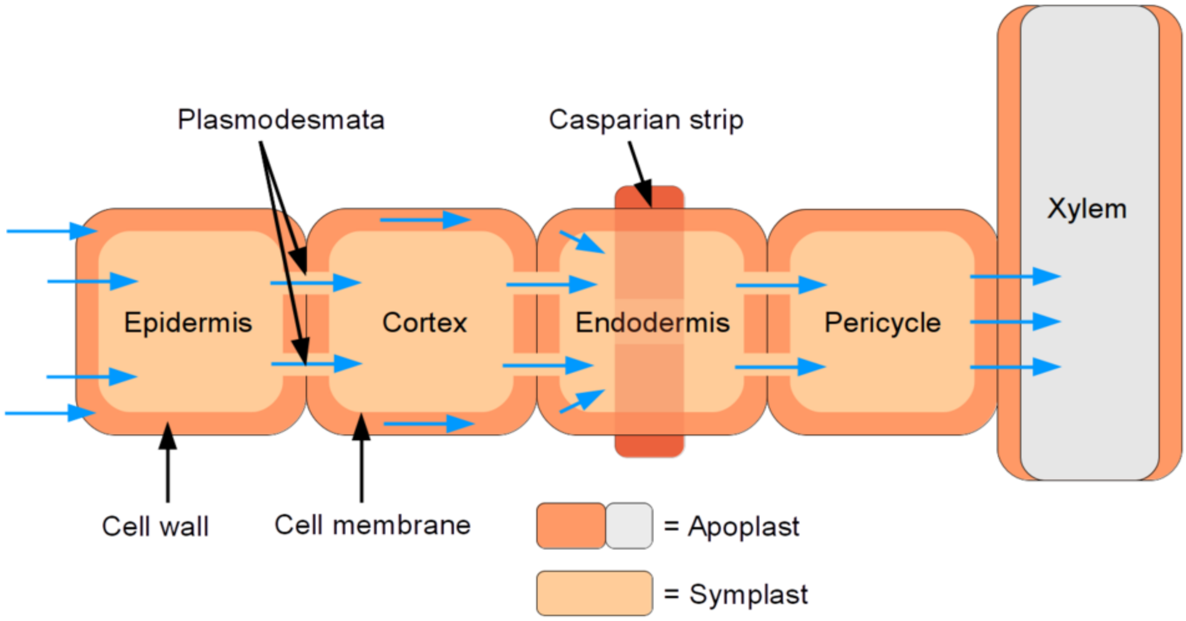
However, when water comes in contact with the root surface, the nature of water transport becomes more complex.

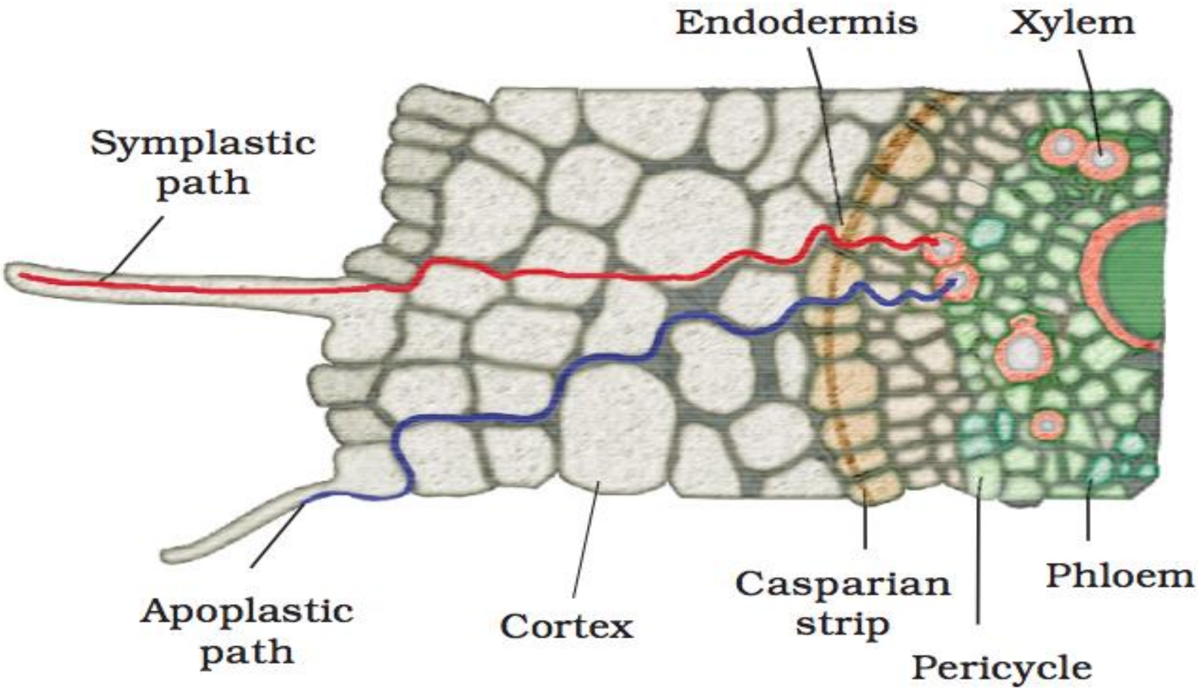
From the epidermis to the endodermis of the root, there are two main pathways through which water can flow; the apoplast and symplast pathways

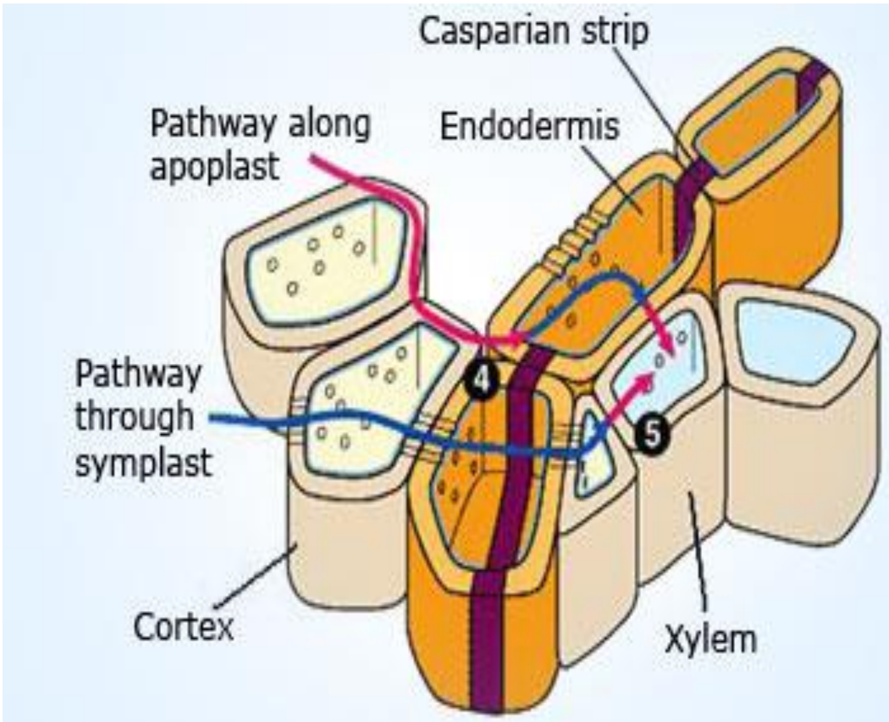
1. In the apoplast pathway, water moves exclusively through the cell wall without crossing any membranes. The apoplast is the continuous system of cell walls and intercellular air spaces in plant tissues.

2. In the symplast pathway, water travels from one cell to the next via the plasmodesmata.

The symplast consists of the entire network of cell cytoplasm interconnected by plasmodesmata.




Endodermis
Xylem
Symplastic
path
Apoplastic
path
Cortex
Casparian
strip
Phloem
Pericycle


Casparian strip
Pathway along
apoplast
Endodermis
Pathway
through
symplast
4
5
Cortex
Xylem

Mechanisms of water absorption by roots:

Different mechanisms involved in water absorption by root-hairs

1. **Passive Absorption**

It occurs in rapidly transpiring plants during daytime, because of opening of stomata and the atmospheric conditions.

Transpiration pull is responsible for dragging water at the leaf end, the pull or force is transmitted down to the root through water column in the xylem elements.

The continuity of water column remains intact due to the cohesion between the molecules.

Roots simply act as a passive organ of absorption.

As transpiration proceeds, at the same time water absorption also takes place to compensate the water loss from leaf end.

Most volume of water entering plants is by means of passive absorption.

2. **Active Absorption**

It is absorption of water by roots with the help of metabolic energy generated by the root respiration.

The force for water absorption originates from the cells of root due to root respiration.

As the root cells actively take part in the process so it is called Active absorption.

The active absorption is carried out by two THEORIES which are:

(a) Active osmotic water absorption

According to this theory, the root cells behave as ideal osmotic pressure system through which water moves up from soil solution to root xylem.

If solute concentration is high and water potential is low in the root cells, water can enter from soil to root cells.

Mineral nutrients are absorbed actively by the root cells due to utilization of adenosine triphosphate (ATP).

The endosmosis of water continues till the water potential both in the root and soil becomes equal.

It is the absorption of minerals that use metabolic energy, but not water absorption.

Hence, absorption of water is indirectly an active process in a plant's life.

(b) Active non-osmotic water absorption

According to the theory, sometimes water is absorbed against concentration gradient.

This requires expenditure (spending) of metabolic energy released from respiration of root cells.

Factors Affecting Water Absorption by Roots

Some of the important factors that influence water absorption by roots could be summarized as below:

Physical Factors

The soil and atmosphere are the chief physical factors which determine the flow rate of water through plant.

Soil Factors: -

1. **Soil water content**

The plant roots can easily absorb the soil moisture in between field capacity and permanent wilting point. When the soil moisture decreases below the wilting point, plant roots have to exert more pressure and thus rate of absorption decreases.

On the other hand, when the soil is completely saturated with water, then soil temperature and aeration are poor and this condition also affects the absorption of water.

2. Soil temperature

Soil temperature is known to influence water absorption and ultimately transpiration to a considerable extent.

In many plants, water absorption below a soil temperature of 10C is reduced sharply and temperature uptake of water is slowed down.

In most instances, temperature above 40°C does not support water absorption and plant can show signs of 25°C soil and wilting.

A freezing temperature reduces water absorption because of following causes:

(a) Decreased root growth

(b) Increased viscosity of water

(c) Increased resistance to movement of water in to roots. Thus, it is caused by decreased permeability of cell membrane and the increased viscosity.

3. Soil aeration and flooding:

Most of plants are not able to water while standing under water logged conditions.

The following are the possible reasons of flood injury.

(a) Poor availability of oxygen and occurrence if higher CO_2 concentration around roots.

(b) Accumulation of toxic substances either in the submerged roots or around them.

(c) Changes in pattern of ion uptake resulting in the accumulation of some toxic ions.

In water logged condition, availability of oxygen is reduced which affects respiratory actively of roots.

In addition, CO_2 concentration is increased, and it affects permeability of membranes and adversely influences water uptake. Reduced oxygen also affects root growth adversely (harmfully).

Translocation of water (Ascent of Sap)

The upward movement of water from the meta-xylem of roots up to the sub- stomatal cavities of leaves via xylem of the stem and veins of leaves is called "Ascent of sap" or conduction of water in an upward direction.

It has been experimentally verified that xylem is the main water conducting tissue.

The term of sap is used for water because the water in plants is never pure due to the high number of dissolved mineral salts.

Xylem and phloem have been seen to be the conducting tissues in higher plants, meanwhile water and minerals are moved through vessels and tracheids of xylem, food and other organic materials are conducted by sieve tubes of the phloem.

Various theories have been forwarded to explain the mechanism involved in ascent of sap.

Some scientists are of the opinion that living cells are actively involved in pumping water in an upward direction while others explain the mechanism of ascent of sap is independent of life activity.

Various theories can be broadly dealt fewer than three headings.

1. Vital theories

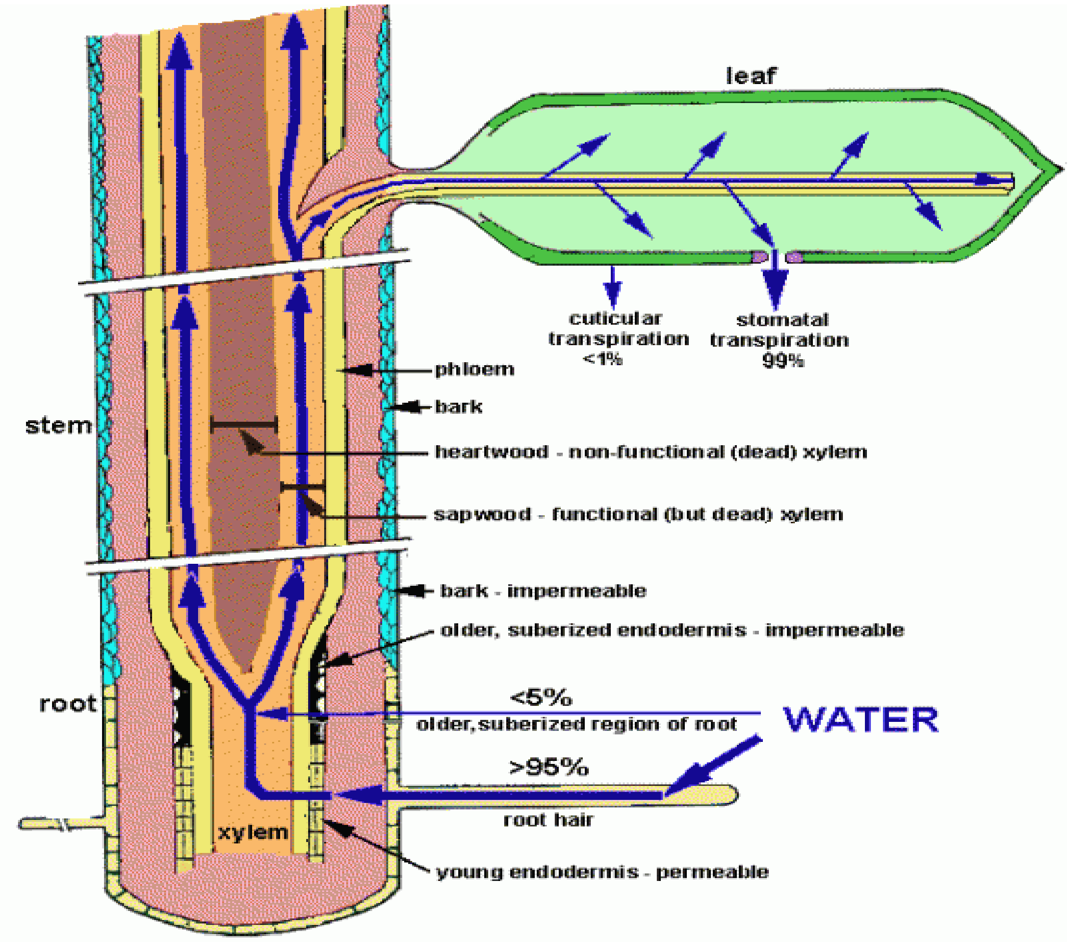
2. Root pressure theory

3. Physical theories

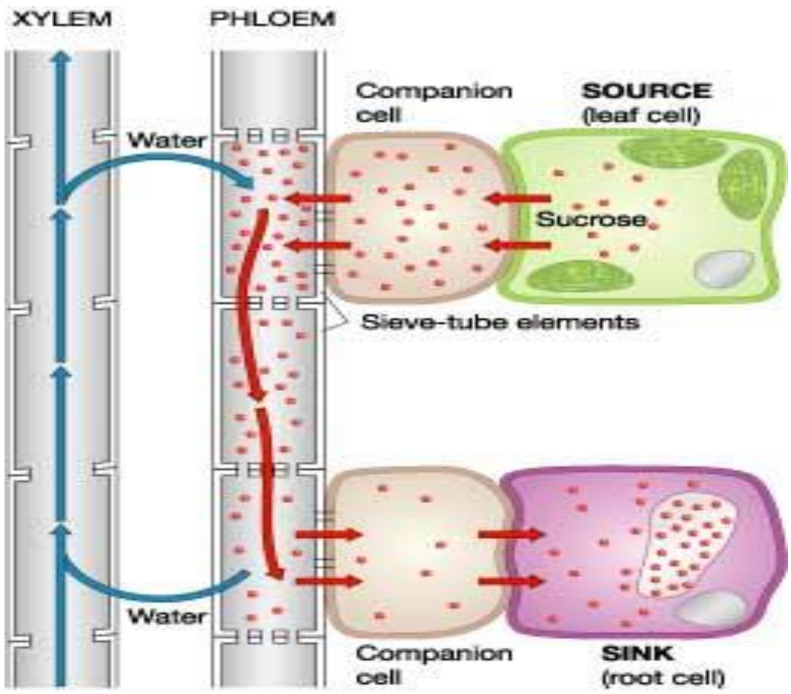
1. Vital Theories

All those theories which consider living cells to be responsible to effect ascent of sap are dealt under vital theories.

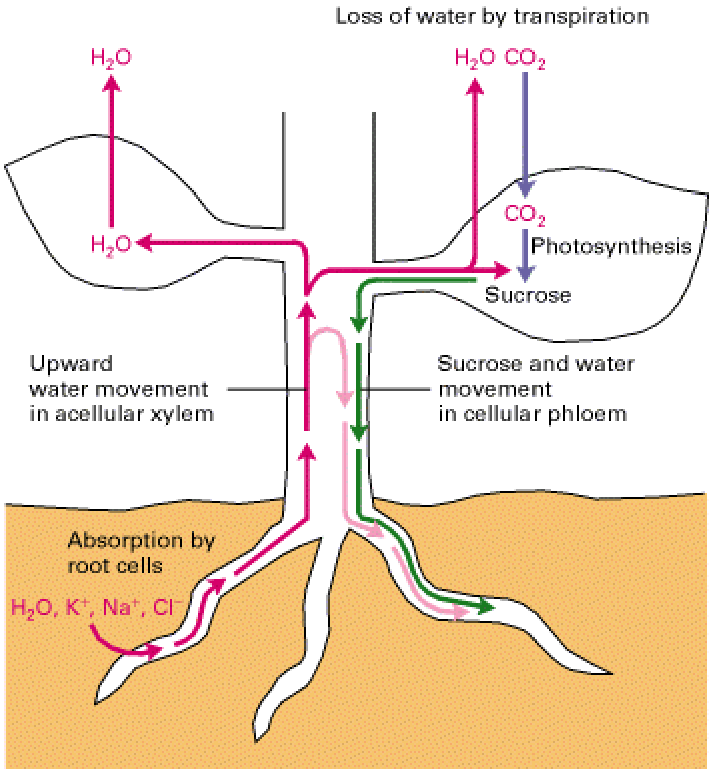
Believers stated that the living cells play an essential role in ascent of sap.



leaf
cuticular transpiration <1%
stomatal transpiration 99%
phloem
bark
stem
heartwood - non-functional (dead) xylem
sapwood - functional (but dead) xylem
bark - impermeable
older, suberized endodermis - impermeable
root
<5%
older, suberized region of root
WATER
>95%
root hair
xylem
young endodermis - permeable

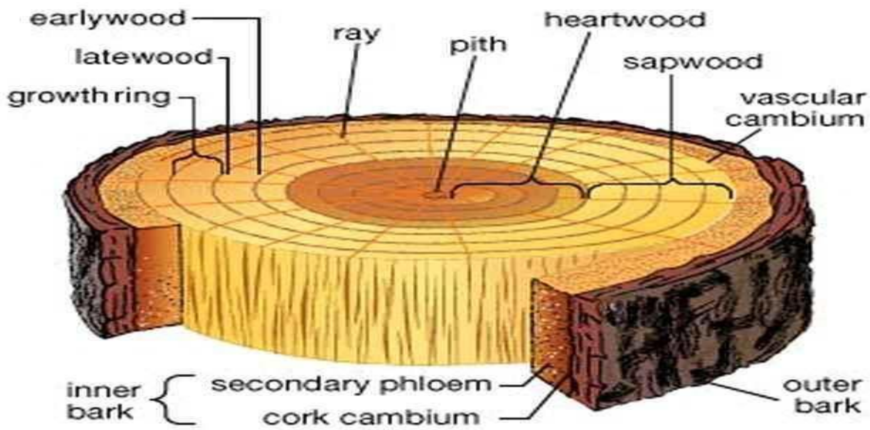


XYLEM
PHLOEM
Companion cell
SOURCE (leaf cell)
Water
Sucrose
Sieve-tube elements
Water
Companion cell
SINK (root cell)



Godlewski in 1884 proposed relay pump theory to explain ascent of sap.

According to him there was a rhythmic change in the osmotic pressure of the living cells of xylem parenchyma and medullary rays which brought about a pumping action of water in an upward and showed that if the lower portion of branch was killed, the leaves above were affected.



2. Root Pressure Theory

If the stem of a plant is cut near its base or incisions are made in the stem, xylem sap is seen to flow out through them. This phenomenon is called "exudation" or "bleeding".

Pristley explained that this process of upward movement of water was due to a hydrostatic pressure developed in the root system.

Since the living roots are essential for the development of root pressure, it seems most reasonable to think that root pressure is purely a matter of diffusion pressure gradient, it is however, maintained by the activity of living cells.

Objections to root pressure theory

Some scientists have objected very strongly the involvement of root pressure in causing ascent of sap.

It is true that root pressure is a dynamic process, but in itself it is not sufficient to drive water in case of tall trees ranging in height from 200 to 400 feet.

Further root pressure has not been observed in all plants. No or little pressure is found in gymnosperms.

3. Physical Theories

All those theories which consider the dead cells of the plant to be responsible for the ascent of sap are called physical theories.

(i) Boehm's theory

Boehm is the view that water ascends in the xylem vessels because of capillary action.

If a capillary tube is kept vertically in the water, the water rises up in the tube automatically to a certain height.

This happens due to capillary force and high surface tension of water.

It is known that the highest rise of water column attained by capillary forces in narrow circular tubes having diameter 0.03 mm is less than 4 feet.

Capillarity also implies that both the ends of the tube must have free surfaces. In case of plants the xylem duct is not in direct contact with soil water to effect ascent of sap. Then this theory fails to account ascent of sap in tall trees.

(ii) Jamin's chain theory

Jamin believed that air and water were alternatively arranged inside the xylem duct.

He explained that when air gets expanded, it moved up carrying along with it the water column present above it.

The theory is unconvincing as it fails to explain the rapid unidirectional flow of sap.

(iii) Transpiration Pull Theory

This theory was proposed by Dixon and Joly (1894) and has been supported by Curtis and Clark (1951), Levitt (1969).

The above theory is also known as Dixon theory of ascent of sap.

The theory assumes that water is pulled from up, but not pushed from below.

The theory has two essential features such as

(i) Cohesion of water
(ii) Adhesion between water and xylem tissues
(iii) Transpiration pull.

Cohesion is the phenomenon of attraction between similar molecules.

The water molecules remain attracted by the cohesive force and cannot be easily separated from one another.

Further, there is attraction between water molecules and the inner wall of xylem ducts.

Then water column cannot be pulled away from the wall of xylem ducts due to strong adhesive and cohesive properties of water and the continuity of water column is maintained from roots to leaves.

The forces acting against the cohesive force of water and try to break up the water column in the plant are the weight of water column itself, the resistance encountered by water in crossing the tissues of the root, the stem and the mesophyll cells of the leaf.

All these forces combined together in tall trees.

The magnitude of the cohesive force of water alone is about 300 atms (unit of pressure) which is sufficient for maintaining the continuity of water column in plants

Transpiration Pulls

It is the pulling force responsible for lifting the water column.

As water is lost in form of water vapour to atmosphere from the mesophyll cells by transpiration, a negative hydrostatic pressure is created in the mesophyll cells which in turn draw water from veins of the leaves.

The negative tension is then gradually transmitted downwards via xylem tissues of the leaf, stem and finally to the roots.

As a result there is a continuous upward movement of water column in the plant.

1 atm. pressure can raise water to a height of more than 32ft so a tension of 13 atm is needed to raise water to a height of 416 feet.

Scientist have measured this tension to be more than 75 atm. in case of trees, more than 400 feet in height.

Thus the transpiration pull acts as pull from above on the-whole of water column of the plant which pushes the water column of xylem vessels of roots lowers leaves i.e. in an upward direction.

This is how ascent of sap is affected in plants.

The whole process can be compared to a person (transpiration pull) pulling a bucket full of water with a steel rope (unbroken and continuous water column).

Transpiration

Plants absorb a large quantity of water, from soil by means of roots and root hairs.

However, only a small fraction (1.2 %) of the absorbed water is utilized by the plants for its metabolic activities .

The remainder (98-99 %) excessive amount of absorbed water is lost to the atmosphere by the physiological process known as **transpiration.**

It is a universal process. **Transpiration** is defined as the loss of water in the form of water vapour from the internal tissues of living plants through the aerial parts such as leaves, green shoots etc., in the presence of sunlight.

Stages in Transpiration

Transpiration occurs through two successive stages:

(i) At first water is lost from the mesophyll cells of the leaf into the intercellular spaces

(ii) Subsequently water diffuses from the intercellular spaces into the outer atmosphere in the form of water vapour either through the stomata or general surface of epidermis of leaves.

Types of Transpiration: -

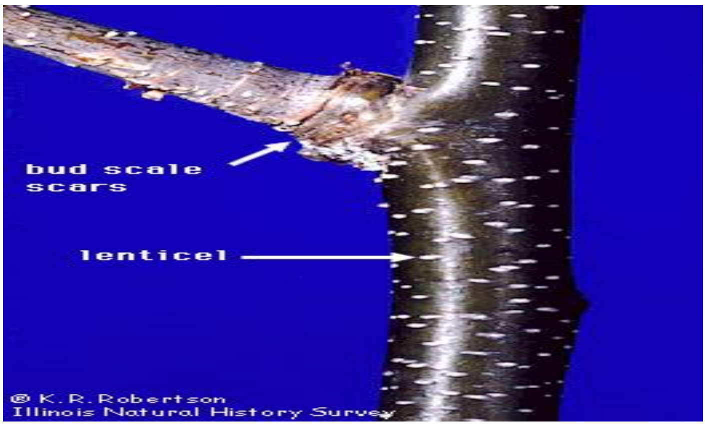
There are three kinds of Transpiration

1. Stomatal Transpiration

Water evaporates through small openings called stomata, which are present on green parts of plants, mainly leaves. This is the most usual method of transpiration.

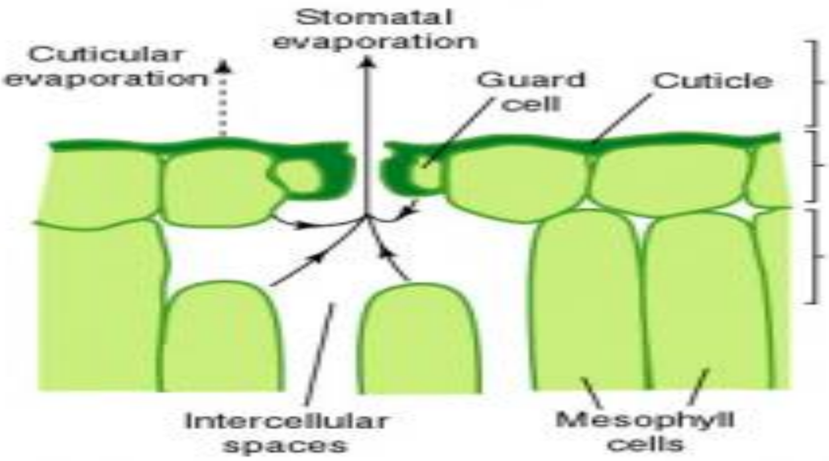
2. Lenticular Transpiration

Sometimes water may evaporate through certain other openings present on the older stems (lenticels) in a process known as lenticular transpiration which consists 0.1 % of total transpiration.



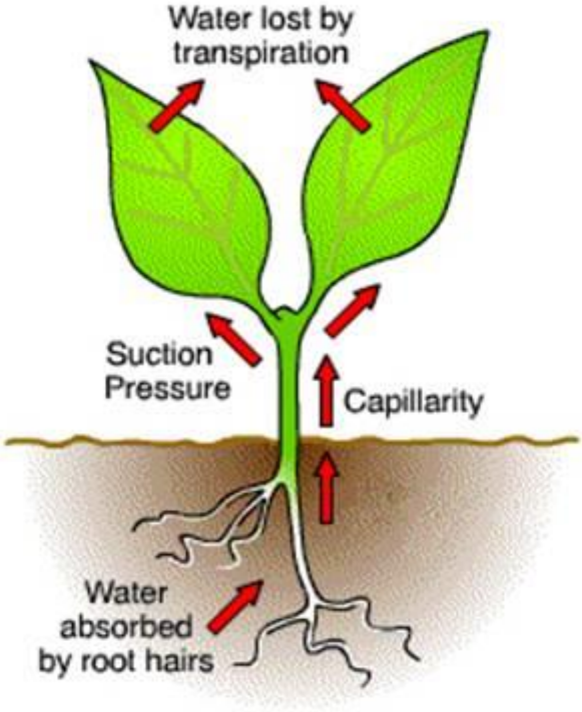
3. Cuticular Transpiration

Loss of water may also take place through cuticle, but the amount is relatively small and makes about 5-10 % of total transpiration, this kind depends on the thickness of cuticle and presence or absence of wax coating on the surface of leaves.



Transpiration serves three essential roles:

1. Movement of minerals up from the root (in the xylem) and sugars (products of photosynthesis) throughout the plant (in the phloem). Water serves as both tie solvent and the avenue of transport
2. Cooling - 80 % of the cooling effect of a shade tree is from the evaporative cooling effects of transpiration. This benefit both plants and humans
3. Turgor pressure - Water maintains the turgor pressure in cells much like air inflates a balloon, giving the non-woody plant parts form. Turgidity is important, so the plant can remain stiff and upright and gain a competitive advantage when it comes to light. Turgidity is also important for the functioning of the guard cells, which surround the stomata and regulate water loss and carbon dioxide uptake.

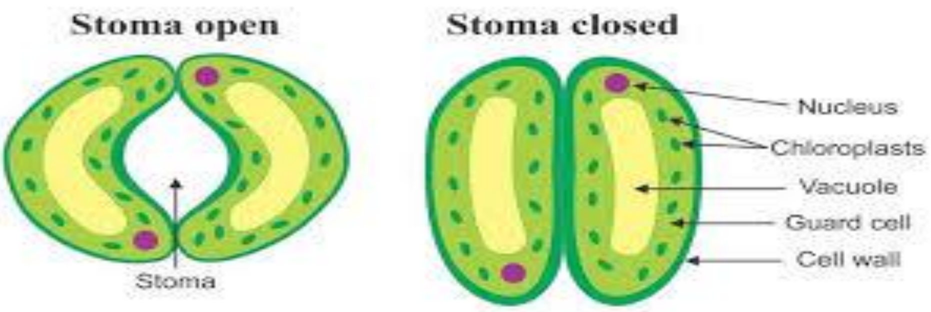


Structure of Stomata

The epidermis of leaves and green stems possess many small pores called stomata (singular: stoma), the length and breadth (width) of the openings is about 10-40 and 3-10 μ respectively.

Each pore remains surrounded by special kidney shaped living epidermal cells called guard-cells.

The pore and the guard-cells jointly called stoma.



The stoma to the interior into a cavity called sub-stomatal cavity which remains connected with the intercellular spaces.

The guard cells possess a nucleus, cytoplasm, and several chloroplasts.

Their inner walls are thick and inelastic while the outer walls are thin and elastic.

Each guard cell surrounded by two or more living cells called subsidiary (supplemental) or accessory cells.

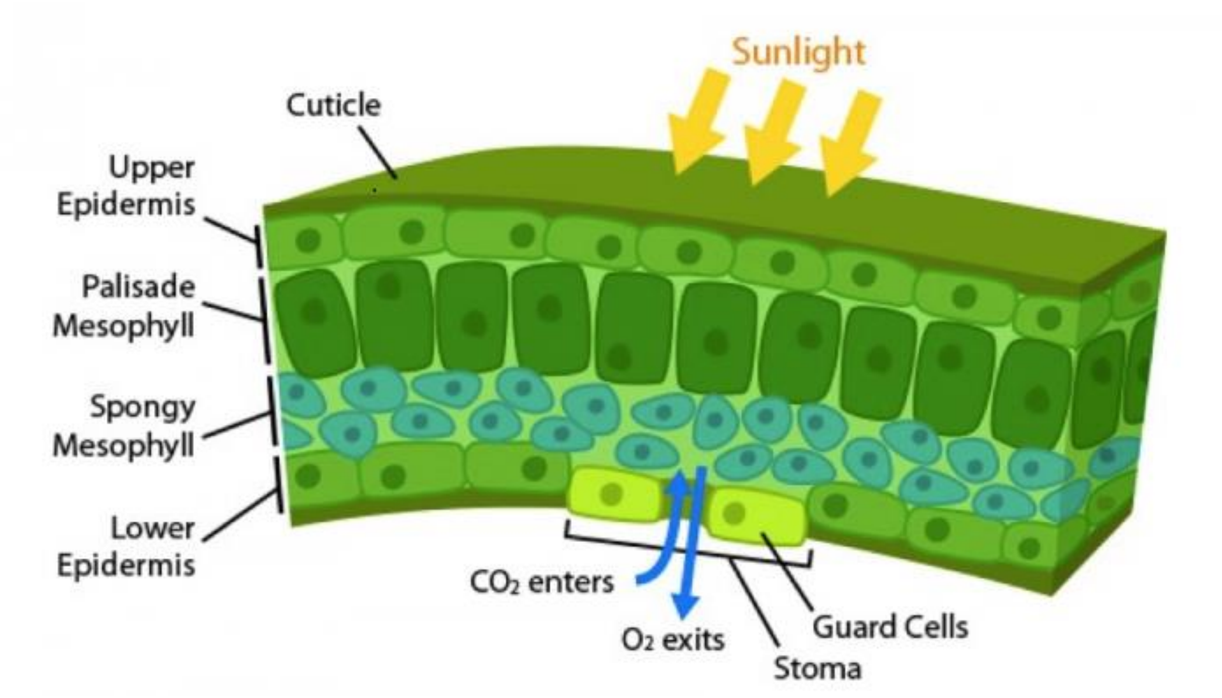
Number and Distribution of Stomata on Leaf

The frequency and distribution of stomata vary in different species and in different parts of individual leaves. In dorsiventral leaves, their number is more on the lower side.

In monocotyledonous leaves, their numbers are equal on lower and upper surfaces, while in floating leaves e.g. water-lily the stomata are found only on the upper surface.

The number of stomata in a leaf varies from 1000-6000 per square centimeter, while all the stomata of a leaf cover about 1-2 percent of total area of leaf.

Stomata distribution in monocotyledonous leaves are arranged in parallel rows, while in dicotyledonous leaves are scattered.



There are five types of stomata according to its distribution summarized as below

1. **Apple Type**: when the stomata found only on the lower surface of the leaf, such as Apple, Peach, and Walnut.
2. **Potato Type**: when the stromata found on the lower surface than the upper surface, such as potato, tomato, and pea.
3. **Oat Type**: when the stomata are found equally on both sides, such as maize, oat and grasses.
4. **Water-Lily Type:** when the stomata are found only on the upper surface of leaf such as Water-Lily plant.
5. **Potamogeton Type:** when the stomata are absent or non-functional such as potamogeton.

Daily Periodicity of Stomatal Movement

The rate of stomatal transpiration doesn't remain the same all the time, but it varies from the morning to night, which depends on the closing and opening of stomata that ultimately depends on light, so daily periodicity of stomatal movement is as below:

I. After the sun-rise in the morning the stomata starts opening in the sun-light, very low rate of transpiration starts.
II. The stomata completely open in between 10 and 11 A.M at this time the rate of transpiration is maximum.
III. High rate of transpiration decreases turgidity of leaf cells this creates less absorption of water by roots, thus the rate of transpiration decreases, this happens between 11 A.M. and I P.M
IV. Accessory cells become turgid due to the high rate of water absorption, these results in opening stomata, which causes increasing the rate of transpiration which at 3 P.M. becomes equal to the rate between 10-11 A.M.

V. At about 4 P.M. the stomata start to close again with decreasing the intensity of light, thus the rate of transpiration starts to decrease.

VI. At sunset the stomata closes completely whole night so transpiration process stops whole night.

Although the stomata remain closed during night, the exchange of gases due to respiration continues.

Mechanism of Transpiration:

The mechanism of transpiration is completed in two stages

(1) The diffusion of water of mesophyll cells into intercellular spaces

(2) The diffusion of water vapour of intercellular spaces in to the outer dry atmosphere.

About 95 % of absorbed water is transpired through stomata.

The intercellular spaces of mesophyll cells remain connected with the sub-stomatal cavity, thus the water vapours continuously diffuse from intercellular spaces to sub-stomatal cavity and the air in these cavities remain saturated with water vapor, so when the air in the outer space is unsaturated, the water diffuses from sub-stomatal cavity in to the atmosphere, thus the process of transpiration continues.

Mechanism of Opening& Closing of Stomata:

Opening and closing of stomata depends upon the turgid and flaccid condition of guard cells respectively.

When the guard cells become turgid, stomata open and they become closed when the guard become flaccid.

The size of stomatal opening depends upon the degree of turgidity of guard cells.

Different theories were proposed by various physiologists to explain the reasons of change in turgidity.

Some of the important theories are as follows:

1st. Theory of Photosynthesis in Guard Cells:

The mechanical interpretation of the stomata function was began in 1856 by Von Mohl.

He based his observations on that the stomata remains open in light and closed at night or in dark, so he stated that the chloroplast presents in the guard cells photosynthesis in light resulting in the formation of carbohydrates and increase the osmotic pressure of guard cells due to which the water enters into the guard by osmosis from surrounding cells and become turgid, while during night due to the lack of photosynthesis the guard cell flaccid and closed.

Photosynthesis → formation of sugar → increase of Osmotic Pressure of Cell-Sap

↓

Entrance of water from mesophyll cells ← Endosmosis ←

↓

Increase in turgidity of guard cells

↓

Stomata open

There are objections regarding this theory

1. The chloroplasts of guard cells of certain plants are completely unable to photosynthesis carbohydrates.
2. The chloroplasts of guard cells perform insufficient photosynthesis and already possess much amount of stored sugar.
3. Some plants when kept in dark, their leaves still possess starch.

The Second Theory of starch-sugar inter-conversion

This theory based on the effect of pH on Starch phosphorylase enzyme which reversibly catalyses the conversion starch + inorganic phosphate into glucose-1-phosphate as below

I. During opening: Photosynthesis occurs during the day due to the presence of light.

This lowers the concentration of Carbon dioxide which is a raw material for the above process.

This reduces the acidity of the guard.

This condition favours conversion of starch to glucose (sugar); which then increases the guard cells' osmotic pressure; water from the nearby epidermal cells will move by osmosis to the guard cell making it more turgid.

The thinner outer walls stretches more causing the guard cell to bulge out (abnormal enlargement) hence opening the stomata.

II. During closing:

At night when there is no light, no photosynthesis takes place that means the level of carbon dioxide in the guard cells increase acidity.

Acidic condition promotes conversion of glucose to starch; and the osmotic pressure of the guard cells reduces than that of the neighbouring cells hence loses water through osmosis.

The cell thus become flaccid and the stomata have no choice than to close.

Light
↓
Photosynthesis in guard cell (GC)
↓
Consume CO_2, Cell pH
↓
SPLase hydrolysis activity
↓
Starch becomes Glucose
↓
Water potential
↓
Guard Cell absorbs water and turgor
↓
Stomata opening

darkness
↓
Respiration in GC
↓
Produce CO, cell pH
↓
SPLase synthesis activity
↓
Glucose to starch
↓
Water potential
↓
Loss of water and flaccid
↓
Stomata closure

Criticisms of starch-sugar inter conversion theory

1. In the light starch disappears and malic acid appears instead of sugar.
2. Less or no starch was reported in the guard cells of many monocots.
3. It was found that presence of phosphate ions causes development of osmotic pressure
4. Phosphorylase helps in converting of starch to glucose-I-phosphate, but not in formation of starch from glucose.

Third K^+ Pump or Inorganic Ion Uptake Theory:

According to this theory of active transport and the influx of Potassium ion in the guard cells and their critical role in stomatal movement, Stomata movements are closely associated with metabolic changes

1. Opening of Stomata

When plants are exposed to light, the ATP generated during photophosphorylation and Respiration of guard cells are utilised for the inf lux (inrush) of K ions and efflux (the movement of liquid) of H ions.

CI accompanies the K^+ into the guard cells in response to electrical differential created by the K intake.

During daytime organic acids, particularly malic acid is produced from starch. It dissociates into Malate ions) and portions, Protons are expelled into the subsidiary cells and malate ions help in balancing the K^+ ions along with Cl^- ions.

Presence of K, CI and malate ions in the guard cell decreases the water potential. Hence the water present in the subsidiary cells enters the guard cell.

Turgor pressure of the guard cell is increased and becomes turgid.

The distal (surface) wall of kidney shaped guard cell becomes more and more convex (having more surface) and draws the inner walls away from each other. This results in the opening of stomata.

In monocots the ends of guard cells become more bulged (swell) and draw apart the middle-thickened region of cells away from each other. It results in opening of stomata.

2. Closing of Stomata

The proton pump is switched off during dark.

The K^+, Cl^- and malate ions move passively into the subsidiary cells from guard cells. H+ ions move into guard cells.

Some amount malate remained in the guard cells is oxidised in respiration.

This results in increase in water potential and exit of water of guard cell into the surrounding cells. Guard cells regain their normal condition and become flaccid. They loose turgor and stomata are closed.

Stomata are opened at high pH and closed at low pH.

Light (dark)
↓
Guard cell photosynthesis (respiration)
↓
AT H* ATP and malate
↓
ATPase hydrolysis ATP, malate dissociates H+
↓
H+ pump out of GC, K'pump into GC
↓
Water potential
↓
GC absorbs water and turgor
↓
Stomatal opening

Environmental Factors Affecting Transpiration

1. Relative humidity.
2. Air Movement- increase air movement increases the rate of transpiration
3. Temperature- increase in temperature increases the rate of transpiration as higher temperature
   - provides the latent (unused) heat of vaporisation
   - increases the kinetic energy so faster diffusion
   - Warms the air

4. Atmospheric pressure: - decrease in atmospheric pressure increases the rate of transpiration.
5. Water supply: transpiration rate is lower if there is little water available as transpiration depends on the mesophyll cell walls being wet, When cells are flaccid the stomata close.
6. Light intensity: greater light intensity increases the rate of transpiration because it causes the stomata to open, so increasing evaporation through the stomata.

Differences between Transpiration and Evaporation

	Transpiration	Evaporation
1	Physiological phenomenon in living plans	Physical phenomenon in any exposed surface.
2	Takes place in stomata which is controlled by guard cells	Takes place in any opening or pore
3	Affected by several factors	Affected by temperature and water content
4	Surface area controlled by guard cells	Surface area is constant

Guttation

When leaves lose water as a liquid phase through special cells called hydathodes it is referred to as Guttation.

These guttation "tears" appear at the leaf tips or margin contain various salts, sugars and other organic substances.

It occurs through specialized pores present at tip of veins of leaves called hydathodes.

When absorption of water exceeds, transpiration a positive pressure is developed which forces water into air cavity and then out through hydathodes.