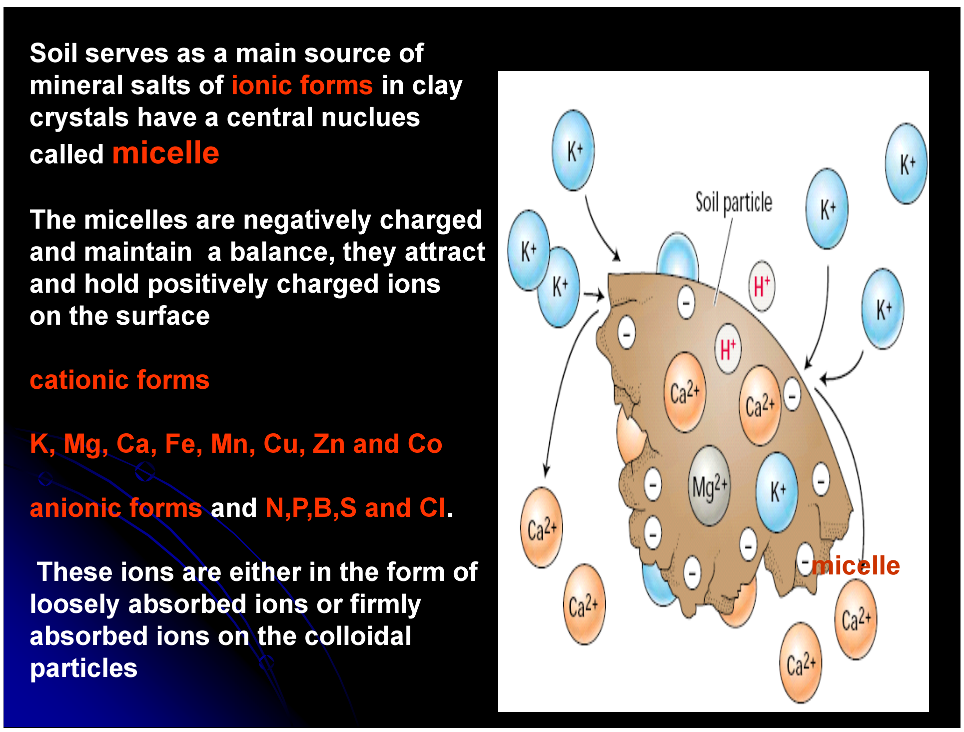
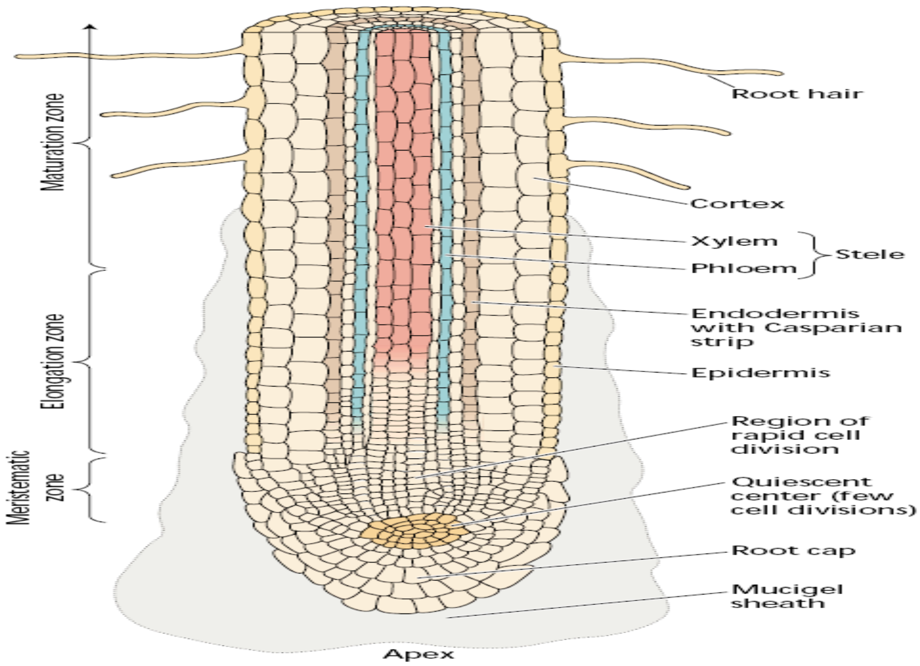
08. MECHANISM OF UPTAKE - PHYSIOLOGICAL ROLE OF NUTRIENTS

Mechanism

Previously it was thought that absorption of mineral salts takes place along with water absorption. But it is now understood that mineral salt absorption and water absorption are two different processes.



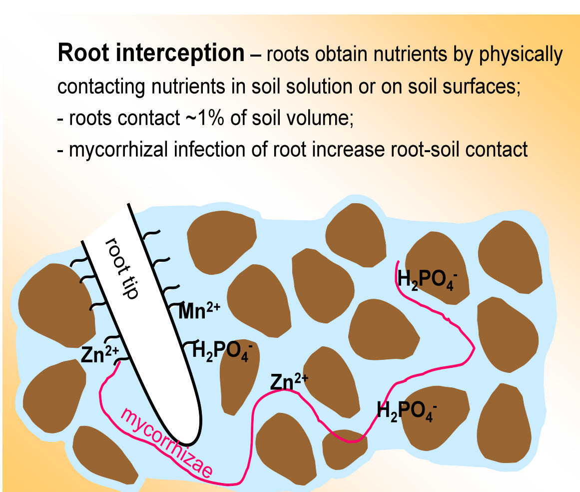
Mineral salts are absorbed from the soil solution in the form of ions. They are chiefly absorbed through the meristematic regions of the roots near the tips.



Plasma membrane of the root cells is not permeable to all the ions. It is selectivity permeable. All the ions of the same salt are not absorbed at equal rate but leads unequal absorption of ions. First step in the absorption of mineral salts is the process of Ion exchange which does not require metabolic energy.

The further processes of the absorption of mineral salts may be of two types.

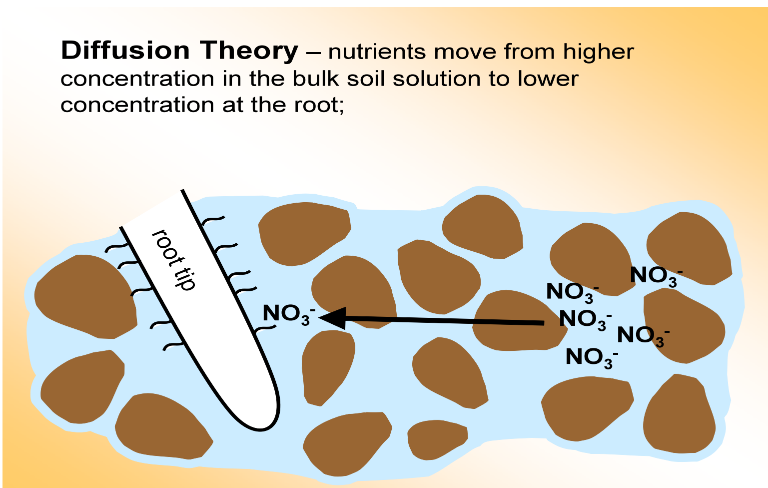
1. Passive and 2. Active



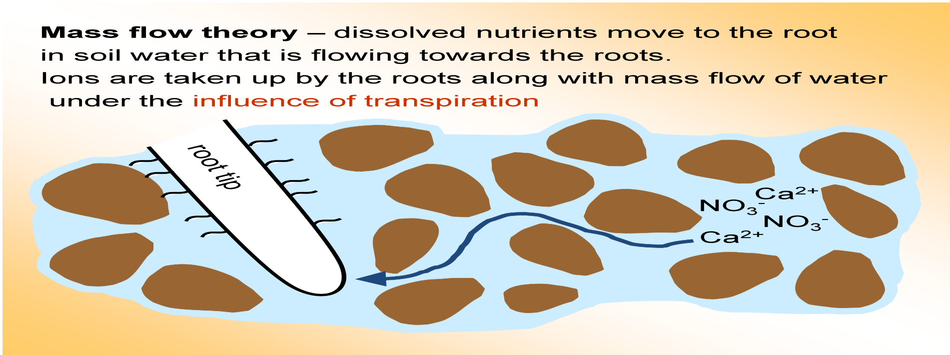
1. Passive absorption

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.

Ion exchange

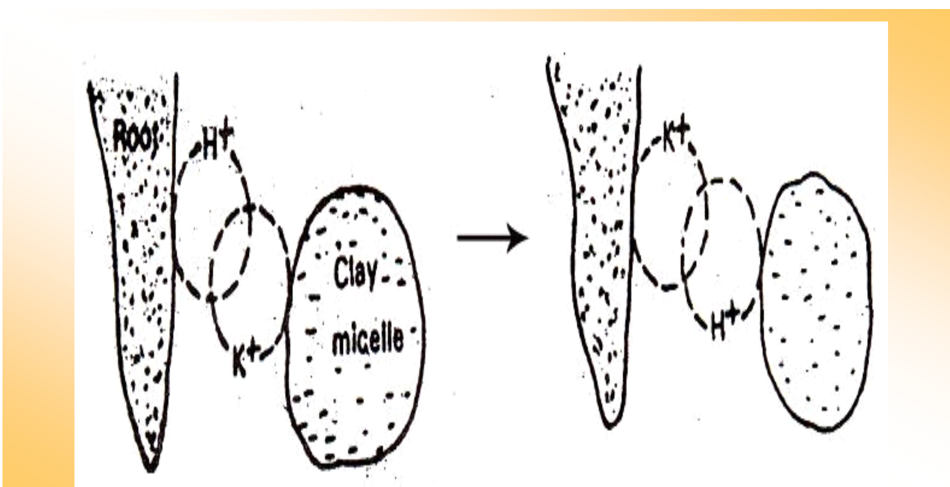


The ions adsorbed on the surface of the plasma membrane of the root cells may be exchanged with the ions of same sign from external solution for eg. The cation K^+ of the external soil solution may exchanged with H^+ ions adsorbed on the surface of the plasma membrane. Similarly anion may be exchanged with OH ions. There are two theories regarding the mechanism of ion exchange.



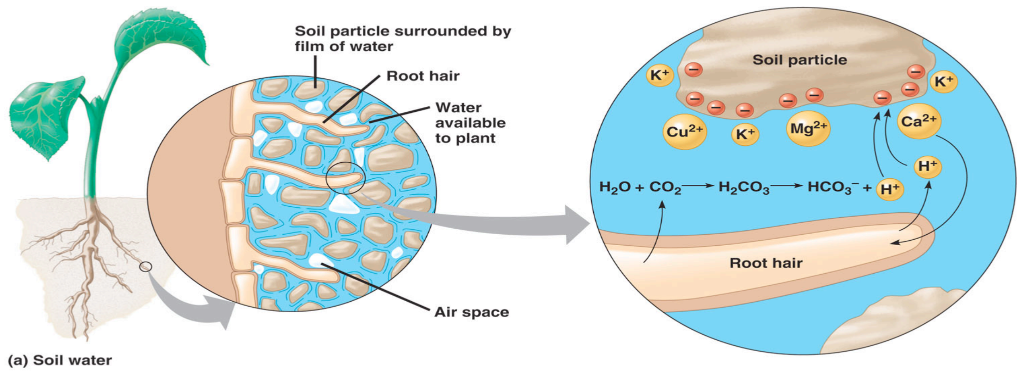
1. Contact exchange theory

According to this theory the ions adsorbed or the surface of root cells and clay particles 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 over by 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.



2. 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 the 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 in ion pairs with bicarbonate. Thus, the soil solution plays an important role in carbonic acid exchange theory.



(a) Soil water

(b) Cation exchange in soil

2. Active absorption of mineral salts

It has been observed that the cell sap in plants accumulates large quantities of mineral slats ions against the concentration gradient. The accumulation of mineral salts against to concentration gradient is an active process which involves the expenditure of metabolic energy through respiration. The active absorption of mineral salts involves the operation of a carrier compound present in the plasma membrane of the cells.

The carrier concept

According to this theory, the plasma membrane is impermeable to free ions. But some compounds present in it acts as carrier and combines with ions to form carrier- ion-complex which can move across the membrane. On the inner side of the membrane this complex leaves releasing ions into the cell while the carrier goes back to the outer surface to pick up fresh ions. They are two hypotheses based on the carrier concept to explain the mechanism of active salt absorption. Although they are not universally accepted.

1. Lundegardhs cytochrome pump theory

Lundegardh and Burstrom (1933) believed that there was a definite correlation between respiration and anion absorption. Thus when a plant is transferred from water to a salt solution the rate of respiration increases. This increase in rate of respiration over the normal respiration has been called as anion respiration or salt respiration.

Lundegardh (1954) proposed cytochrome pump theory which is based on the following assumptions.

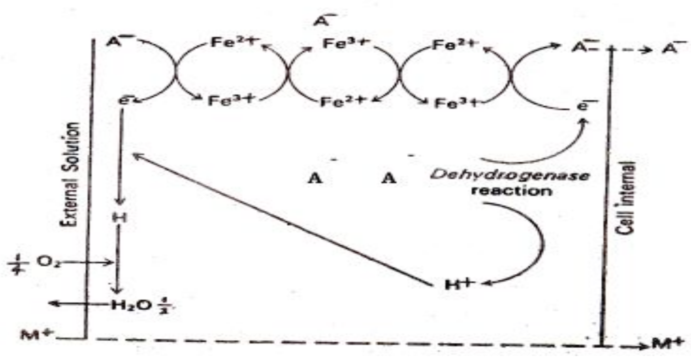
1. The mechanism of anion and cation absorption is different
2. Anions are absorbed through cytochrome chain by an active process.

(Cytochromes are ion – porphyrin proteins that act as enzymes and helps in election transfer during respiration).

3. Cations are absorbed passively.

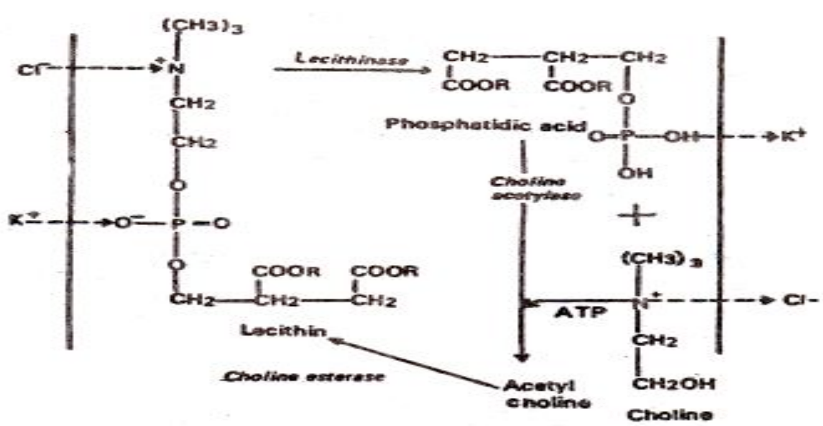
According to this theory

1) Dehydrogenase reactions on inner side of the membrane give rise to protons (H^+) and electrons (e^-).
2) The electrons 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 oxidized 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 oxidized cytochrome becomes reduced by taking an electron produced through the dehydrogenase reactions and the anion (A) is released.
7) As the result of anion absorption, a cation (M) moves passively from outside to inside to balance the anion.



2. Bennert – Clark's protein Lecithin Theory

In 1856, Bennet – Clark suggested that because the cell membranes chiefly consist of phospholipids and proteins and certain enzymes seem to be located on them, the carrier could be a protein associated with the phosphatide called as lecithin. He also assumed the presence of different phosphatides to correspond with the number of known competitive groups of cations and anions.



According to this theory

1. Phosphate group in the phosphatide is regarded as the active centre binding the cations and the basic choline group as the anion binding centre.
2. The ions are liberated on the inner surface of the membrane by decomposition of lecithin by the enzyme lecithinase.

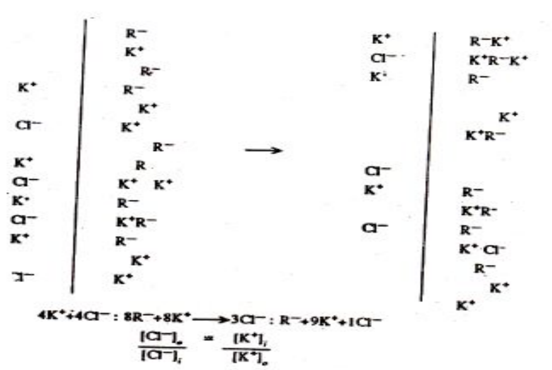
3. The regeneration of the carrier lecithin form phosphatidic acid and choline takes place in the presence of the enzyme choline acetylase and choline esterase and ATP. The latter acts as a source of energy.

Donnans' Equilibrium

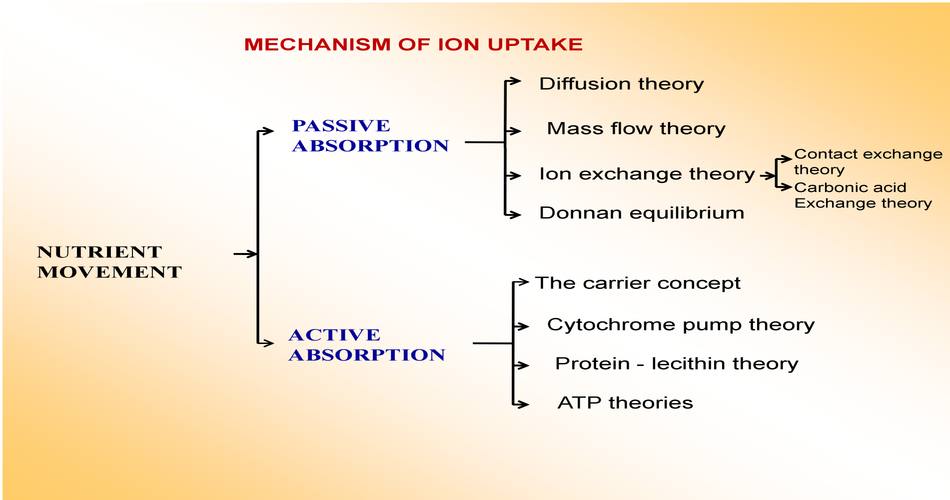
The accumulation of ions inside the cells without involving expenditure of the metabolic energy can be explained to some extent by Donnan's equilibrium theory.

According to this theory there are certain pre existing ions inside the cell which cannot diffuse outside through membrane. Such ions are called as in diffusible or fixed ions. However, the membrane is permeable to both anions and cations of the outer solutions.

Suppose there are certain fixed anions in the cell which is in contact with outer solution containing anions and cations. Normally equal number of anions and cations would have diffused into the cell through an electrical potential to balance each other, but to balance the fixed anions more cations will diffuse into the cell. This equilibrium is known as Donnan's equilibrium. In this particular case, there would be an accumulation of cations inside the cell.



If however, there are fixed cations inside the cell, the Donnan's equilibrium will result in the accumulation of anions inside the cell.



Specific roles of essential mineral elements

A. Macronutrients

1. Nitrogen

- 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.

2. Phosphorus

- It is important constituent of nucleic acids, phospholipids, coenzymes NADP, NADP H_2 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.

Potassium

- 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

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

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.

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
- Sulpho hydryl groups are necessary for the activity of many enzymes.

Iron

- Important constituent of iron porphyrin – proteins like cytochromes, peroxidase, 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.

Micro nutrients

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.

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

Copper

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

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.

Molybdenum

- 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.