Introduction to crop physiology

(Importance in agriculture)

Introduction

- Plant physiology is the study of vital phenomena in plants.
- It is the science concerned with processes and functions, the response of plants to changes in the environment, and the growth and development that result from the response.
- Process means a natural continuing sequence of events.
- Examples of processes that occur in living plants are photosynthesis, respiration, ion absorption, translocation, stomatal opening and closing, assimilation, transpiration, flowering, and seed formation.
- To describe and explain the plant processes is one of the task of plant physiology.
- Function refers to the natural activity of a thing, whether a cell, tissue, organ, chemical substance.
- A second task of plant physiology is to describe and explain the function of each kind of organ, tissue, cell and cellular organelle in plants and also the function of each chemical constituent, whether ion, molecule, or macromolecule.
- The third task of plant physiology is to explain how processes and functions respond to change in environment e.g. temperature and light (external factors).
- The overall goal of plant physiology is to evolve a detailed and comprehensive knowledge of all the natural phenomenon that occur in living plants and thus to understand the nature of plant growth, development, and movement.

Role of plant physiology in agriculture

- Knowledge of plant physiology is essential to all fields of agronomy, floriculture, forestry, horticulture, plant breeding, plant pathology etc.

Practical aspects in agriculture-

- Increasing the efficiency of photosynthetic conversion
- Breeding for genetic changes in plants with goal of increased display of leaves to create better light capturing systems

- Improved biological nitrogen fixation to reduce dependency of chemical fertilizers
- Means of reducing environmental stresses
- Increase in crop yields by application of growth regulators (when and how)
- Increasing efficiency of nutrient uptake in soil by obtaining superior Mineral nutrition
- Detection of deficiency and toxicity of mineral elements.
- Several diseases in plants have been corrected by using mineral elements.
- E.g. Application of zinc controls khaira disease in rice. Photoperiodism & Vernalization
- Growing of certain plants and make them flower in off seasons by suitable alteration of photoperiod and providing low temperature treatment.

Production physiology

- Production (photosynthesis)
- Storage (Sink potential)
- Control of distribution in plants

Photosynthesis

- C4 plants more efficient than C3

Growth regulators

- Growth promoters and growth retardants.
- Auxin, gibberellin, cytokinin, ABA, Ethylene
- Others like CCC, cycocel, Maleic hydrazide (MH)

Physiological breeding

- E.g. responsiveness of varieties to application of nitrogen.

Study of water relations in plant

- Helpful to decide the irrigation schedule.

Seed dormancy

- Several plants are known to require a definite period of dormancy before they can be made to germinate e.g. apple, peach, potato etc.
- They require winter or prechilling treatment for germination.
- GA treatment can help in germination and breaking dormancy.

Inhibition of sprouting

- Potato tubers and onion bulbs cannot be stored at ordinary temperatures as these sprout and deteriorate in quality.
- Can be prevented by methyl ester of NAA and Maleic hydrazide treatment. Promotion of flowering
- Ethephon has been reported to increase the female flowers.
- NAA used for flowering pineapple.

Abscission

- Auxins have been found effective in prevention of premature fruit drop.
- NAA application can prevent premature fall of cotton balls.

Weed control

- Auxins-
- 2,4 D- 2,4 dichlorophenoxy acetic acid
- 2,4,5 T- 2,4,5 trichlorophenoxy acetic acid
- 2,4 D is selective weed killer. Toxic to broad leaved plants or dicots while non-toxic to monocots or narrow leaved plants.

Tissue culture

- In vitro growth of plants under aseptic conditions.
- It is a valuable technique in crop improvement program.
- Micropropogation in case of orchids, bananas etc.
- Production of disease free plants.
- Production of haploids and their use in breeding.
- Somaclonal variations

Reference-

Introductory plant physiology by Noggle and Fritz
Plant physiology by Pandey and Sinha.

Plant Cell: An overview

THE FUNDAMENTAL UNITS OF LIFE

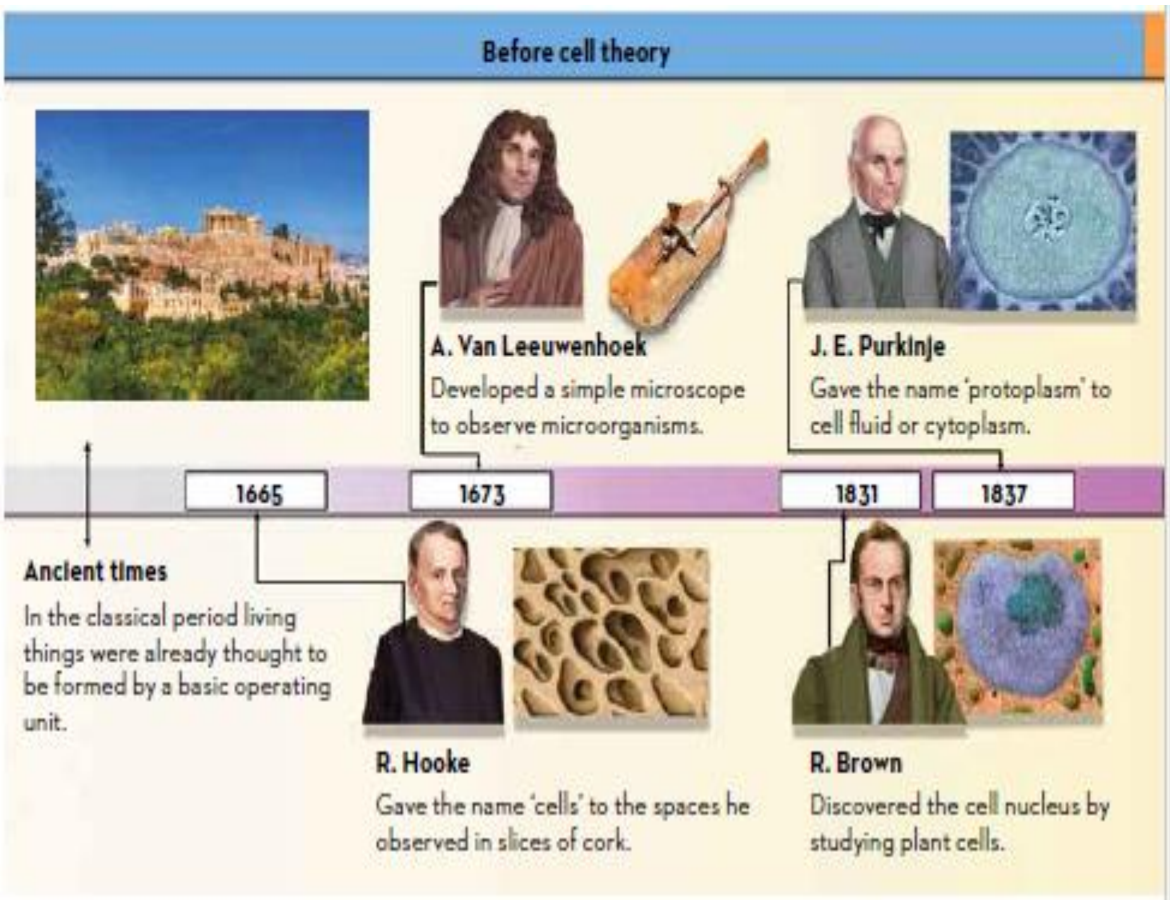
- More than 300 years ago, an English scientist named Robert Hooke built a microscope.
- He used the microscope to look at cork, which is part of a cork oak tree's bark.
- What he saw looked like the openings in a honeycomb.
- The openings reminded him of the small rooms, called cells, where monks lived.
- He called the structures cells, from the Latin word *cellula*, which means "small rooms."

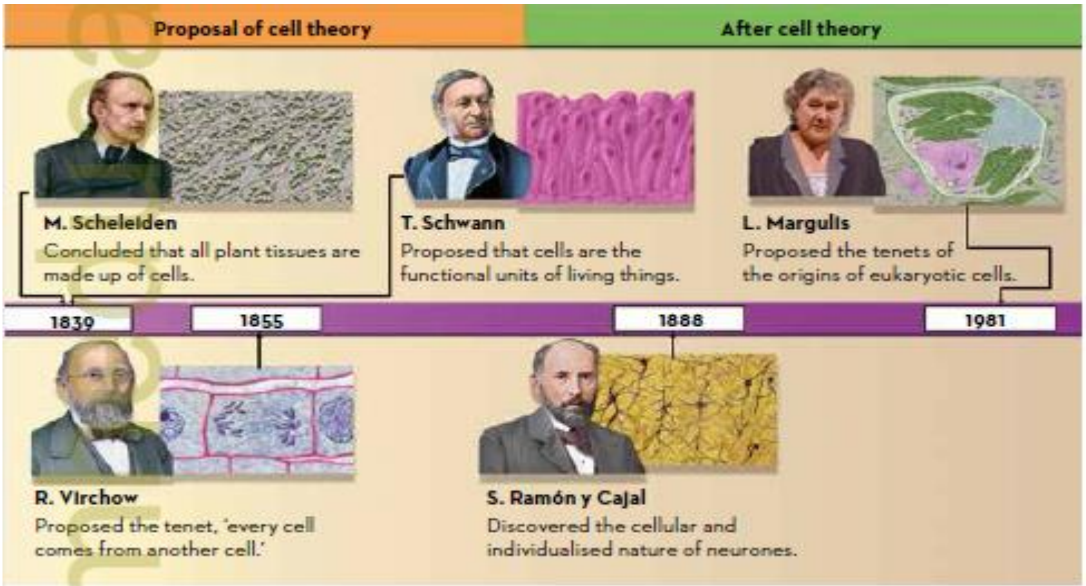
To Robert Hook cells of cork looked like openings of honeycomb

The Cell Theory

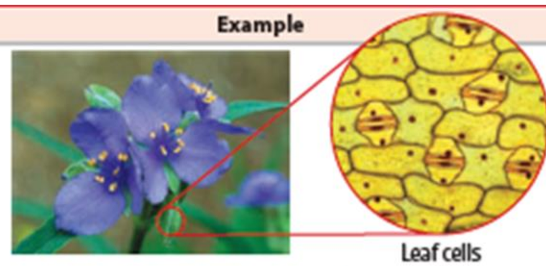
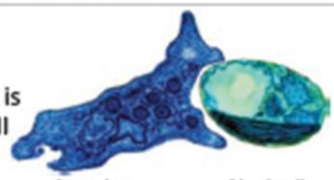
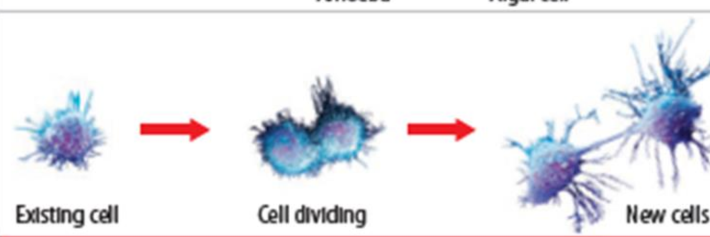
Cell theory is the set of tenets proposed throughout the 19th century by M. Schleiden, T. Schwann and, some years later, R. Virchow.

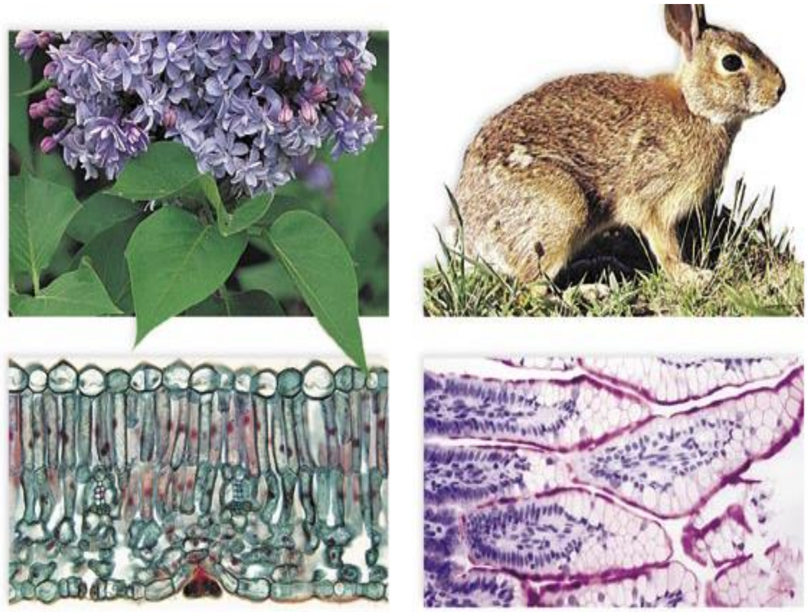
- Cells are the **structural units** of living things, i.e. all living things are made up of cells.
- Cells are the **functional units** of living things, i.e. they perform the three vital functions: nutrition, interaction and reproduction.
- Cells are the **unit of origin** of living things, i.e. every cell comes from another cell.
- Cells are the **hereditary unit**, i.e. cells pass their characteristics to their offspring.





THE CELL THEORY

Principle	Example
All living things are made of one or more cells.	
The cell is the smallest unit of life.	This unicellular amoeba is surrounding an algal cell to get food and energy. 
All new cells come from preexisting cells.	



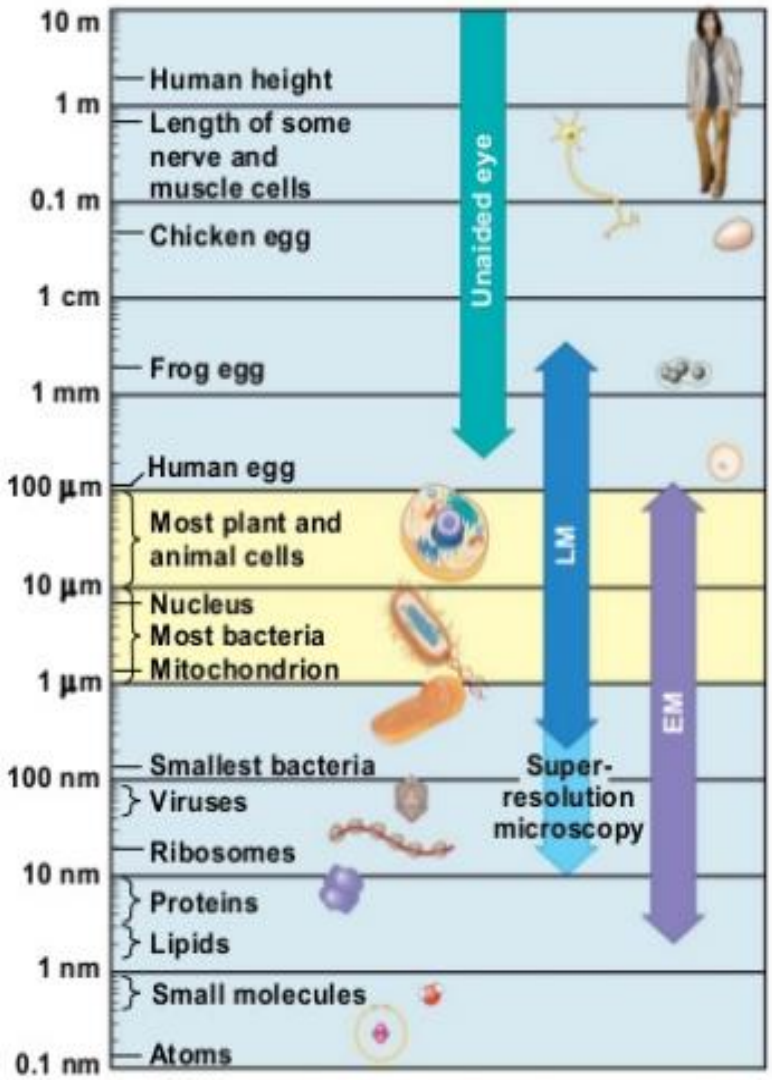
All organisms, including plants and animals, are composed of cells. This is not readily apparent because microscope is usually needed to see the cells.

a. Lilac plant.
b. Light micrograph of a cross section of a lilac leaf showing many individual cells.
c. Rabbit.
d. Light micrograph of a rabbit's intestinal lining showing that it, too, is composed of cells. The dark-staining bodies are nuclei.

Cell size

- Cells are quite small. A frog's egg, at about 1 millimeter (mm) in diameter, is large enough to be seen by the human eye. But most cells are far smaller than 1 mm; some are even as small as 1 micrometer (µm)—one thousandth of a millimeter.

- Cell inclusions and macromolecules are smaller than a micrometer and are measured in terms of nanometers (nm).



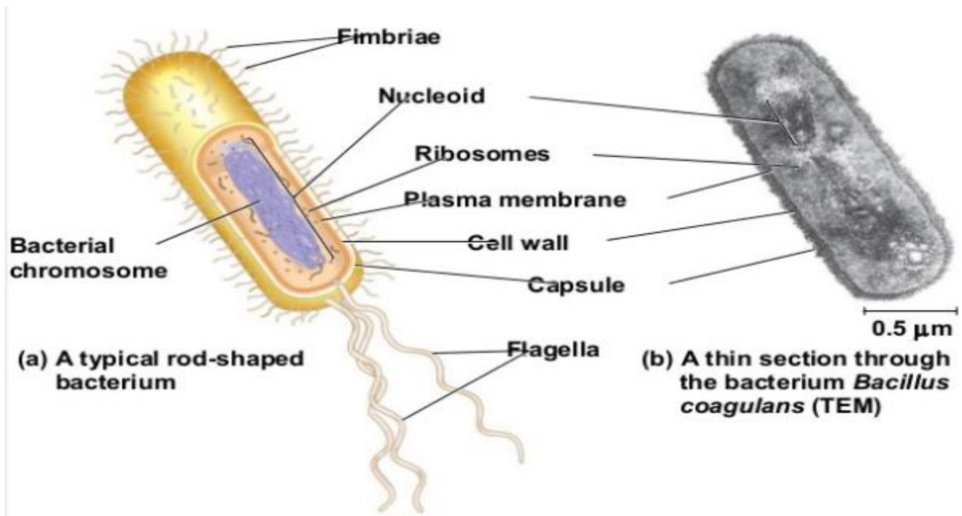
Basic features of all cells

- Plasma membrane
- Semifluid substance called cytosol
- Chromosomes (carry genes)
- Ribosomes (make proteins)
- The basic structural and functional unit of every organism is one of two types of cells: prokaryotic or eukaryotic
- Organisms of domains Bacteria and Archaea consists of prokaryotic cells
- Protists, fungi, animals and plants all consist of eukaryotic cells

Prokaryotic cells are characterized by having

- No nucleus
- DNA in an unbound region called nucleoid
- No membrane bound organelles
- Cytoplasm bound by plasma membrane

A prokaryotic cell



Lacking a true nucleus and the other membrane-enclosed organelles of the eukaryotic cell, the prokaryotic cell appears much simpler in internal structure. Prokaryotes include bacteria and archaea.

Eukaryotic cells are characterized by having

- DNA in nucleus that is bound by membranous nuclear envelope
- Membrane-bound organelles
- Cytoplasm in the region between the plasma membrane and the nucleus
- Eukaryotic cells are generally much larger than the prokaryotic cells.

Characteristic	Prokaryotic cell	Eukaryotic cell
Size	Generally small (1–10 μm)	Generally large (5–100 μm)
Genome	DNA with nonhistone protein; genome in nucleoid, not surrounded by membrane	DNA complexed with histone and nonhistone proteins in chromosomes; chromosomes in nucleus with membranous envelope
Cell division	Fission or budding; no mitosis	Mitosis, including mitotic spindle; centrioles in many species
Membrane-bounded organelles	Absent	Mitochondria, chloroplasts (in plants, some algae), endoplasmic reticulum, Golgi complexes, lysosomes (in animals), etc.
Nutrition	Absorption; some photosynthesis	Absorption, ingestion; photosynthesis in some species
Energy metabolism	No mitochondria; oxidative enzymes bound to plasma membrane; great variation in metabolic pattern	Oxidative enzymes packaged in mitochondria; more unified pattern of oxidative metabolism
Cytoskeleton	None	Complex, with microtubules, intermediate filaments, actin filaments
Intracellular movement	None	Cytoplasmic streaming, endocytosis, phagocytosis, mitosis, vesicle transport

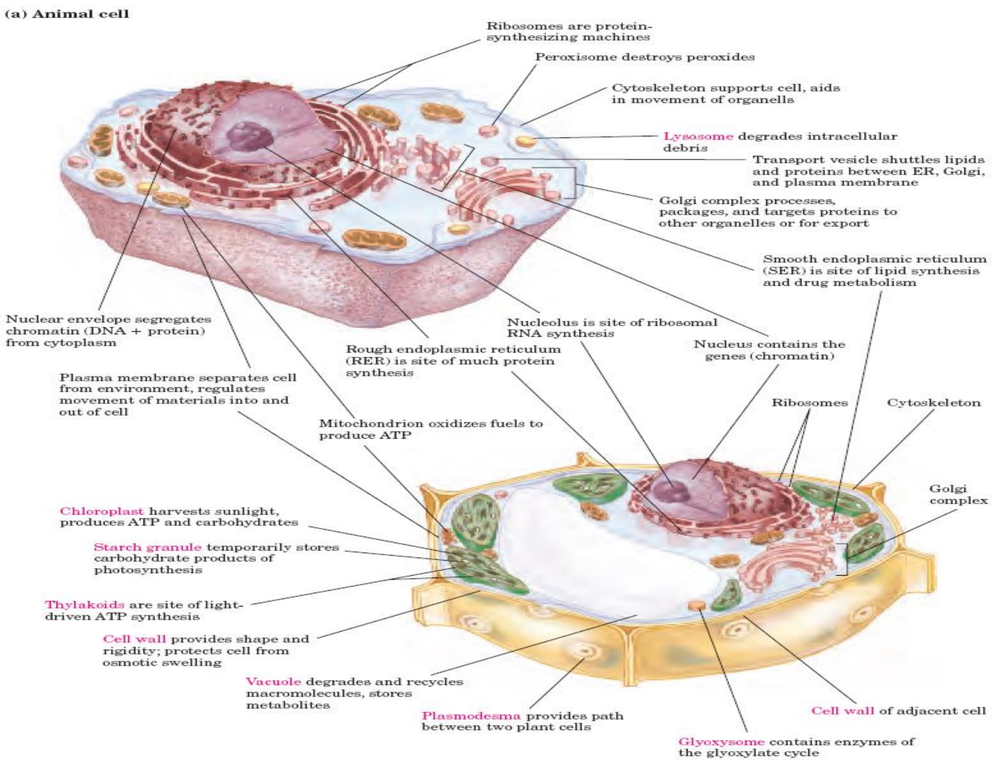
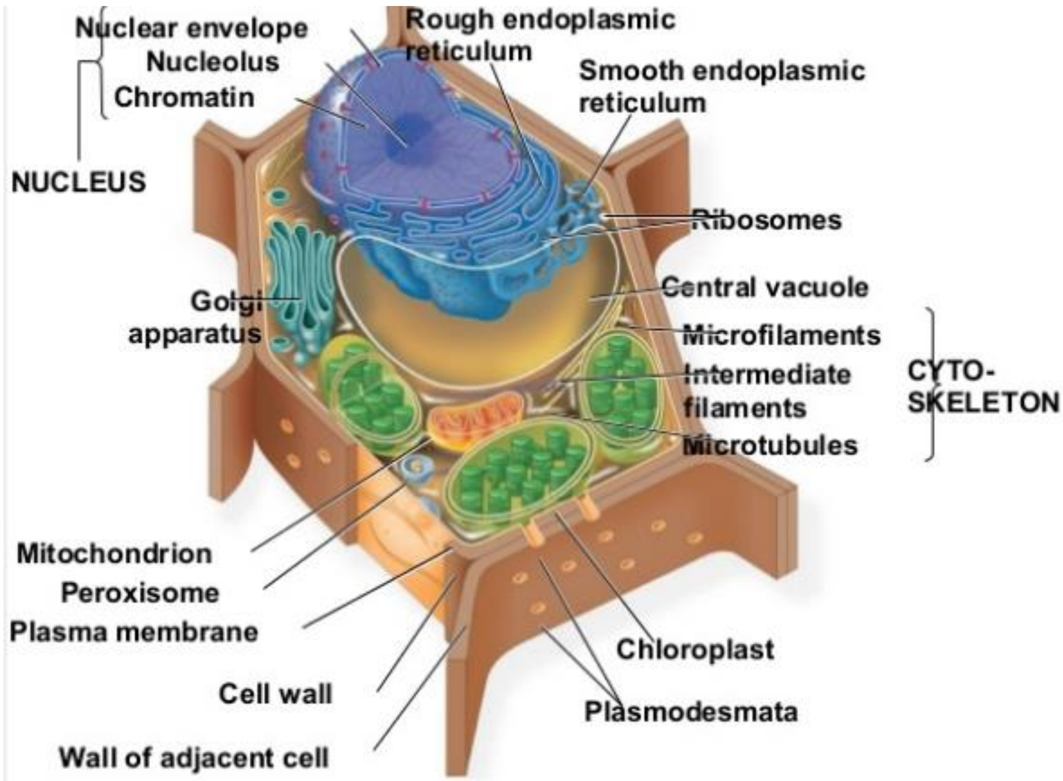
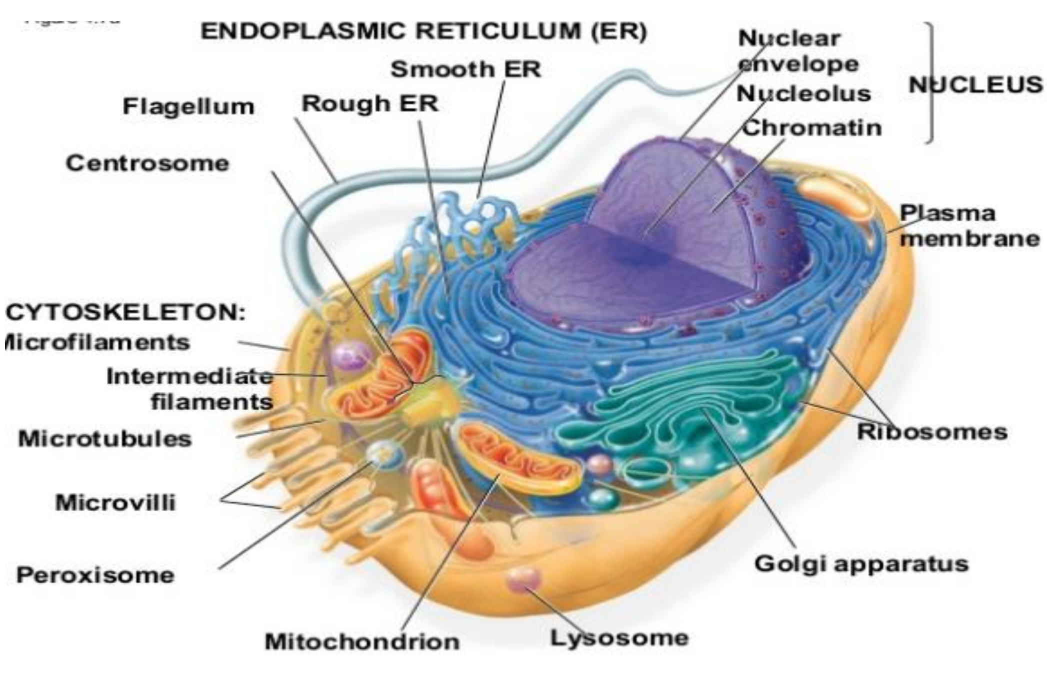


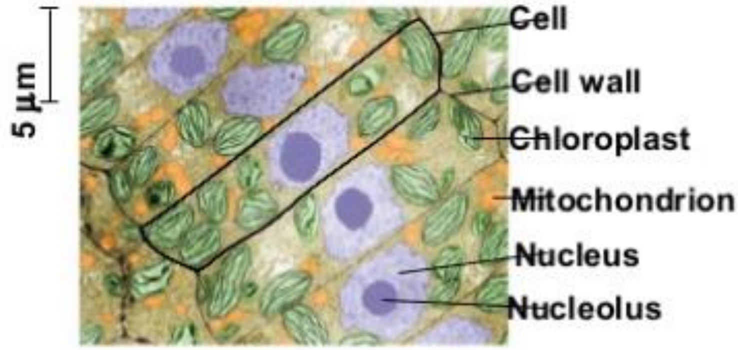
FIGURE 1–7 Eukaryotic cell structure. Schematic illustrations of the two major types of eukaryotic cell: (a) a representative animal cell and (b) a representative plant cell. Plant cells are usually 10 to 100 μm in diameter—larger than animal cells, which typically range from 5 to 30 μm. Structures labeled in red are unique to either animal or plant cells.

Plant cell

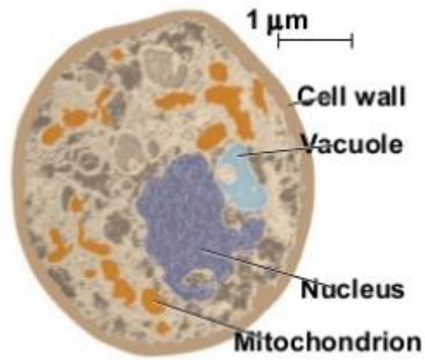


Animal cell

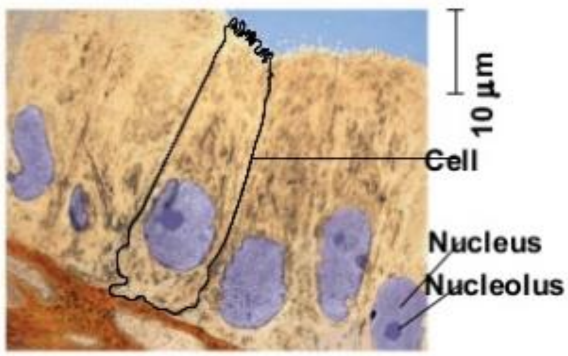




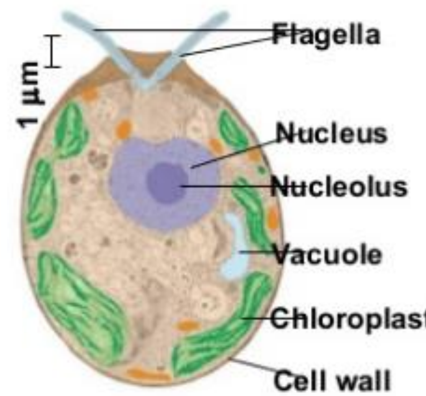
Cells from duckweed (colorized TEM)



A single yeast cell (colorized TEM)



Human cells from lining of uterus (colorized TEM)



Chlamydomonas (colorized TEM)

	Animal Cell	Plant Cell
Shape:	Round	Rectangular
Glyoxysomes:	No	Some plant cells have glyoxysomes.
Ribosomes:	Present	Present
Centrioles:	Always present	Only present in lower plant forms.
Lysosomes:	Lysosomes occur in cytoplasm.	Lysosomes usually not evident.
Plasma Membrane:	Yes; only cell membrane	Yes; cell wall and a cell membrane
Mitochondria:	present	present
Cell wall:	None	Yes

	Animal Cell	Plant Cell
Nucleus:	Present	Present
Chloroplast:	Animal cells don't have chloroplasts	Plant cells have chloroplasts because they make their own food
Flagella:	May be found in some cells	May be found in some cells
Plastids:	No	Yes
Vacuole:	One or more small vacuoles (much smaller than plant cells).	One, large central vacuole taking up 90% of cell volume.

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Plant cell may be defined as ‘ as an organized uninucleate mass of protoplasm, bounded by cell wall, existing singly or in groups and containing structures of various sorts.

A typical plant cell consists of:

A. Cell wall

B. Cytoplasm

C. Nucleus

Cytoplasm and the nucleus together are known as protoplasm.

The membrane and the protoplasm are collectively referred to as protoplast.

Cell wall

- A cell wall is a tough, flexible and sometimes fairly rigid layer.
- It is located outside the cell membrane and provides these cells with structural support and protection.
- A major function of the cell wall is to act as a pressure vessel, preventing over-expansion when water enters the cell.

- They are found in plants, bacteria, fungi, algae, and some archaea.
- Animals and protozoa do not have cell walls.

➢ The composition in a cell wall vary between species, and in plants and fungi also differ between cell types and developmental stages.

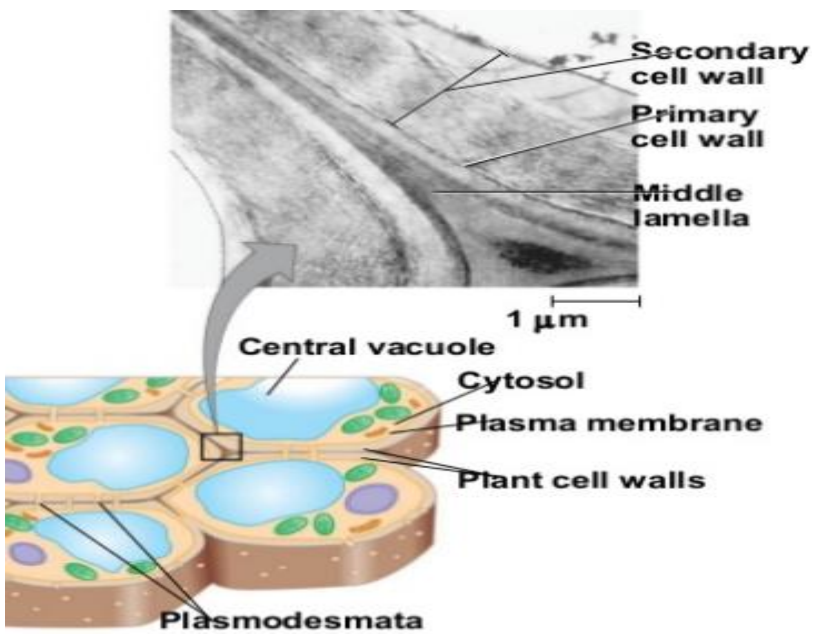
➢ In plants, cell wall is made up of cellulose, which is a polymer of glucose.

➢ In bacteria, peptidoglycan forms the cell wall.

➢ Archaean cell walls have various compositions, and may be formed of glycoprotein, pseudopeptidoglycan, or polysaccharides.

➢ Fungi possess cell walls made of the glucosamine polymer chitin, and algae typically possess walls made of glycoproteins and polysaccharides.

➢ Unusually, diatoms have a cell wall composed of silicic acid.

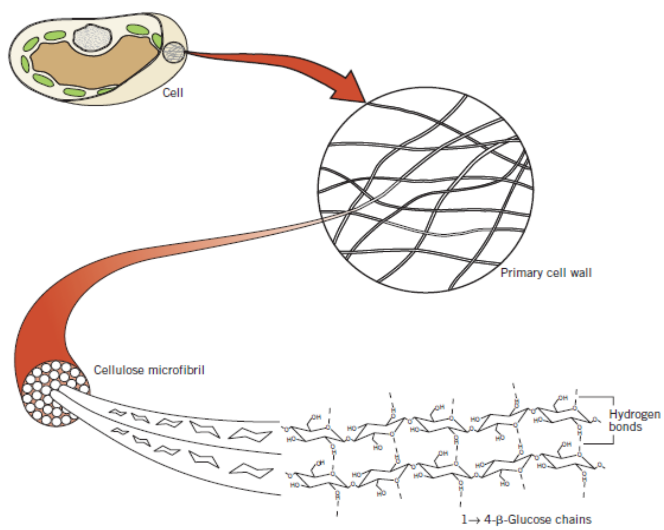


Plant cell walls have multiple layers-

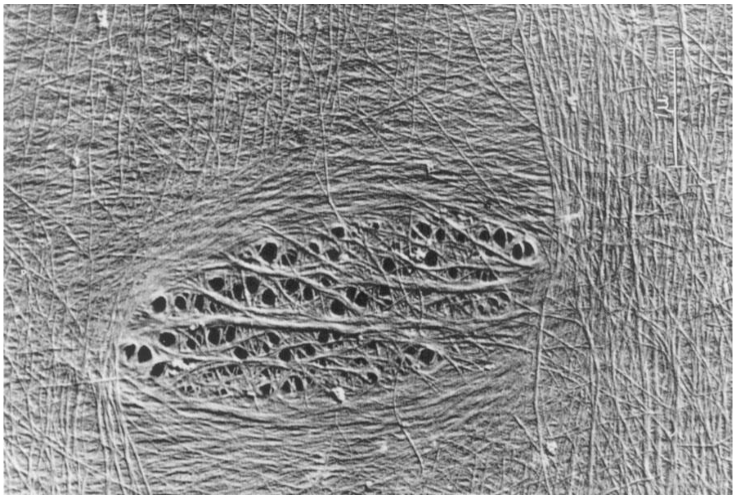
- Primary cell wall- relatively thin and flexible. Surround the young and actively growing cells.
- Middle lamella- thin layer between primary walls of the adjacent cells
- Secondary cell wall (in some cells)- added between the plasma membrane and the primary cell wall. They are laid down as the cells mature and are no longer growing.
- Plasmodesmata are channels between adjacent plant cells.

Primary cell wall

- The primary wall is very thin, measuring only a few micrometers in thickness. Its principal constituent is long, threadlike chains of *β−1→4−linked glucose* units, called cellulose.
- The individual cellulose molecules are bundled in long, parallel arrays called microfibrils.
- Each microfibril is approximately 5 to 12 nm in diameter and contains, in higher plants, approximately 36 individual cellulose chains in cross-section.
- A single cellulose chain may contain as many as 3,000 or more glucose units but, because the chains begin and end at different places within the microfibril, an individual microfibril may contain several thousand cellulose chains and reach lengths of several hundred micrometers.

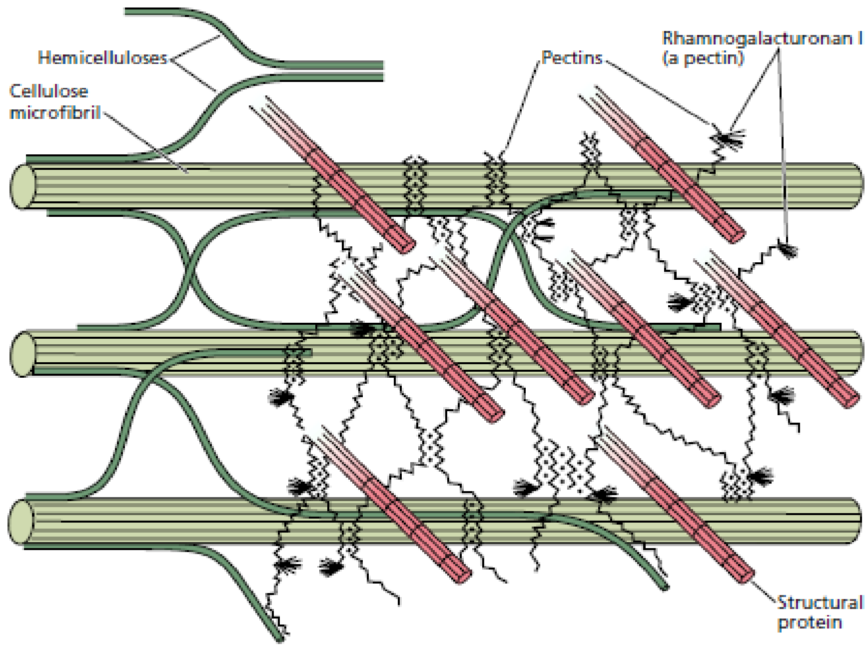


The principal structural components of cell walls are cellulose microfibrils constructed of (1→4)-linked β-glucose chains. Adjacent cellulose chains within the microfibril are joined by intermolecular hydrogen bonds**.**



The primary cell wall. An electron micrograph of the primary wall of a parenchyma cell from the coleoptile of an oat (*Avena) seedling. Note the pores* through which plasmodesmata pass.

- Adjacent cellulose chains within a microfibril are held together by hydrogen bonds between hydroxyl (—OH) groups on adjacent glucose units.
- This bonding arrangement makes a microfibril very strong. In fact, the tensile strength of a microfibril, or its ability to withstand tension without breaking, is similar to that of a steel wire of the same size
- The cellulose microfibrils within the primary wall are held in position by cross-linking glycans (hemicellulose).
- Cross-linking glycans are noncellulosic polysaccharides that bind to the cellulose microfibrils, but are also long enough to bridge the distance between neighboring microfibrils and link them into a semi-rigid network.
- As much as 35 percent of the primary wall consists of pectins, or pectic substances. Pectin is a complex, heterogeneous mixture of noncellulosic polysaccharides especially rich in galacturonic acid.
- Primary cell walls also contain approximately 10 percent glycoprotein which have an unusually high content of the amino acid hydroxyproline.
- The outer part of the primary cell wall of the plant epidermis is usually impregnated with cutin and wax, forming a permeability barrier known as the plant cuticle.



Schematic diagram of the major structural components of the primary cell wall and their likely arrangement

Some of the functions of the primary wall:

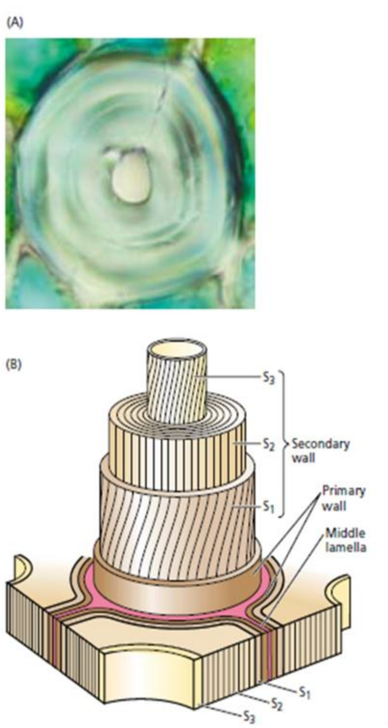
- Structural and mechanical support.
- maintain and determine cell shape.
- resist internal turgor pressure of cell.
- control rate and direction of growth.
- ultimately responsible for plant architecture and form.
- regulate diffusion of material through the apoplast.
- carbohydrate storage - walls of seeds may be metabolized.
- protect against pathogens, dehydration, and other environmental factors.
- source of biologically active signalling molecules.
- cell-cell interactions.
- Primary walls originate *de novo* during the final stages of cell division, when the newly formed cell plate separates the two daughter cells and solidifies into a stable wall that is capable of bearing a physical load from turgor pressure**.**

Middle lamella

- Pectins are also the principal constituent of the middle lamella.
- The middle lamella lies between the primary walls of adjacent cells. It is the ‘‘cement’’ that holds the cells together.
- The softening of fruit as it ripens, for example, is due in part to the action of the enzyme polygalacturonase, which degrades the pectic substances in the middle lamella and loosens of the bonds between the cells.

Secondary walls

- After wall expansion ceases, cells sometimes continue to synthesize a wall, known as a secondary wall.
- Secondary walls are often quite thick, as in tracheids, fibers, and other cells that serve in mechanical support in plant.
- Often such secondary walls are multilayered and differ in structure and composition from the primary wall. For example, the secondary walls in wood contain xylans rather than xyloglucans, as well as a higher proportion of cellulose.
- Secondary walls are often (but not always) impregnated with lignin.



(A) Cross section of a *Podocarpus* sclereid*, in* which multiple layers in the secondary wall are visible.
(B) Diagram of the cell wall organization often found in tracheids and other cells with thick secondary walls. Three distinct layers (S1, S2, S3) are formed interior to the primary wall.

- As lignin forms in the wall, it displaces water from the matrix and forms a hydrophobic network that bonds tightly to cellulose and prevents wall enlargement.
- Lignin adds significant mechanical strength to cell walls and reduces the susceptibility of walls to attack by pathogens.

Properties

- The wall gives cells rigidity and strength, offering protection against mechanical stress.
- In multicellular organisms, it permits the organism to build and hold its shape (morphogenesis).
- The cell wall also limits the entry of large molecules that may be toxic to the cell.
- It further permits the creation of a stable osmotic environment by preventing osmotic lysis and helping to retain water.
- The composition, properties, and form of the cell wall may change during the cell cycle and depend on growth conditions.

<u>Plasma membrane</u>

(Structure and function)

- All cells are surrounded by a plasma membrane. Eukaryotic cells also contain internal membranes and membrane bound organelles
- The plasma membrane is the boundary that separates the living cell from its surroundings
- The plasma membrane exhibits **selective permeability,** allowing some substances to cross it more easily than others
- Various transport proteins embedded in the plasma membrane are responsible for this selective traffic of solutes- water-soluble ions and small uncharged molecules across the membrane.
- The accumulation of ions or molecules in the cytosol through the action of transport proteins consumes metabolic energy.
- The **fluid mosaic model** states that a membrane is a fluid structure with a "mosaic" of various proteins embedded in it.

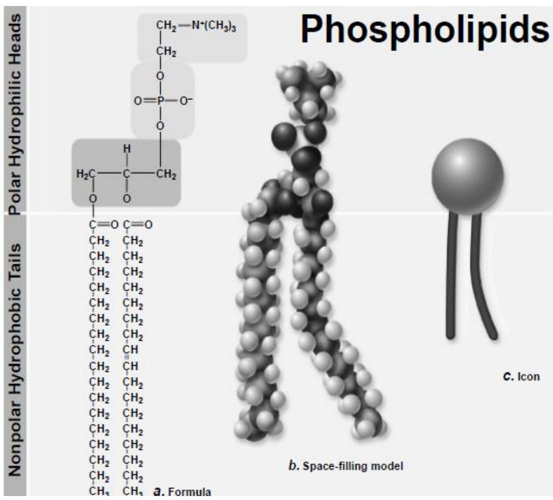
Singer and Nicolson (1972)

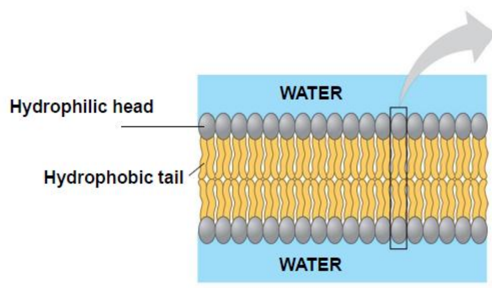
- According to the **fluid mosaic model**, all the biological membranes have the same basic molecular organization.
- They consist of a double layer (bilayer) of lipid in which the proteins are embedded.
- Each layer is called a *leaflet* of the bilayer.
- In most membranes, proteins make up about half of the membrane's mass.
- However, the composition of the lipid components and the properties of the proteins vary from membrane to membrane, conferring each membrane its unique functional characteristics.

LIPIDS

- The most prominent membrane lipids found in plants are <u>phospholipids</u>, a class of lipids in which two fatty acids are covalently linked to glycerol, which is covalently linked to the phosphate group.
- Attached to the phosphate group in the phospholipid is a variable component called <u>*head group*</u>, such as serine, choline, glycerol or inositol.

- The nonpolar hydrocarbon chains of the fatty acids form a region that is exclusively hydrophobic—that is, that excludes water.
- In contrast to the fatty acids, the head groups are highly polar; consequently, phospholipid molecules display both hydrophilic and hydrophobic properties (i.e., they are *amphipathic*).





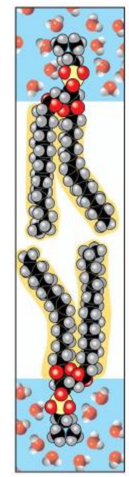
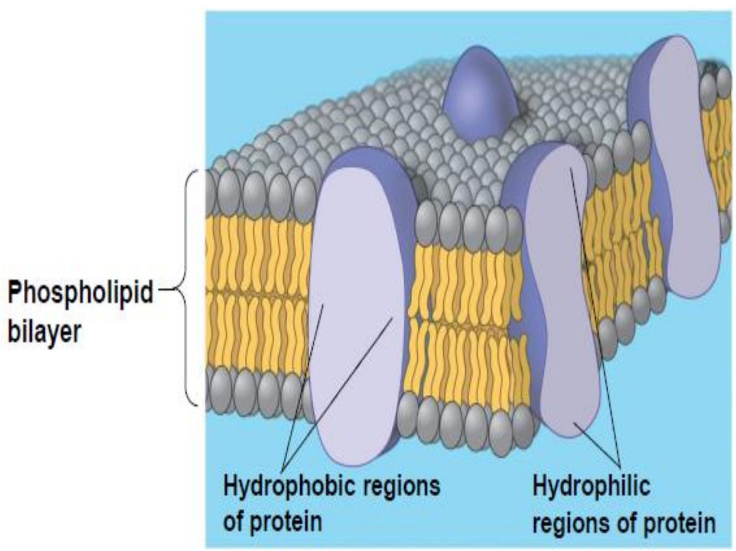


Fig. 7.2 Phospholipid bilayer (cross section)



The fluid mosaic model for membrane

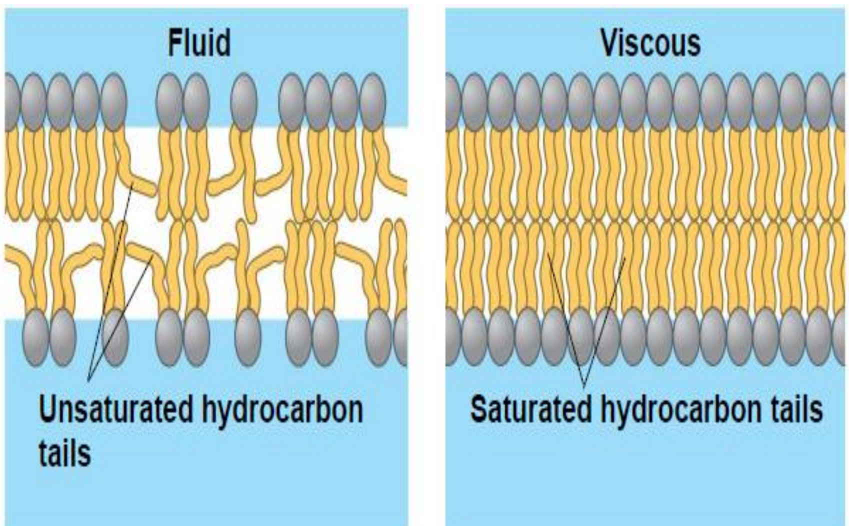
Sterols

- Another component of plant cells is the family of sterols.
- In plants most common is β-sitosterol.

- Sterols contribute to the formation and assembly of membranes and the waxy cuticles on the surface of plants.

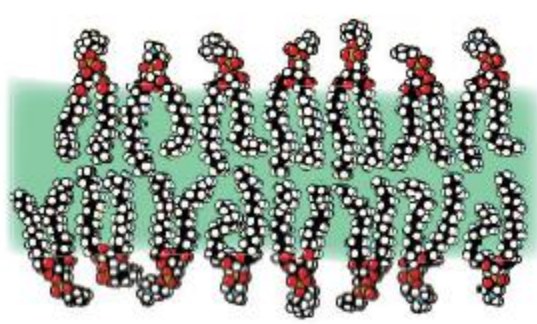
The nature & importance of lipid

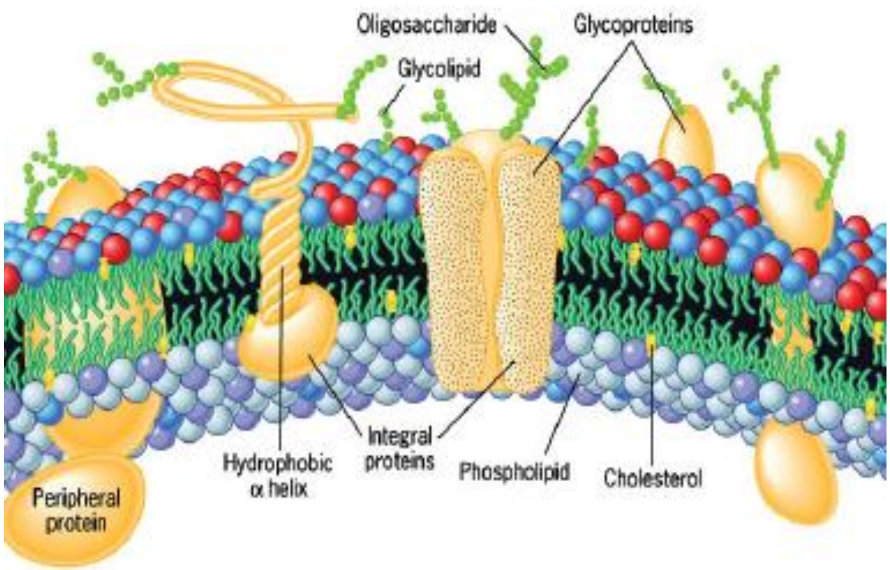
- Fluidity- Determines the physical state of membrane
- Membrane lipids also provide the precursors for highly active chemical messengers that regulate cellular function.
- Various types of measurements indicate that the combined fatty acyl chains of both leaflets of the lipid bilayer span a width of about 30 Å and that each row of head groups (with its adjacent shell of water molecules) adds another 15 Å.
- Thus, the entire lipid bilayer is only about 60 Å (6 nm) thick.



The fluidity of the membrane

- Phospholipids in the plasma membrane can move within the bilayer
- Most of the lipids, and some proteins, drift laterally





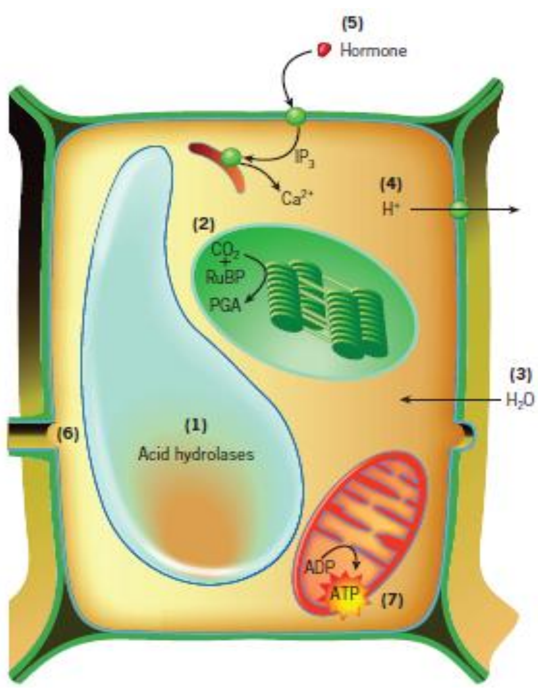
STRUCTURE OF PLASMA MEMBRANE

Proteins

- The proteins associated with the lipid bilayer are of three types: integral, peripheral, and anchored.
- **Integral proteins** are embedded in the lipid bilayer.
- Most integral proteins span the entire width of the phospholipid bilayer, so one part of the protein interacts with the outside of the cell, another part interacts with the hydrophobic core of the membrane, and a third part interacts with the interior of the cell, the cytosol.
- Proteins that serve as ion channels are always integral membrane proteins, as are certain receptors that participate in signal transduction pathways.
- **Peripheral proteins** are bound to the membrane surface by noncovalent bonds, such as ionic bonds or hydrogen bonds.
- Peripheral proteins serve a variety of functions in the cell. For example, some are involved in interactions between the plasma membrane and components of the cytoskeleton, such as microtubules and actin microfilaments.
- **Anchored proteins** are bound to the membrane surface via lipid molecules, to which they are covalently attached.
- These lipids include fatty acids (myristic acid and palmitic acid), prenyl groups derived from the isoprenoid pathway (farnesyl and geranylgeranyl groups), and glycosylphosphatidylinositol (GPI)-anchored proteins.
- Membrane carbohydratesThe plasma membranes of eukaryotic cells also contain carbohydrate.

- Depending on the species and cell type, the carbohydrate content of the plasma membrane ranges between 2 and 10 percent by weight.
- More than 90 percent of the membrane's carbohydrate is covalently linked to proteins to form glycoproteins; the remaining carbohydrate is covalently linked to lipids to form glycolipids.
- Cells recognize each other by binding to surface molecules, often containing carbohydrates, on the extracellular surface of the plasma membrane.

Membrane functions in plant cell



1.compartmentalization.

2. *Scaffold for biochemical activities*

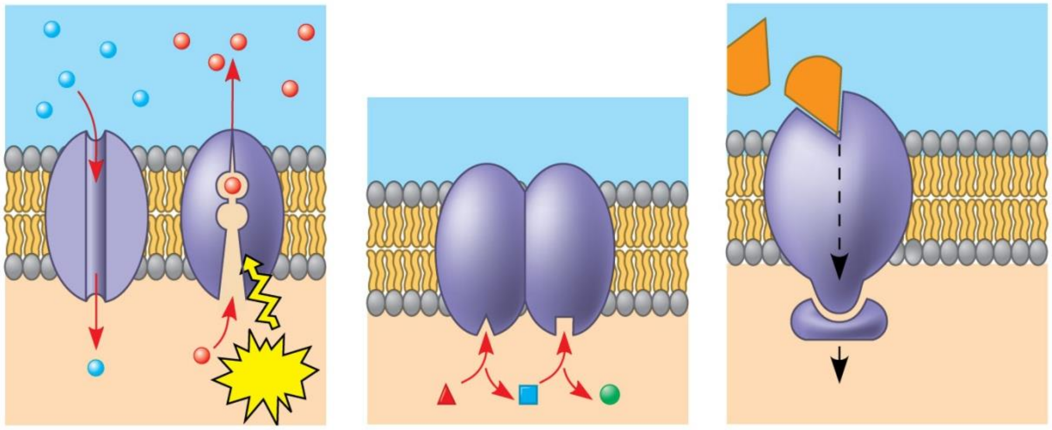
3.*Providing a selectively permeable barrier*

4. *Transporting solutes*

5. *Responding to external stimuli*

6. *Intercellular interaction*

7.***Energytransduction***



DIFFUSION

OSMOSIS

FACILITATED TRANSPORT

ACTIVE TRANSPORT

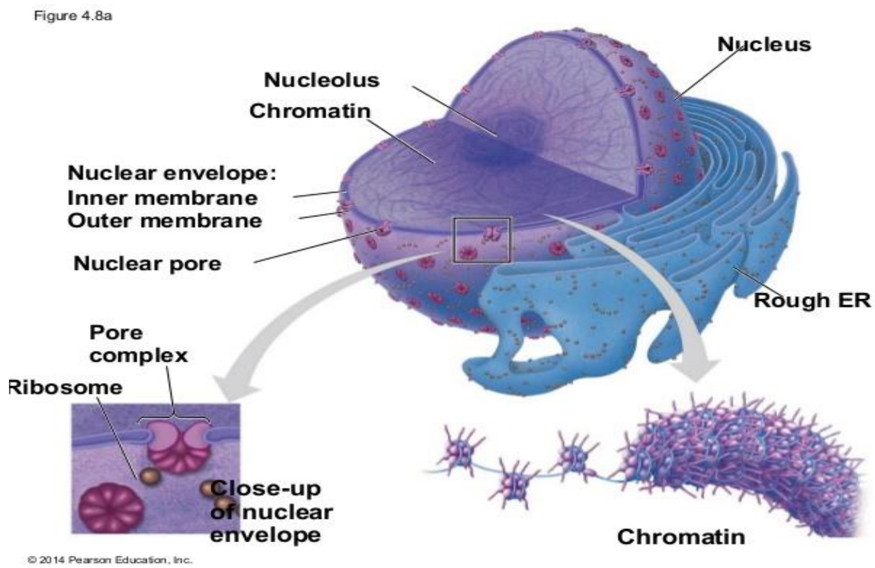
<u>Organelles</u>

Structure and function

The eukaryotic genetic instructions are housed in the nucleus and carried by the ribosomes

- The nucleus contain most of the DNA in the eukaryotic cells.
- Ribosomes use the information from the DNA to make the protein.
- The nucleus contains most of the genes in the eukaryotic cell.
- Its diameter is about 5μm.
- The **nuclear envelope** encloses the nucleus separating its contents from the cytoplasm.
- The nuclear envelope is a double membrane; each membrane consisting of lipid bilayer.
- The envelope is perforated by **pore** structures. They regulate the entry and exit of proteins and RNAs, as well as large complexes of macromolecules.

The nucleus and its envelope

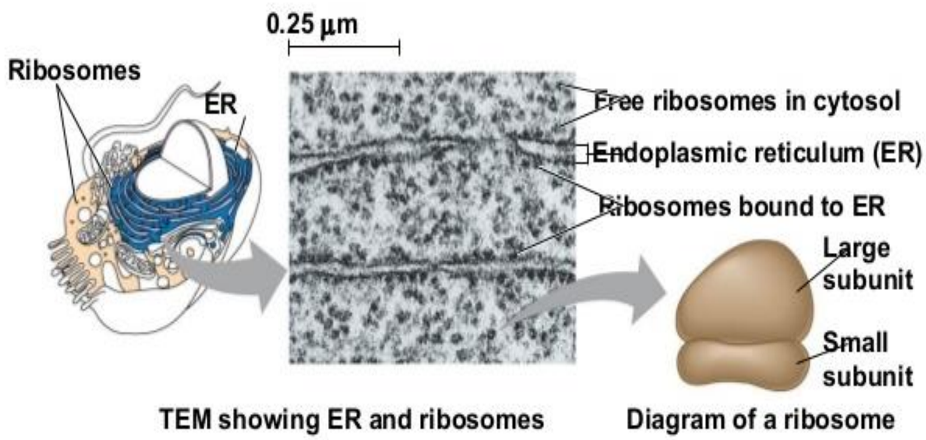


- Within the nucleus, the DNA is organized into discrete units called **chromosomes**, structures that carry the genetic information.

- Each chromosome contains one long DNA molecule associated with many proteins.
- The DNA and proteins making up chromosomes is called **chromatin**.
- Chromatin condenses to dense chromosomes as the cells prepare to divide.
- The **nucleolus** located within the nucleus is the site of rRNA synthesis.

Ribosomes: Protein factories

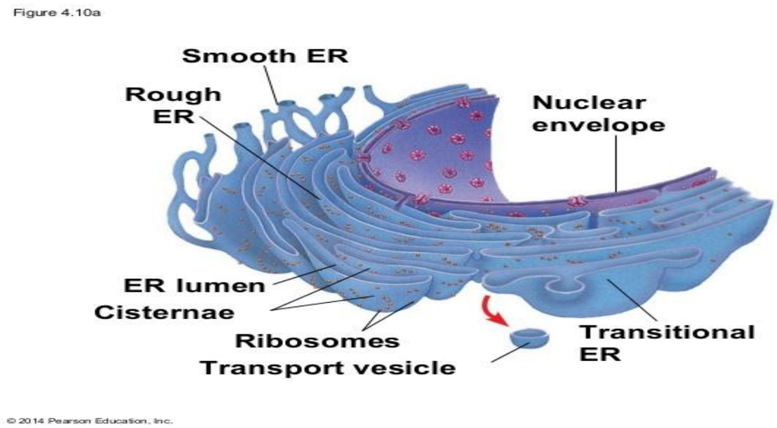
- Ribosomes are the complexes made up of ribosomal RNA and protein.
- They carry out the protein synthesis in two locations- in the cytoplasm (free ribosomes) on the outside of the endoplasmic reticulum or nuclear envelope(bound ribosomes)

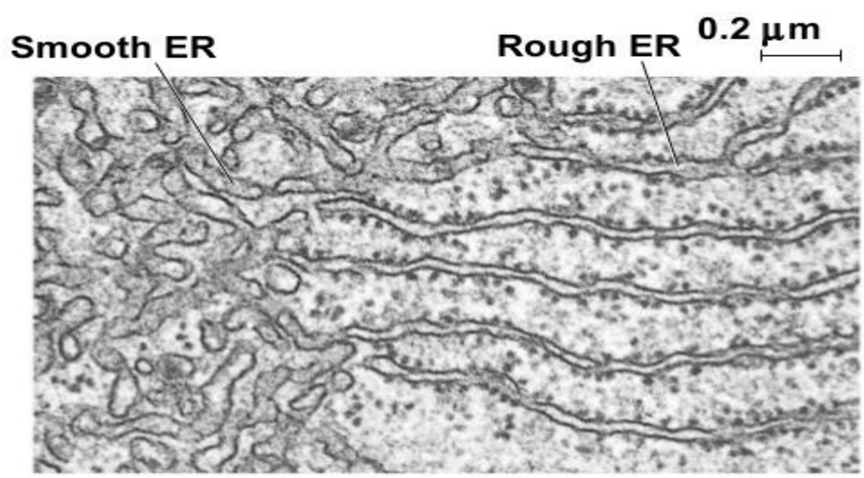


Endoplasmic reticulum: Biosynthetic factory

- *Endoplasmic* means "within the cytoplasm"
- *Reticulum* means "little net"
- It accounts for more than half the total membrane in many eukaryotes.
- ER consists of network of membranous tubules and sacs called cisternae (cisternae means reservoir for a liquid).
- The ER membrane separates the internal component of the ER, called the ER lumen (cavity) or cisternal space from the cytosol.
- The ER membrane is continuous with the nuclear envelope.
- Divided into two distinct types based on structure and function-

- **Smooth ER**- outer surface lacks ribosomes
- **Rough ER**- contains ribosomes on the outer surface of the membrane.





Functions of SER

- Synthesis of lipids
- Metabolism of carbohydrates
- Detoxification of drugs and poisons
- Storage of calcium ions

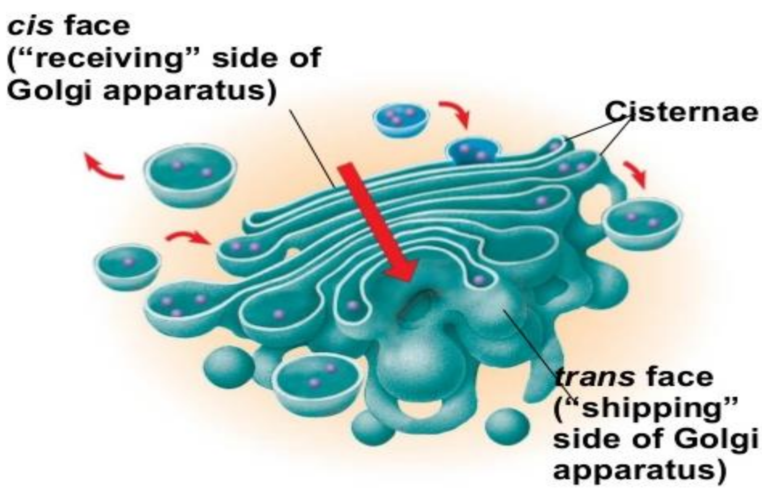
Functions of RER

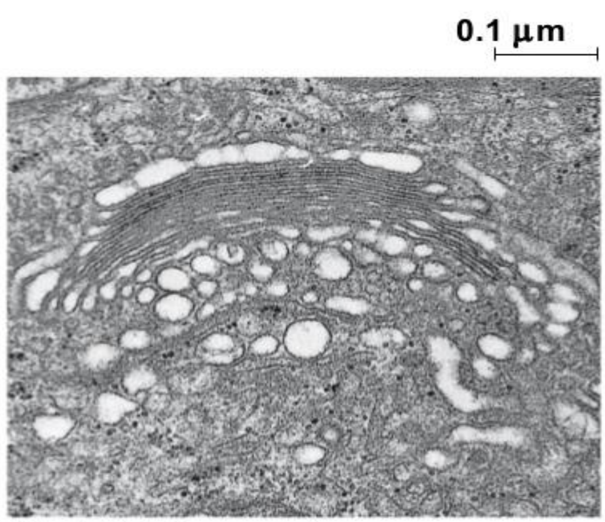
- Has bound ribosomes secrete **glycoproteins**
- Distributes **transport vesicles**

- Is a membrane factory for the cell

Golgi Apparatus: Shipping and Receiving centre

- Golgi apparatus is like a warehouse for receiving, sorting, shipping and even manufacturing.
- It consists of flattened membranous sacs- cisternae.
- A cell may have 100s of these sacs.
- A Golgi stack has structural directionality-
- *Cis* face means on the same side i.e. located near the E.R.
- *Trans* face means on the opposite side





TEM of Golgi apparatus

Functions of golgi apparatus

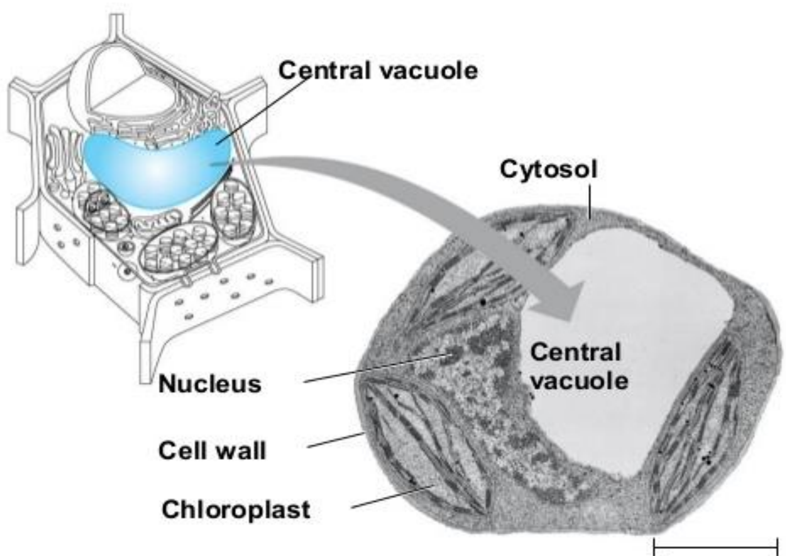
- Modifies products of ER
- Manufactures certain macromolecules
- Sorts and packages materials into transport vesicles

Lysosomes

- Lysosomes are membrane bound vesicles that contain hydrolytic enzymes.
- The hydrolytic enzymes degrade proteins, nucleic acids, lipids and carbohydrates and are formed in the endoplasmic reticulum.

Vacuole

- Derived from ER and golgi apparatus.
- Mature living plant cells contain large, water-filled central vacuoles that can occupy 80 to 90% of the total volume of the cell.
- Each vacuole is surrounded by a **vacuolar membrane, or tonoplast.**
- The vacuole contains water and dissolved inorganic ions, organic acids, sugars, enzymes, and a variety of secondary metabolites, which often play roles in plant defense.
- The plant vacuoles contain hydrolytic enzymes, including proteases, ribonucleases, and glycosidases. These enzymes are useful to recycle valuable nutrients when the cell undergoes senescence.

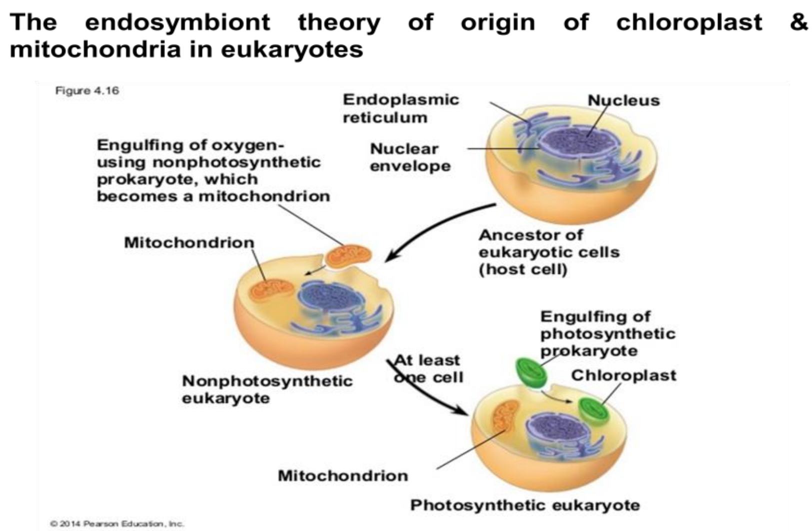


Plant cell vacuole

Energy producing organelles

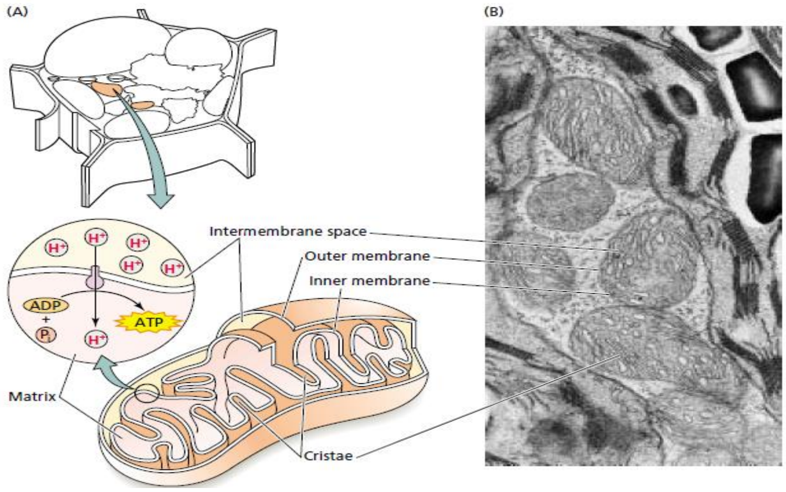
- Mitochondria
- Chloroplast
- Both have double membrane
- They are *semiautonomous* organelles

The endosymbiont theory of origin of chloroplast & mitochondria in eukaryotes



Mitochondria

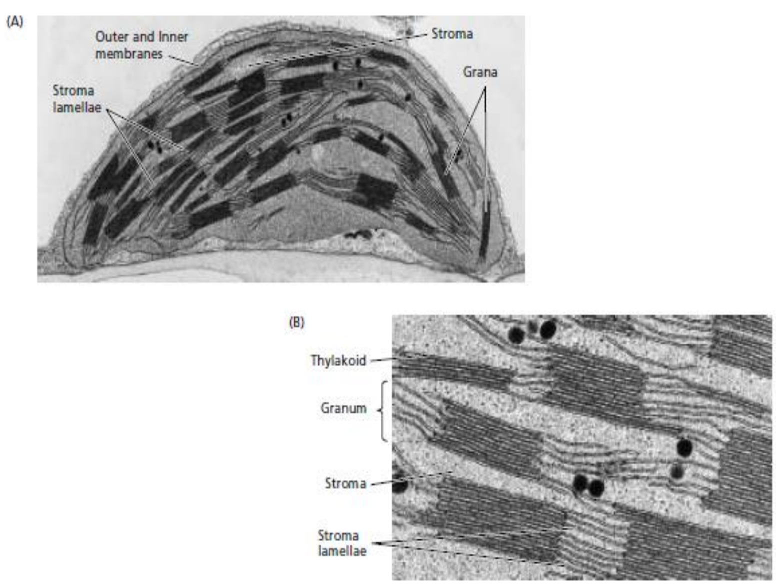
- **Mitochondria (singular** *mitochondrion) are the cellular sites of respiration, a process* in which the energy released from sugar metabolism is used for the synthesis of ATP (adenosine triphosphate) from ADP (adenosine diphosphate) and inorganic phosphate (Pi).
- Mitochondria can vary in shape from spherical to tubular, but they all have a smooth outer membrane and a highly convoluted inner membrane.
- The infoldings of the inner membrane are called cristae (singular crista).
- The compartment enclosed by the inner membrane, the mitochondrial matrix, contains the enzymes of the pathway of intermediary metabolism called the Krebs cycle.

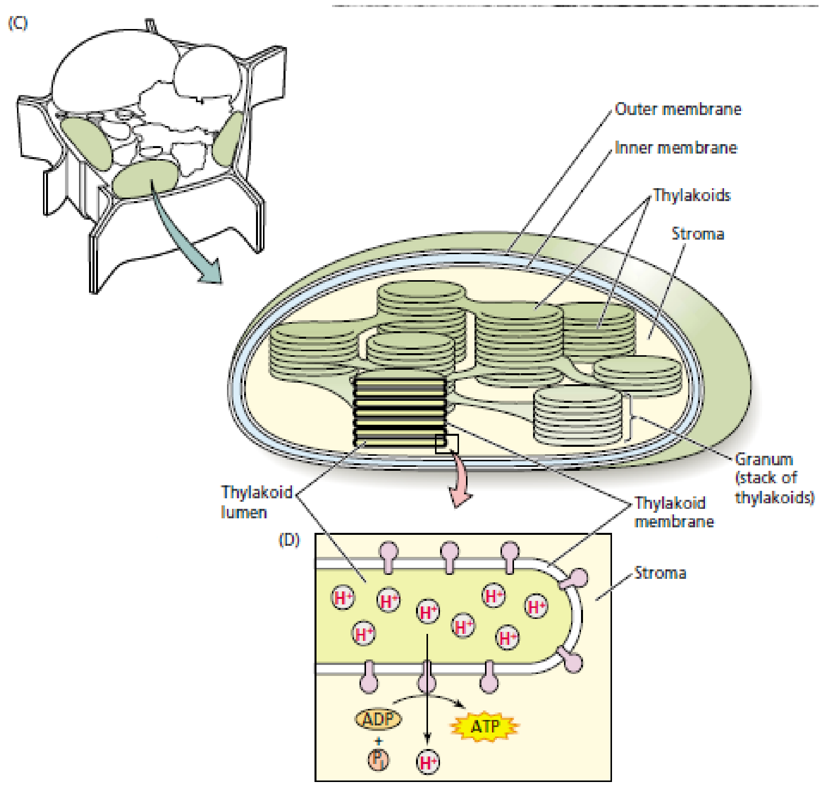


- In contrast to the mitochondrial outer membrane and all other membranes in the cell, the inner membrane of a mitochondrion is almost 70% protein and contains some phospholipids that are unique to the organelle (e.g., cardiolipin).
- The proteins in and on the inner membrane have special enzymatic and transport capacities.

Chloroplasts

- Chloroplasts belong to another group of double membrane–enclosed organelles called **plastids.**
- Chloroplast membranes are rich in glycosylglycerides.
- Chloroplast membranes contain chlorophyll and its associated proteins and are the sites of photosynthesis.
- In addition to their inner and outer envelope membranes, chloroplasts possess a third system of membranes called **thylakoids.**





- A stack of thylakoids forms a **granum** (plural *grana)*.
- *Proteins* and pigments (chlorophylls and carotenoids) that function in the photochemical events of photosynthesis are embedded in the thylakoid membrane.
- The fluid compartment surrounding the thylakoids, called the **stroma,** is analogous to the matrix of the mitochondrion.
- Adjacent grana are connected by unstacked membranes called **stroma lamellae** (singular *lamella).*

Microbodies

- Plant cells also contain **microbodies, a class of spherical** organelles surrounded by a single membrane and specialized for one of several metabolic functions.
- The two main types of microbodies are peroxisomes and glyoxysomes.

Peroxisomes

- **Peroxisomes** are found in all eukaryotic organisms, and in plants they are present in photosynthetic cells.

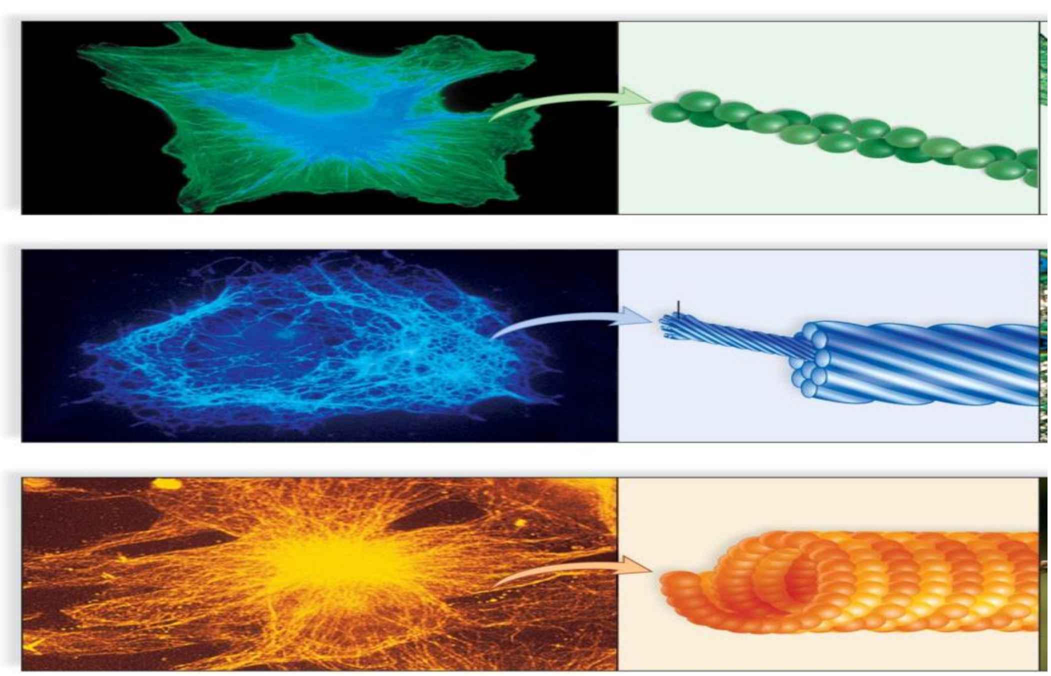
- Peroxisomes function both in the removal of hydrogens from organic substrates, consuming O_2 in the process.

Glyoxysomes

- The **glyoxysome,** is present in oil-storing seeds.
- Glyoxysomes contain the glyoxylate cycle enzymes, *which help convert stored fatty acids into* sugars that can be translocated throughout the young plant to provide energy for growth.

The Cytoskeleton

- The cytosol is organized into a three-dimensional network of filamentous proteins called the **cytoskeleton.**
- This network provides the spatial organization for the organelles and serves as a scaffolding for the movements of organelles and other cytoskeletal components.
- It also plays fundamental roles in mitosis, meiosis, cytokinesis, wall deposition, the maintenance of cell shape, and cell differentiation.
- Three types of cytoskeletal elements have been demonstrated in plant cells: **microtubules**, **microfilaments**, and **intermediate filament–like structures**.
- Each type is filamentous, having a fixed diameter and a variable length, up to many micrometers.



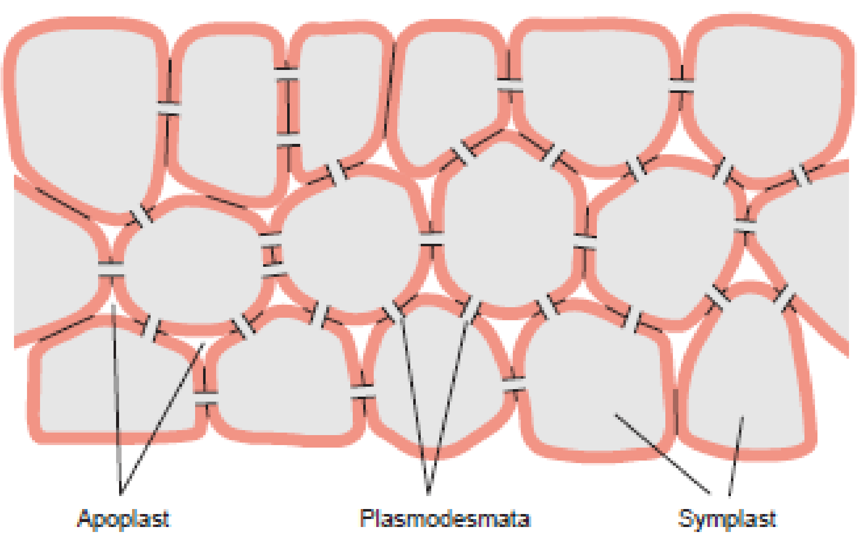
1.ACTIN FILAMENTS

2.INTERMEDIATE FILAMENTS

3.MICROTUBULES

PLASMODESMATA

- Plasmodesmata (singular *plasmodesma) are tubular extensions* of the plasma membrane, 40 to 50 nm in diameter, that traverse the cell wall and connect the cytoplasms of adjacent cells.
- Because most plant cells are interconnected in this way, their cytoplasms form a continuum referred to as the symplast.
- Intercellular transport of solutes through plasmodesmata is thus called symplastic transport



Comparison of Prokaryotic Cells and Eukaryotic Cells

	Prokaryotic Cells (1–20 μm in diameter)	*Eukaryotic Cells (10–100 μm in diameter)*	
		Animal	*Plant*
Cell wall	Usually (peptidoglycan)	No	Yes (cellulose)
Plasma membrane	Yes	Yes	Yes
Nucleus	No	Yes	Yes
Nucleolus	No	Yes	Yes
Ribosomes	Yes (smaller)	Yes	Yes
Endoplasmic reticulum	No	Yes	Yes
Golgi apparatus	No	Yes	Yes
Lysosomes	No	Yes	No
Mitochondria	No	Yes	Yes
Chloroplasts	No	No	Yes
Peroxisomes	No	Usually	Usually
Cytoskeleton	No	Yes	Yes
Centrioles	No	Yes	No
9 + 2 cilia or flagella	No	Often	No (in flowering plants) Yes (sperm of bryophytes, ferns, and cycads)

<u>Water</u>

Water is essential for all living organisms

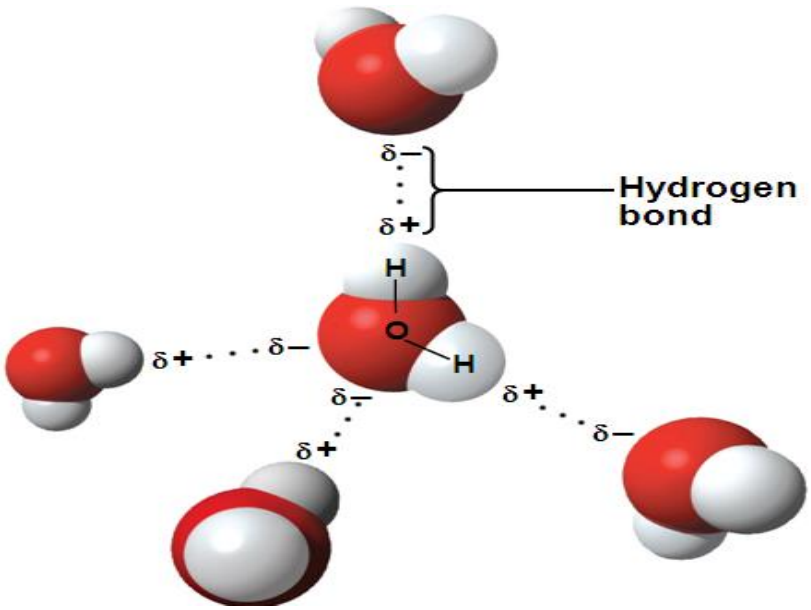
- Most organisms are comprised of at least 70% or more water. Some plants, like a head of lettuce, are made up of nearly 95% water.
- When organisms go dormant, they loose most of their water. For example, seeds and buds are typically less than 10% water.
- Water is the limiting resource for crop productivity in most agricultural systems.

Importance/ Function of water

- is a major component of cells
- is a solvent for the uptake and transport of materials
- is a good medium for biochemical reactions
- is a reactant in many biochemical reactions (*i.e., photosynthesis)*
- provides structural support via turgor pressure (*i.e., leaves)*
- plant movements are the result of water moving into and out of those parts (*i.e., diurnal movements,* stomatal opening, flower opening)
- cell elongation and growth

Properties

- Water consists of an oxygen atom covalently bonded to two hydrogen atoms.
- The oxygen atom is strongly **electronegative,** which means that it has a tendency to attract electrons.
- The shared electrons that make up the O—H bond are, on the average, closer to the oxygen nucleus than to hydrogen. As a consequence, the oxygen atom carries a partial negative charge, and a corresponding partial positive charge is shared between the two hydrogen atoms.
- This asymmetric electron distribution makes water a **polar** molecule.
- Overall, water remains a neutral molecule, but the separation of partial negative and positive charges generates a strong mutual (electrical) attraction between adjacent water molecules or between water and other polar molecules.
- This attraction is called **hydrogen bonding**.



- In addition to interactions between water molecules, hydrogen bonding also accounts for attractions between water and other molecules or surfaces.
- Hydrogen bonding, for example, is the basis for hydration shells that form around biologically important macromolecules such as proteins, nucleic acids, and carbohydrates

TABLE 1.1 Some physical properties of water compared with other molecules of similar molecular size. Because thermal properties are defined on an energy-per-unit mass basis, values are given in units of joules per gram

	Molecular mass (Da)	Specific heat (J/g/°C)	Melting point (°C)	Heat of fusion (J/g)	Boiling point (°C)	Heat of vaporization (J/g)
Water	18	4.2	0	335	100	2452
Hydrogen sulphide	34	—	−86	70	−61	—
Ammonia	17	5.0	−77	452	−33	1234
Carbon dioxide	44	—	−57	180	−78	301
Methane	16	—	−182	58	−164	556
Ethane	30	—	−183	96	−88	523
Methanol	32	2.6	−94	100	65	1226
Ethanol	46	2.4	−117	109	78	878

- The term **specific heat** is used to describe the thermal capacity of a substance or the amount of energy that can be absorbed for a given temperature rise.
- The specific heat of water is 4.184 J $g^{-1}\,{}^{\circ}C^{-1}$
- Because of its highly ordered structure, liquid water also has a high **thermal conductivity**.

- This means that it rapidly conducts heat away from the point of application.
- The combination of high specific heat and thermal conductivity enables water to absorb and redistribute large amounts of heat energy without correspondingly large increases in temperature.
- For plant tissues that consist largely of water, this property provides for an exceptionally high degree of temperature stability.

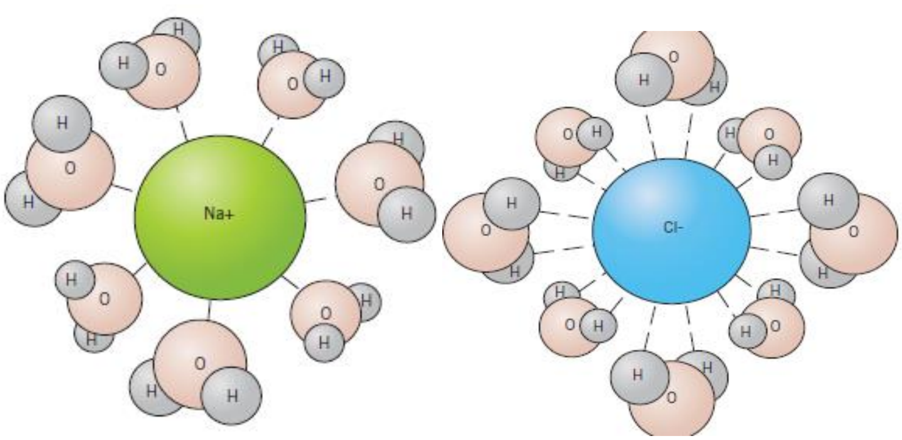
WATER EXHIBITS A HIGH HEAT OF FUSION AND HEAT OF VAPORIZATION

- Energy is required to cause changes in the state of any substance, such as from solid to liquid or liquid to gas, without a change in temperature.
- The energy required to convert a substance from the solid to the liquid state is known as the **heat of fusion.**
- The high heat of fusion of water is attributable to the large amount of energy necessary to overcome the strong intermolecular forces associated with hydrogen bonding.
- Just as hydrogen bonding increases the amount of energy required to melt ice, it also increases the energy required to evaporate water.
- Because this energy must be absorbed from its surroundings, the heat of vaporization accounts for the pronounced cooling effect associated with evaporation.

WATER IS THE UNIVERSAL SOLVENT

The excellent solvent properties of water are due to the highly polar character of the water molecule.

- Water has the ability to partially neutralize electrical attractions between charged solute molecules or ions by surrounding the ion or molecule with one or more layers of oriented water molecules, called a **hydration shell.**



POLARITY OF WATER MOLECULES RESULTS IN COHESION AND ADHESION

- The strong mutual attraction between water molecules resulting from hydrogen bonding is also known as **cohesion.**
- Surface tension arises because the cohesive force between water molecules is much stronger than interactions between water and air.
- The result is that water molecules at the surface are constantly being pulled into the bulk water.
- The surface thus tends to contract and behaves much in the manner of an elastic membrane.

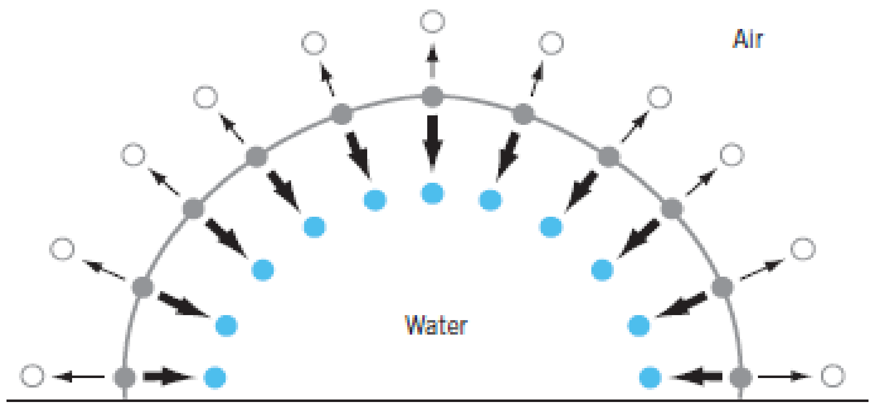


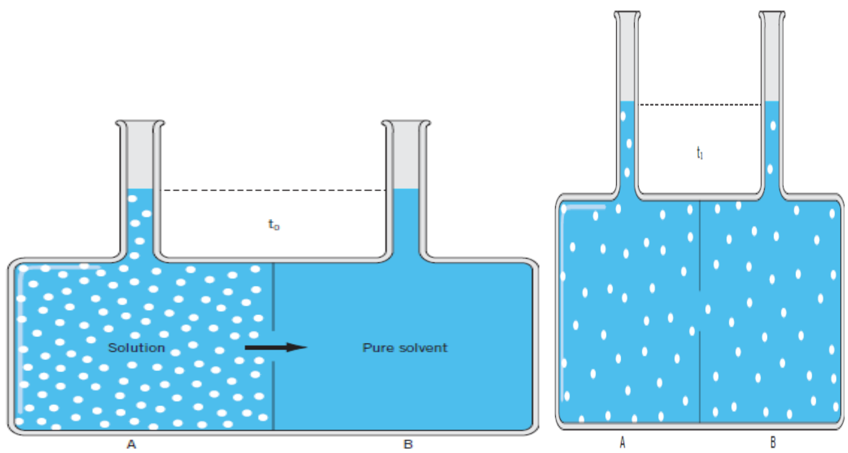
FIGURE 1.3 Schematic demonstration of surface tension in a water drop. Intermolecular attractions between neighboring water molecules (heavy arrows) are greater than attractions between water and air (light arrows), thus tending to pull water molecules at the surface into the bulk water.

- Cohesion is directly responsible for the unusually high **tensile strength of water.**
- Tensile strength is the maximum tension that an uninterrupted column of any material can withstand without breaking.
- The same forces that attract water molecules to each other will also attract water to solid surfaces, a process known as **adhesion.**
- Adhesion is an important factor in the capillary rise of water in small-diameter conduits.

WATER MOVEMENT MAY BE GOVERNED BY DIFFUSION OR BY BULK FLOW

Movement of materials by ***bulk flow*** *(or mass flow) is* **pressure-driven**.

- Bulk flow occurs when an external force, such as gravity or pressure, is applied. As a result, all of the molecules of the substance move in a mass.
- Movement of water by bulk flow is a part of our everyday experience. Water in a stream flows in response to the hydrostatic pressure established by gravity.
- *Diffusion is also a part of our everyday* experience. When a small amount of sugar is placed in a cup of hot drink, the sweetness soon becomes dispersed throughout the cup.
- The scent of perfume from a bottle opened in the corner of a room will soon become uniformly distributed throughout the air.
- Diffusion can be interpreted as a *directed movement from a region of a high* concentration to a region of lower concentration, but it is accomplished through the *random thermal motion* of individual molecules.
- While bulk flow is pressure-driven, diffusion is driven principally by **concentration differences.**



Diffusion in solutions is usually associated with the directed movement of a solute molecule from a region of high concentration to a region of lower concentration due to the random thermal motion of the solute molecules.

- Diffusion is a significant factor in the uptake and distribution of water, gases, and solutes throughout the plant.
- In particular, diffusion is an important factor in the supply of carbon dioxide for photosynthesis as well as the loss of water vapor from leaves.

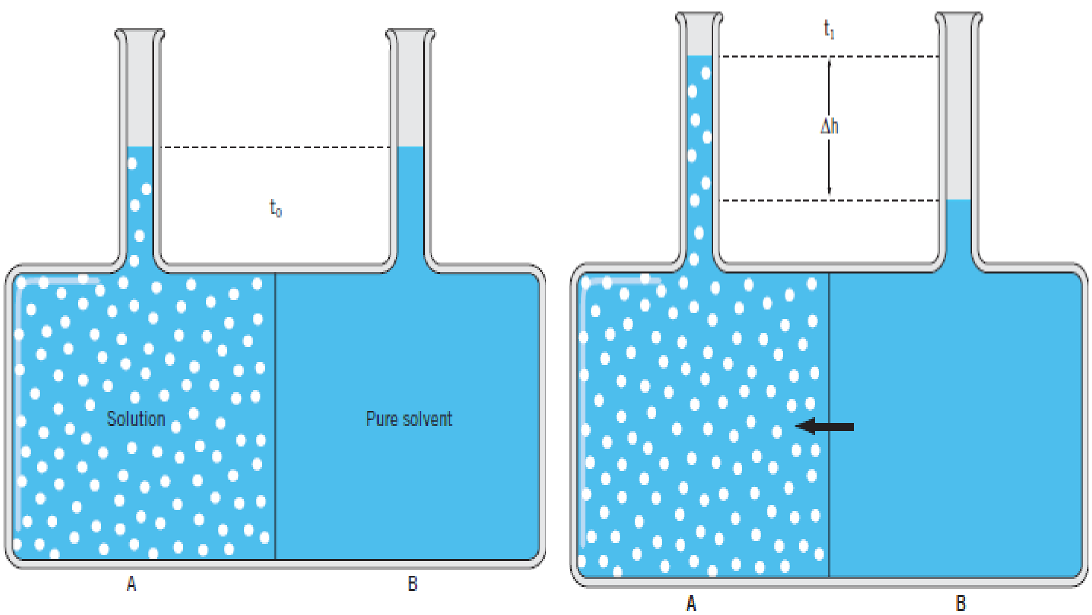
Fick's law

$$J = -D \cdot A \cdot \Delta C \cdot l^{-1}$$

- *J is the **flux or the amount of material crossing a unit*** area per unit time (for example, mol m−2 s−1).
- *D is the* **diffusion coefficient, a proportionality constant that is** a function of the diffusing molecule and the medium through which it travels.
- *A and l are the cross-sectional area and the length of the diffusion path, respectively.*

OSMOSIS IS THE DIFFUSION OF WATER ACROSS A SELECTIVELY PERMEABLE MEMBRANE

- Diffusion of water, a process known as *osmosis, will occur only* when the two chambers are separated from one another by a **selectively permeable membrane.**
- **A selectively** permeable membrane allows virtually free passage of water and certain small molecules, but restricts the movement of large solute molecules.



Osmosis is the directed movement of the solvent molecule (usually water) across a selectively permeable membrane.

Chamber A is separated from chamber B by a selectively permeable membrane. The selectively permeable membrane allows the free movement of the solvent (water) molecules between chambers A and B, but restricts the movement of the solute molecules.

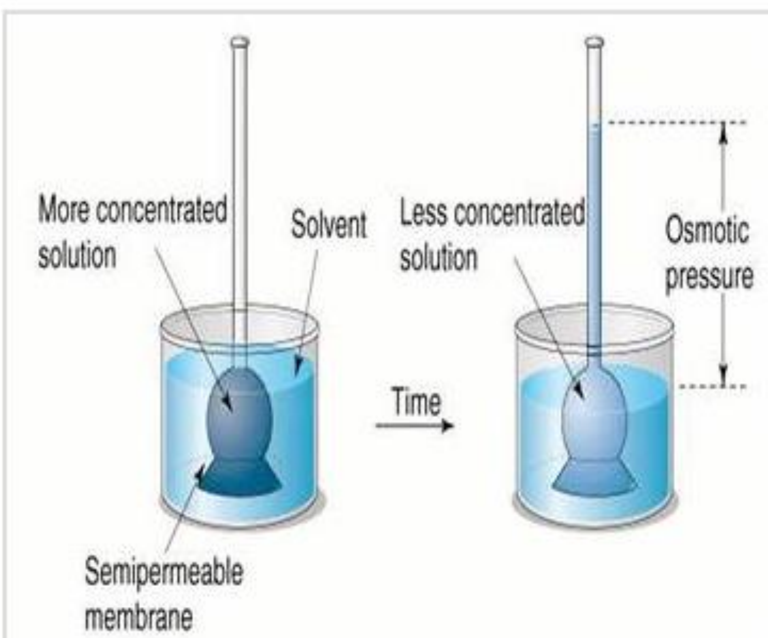
Diffusion vs osmosis

Water

Cells as an osmotic system

Living cells in plants form osmotic systems due to the presence of semi-permeable plasma membrane and the cell sap having a certain osmotic pressure.

- The tonoplast or the vacuolar membrane also possesses the same nature.
- The solvent in case of plants is always water.
- The cell wall is permeable.
- Osmotic presuure
- When a cell or a solution is separated by semipermeable membrane from water, pure water tends to enter the solution by osmosis.
- Now the pressure required to prevent the osmotic entry of water into solution.
- Osmotic pressure of a solution is the pressure which must be applied to it in order to prevent the passage of solvent due to osmosis.
- In other words, it is that pressure which is needed to check the process of osmosis.

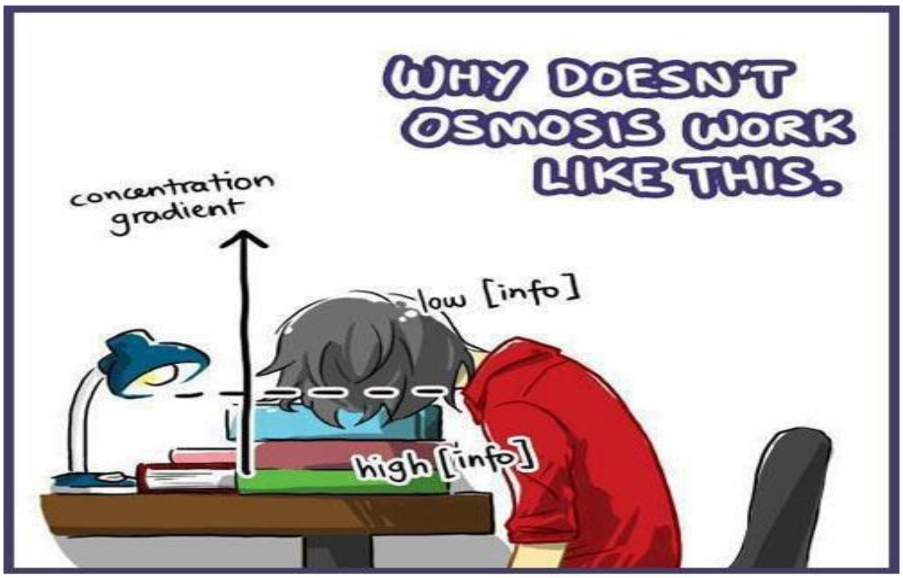


- If a living plant cell or tissue is placed in water or hypotonic solution (whose O.P. is lower than that of cell sap) water enters into the cell sap by osmosis. This process is called as **end- osmosis**.

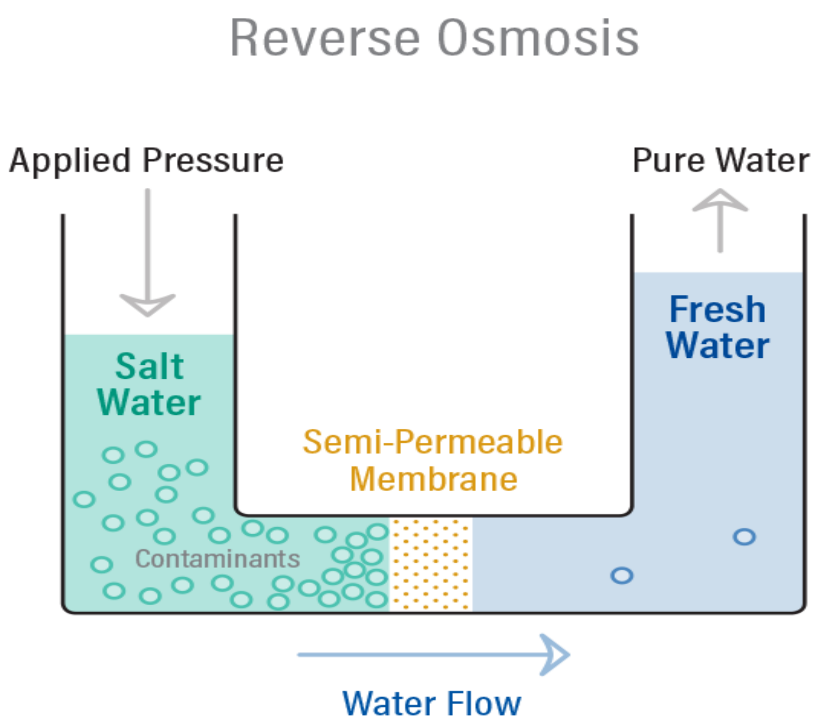
- As a result of entry of the water into the cell sap, a pressure is developed which presses the protoplasm against the cell wall and the cell becomes turgid. This pressure is called as turgor pressure.
- If on the other hand, the plant cell or the tissue is placed in hypertonic solution (whose O.P. is higher than that of cell sap) the water comes out of the cell sap into the outer solution and the cell becomes flaccid. This process is known as **exosmosis**.
- Cell or tissue will remain as such in isotonic solution.

Importance of osmosis

- Large quantities of water are absorbed by roots from the soil by osmosis.
- Cell to cell movement of water and other substances dissolved in it involves this process.
- Due to osmosis the turgidity of the cells and hence the shape or form of their organs is maintained.
- The resistance of plants to drought and frost increases with increase in osmotic pres sure of their cells.
- Variety of plant movements are due to osmosis. E.g. opening and closing of stomata



REVERSE OSMOSIS ???



Imbibitions

- Imbibition in plant cells refers to the absorption and adsorption of water by insoluble, solid, hydrophilic protoplasmic and cell wall constituents.
- Water is imbibed as a result of both diffusion and capillary action.
- It is a process that occurs only when the solid plant material (e.g. dry wood, dead or living seeds) come in contact with water.

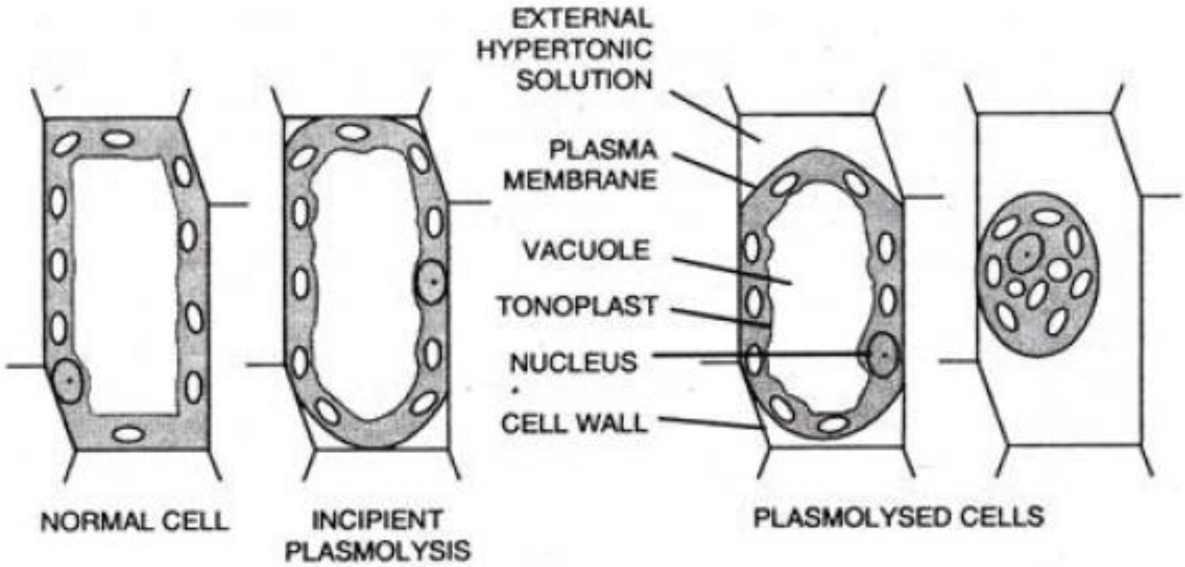
  Significance-

- Imbibition is essential for dry seeds before they start germination.
- The first step in the absorption of water by the roots is the imbibition of water by cell walls of the root hairs.

Plasmolysis

- In normal condition the protoplasm is tightly pressed against the cell wall.
- If this plant cell or tissue is placed in a hypertonic solution, water comes out from the cell sap into the outer solution due to ex-osmosis and the protoplasm begins to contract from the cell wall. This is called as **incipient plasmolysis**.

- If the outer hypertonic solution is very much concentrated in comparison to the cell sap, the process of ex-osmosis and contraction or shrinkage of protoplasm continues and ultimately the protoplasm separates from the cell wall and assumes a spherical form. This phenomenon is called as **plasmolysis** and the cell or the tissue is said to be plasmolysed.



Stages in plasmolysis

- If a plasmolysed cell or tissue is placed in water, process of end-osmosis takes place. Water enters into the cell sap, the cell becomes turgid, and the protoplasm again assumes its normal shape and position.

- This phenomenon is called **deplasmolysis**.

Advantage of plasmolysis

- It indicates the semi-permeable nature of the plasma-membrane.

- This phenomenon is utilized in salting of meat and fishes and addition of concentrated sugar solution to jams and jellies to check the growth of fungi and bacteria which become plasmolysed in conc. solution.

- It is also used in determining the O.P. of the cell sap.

Diffusion pressure deficit (DPF)

- When a solvent is separated from a solution, the solvent molecules being higher in concentration will diffuse towards the solution under pressure. This pressure is known as *diffusion pressure deficit*.

- In other words it can be said that this movement is due to certain deficit in the diffusion pressure of the solution as compared to the solvent or it is due to diffusion pressure deficit of the solution.
- The solution will try to wipe off this deficit by pulling or sucking more of the solvent molecules.
- DPD is also known as suction pressure.

  DPD = OP - TP

In a fully turgid cell.

Due to the entry of the water the osmotic pressure of the cell sap decreases while the turgor pressure is incresed so much that the turgor pressure is equals to osmotic pressure. (TP=OP)

So, DPD = O

On the other hand, the removal of water from the cell sap (ex-osmosis) results in an increase in its OP and decrease of the turgor pressure so much that in fully plasmolyzed cell, the value of turgor pressure becomes zero.

So, DPD = O.P.

Water potential

- Also called chemical potential of water
- A quantitative expression of the free energy associated with water.
- Free energy means a potential for performing work or the energy that is free and available for performing work.
- Water potential is denoted by the Greek letter psi (Ψ) and is measured in bars.
- By convention the water potential of pure water is given the value ZERO.
- Because pure water has the highest concentration of water molecules, and thus the highest water potential, the water potential of all other solutions must be lower than zero i.e. negative.
- Water moves down a chemical potential gradient from a region of high chemical potential to a region of low chemical potential.
- When a typical plant cell containing cell wall, vacuole and cytoplasm is placed in a medium containing pure water, there are a number of factors which determine the water potential of the cell sap.

1.Solute potential and

2.Pressure potential

Solute potential (Ψs)

- It is a component of water potential which is also called osmotic potential.
- It represents the amount of solute present and is denoted as Ψ_S.
- The osmotic potential of pure water is zero and gets lowered when solute molecules are added to it.
- Dissolving of solutes increases the disorder of water and reduce the free energy of water by diluting the water.
- Solute potential is the potential of solution to gain water.

Pressure potential (Ψ_P)

- The component of water potential due to the hydrostatic pressure that is exerted on water in a cell.
- Pressure potential which is denoted as Ψp is equivalent to either the wall pressure or turgor pressure.
- In turgid plant cells it usually has a positive value.
- In xylem cells there is a negative pressure potential, or tension, as a result of transpiration.

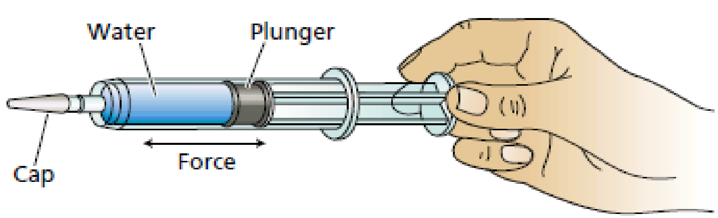


FIGURE 3.5 A sealed syringe can be used to create positive and negative pressures in a fluid like water. Pushing on the plunger compresses the fluid, and a positive pressure builds up. If a small air bubble is trapped within the syringe, it shrinks as the pressure increases. Pulling on the plunger causes the fluid to develop a tension, or negative pressure. Any air bubbles in the syringe will expand as the pressure is reduced.

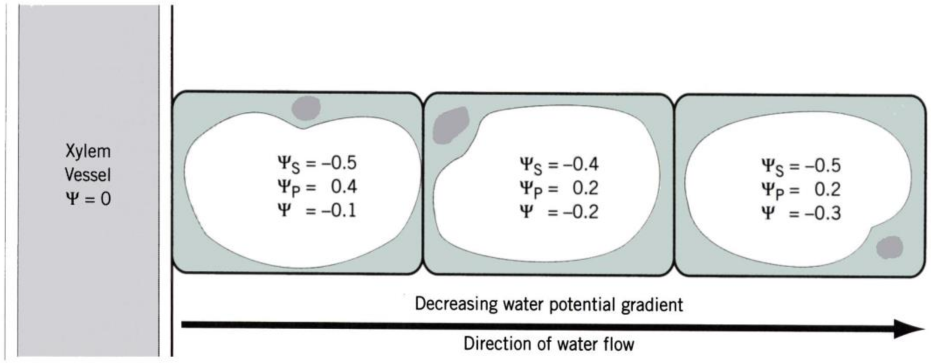
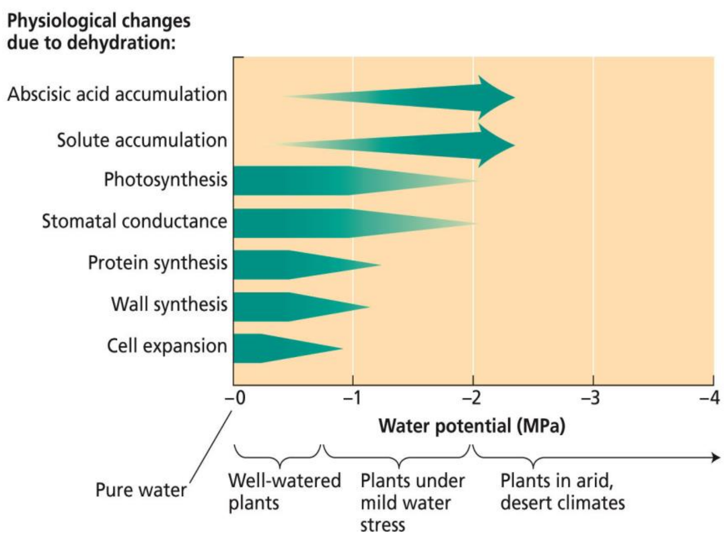


FIGURE 10.9 Diagram illustrating the contributions of osmotic potential (Ψ_S), turgor pressure (Ψ_P), and water potential (Ψ) to water movement between cells. The direction of water movement is determined solely by the value of the water potential in adjacent cells.

Water potential of plants under various growing conditions



Diffusion Pressure Deficit (DPD)	Water Potential
1. DPD was originally called suction pressure.	It is called ψ_w where ψ is psi and the chemical potential of water equivalent to DPD with a negative sign.
2. It is measured in atmospheres.	It is measured in bars.
3. DPD is the difference between the diffusion pressure of a solution and pure solvent.	Water potential is the difference between free energy of water molecules in pure water and solution.
4. DPD = OP - TP where OP = Osmotic pressure and TP = Turgor pressure.	$\psi_w = \psi_m + \psi_s + \psi_p$ where ψ_m = Matric potential; ψ_s = Solute potential; ψ_p = Pressure potential
5. Water moves from lower DPD to higher DPD.	Water moves from higher water potential to lower water potential.

Soil water

1**. Gravitational or free water-** Water which flows down due to the force of gravity is known as gravitational water. However, it is a big soil water reservoir and is trapped out through tube wells.

2. **Capillary water**: A certain amount of rain water is retained within the intercellular spaces of the soil particles in the form of a capillary network. It is called capillary water and is used by the plants.

3. **Hygroscopic water** :Some water molecules form a thin sheet of water around soil particles. It is called hygroscopic water (water of imbibition).

- Holard –total amount of water present in the soil.
- Chesard- amount of water available to plants.
- Echard- amount of water cannot be absorbed by plants.

Water

Absorption of water

- The total amount of water present in the soil is termed as **Holard.**
- The amount of available water in the soil is termed as **Chesard**.
- The unavailable water in the soil is termed as **Echard.**

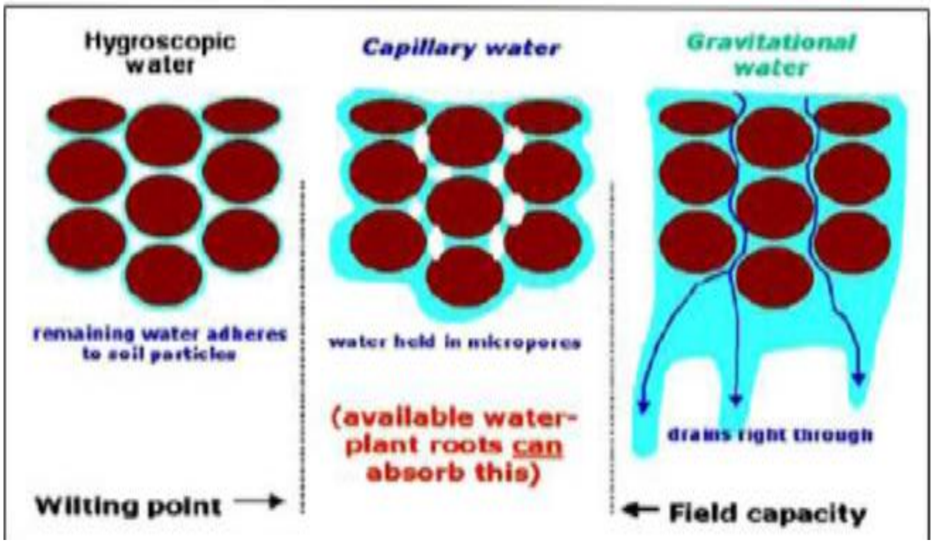
Classification of soil particles & some of their properties

Particle Class	Particle (mm) Size	Water Retention	Aeration
Coarse sand	2.00–0.2	poor	excellent
Sand	0.20–0.02		
Silt	0.02–0.002	good	good
Clay	less than 0.002	excellent	poor

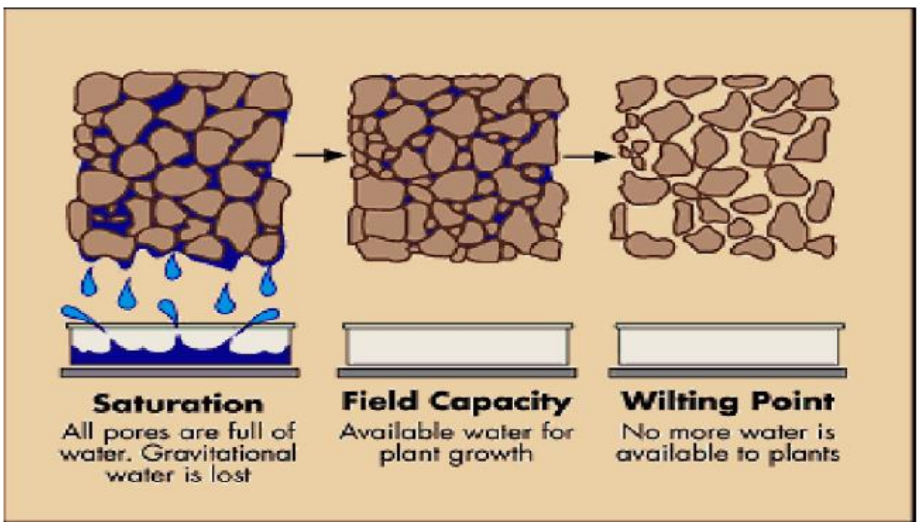
- After the rain some water drains away (run off water) and some water percolate (downward movement of water in the soil) through large soil pores under the influence of gravity and it is called **gravitational water**.

  The water in the soil may present in three forms:

- **Capillary water:** It is available water to the plant which fills the space between the non colloidal smaller particles of the soil.
- **Hygroscopic water:** Water which held by soil particles of colloidal complex due to adhesive force. This is also unavailable water to plants.
- **Chemically combined water:** The water which is chemically bind to the chemical compounds in the soil and also unavailable to the plants.



Stages of water holding



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

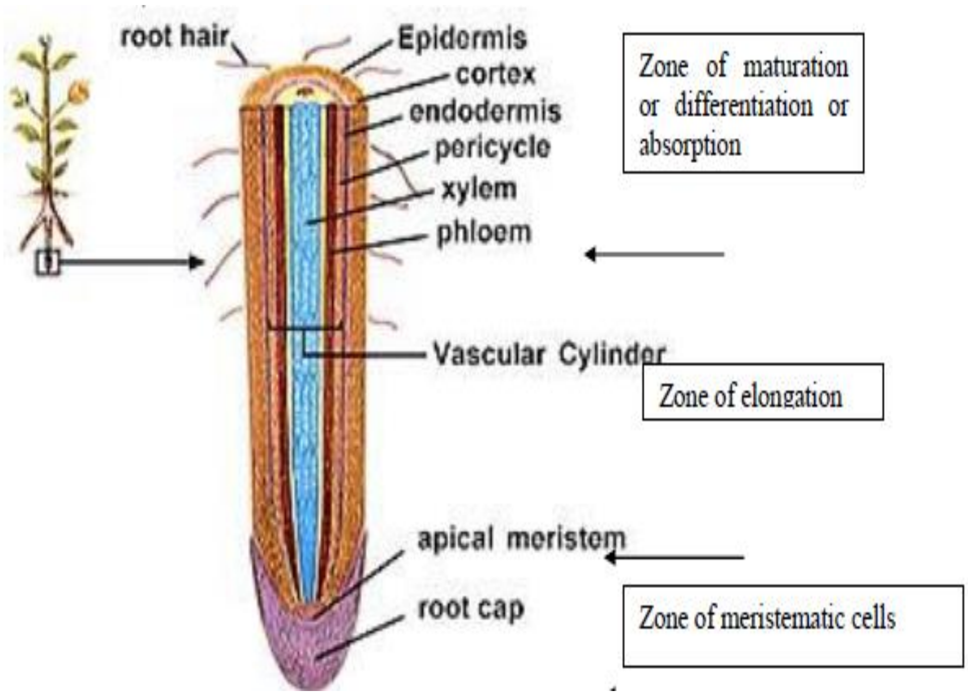
Root: The absorbing organ

- Roots absorb water mainly from the apical region. Apical region of root shows three clear demarcations:

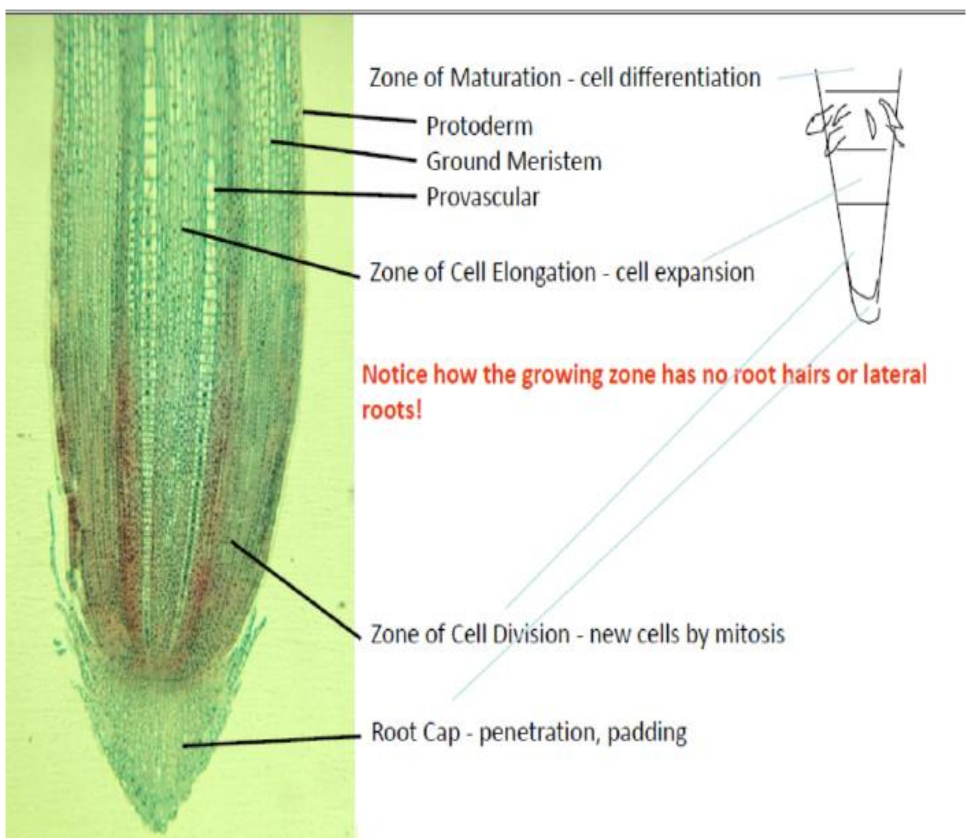
1. zone of meristematic cells,

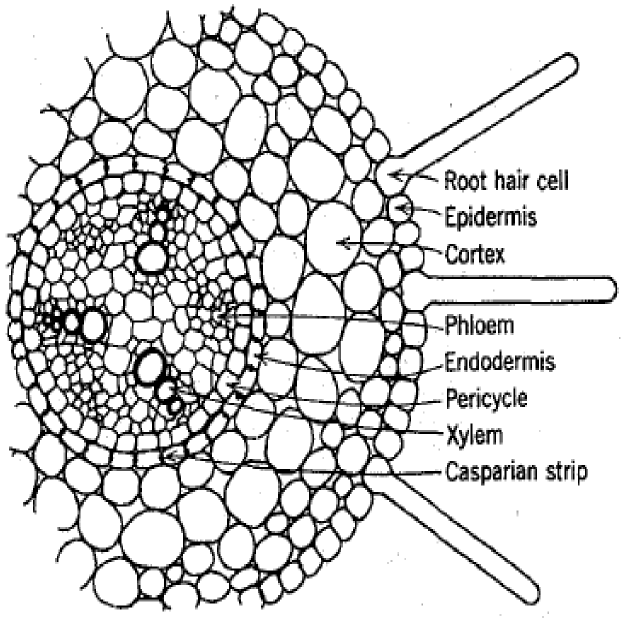
2. zone of elongation and

3. zone of absorption or differentitation or maturartion.



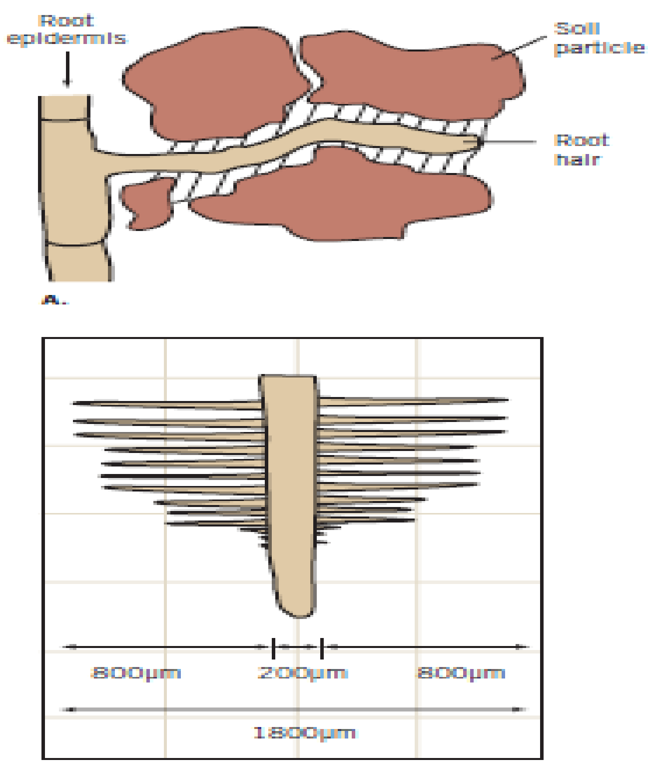
Diagrammatic illustration of the relationship between differentiation of root tissues and water uptake.





- **Root Hair:** Root hair is the special modified cells of epidermis meant for the absorption of water.

The wall of root hair consists of cellulose and pectic compounds which are highly hydrophilic (Water loving) in nature and have great capacity of water absorption.



Root hairs and water uptake.

(A) Root hairs enhance water uptake by their ability to penetrate water-containing capillary spaces between soil particles.

(B) Root hairs increase by several times the volume of soil that can be extracted of water by a root**.**

- **Endodermis:**

Endodermis is the boundary layer of stele and its cells have a particular type of radial thinking (of suberin or cutin or lignin) in cell wall. This thickening is known as casparian‟s strip. Due to this radial thinking of suberin water can not pass apoplastically. However, certain passenger cells facilitate such movement from cortex to stele.

- **Xylem:**

The conducting cells in the xylem have a specialized anatomy that enables them to transport large quantities of water with great efficiency. There are two important types of tracheary elements in the xylem: **tracheids** and **vessel elements**.

Vessel elements are found only in angiosperms while tracheids are present in both angiosperms and gymnosperms.

Both these elements are dead when functional and they have no membrane or organelles. They are like hollow tubes reinforced by lignified secondary walls.

From the epidermis of root hair there are two pathways in which water can flow:

1: Apoplast pathway:

- Water moves exclusively through cell walls without crossing any membranes.
- **The apoplast is a continuous system of cell walls and intercellular air spaces in plant tissue**.

2: Transmembrane and symplast pathway:

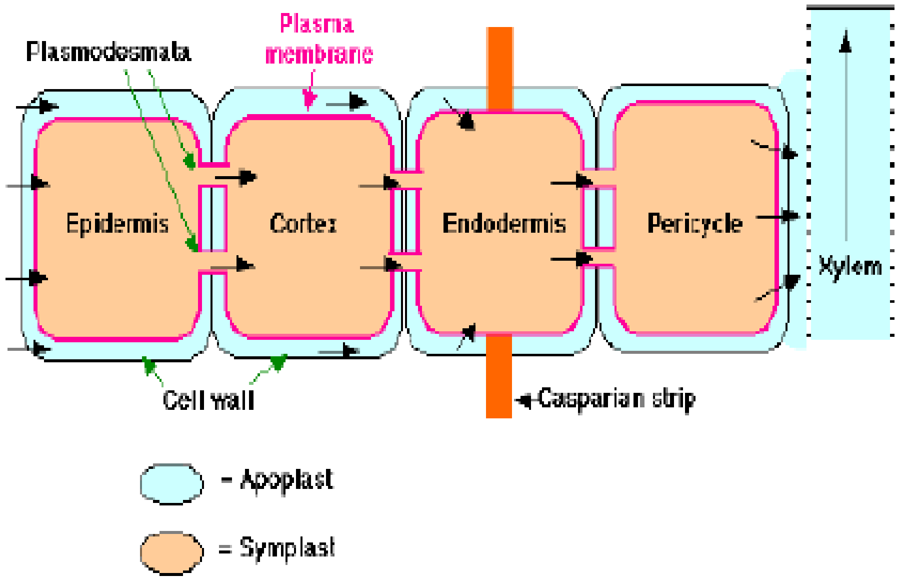
- Water sequentially enters a cell on one side, exits the cell on the other side, and enters the next cell, and so on.
- **The symplast consist of the entire network of cell cytoplasm interconnected by plasmodesmata.**

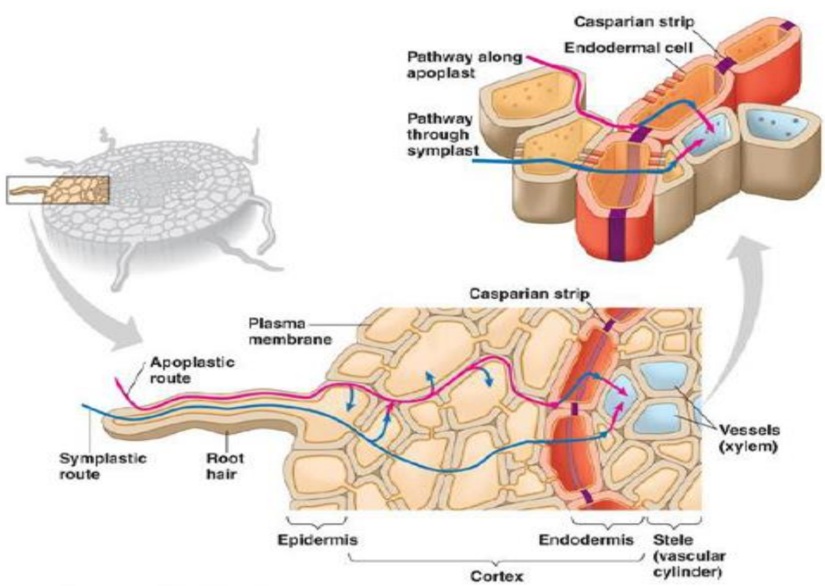
Mechanism of water movement in roots

APOPLAST

SYMPLAST

TRANSMEMBRANE





Mechanism of water absorption

1. Active absorption

2. Passive absorption

- **Active Absorption**: Here water is absorbed by the activity of roots itself or root play active role and shoot activity did not influence this absorption. It is common in plants with low transpiration rate.

a. Osmotic theory: First step of water absorption is imbibition by cell wall of root hair and as cell wall is permeable water as well as solutes enter through it and reach at cell membrane.

- Now outer soil water is separated from cell sap of root hair by means of selective membrane (cell membrane). The water absorbed due to osmotic difference between soil and cell sap.

- Root pressure is best evidence of this theory.

Imbibition of soil water by hydrophilic cell wall

↓

O.P Cell sap > O.P soil water

↓

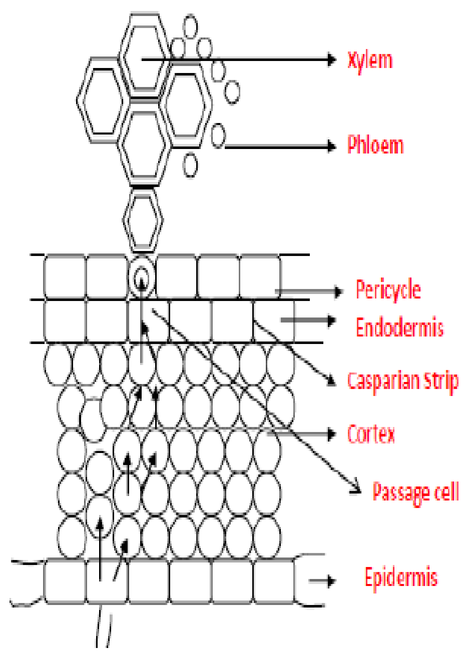
DPD in root hair becomes higher

↓

Water from cell wall enter into them thro' membrane by osmotic diffusion

↓

As a result, O.P, DPD of root becomes lower and T.P increased



The cortical cells adjacent have higher DPD, OP in comparison to root hair

Likewise, water moves by osmotic diffusion and reaches endodermis

↓

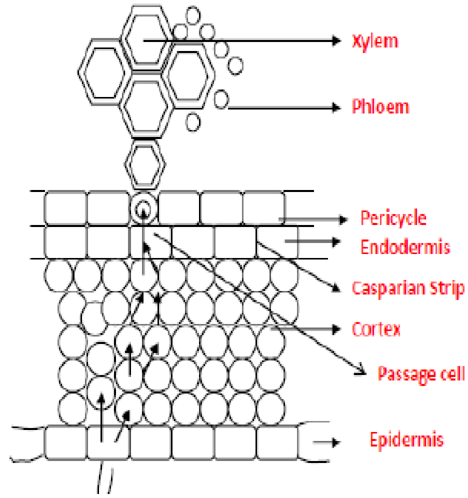
Endodermis water moves thro' passage cell (because casparian cell)

↓

Now water reaches pericycle, pericylce becomes turgid and their DPD is decreased

↓

Last step, water is drawn into xylem from turgid pericycle cells (protoxylem in contact)



Pressure developed in the xylem of root due to entry of water- **Root pressure**

- Root pressure not found in gymnosperms
- Not found in fast transpiring plants
- Amount of water exuded from cut ends not equal to water lost due to transpiration.

B. **Non-osmotic theories**

- Water absorption occurs against the concentration gradient. Energy required which is obtained from respiration.
- Factors reducing respiration reduce the water absorption.

Passive absorption

- Transpiration creates a tension in water in the xylem of the leaves.
- Tension is transmitted to water in the xylem of the roots through the xylem of the stem and water rises upwards to reach the transpiring surface.
- Hence the soil water enters cortical cells through root hairs to reach the xylem of the roots to maintain the supply of water.
- The force of entry of water in leaves is due to rapid transpiration and the root cells remain passive.

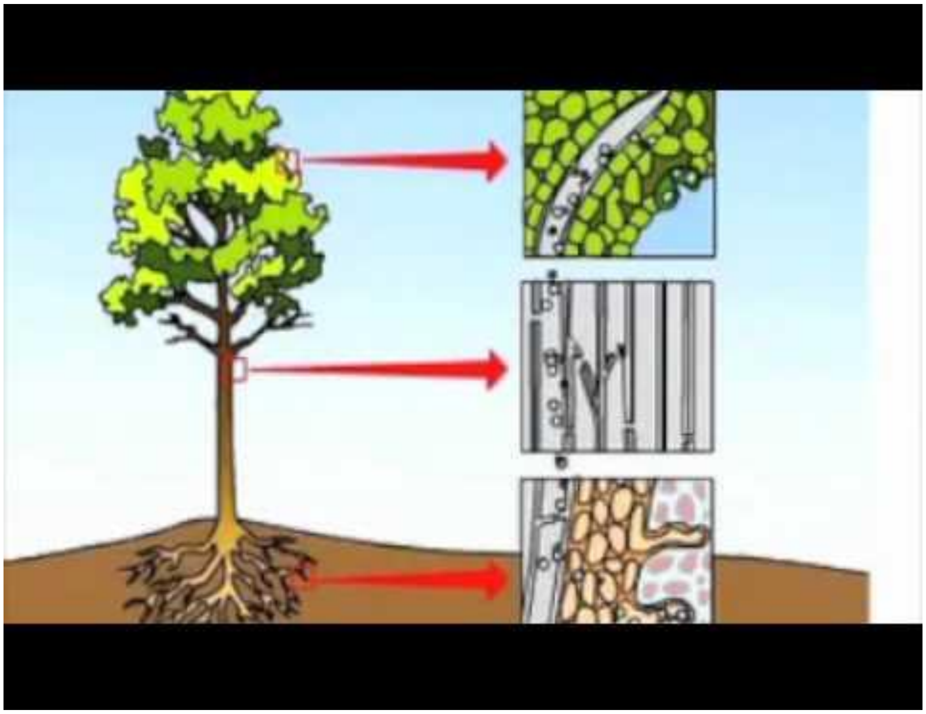
Factors affecting water absorption

External factors

- **Available soil water-**
- Amount of water,
- capillary water,
- soil aeration
- **Concentration of soil solution**
- High salt concentration (High OP)
- Physiologically dry soil
- **Soil temperature**
- 20-30^{o} C most suitable
- Lower temperature-
- Slows the metabolic activity
- Decreases permeability of membrane
- Increases viscosity of water
- **Soil aeration-**
- Proper aeration required
- Deficiency of O_2 affect metabolism
- Water logged area results in plant death.
- **Internal factors**
- Transpiration
- Absorbing root systems
- Metabolism

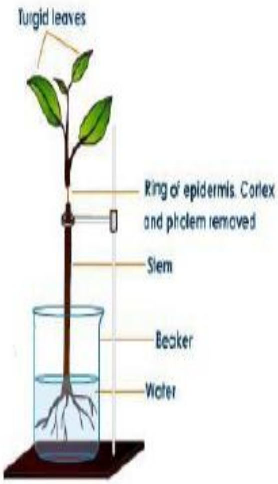
Water

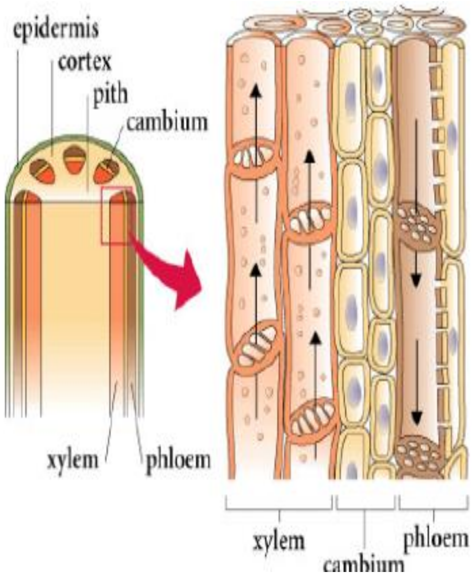
Ascent of Sap

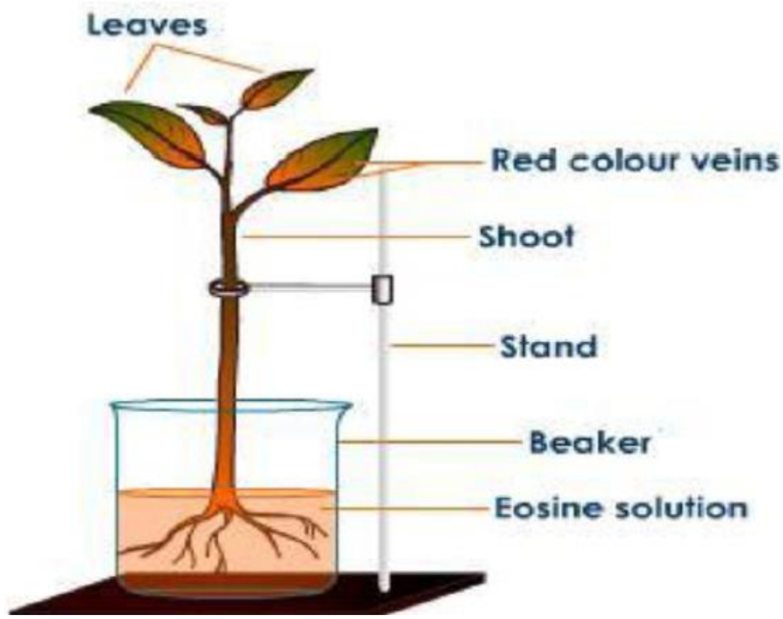


Ascent of sap

- The phenomenon of ascending of absorbed water against gravitation through xylem is called ascent of sap.
- Or Upward movement of water is ascent of sap.







Mechanism of Ascent of Sap

- In small trees and herbaceous plants, the ascent of sap can be explained easily.
- In tall trees like eucalyptus an conifers reaching heights of (300-400ft) where water has to rise upto height of several hundred feet, number of theories have been put across-
- **Vital theory**
- **Root pressure theory**
- **Physical force theory**
- **Transpirational pull and cohesion of water theory**

Vital theories

- According to vital theories, the ascent of sap is under the control of vital activities in the stem

1. According to **Godlewski** (1884)-
   - Ascent of sap takes place due to pumping activity of xylem tissues which are living
2. According to **Bose** (1923)-
   - Upward translocation of water takes place due to pulsatory activity of living cells of the inner most cortical layer just outside the endodermis.

ROOT PRESSURE THEORY

- If a plant stem is cut a few inches above from its base with a sharp knife, the xylem sap is seen flowing out through the cut end. This phenomenon is called *"exudation or bleeding"*.
- It is due to hydrostatic pressure developed in root system. It is termed as root pressure, a *sort of hydrostatic pressure which develops in the roots due to accumulation of absorbed water*. According to this theory the upward movement of water is possible due to root pressure.

Objections to root pressure theory

1. Root pressure is not reported in tallest group of plants. (Gymnosperms)
2. The amount of water exude from stem cut end is not equal to water loss through transpiration.

Physical force theories

- Physical force theories believe that living cells are not involved in ascent of sap. It is a purely physical phenomenon.
- In this group **capillary theory** (ascent of sap by capillary action), **Imbibitional theory** and **atmospheric pressure** theory are included.
- However, for explaining the mechanism of ascent of sap, the most acceptable theory is Transpiration pull of Cohesion-tension theory which was proposed by Dixon and Jolly (1894).

Transpirational pull or cohesion-tension theory

- The theory was originally proposed by Dixon and Jolly (1894).

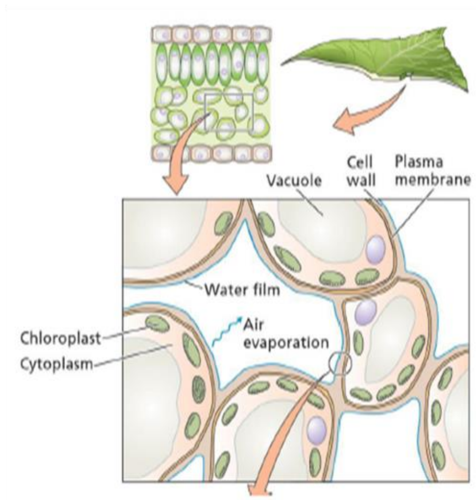
Mechanism of ascent of sap

- The loss of water from the surface of leaf mesophyll cells due to transpiration reduces the water amount and causes an increase in the osmotic pressure of these cells.
- Thus a reduced water potential is developed in mesophyll cells.
- Water from the adjacent cells and ultimately from the conducting tissue is pulled to meet this loss of water and as a result a pull is developed in the mesophyll cells and xylem cells of the leaf.

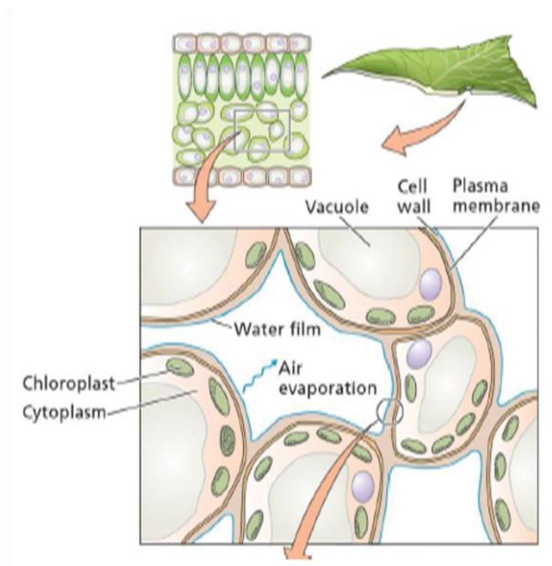
- Now water present in the xylem cells is placed under tension which is ultimately transmitted to the root through the stem tracheids.
- The tensions needed to pull water through the xylem are the result of evaporation of water from leaves.
- Water is brought to leaves via xylem of the leaf vascular bundle, which branches into veins in the leaf.
- From the xylem, water is drawn in to the cells of the leaf and along the cell wall.

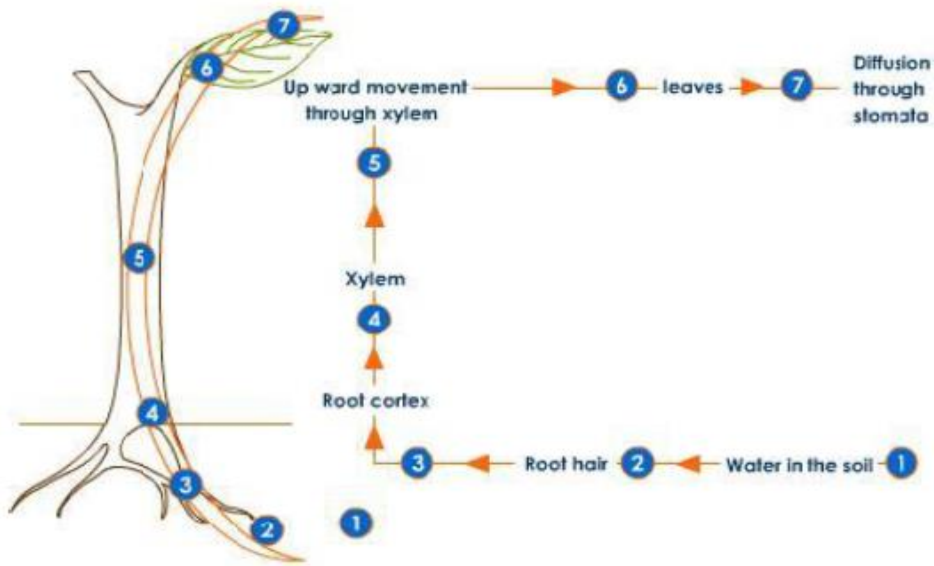
Water evaporation in the leaf affects xylem

- Transpiration pull, which causes water to move up the xylem begins in the cell walls of leaf cells.
- Water adheres to cellulose and other hydrophilic wall components.
- Mesophyll cells within leaf are in direct contact with atmosphere via all the air spaces in the leaf.



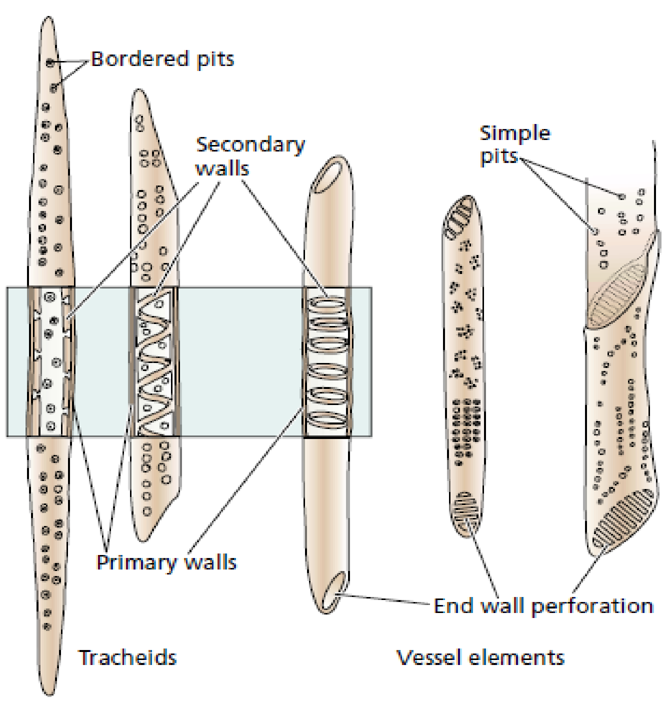
- So, negative pressure exists in leaves cause surface tension on the water.
- As more water is lost to the atmosphere, the remaining water is drawn into the cell wall.
- As more water is removed from the wall the pressure of the water becomes ***more –ve.***
- ***This induces a motive force to pull water up the xylem.***

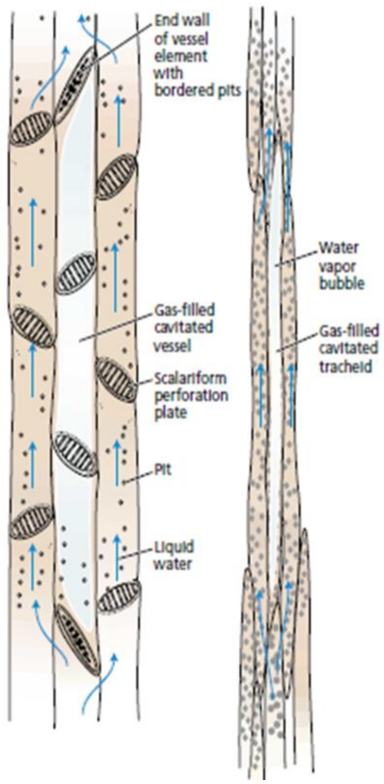




Water transports through tracheids and vessels

- **Tracheids** are elongated, spindle-shaped cells that are arranged in overlapping vertical files. Water flows between tracheids by means of the numerous **pits in** their lateral walls.
- **Vessel elements** tend to be shorter and wider than tracheids and have perforated end walls that form a perforation plate at each end of the cell
- Unlike tracheids, the perforated end walls allow vessel members to be stacked end to end to form a larger conduit called a vessel.

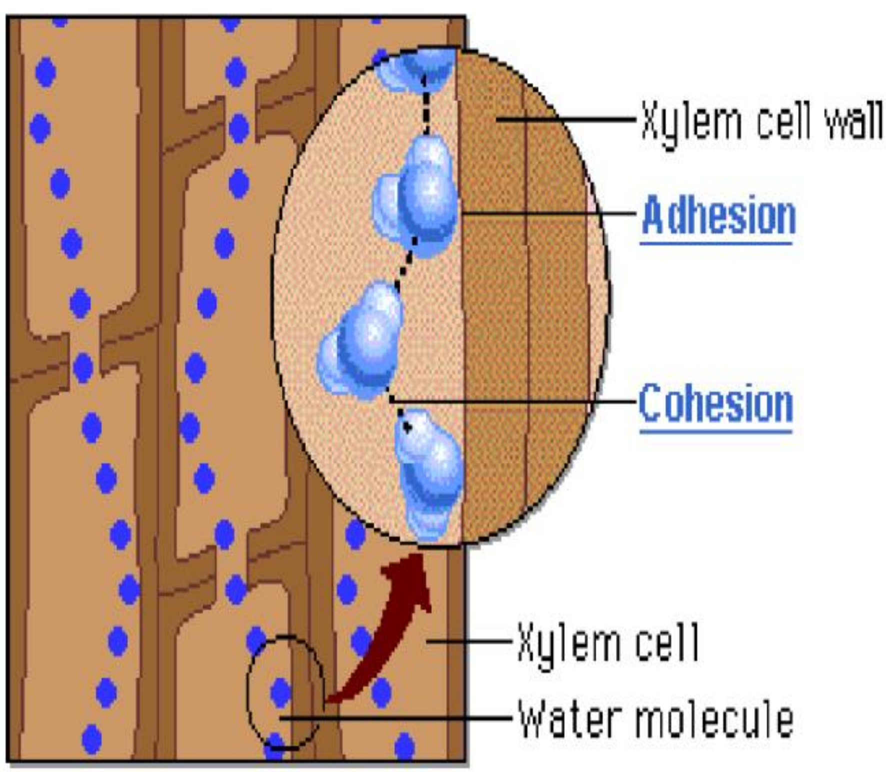




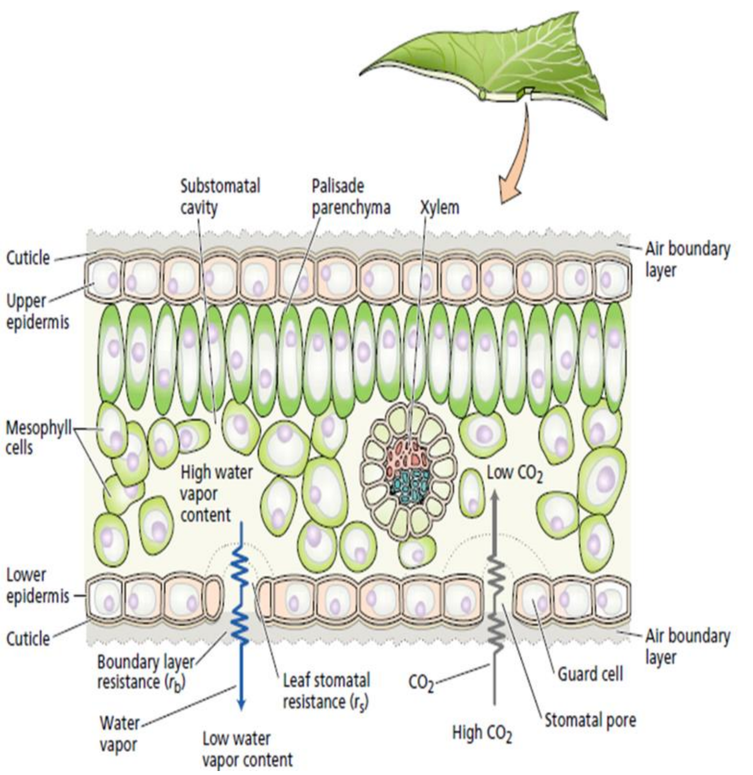
Tracheids (right) and vessels (left) form a series of parallel, interconnected pathways for water movement.

Cavitation blocks water movement because of the formation of gas-filled (embolized) conduits.

Because xylem conduits are interconnected through openings (“bordered pits”) in their thick secondary walls, water can detour around the blocked vessel by moving through adjacent tracheary elements



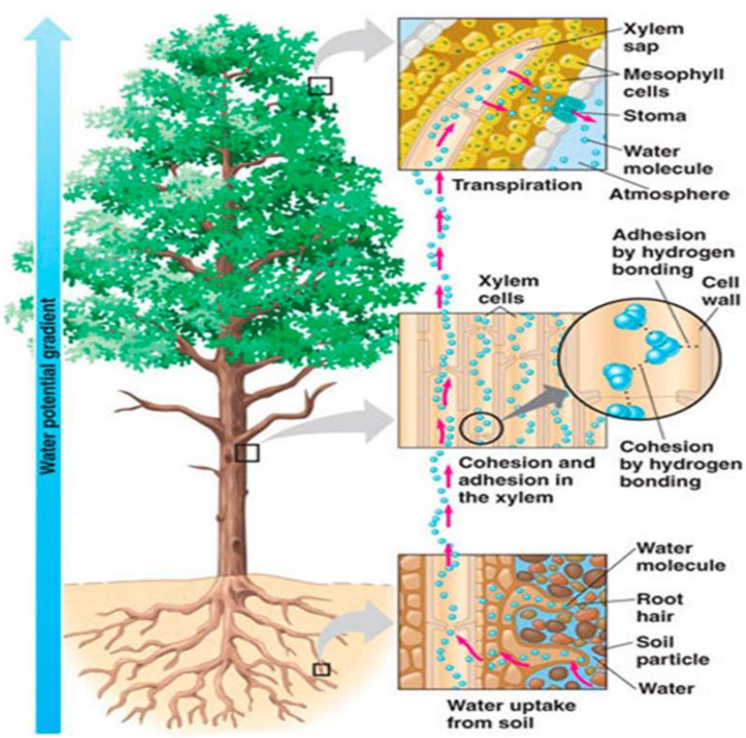
Water movement from leaf to atmosphere



Water pathway through the leaf. Water is pulled from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces within the leaf.

Water vapor then diffuses through the leaf air space, through the stomatal pore, and across the boundary layer of still air found next to the leaf surface.

CO_2 diffuses in the opposite direction along its concentration gradient (low inside, higher outside).



Summary of water transport within the xylem of a tree

Transpiration

- ***"The loss of water from the living tissue of aerial parts of the plant in the form of water vapour is termed as transpiration and in the form of liquid is known as guttation."***

Guttation in leaves from strawberry (*Fragaria grandiflora).* In the early morning, leaves secrete water droplets through the **hydathodes**, located at the margins ofthe leaves.

Difference between Transpiration and Evaporation

	Transpiration	Evaporation
1	It is a modified physical phenomenon found in plants.	It is a physical process and found taking place on any free surface.
2	It is regulated by the activity of guard cells.	No such mechanism is found in evaporation.
3	In the process, only living cells exposed to the atmosphere are involved.	It can occur from both living and non-living surfaces.
4	This involves different types of pressures such as vapour pressure, diffusion pressure, osmotic pressure etc.	In the process, no such forces are involved.
5	It helps in keeping the surface of leaf and young stem wet to protect from sun burning.	It causes dryness of the free surface

Kinds of transpiration

1. **Cuticular Transpiration:** Cuticle is a layer of wax like covering on the epidermis of leaves and herbaceous stem.

   Up to 20 per cent of the total transpiration may take place through it.

2. **Lenticular Transpiration:** Lenticles are the areas in the bark which are filled with loosely arranged cells known as complementary cells.

   The water vapour lost through lenticles amounts to about 0.1 per cent of the total loss. It is quite negligible in comparision to total loss by the whole plant.

3. **Stomatal Transpiration:** Stomata are minute pores in the epidermis their opening and closing being controlled by guard cells.

   Maximum diffusion of water vapour take place through these pores and accounts for 80-90% per cent of the total loss.

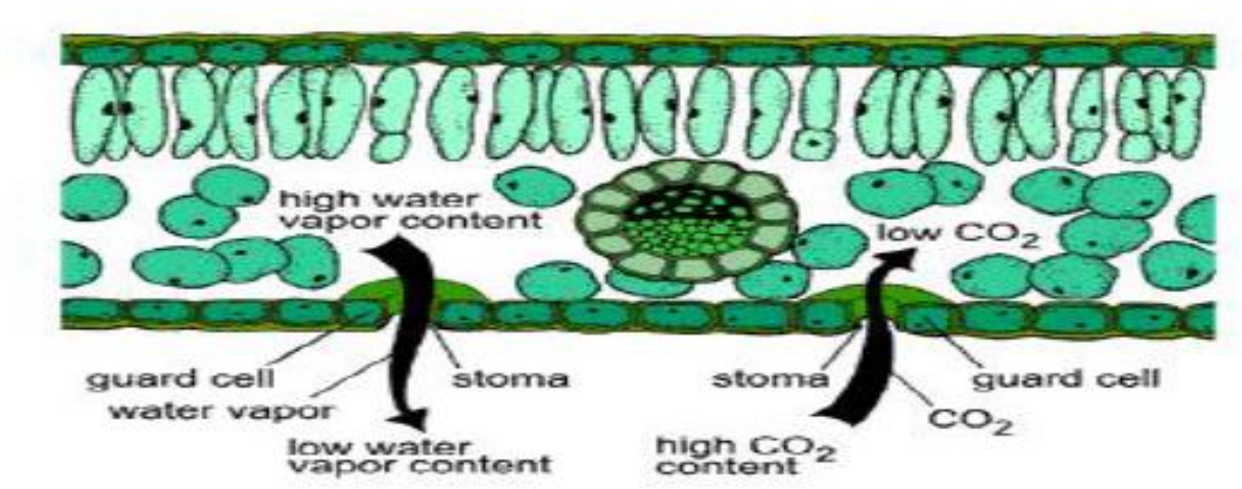
Transpiration is a necessary evil

- Transpiration is purely incidental due to structural arrangements of plants for exit and entry of gases.

- Transpiration is unavoidable because as long as there is need for entrance and outlet of oxygen and carbon dioxide for photosynthesis and respiration, cells exposed and water will transpire.

- Transpiration is regarded as an unavoidable (necessary) evil. It is unavoidable because leaf structure (stomata) favorable for uptake of Co_2 and O_2 necessary for photosynthesis and respiration is also favorable for the loss of water through transpiration.

- Transpiration is an evil because often it causes injury by dehydration due to heavy transpiration loss when the atmospheric conditions are aggressive such as high light intensity, hot winds, and depleted soil moisture and poor water retentive capacity of soil.



Importance of transpiration

- It creates suction force and help in the ascent of sap.
- It helps in the absorption of water and minerals by roots.
- It helps in evaporating excess amount of water from moist soil.
- It plays a role in translocation of food from one part of the plant to the other.
- It brings opening and closure of stomata which indirectly influences the gaseous exchange for the processes of photosynthesis and respiration.
- It helps in dissipating the excess energy absorbed from the sun, which will otherwise raise the leaf temperature.
- It maintains suitable temperature of leaves by imparting a cooling effect.

Antitranspirants

- In transpiration, almost 98 per cent of water absorbed by the plants is lost and only very less amount is utilised by the plant for its own purpose. Due to this plants have to face several problems. If, somehow, this enormous loss of water can be reduced, it will be an advantage to agriculturists and also to nature.
- The term *antitranspirant is used to designate any material applied to plants for the purpose of retarding transpiration.*
- Some examples of antitranspirants are colourless plastics, silicone oils, low- viscosity waxes, phenylmercuric acetate, abscissic acid, CO_2 etc.

- Colourless plastics, silicone oils and low viscosity waxes belong to one group as these are sprayed on the leaves with the object of forming a film permeable to CO_2 and oxygen but not to water. Only limited success in this approach has been achieved.
- Fungicide phenylmercuric acetate has given promising results as antitranspirant. When applied in low concentration (10^{-4} M), it exercised very little toxic effect upon leaves and resulted in partial closure of stomatal pores for over two weeks.
- Similarly abscisic acid also induces stomatal closure.
- Carbon dioxide is an effective antitranspirant. A little rise in CO_2 concentration from the natural 0.03% to 0.05% induces partial closure of stomata. Its higher concentration cannot be used which results in complete closure of stomata affecting adversely the photosynthesis and respiration. However, usage of CO_2 has one advantage that it inhibits photorespiration. But CO_2 usage cannot be economical and is practically feasible only in experimental glass houses.

Factors affecting transpiration

External

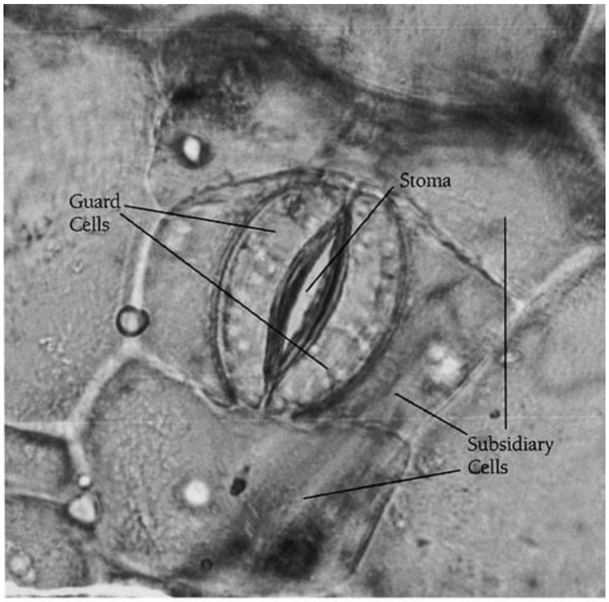
- Atmospheric humidity
- Temperature
- Wind
- CO_2
- Light, Water supply

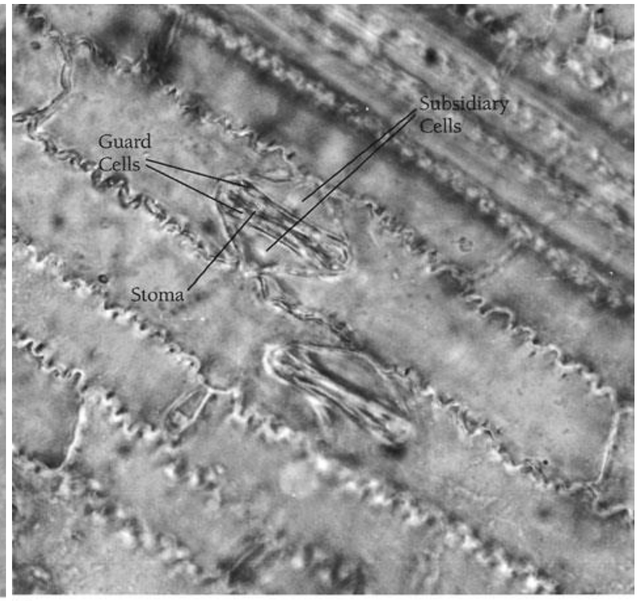
Internal

- Stomatal frequency
- Leaf structure

Measurement of transpiration

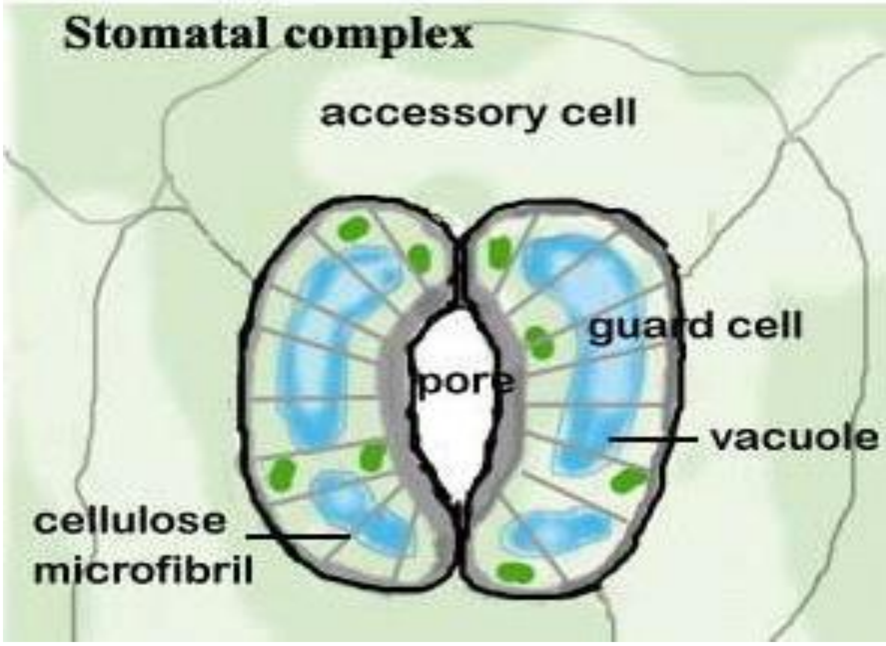
- Cobalt chloride paper method
- Potometer





Stomatal physiology

- Stomata from greek word for "mouth" are structural features of aerial organs of most plants.
- The term *stoma* (singular) denotes a microscopic pore or hole through the surface of the plant organ, which allows communication between the interior of the leaf and the external environment, and a pair of specialized cells- the guard cells- that surround the pore.
- Stomata are minute pores of elliptical shape surrounded by two specialized epidermal cells called **guard cells**. The guard cells are kidney-shaped in dicots and dumble- shaped in the members of Gramineae (monocots).
- The part of wall of the guard cells surrounding the pore is thickened and inelastic due to the presence of a secondary layer of cellulose but rest of the walls is thin, elastic and permeable.
- Each guard cell has a cytoplasmic lining and a central vacuole containing cell sap.
- Its cytoplasm contains a nucleus and number of chloroplasts, often poorly developed and incapable of photosynthesis.
- The epidermal cells surrounding guard cells are specialized and called **subsidiary cells** which support the movement of guard cells.



Common features of guard cells

(1) Thickened inner walls;

(2) Radial micellation - the cellulose microfibrils radiate out around the circumference of the pore;

(3) Chloroplasts - these are the only epidermal cells with chloroplasts;

(4) Connected end-to-end.

- The subsidiary cells are epidermal cells that may be specialized and different from the other epidermal cells. Interestingly, cutin covers most of the cells in the substomatal cavity; only regions near the actual opening are free of cuticle and most water is lost from this area.

Stomata distribution

1. Apple or mulberry type. Stomata are found distributed only on the under surface of leaves, *e.g. peach, mulberry, walnut etc. Such leaves are hypostomatic type.*

2. Potato type. Stomata are found distributed more on the lower surface *(multislomatic)and less on its upper surface (paucistomatic)*, *e.g. potato, cabbage, bean, tomato, pea etc. Such leaves are amphistomatic and anisostomatic type.*

3. Oat type. Stomata are found distributed equally on the two surfaces, *e.g. maize,oats, grasses etc. Such leaves are amphistomatic and isostomatic type.*

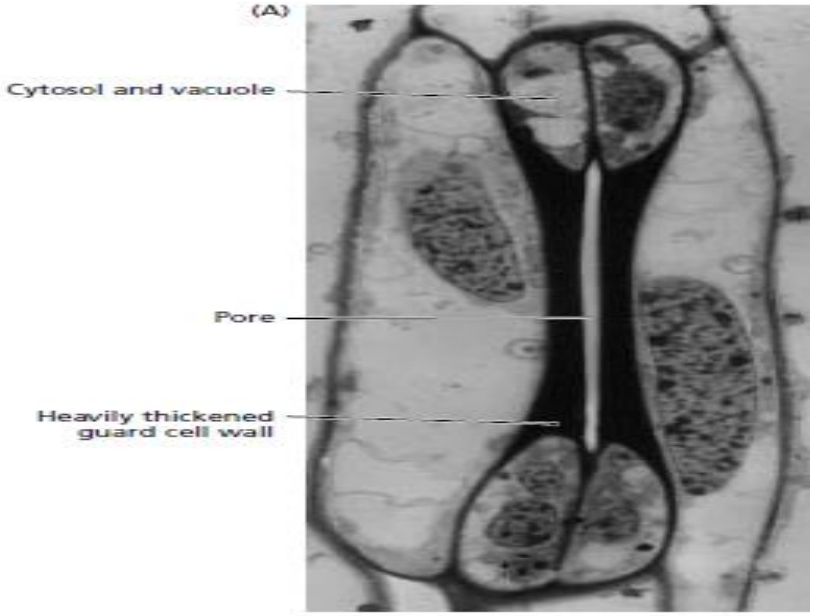
4. Wild lily type. Stomata are found distributed upon the upper epidermis, *e,g, water lily, Nymphaea and many aquatic plants. Such leaves are epistomalic type,*

5. Potamogeton type. Stomata are altogether absent or if present they are vestigial, *e.g. Potamogeton and submerged aquatics.*

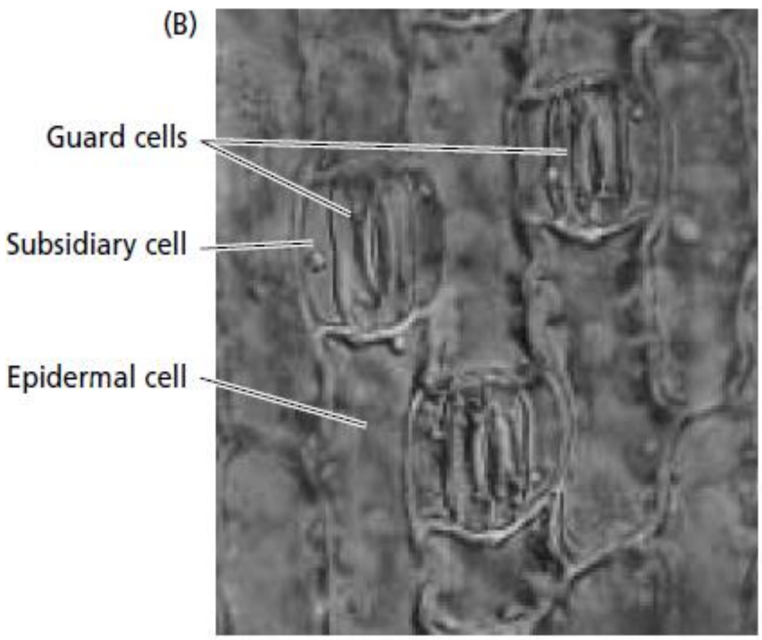
Structure of stomatal complex in monocot and dicot species

- In grasses, guard cells have a characteristic dumbbell shape, with bulbous ends. The pore, proper is a long slit located between the two "handles" of the dumbbells.
- These guard cells are always flanked by a pair of differentiated epidermal cells called **subsidiary cells**, which help the guard cells control the stomatal pores.
- The guard cells, subsidiary cells, and pore are collectively called the **stomatal complex**.

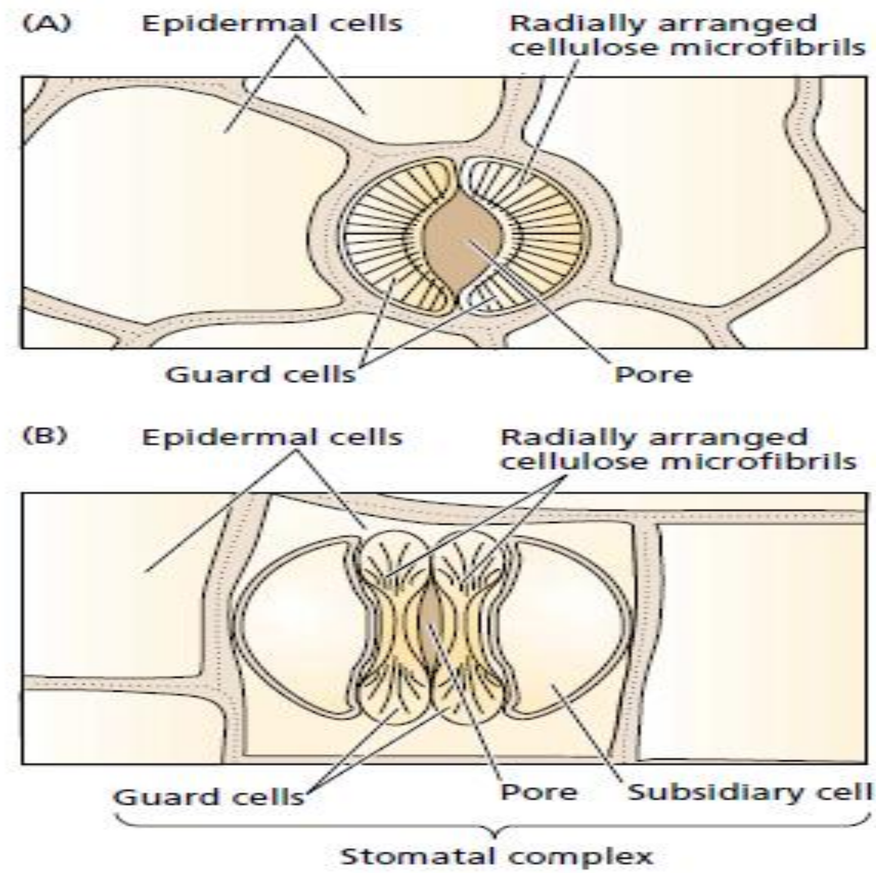
(A)

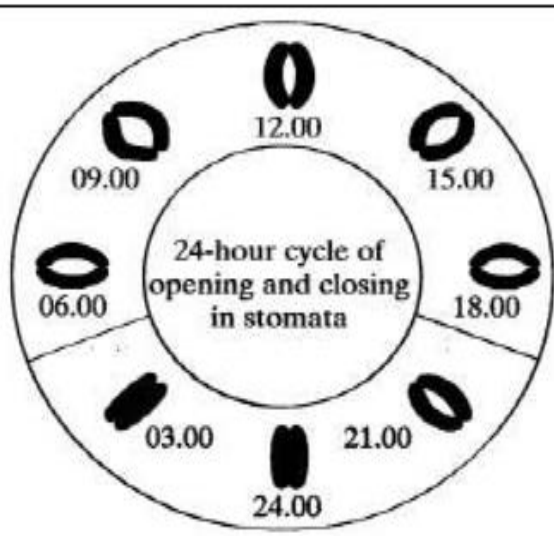


(B)



- In dicot plants and nongrass monocots, kidney-shaped guard cells have an elliptical contour with the pore at its center.
- Although subsidiary cells are not uncommon in species with kidney-shaped stomata, they are often absent, in which case the guard cells are surrounded by ordinary epidermal cells.



	Stomata are not remaining open or close for a whole day. There aperture is change with the time.

Stomata movements

- **Photoactive movements-** Light directly or indirectly controls stomatal movements. Such stomata remain open during the daytime and closed at night.
- **Skotoactive movements-** Stomata remain closed during daytime and open during night. Such cases are found in succulent plants.
- **Hydroactive movements-** In certain cases, stomata open due to excessive loss of water from epidermal cells and close due to turgid condition of epidermal cells. This is usually found during mid-day.
- **Autonomous movements-** In some cases, stomata open and close at a rate of 10-15 minutes showing diurnal or rhythmic pulsation.
- **Passive and active movements-** Opening of stomata is considered an active process while closing is the passive process and this is caused by the turgor changes in the guard cells.

Mechanism of opening and closing of stomata

Theory of photosynthesis in guard cells

- 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.
- <u>**Objection:**</u>

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

(ii) Chloroplast of monocot guard cells are nonfunctional (inactive) photosynthetically.

Theory of starch- sugar Interconversion

- Sayre (1926) observed that stomata open in neutral or alkaline pH, which prevails during day time due to constant removal of carbon-dioxide by photosynthesis.
- Stomata remain closed during night when there is no photosynthesis and due to accumulation of carbon-dioxide, carbonic acid is formed that causes the pH to be acidic.

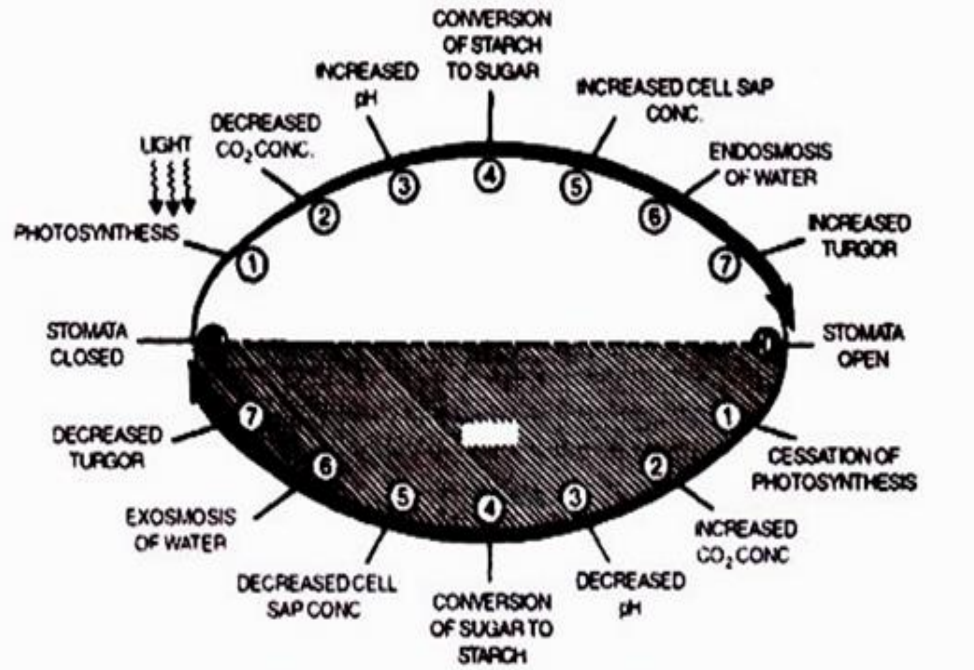


Fig. 4.6 Summary diagram of the mechanism of opening and closing of stomata as explained by starch-sugar interconversion theory.

- Limitation-
- Effect of light is seen for stomatal opening
- Some guard cells lack starch

Starch to Glucose interconversion theory

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

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

(ii) $\text{Glucose-6,P} \xrightarrow{\text{Phosphate}} \underbrace{\text{Glucose + ip}}$

$$\Downarrow$$

Conc. of GC increased

$$\downarrow$$

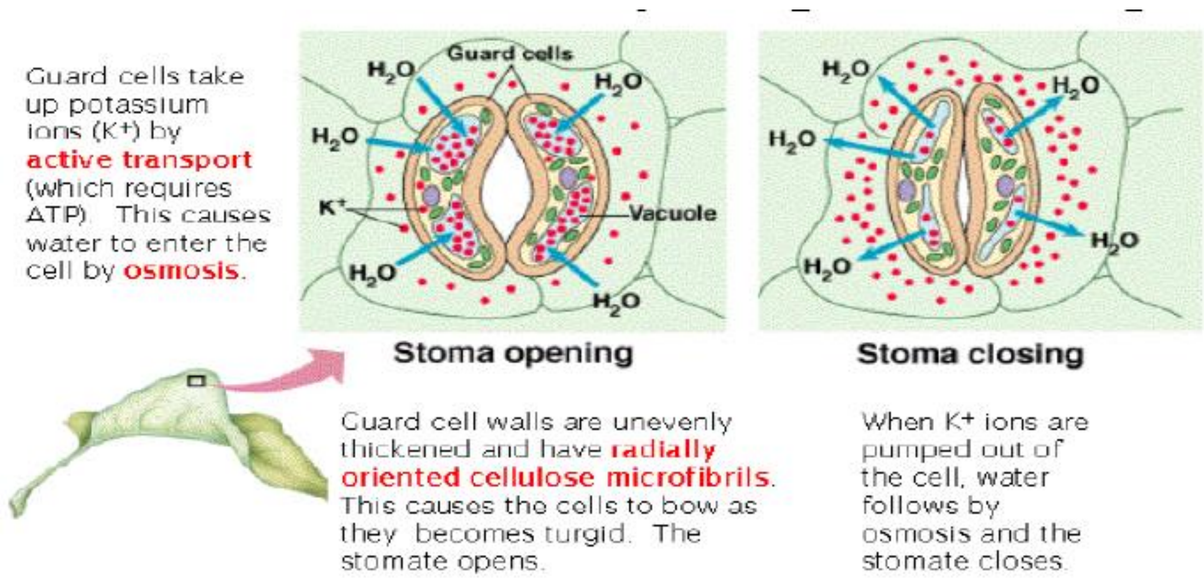
Open stomata $\leftarrow$ GC turgid $\leftarrow$ osmotic entry of H_2O

(iii) Glucose + ATP $\xrightarrow{hexokinase}$

Glucose – 1, P → Starch → Stomata closed

Theory of proton transport and hormonal regulation

- Given by Levitt (1973-74). This is modern & most accepted theory for stomatal opening & closing.
- It appears to be an active mechanism which needs ATP.
- First of all Fujino observed that influx of K^+ ions in guard cells during stomatal opening.



Opening of stomata depends upon following conditions

(a) Presence of light.

(b) Decrease in starch contents of guard cells.

(c) Increased concentration of malic acid in guard cells.

(d) Influx of K^+ ions in guard cells.

(e) Efflux of H^+ ions from guard cells.

(f) Intake of CI ions by guard cells.

(g) Low CO_2 concentration in an around guard cells.

(h) High pH (more than 7) in guard cells (hence, alkaline medium of the cell sap in guard cells).

(i) High T.P. in guard cells due to endosmosis, (turgidity of cells).

(j) TP more towards thin wall of guard cell & stomata open.

- In the guard cells, starch is converted into malic acid in presence of light (during day time).

$$\text{Starch} + H_2O \longrightarrow \text{Hexose Sugars}$$

$$\underset{\text{Hexose}}{2C_6H_{12}O_6} + 3O_2 \longrightarrow \underset{\text{Malic acid}}{3C_4H_6O_5} + 3H_2O$$

Malic acid then dissociated into Matale anions and protons.

$$\underset{\text{Malic acid}}{[R(COOH)_2]} \longmapsto \underset{\text{Malate Anions}}{R(COO)_2^-} + \underset{\text{Protons}}{2H^+}$$

- Protons (H^+) thus formed are used by the guard cells for the uptake of K+ ions (in exchange for the protons H^+).

- This is an active ionic exchange and requires ATP energy and cytokinin (a plant hormone). In this way, the concentration of K^+ ions increases in guard cells. At the same time, the concentration of H+ ions decreases in guard cells.

- The pH of the cell sap in guard cells also increases simultaneously (pH becomes more than 7 and the medium becomes alkaline).

- There is also an increased uptake of CI” (anions) by the guard cells to maintain the electrical and ionic balance inside and outside the guard cells. The malate anions formed in the guard cells are neutralized by the K+ ions. This results in the formation of potassium malate.

- Potassium malate enters the cell sap of the guard cells thereby reducing the water potential while increasing the osmotic concentration (and the O.P.) of the cell sap. Hence, endosmosis occurs, guard cells become turgid and kidney-shaped and the stomata opens.

Closing of Stomata in Absence of Light (Darkness/Night Time):

(a) Absence of light.

(b) Decreased concentration of malic acid in guard cells.

(c) Efflux of K^+ ions from guard cells.

(d) Influx of H^+ ions in guard cells.

(e) Acidic medium of the cell sap in guard cells.

(f) Loss of Cl^- ions from guard cells.

(g) Increases CO_2 concentration in and around guard cell due to release of CO_2 in respiration combined with the absence of photosynthetic activity in dark.

(h) Presence of plant growth inhibiting hormone abscissic acid (ABA),

(i) Loss of turgidity and loss of kidney-shape by guard cells.

- All these conditions represent the reversal of the daytime events. Under these conditions, the guard cells lose water by exosmosis and become flaccid. This causes closing of the stomata.

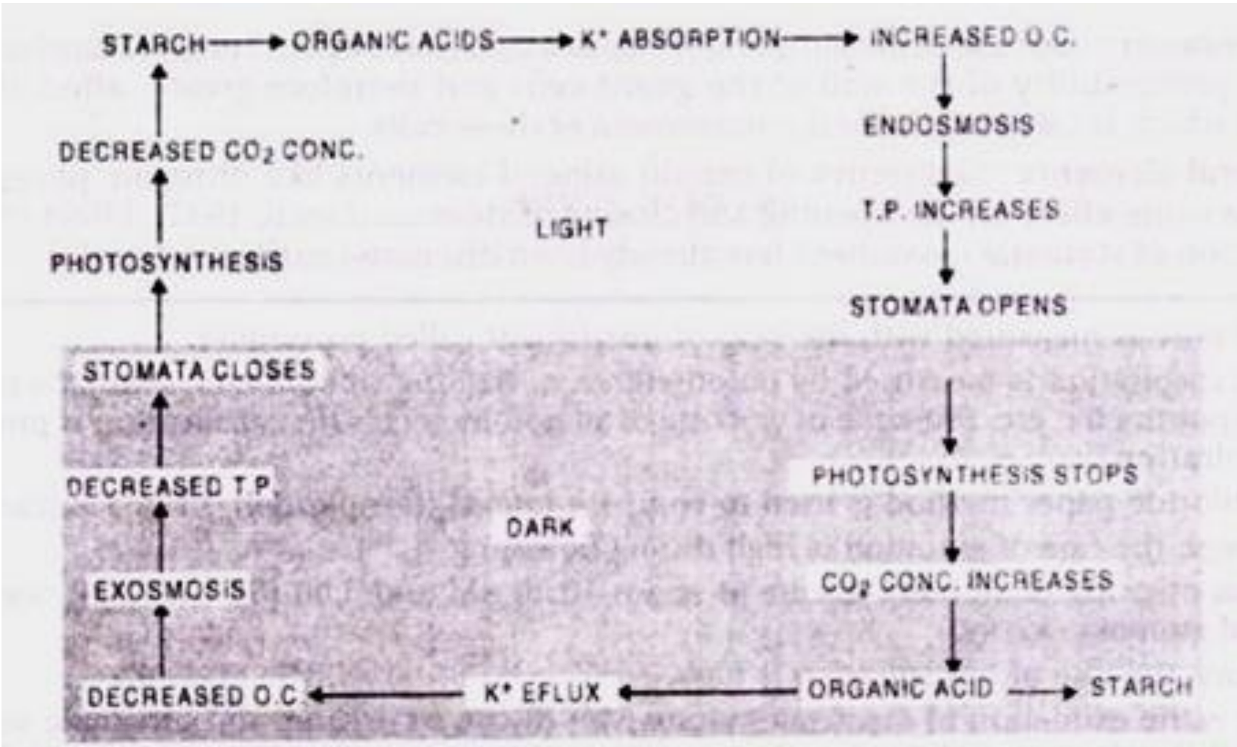
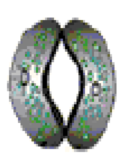
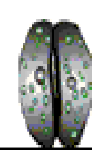


Fig. 4.8 Schematic diagram to explain active potassium ion (K^+) transport in plants.

MECAHNISM OF STOMATA OPENING AND CLOSING	
During day light	During night/dark
Accumulation of K^+ ions by the guard cells	Loss of K^+ ions by the guard cells
Increased solute concentration	Decreased solute concentration
Decreased water potential	Increased water potential
Endosmosis of water	Exosmosis of water
Increased turgidity	Decreased turgidity
Stoma open 	Stoma close 

Role of hormones

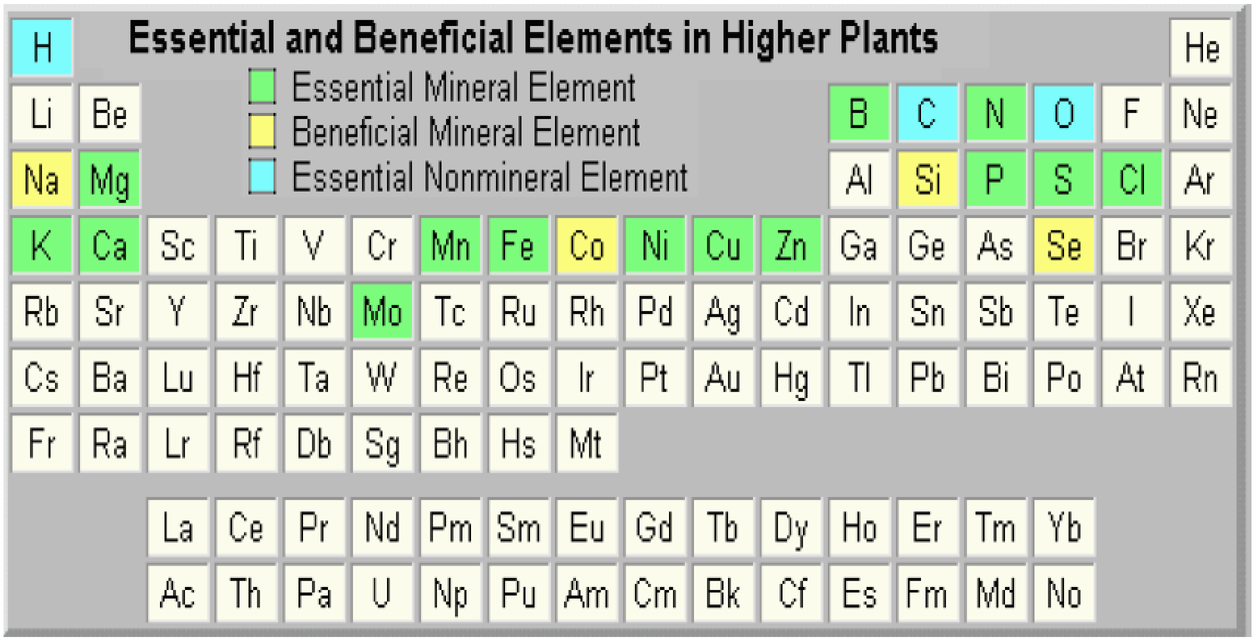
- Presence of Cytokinin (Plant growth regulator) is needed for the active uptake of K^+ ions
- Presence of ABA (abscissic acid, a plant growth inhibiting hormone) favours closing of stomata by blocking uptake of K^+ by guard cells in the dark. It also prevents efflux of H^+ ions from guard cells. ABA and CO_2 cone, together help in lowering the pH in guard cells and making the medium acidic. This helps in closing of stomata. ABA act as stress hormone during drought condition.

Factors affecting opening

- Light
- CO_2 conc
- Hormones

<u>MINERAL NUTRITION</u>

ESSENTIAL & BENEFICIAL ELEMENTS IN HIGHER PLANTS



Five general types of nutrient deficiency symptoms

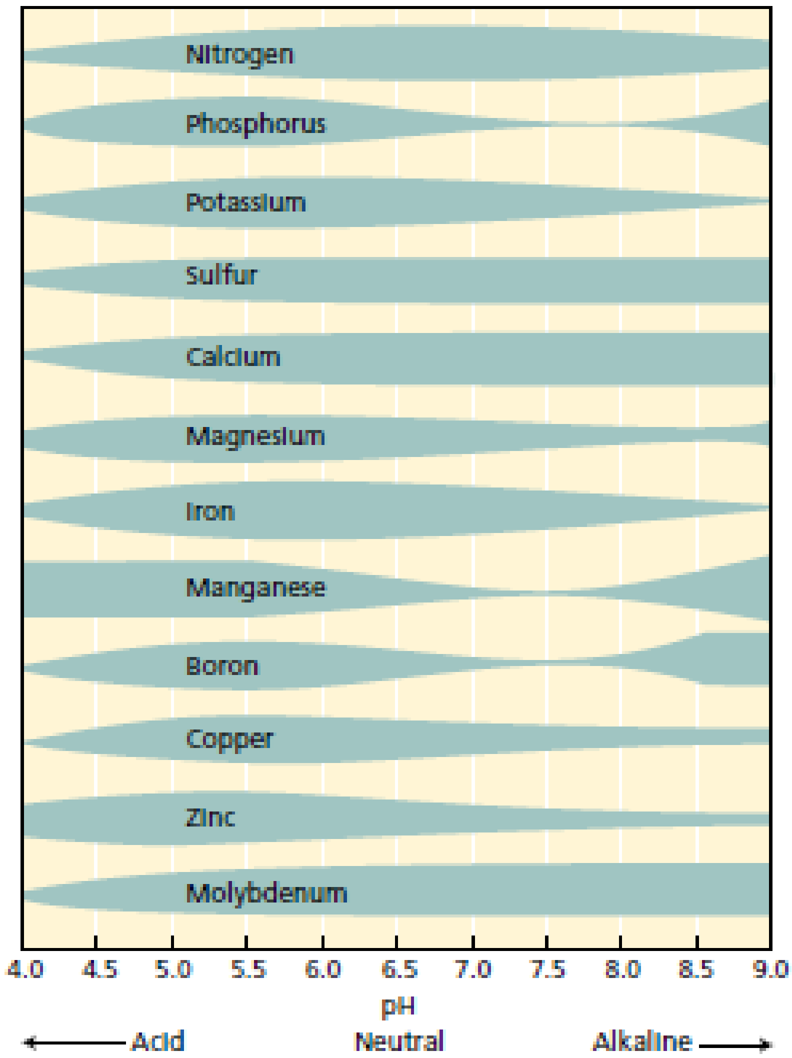
- **Chlorosis**- Yellowing due to the reduction in chlorophyll

- Uniform or interveinal

Interveinal Chlorosis: yellowing in between leaf veins, yet veins remain green.

- **Necrosis-** Death of the plant tissue, tissue browns and dies.
- Lack of new growth or terminal growth resulting in **rosetting**.
- **Anthocyanin accumulation** (when metabolic processes are disrupted) resulting in reddish colour.
- **Stunting:** decreased growth; shorter height of the affected plants.
- **Mottling:** spotted, irregular, inconsistent pattern.
- **Burning**: severe localized yellowing; scorched appearance.
- **Generalized:** symptoms not limited to one area of a plant, but rather spread over the entire plant.

- **Localized:** symptoms limited to one leaf or one section of the leaf or plant.
- **Influence of soil pH on the availability of nutrient elements in organic soils**. The width of the shaded areas indicates the degree of nutrient availability to the plant root. All of these nutrients are available in the pH range of 5.5 to 6.5.



The chemical compounds required by an organism are termed as nutrients

Nutrition may be defined as the supply and absorption of chemical compounds needed for plant growth and metabolism

For plant growth and metabolism, 16 elements are essential.

C, H, O, N, P, K, Ca, S, Mg, Fe, Mn, Zn, B, Cu, Mo and Cl

Essential nutrients of plants

Element	Chemical symbol	Atomic weight	Ionic forms Absorbed by plants	Approximate dry concentration
• ***Macronutrients***				
Nitrogen	N	14.01	NO_3^-, NH_4^+	4.0 %
Phosphorus	P	30.98	PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$	0.5 %
Potassium	K	39.10	K^+	4.0 %
Magnesium	Mg	24.32	Mg^{2+}	0.5 %
Sulfur	S	32.07	SO_4^{2-}	0.5 %
Calcium	Ca	40.08	Ca^{2+}	1.0 %
• ***Micronutrients***				
Iron	Fe	55.85	Fe^{2+}, Fe^{3+}	200 ppm
Manganese	Mn	54.94	Mn^{2+}	200 ppm
Zinc	Zn	65.38	Zn^{2+}	30 ppm
Copper	Cu	63.54	Cu_2^+	10 ppm
Boron	B	10.82	BO_3^{2-}, $B_4O_7^{2-}$	60 ppm
Molybdenum	Mo	95.95	MoO_4^{2-}	2 ppm

Chlorine	Cl	35.46	Cl^-	3000 ppm
• ***Essential But Not Applied***				
Carbon	C	12.01	CO_2	40 %
Hydrogen	H	1.01	H_2O	6 %
Oxygen	O	16.00	O_2, H_2O	40 %

- Plant tissues also contain other elements (Na, Se, Co, Si, Rb, Sr, F, I) which are not needed for the normal growth and development.

These essential elements are classified into two groups

- Major elements (macro nutrients)
- Minor elements (Micro nutrients or Trace elements)

Major elements

- The essential elements which are required by the plants in comparatively large amounts are called as major elements or macro nutrients.

  C, H, O, N, P, K, Ca, S, Mg.

Minor elements

- The essential elements which are required in very small amounts or traces by the plants are called as minor elements or micronutrients or trace elements.

  Fe, Zn, Mn, B, Cu and Mo.

The term essential mineral element was proposed by Arnon and Stout (1939). The authors concluded that for an element to be considered essential, three criteria must be met.

- A given plant must be unable to complete its life cycle in the absence of mineral elements.
- The function of the element must not be replaceable by another mineral element

- The elements must be directly involved in plant metabolism. For eg. as a component of an essential plant constituents or it must be required for a distinct metabolic step such as an enzyme reaction.

Nutrient deficiency symptoms & mobility within plants

- Mobility- The ease with which an element is transported to new plant parts.
- The extent of mobility affects the appearance of deficiency symptoms.
- **Nutrient mobility in plants**
-

Mobiile	**Immobile**
Symptoms appear on the older leaves first	**Symptoms appear in the younger leaves first**
	Sulphur
Nitrogen	Calcium
Phosphorus	Boron, Manganese, Zinc
Potassium	Copper
Magnesium	Molybdenum
	Chloride

Specific roles of essential mineral elements

Nitrogen specific role

- Nitrogen is important constituent of proteins, nucleic acids, porphyries (chlorophylls & cytochromes) alkaloids, some vitamins, coenzymes etc
- Thus N plays very important role in metabolism, growth, reproduction and heredity.

Deficiency symptoms

- Plant growth is stunted because protein content cell division and cell enlargement are decreased

- N deficiency causes chlorosis of the leave i.e yellowing older leaves are affected first
- In many plants eg. tomato, the stem, petiole and the leaf veins become purple coloured due to the formation of anthocyanin pigments.

N deficiency symptoms

Yellowing of mature lower leaves- nitrogen is highly mobile in plants

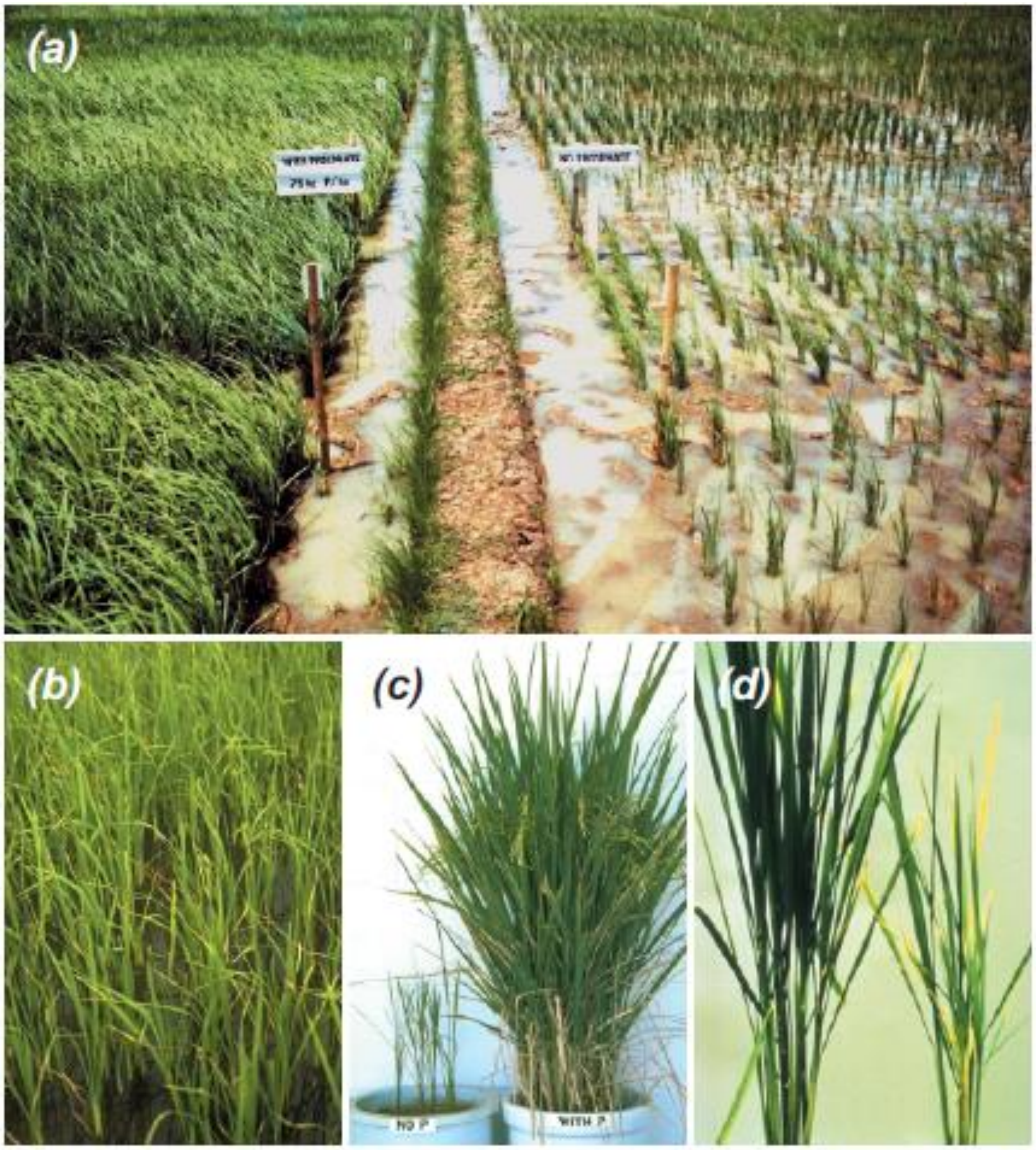
(a) Nitrogen ommission from a plot
(b) Small size of leaves
(c) & (d) Reduced tillering observed in (c)

Phosphorus

- **It is important constituent of nucleic acids, phospholipids, coenzymes NADP, NADPH and ATP**
- **Phospholipids along with proteins may be important constituents of cell membranes**
- **P plays important role in protein synthesis through nucleic acids and ATP**
- **Through coenzymes NAD, NADP and ATP, it plays important role in energy transfer reactions of cell metabolism eg. photosynthesis, respiration and fat metabolism etc.**

Deficiency symptoms

- **P deficiency may cause premature leaf fall**
- **Dead necrotic areas are developed on leave or fruits**
- **Leaves may turn to dark green to blue green colour. Sometimes turn to purplish colour due to the synthesis and accumulation of anthocyanin pigments.**



Phosphorus deficiency symptoms in rice

(a) Tillering is reduced where P is deficient. (b) Even under less pronounced P deficiency, stems are thin and spindly, and plant development is retarded. (c), (d) Plants are stunted, small, and erect compared with normal plants.

Potassium

Specific role

- Although potassium is not a constituent of important organic compound in the cell, it is essential for the process of respiration and photosynthesis
- It acts as an activator of many enzymes involved in carbohydrate metabolism and protein synthesis
- It regulates stomatal movement
- Regulates water balance

Deficiency symptoms

- Mottled chlorosis of leaves occurs
- Necrotic areas develop at the tip and margins of the leaf
- Plants growth remains stunted with shortening of internodes.



Leaf margins become yellowish brown

Calcium

- It is important constituent of cell wall
- It is essential in the formation of cell membranes
- It helps to stabilize the structure of chromosome
- It may be an activation of may enzymes

Deficiency symptoms

- Calcium deficiency causes disintegration of growing meristematic regions of root, stem and leaves
- Chlorosis occurs along the margins of the younger leaves
- Malformation of young leaves takes place

Blossom End Rot of Tomato Calcium Deficiency

Fig.26: Water-soaked spot (blossom end rot) on tomato fruits

Occurs when calcium is not readily available to developing fruits

Magnesium

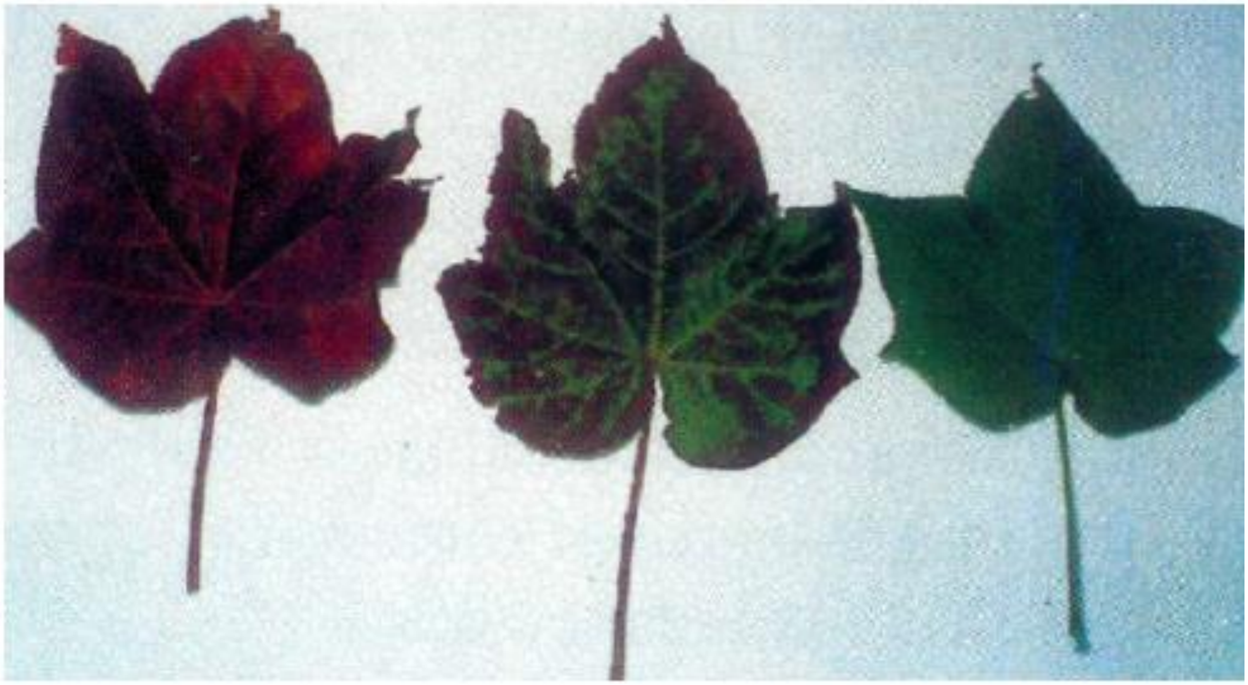
- **It is very important constituent of chlorophylls**
- **It acts as activation of many enzymes in nucleic acid synthesis and carbohydrate metabolism**
- **It plays important role in binding ribosomal particles during protein synthesis.**

Deficiency symptoms

- **Mg deficiency causes mottled chlorosis with veins green and leaf tissues yellow or white appearing first on older leaves**
- **Dead necrotic patches appear on the leaves**
- **In cotton Mg deficiency leads o reddening of leaves and disorder is called as reddening in cotton.**

Magnesium (Mg) Deficiency on Poinsettia

Interveinal Chlorosis on Mature Leaves



Sulphur

- **It is important constituent of some amino acids (cystine, cysteine and methionine) with which other amino acids form the protein**
- **S helps to stabilize the protein structure**
- **It is also important constituent of vitamin i.e biotin, thiamine and coenzyme A**
- **Sulphhydryl groups are necessary for the activity of many enzymes.**

Deficiency symptoms

- **Deficiency causes chlorosis of the leaves**
- **Tips and margins of the leaf roll in ward**
- **Stem becomes hard due to the development of sclerenchyma.**

Mineral Nutrition

Iron

- Important constituent of iron porphyrin – proteins like cytochromes, peroxidases, catalases, etc.
- It is essential for chlorophyll synthesis
- It is very important constituent of ferredoxin which plays important role in photochemical reaction in photosynthesis and in biological nitrogen fixation.

Deficiency symptoms

- Iron deficiency causes chlorosis of young leaves which is usually interveinal.
- These symptoms appear initially on younger leaves because iron cannot be readily mobilized from older leaves.

Zinc

- It is involved in the biosynthesis of growth hormone auxin (indole 3 acetic acid)
- It acts activator of many enzymes like carbonic anhydrase and alcohol dehydrogenase, etc.

Deficiency symptoms

- Zinc deficiency causes chlorosis of the young leaves which starts from tips and the margins
- The size of the young leaves is very much reduced. This disorder is called as 'little leaf disease'
- Stalks will be very short (reduced internodal growth)
- Khaira disease in rice- The entire seedling looks brown (due to chlorosis) & ultimately dies.

Manganese

- It is an activator of many respiratory enzymes
- It is also an activator of the enzyme nitrite reductase
- It is necessary for the evolution of oxygen (photolysis) during photosynthesis

Deficiency symptoms

- The young leaves are affected by mottled chlorosis
- Veins remain green
- Small necrotic spots developed on the leaves with yellow strips
- Grey spec disease in oats, Pahla blight in sugarcane

Copper

- It is an important constituent of plastocyanin (copper containing protein)
- It is also a constituent of several oxidizing enzymes.

Deficiency symptoms

- Copper deficiency causes necrosis of the tip of the young leaves
- It also causes exanthema or die-back of citrus and fruit trees
- Also causes reclamation disease or white tip disease of cereals and leguminous plants.

Boron

- Boron facilitates the translocation of sugars by forming sugar borate complex.
- It involves in cell differentiation and development since boron is essential for DNA synthesis
- Also involves in fertilization, hormone metabolism etc.

Deficiency symptoms

- Boron deficiency causes death of shoot tip
- Flower formation is suppressed
- Root growth is stunted

Molybdeneum

- It is constituent of the enzyme nitrate reductase and thus plays an important role in nitrogen metabolism
- It is essential for flower formation and fruit set.

Deficiency symptoms

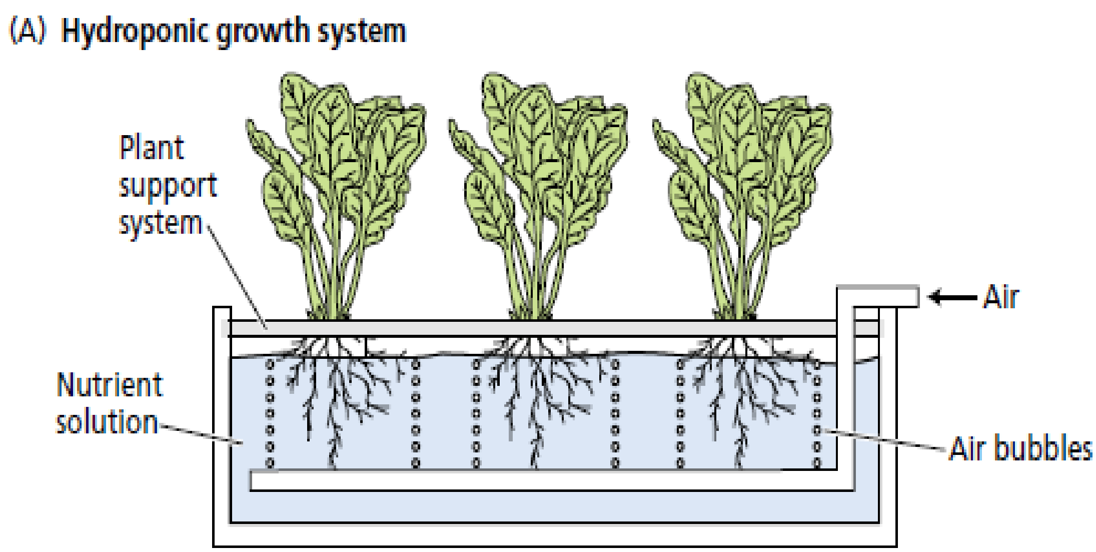
- Molybdenum deficiency causes interveinal chlorosis of older leaves
- Flower formation is inhibited
- Causes whiptail disease in cauliflower plants.

MOLYBDENUM DEFICIENCY ON POINSETTIA

CAULIFLOWER WHIPTAIL

Mineral nutrient	Functions
Group 1	**Nutrients that are part of carbon compounds**
N	Constituent of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, hexoamines, etc.
S	Component of cysteine, cystine, methionine, and proteins. Constituent of lipoic acid, coenzyme A, thiamine pyrophosphate, glutathione, biotin, adenosine-5′-phosphosulfate, and 3-phosphoadenosine.
Group 2	**Nutrients that are important in energy storage or structural integrity**
P	Component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, etc. Has a key role in reactions that involve ATP.
Si	Deposited as amorphous silica in cell walls. Contributes to cell wall mechanical properties, including rigidity and elasticity.
B	Complexes with mannitol, mannan, polymannuronic acid, and other constituents of cell walls. Involved in cell elongation and nucleic acid metabolism.
Group 3	**Nutrients that remain in ionic form**
K	Required as a cofactor for more than 40 enzymes. Principal cation in establishing cell turgor and maintaining cell electroneutrality.
Ca	Constituent of the middle lamella of cell walls. Required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids. Acts as a second messenger in metabolic regulation.
Mg	Required by many enzymes involved in phosphate transfer. Constituent of the chlorophyll molecule.
Cl	Required for the photosynthetic reactions involved in O_2 evolution.
Mn	Required for activity of some dehydrogenases, decarboxylases, kinases, oxidases, and peroxidases. Involved with other cation-activated enzymes and photosynthetic O_2 evolution.
Na	Involved with the regeneration of phosphoenolpyruvate in C_4 and CAM plants. Substitutes for potassium in some functions.
Group 4	**Nutrients that are involved in redox reactions**
Fe	Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N_2 fixation, and respiration.
Zn	Constituent of alcohol dehydrogenase, glutamic dehydrogenase, carbonic anhydrase, etc.
Cu	Component of ascorbic acid oxidase, tyrosinase, monoamine oxidase, uricase, cytochrome oxidase, phenolase, laccase, and plastocyanin.
Ni	Constituent of urease. In N_2-fixing bacteria, constituent of hydrogenases.
Mo	Constituent of nitrogenase, nitrate reductase, and xanthine dehydrogenase.

- **Hydroponics-** The technique of growing plants with their roots immersed in nutrient solution without soil is called solution culture or hydroponics.



Nutrient uptake mechanisms

- Previously, it was thought that the absorption of mineral salts from the soil took place along with the absorption of water, but it is now well established that the mineral salt absorption and water absorption are two independent processes.
- Mineral salts are absorbed from the soil solution in the form of ions.
- They are chiefly absorbed through the meristematic regions of the roots near tips.
- Plasma membrane of the root cells is not permeable to all the ions.
- It is selectively permeable. All the ions of the same salt are not absorbed at equal rate but there is unequal absorption of ions.
- First step in the absorption of mineral salts is the process of Ion-Exchange which does not require metabolical energy but greatly facilitates mineral salt absorption.

Passive absorption of minerals

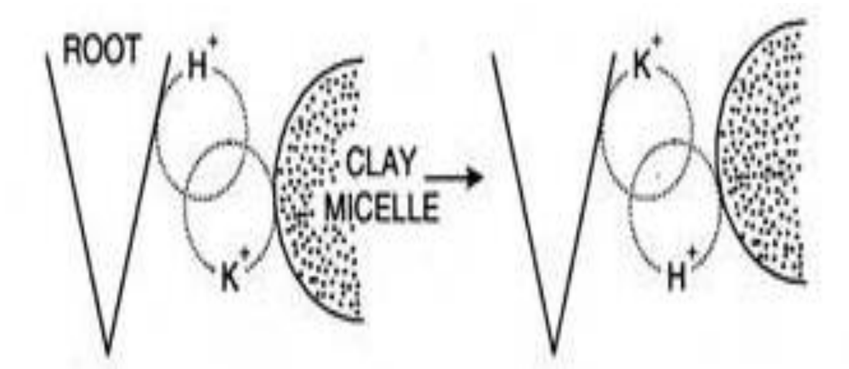
- When the concentration of mineral salts is higher in the outer solution than in the cell sap of the root cells, the mineral salts are absorbed according to the concentration gradient by simple process of diffusion.
- This is called as passive absorption because it does not require expenditure of metabolic energy.
- In Passive absorption—
- Mineral salt absorption is not affected by temperature and metabolic inhibitors.
- Rapid uptake of ions occurs when plant tissues are transferred from a medium of low concentration to high concentration.

Mass flow theory

- According to this theory ions are absorbed by the root along with mass flow of water under the effect of transpiration.
- An increase in transpiration pull increases the uptake of ions by the roots, (the uptake of ions by free diffusion).
- Thus, mass flow of ions through the root tissues occurs due to transpiration pull in the absence of metabolic energy.

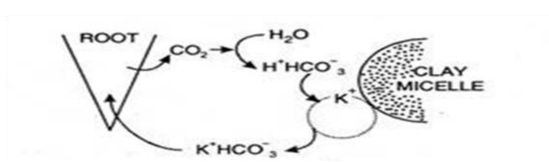
Contact exchange theory

- According to this theory, the ions adsorbed on the surface of root cells and clay particles (or clay micelles) are not held tightly but oscillate within small volume of space.
- If the roots and clay particles are in close contact with each other, the oscillation volume of ions adsorbed on root-surface may overlap the oscillation volume of ions adsorbed on clay particles, and the ions adsorbed on clay particle may be exchanged with the ions adsorbed on root-surface directly without first being dissolved in soil solution.



Carbonic acid exchange theory

- According to this theory, the CO_2 released during respiration of root cells combines with water to form carbonic acid (H_2CO_3).
- Carbonic acid dissociates into H^+ and an anion HCO_3^- in soil solution. These H^+ ions may be exchanged for cations adsorbed on clay particles.
- The cations thus released into the soil solution from the clay particles, may be adsorbed on root cells in exchange for H^+ ions or as ion pairs with bicarbonate.
- Thus, soil solution plays an important role in carbonic acid exchange theory.



Donnan equilibrium

- This theory explains the passive accumulation of ions against the concentration gradient or electrochemical potential (ECP) without ATP.

- At the inner side of cell membrane which separates from outside (external medium), there are some anions which are fixed or non diffusible and membrane is impermeable to these anions, while cations are diffusible.
- Cell membrane is composed of macromolecules of proteins and lipids that have many carboxyl groups (-COOH) and phosphate (HPO3-) groups, from which positively charged particles like protons of hydrogen (H+) can dissociate, leaving the macromolecules with negative charge.
- Thus the membrane is usually negatively charged. The negative charges are not diffusible because they are within the membrane structure.
- These negatively charged ions on the membrane called fixed ions.
- The negatively charged membrane is called Donnan phase.
- Now, suppose that a solution of potassium chloride (KCl) is present outside the Donnan phase.
- The cations (K+) will tend to diffuse through the membrane because of electronic potential difference.
- The cations will finally come to equilibrium with fixed negative charges of the membrane. The Cl- ions with negative charge will not move into the cell because of this electronic potential.
- The Cl- ions which remain outside the membrane will set up an electric potential difference at the membrane surface which is negative, on account of Cl- ions, compared to the external solution.
- Such an electric potential is called Donnan potential. The Donnan potential will allow K+ to diffuse through the membrane and repel the Cl- ions (opposite charges repel each other), this equilibrium is called Dannan Equilibrium.
- In general, Donnan equilibrium may be expressed in the following equation:

$$\frac{\text{concentration of positive ions (inside)}}{\text{concentration of positive ions (outside)}} = \frac{\text{concentration of negative ions (outside)}}{\text{concentration of negative ions (inside)}}$$

As at Donnan equilibrium, more cations (positively charged ions) tend to pass through the membrane the cations will accumulate in the cell against diffusion gradient.

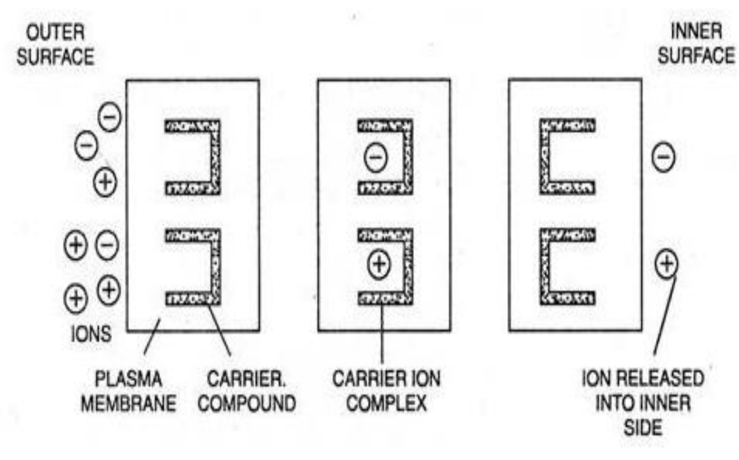
Active absorption of minerals

- The active transport of ions from the outer space of the cell to the inner space is generally occurs against the concentration gradient and hence requires metabolic energy, this energy is obtained from metabolism of the cell either directly or in directly.
- It includes the theories related with carrier concept such as Cytochrome Pump hypothesis, ATP theories, Protein-Lecithin as carrier theories etc.

Carrier Concept Theory (Honert, 1973) (for movement of both cation & anion)

- According to this theory, the ion transport process is carried out by means of carriers, which may be organic molecules or vesicles.
- This theory explains that the plasma membrane is impermeable to free ions. The carrier combines with ions to form carrier ion complex, which can move across the membrane.

- On the inner surface of the membrane, this complex breaks releasing ions into the cell while the carrier goes back to the outer surface to pick fresh ions.
- Here, the metabolic energy is required in the process of formation of carrier-ion complex, its transport, and breakdown of complex, regeneration of carrier and movement of carrier molecules back.



Protein-lecithin as Carrier (Bennet-Clark, 1956)

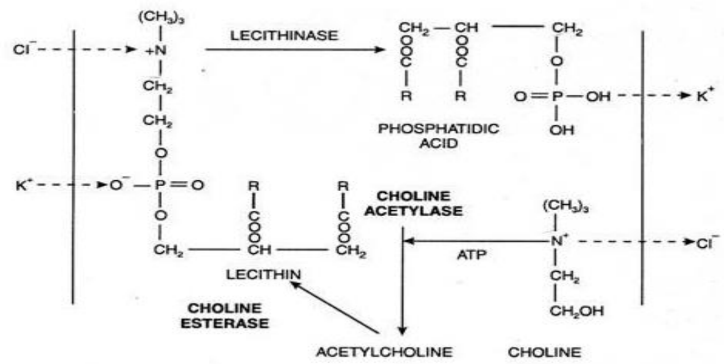
- It is suggested that because the cell membranes chiefly consist of phospholipids and proteins and also certain enzymes seem to be located on them, the carrier could be a protein associated with the phosphotide called as lecithin.
- This theory believes in the participation of some amphoteric compounds as carriers with which both cations and anions can combine.

According to this theory-

1. The acidic phosphate group in the phosphatide is regarded as the active centre binding the cation, and the basic choline group (N^+) as the anion binding centre.

2. The ions are liberated on the inner surface of the membrane by decomposition of the lecithin by the enzyme lecithinase.

3. The regeneration of the carrier lecithin from phosphatidic acid and choline takes place in the presence of the enzymes choline acetylase and choline esterase and ATP. The ATP acts as a source of energy.



Cytochrome-pump Theory
(For the movement of anions only)

- Lundegardh and Burstrom (1933) claimed that a quantitative relaionship exists between anion absorption and respiration.

- When a plant is transferred from water to salt solution, the rate of respiration will increases. They called this increase in respiration as Salt Respiration.

- Anions could be transported across the membrane by cytochrome system. Energy is supplied by direct oxidation of respiratory intermediates.

- This mechanism of ion transport is based on electrochemical gradient generated by electron transport.

- Dehydrogenase reactions on inner side of the membrane give rise to protons (H^+) and electrons (e^-).

2. The electron travels over the cytochrome chain towards outside the membrane, so that the Fe of the cytochrome becomes reduced (Fe^{++}). on the outer surface and oxidized (Fe^{+++}) on the inner surface.

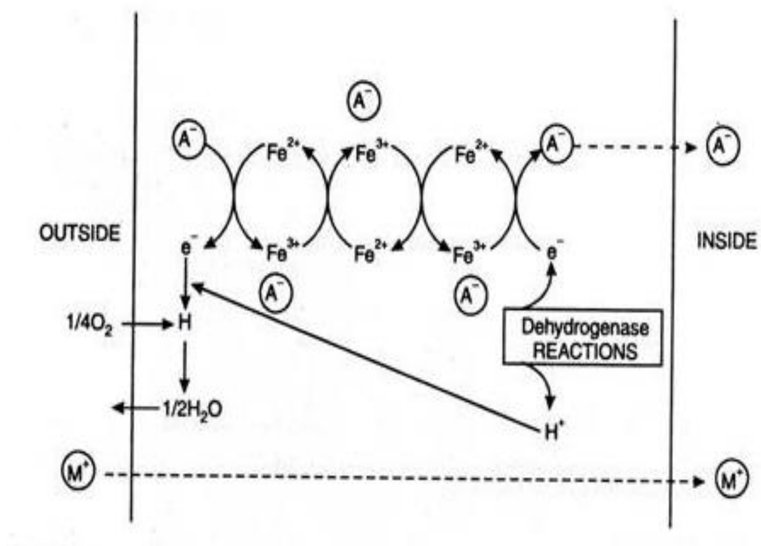
3. On the outer surface, the reduced cytochrome is oxidised by oxygen releasing the electron (e^-) and taking an anion (A^-)

4. The electron thus released unites with H^+ and oxygen to form water.

5. The anion (A-) travels over the cytochrome chain towards inside.

6. On the inner surface, the oxidised cytochrome becomes reduced by taking an electron produced through the dehydrogenase reactions and the anion (A-) is released.

7. As a result of anion absorption, a cation (M+) move passively from outside to inside to balance the anion.



ATP theories

- According to this theory, ion uptake into the cell is energized by ATP molecules. The energy from hydrolysis of ATP molecules can be made available to energies ion pumps through the action of enzymes.
- Case I
- Here, the organic compound is first phosphorylated which on dephosphorylation makes the organic compound capable to combine with cation. The cation is released when phosphorylation occurs again.
- Case II
- In this case, the phosphorylated organic compound combines with cation and the cations are released on hydrolysis of the complex (dephosphorylation).
- Thus, the role of ATP in this theory is of two kinds. i.e., by removal or addition of phosphate group.

Factors affecting nutrient uptake

i. Temperature

The increase in temperature increases both active and passive salt absorption processes and lowering of temperature decreases them.

ii. pH

It indirectly affects the salt absorption as the pH affects the availability of ions in the medium.

iii. Light

As opened stomata allow more transpiration and increased mass flow and photosynthesis provides energy and O_2 for salt uptake, light indirectly affects the rate of salt absorption by affecting the opening and closing of stomata and the process of photosynthesis.

iv. O_2 content

The deficiency of O_2 decreases salt uptake as the active phase of salt absorption is inhibited by the absence of O_2.

v. Interaction of other ions

The absorption of one ion may be influenced by the presence of other ion. The interaction may be associated with the availability and specificity of binding sites on carriers.

vi. Growth

Different types of growth affect salt absorption in different ways, eg., growth involving increase in surface area, number of cells, synthesis of new binding sites or carriers and volumes of water uptake stimulate salt absorption. Heavily suberised root is unable to absorb salts. Vegetative growth and increased metabolic activity accompanied with more water uptake enhance salt absorption.

Mycorrhizae ????