LECTURE 3B

UPTAKE OF NUTRIENTS BY PLANTS

Lecture Subtopics

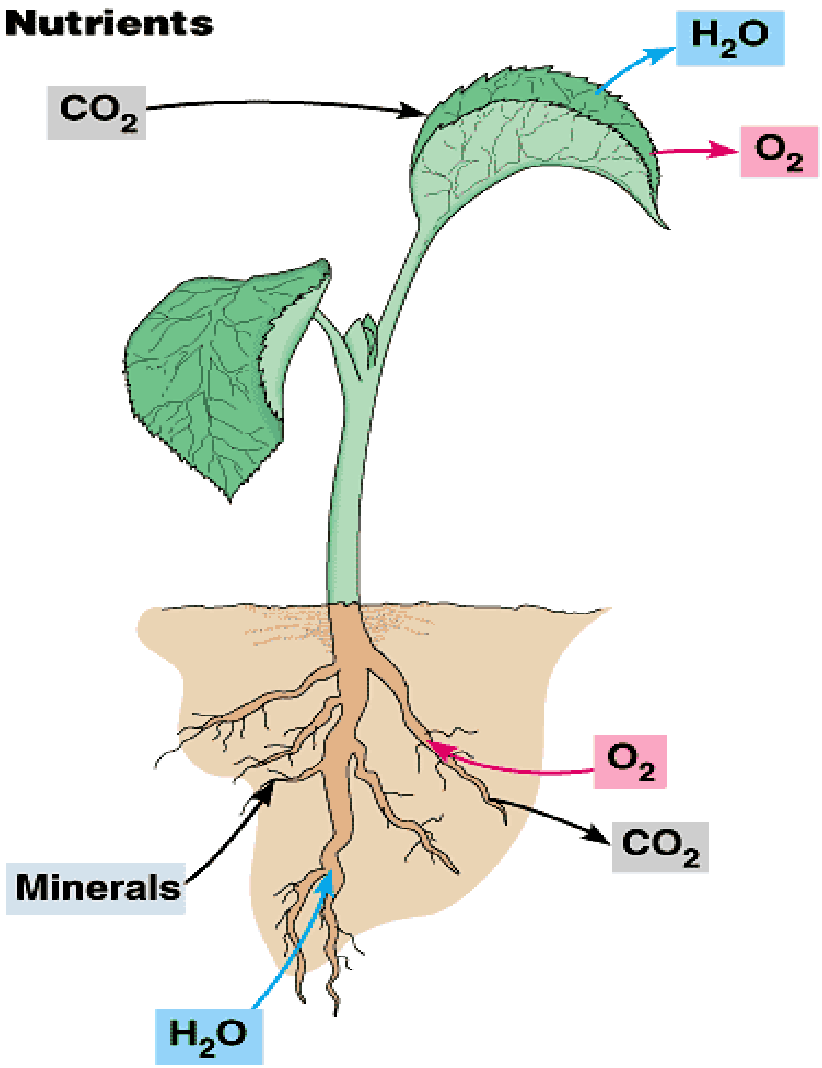
- Passive Absorption.
- Active Absorption.
- Movement of Solutes in the Cells
- Ions accumulation
- Mechanism of ion uptake
- Antagonism
- Factors affecting ion absorption

UPTAKE OF NUTRIENTS BY PLANTS

- Mineral uptake is the process in which minerals enter the cellular material, typically following the same pathway as water.
- The most normal entrance portal for mineral uptake is through plant roots.
- During transport throughout a plant, minerals can exit xylem and enter cells that require them.
- Mineral ions cross plasma membranes by a chemiosmotic mechanism.
- Plants absorb minerals in ionic form: nitrate (NO_3^-), phosphate (HPO_4^-) and potassium ions (K^+); all have difficulty crossing a charged plasma membrane.

UPTAKE OF NUTRIENTS BY PLANTS

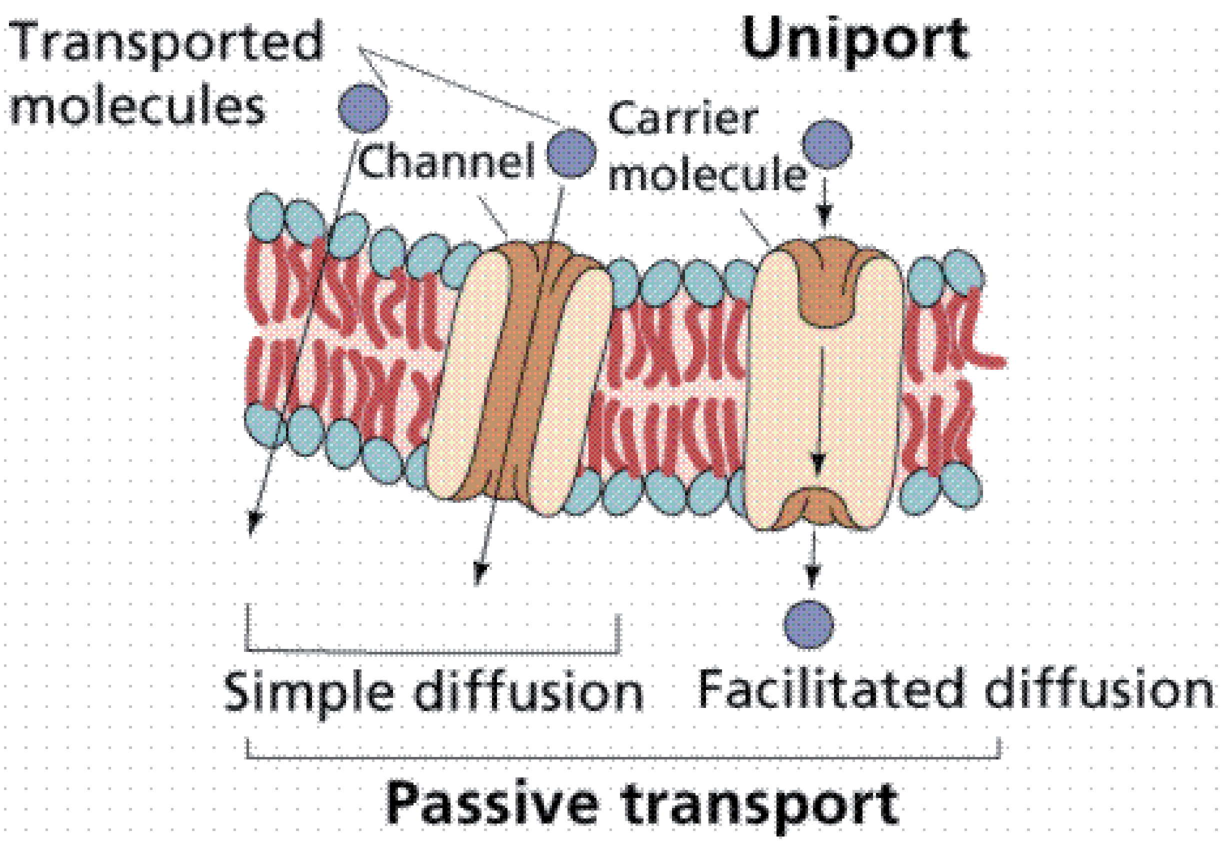
- The uptake of nutrients occurs at both the roots and the leaves.
  - water and minerals
  - CO_2



UPTAKE OF NUTRIENTS BY PLANTS

- Ions may be taken up by the plant cells by two methods:
- 1. Passive Absorption.
- 2. Active Absorption.

Passive Absorption of Ions



Passive Absorption of Ions

- It is the absorption of minerals without direct expenditure of metabolic energy.
- In passive absorption

I. Mineral salt absorption is not affected by temperature and metabolic inhibitors

II. Rapid uptake of ions occurs when plant tissues are transferred from a medium of low concentration to high concentration.

- The major hypotheses (theories) that explain the mechanism of passive transport of ions are:
- 1. mass flow theory.
- 2. Contact Exchange theory.
- 3.Carbonic Acid Exchange Theory
- 4. Donnan Equilibrium

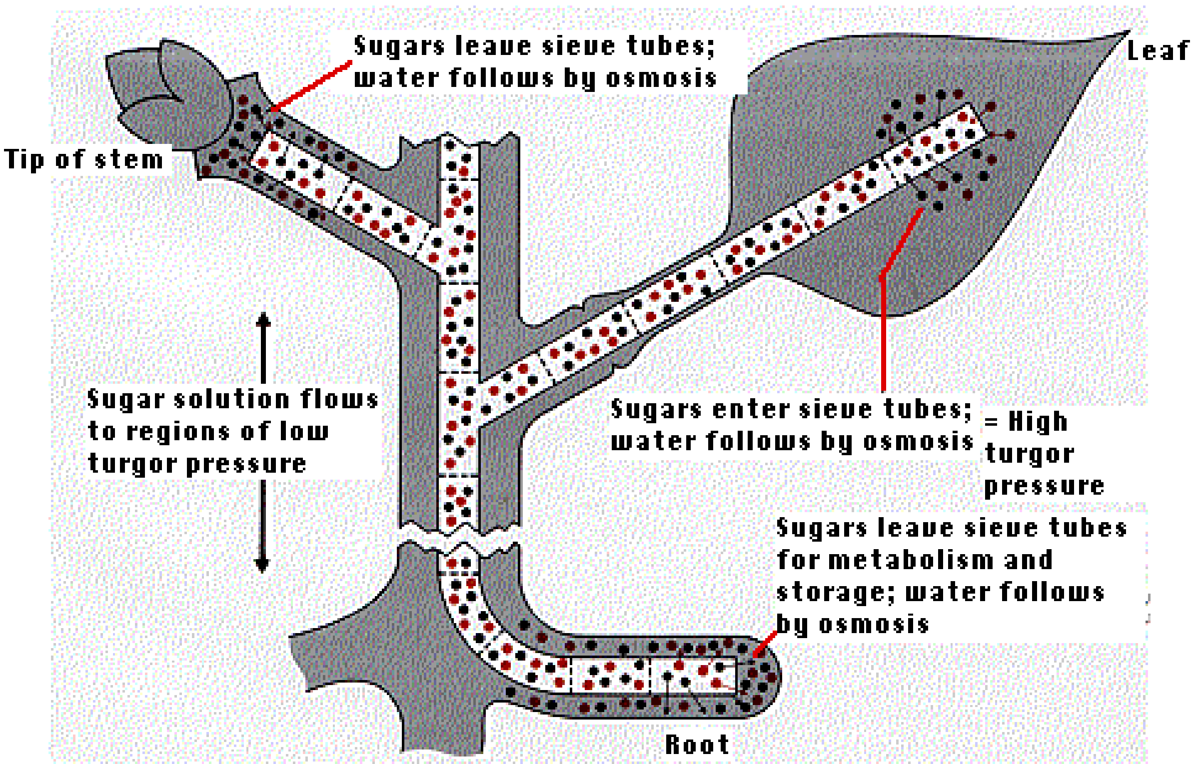
Passive Absorption of Ions

1- Mass flow theory

- According to this theory ions are absorbed by the root along with mass flow of water under the effect of transpiration.
- This theory failed to explain the salt accumulation against osmotic gradient.
- 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.

Passive Absorption of Ions

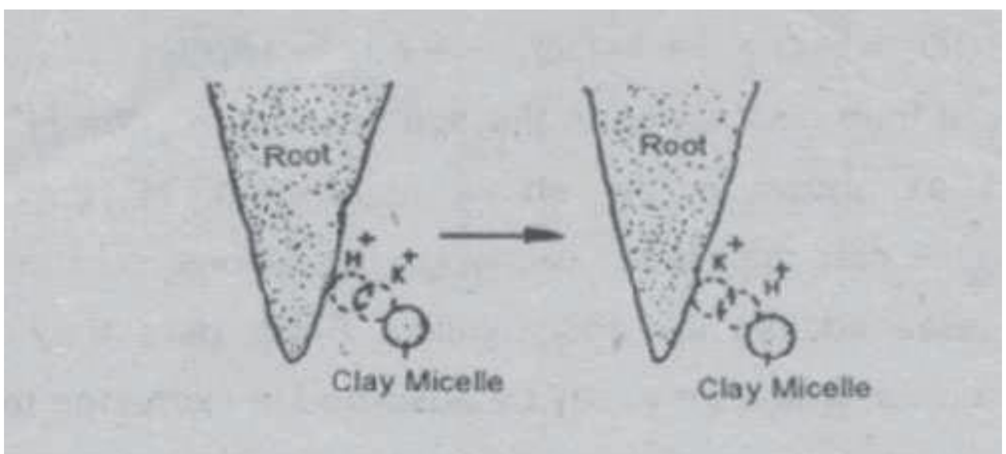
1- Mass flow theory

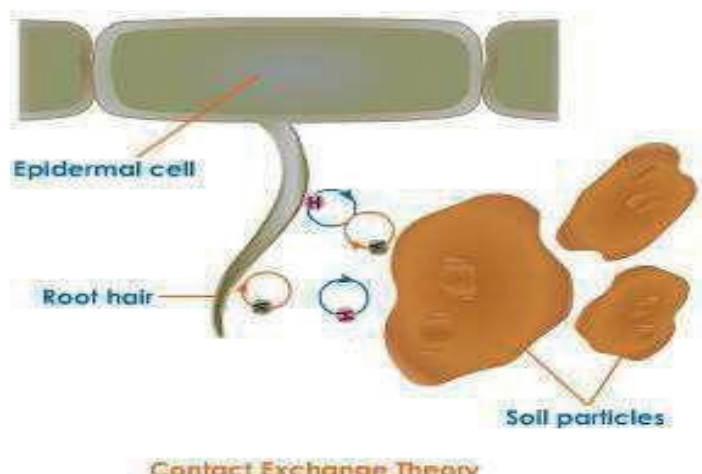


Passive Absorption of Ions

2. Contact Exchange Theory

- According to this theory, the ions adsorbed on the clay micelles get adsorbed to the root in exchange for H^+ ions, previously, adsorbed on the root.
- Ions adsorbed on solid particles oscillate within a small space. When two particles are close enough, the oscillation space of an ion adsorbed to one particle overlaps the oscillation space of an ion adsorbed to another particle. Thus exchange of ions may take place.

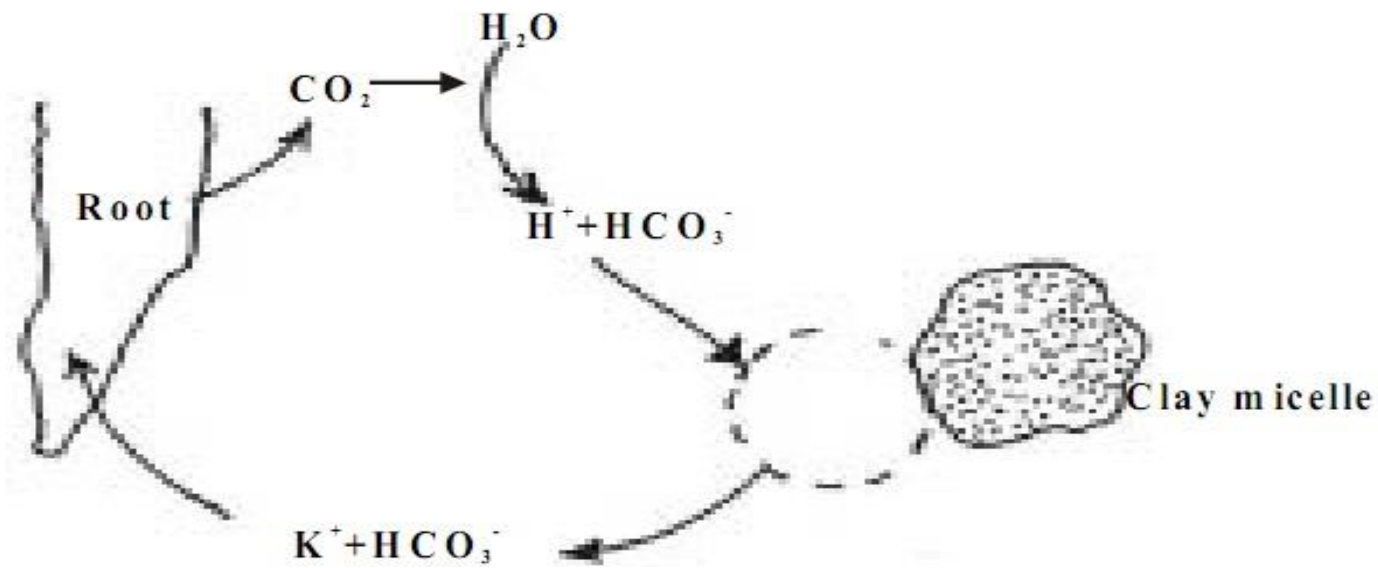




Passive Absorption of Ions

3. Carbonic Acid Exchange Theory

$$CO_2 + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO^{-}{}_3$$



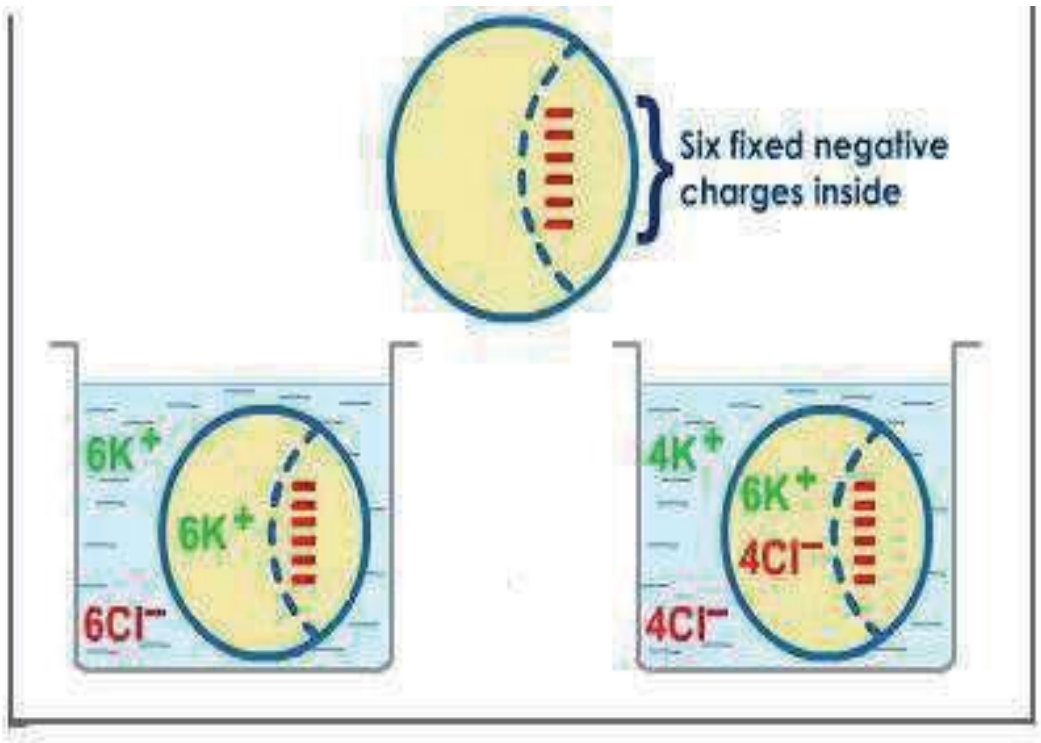
Passive Absorption of Ions

3. Carbonic Acid Exchange Theory

- The soil solution provides medium for exchange of ions between the root and clay micelles.
- Carbon dioxide released in respiration of root forms carbonic acid by reacting with water of the soil solution.
- Carbonic acid then dissociates in the soil solution to form H^+ and $HCO^{-}{}^{3}$ ions shown above expression.
- H^+ ions are adsorbed to the clay micelles in exchange for cations, such as K^+, which are released into the soil solution.
- From here they may diffuse to the root, where they may be adsorbed in exchange for H^+ ions.

Passive Absorption of Ions

4- Donnan Equilibrium



Passive Absorption of Ions

4- Donnan Equilibrium

- Cell membrane is composed of macromolecules of proteins and lipids that have many carboxyl groups (-COOH) and phosphate (HPO_3^-) 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.

Passive Absorption of Ions

4- Donnan Equilibrium

- 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.
- They can, however, diffuse by chemical potential difference or difference of concentration of Cl- on both sides of the membrane. Some K+ ions will also move into the cell by chemical potential gradient.

Passive Absorption of Ions

4- Donnan Equilibrium

- 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.

Passive Absorption of Ions

3- Donnan 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.

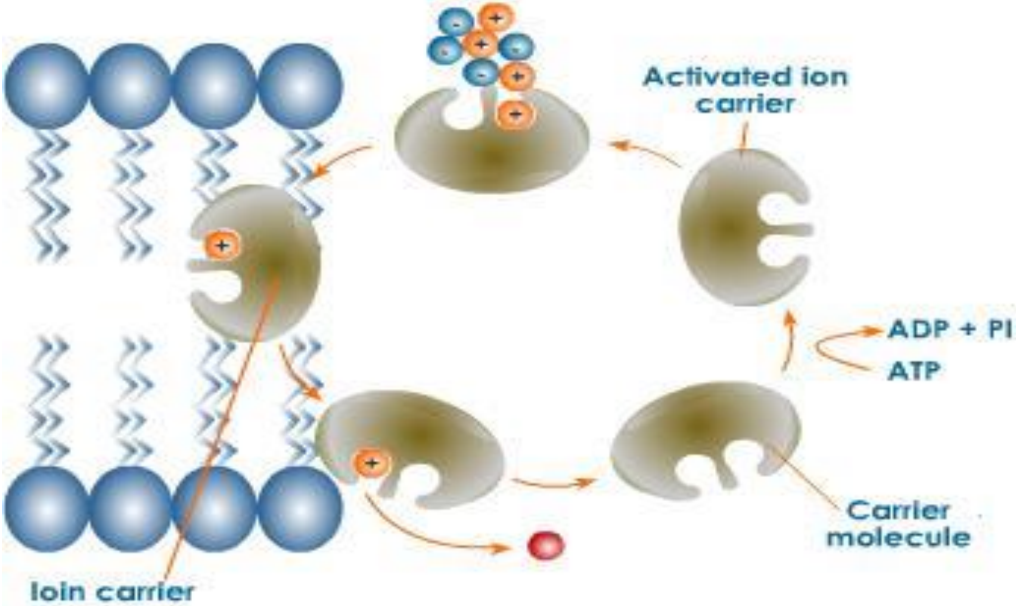
Active Absorption of Ions

- 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.
- The major hypotheses that explain the mechanism of active transport of ions are:

1. Carrier Concept – transport by a carrier protein.
2. Cytochrome Pump – transport by electrochemical gradient generated by electron transport.

Active Absorption of Ions

1. <u>Carrier Concept</u>



1. carrier —kinase (ATP → ADP)→ carrier*

(carrier activation)

2. carrier* —ion (+ or −)→ carrier*-ion

(carrier-ion complex)

3. carrier*-ion —phosphatase?→ carrier + ion

(ion release)

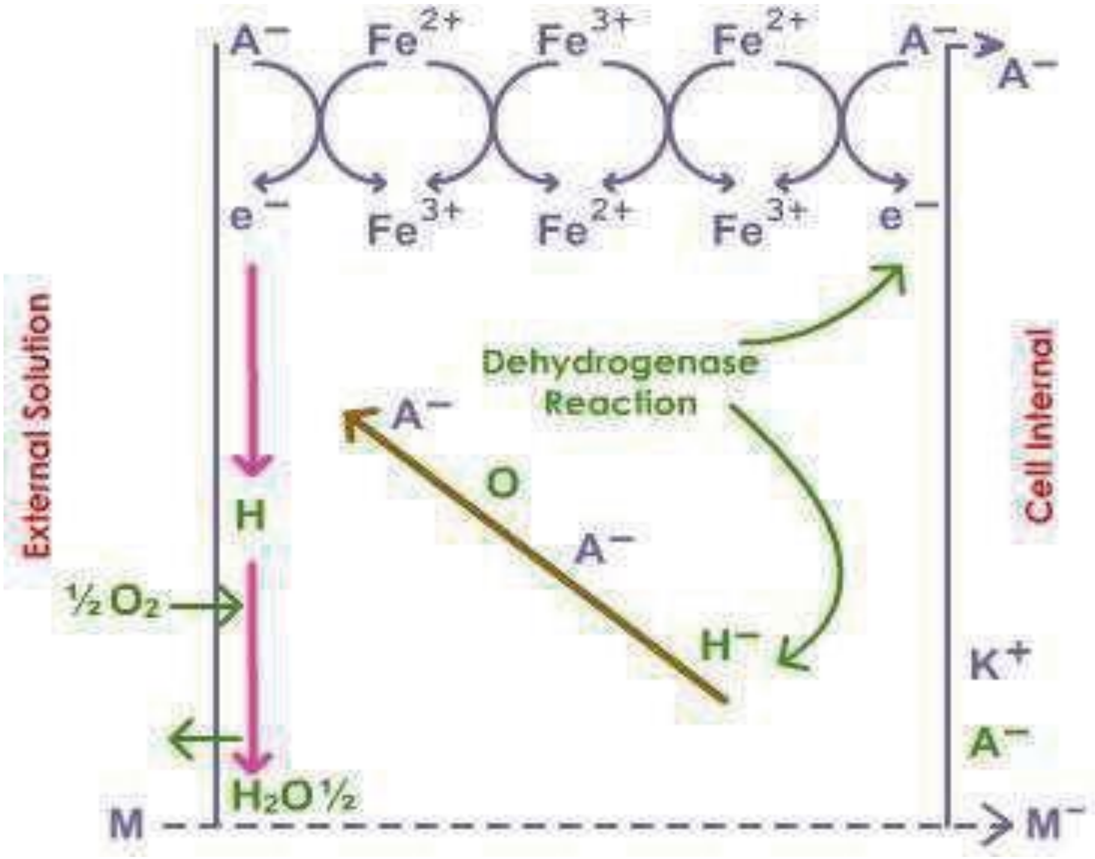
Active Absorption of Ions

1. **Carrier Concept**

- According to this hypothesis the carrier protein picks up an ion from one side of the membrane and discharges it on the other side. The picking up and discharge of the ion requires energy. Energy is obtained by hydrolysis of ATP.
- ATP changes into ADP and energy released is used to change the conformation of the carrier which may be ATPase itself, so that the ion is picked up on one side of the membrane and released on the other.
- After discharge of an ion, carrier protein is reprimed to pick up an other ion. The carrier protein may carry one ion inwards and may exchange it with another ion at the inner surface of membrane, so that the other ion is carried by the same carrier outwards.

Active Absorption of Ions

2. **Cytochrome Pump Salt Respiration or Electron Transport Theory:**



Active Absorption of Ions

2. **Cytochrome Pump Salt Respiration or Electron Transport Theory:**

- 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.
- When hydrogen is removed from a substrate in respiration and carried along an electron transport chain, it is changed into two charged species:

H (hydrogen atom) H+ ⟶ (hydrogen ion) + e- (electron)

Active Absorption of Ions

2. **Cytochrome Pump Salt Respiration or Electron Transport Theory:**

- The H+ and e- are separated on opposite sides of the mitochondrial membrane by the electron carrier enzymes, which are so arranged in the inner mitochondrial membrane that they carry hydrogen ion to the outside and electron to the inside.
- The hydrogen atoms transported through the membrane must be derived from water by the following reaction:

$$H_2O \longrightarrow OH^- + H^+$$

$$H^+ + e\text{- (from electron carrier)} \longrightarrow H$$

Active Absorption of Ions

2. **Cytochrome Pump Salt Respiration or Electron Transport Theory:**

- The OH- ions of water remain inside the membrane. Since H+ on the outside and OH- ions on the inside of the membrane, the outside of the membrane becomes positively charged and the inside is negatively charged.
- This also generates a pH gradient, because outside of the membrane is more acidic because of accumulation of H+ ions and inside of the membrane is basic on account of the presence of OH- ions.
- Proton gradients are produced both in mitochondrial membrane and the thylakoid membrane of chloroplasts.
- In mitochondria H+ ions move outwards, while in chloroplast membranes they move inwards along electron transport chain.

Active Absorption of Ions

2. <u>**Cytochrome Pump Salt Respiration or Electron Transport Theory:**</u>

- Proton gradients as proposed by Mitchell's chemiosmotic hypothesis must be generated in the plasmalemma of cells for active transport of solutes.
- Electric potential difference present in the plasmalemma suggests that charge separation occurs across this membrane also.
- Electron carriers are also required for charge separation, but it is not yet known what substances in plasmalemma act as electron carriers. ATPase has been found in this membrane, which may generate proton gradient.

Active Absorption of Ions

2. **Cytochrome Pump Salt Respiration or Electron Transport Theory:**

- On the establishment of proton gradient, the cations move actively in exchange for H^+ ions in a direction opposite to that of H^+ ions and anions move passively to satisfy the charge balance.
- Similarly, when anions move actively in exchange for OH^- ions, the cations move passively to maintain the charge balance. H^+ ions crossing the membrane react with OH^- ions to form H_2O.
- Similarly, OH^- ions transported through the membrane react with H^+ ions to produce water.

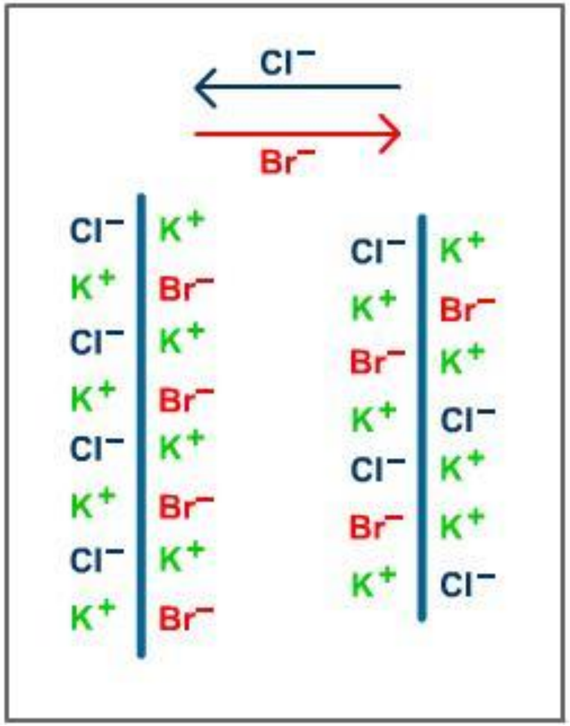
Active Absorption of Ions

2. **Cytochrome Pump Salt Respiration or Electron Transport Theory:**

- Diagrammatic representation of cytochrome pump hypothesis on salt absorption, anions (A-) are actively absorbed via a cytochrome pump and cation (M+) are passively absorbed.
- The rate of respiration, which is solely due to anion absorption, is called as anion respiration or salt respiration.
- The original rate of respiration (without anion respiration) can be observed in distilled water and is called ground respiration.

Movement of Solutes in the Cells

- The diffusion of ions depends not only on the osmotic or chemical potential gradient but on the electrical potential also, because ions are particles which have electric charges on them.
- The chemical potential gradient is produced if the concentration of an ion on one side of the membrane is higher than the other side.
- An example will explain the difference between electrical and chemical potential gradients.



Movement of Solutes in the Cells

- An electrical potential gradient may result from the presence of charged particles or ions on both sides of the membrane or by the charges associated with the surface of the membrane on both sides.
- If a cation (positively charged ion) is more concentrated inside the cell than outside but inside of the cell is negatively charged with respect to out side, the cation will tend to diffuse out of the cell down the chemical potential gradient, but it will tend to diffuse into the cell down the electrical potential gradient.
- The final direction of movement of the solution will be determined by the gradient (electrical or chemical), which is the steepest.

Ion Accumulation

- The penetration of ions of mineral salts into the cells continues even if the concentration of ions inside is more than in the external solution.
- This phenomenon is called accumulation.
- It follows no rules of diffusion.

Selective Uptake of Ions

- Algal cells have been observed to accumulate larger amounts of K^+ ions and to reject other ions such as Na^+.
- Root cells of higher cells also behave in the same way.
- Monovalent cations, such as K^+ are taken up more readily than divalent cations, like Ca^{++} or polyvalent cations.
- Similarly, monovalent anions, like Cl^-, Br^- or NO^-_3, accumulate more in the cells than divalent (SO^-_4) or polyvalent anions.
- Certain plants, like halophytes, accumulate large quantities of Na+ ions. This is why such plants can survive in saline conditions.

Antagonism

- The presence of one ion in a solution reduces the uptake of another ion by the cell. This phenomenon is known as antagonism.
- A plant tissue placed in a dilute solution of potassium chloride will rapidly accumulate potassium ions, which may reach a high level, that is toxic to the cells.
- If, however, trace amounts of calcium are present in the solution, the absorption of potassium is much reduced and its poisonous effects are avoided.
- Calcium is thus said to antagonize the uptake of potassium. It also antagonizes sodium.

Antagonism

- Potassium or calcium also antagonize magnesium uptake.
- It appears from these facts that ions which antagonize one another effectively must be unrelated (not in the same group in the periodic table).
- Sodium will not antagonize potassium uptake, because both are included in the same group. Like wise barium will not antagonize calcium. Sodium or potassium will antagonize barium or calcium.
- Antagonizing ions are required in very small quantities to show their effects.

Antagonism

- Antagonism has advantages and disadvantages for the field plants. For instance, many soils have surplus ions of potassium or calcium, which may produce toxic effects, had there been no antagonism.
- Excess of certain ions in the soil solutions may prevent the uptake of other ions that are essential for the plants and hence may produce deficiency symptoms in the plants, although the required ions are present in sufficient quantities in the soil.
- Excess of sodium ions in the soil, for example, may produce calcium deficiency by antagonizing the uptake of calcium, although calcium may be present in sufficient amounts in the soil.

Factors affecting ion absorption

- Absorption of mineral salts is affected by the number of external and internal factors.

External factors

- Light
- Hydrogène ion concentration (pH).
- Temperature
- Oxygen
- Interaction

Internal factors

- Growth and morpho-physiological status
- Aging

External factors

1. **Temperature.**

- Absorption of mineral salt is affected by change in temperature. In general, an increase in temperature results increase in the absorption of salts up to a certain optimum level.
- At very high temperature the absorption is considerably inhibited. The inhibition might be due to denaturation of proteins which are directly or indirectly involved in mineral salt absorption.
- The change in temperature also affects the process of diffusion.
- The rate of diffusion depends upon the kinetic energy of diffusing molecules or ions which, in turn, dependent upon temperature.

External factors

2- Hydrogen ion concentration (pH).

- Change in the hydrogen ion concentration (pH) of the soil solution affects the availability of ions to the plants.
- In general, decrease in the pH of soil solution accelerates the absorption of anions.
- For example, boron is taken up as the undissociated acid, H_3BO_3 as the H_2BO_3? ions. It is absorbed at lower pH.
- In contrast to the anions, increase in pH will favour the absorption of cations.
- However, pH values across the physiological range may damage the plant tissue and inhibit the salt absorption.

External factors

3. Light.

- Light has no direct effect, but indirectly by transpiration and photosynthesis, influences salt absorption.

4. Oxygen.

- The active salt absorption is inhibited by the absence of oxygen.

5. Interaction.

- The absorption of one ion is affected by the presence of other ions in the medium.
- For example, Viets (1944) demonstrated that the absorption of potassium is affected by the presence of calcium, magnesium and other polyvalent cations in the soil solution.
- Epstein (1978) demonstrated the interaction of several ions (K, Cs, Li, Rb and Na) as competitive for binding sites on carriers. For example, K, Rb and Cs compete with one another for the same binding sites. Li and Na, on the other hand, are not competitive because they have different binding sites.

External factors

1. **Growth**.

- Active cell division, elongation and developmental processes promote the absorption of mineral salts.

2. **Aging**.

- As the root matures it increases the surface area which is favourable for salt absorption, but due to heavy suberization the mineral salt uptake is greatly reduced.