زانكۆی سەلاحەدین - هەولێر
Salahaddin University-Erbil

Plant Physiology

(EdB0403)-1st Semester
For 4 year students

College of Education, Biology Department

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Sec.1: Photosynthesis

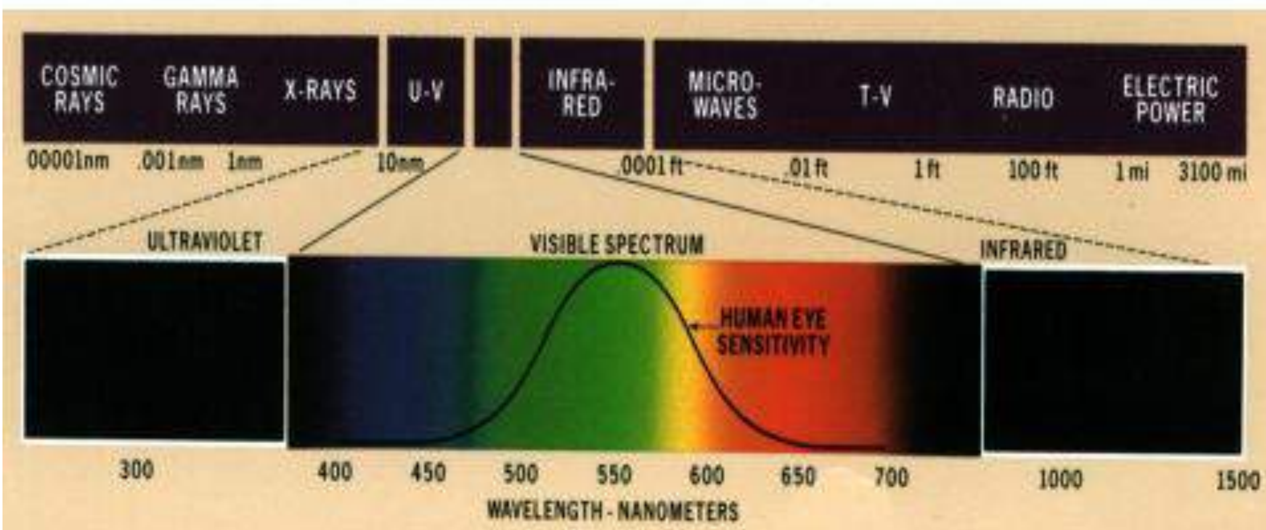
An anabolic, endergonic, carbon dioxide (CO_2) requiring process that uses light energy (photons) and water (H_2O) to produce organic macromolecules (glucose).

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

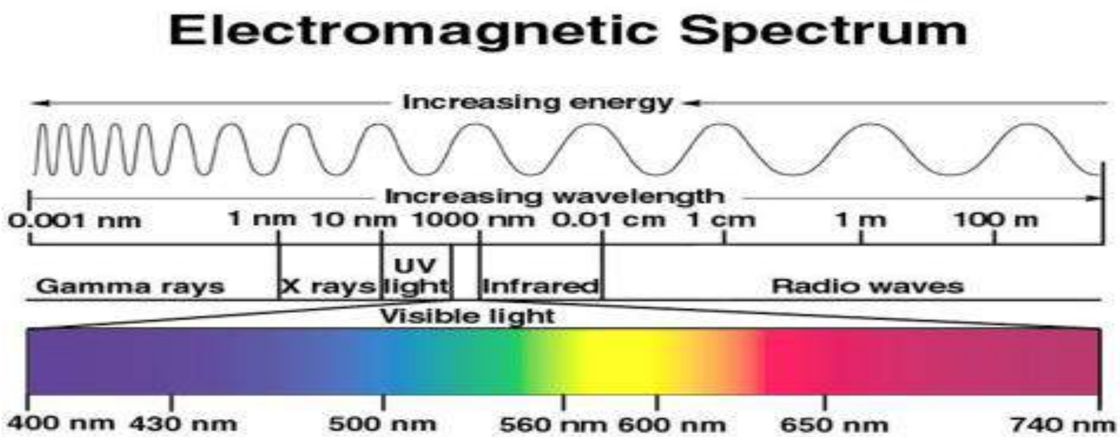
What is light

Photon - a light particle.

- Wavelength – Length of a complete wave of light.
- Frequency – The number of waves per unit length. Sunlight is an electromagnetic radiation coming from the sun. It has a wide spectrum – from cosmic rays to radio waves.



- Visible Light Is only a Small Portion of the Electromagnetic Spectrum

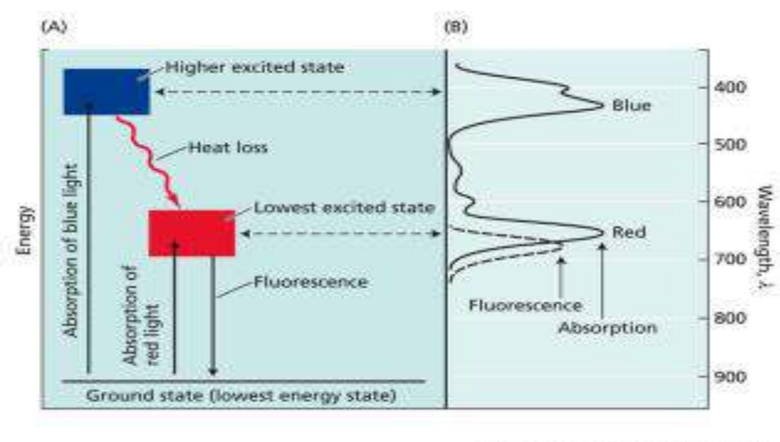


Light absorption and emission by chlorophyll

Stable for only about several nanoseconds (10^{-9}s), any process that captures its energy must be extremely rapid. In the lowest excited state, the excited chlorophyll has four alternative pathway to dispose energy:

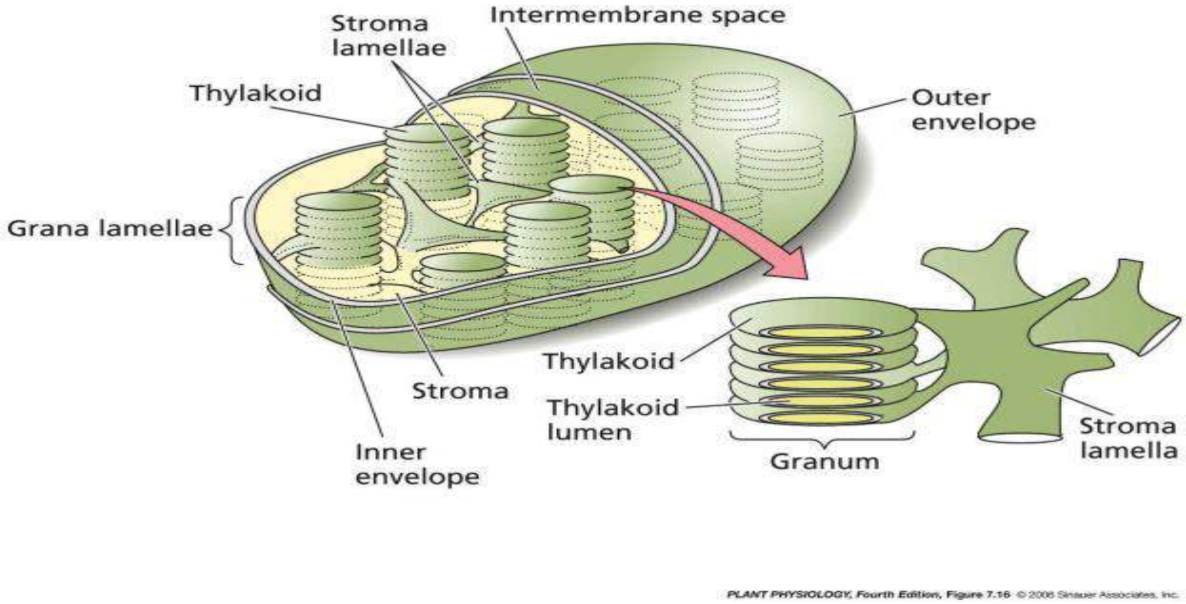
Fluorescence, Heat, Energy transfer and Photochemistry (Photosynthesis)

Light absorption and emission by chlorophyll



Stable for only about several nanoseconds (10^{-9}s), any process that captures its energy must be extremely rapid.

About 20-100 Chlo/mesophyll cell. Inside the Chloroplast: Intertwined and Stacked Network of more Membranes, Thylakoids. Granum/Grana is Stack of Thylakoids.
Stroma: Areas between Grana, Chloroplast Has 3 Membrane Systems, Forming 3 Compartments



A pigment is any substance that absorbs light, the color of the pigment comes from the wavelengths of light reflected. Chlorophyll is the green pigment common to all photosynthetic cells, absorbs all wavelengths of visible light except green, which it reflects to be detected by our eyes. All photosynthetic organisms have chlorophyll a. accessory pigments absorb energy that chlorophyll a does not absorb:
chlorophyll b, xanthophylls and carotenoids (Beta-Carotene).

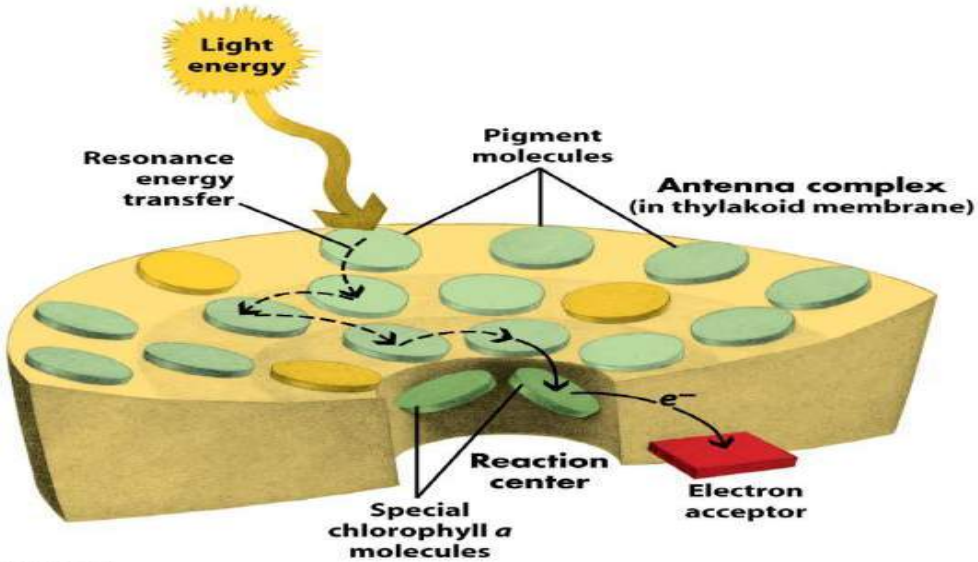


Figure 7-10
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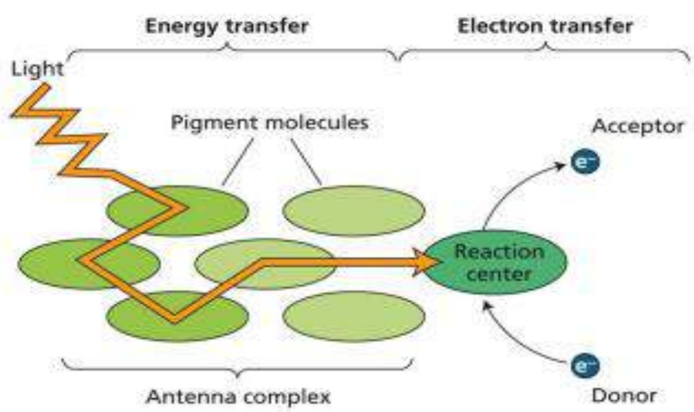
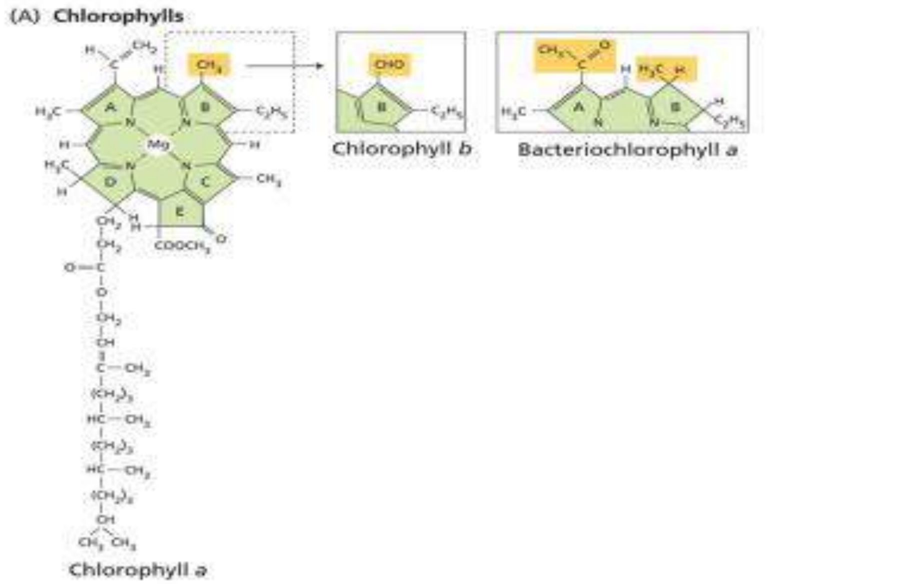
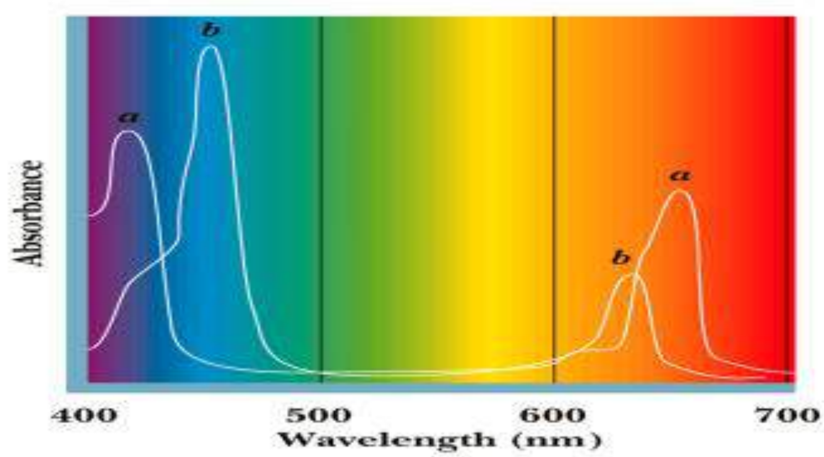
Basic concept of energy transfer during photosynthesis



Molecular structure of some photosynthetic pigments



Absorption spectrum of Chlorophyll a and b



Photosynthesis Stages:

Two Stage Process:

Light Dependent Reactions: Require Light to Occur, Involves the Actual Harvesting of Light Energy, Occur in on the Grana.

Dark or Light Independent Reactions, Chemical reactions, do not need light to occur, involve the creation of the carbohydrates, occur in the stroma, products of the light reaction are used to form c-c covalent bonds of carbohydrates.

Light Reactions:

When light strikes magnesium (Mg) atom in center of chlorophyll molecule, the light energy excites a Mg electron and it leaves orbit from the Mg atom. The electron can be converted to useful chemical energy. the excited electron (plus additional light energy) eventually provides energy so a phosphate group can be added to a compound called adenosine diphosphate (ADP), yielding adenosine triphosphate (ATP)- ATP Is an important stored energy molecule.

Photolysis (Hill Reaction)

The 2 water molecules are split into hydrogen and oxygen. the hydrogen is attached to a molecule called nicotinamide adenine dinucleotide phosphate (NADP) produces NADPH2. The oxygen is given off as oxygen gas.

2 H20 + NADP + light $\rightarrow$ NADPH2 + O2

During the light reaction, there are two possible routes for electron flow:

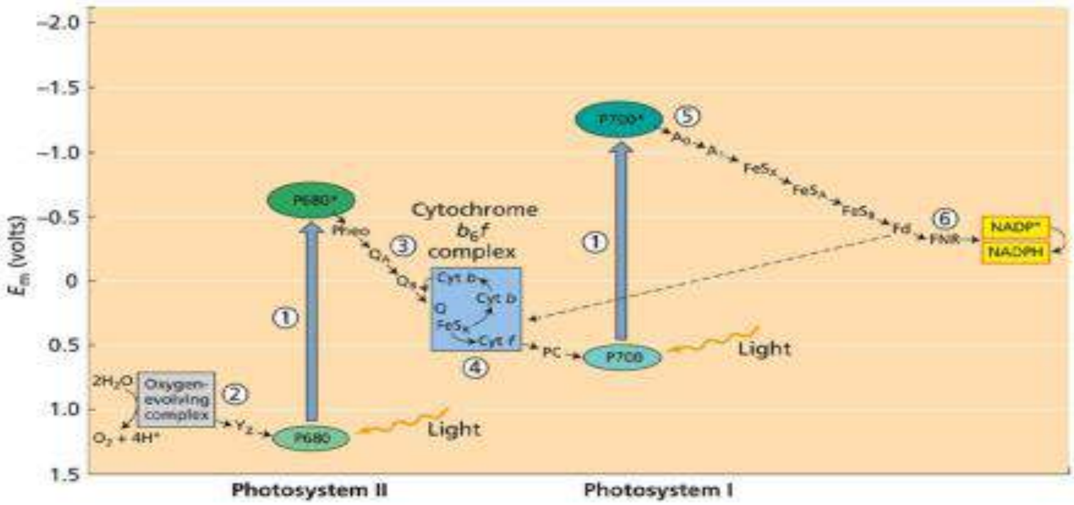
A.Cyclic Electron Flow

Occurs in the thylakoid membrane. Uses Photosystem I only. P700 reaction center- chlorophyll a.Uses Electron Transport Chain (ETC). Generates ATP only.

B.Noncyclic Electron Flow

Occurs in the thylakoid membrane. Uses PS II and PS I. P680 rxn center (PSII) - chlorophyll a. P700 rxn center (PS I) - chlorophyll a. Uses Electron Transport Chain (ETC). Generates O2, ATP and NADPH.

Z scheme for photosynthetic organisms



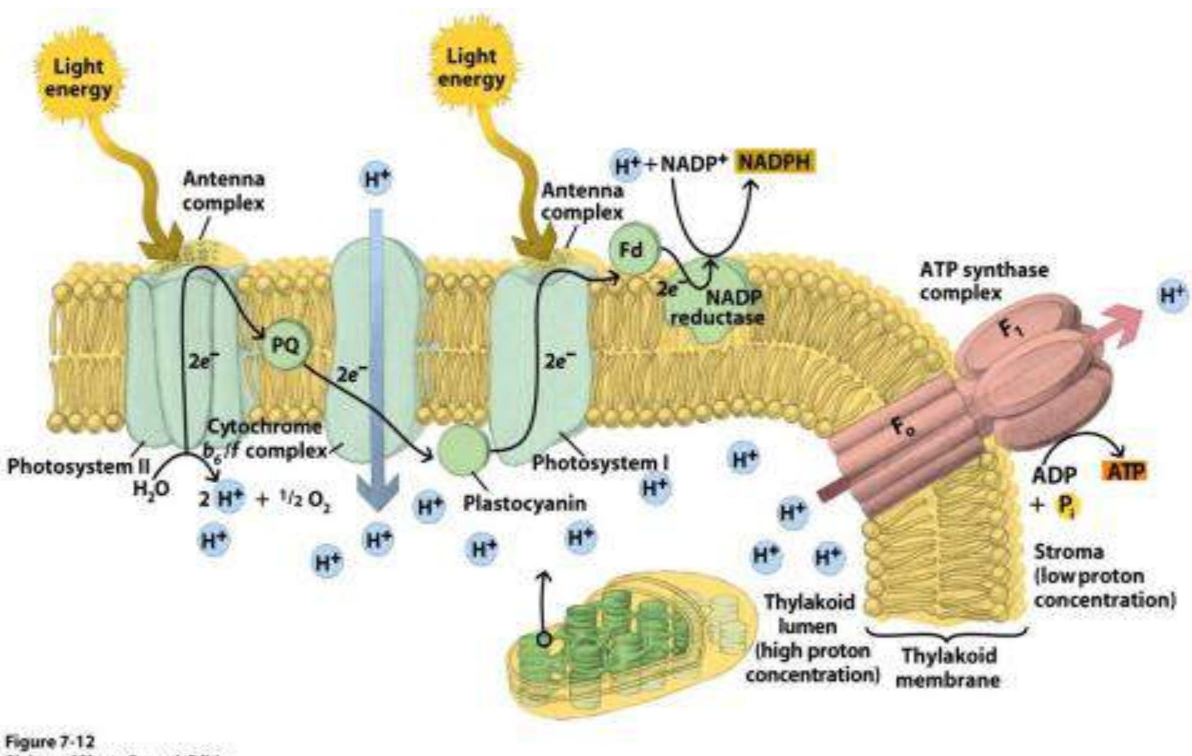


Figure 7-12
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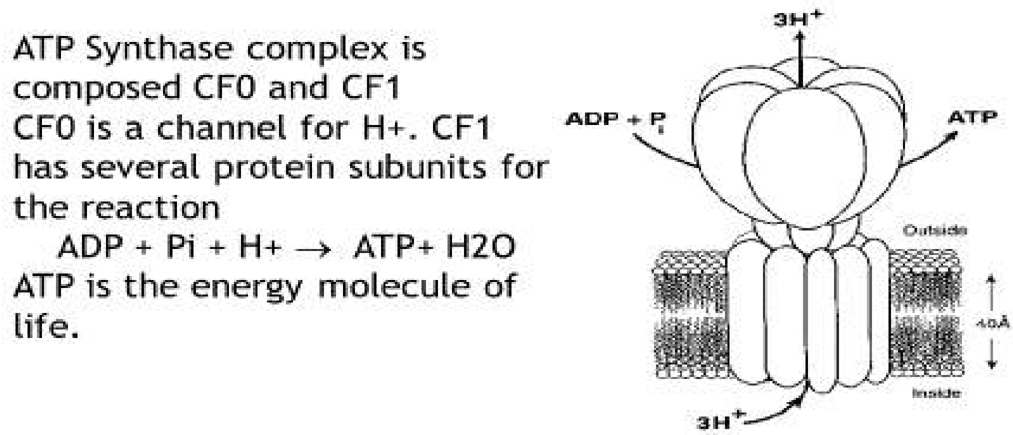
Photophosphorylation

Light-Driven ATP Synthesis. Electron transfer through the proteins of the Z scheme drives the generation of a proton gradient across the thylakoid membrane. Protons pumped into the lumen of the thylakoids flow back out, driving the synthesis of ATP. ATP Synthase complex is composed CF0 and CF1 CF0 is a channel for H+ CF1 has several protein subunits for the reaction:

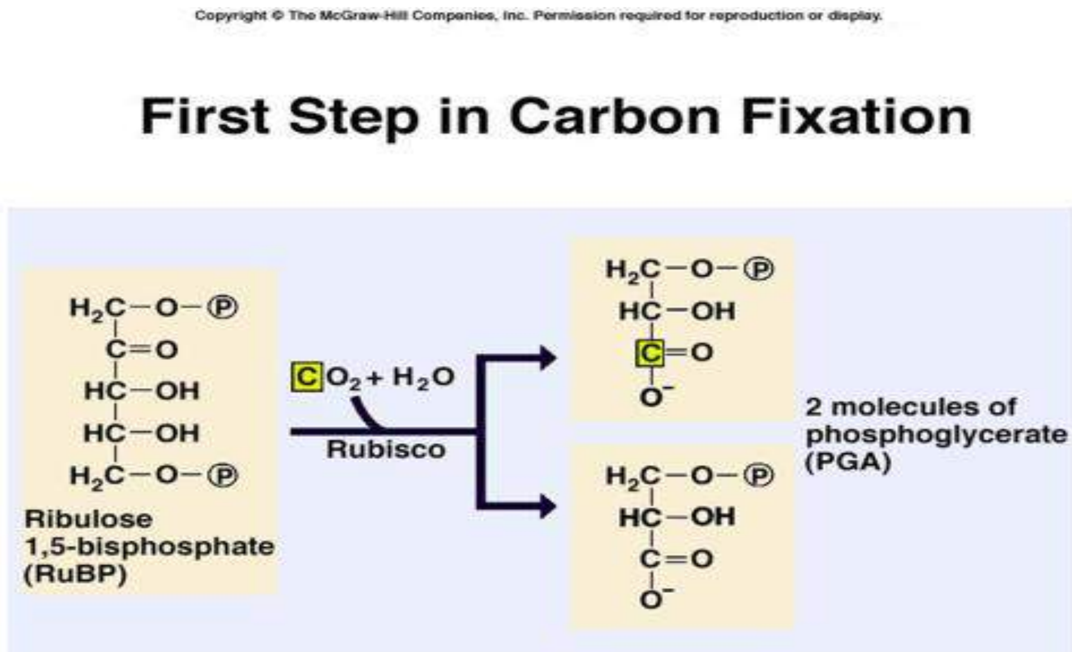
ADP + Pi + H+ $\rightarrow$ ATP+ H2O

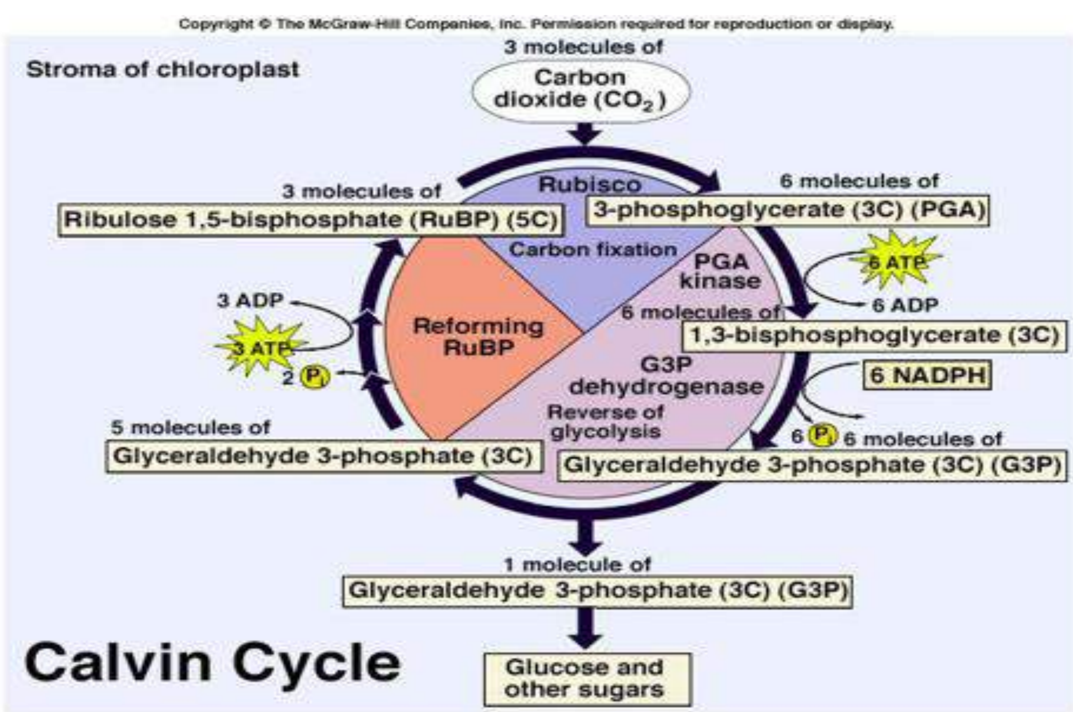
ATP is the energy molecule of life.



Sec.2: Dark Light Independent Reactions:

Occur in the stroma of the chloroplasts and do not require light energy to occur. Ribulose bisphosphate carboxylase oxygenase (Rubisco) fixes CO2 & O2, is enzyme in Calvin Cycle (1st step), Most abundant protein on Earth, 25% total leaf protein.





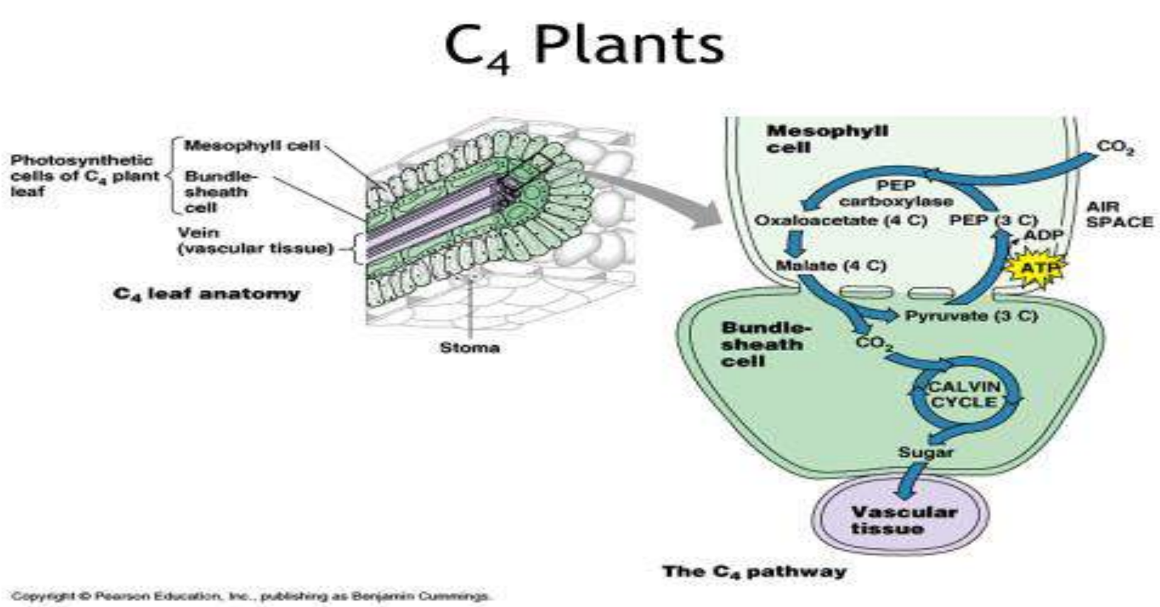
Model of carbon dioxide fixation:

1. C3 Plants (Calvin pathway)

Most plants use an enzyme called RuBP Carboxylase (RuBisCo) to carry out the CO2 fixation. enzymes are natural proteins that help catalyze/carry out reactions. rubisco is the most abundant enzyme on earth. this occurs in the mesophyll cells palisade or spongy. creates a 3-carbon product ready for sugar formation called C3 plants because the 1st stable carbon chain made from CO2 has 3 carbons. C3 crops wheat, soybeans, cotton, tobacco, small grains, legumes, tomatoes, potatoes, peppers, cucurbits

2. C4 Plants (Hatch-Slack Pathway):

Process of CO2 fixation for many plants of dry or tropical origins. plants use a different enzyme called PEP in the mesophyll cells for CO2 fixation. PEP Carboxylase has a much higher affinity for CO2 than does Rubisco. At low CO2 Pressures, Rubisco Doesnt Distinguish Well between O2 and CO2 so stomata usually have to be wide open for PS to occur. creates a 4-carbon product. This 4-carbon is then transported into bundle sheath cells where the CO2 Is released and then immediately fixed by Rubisco as Part of the C3 Cycle. Bundle sheath cells are specialized cells that surround the vascular bundles in the leaves. same fixation with Rubisco as in C3 plants but occurs in the bundle sheath cells, not mesophyll cells.

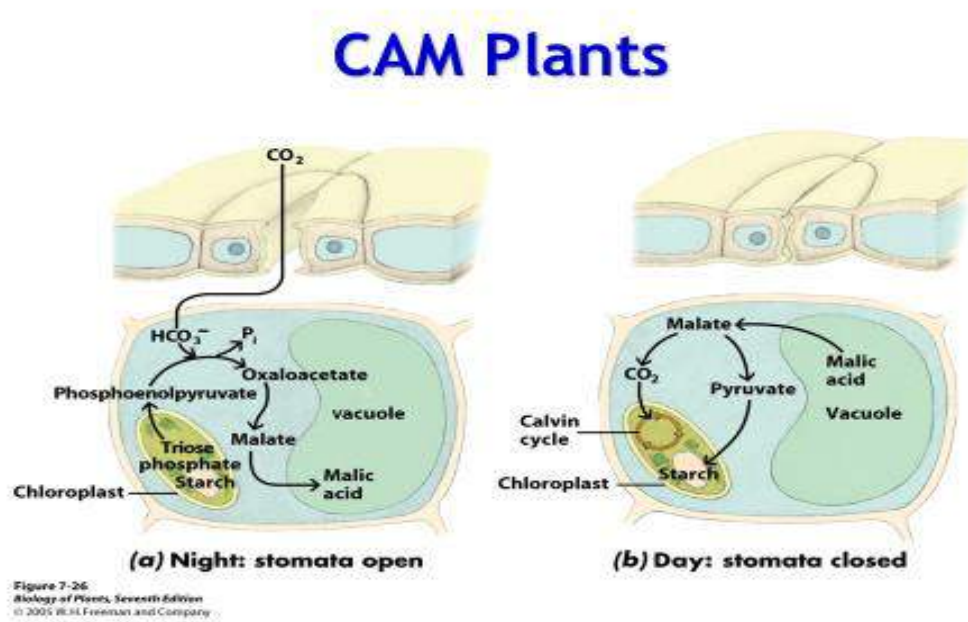


3. Crassulacean Acid Metabolism (CAM plants):

Another type of PS carried out only by xerophytes (cactus and ice plants) in hot, dry environments.

At Night: Stomata are open, plants fix CO2 into a 4-carbon product and 4-Carbon product stored overnight in vacuole

At Day: Stomates closed, light rxn occurs, Calvin Cycle - occurs when CO2 is present.



PEP Carboxylase vs. Rubisco

PEP carboxylase works well at warm temperatures but not optimally at cool temps. This is the reason why C4 grasses are referred to as warm season grasses, and why they dont compete well with C3 grasses at cooler temps. C4 grasses have an edge in dry warm sites or open sunny sites as they can keep leaf stomata closed during mid-day and extract every last CO2 molecule in the leaf. in contrast, C3 grasses that keep stomata closed in dry sunny sites undergo high amounts of respiration.

Photorespiration:

In the "normal" reaction, CO2 is joined with RUBP to form 2 molecules of 3PGA. In the process called photorespiration, O2 replaces CO2 in a non-productive, wasteful reaction. Less ATP Is Produced from the Photorespiration. The appearance of C4-type plants appears to be an evolutionary mechanism by which photorespiration is suppressed.

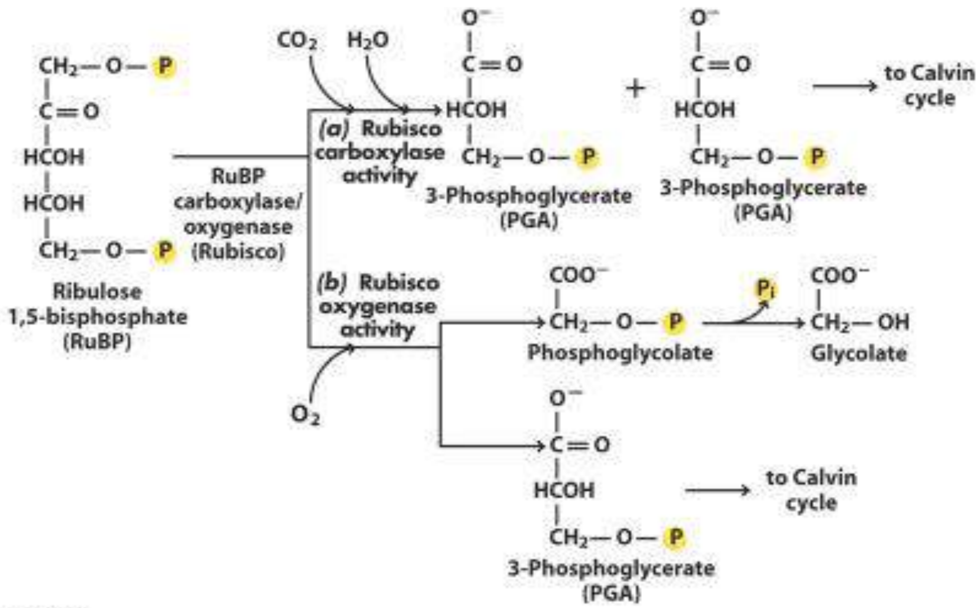


Figure 7-19
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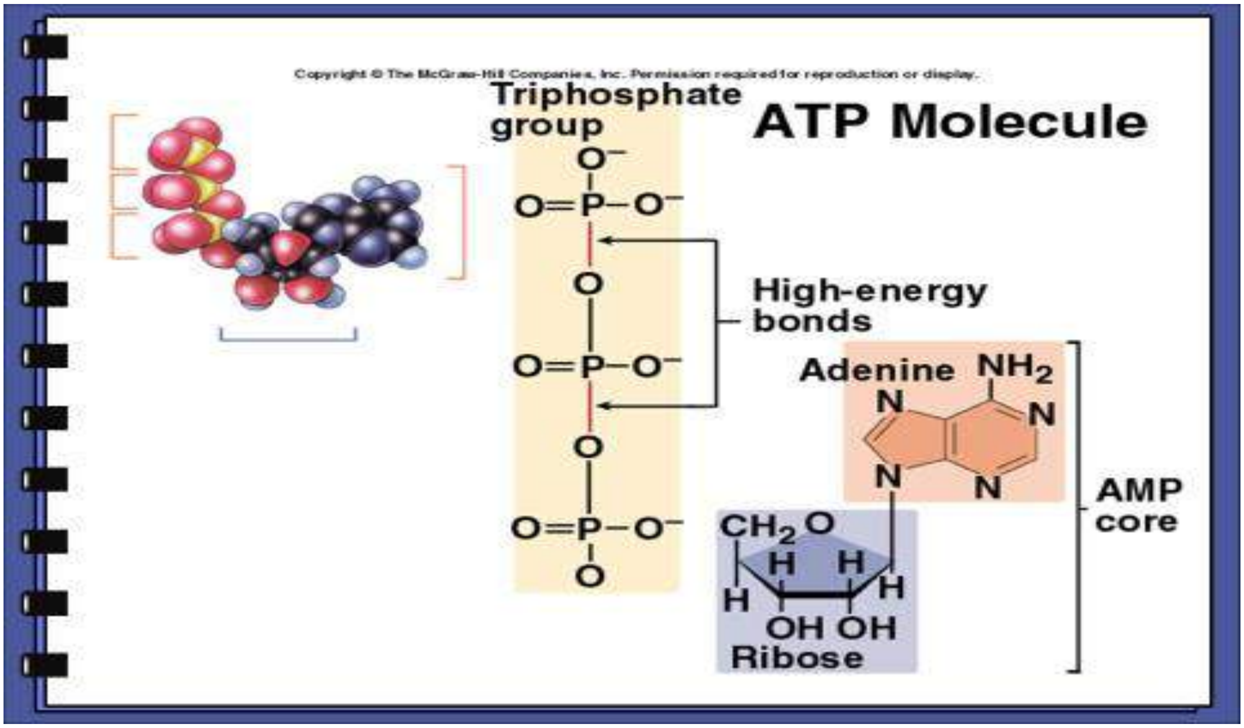
Light Compensation Point

Level of light intensity where the rate of respiration (CO2 produced) equals the rate of PS (CO2 consumed). greater light intensity should result in net dry matter (carbohydrate accumulation). lower light intensity will result in net dry matter loss over time.

Sec.3: Respiration

Processes can be:

energy consuming (endergonic) or energy releasing (exergonic) and catabolic (breakdown) or anabolic (synthesis). Respiration is breaking down sugars to chemical energy (ATP) for Growth, Development and Reproduction. Occurs in Mitochondria of Cells. Mitochondria are membrane-enclosed organelles distributed through the cytosol of most eukaryotic cells. Their main function is the conversion of the potential energy of food molecules into ATP.



Aerobic Respiration

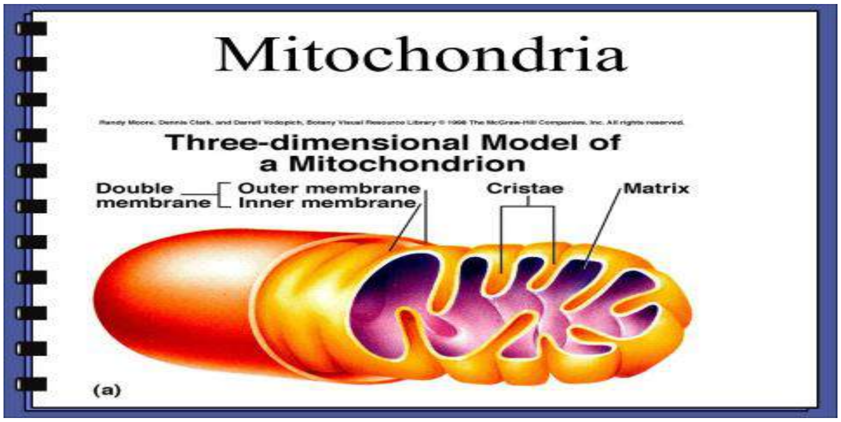
Requires Oxygen. Main Type of Respiration that Occurs in most Plants and Animals. Involves Complete Breakdown of Glucose back to CO2 and Water. Not all of the Energy in Glucose Is Converted to ATP Formation.   Only about 40% Efficient. Extra Energy is given off as Heat. In Plants, Heat Quickly Dissipates.

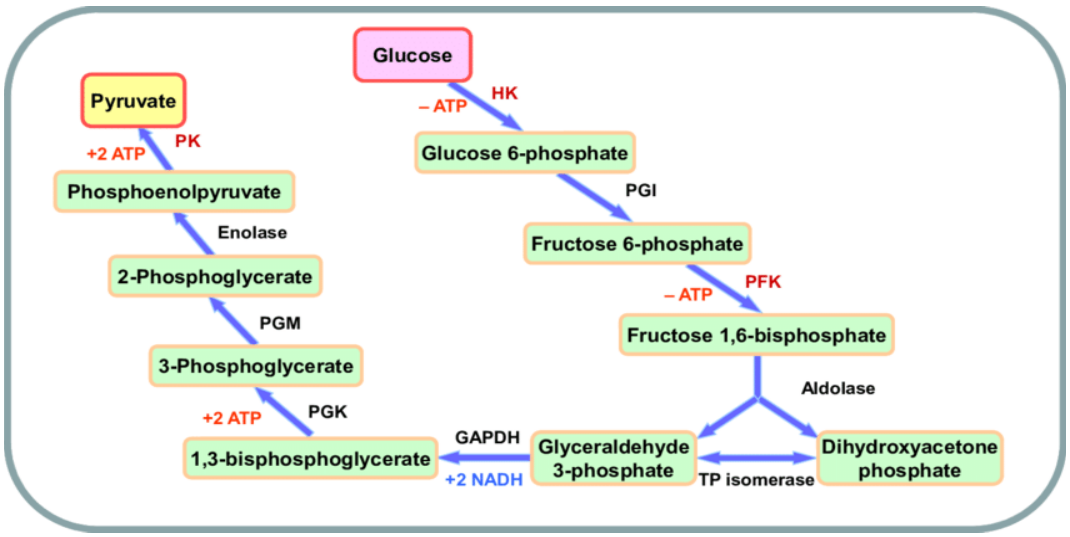
Respiration has 3 main steps:

1-Glycolysis: Breakdown of Glucose (6C) to 2 pyruvate (3C each) in cytoplasm. Pyruvate molecules move to the mitochondria.

Glucose + 2 ATP = 2 NADH + 4 ATP + 2 pyruvate

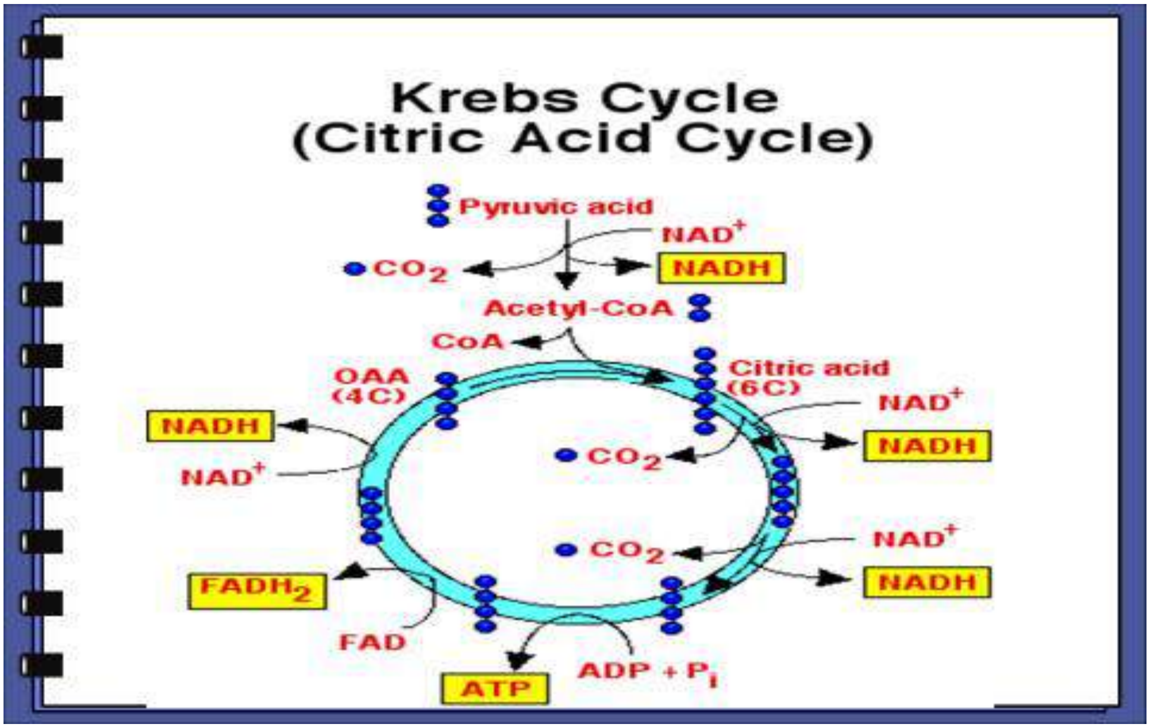
Net energy outcome 2 NADH and 2 ATP





2- Krebs Cycle

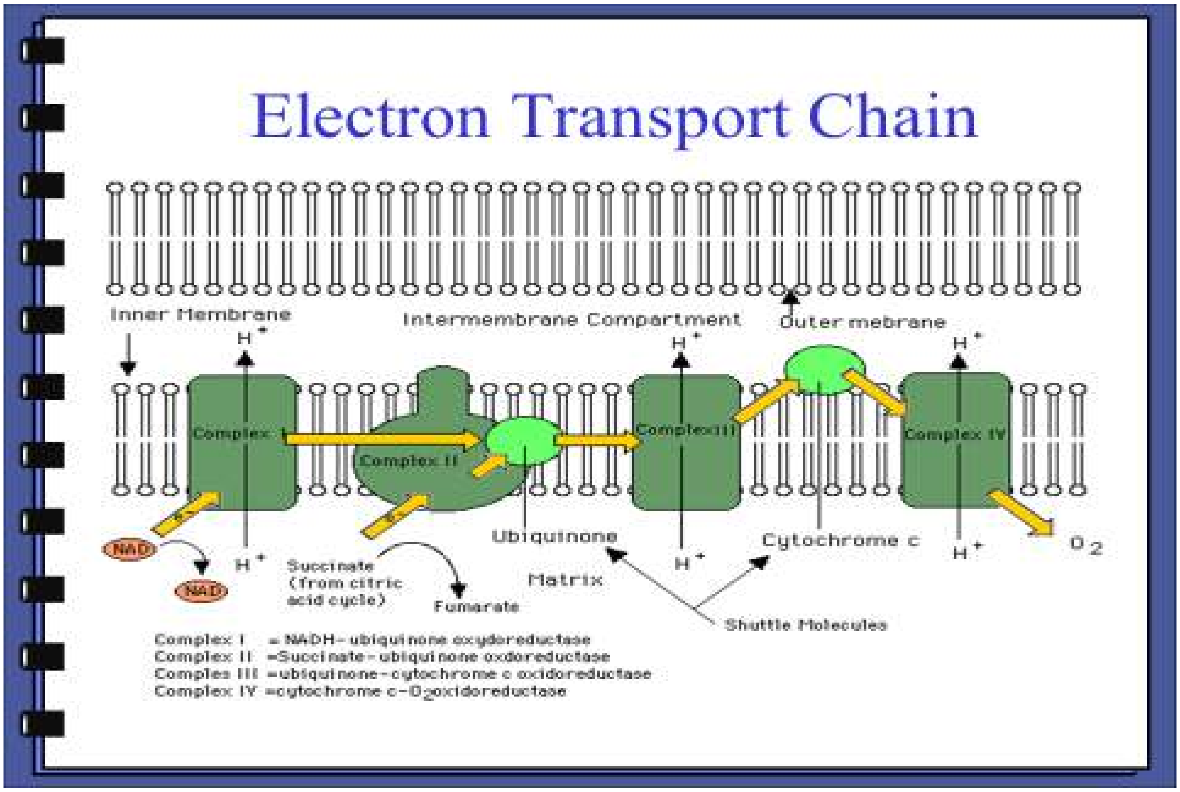
Tricarboxylic acid Cycle (TCA Cycle) or Citric Acid Cycle. Occurs in Mitochondrial Matrix. pyruvate broken down to CO_2 and the remaining 2 Cs (acetyl group) are added to Coenzyme A, Also can get Acetyl CoA from fats. A Cyclic Series are used in other metabolic pathways to make various compounds such Proteins, Lipids, Cell Wall Carbohydrates, DNA, Plant Hormones, Plant Pigments, Many other Biochemical Compounds.



3- Electron-Transport Chain

Oxidative Phosphorylation

Final step in energy generation most energy released here. e- of NADH and FADH2 move through the chain, moving to lower energy level. Occurs in the inner membrane of the mitochondria. Specialized molecules accept and donate e- as they move down chain. Create an electrochemical gradient, As e- move down chain, H+ move across the membrane, altering the concentration of H+ on either side = gradient. Gradient used to generate ATP. Oxygen Is Required for this Step. Water Is Produced.



Review of the Energy Yield from

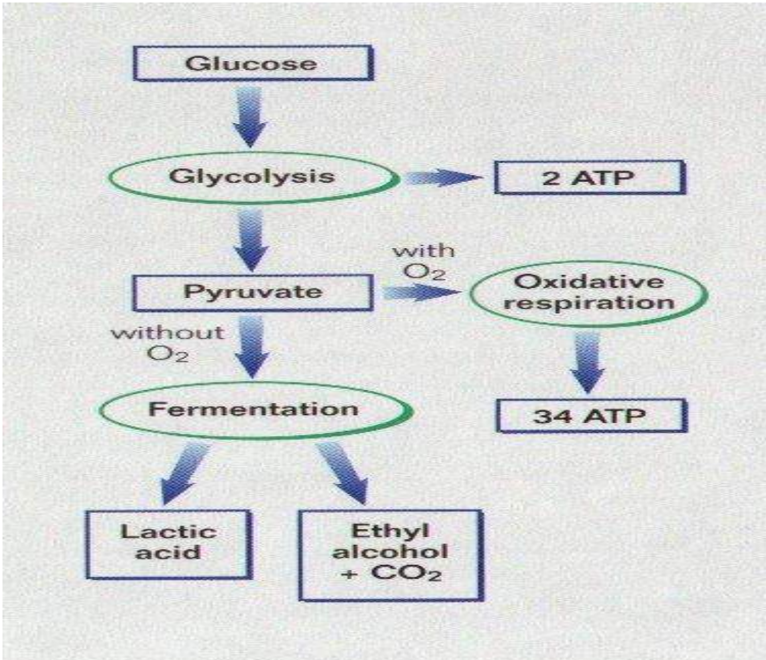
-Glycolysis:

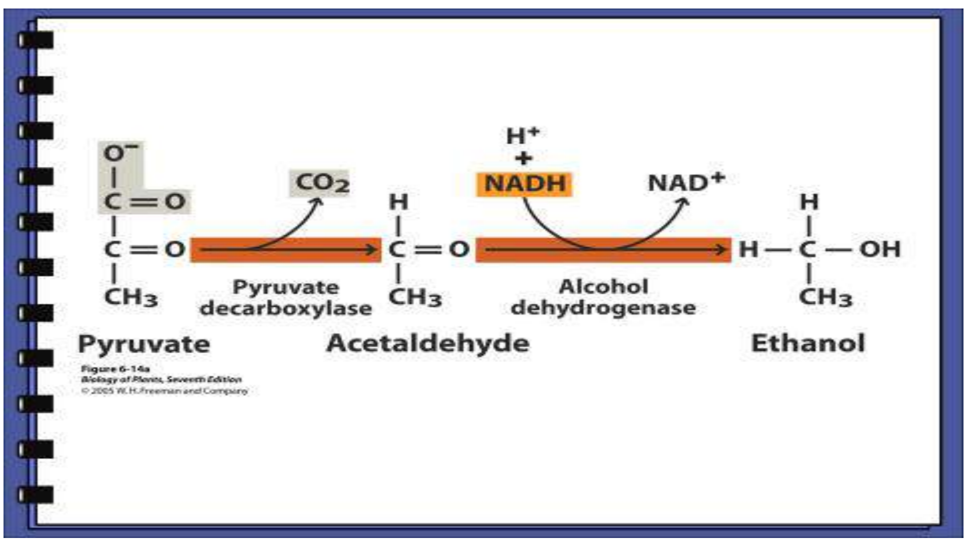
glucose (2pyruvate + 2NADH+2ATP	6-8 ATPs
pyruvate (acetyl CoA + NADH	6 ATPs
acetyl CoA(2CO2+3NADH+FADH2+GTP	2x12ATPs
OVERALL yield from glucose	36-38 ATPs

Because NADH from cytosol to ETC within mitochondria carried by the dihydoxyacetone phosphate shuttle yields 2 ATP/NADH while the malate shuttle yields 3 ATP/NADH.

Anaerobic Respiration

Fermentation: Occurs in Low-Oxygen Environments. Wet or Compacted Soils for Plants. ATP Is still produced from Glucose but not as efficiently as with Aerobic Respiration. 2 ATP molecules per glucose molecule





Sec.4: Translocation in the Phloem

Three lines of evidence to show that translocation takes place in the phloem:

1) Aphid studies
2) Ringing experiment
3) Use of radioactive isotopes

These studies also show that transport in the phloem is bi-directional and rate of phloem translocation average about 30 cm hour-1 or even faster.

Materials translocated in phloem sap

Water is the most abundant substance transported in the phloem. Dissolved in the water mainly carbohydrates; sucrose: the sugar that is most important and abundant in translocation, sucrose is a disaccharide, i.e., made up of two sugar molecules. Non-reducing sugars, which are translocated sucrose, galactose, stachyose, raffinose and verbascose. Translocated sugar alcohols include mannitol and sorbitol. Reducing sugars, which are not generally translocated in the phloem. The reducing groups are aldehyde (glucose and mannose) and ketone (fructose) groups.

Nitrogen is found in amino acids and amides, especially glutamate and aspartate and their respective amides, glutamine and asparagine.

Almost all the endogenous plant hormones, including auxin, gibberellins, cytokinins, and abscisic acid.

Nucleotide phosphates and proteins have also been found in phloem sap. Proteins found include filamentous Pproteins (which are involved in the sealing of wounded sieve elements), protein kinases (protein phosphorylation), ubiquitin (protein turnover), chaperones (protein folding), and protease inhibitors (protection of phloem proteins from degradation and defense against phloem-feeding insects).

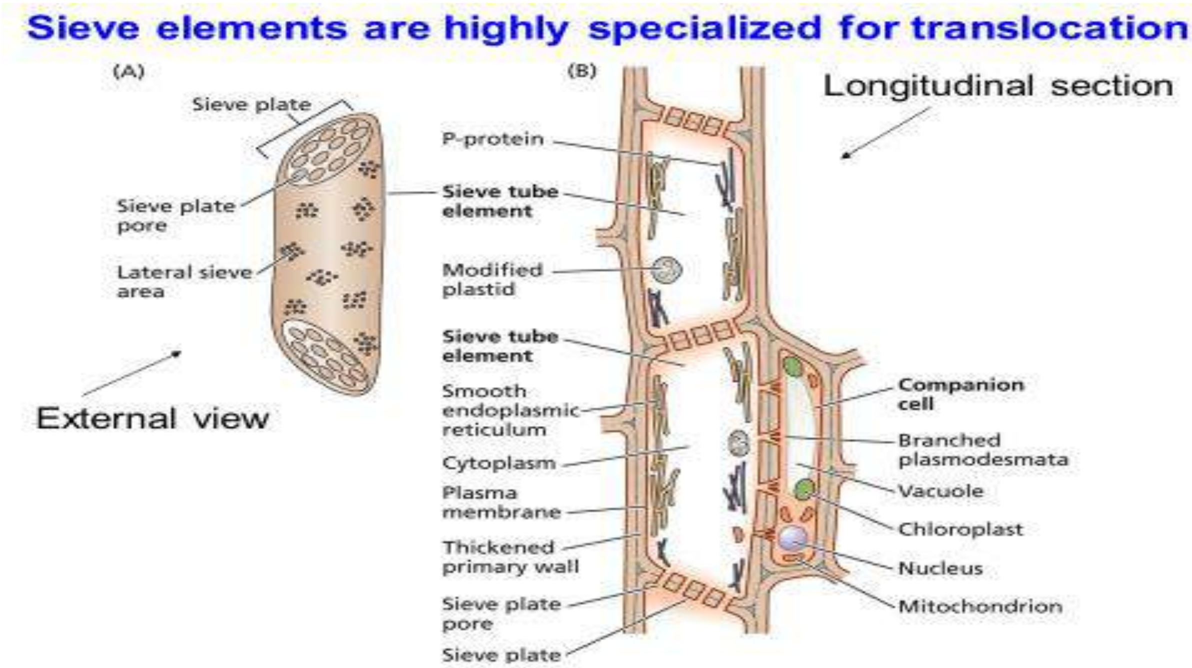
Inorganic solutes that move in the phloem include potassium, magnesium, phosphate, and chloride. In contrast, nitrate, calcium, sulfur, and iron are relatively immobile in the phloem.

Source to Sink

Metabolites move from source to sink.

Source = is area of supply or exporting organs for examples: mature leaves, storage organs, seed endosperm, storage root of second growing season beet.

Sink = areas of metabolism (or storage), non-photosynthetic organs and organs that do not produce enough photosynthetic products to support their own growth or storage. Example: roots, tubers, developing fruits/seeds, immature leaves.



Mechanisms of translocation in phloem- *Mass Flow (pressure flow) Hypothesis*

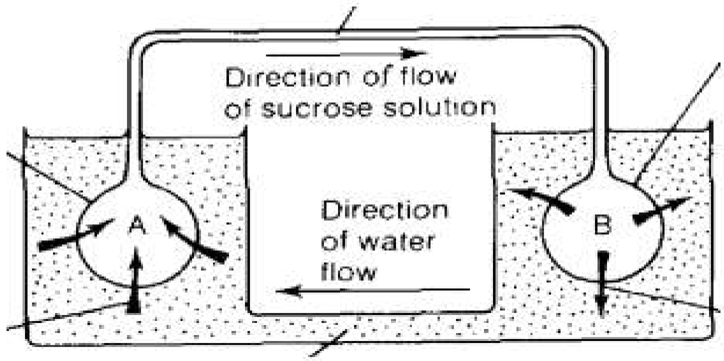
Phloem transport is analogous to the operation of a double osmometer. If solute is added to bulb A → osmotic potential decreases → osmotic uptake of water → pressure increases → bulk flow of water and solute to bulb B → pressures increases in bulb → water potential in B greater than in beaker → osmotic flow of water into the beaker → water returns to side A via the connection. This system could be maintained indefinitely if there is a mechanism to remove solute (sucrose) at the end (sink) and a mechanism to add solute (source).

At the source (leaves):

Photosynthesizing cells in leaves make sucrose
→water potential increases
→water enters cells from xylem creating high pressure potential

At the sink (root):

sucrose either respired or stored as starch
→ water potential decreases
→low pressure potential



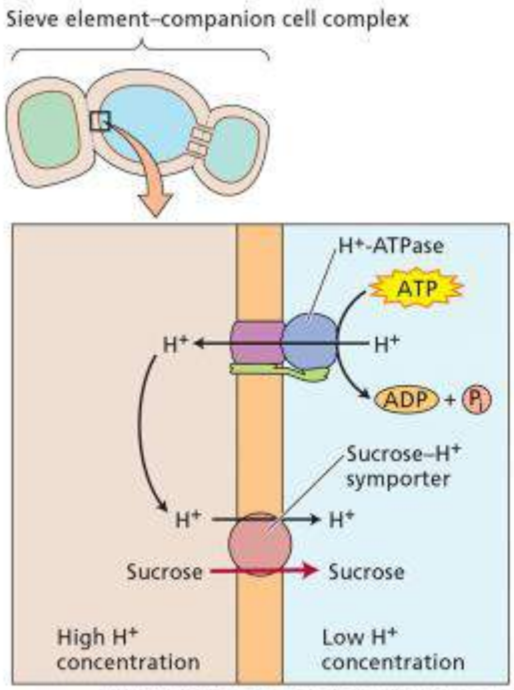
A *gradient of pressure potential* exists between the source & the sink with *phloem* linking them and as result liquid flows from the leaves to other tissues along the sieve tube elements.

Phloem loading

is the transfer of material into the phloem at the source:

1-Allow for apoplastic (from protoplast to wall to protoplast) or symplastic (from protoplasts to protoplast via plasmodesmata) transport. In some species, sucrose transport is symplastic - from mesophyll protoplast to cc-se protoplast via plasmodesmata. In others, sucrose loading into the cc-se complex involves an apoplastic step (mesophyll protoplasts to apoplast to cc-se protoplast.

2- The sucrose/proton cotransport system. According to this model, protons are pumped out of the sieve cells into the apoplast by a membrane-bound H+-ATPase → the proton concentration increases in the apoplast → pH decreases → K+ is brought into the sieve cell to balance the charge → the proton gradient provides the driving force for transporting sucrose against a gradient → the sucrose and protons bind to a carrier protein in the membrane and are released in the sieve tube member. Evidence: the pH is high in sieve tubes; if the pH of the apoplast is increased there will be no sucrose uptake; there is a high potassium conc. in sieve tube members.



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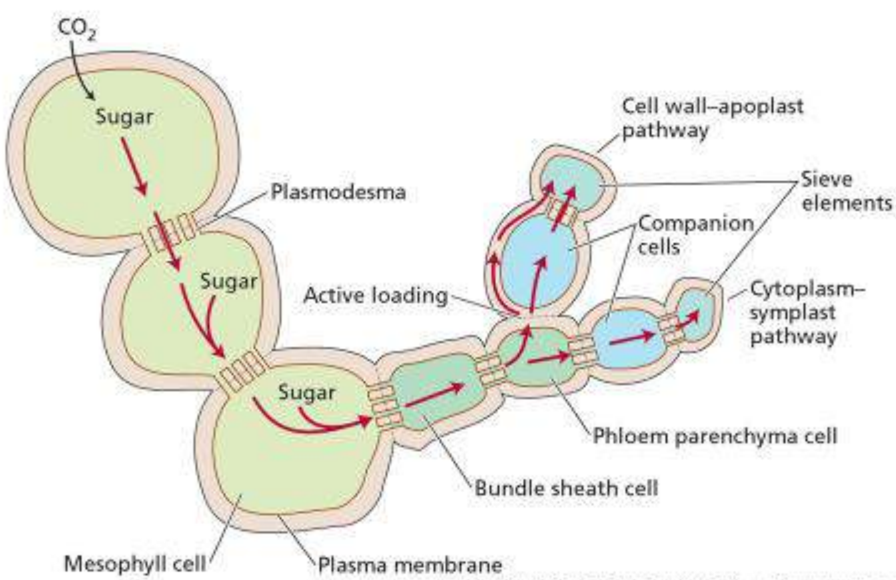
Phloem loading uses a proton/sucrose symport.

Sugars are moved from photosynthetic cells and actively (energy) loaded into companion & sieve cells.



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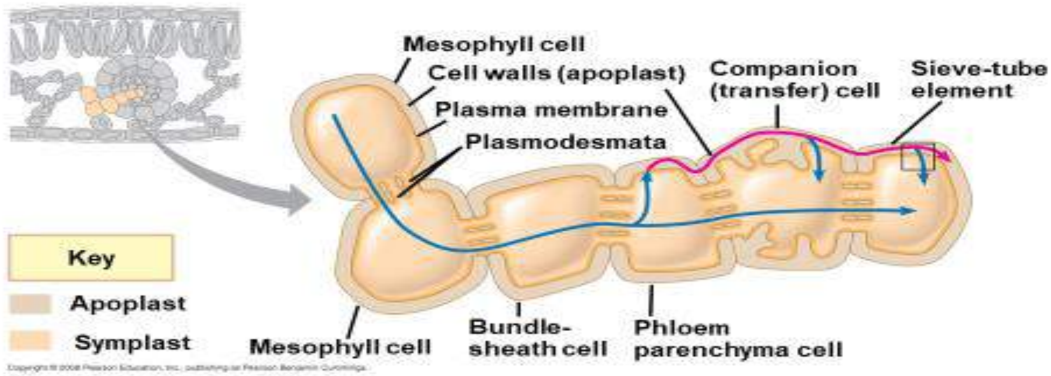


Phloem unloading:

is the removal of this material from the phloem in the sink.

There must be a mechanism to unload solute at the sink. Sucrose is unloaded into the apoplast in some tissues (*i.e.*, ovules) and into the symplast of others (growing/respiring tissues like young leaves, meristems).

Apoplastic transport and unloading can occur via two methods: (a) sucrose is hydrolyzed by acid invertase to glucose and fructose upon reaching the sink. This maintains the gradient for transport. The glucose and fructose are taken up by the sink cells and stored or further metabolized as in maize; or (b) sucrose is unloaded into the sink by a carrier co-transport system like in sucrose loading.

P protein

MW 14,000-158,000 , synthesized in companion cells, Originally thought to be a carbohydrate, called slime because it gelled when exposed to the air , Various forms; bundles of fibers or amorphous areas or even crystalline , Only in angiosperms , at least two proteins, PP1 and PP2, Once the sieve pores form, the P-protein disperses through the pore. P protein plugs the pore when the cell is damaged.

Sec.5: Water & Plant relation

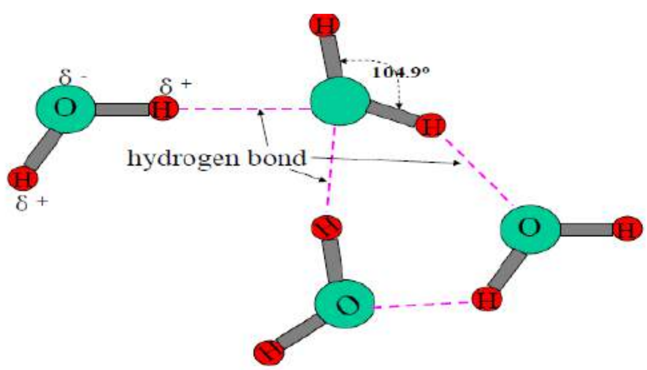
The Role of Water in Plant Life

- Component of protoplasm, Water comprise 85-95% of vegetables, 35-75% of wood, 5-15% of seed. 500g of water / g of organic matter made.
- Substrate for plant metabolism.
- Solvents for plant absorption and transportation.
- Balance plant temperature.
- provides structural support via turgor pressure.
- Plant movements are the result of water moving into and out of those parts (*i.e.*, stomatal opening, flower opening).

Physical and chemical properties of water:

1-Water is Polar

The water molecule has a positively-charged (hydrogen side) and negatively-charged side (oxygen). The covalent bond between O-H is polarized. Hydrogen bonds are a weak bond that forms between a hydrogen atom that is covalently bonded to an electronegative atom (like oxygen) and another electronegative atom.



2-Water is a liquid at physiological temperatures (between 0-100 C)

Water has a high boiling point and a high melting point when compared to other similar- sized molecules such as ammonia, carbon dioxide, hydrogen sulfide. These other molecules are gases at room temperature.

3-Water has a high heat of vaporization

It takes a lot of energy (cal. 44 kJ mol^{-1}) to convert water from a liquid to a gas; or stated another way, *Water resists evaporation.* This property is responsible for water's use in evaporative cooling systems.

4-Water has a high specific heat (heat capacity)

It takes a lot of energy (4.184 J g^{-1} C^{-1}, where 1 cal = 4.184 J) to raise the temperature of water. Thus, water is slow to heat up and cool down, or stated another way, *water resists temperature changes*. This property is important in water's role as a thermal buffer. It's not surprising that desert plants are succulent - to help resist temperature fluctuations.

5. Water has a high heat of fusion

It takes a lot of energy to convert water from a solid to a liquid, or put another way, *water resists freezing*. Energy is required to break the collective hydrogen bonds holding water in its solid configuration. a lot of energy (6 kJ mol^{-1}) must be released by water to freeze.

6. Water has a high surface tension

It takes a lot of energy to break through the surface of water, because water molecules at the surface are attracted (cohesion) to others within the liquid much more than they are to air. This phenomenon is important at air/water interfaces and explains why: (1) water rises up a thin tube (capillary action); (2) raindrops are round (the molecules at the surface attract one another).

7. Water is a universal solvent

Water dissolves more different kinds of molecules than any other solvent. Hydrophilic (water-loving) molecules dissolve readily in water (likes dissolve likes); hydrophobic (water-fearing) ones do not.

8. Water has high tensile strength and incompressibility

Thus, water is good for hydraulic systems because when it is squeezed it doesn't compress and produces positive pressures (hydrostatic pressures). This pressure provides the driving force for cell growth and other plant movements.

10. Water is transparent to light

This is important because chloroplasts (inside a cell) are obviously surrounded by water. If water were opaque, plants couldn't photosynthesize.

11. Water is chemically inert.

It doesn't react unless it is enzymatically designed to do so.

12. Water dissociates into protons and hydroxide ions

This serves as the basis for the pH system.

Mechanisms of water movement:

The actual movement is the result of two processes: diffusion and bulk flow. A cell membrane is the thickness of a phospholipids bilayer, possesses integral proteins; the one involved with water transport is called an aquaporin. The aquaporin protein serves as a water-filled pipe across the membrane.

A-Diffusion

The net, random movement of individual molecules from one area to another. The molecules move from [hi] → [low], following a concentration gradient. The net movement stops when a dynamic equilibrium is achieved so diffusion is passive movement of any material from an area of higher concentration to an area of lower concentration. For a cell: The rate of movement in diffusion is shown by Fick's Law:

$$J_s = -D_s \bullet \Delta C_s / \Delta x$$

J_s is the rate of movement or flux density usually measured as the moles of substances crossing a square meter of area per second.

D_s is the diffusion coefficient indicating how easily substances moves through the medium. If the medium is air, then the coefficient is high and movement is rapid. In liquid, the coefficient is low and movement is slow by comparison.

ΔC_s is the concentration difference between the area of high and area of low concentration.

The negative sign indiates that the movement is from the area of high to the area of low concentration. Δx is the distance between the areas of high and low concentration.

Factors influencing the rate of diffusion

1. ***Concentration Gradient***

Solutes move from an area of high concentration to one of lower concentration; in other words, in response to a concentration gradient (ΔC_s). ΔC_s is the concentration difference between the area of high and area of low concentration.

2. ***Molecular Speed*****.**

It related to molecular weight (heavier particles move more slowly than lighter, smaller ones).

3. ***Temperature*** - Directly proportional to temperature , increases the rate of molecular movement, therefore, increases the rate of diffusion.

4. ***Pressure*** - increases speed of molecules, therefore, increase the rate of diffusion.

5. The mole fraction- Solute particles decrease the free energy of a solvent. The critical factor is the number of particles, not charge or particle size. Essentially solvent molecules, such as water in a biological system, move from a region of greater mole fraction to a region where it has a lower mole fraction. The mole fraction of solvent = # solvent molecules/ total (# solvent molecules + # solute molecules).

Diffusion works only over short distances

If we think about sucrose, the transport form of photosynthate in plants, moving in a plant by diffusion, the distance must be very short. For sucrose the Ds is $0.5 \times 10^{-9} m^2 s^{-1}$, the diameter of a cell is 50 µm (= 50×10^{-6}m)...

Some algebra applied to Fick's law gives us:

$t = x^2 \times Ds^{-1}$

Now we plug in the values above:

$t = (50 \times 10^{-6} m)^2 \times (0.5 \times 10^{-9} m^2 s^{-1})^{-1} = 5$ seconds

So diffusion can explain a rate of movement for a sucrose molecule across a cell. ***But diffusion will fail to explain movement when the distance gets larger***. To test that out, imagine sucrose made in the tip of a sugar cane leaf diffusing to the base of that leaf. That distance is about 1 meter. When you plug 1 meter in for the distance in the formula above, the time calculates out to 63.42 years. So diffusion is too slow to explain how sucrose gets out of a sugar cane leaf.

B. Osmosis

This is a specialized case of diffusion; it represents the diffusion of a solvent (typically water) across a membrane.

C. Dialysis

Another specialized case of diffusion; it is the diffusion of solute across a semi-permeable membrane.

D. Bulk (or Mass) Flow.

This is the mass movement of molecules in response to a pressure gradient. The molecules move from hi → low pressure, following a pressure gradient. Bulk flow subject to Poiseuille's Equation

Bulk flow explains long-distance water movement

Bulk flow is the movement of a substance under influence of pressure from an area of greater pressure to an area of lesser pressure. Rather than individual molecules moving on the basis of their own kinetic energy, large volumes of molecules move together in bulk. The rate of bulk flow is shown in the Poiseuille Equation:

$$\text{Flow} = \pi\, r4\, (8\eta)^{-1} \bullet \Delta\Psi p\, \Delta x^{-1}$$

The rate of flow is proportional to the fourth power of the radius of the pipe (channel, etc.). In other words, increasing the pipe radius by a factor of two will increase the flow rate by a factor of 16. The rate of flow is inversely proportional to 8 times the viscosity of the fluid. The rate of flow is directly related to the pressure difference between the ends of the pipe. Increasing the pressure at one end of the pipe increases the rate of flow. Bulk flow can obviously work in phloem and xylem as these are basically pipes.

Sec.6: Water Potential

Water potential (Ψw) - chemical potential of water, compared to pure water at the same temperature and pressure. The units are in pressure because: (a) plant cells are under pressure; and (b) it is easier to measure pressure. Water potential is a measure of the energy state of water. This is a particularly important concept in plant physiology because it determines the direction and movement of water. Pressure is measured in MPa (megapascals). 1 MPa = 10 bars = 10 atm.
1 atm = 760 mm Hg = 14. 7 lbs sq in-1).

Equation for water potential:

Water potential is the sum of the contributions of the various factors that influence water potential

$$\Psi w = \Psi p + \Psi s + \Psi g + \Psi m$$

where Ψw = water potential; Ψp = pressure potential; Ψs = solute or osmotic potential; and Ψg = gravity potential and Ψm matric potential.

1. Solute (or osmotic) potential (Ψs)

This is the contribution due to dissolved solutes. Solutes always decrease the free energy of water, thus there contribution is always negative. The solute potential of a solution can be calculated with the van’t Hoff equation:

$\Psi s = -miRT$ where m = molality (moles/1000 g); i = ionization constant (often 1.0); R = gas constant (0.0083 liter x MPa/mol deg); and T = temperature (K). Solute potential is also called the osmotic potential because solutes affect the direction of osmosis. Ψs of any solution at atmospheric pressure is always negative – why? Answer = less free water molecules to do work.

2. Pressure or Pressure Potential (Ψp)

Due to the pressure build up in cells thanks to the wall. It is usually positive, although may be negative (tension) as in the xylem. Pressure can be measured with an osmometer.

3. Matric potential (Ψm)

This is the contribution to water potential due to the force of attraction of water for colloidal, charged surfaces. It is negative because it reduces the ability of water to move. In large volumes of water it is very small and usually ignored. However, it can be very important in the soil, especially when referring to the root/soil interface. Matric potential is limited in cells, and because the height of the cell in the lab is negligible.

4. Gravity potential (Ψg)

Gravity causes water to move downward unless the force of gravity is opposed by an equal and opposite force. The term Ψg depends on the height (h) of the water above the reference-state water, the density of water (rw), and the acceleration due to gravity (g). In symbols, we write the following:

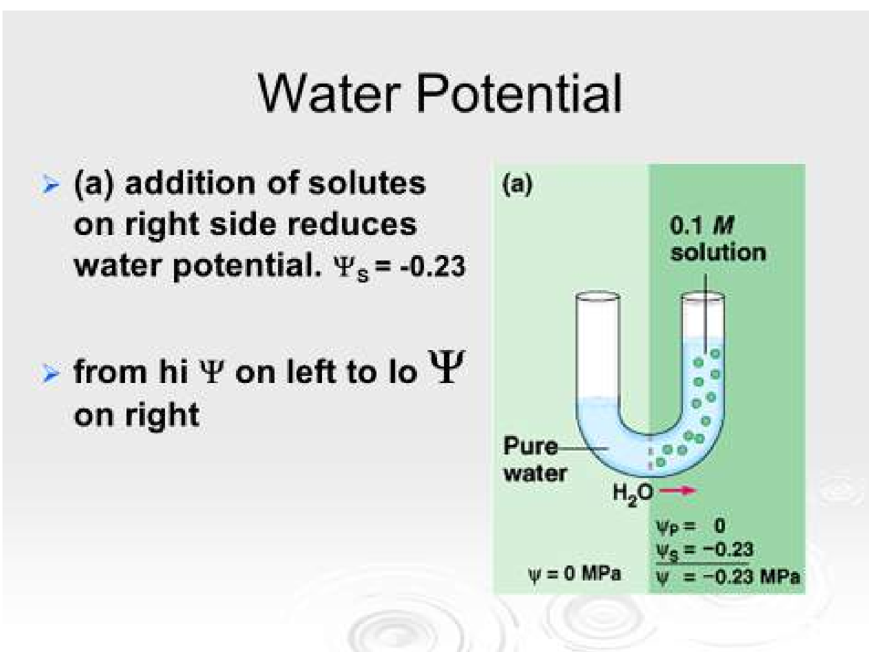
$$\Psi g = rwgh$$

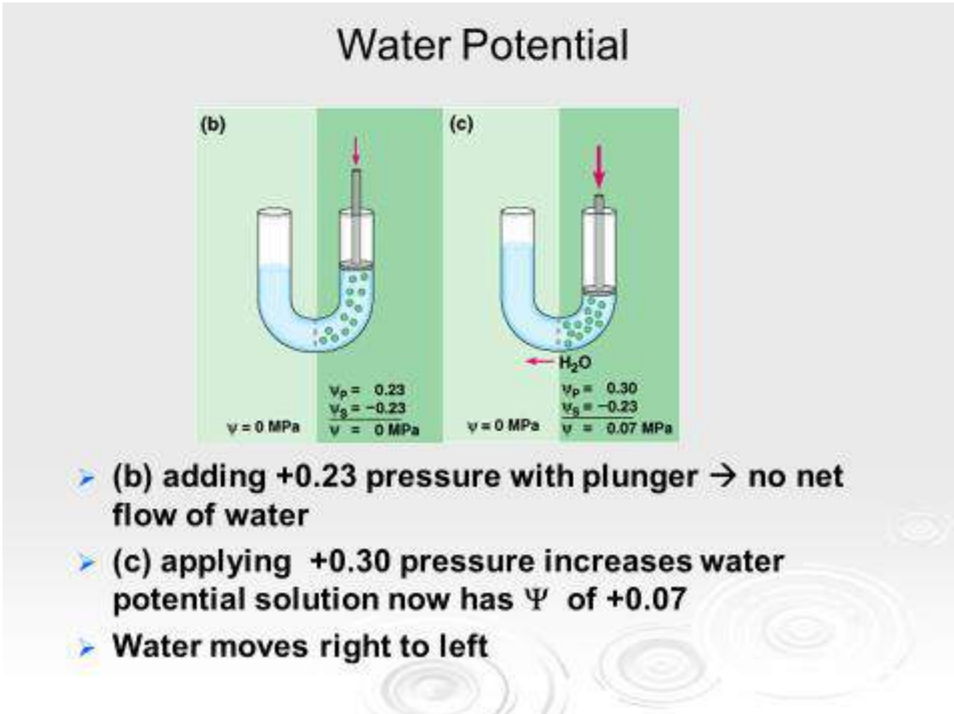
where rwg has a value of 0.01 MPa m^{-1}. Thus a vertical distance of 10 m translates into a 0.1 MPa change in water potential. When dealing with water transport at the cell level, the gravitational component (Ψg) is generally omitted because it is negligible compared to the osmotic potential and the hydrostatic pressure.

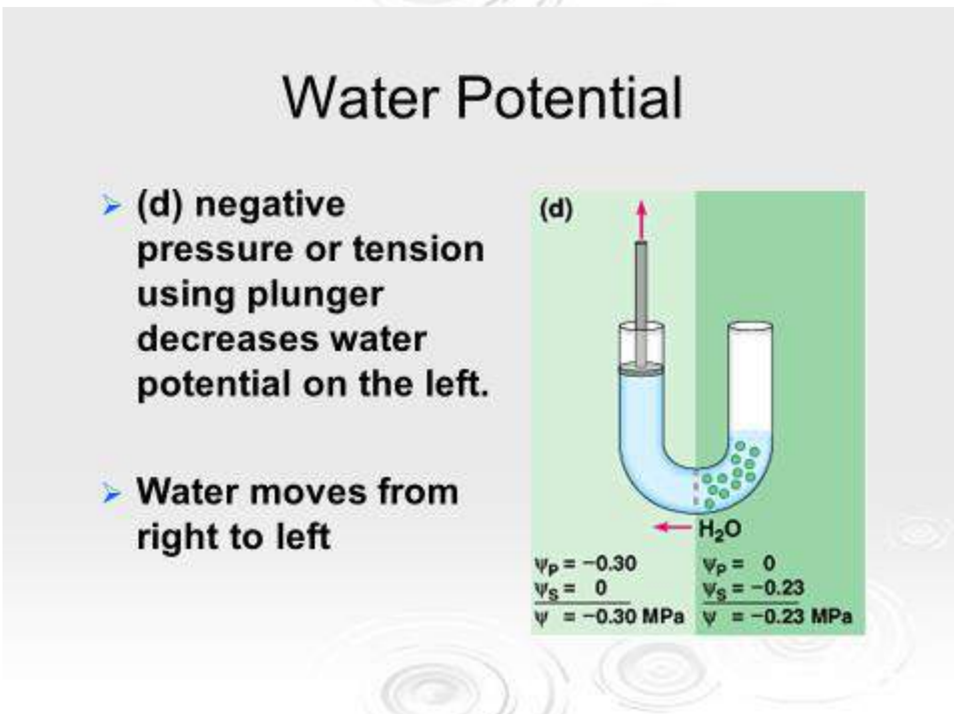
The water potential expression simplifies to:

$\Psi w = \Psi s + \Psi p$ Ψ = psi

Pure water in an open container has a water potential of zero at one atmosphere of pressure.



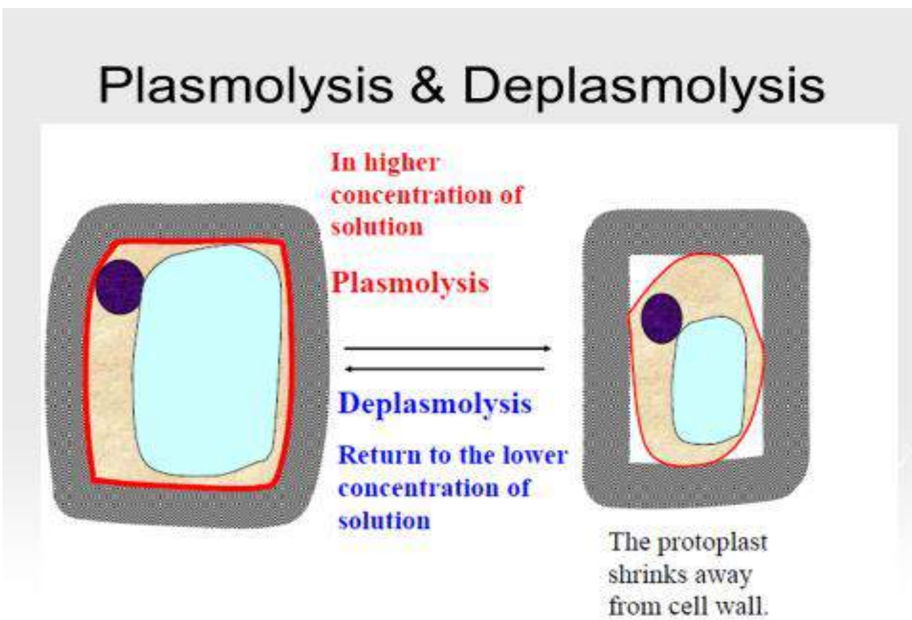


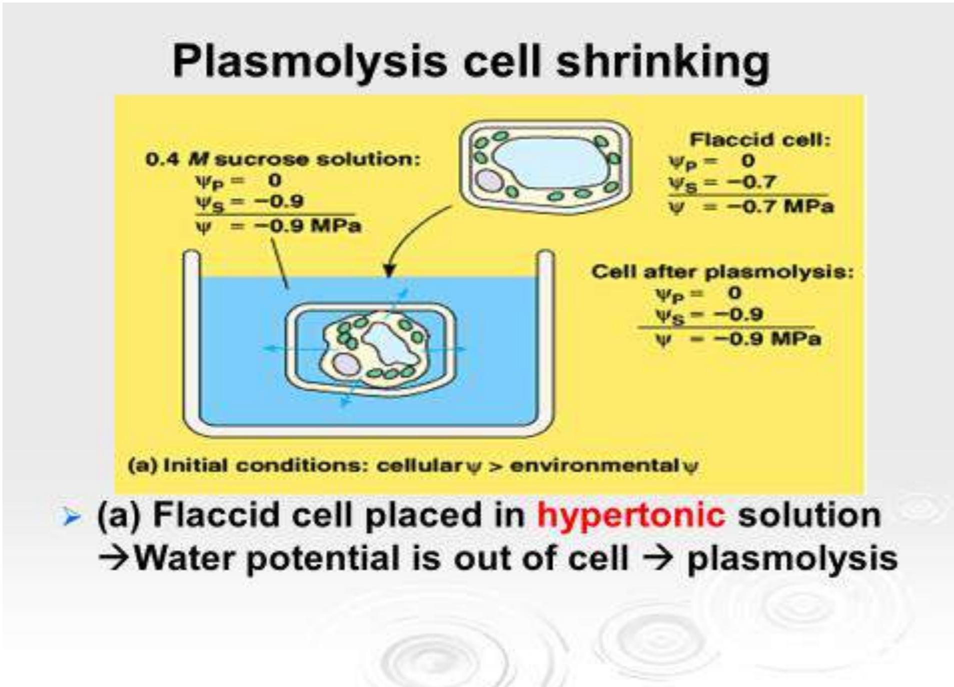


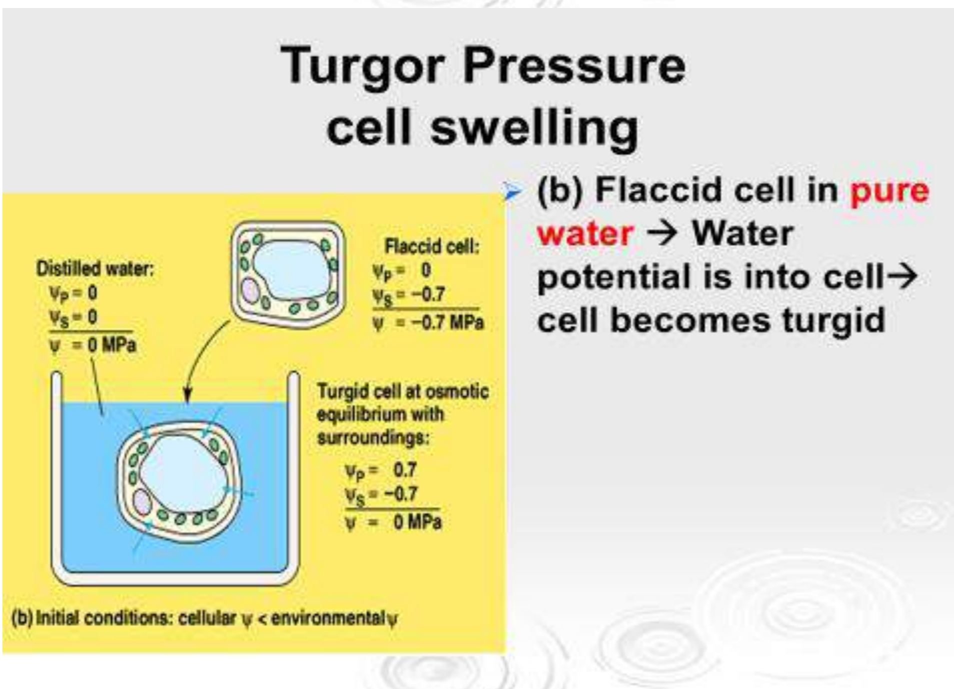
Permeability:

Permeability is a property of membrane. The extent to which a membrane permits or restricts the entry or movement of a substance is called membrane permeability. It depends upon the composition, size and chemical nature of solute. It can be measured by determining the rate at which solute passes through a membrane under specific condition. The membrane may be permeable, semi-permeable and impermeable.

Turgidity and plasmolysis:
A cell in a hypotonic solution, i.e. one with a lower solute concentration and therefore a more positive osmotic potential than the cell cytoplasm will take up water, generating a hydrostatic pressure (turgor pressure) in the cell. In such a cell, the cell contents exert a pressure on the cell wall and the cell is turgid. A cell in a hypertonic solution (i.e. one with a higher solute concentration, and therefore a more negative osmotic potential than the cell cytoplasm) will tend to lose water, until the hydrostatic potential becomes negative. At this point, the plasma membrane will pull away from the cell wall and the cell will be plasmolysed (flaccid). The point of incipient plasmolysis occurs when the plasma membrane is in contact with the cell wall, but no hydrostatic (turgor) pressure is generated.







Short-Distance Transport:
Involves simple diffusion, osmosis and active transport.
Routes:

- Cell-to-Cell Across Cell Membranes
- Symplast (involves cytoplasm and plasmodesmata).
- Apoplast (transport through porous cell walls).

Aquaporins:

Are series proteins which located in plasmic membrane or tonoplast play important role in water transport because they have less resistance to water and speed up water transport across membrane. Aquaporins facilitate the diffusion of water and small neutral solutes across plant cell membranes.

Sec.7: Soil Plant Water Relation

- Saturated water- soil before drained.
- Gravitational water - water that drains and is not tightly bound; Ψ = 0 MPa
- Field capacity - soil that holds all the water it can against gravity.
- Capillary water -water held by capillary action.
- Water at field capacity; Ψ = - 0.015- 0.03 MPa
- Permanent wilting percentage - soil moisture content at which plants can't get enough water. For most, Ψ = -1.5 MPa
- Clay holds more water than sand at any $\rightarrow\Psi$. Smaller particles in clay they have a larger total surface and hence, has more charged surfaces that will bind water tightly.

Capillary action: is the movement of water up a thin tube due to surface tension and the cohesive and adhesive properties of water. The height to which a column of water can move is inversely related to the radius of the pipe and is mathematically expressed as:

$h = 14.87/r$ Where r = radius in µm; and h = height in meters.

How much pressure is required to move water to the top of a tall tree, 100 meters tall?

We can measure the velocity of flow in the xylem to be 4 - 13 mm s^{-1} in vessels with a diameter of 100 - 200 mm. For our calculations, let's use a flow rate of 4 mm s^{-1} (= 4×10^{-3} m s^{-1}) and a vessel radius of 40 µm (= 0.00004 m).

According to Poiseuille's Law, flow rate is directly proportional to the pressure gradient and the cross sectional area of the pipe but inversely proportional to the viscosity of the fluid. Thus, this is mathematically expressed as the Poiseuille equation:

$JV = ((\pi)(r4)(\Delta P))/8(\eta)$ where η = viscosity of water (assume it is the same as in a cell, 10^{-3} Pa s)

Now, divide the equation by the cross-sectional area of a vessel (π r2). Thus, the equation simplifies to:

$Jv = ((r2)(\Delta P))/8(\eta)$

Substituting the values for flow and vessel diameter:

4×10^{-3} m/sec = $(0.00004\ m)^2(P)/ 8\ (10^{-3}$ Pa s)

P = 20,000 Pa m^{-1}

P = 0.02 MPa m^{-1}

According to this hypothesis, water is drawn up and out of the plant by the force of transpiration. Because of the cohesive/adhesive properties of water, as one water molecule evaporates at the opening it pulls the other molecules and sends this pull all the way down the column.

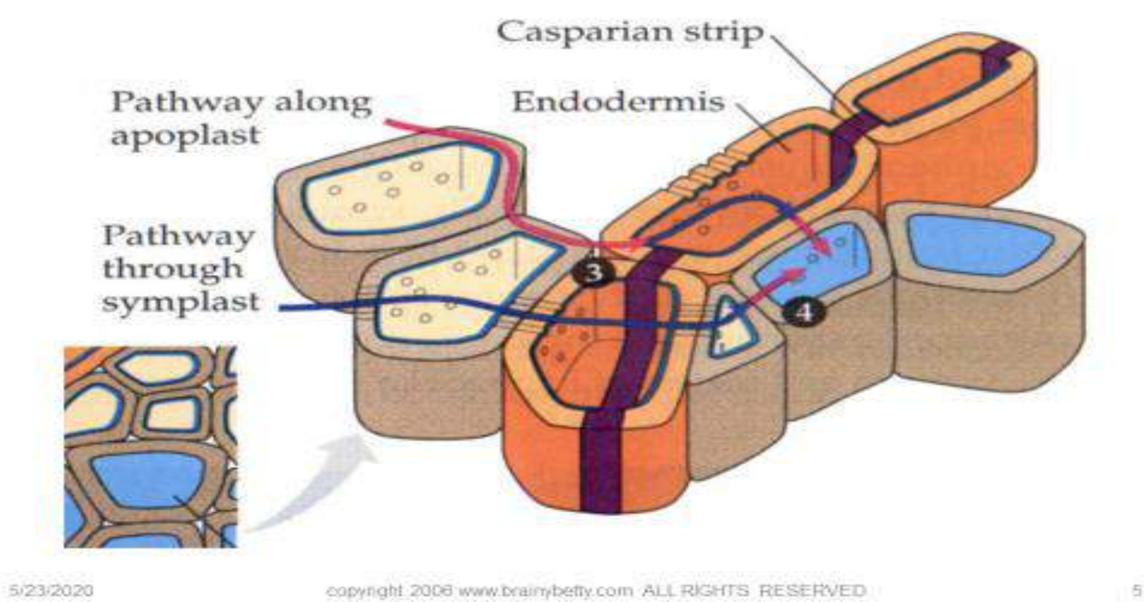
Pathway of Water Movement and forces

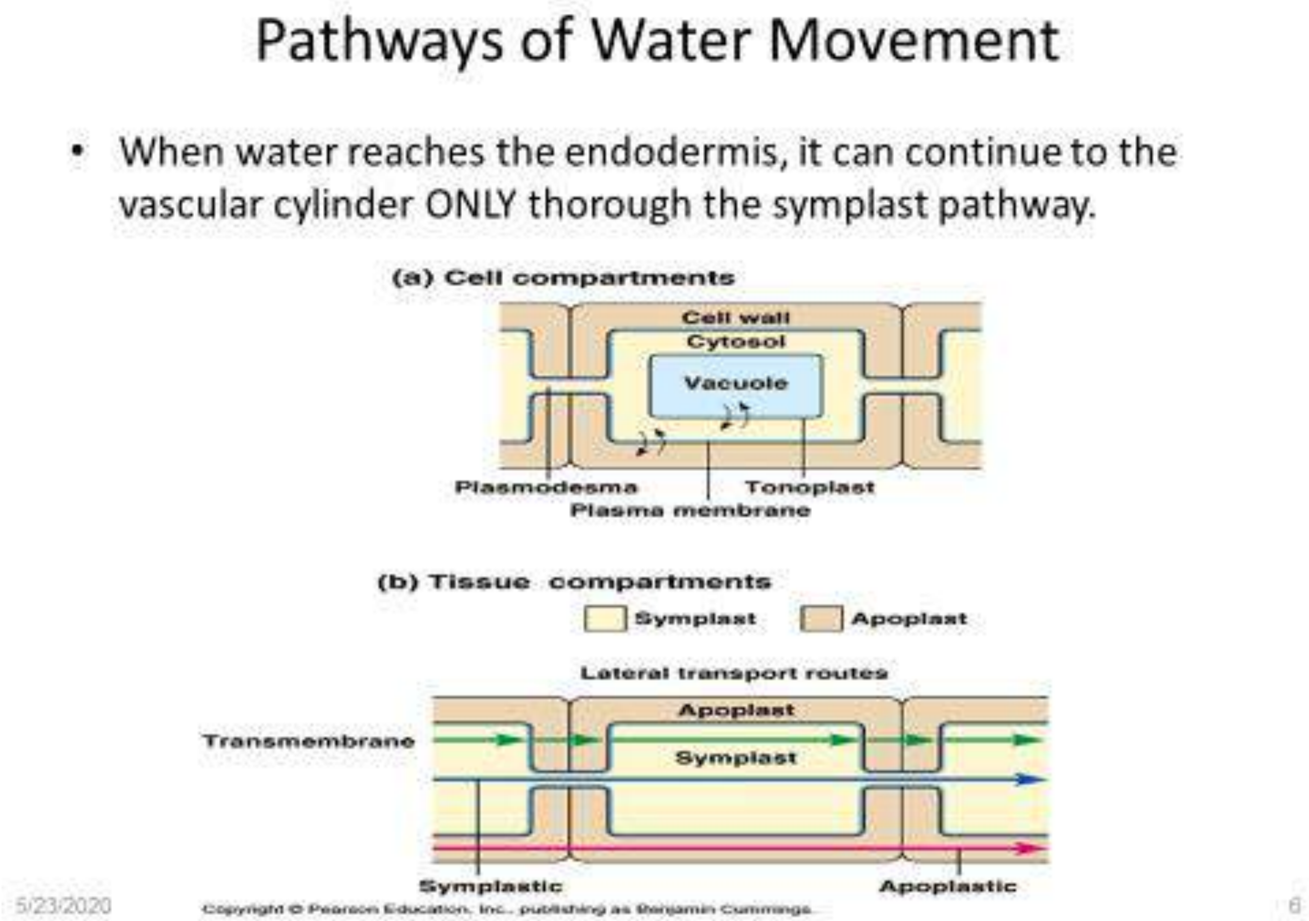
Water moves by three different pathways toward the center of the root. **Apoplast** through cell walls without ever entering the cells. The pathway along apoplast involves the movement of water through the “nonliving” portions of cells.

Symplast-- it moves from the cytoplasm of one cell to the cytoplasm of another cell through plasmodesmata (living” portions).

When water reaches the endodermis, it can continue to the vascular cylinder ONLY thorough the symplast pathway.

Transmembrane pathway: water sequentially enters a cell on one side, exits the cell on the other side. In this pathway, water crosses at least two membranes for each cell in its path.





Osmosis

Water moves into root hairs by osmosis from the soil, the gradient is established by:

- Constant movement of water out of soil
- Higher mineral concentration in the stele by selective passage of ions through the endodermis

Root pressure:

Root cells actively pump inorganic ions into the xylem and the root endodermis holds the ions there. As ions accumulate in the xylem, water enters by osmosis, pushing the xylem sap upward ahead of it. This force, called root pressure, can push xylem sap up to a few metres. Root pressure is <u>not enough</u> to bring water up all trees.

Guttation:
root pressure forces excess water out of leaf. Transpiration at night is low. Roots accumulates minerals and ions, which build up root pressure. Excess water is forced out of leaf as liquid.

Capillary action (capillarity)
The rise of liquids in narrow tubes. The height of the column depends on equilibrium of the forces of adhesion, cohesion and gravity.

Cohesion-tension theory
Root pressure and capillarity make minor contributions to water movement.
Transpiration—the evaporation of water from plants through open stomata causing negative pressure or tension to develop within leaves and xylem tissue.

- Transpiration pull: Suction force caused by transpiration, Main factor that causes water to move up the xylem.
- Transpiration stream: Stream of water moving up the plant.
-

Transpiration:
More than 95% of water loss in air, and only1-5% for plant metabolism.
(1) Liquid form—guttation.
(2) Gas form—transpiration.
Transpiration is a process of loss water from plant in a form of water vapor.

Organs for transpiration:
1-Lenticular transpiration about 0.1%
2- Most of transpiration passes throughout leaf of plant called Leaf transpiration or Stomatal transpiration 90-95%.
3- Cuticular transpiration 5-10 ％,

Stomatal transpiration:
Stomata ——pore for gas exchange (main CO_2, O_2, Water vapor).

Physiology of Guard Cell Action:

Since water is the driving force for GC action, this means that there must be a gradient in water potential between the GC and the surrounding cells (subsidiary cells). Thus, to open a stoma, there must be a mechanism to generate a water potential gradient.

Solute Transport in the Xylem

1-Water and dissolved ions are the main substances in vessels/tracheids. Xylem sap may also contain organic materials, usually in relatively low.

2. Carbohydrates - make up 16-25% of sap.
3. Amines/amides (0.04-4%) such as asparagine, glutamine, aspartic acid, ureides like ureas, citrulline, allantoin and allantoic acid. These compounds serve to transport nitrogen.
4. ATP, hormones, sugar alcohols like sorbitol and mannitol.

5. Inorganic substances including magnesium and potassium.

Ions and mineral salts

- Most are present in higher concentrations in cell sap than in soil solution.
- Taken in by active transport.
- Some are present in high concentrations in soil will enter by diffusion.
- Transport of solutes down a chemical gradient (e.g., by diffusion) is known as passive transport. Movement of solutes against a chemical potential gradient is known as active transport and requires energy input.
- The extent to which a membrane permits or restricts the movement of a substance is called membrane permeability.
- Membranes contain specialized proteins—channels, carriers, and pumps—that facilitate solute transport.

Channels are transport proteins that span the membrane, forming pores through which solutes diffuse down their gradient of electrochemical potentials**.**

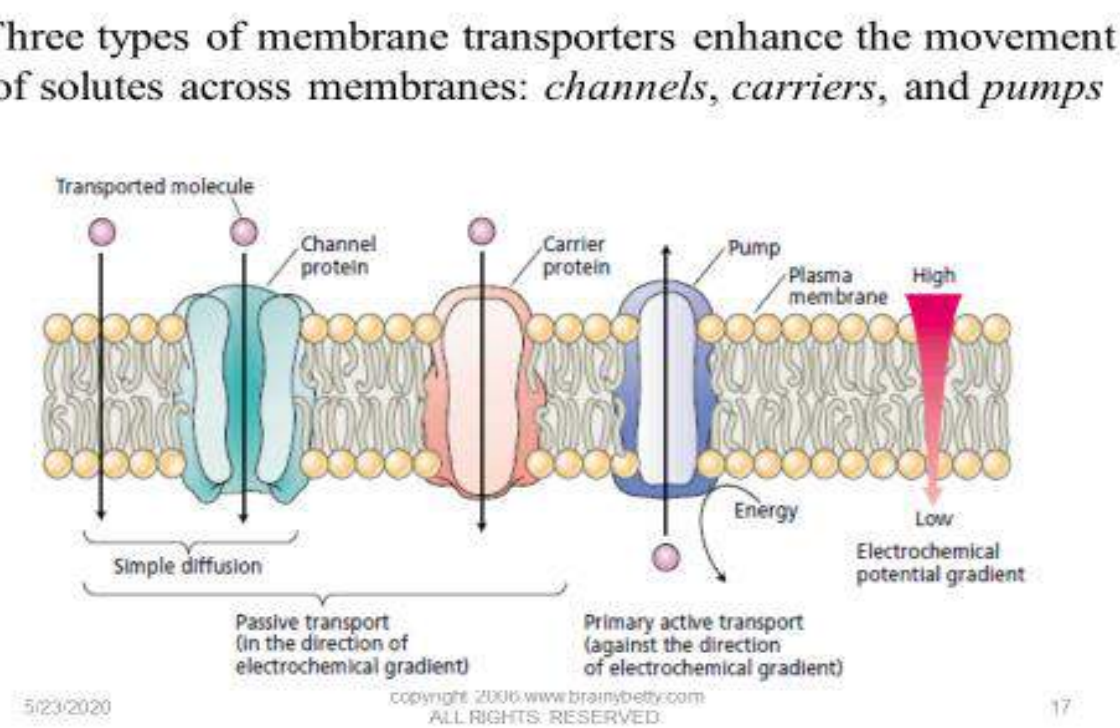
Carriers bind a solute on one side of the membrane and release it on the other side.

A family of H+-pumping ATPases provides the primary driving force for ransport across the plasma membrane of plant cells. Two other kinds of electrogenic proton pumps serve this purpose at the tonoplast. Plant cells also have calcium- pumping ATPases that participate in the regulation of intracellular calcium concentrations, as well as ATP binding transporters that use the energy of ATP to transport large anionic molecules. The gradient of electrochemical potential generated by H+ pumping is used to drive the transport of ions.

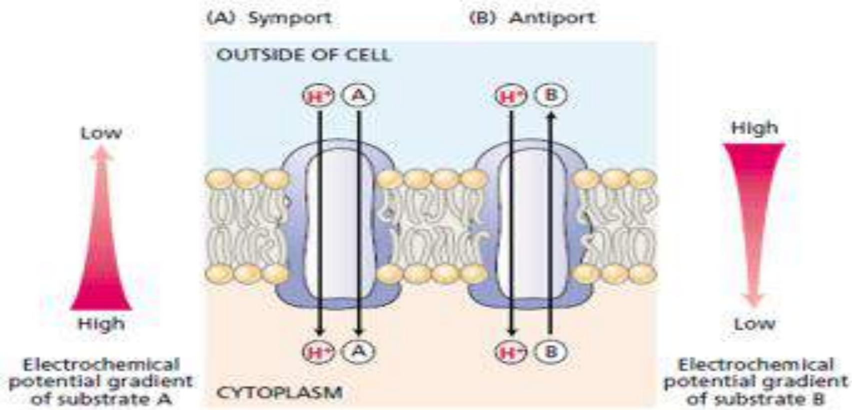
Porters

Are mostly transport proteins which couple the transport of an ion with the inward movement of a proton or protons.

The transport can be **symport** (**cotransport)**, the proton and the ion moving in the same direction, or **antiport** (**countertransport**), the two moving in opposite directions.
(A) In a 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 an antiport, the energy dissipated by a proton moving back into the cell is coupled to the active transport of a substrate (for example, 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.



Symport & antiport



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