UPTAKE OF MINERAL NUTRITION

- The majority of plant nutrients are taken up by the plant in ionized form from films of water surrounding soil particles.
- Nutrients move in aqueous solution.
- They cannot cross lipid membranes unless transport proteins are present
- The root surface (the rhizodermis) makes limited contact with the nutrient film surrounding soil particles.
- Root hairs and, in many species, mycorrhizal fungi greatly increase the surface area in contact

✓ Transport within the root may be across cell membranes (transmembrane)

✓ Through the cell cytoplasm (cellular transport) or

✓ Between cells (apoplastic)

- Plasmodesmata provide continuous contact between the cytoplasm of adjacent cells giving direct cell-to-cell (symplastic) transport without contact with the apoplast.
- Cells of the endodermis have suberized cell walls which form a water impermeable barrier surrounding the vascular tissue of the root.
- It prevents apoplastic movement of nutrients which must therefore either travel symplastically through the endodermis or enter the vascular system from below the endodermis
- Water and nutrients leaving the endodermis enter xylem parenchyma cells that surround xylem vessels.
- These cells actively accumulate nutrients to a high concentration before they are loaded into the xylem for transport to the rest of the plant
- Xylem extends throughout the plant and water flows to wherever transpiration is taking place.
- The apoplast of all tissues is in close contact with xylem fluid and nutrients are taken up from this space by cells.
- Rapidly growing tissues (e.g. fruits, tubers) may have low transpiration and in these tissues redistribution of ions in the phloem may be important.

Nutrients become available at the root surface as a result of three processes:

- **Interception**, growth of roots into new nutrient-rich area;
- **Mass flow**, movement of ions in the water flow driven by transpiration; and
- **Diffusion**, passive movement of ions to regions depleted in nutrients

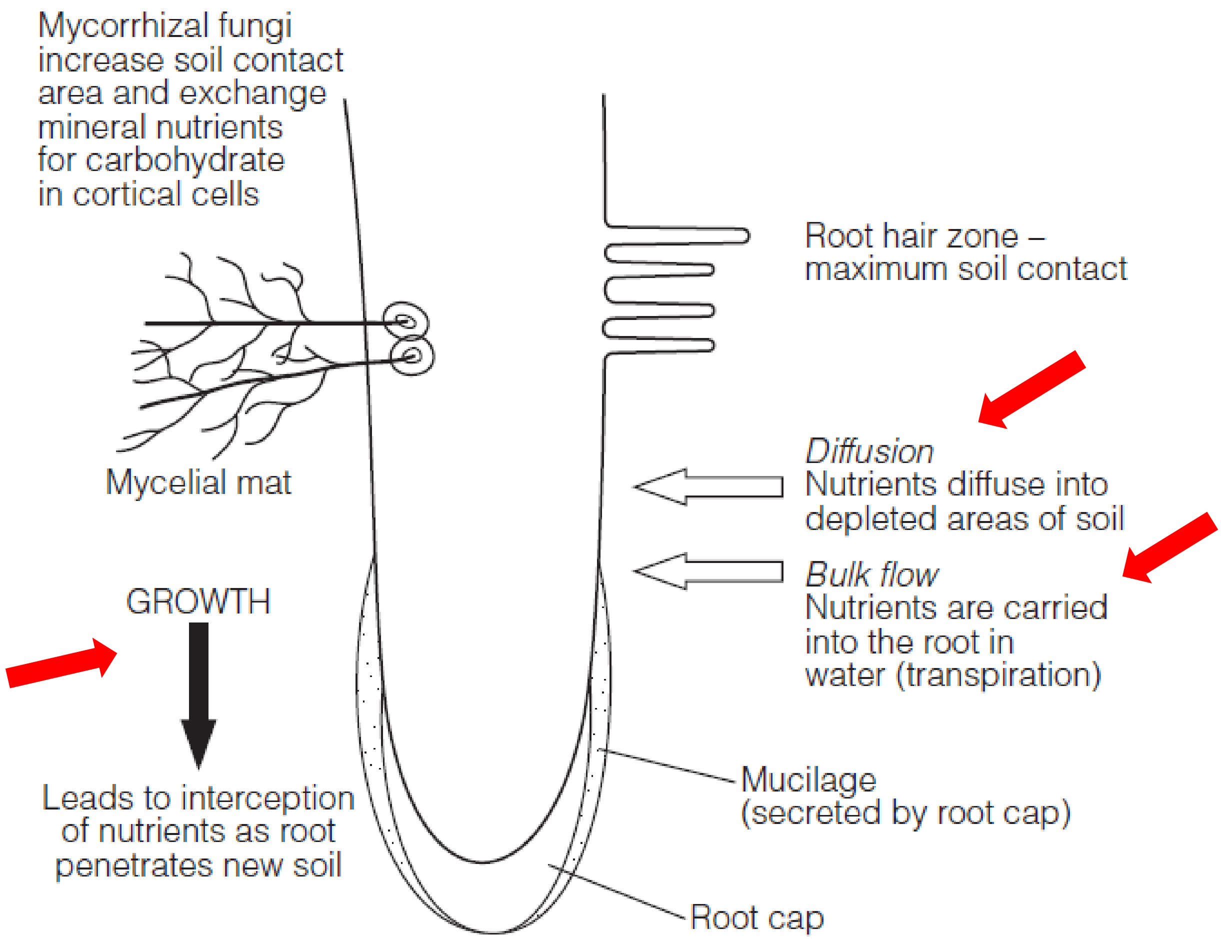


Fig. 1. Key features of nutrient uptake by roots.

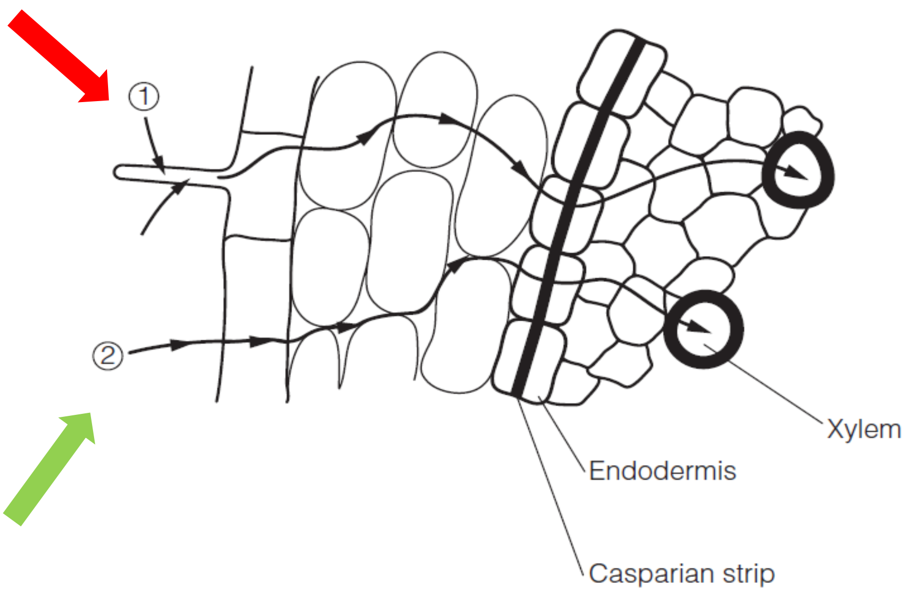


Fig. 2. Pathways of nutrient transport in roots. (1) Symplastic throughout; (2) apoplastic until endodermis, then symplastic.

Source: https://www.biologydiscussion.com/plants/movement-of-water/movement-of-water-in-roots-3-pathways-with-diagram/14906

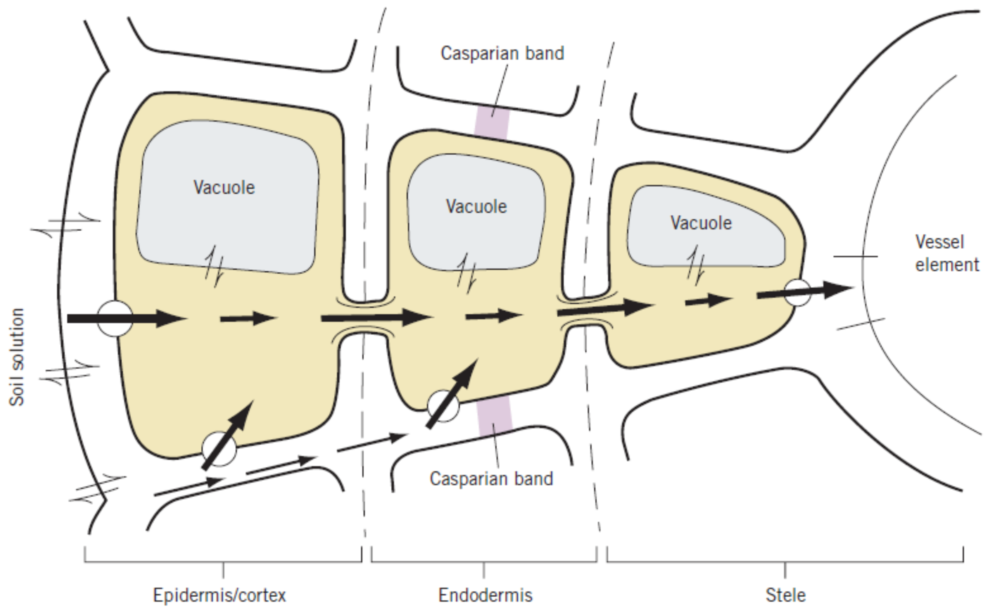


FIGURE 3.12 The radial paths of ion movement through a root. Arrows indicate the alternative paths that may be taken by nutrient ions as they move from the soil solution into the vascular elements in the stele. Arrows with circles indicate active transport of ions across plasma membranes.

THE ENDODERMIS

- The **endodermis** develops near the point of development of the root vascular tissue
- Cells of the endodermis have suberinized cell walls which form a water-impermeable barrier surrounding the vascular tissue of the root.
- This prevents water and nutrients moving into the vascular tissue through the apoplast and the only transport possible at this point is **symplastic**.
- Most nutrient ions entering the vascular tissue will therefore have passed through living root cells at some point. This permits **selectivity** and filtration of the transported ions.
- Older endodermal cells become entirely enclosed in a suberin layer. These cells provide a barrier to the back-flow of water from the xylem

TRANSPORT IN XYLEM

- Influx into the xylem occurs via specific membrane proteins down the concentration gradient.
- Nutrient flow in the xylem to leaves and shoots occurs in the transpiration stream
- Mineral nutrient ions and water move in the xylem and reach all parts of the plant.
- Xylem tubules branch out from the main **vascular bundles** of the stem to reach leaves and buds and branch again to form finer tubules in the **leaf veins.**
- Some nutrient ions may be redistributed through the plant in the **phloem**, while others only move in the xylem.

- Some areas of the plant undergoing rapid growth, e.g. fruits and tubers, do not have high transpiration rates and the xylem flow is low. This may lead to nutrient deficiency if nutrient transport in the phloem does not occur
- Ions may be moved from xylem to phloem by **transfer cells** that lie between the two pathways or ions may leave source tissue as it loads organic nutrients into the phloem
- Not all ions are **phloem mobile** and there are marked differences between species

COLLOIDS

- Particles that are small enough to remain in suspension but too large to go into true solution are called colloids
- The light-scattering phenomenon, known as the **Tyndall effect**, is a distinguishing characteristic of colloidal suspensions
- A colloidal suspension is a two phase system. It consists of a solid phase, the colloidal **micelle**, suspended in a liquid phase
- Soils vary widely with respect to composition, structure, and nutrient supply inorganic and organic soil particles (**colloids**)
- Soil colloids retain nutrients for release into the soil solution where they are available for uptake by roots.
- The soil colloids serve to maintain a reservoir of soluble nutrients in the soil because

(1) colloids present a large specific surface area

(2) the colloidal surfaces carry a large number of charges (mostly negative)

- The charged surfaces in turn reversibly bind large numbers of ions, especially positively charged cations from the soil solution.
- This ability to retain and exchange cations on colloidal surfaces is the single most important property.

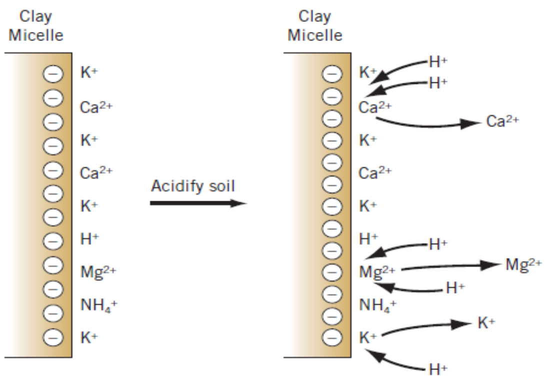


FIGURE 3.2 Ion exchange in the soil. (*A*) Cations are adsorbed to the negatively charged soil particles by electrostatic attraction. (*B*) Acidifying the soil increases the concentration of hydrogen ions in the soil. The additional hydrogen ions have a stronger attraction for the colloidal surface charges and so displace other cations into the soil solution.

- **Transport**

Molecular or ionic movement from one location to another.

It is mainly regulated by membrane proteins.

- **Translocation**

Transport of sucrose from leaf to roots and other parts of the plant through phloem.

SOURCE → SINK

PASSIVE and ACTIVE TRANSPORT

- Movement of molecules by diffusion is spontaneous (downhill, down the gradient of free energy or chemical potential or concentration)
- This is Passive transport and continues until equilibrium (Fick's Law)
- Movement of the molecules against the gradient of concentration or chemical potential is not spontaneous (uphill)
- It is called Active transport and requires work to be done on the system by applying cellular energy (coupled transport to the hydrolysis of ATP)

For uncharged solute

- The gradient is a difference of concentration
- Major forces that act on a biological transport are concentration, hydrostatic pressure, gravity, electric field
- Chemical potential is the sum of concentration, electric potential and hydrostatic pressure (sum of all forces that may act on a molecule to drive the transport)

For charged solute (ions)

- The electrical component of chemical potential plays major role
- The ionic species have their own chemical potential
- They diffuse both according to their concentration gradients and electrical potential difference between the two compartments
- Ions can be driven passively against their concentration gradient by applying voltage/electric field (electrochemical potential)
- Membrane permeability is the extent to which the membrane permits the movement of substances
- The K^+ and Cl^- ions in KCl solution will permeate through the membrane independently of each other
- The membrane's permeability to the ions will also differ
- Permeability depends on the lipid composition of membrane, chemical properties of solute, membrane proteins

- This creates a difference in the electrical potential which is known as Nernst Potential (E)
- Nernst equation describes the distribution of ions across the membrane
- Membrane potential is mainly determined by H^+-ATPase

MEMBRANE TRANSPORT PROCESS

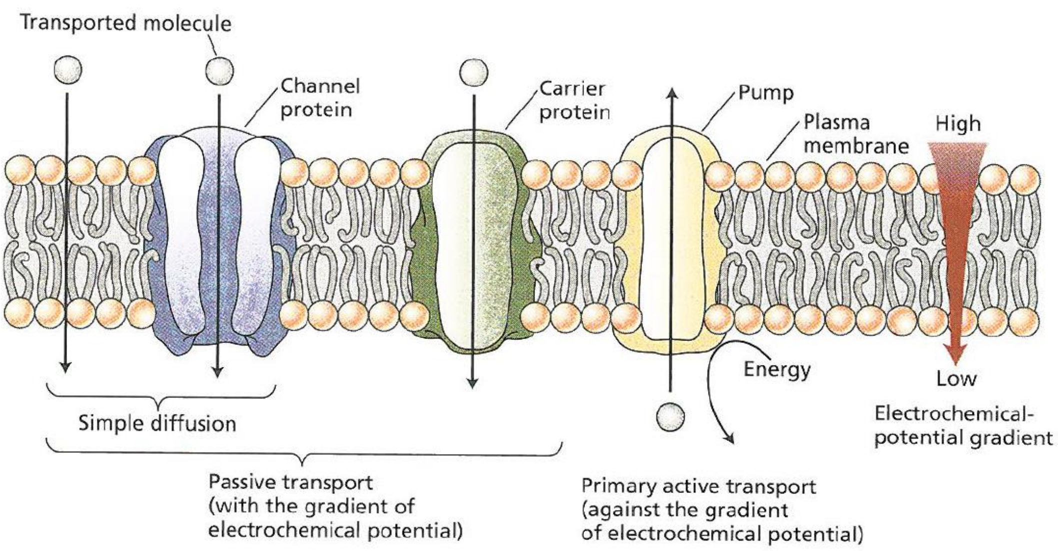
Facilitated by specialized proteins

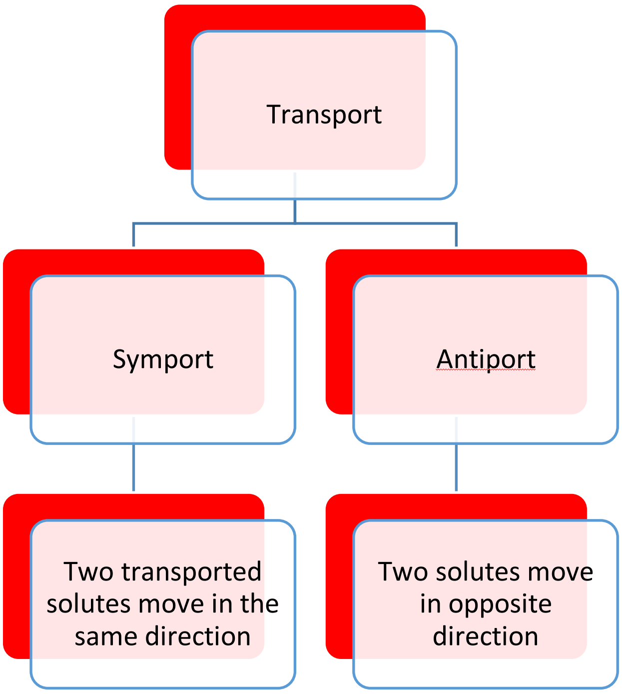
- Channels
- Carriers
- Pumps

Net result of transport process is that most ions maintained at disequilibrium

Plasma membrane / Tonoplast

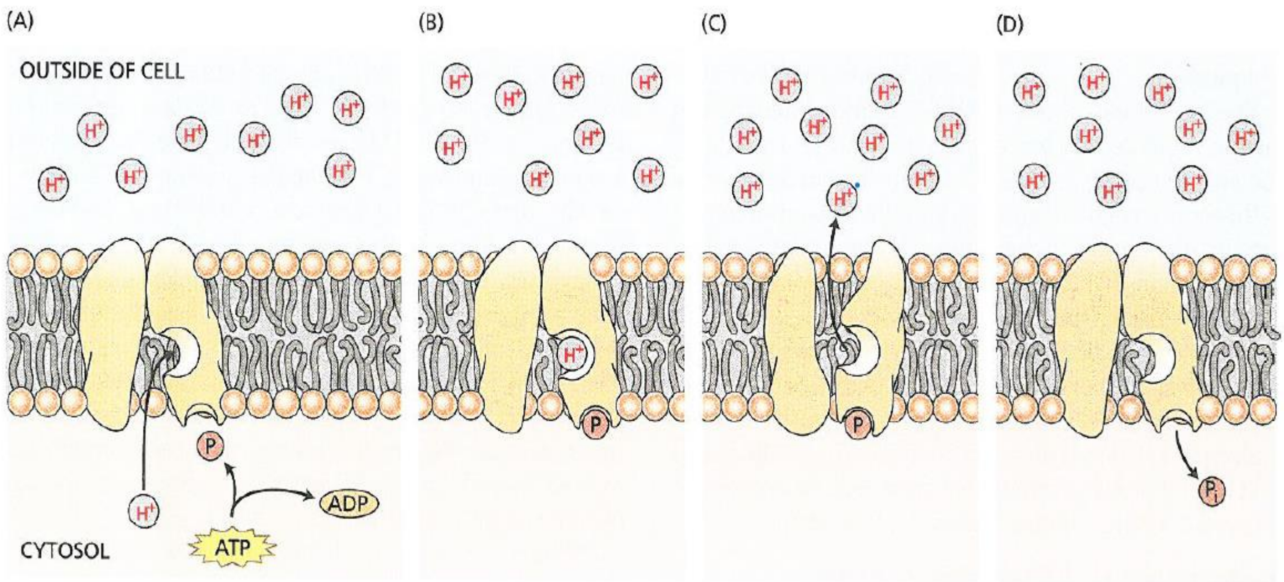
- Channels can be selective/nonselective
- They can be regulated by voltage, intracellular signalling, ligands, hormones and light
- Carriers bind specific substances and transport at a rate lower than channels
- Pumps require energy for transport. Active transport (eg. H^+ and Ca^{+2}) is mediated by pumps [H^+-ATPase (plasma membrane); V-ATPase & H^+-pyrophosphatases (tonoplast)]
- Secondary active transporters take energy from downhill movement of protons to mediate uphill
- Transporters exist for various nitrogenous compounds
- There are various cationic channels classified on the basis of their cations
- Aquaporins facilitate flux of water and other specific molecules

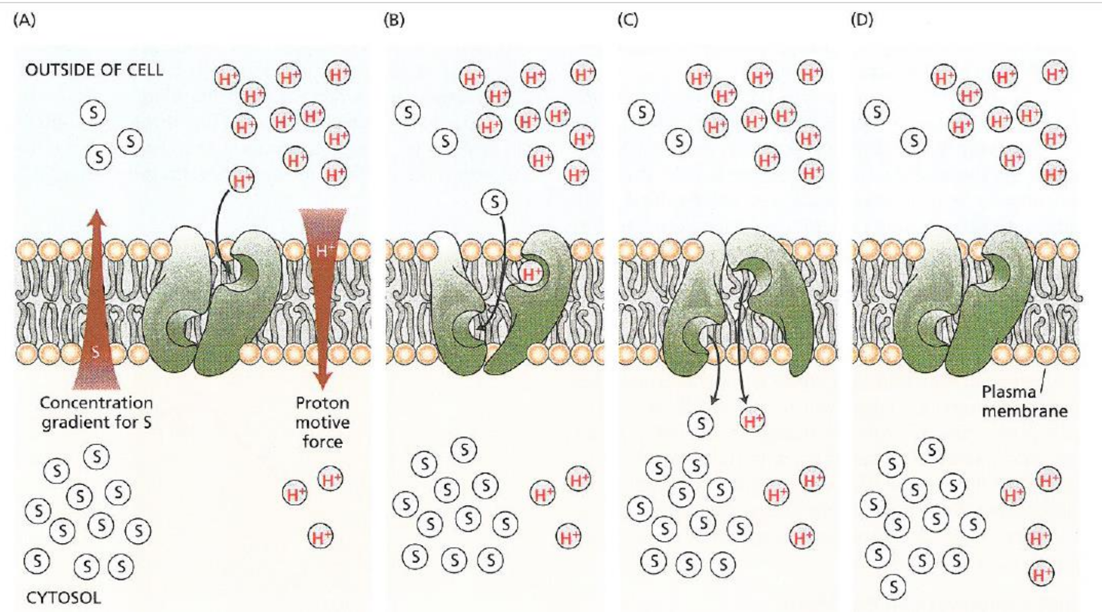




Na^{+} K^{+} antiport on tonoplast/plasma membrane

Ca^{+2} H^{+} in plasma membrane





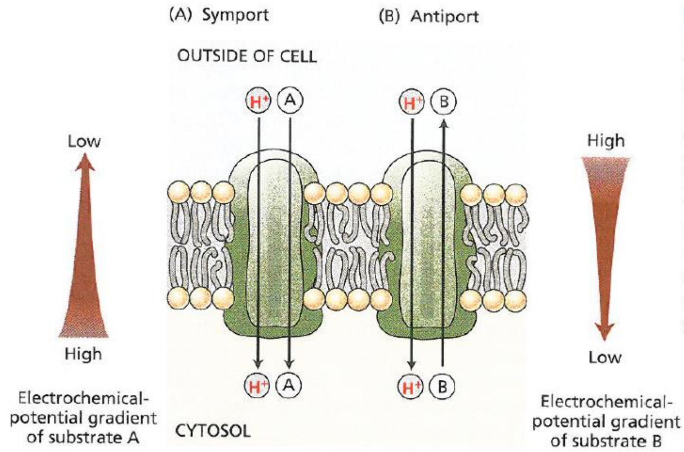
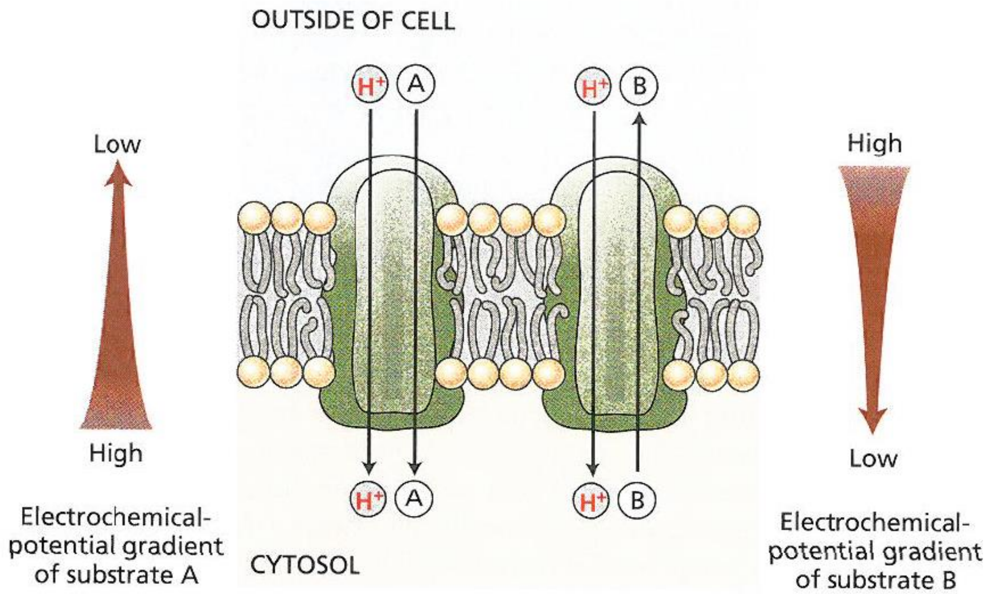


Figure 6.10 Two examples of secondary active transport coupled to a primary proton gradient. (A) In symport, the energy dissipated by a proton moving back into the cell is coupled to the uptake of one molecule of a substrate (e.g., a sugar) into the cell. (B) In antiport, the energy dissipated by a proton moving back into the cell is coupled to the active transport of a substrate (e.g., a sodium ion) out of the cell. In both cases, the substrate under consideration is moving against its gradient of electrochemical potential. Both neutral and charged substrates can be transported by such secondary active transport processes.



Source: Plant Physiology – Lincoln Taiz & Eduardo Zeiger 6th ed (Sinauer Associates, Inc.)

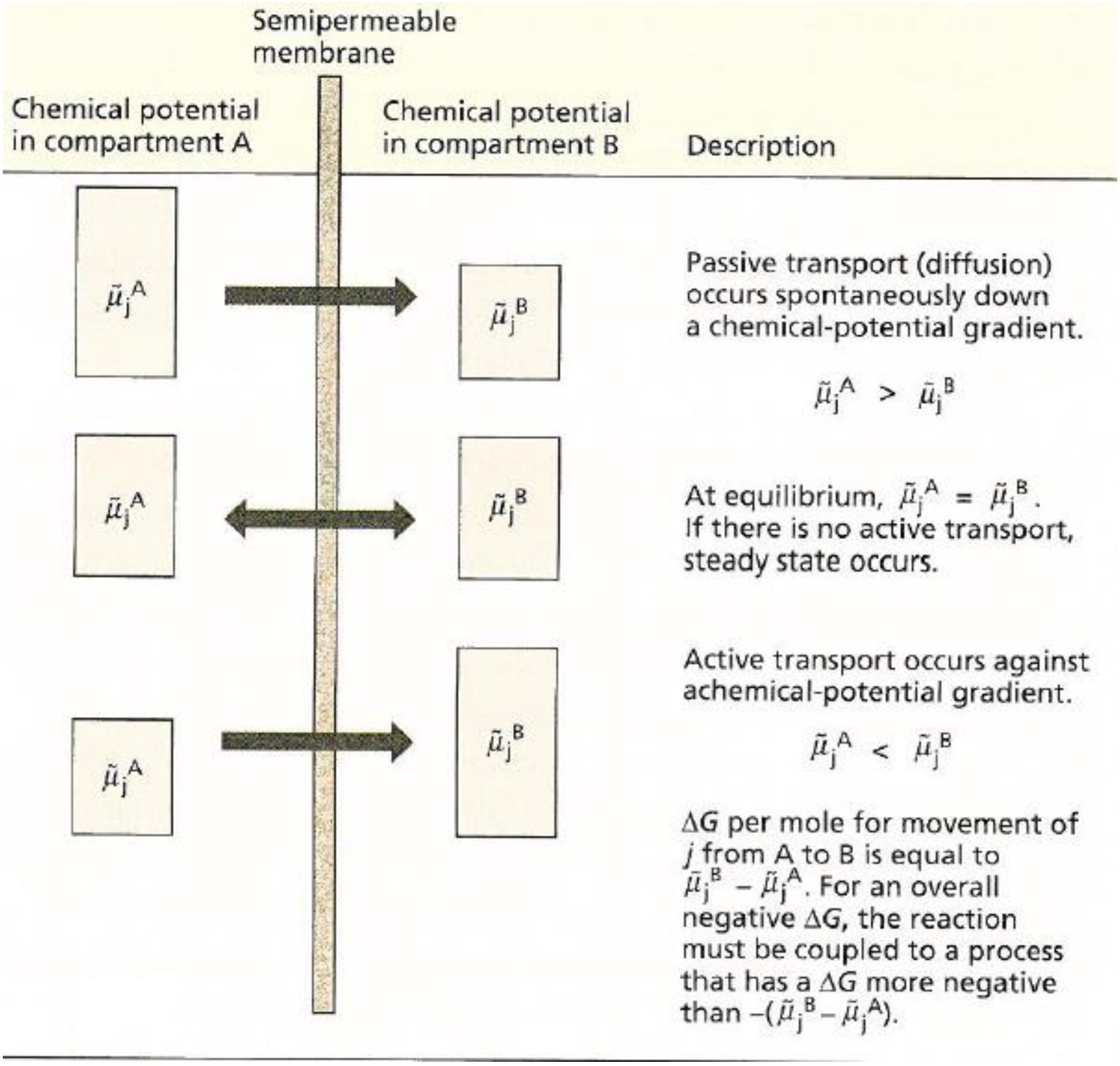
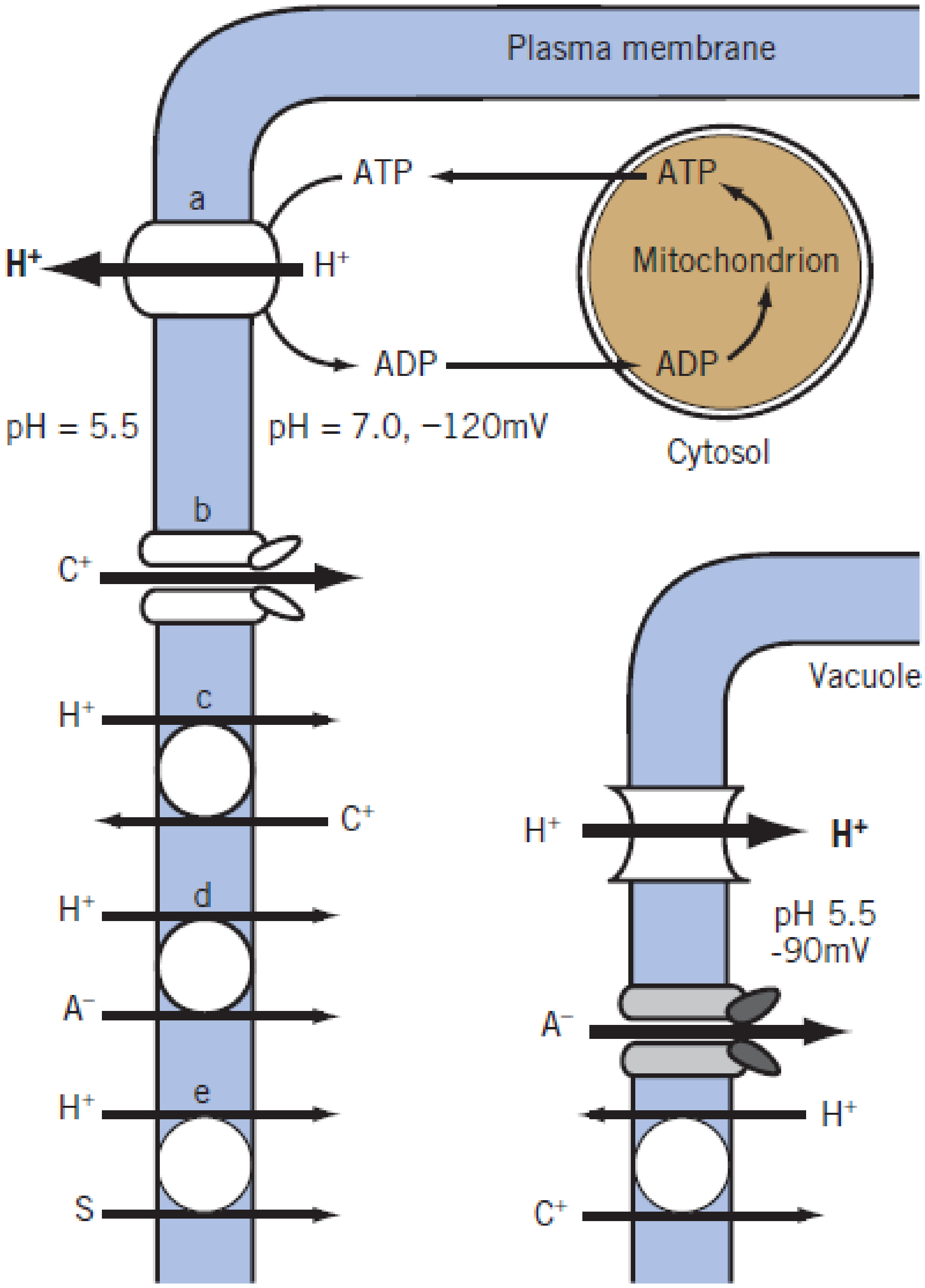


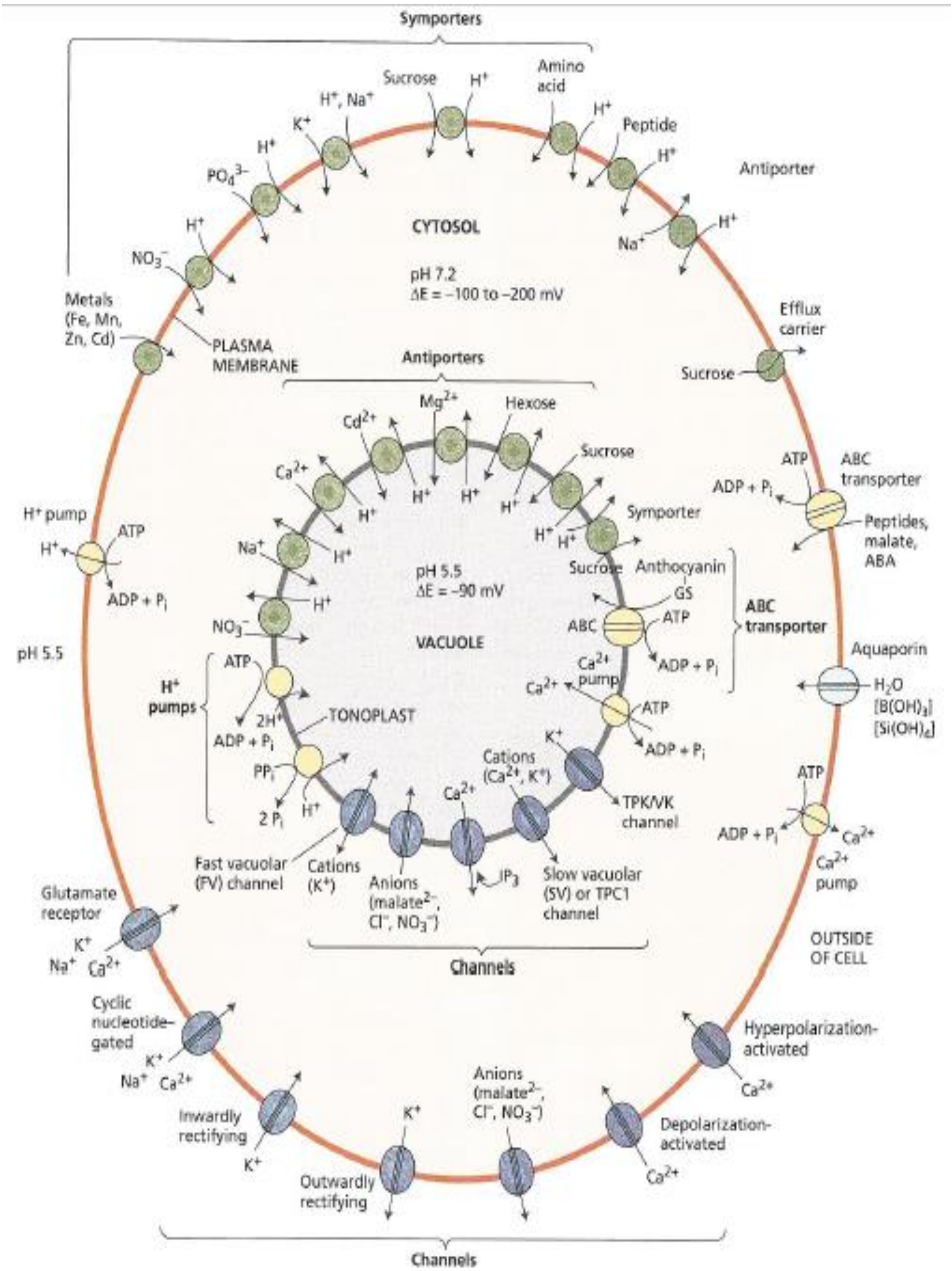
Figure 6.1 Relationship between chemical potential, $\tilde{\mu}$, and the transport of molecules across a permeability barrier. The net movement of molecular species *j* between compartments A and B depends on the relative magnitude of the chemical potential of *j* in each compartment, represented here by the size of the boxes. Movement down a chemical gradient occurs spontaneously and is called passive transport; movement against, or up, a gradient requires energy and is called active transport.

Source: Plant Physiology – Lincoln Taiz & Eduardo Zeiger 6th ed (Sinauer Associates, Inc.)



Source: Introduction to Plant Physiology – William G. Hopkins (John Wiley and Sons, Inc.)

Schematic diagram relating the activity of a membrane ATPase-proton pump to solute exchange. The proton pump (*a*) uses the energy of ATP to establish both a proton radient and a potential difference (negative inside) across the membrane. The energy of the proton gradient may activate an ion channel (*b*), or drive the removal of ions from the cell by an antiport carrier (*c*), or drive the uptake of ions or uncharged solute by a symport carrier (*d*, *e*). Similar pumps and carriers operate across the vacuolar membrane. C+, cation; A−, anion; S, uncharged solute.



Overview of various transport proteins in the plasma membrane and tonoplast of the plant cells

Source: Plant Physiology – Lincoln Taiz & Eduardo Zeiger 6th ed (Sinauer Associates, Inc.)

Further Reading:

Fundamentals of Plant Physiology – V.K. Jain (S. Chand Publication)
Introduction to Plant Physiology – William G. Hopkins (John Wiley and Sons, Inc.)
Plant Physiology – Lincoln Taiz & Eduardo Zeiger 6th ed (Sinauer Associates, Inc.)
Plant Physiology – Devlin & Witham. CBS Publishers & Distributors
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