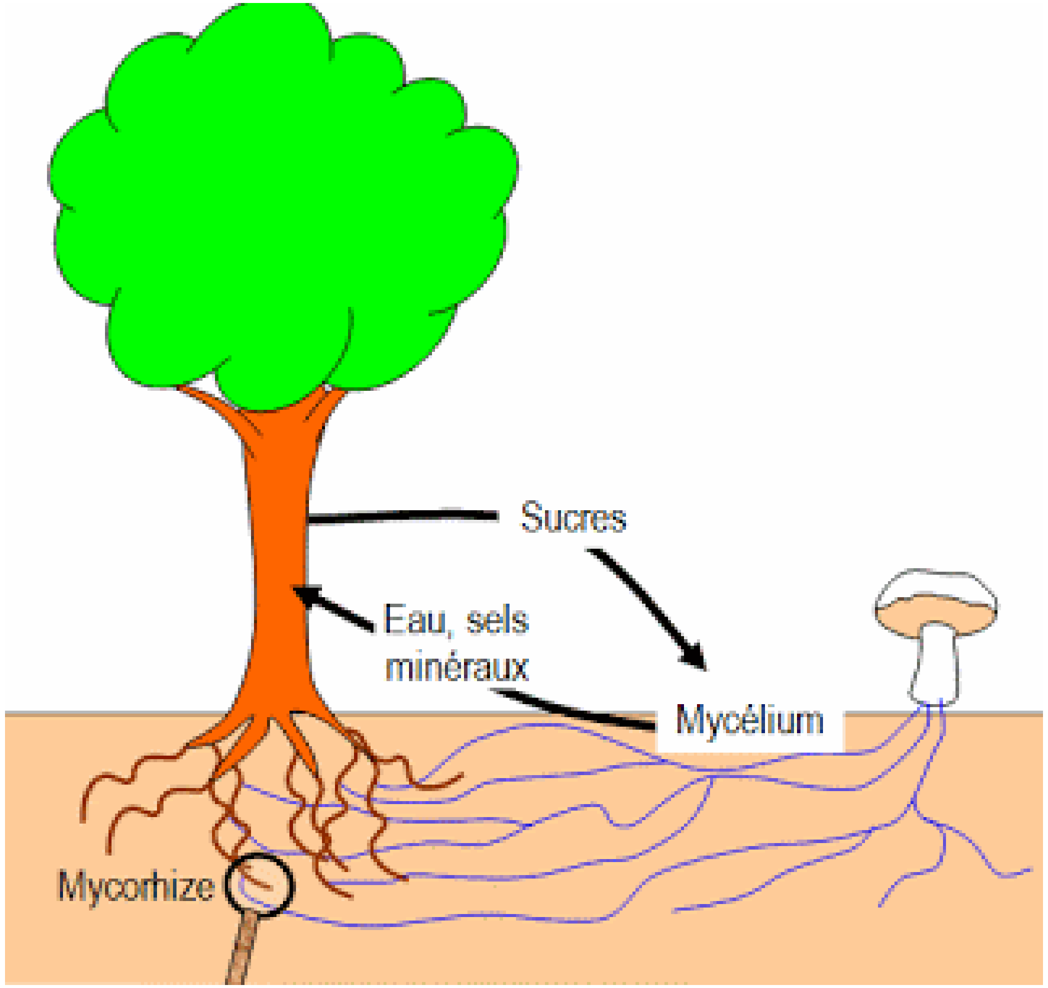
Chap 3. Plant Mineral Nutrition

Introduction

- Mineral salts are important for plant development; they are present in the form of **ions** and penetrate the root cells.
- The plant feeds on mineral salts and obtains them through symbiosis between <u>bacteria or fungi (mycorhizae) and the roots.</u>

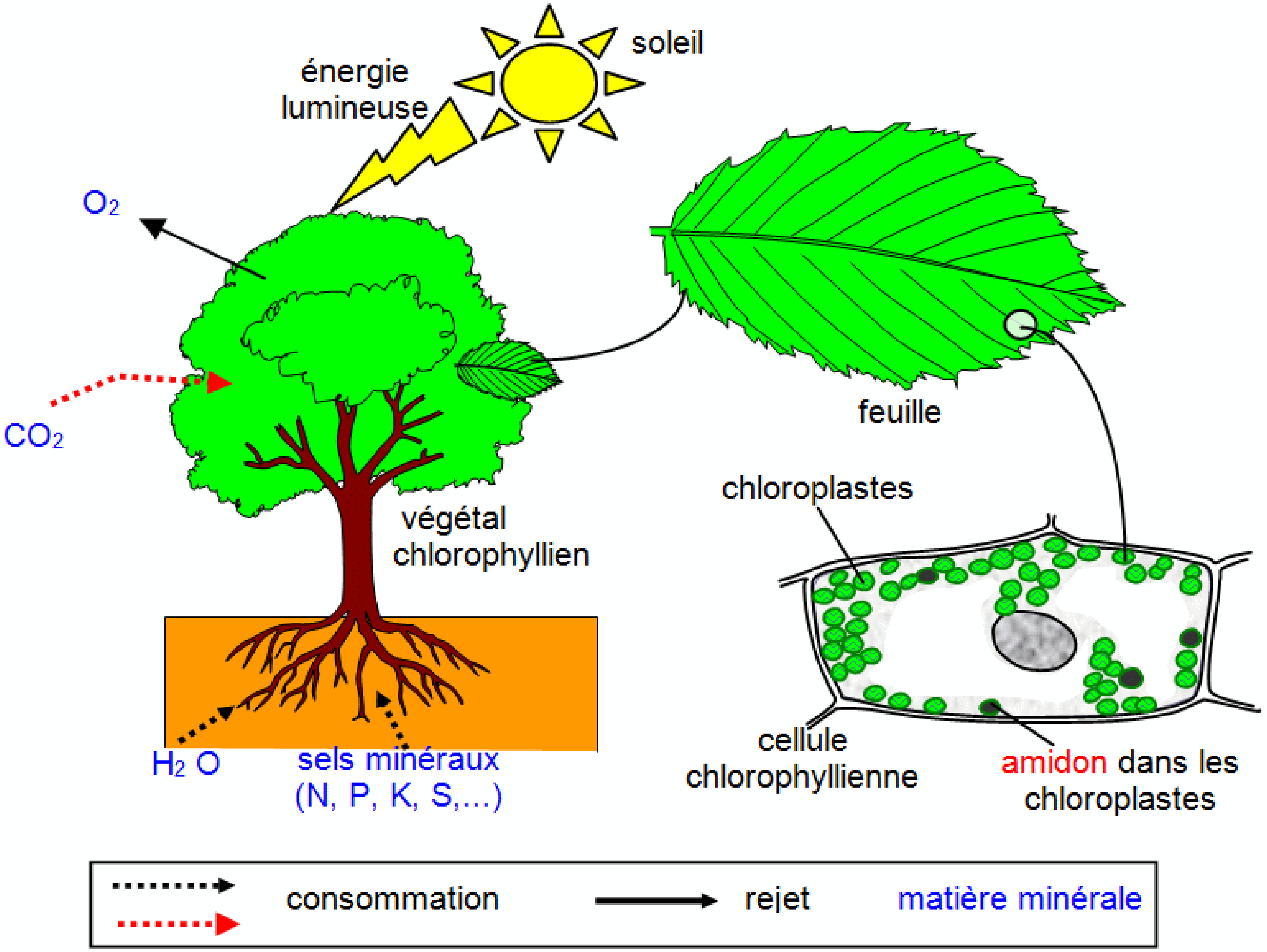


Introduction

Chlorophyllous plants obtain the minerals they need from their environment (soil, water and air). A lack of these elements disrupts their development.

1. Acquisition of nutrients

In most terrestrial plants, inorganic nutrients are absorbed through the root cells. Transport proteins (carriers, channels and transporters) are responsible for this transport.



D'après banque de schémas de *svt.ac-dijon.fr*

2. Determining nutrient requirements

Some elements have been deemed essential for plant growth. An element becomes essential when its absence prevents the plant from completing its life cycle (Arnon and Stout 1939) or when it has a clear physiological role (Epstein 1999). If plants receive these essential elements, as well as solar energy, they can synthesize all the compounds they need for growth.

The **main mineral elements that plants need** for growth are known as **essential elements** and are classified according to the quantities absorbed (see Table).

Adequate tissue levels of elements that may be required by plants

Element	Chemical symbol	Concentration in dry matter (% or ppm)[a]	Relative number of atoms with respect to molybdenum
Obtained from water or carbon dioxide			
Hydrogen	H	6	60,000,000
Carbon	C	45	40,000,000
Oxygen	O	45	30,000,000
Obtained from the soil			
Macronutrients			
Nitrogen	N	1.5	1,000,000
Potassium	K	1.0	250,000
Calcium	Ca	0.5	125,000
Magnesium	Mg	0.2	80,000
Phosphorus	P	0.2	60,000
Sulfur	S	0.1	30,000
Silicon	Si	0.1	30,000
Micronutrients			
Chlorine	Cl	100	3,000
Iron	Fe	100	2,000
Boron	B	20	2,000
Manganese	Mn	50	1,000
Sodium	Na	10	400
Zinc	Zn	20	300
Copper	Cu	6	100
Nickel	Ni	0.1	2
Molybdenum	Mo	0.1	1

Source. Epstein 1992, 1977 In (Taiz and zeiger)

Mineral elements and soil fertility (nature and importance).

The main mineral elements essential for plants are :

a. **The main macro-elements:** nitrogen (N), phosphorus (P) and potassium (K);

- **Nitrogen** is a major element for plant growth, and its deficiency has a very strong impact on growth reduction. It is a constituent of proteins, amino acids, chlorophyll and DNA.

- **Phosphorus** is involved in photosynthesis, metabolic energy management (ATP) and the formation of enzymes and numerous molecules. It stimulates the growth and development of roots and fruit.

- **Potassium** plays a very important role in controlling osmotic pressure, stomatal regulation and water conservation, as well as in resistance to water stress, frost and disease.

b. Secondary elements: calcium (Ca), magnesium (Mg), sulphur (S), sodium (Na).

c. Trace elements: Manganese (Mn), Zinc (Zn), (Cl), Boron (B), Molybdenum (Mo), Cobalt (Co). These elements are found in enzymes and vary between species.

Some of these nutrients can be found in the following species : **Sulphur** in *cruciferous plants*, **Potassium** in *algae*, **Silicon** in *grasses, horsetails and ferns.*

Others elements are found in plant organs: The **seed** is richer in **P** and lower in **K** than the complete plant. **Older parts** are richer in **Ca** than **younger parts** (the younger plant organs are rich in **K, P and N**).

To replenish these reserves, plants must be supplied with fertilizers adapted to the soil. These inputs depend on the richness of the soil and the needs of the plants.

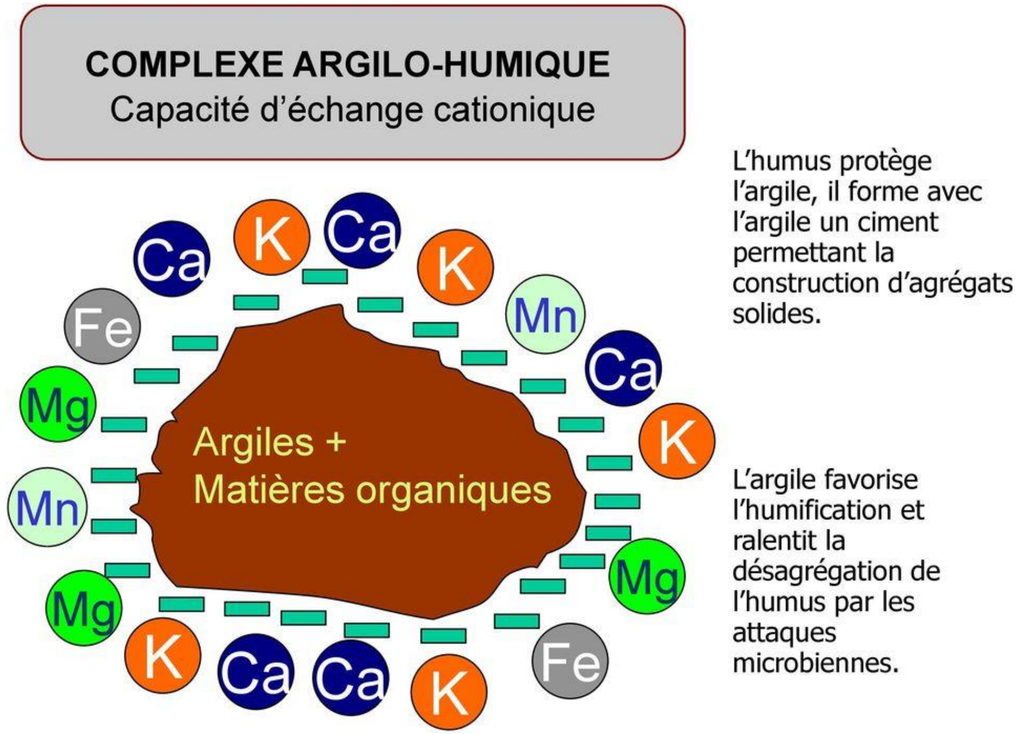
3. Origins of minerals

In the soil, the ions are in solution, and their states change according to the pH and the nature of the soil. They are in colloidal solutions (in the clay-humus complex). The **Clay-Humus Complex (CHC)** is a structure composed of *clay and humus*. **Humus** is the "stable" fraction of soil organic matter, i.e. it is not very prone to mineralisation, but it plays a part in structuring the soil.

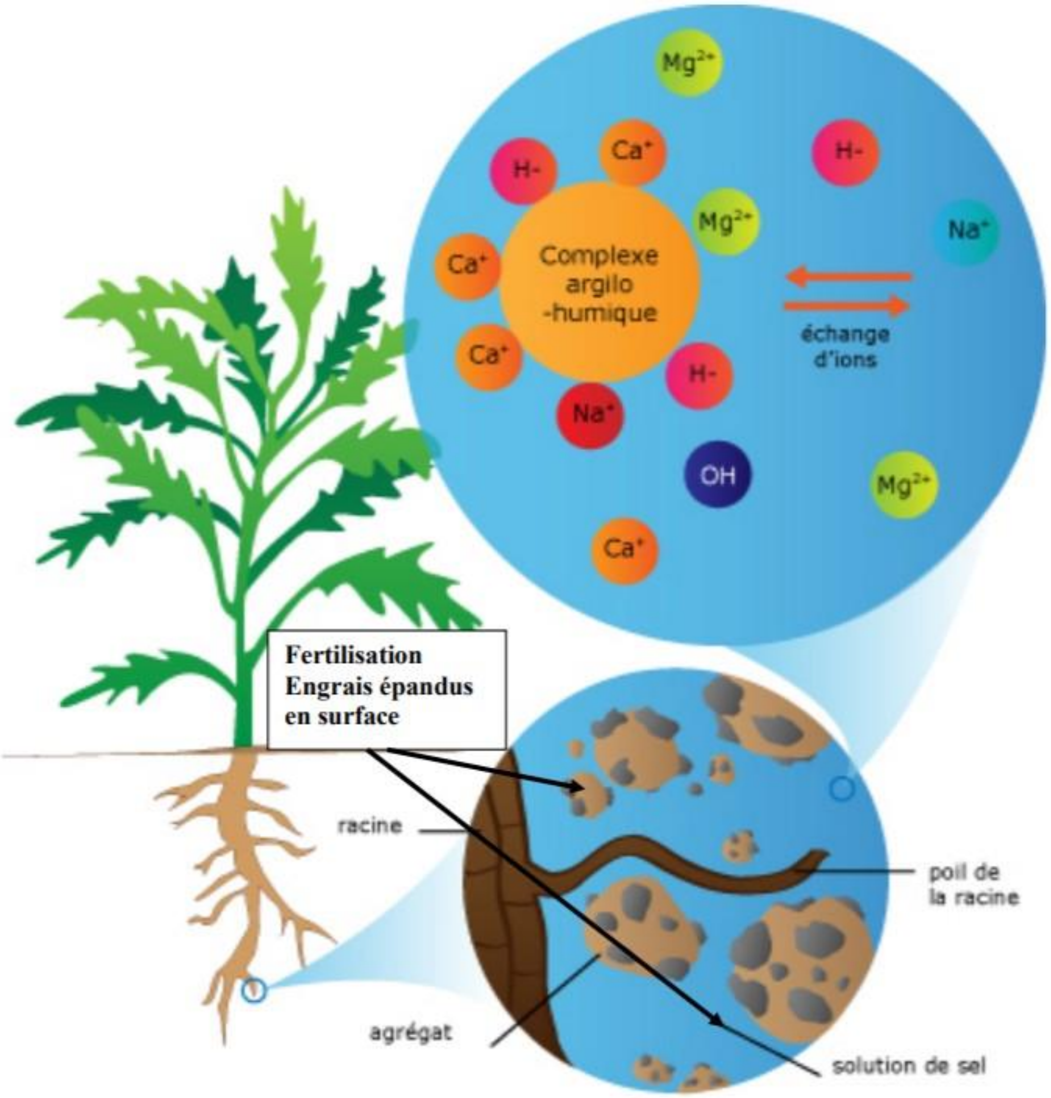
Clay and humus particles are both negatively charged and retain cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}...), which are essential elements for plants.

Please note. A soil full of CHA is considered rich and fertile.

Cations are exchanged between the clay-humus complex and the soil solution, a process known as cation exchange capacity (CEC). The higher the CEC, the less cations are leached out, making them more accessible to plants.



Simple diagram of the clay-humus complex



4. Methods and mechanisms of mineral absorption

- Ion mechanisms: Some mineral nutrients can be absorbed by the leaves, in addition to nutrients added to the soil as fertilizer. Some mineral nutrients can be applied to the leaves by spraying (foliar application), so that the leaves can absorb these nutrients. Foliar application supplements the mineral deficit in the soil, and can play a role in activating plant growth. Foliar application of mineral nutrients such as **Iron**, **Manganese** and **Copper** can be more effective than soil application, where they are adsorbed onto soil particles and are less available to the root system.

Foliar absorption of iron by a chlorotic plant is the only way for iron to be absorbed in calcareous soils: the ions therefore pass through the cytoplasm by the symplastic (by plasmodesmata) route to the xylem and then into the raw sap. Some ions are retained in the walls, such as **calcium**, while others are accumulated in the vacuole and are excreted. The vacuole is an organ that accumulates wastes and is also a reserve organites.

- Absorption mechanisms

In ion absorption, there are several components involved in the transport of ions and small molecules. There are three possible ways of penetration: simple diffusion, passive transport and active transport.

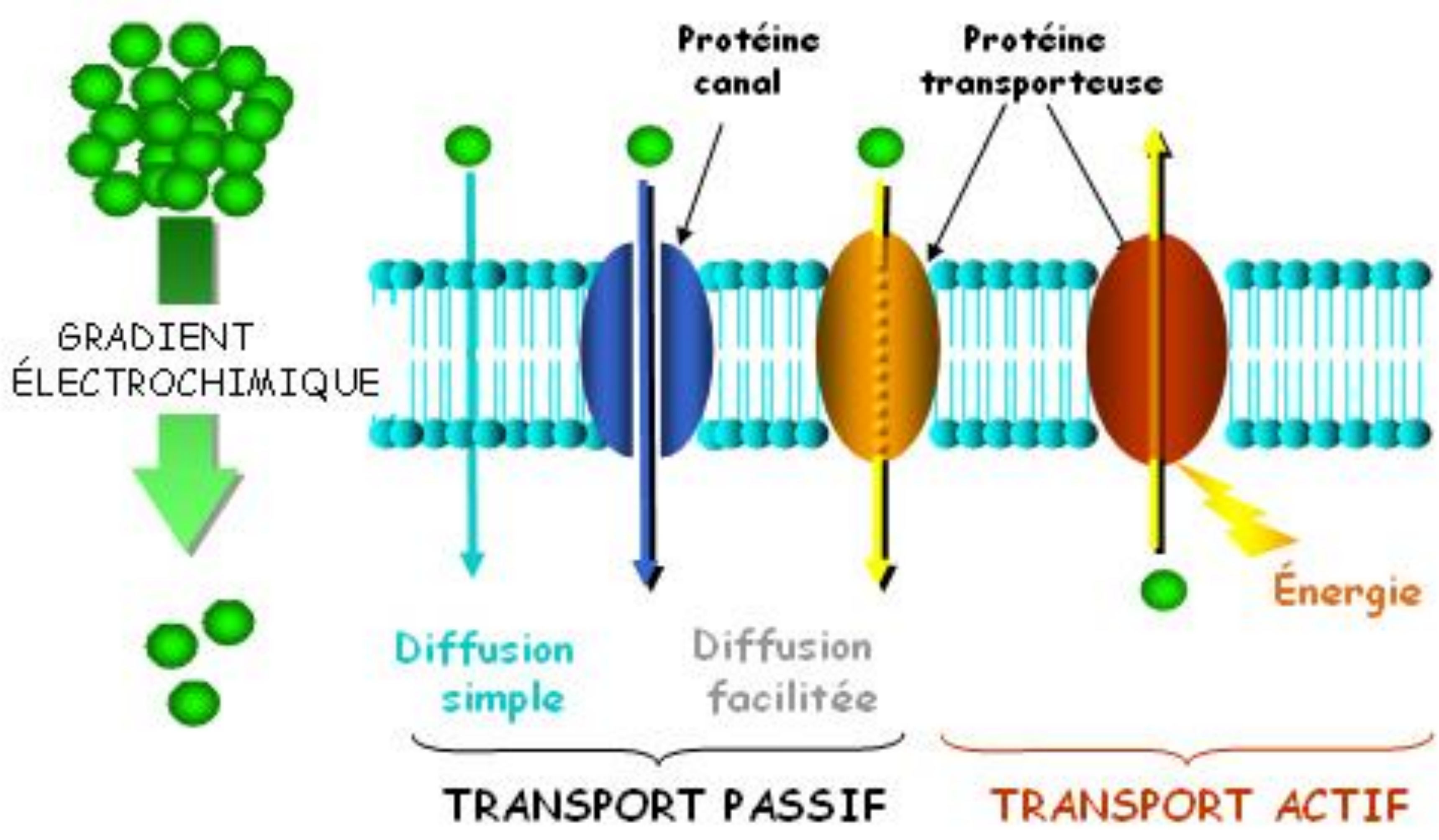
Simple diffusion: Water, non-polar and polar molecules (urea, glycerol and CO_2) penetrate the cell membrane by simple diffusion. This diffusion phenomenon is expressed by **Fick's law** : $DQ/dT = k.a.\Delta c$

k: Diffusion coefficient, **a:** Diffusion surface, **Δc:** Concentration variation.

Diffusion tends towards a state of equilibrium so that the concentration gradient is zero. Small molecules are transported by two types of membrane proteins. There are carrier proteins and protein channels (see Fig. below).

In biology, a **gradient** refers to a variation in the concentration of a substance or physiological property. It often refers to a concentration gradient on either side of a cytoplasm membrane.

Transport of minerals



- Passive transport and easy distribution

Transport takes place via protein channels and carrier proteins. If the molecule is uncharged, transport is determined by the concentration gradient. If the molecule is charged, transport is determined by the concentration gradient and by the electrochemical gradient.

We therefore have transport in the direction of the gradient, which results in a membrane potential.

In facilitated diffusion, transport takes place in the direction of the gradient. Molecules are transported by protein channels, carrier proteins and membrane permeability. There are 2 types of carrier proteins: proteins which allow passive transport and proteins which carry out this transport using energy (active transport).

- The active mechanism

Lapicque demonstrated the phenomenon of epicmesis : the active absorption of ions and small molecules.

A plant cell in an hypertonic solution, concentrated in sucrose, is plasmolyzed. After a while, the cell becomes turgid again: the cell re-establishes its hypertonicity by absorbing ions (or small molecules) against the electro-chemical potential gradient. This phenomenon explains why a cell is able to concentrate ions.

These movements require: chemical energy such as ATP, and physical energy such as the ionic gradient due to electron movement. This energy enables ionic pumps to function, and the most common type is the proton pump.

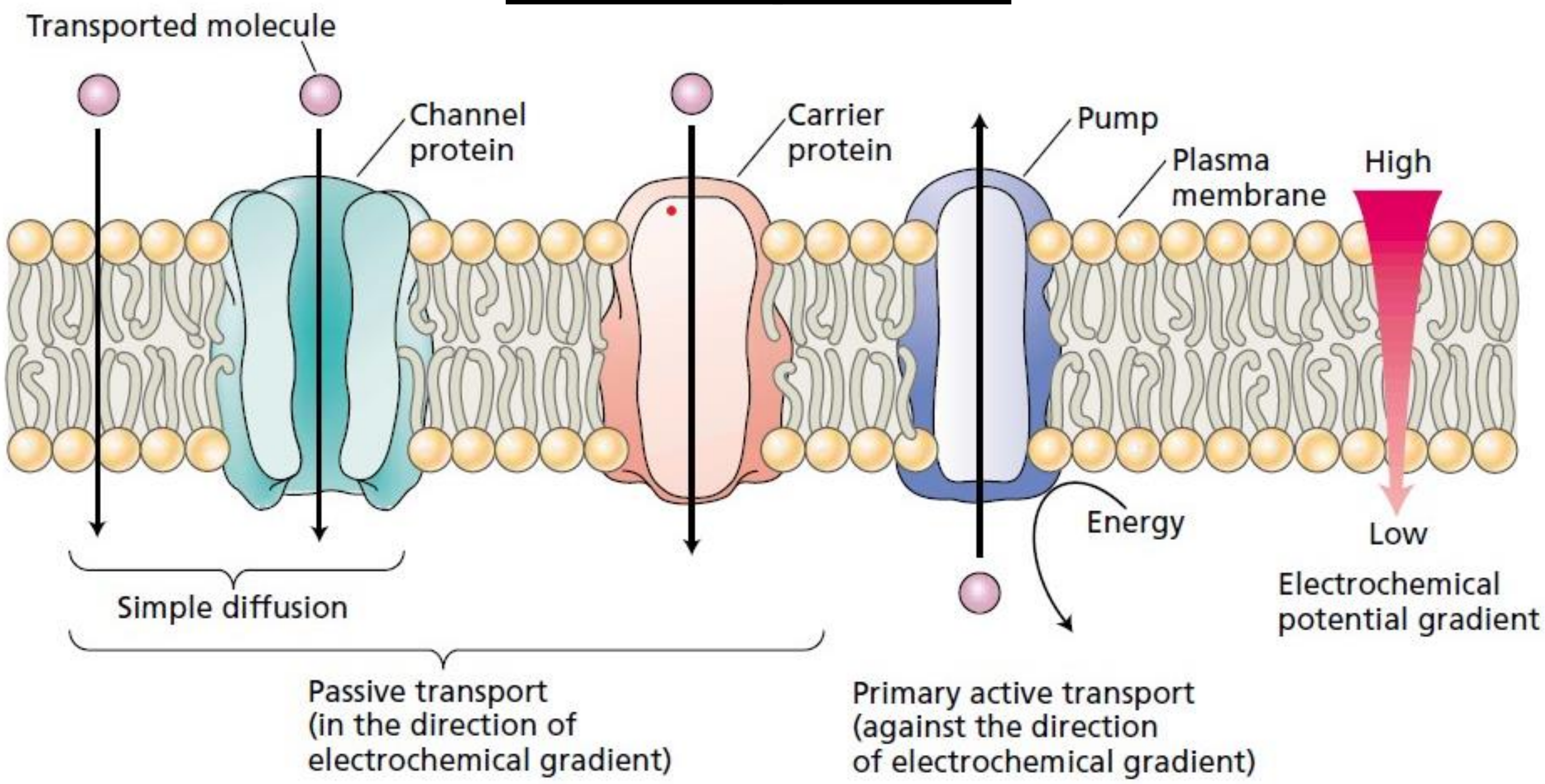
There are **2 types of pump** (see next figure):

Redox pumps: Circulation is achieved by electron displacement. These pumps produce ATP.

ATPase-type pumps: These expel protons from the plasmalemma or tonoplast (active transport). They use energy.

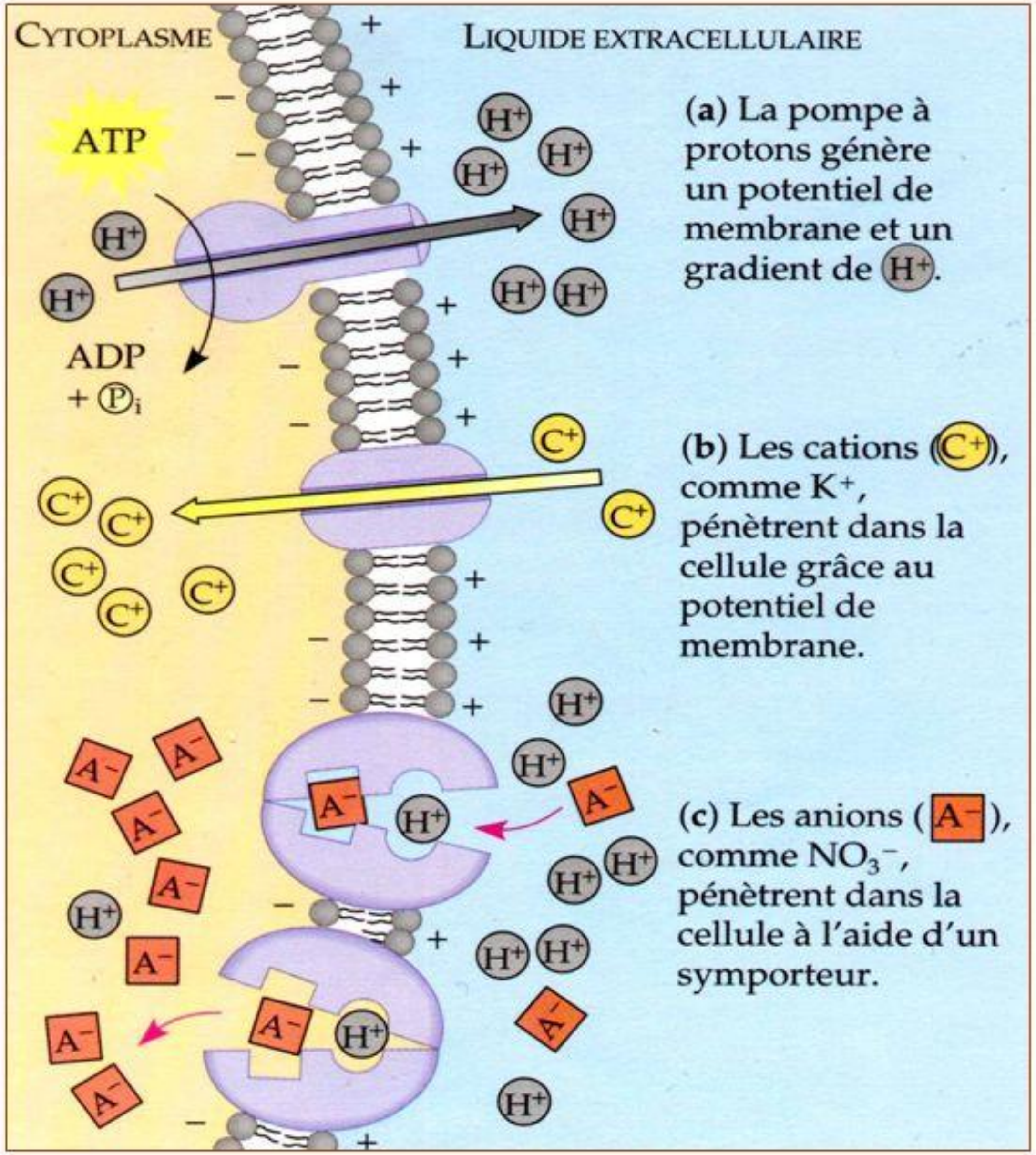
Proton pumps

Three classes of membrane transport proteins: channels, carriers and pumps. <u>Channels and carriers can mediate the passive transport</u> of solutes across membranes (by simple diffusion or facilitated diffusion), along the electrochemical potential gradient of the solute.



Channel proteins act as membrane pores and their specificity is determined mainly by the biophysical properties of the channel. **Carrier proteins** bind to the transported molecule on one side of the membrane and release it on the other. **Primary active transport** is carried out by pumps and uses energy directly, usually from ATP hydrolysis, to pump solutes against their electrochemical potential gradient.

Pompe à proton et cotransport



L'Énergie de l 'ATP sert à transporter des ions H^+.

==> formation d 'un **gradient de concentration** et d 'un **gradient électrique.**

Le gradient électrique permet à des ions + de pénétrer CONTRE leur gradient de concentration.

Des **symporteurs** permettent à des anions de pénétrer CONTRE leur gradient de concentration et CONTRE leur gradient électrique en voyageant avec des ions H^+.

This emission of protons creates the "**proton motive force**", which in turn energizes the movement of other ionic species. This is known as secondary active transport, which takes place in the opposite direction to the gradient, thus requiring energy. If only one solute is transported, it is called a uniport system. If two solutes cross in the same direction, it is a symport system. If the 2 solutes cross in different directions, this is called antiport transport.

Easy transport: or simple diffusion
Passive transport: no need for energy
Simple diffusion: from the more concentrated medium to the less concentrated medium until equilibrium is reached

Active transport: consumes energy
accumulation: from less concentrated medium to more concentrated medium until equilibrium is reached

3. Role of ions in the plants

- ***Physical roles.*** Phosphates help magnesium to enter the body, while calcium hinders its entry.

The ions allow →

- Maintaining turgidity,
- pH (buffer system),
- The creation of membrane potentials: These potentials act on the permeability of the membrane.

- ***Physiological roles***

Its constituent roles are played by phosphorylated elements such as phospholipids, phosphorylated compounds, nucleotides and nucleic acids.

- Sulphur: in amino acids and proteins.

- Calcium: in the walls, where it forms pectates with peptides, in the vacuole, in the form of calcium oxalate crystals

In the cytoplasm, it is associated with calmodulin.

Calcium: in chloroplasts (forms plastocyanins)

in mitochondria (forms cytochrome oxidases)

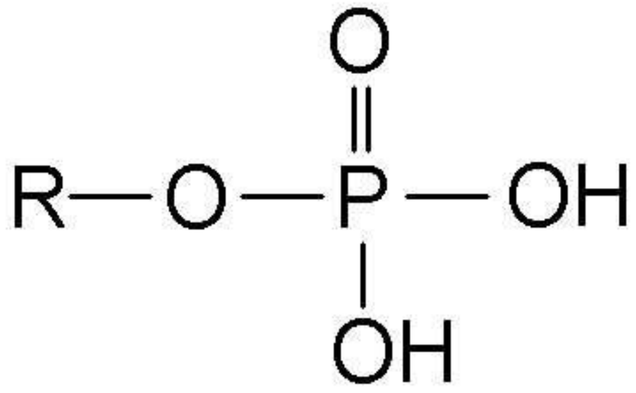
Most often, in places where toxic products are stored products (vacuoles)

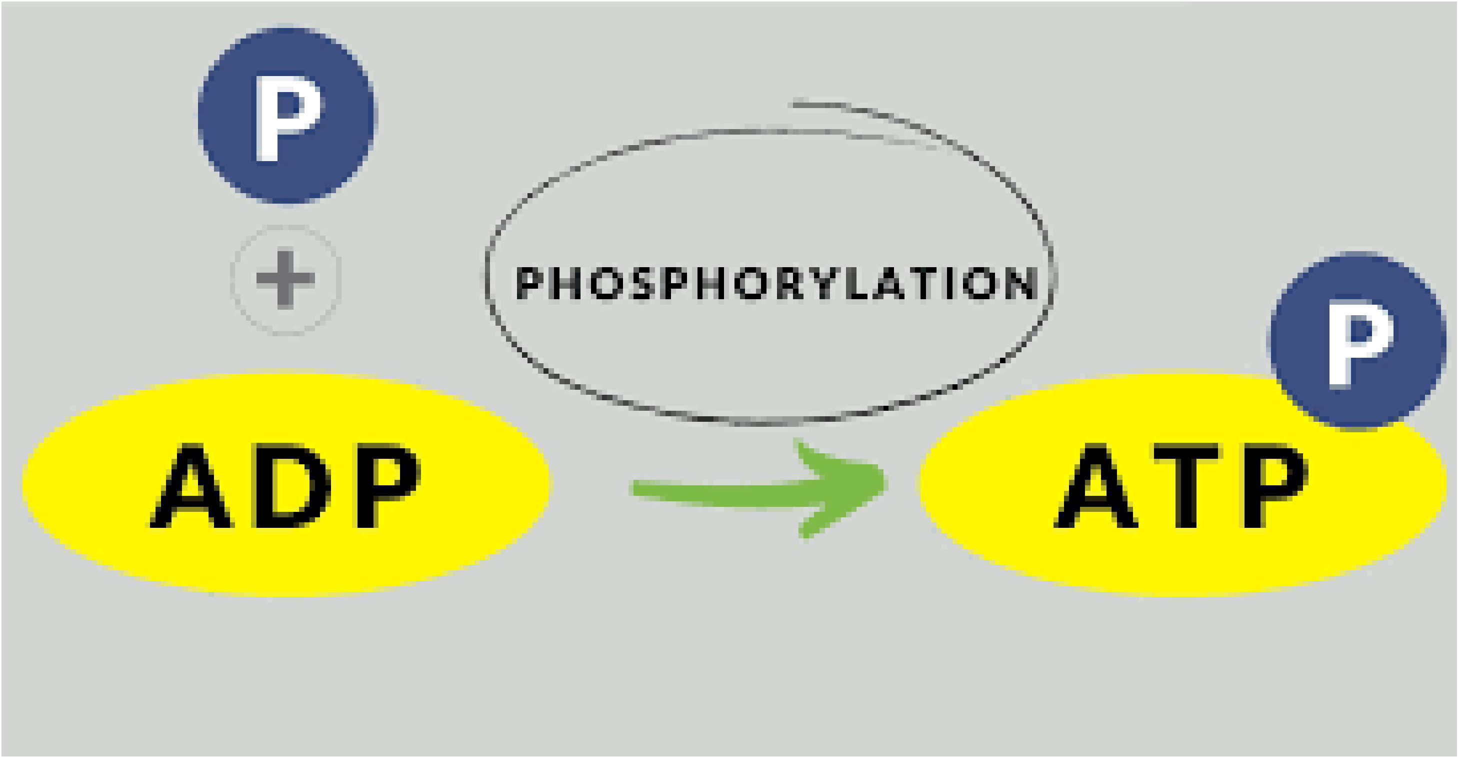
Iron: in hemes and cytochromes,

Phosphorus: in large quantities during flowering and in the seeds,
Potassium: involved in carbohydrate metabolism,

Molybdenum: in nitrate reductases and nitrogenases.

Phosphorylated element: Phosphorylation is a chemical modification involving the addition of a phosphate group (PO_4^{-3}) to a molecule, taken from a molecule of ATP (which will become an ADP).





Some Particularities

a. Calcium (Ca) :

- In **Ca-rich soil** (with a high pH, a basic environment), we find calcicole (tolerant) plants,

- In **Ca-poor soils** (with a low Ca content and a low pH, acidic environment), we find calcifugic plants that do not tolerate calcareous soils or soils with alkaline tendencies.

b. Iron (Fe): In a basic soil, iron cannot be absorbed because it precipitates.

c. Sodium :

Soil with a high salt content: halophytic or halophilic plants (salt tolerant),

Soil with a low salt content: halophytic plants (which cannot tolerate salt).