TROPISM

- Plants generally react to the changes that occur in their environment. There are some environmental factors that cause clearly visible changes in plants. Two of these environmental factors are:
  - **light**
  - **Gravity**

A common effect of light and gravity on plant is **an alteration in the direction of plant growth**.

- Such alteration of the direction of growth often results in a **bending or curving of part of the plant either away from or towards the source of the particular environmental factor**.
- These environmental factors are referred to as **external stimuli**.

Tropism is a **growth movement** whose direction is determined by the direction from which the stimulus strikes the plant.

Positive = the plant, or a part of it, grows in the direction from which the stimulus originates.

Negative = growth away from the stimulus.

- Plants respond to:

Light = phototropism

- Stems are positively phototropic.
- Roots are negatively phototropic.

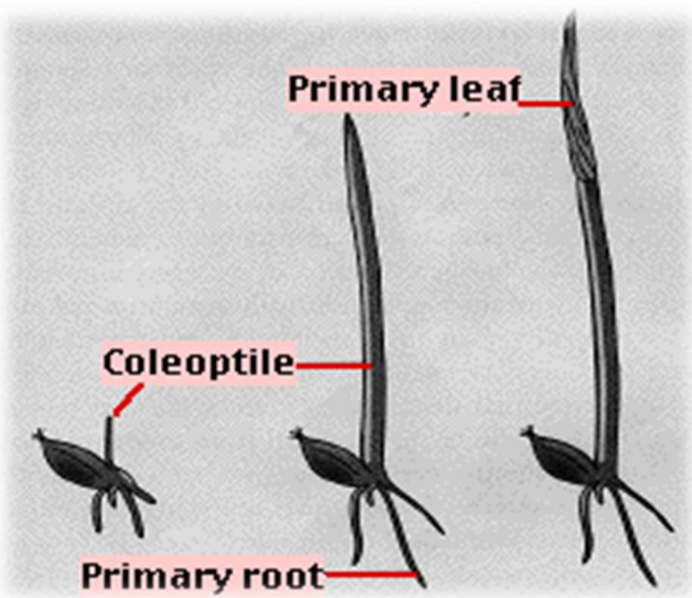
Gravity = gravitropism

- Stems are negatively gravitropic.
- roots are positively gravitropic.

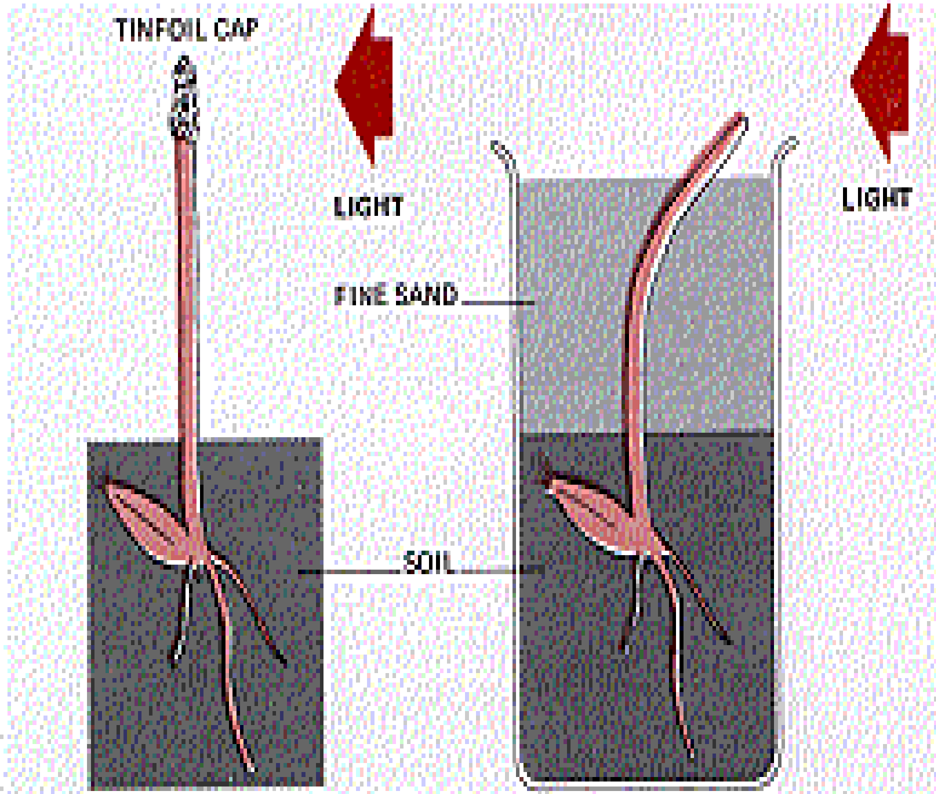
The adaptive value of these tropisms is clear.

- Roots growing down and/or away from light are more likely to find the soil, water, and minerals they need.
- Stems growing up into the atmosphere will be able to expose the leaves to light, so that photosynthesis can occur.

PHOTOTROPISM



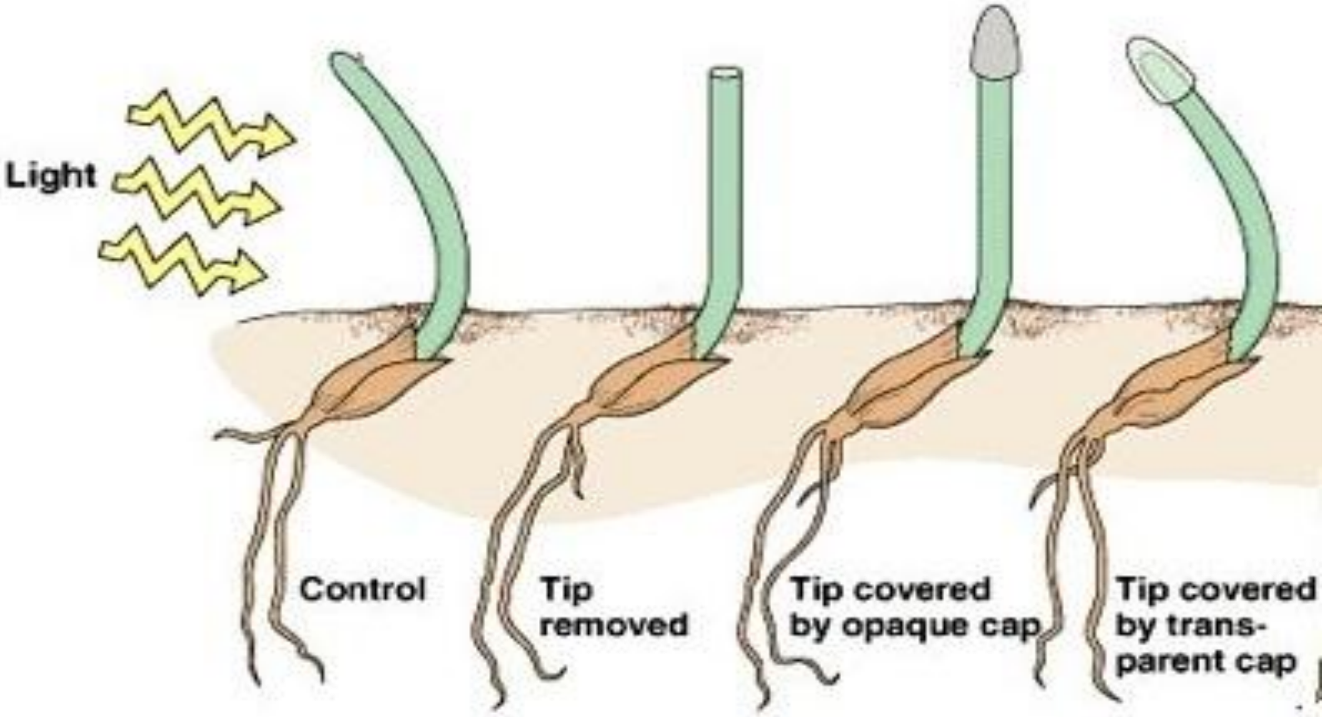
- The phenomenon of bending or curvature of plant or parts of plant in response to light is known as phototropism.
- The initial discovery of phototropism was by Charles Darwin and his son Francis in 1880.
- They used grass seedlings for their experiments.



- The Darwin's studied **only the responses of the coleoptile to the light stimulus.** In their experiments they found that **the tip of the coleoptile was necessary for phototropism but that the bending takes place in the region below the tip.**

•If they placed an opaque cover over the tip, phototropism failed to occur even though the rest of the coleoptile was illuminated from one side.

•However, when they buried the plant in fine black sand so that only its tip was exposed, there was no interference with the tropism — the buried coleoptile bent in the direction of the light.



- In further experiments with the reed canary grass and oat it was observed that curvature did not occur in reed canary grass when the tip of the coleoptiles was cut off.
- When the tip was covered with an opaque cap no curvature was seen but
- when the tip was covered with a transparent cover however some curvature was observed.

From these experiments, it seemed clear that

- the stimulus i.e. light was detected at one location (the tip)
- the response i.e. bending was carried out at another (the region of elongation).

This implied that the tip was, in some way, communicating with the cells in the region of elongation.

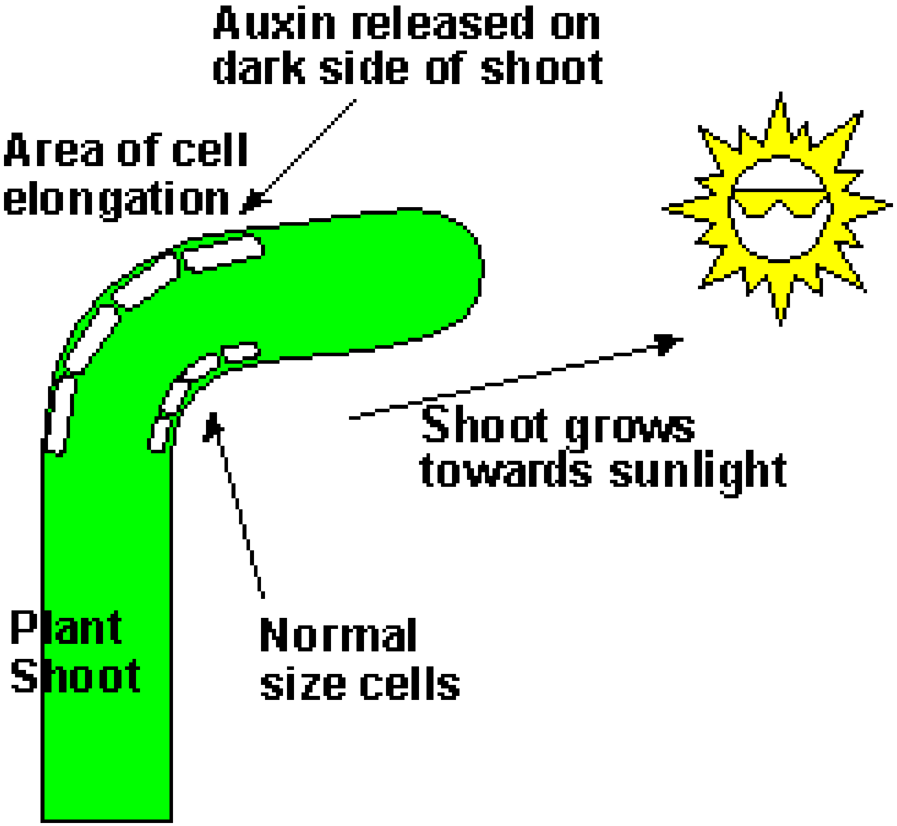
These observations generated several questions then, and in later years people wanted to know,

- How is the plant able to tell the direction of the external stimulus
- Which part of the plant perceives the stimulus
- What is the process of perception
- How are the cells perceiving the stimulus and transmitting the message to the parts of the plant that respond to the stimulus
- What actually happens within the cells that respond to the stimulus

Partial answers have been obtained for some of these questions but we are still in the dark about the others.

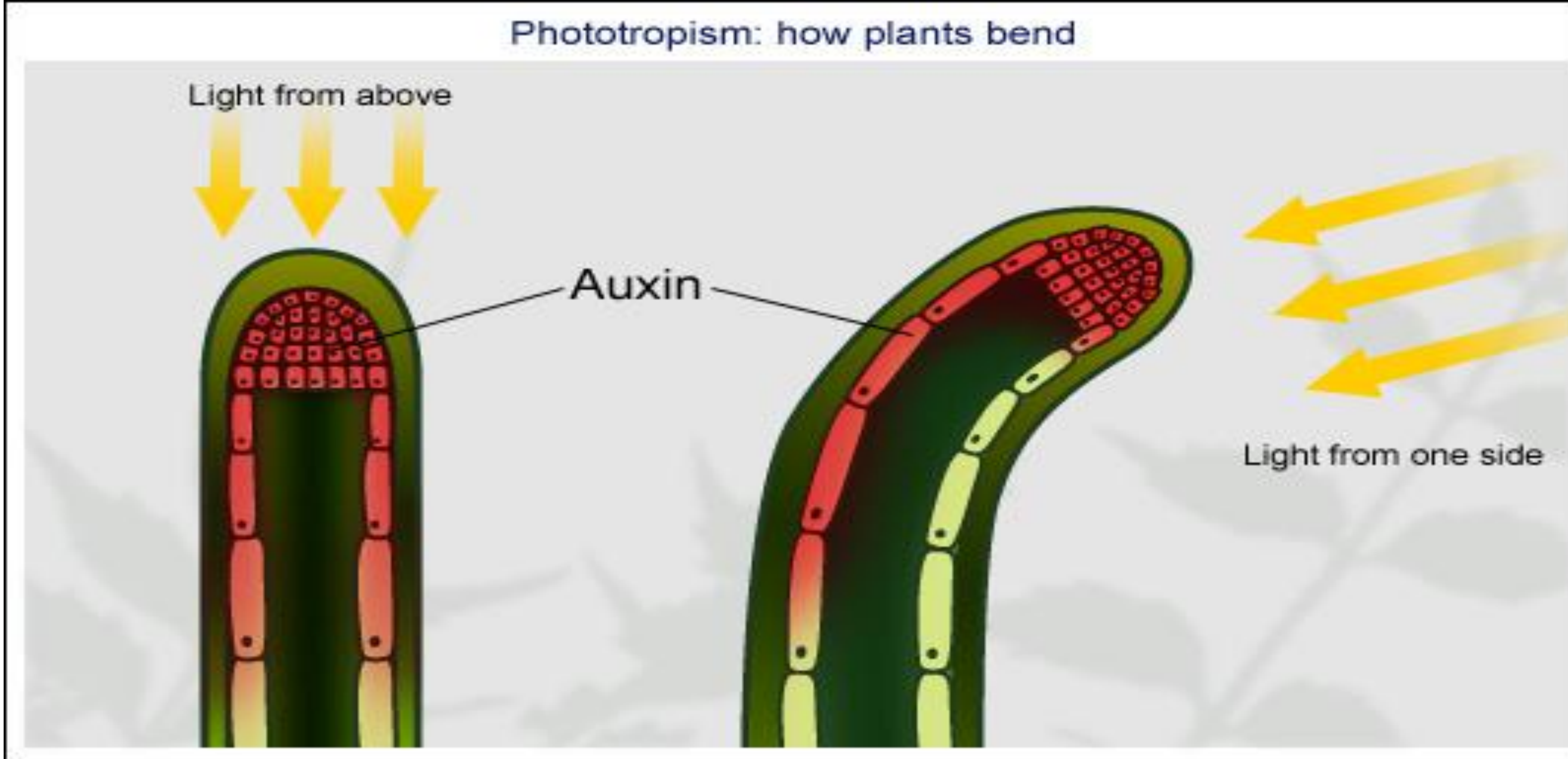
Cholodny-Went theory – 1920

- The early experiments conducted on coleoptiles also showed that **something was being transmitted from the coleoptile tip down the coleoptile** that cause the bending
- In 1920 a hypothesis was put forth by Cholodny and Went to explain the bending which was known as Cholodny-Went theory. This theory maintains that the curvature observed as a result of unilateral lighting was due to **uneven distribution of a plant hormone – auxin**.



- When light is shone on a coleoptile from one direction the bend which occurs is due to an unequal elongation of cells on the side towards and on the side away from light. Elongation of the cells on the lighted side of the coleoptiles is slowed down compared to elongation of cells on the shaded side.

This results in unequal extension of the lighted and shaded sides of the coleoptiles. To accommodate these elongation inequalities, the coleoptile bends towards the light.



The plant hormone auxin causes plant cells to elongate. When a shoot is directly under light, auxin produced in the growing tip spreads equally down both sides of the plant. If light is from one side only, auxin collects on the shady side causing the cells on that side to elongate. That lopsided elongation produces a bend in the plant stem.

- The Cholodny-Went theory explains that the unequal growth was due to **lateral transport of auxins away from the lighted to the shaded sides** of the plant when tip was exposed to unilateral light.

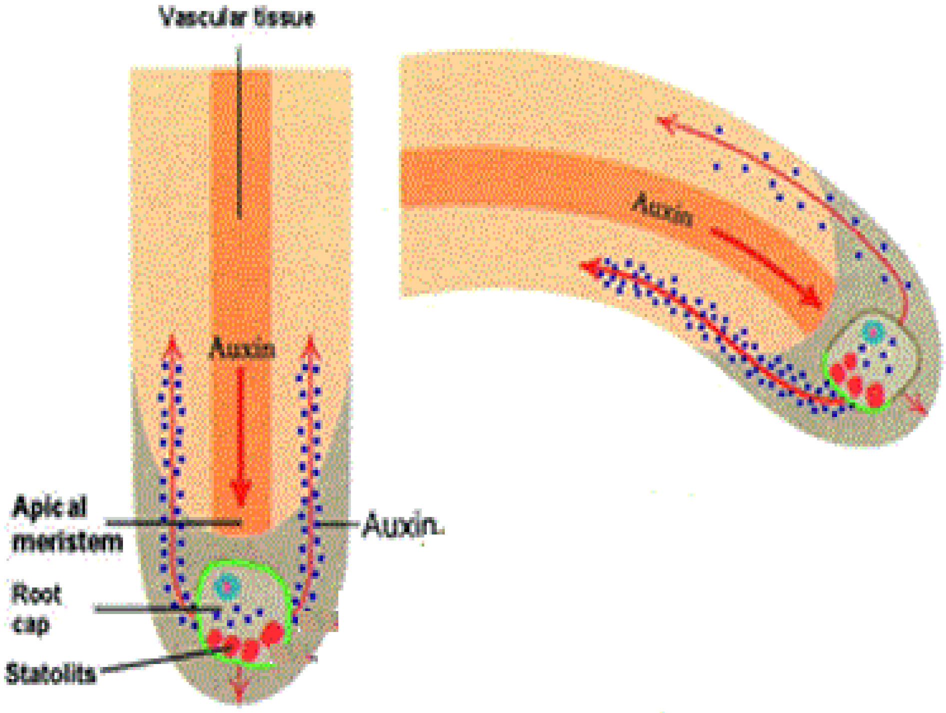
GRAVITROPISM

This is the directional growth of a plant part towards or away from the source of gravity.

- Root generally grow towards the source of gravity – **positively gravitropic**.
- Shoot grow away from the source of gravity – **negatively gravitropic.**

GRAVITROPISM – ROOTS

- Primary roots are generally more sensitive to gravity than the lateral roots. Thus primary roots grow vertically downwards while lateral root grow horizontally
- In higher plants gravity sensing by primary root is the function of its **root cap**.
- The cells with the gravity sensitive inclusions are found in the central cylinder of the root cap region – **columella**.
- These cells are known as **Statocytes cells** which contain gravity sensitive inclusions, probably **starch grains** i.e. **statoliths**.



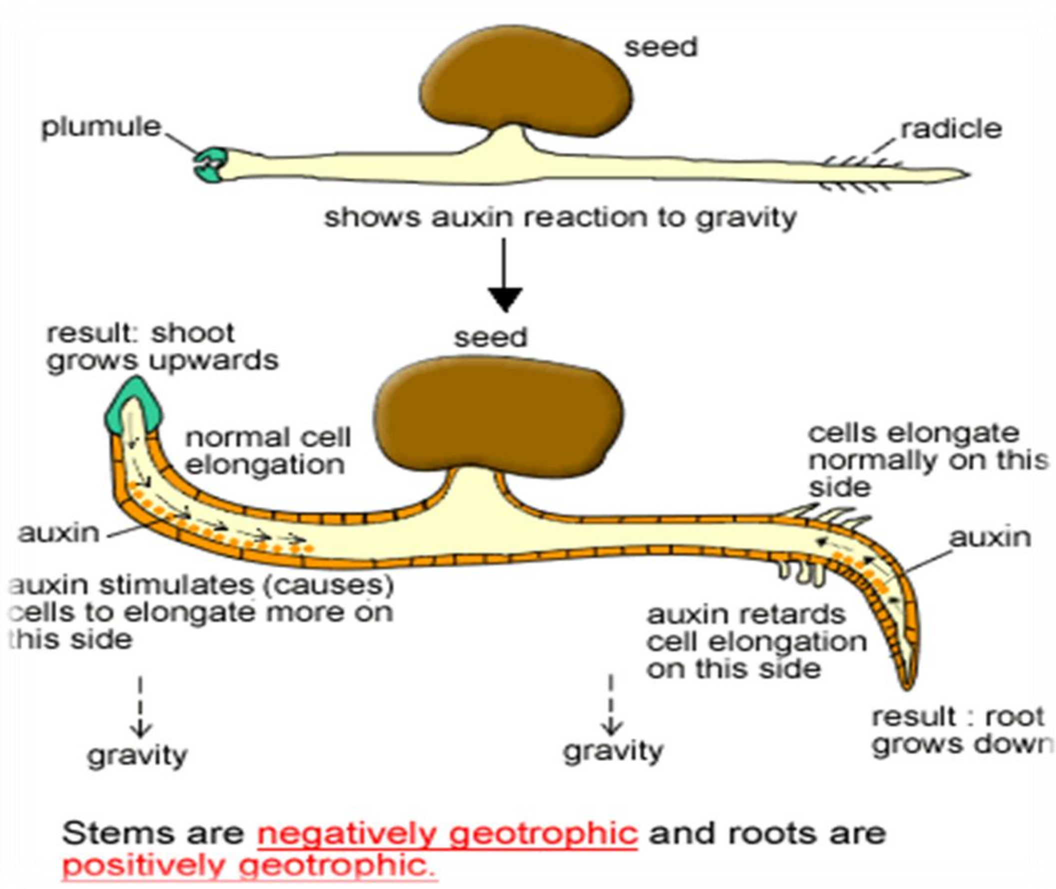
- Curvature of the root occurs in the elongation zone of the root and is downward towards the source of gravity. It results from faster growth of cells on the upper side than on the lower sides of the horizontal root.

•In horizontally placed seedling, **auxin accumulates under gravity on the lower side**. In roots this leads to a higher concentration of auxin on the lower than the upper side. **High concentration of auxin inhibits elongation of cells in roots**.

•The cells on the upper side which have a lower concentration of auxin would elongate more compared to the cells on the lower side which have higher auxin concentration.

•**THUS THE ROOT BENDS DOWNWARDS IN THE DIRECTION OF GRAVITY**

GRAVITROPISM – SHOOTS



- Coleoptiles that have been placed horizontally bend and grow vertically upwards. This is because cells on the lower side elongates much more than those on the upper side of the horizontal coleoptiles. Higher concentration of auxin stimulates elongation

Cells at the coleoptiles tip seem to be the principal gravity sensor however other cells below the tip in growing region also may be involved in gravity sensing. For instance when the coleoptile tip is cut, it does not lose its ability to sense gravity totally.

MINERAL NUTRITION

- All living organisms require food for the accomplishment of their life processes. The food is used as a source of

- Energy required in various biochemical reactions – ATP
- Simple biomolecules that are the building blocks for more complex biomolecules that makes up the structure of the plant. eg glucose in cell wall, phospholipids in cell membranes, various amino acids which are part of enzymes and coenzymes required for biochemical reactions.

- The foods that animals take in normally are energy rich complex biomolecules either from plants or other sources.

- Some fungi and bacteria that are saprophytic also obtain their food by breaking down animal and plant remains.

- In contrast plants manufacture their food from simple elements in the environment.
- The presence of chlorophyll in plants enables them to utilize the sun’s energy for synthesizing energy rich biomolecules like glucose and amino acids.

- Studies on the nutrition of plants began in 1800 with analysis of plants by both botanists and chemists.
- These analyses showed that plants contained certain inorganic elements which could only come from the environment.
- Towards the end of 1800's it was demonstrated that some 10 of these inorganic elements were required for plant growth.

- In their absence plants grew abnormally and their reproductive process was also abnormal. These elements were then referred to as **essential inorganic nutrients.**
- Currently more than 16 elements are known to be essential for the plant's nutrition. The concentration of various elements that have been estimated during plant analyses separated these elements into two groups.

- Macronutrients – These elements are required in large amounts by plants and also occur in relatively high concentrations in plants.

- Micronutrients – These elements are required at very low concentrations. Micronutrients are also called trace elements in older literature.

- For example in maize, the percentage concentrations of various macro and micronutrients were as follows:
- Macronutrients :

Nitrogen	2.81
Potassium	1.86
Calcium	0.40
Phosphorus	0.28
Magnesium	0.27
Sulphur	0.18
Oxygen	large proportion
Carbon	large proportion
Hydrogen	large proportion

- Micronutrients
- Iron 0.000110
- Chloride 0.003100
- Copper 0.000006
- Manganese 0.000080
- Zinc 0.000027
- Molybdenum 0.000001
- Boron 0.000014

- The studies on nutritional requirements of plants have also established that some elements seem to be required by only a limited group of plants. Eg legumes seem to have improved growth when **cobalt** is added to their rooting medium.

- It is now known that the cobalt is used by bacteria that are in a symbiotic relationship with legumes. These bacteria are found in the roots of legumes and they convert gaseous atmospheric nitrogen to nitrogenous compounds for the plant.

- Although sodium can be tolerated by halophytes it has not been demonstrated to be essential for the plants metabolism in general.

- Still some people maintain that sodium is an essential element for C4 plants and some halophytes.

- Soyabeans also appear to require **nickel**. In absence of nickel, plants often accumulate urea which is toxic at high concentrations. This results in necrosis at leaf tips and reduction in the overall growth rate of the plant.

- Necrosis is a disease symptom which shows as browning because of death of cells in a particular area.

Functions of elements

- The functions of elements can be specific or non-specific when other elements can substitute for each other.

Non Specific function

- Maintenance of osmotic pressure necessary for water uptake into plant can be performed by inorganic ions eg. Sodium, potassium or chlorine

Specific functions

- Specific functions for elements span the entire range of the plant's life processes. Some elements also have more than one function in the plant. The functions may be

a. Structural – i.e. the elements be part of structures that make up the plant cell.

Examples:

1. Calcium combines with pectic acid to form the middle lamella of the plant cell.
2. Phosphorus is a constituent of phospholipids, a part of plasma membrane.
3. Carbon, oxygen and hydrogen are constituents of glucose chains that make up the cell wall.

b. Non Structural

Components of various biomolecules that are not part of the cell structure

1. Phosphorus – component of nucleic acid which make up the genes, energy carrying compound (ATP, ADP) and several coenzymes (non protein organic compounds that require enzymes for activity eg. pyridoxal phosphate).

2. Magnesium – part of the chlorophyll molecule.

3. Nitrogen – component of amino acids and hence proteins(proteins are made up of amino acid chains), nucleic acids, chlorophylls and coenzymes eg NAD

4. Carbon, hydrogen, oxygen – components of

- Carbohydrates, eg glucose, sucrose, starch,
- Lipids, eg oleic acid, linoleic acids, oils, waxes
- Proteins – components of amino acids eg. Glycine, alanine, proline

5. Sulphur – component of some amino acids and hence proteins eg. Methionine, cysteine and coenzyme A

c. Metabolic reactions -Photosynthesis

1. Cl and Mn – are involved in the light reaction of photosynthesis – specifically reactions leading to release of oxygen.

2. Na – required by C4 and CAM plants for regeneration of phosphoenolpyruvate – compound combining with carbon dioxide in the 1st carboxylation reaction in these plants.

d. Catalysis

1. Components of enzymes

Most micronutrients are components of enzymes that are required for the activity of these enzymes.

- Fe – cytochrome oxidase (transfers electrons to oxygen during the respiration process) and nitrogenase(converts atmospheric nitrogen to ammonia)
- Mo – nitrogenase enzyme (converts atmospheric nitrogen to ammonia)
- Zn – carboxypeptidase (hydrolyses last peptide bond in a polypeptide chain in protein breakdown processes)
- Cu – plastocyanin (involved in electron transfer during the light reaction of photosynthesis)

2. Activators or regulators of enzymes - Other essential elements are activators or regulators of enzymes. They might change the shape of the enzyme such that the catalytic site is exposed or obstructed

- Mg^{2+} → ATPase (ATPase is an enzyme which requires Mg for its activity)
- K^+ →kinases (Kinase is an enzyme which requires K for it activity)

e. Osmotic activity

- Some essential elements are involved in the maintenance of osmotic potential and ionic balance in plant cells.

1. K – stomatal opening and closure is dependent on osmotic potential in the guard cells. The osmotic potential is generated by influx (inward movement) of potassium ion into the guard cells. This leads to uptake of water by the guard cells which swell and the stomata open.

   During the efflux (outward movement) of potassium ion from the guard cells, the osmotic potential is reduced and water moves out of the guard cells into the surrounding cells. The guard cells then lose their turgidity and shrink closing the stomata.

2. Na – involved in generating osmotic potential in halophytes for water uptake.
3. Cl – involved in osmotic regulation and ionic balance

f. Cell Permeability

1. Ca – directly affects the physical structure of cell membranes. Membrane integrity is maintained only in the presence of calcium. Thus Ca affects the function of the cell membrane which is selective uptake of substances into the cell.
2. B – has been found to maintain membrane wholeness of the cell.

ION UPTAKE

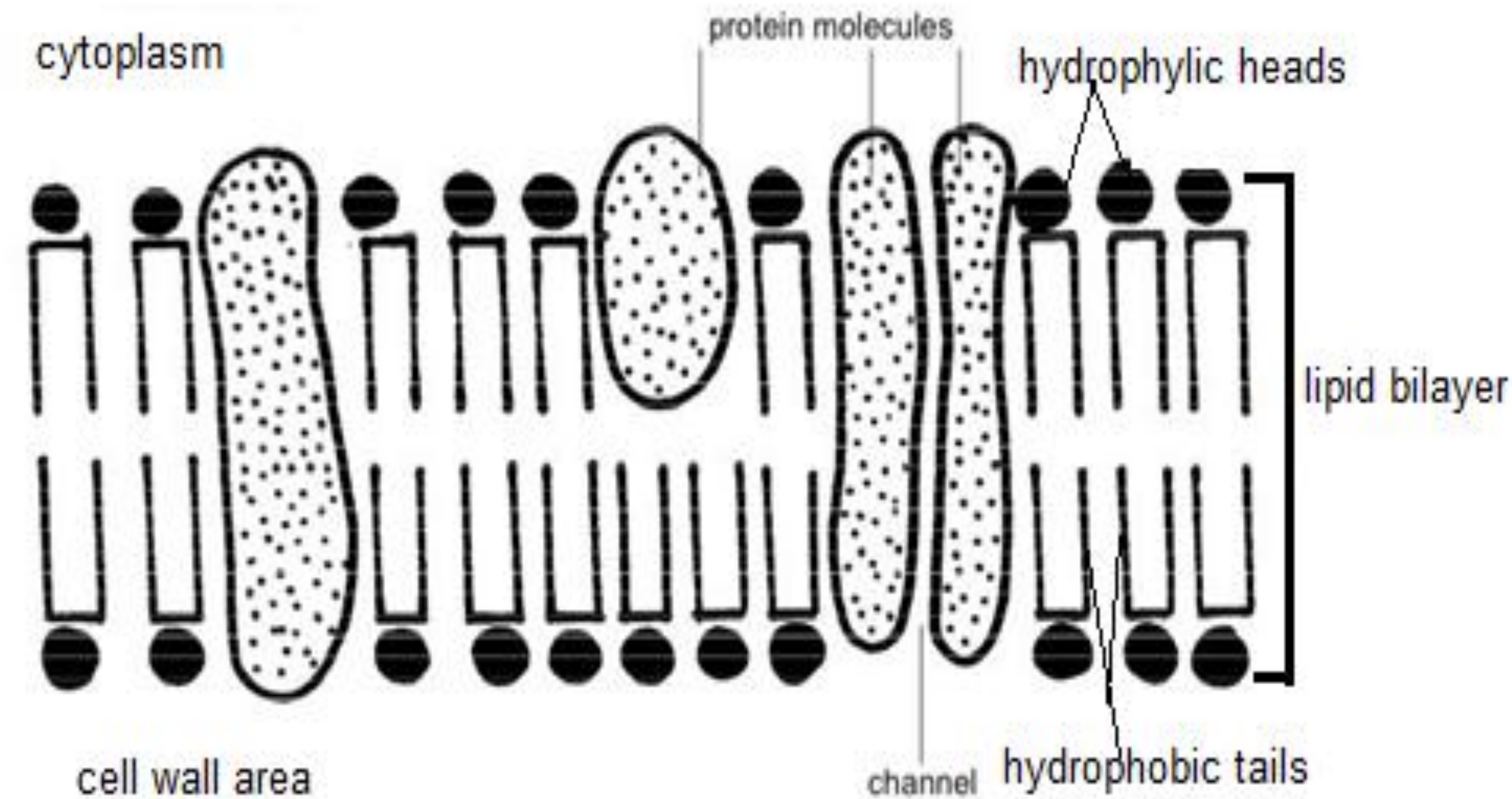
- With the **exception** of O_2, CO_2 which are taken up in a gaseous form by all plants and N_2 which is utilized by the symbiotic association between legumes and rhizobia, all the essential elements are taken from the soil by plant roots.
- **Inorganic ions are taken up into plants via the epidermis of the younger portion of the roots where secondary growth has not yet initiated.** Ions enter the epidermal cells of the plant and passes into the internal cells (cortex) until they are secreted into the transport tissue – xylem.

MODE OF ION UPTAKE

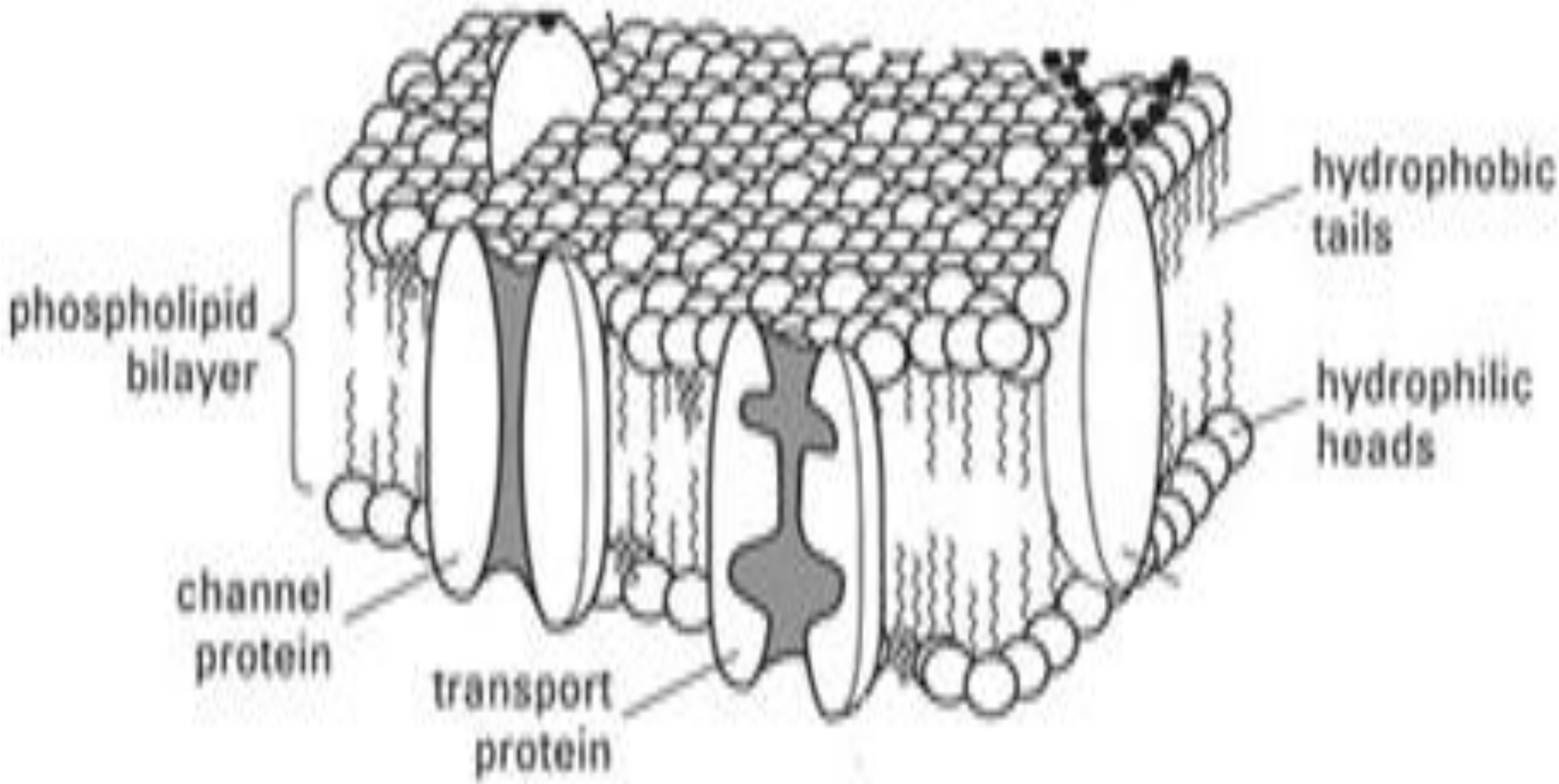
- It has been **observed that the concentration of ions in the root cells is several times higher than that in the soil solution** eg. Root cells of pea (*Pisum sativum*) were found to contain 75 times more K+ than nutrient solutions in which they were growing.
- **The normal movement of ions is from high to lower concentration.** The question then arises is why the ions in the roots do not move back to the soil. This is due to the semi permeable nature of the cell membrane that prevents the movement of ions from the cell back into the soil solution.

- **The cell membrane/plasma membrane consists of a lipid bilayer with interspersed proteins.** The bilayer consists of **hydrophilic heads** (water loving) and **hydrophobic tails** (water avoiding).
- The arrangement of the bilayer is such that the hydrophobic tails face each other towards the inner side and the hydrophilic heads are on the outer surface facing the cytoplasm.
- The lipid bilayer do not allow polar molecules (the molecules which carry charge. For eg K^+ and NO_3^{--}) to pass through but allow only non polar molecules (the molecules which do not carry charge. For eg fats and oils).

Cross section of a membrane



3D model of a cell membrane



- The protein molecules in the membrane either go across the bilayer or are in one half of the bilayer.
- Those proteins that go across the membrane acts as transport proteins moving the ions from the soil solution into the cell.
- These proteins show specificity for ions i.e. specific protein moves a particular ion into the cell. **They act as channels, carriers and pumps.**

- The **channel proteins** have a passage way through which ions move.

- The **carrier proteins** pickup ions rotate within the membrane and release the ions into the cytoplasm.

- The **pump proteins** use energy from ATP to pump ions across the membrane.

- The transport can either be an active process or passive process. **Carriers and channel proteins transport ions passively** i.e. they do not use ATP and they move ions from the regions of higher to lower concentration by simple diffusion.

- Whereas the **pump proteins move ions actively** because, they use energy in the form of ATP and they move the ions from regions of lower to higher concentration.

PATHWAY FOR ION AND WATER MOVEMENT

- There are **3 pathways** by which water, ions and other substances move into plants i.e. **apoplastic, symplastic and transcellular.**

Apoplastic Pathway:

- This is a movement within the cell walls and the intercellular spaces of the plant. The cell walls of cells making up various tissues are thought to be a continuous structure across the root or stem.
- In the root however this continuum is broken in the hypodermis (right beneath the epidermis) and the endodermis (just outside the pericycle).

- Both these tissues have cells with impermeable substances (suberin) in their radial walls – casparian strips – which prevent substances moving across them.
- In those plants having hypodermis, after water or ions enter the epidermis they cannot progress through the cell wall at the hypodermis and therefore at this particular point substances or ions have to find an alternative pathway by which they can continue the movement to the xylem.
- In plants lacking hypodermis, water and ion movement continues **apoplastically** until they reach the endodermis where an alternative pathway is used.

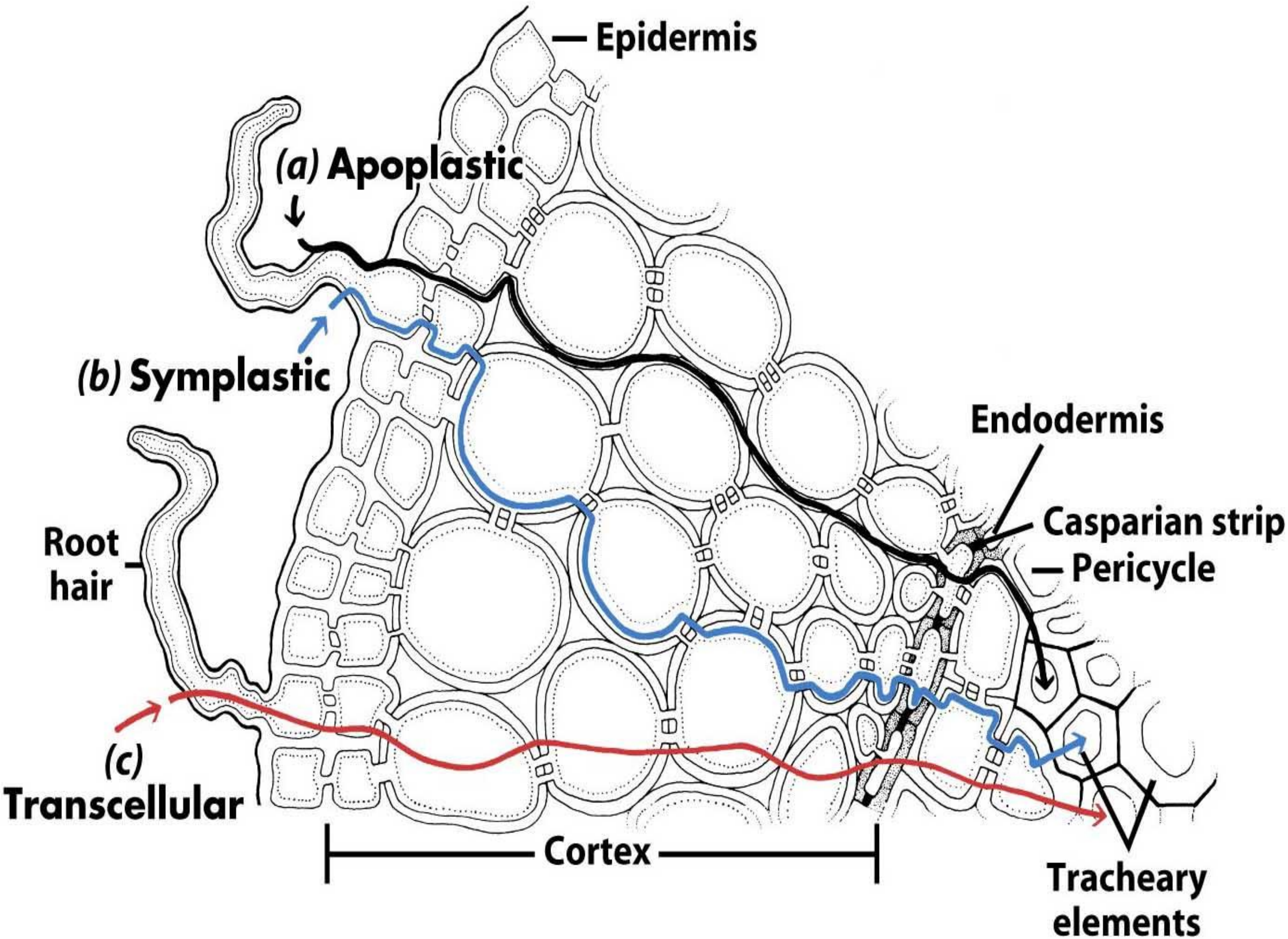
Symplastic Pathway:

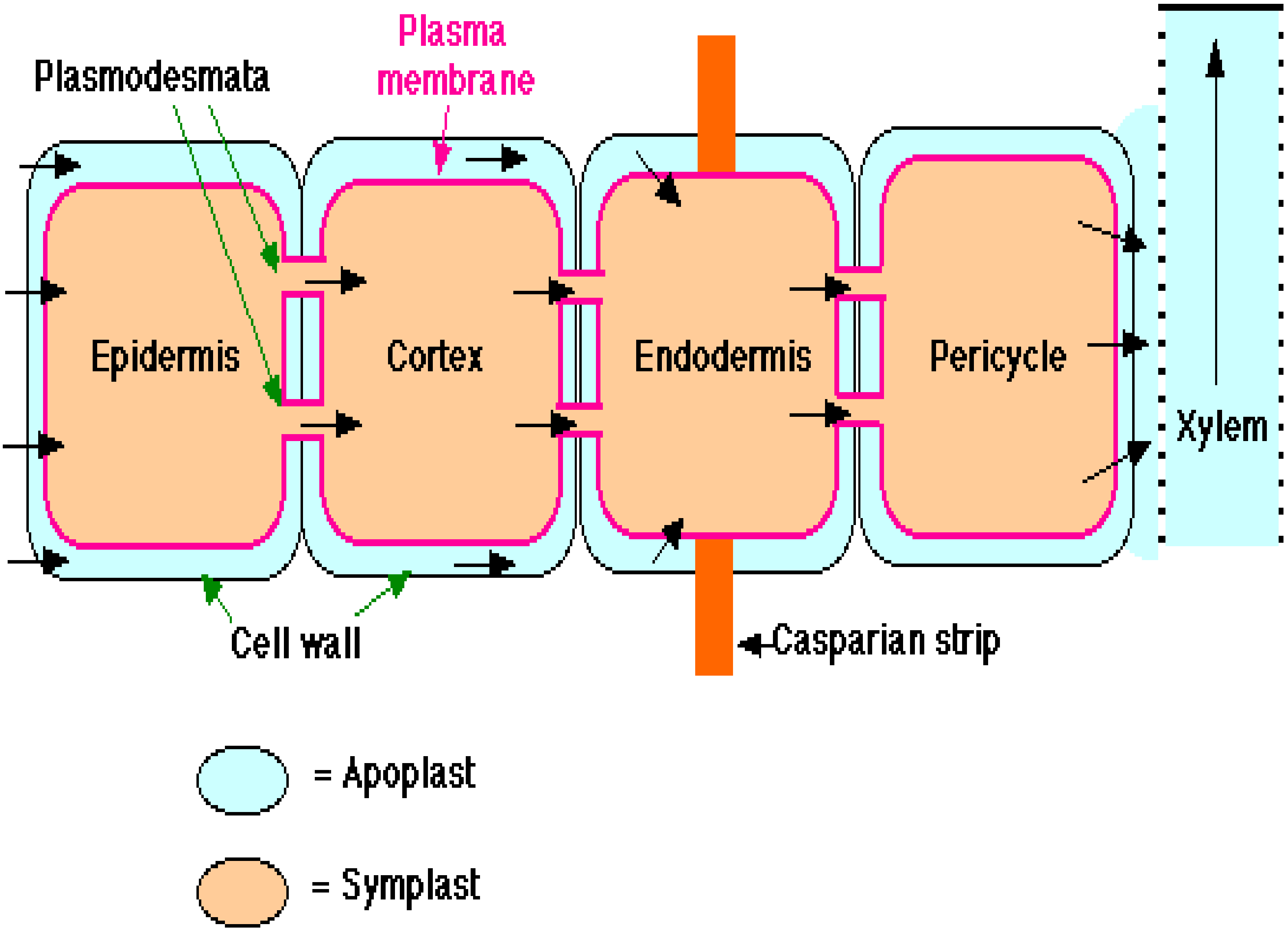
- The protoplast of plant cells are interconnected through narrow strands of cytoplasm – plasmodesmata – spanning the cell wall.
- Thus the cytoplasm of the cells within any organ of the plant form a continuum and substances can move through this continuous cytoplasm from one point of the plant to the other.
- **This is called the symplastic pathway**. Water and ions can move through the **symplast** until they get to the xylem, where they enter the **apoplast.**

Transcellular Pathway: (Vacuolar).

- Substances move from cell to cell going from cytoplasm through vacuole and exiting the cytoplasm before moving into adjacent cell.

- Cell wall ------- cell membrane ------ cytoplasm ------ vacuole(cell sap) ------- cytoplasm ------- cell membrane-----into another cell


Epidermis
(a) Apoplastic
(b) Symplastic
Endodermis
Casparian strip
Pericycle
Root hair
(c) Transcellular
Cortex
Tracheary elements


Plasmodesmata
Plasma membrane
Epidermis
Cortex
Endodermis
Pericycle
Xylem
Cell wall
Casparian strip
= Apoplast
= Symplast