ASCENT OF SAP

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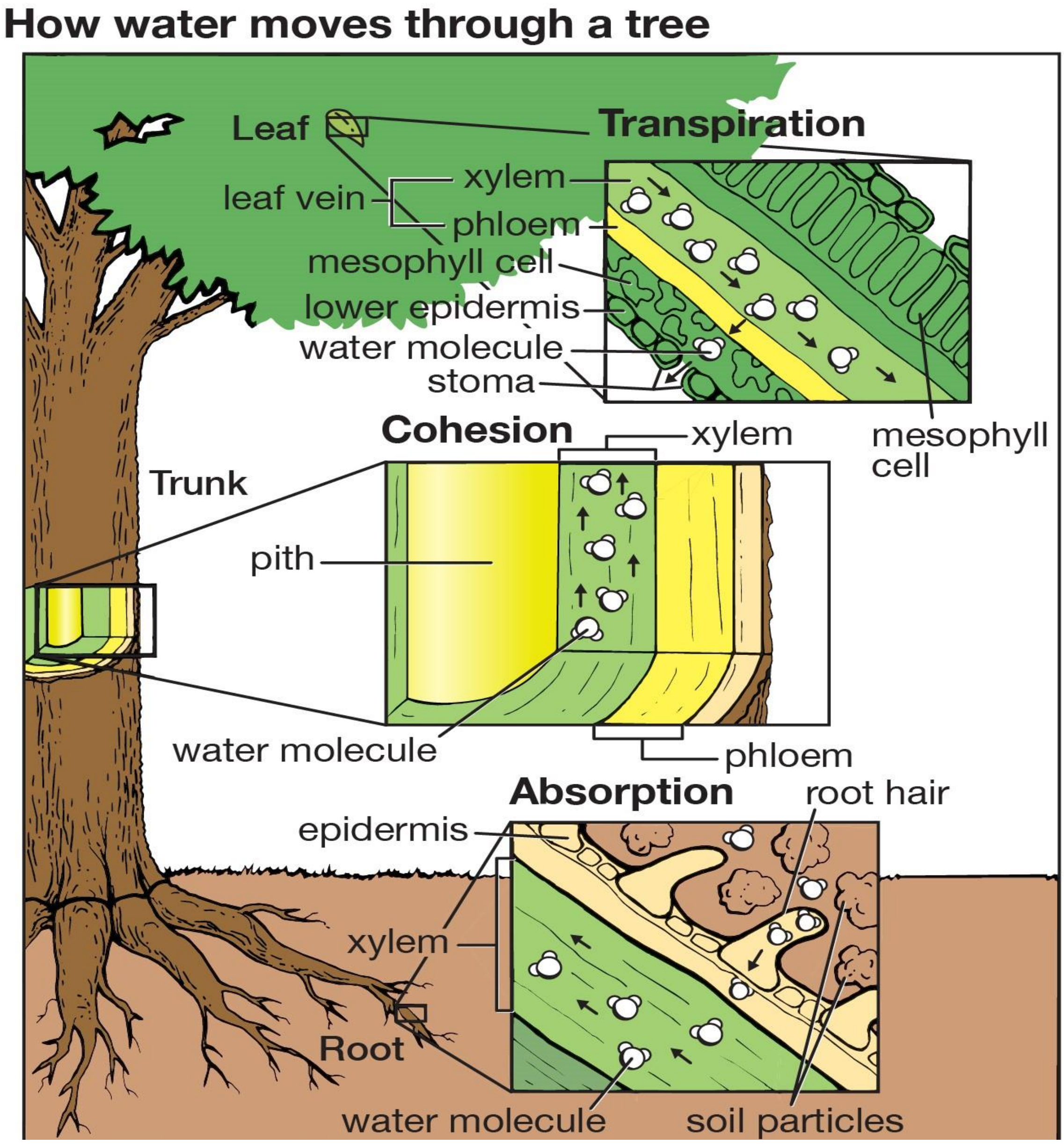
The water after being absorbed by the roots is distributed to all parts of the plants. In order to reach the topmost part of the plant, the water has to move upward through the stem.



The upward movement of water is called as Ascent of sap.

Ascent of sap can be studied under the following two headings.

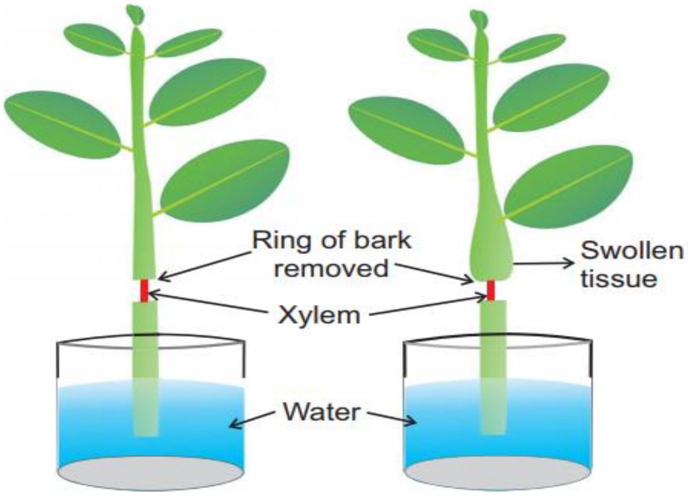
1. Path of ascent of sap

2. Mechanism of ascent of sap.

1. Path of ascent of sap

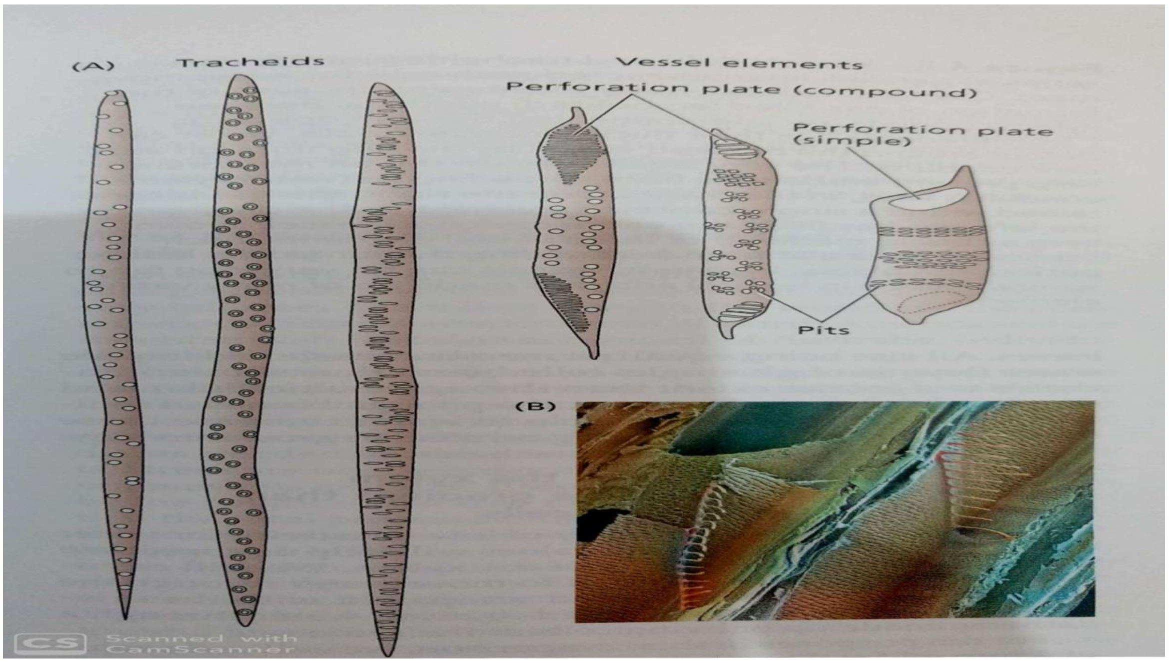
Ascent of sap takes place through xylem. It can be shown by the experiment. A leafy twig of **Balsam plant** is cut under water and placed in a beaker containing water with some Eosine (a dye) dissolved in it. After sometimes **coloured lines** will be seen moving upward in the stem. If sections of stem are cut at this time, only the xylem elements will appear to be filled with coloured water.

2. Ringing experiment



A leafy twig from a tree is cut under water and placed in a beaker filled with water. A ring of bark is removed from the stem. After sometime it is observed that the leaves above the ringing part of the stem remain fresh and green.

It is because water is being continuously supplied to the upper part of the twig through xylem.



Mechanism of ascent of sap

In small trees and herbaceous plants, the ascent of sap can be explained easily, but in tall trees like Eucalyptus and conifers reaching a height of 300-400 feet), where water has to rise up to the height of several hundred feet, the ascent of sap, it feet, becomes a problem.

To explain the mechanism of Ascent of sap, a number of theories have been put forward.

A. Vital Theory

B. Root Pressure Theory

C. Physical Force Theory

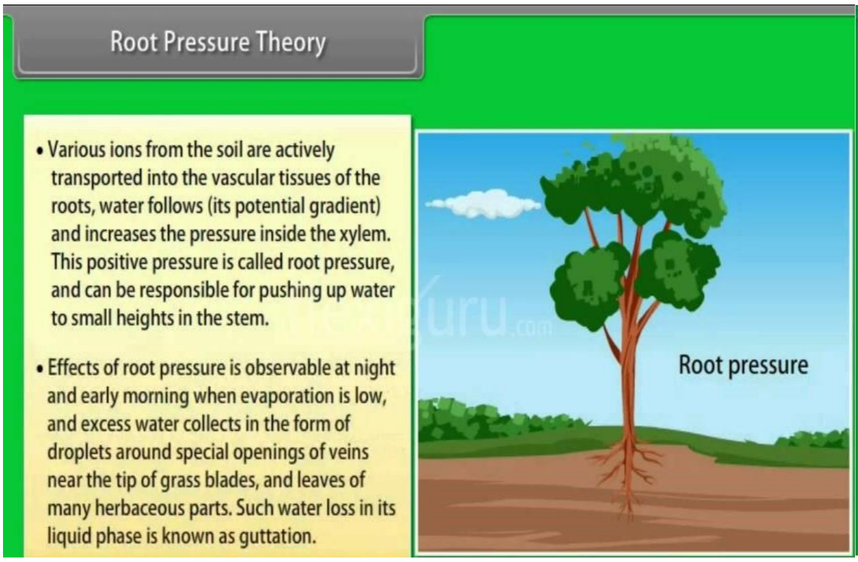
D. Transpiration Pull and Cohesion of Water Theory

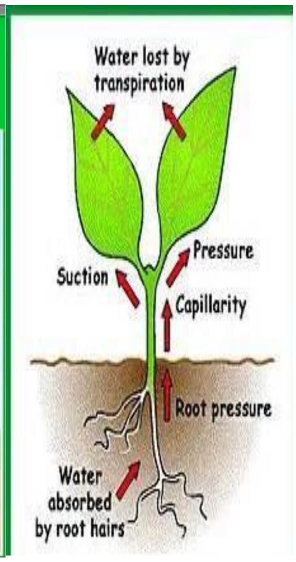
A. Vital theories According to vital theories, the ascent of sap is under the control of vital activities in the stem.

1. According to Godlewski (1884) – Ascent of sap takes place due to the pumping activity xylem tissues which are living.

2. According to Bose (1923) – upward translocation of water takes place due to pulsatory activity of the living cells of the inner must cortical layer just outside the endodermis.

B. Root pressure theory Although, root pressure which is developed in the xylem of the roots can raise water to a certain height but does not seem to be an effective force in ascent of sap due to the following reasons. Magnitude of root pressure is very low.



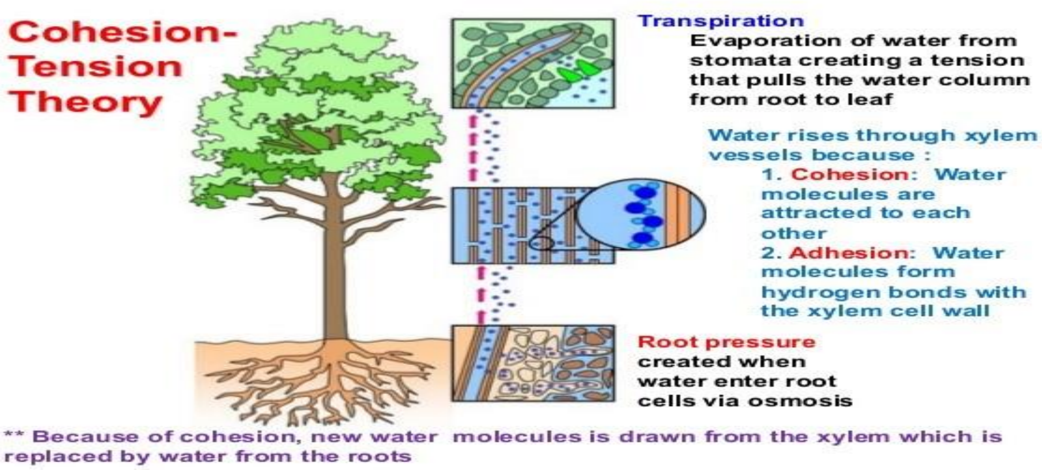


C. Physical force theories Various physical forces may be involved in ascent of sap.

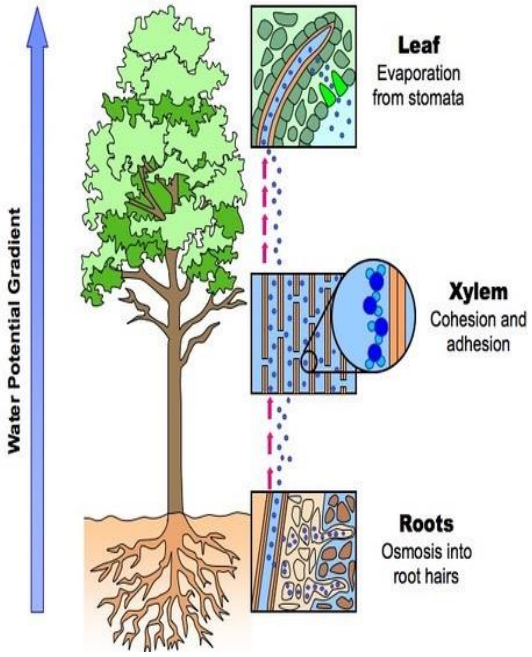
1. Atmospheric pressure This does not seem to be convincing because it cannot act on water present in xylem in roots, in case it is working, and then also it will not be able to raise water beyond 34.

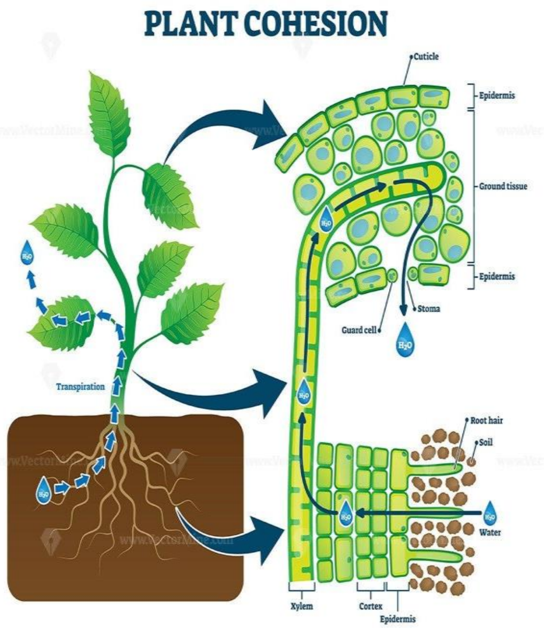
2. Imbibition Sachs (1878) supported the view that ascent of sap could take place by imbibition through the walls of xylem.

D. Transpiration pull and cohesion of water theory This theory was originally proposed by Dixon and Jolly (1894) later supported and elaborated by Dixon (1924).



This theory is very convincing and has now been widely supported by many workers. Although H- bond is very weak but they are present in enormous numbers as in case of water, a very strong mutual force of attraction or **cohesive force** develops between water molecules and hence they remain in the form of a continuous water column in the xylem.



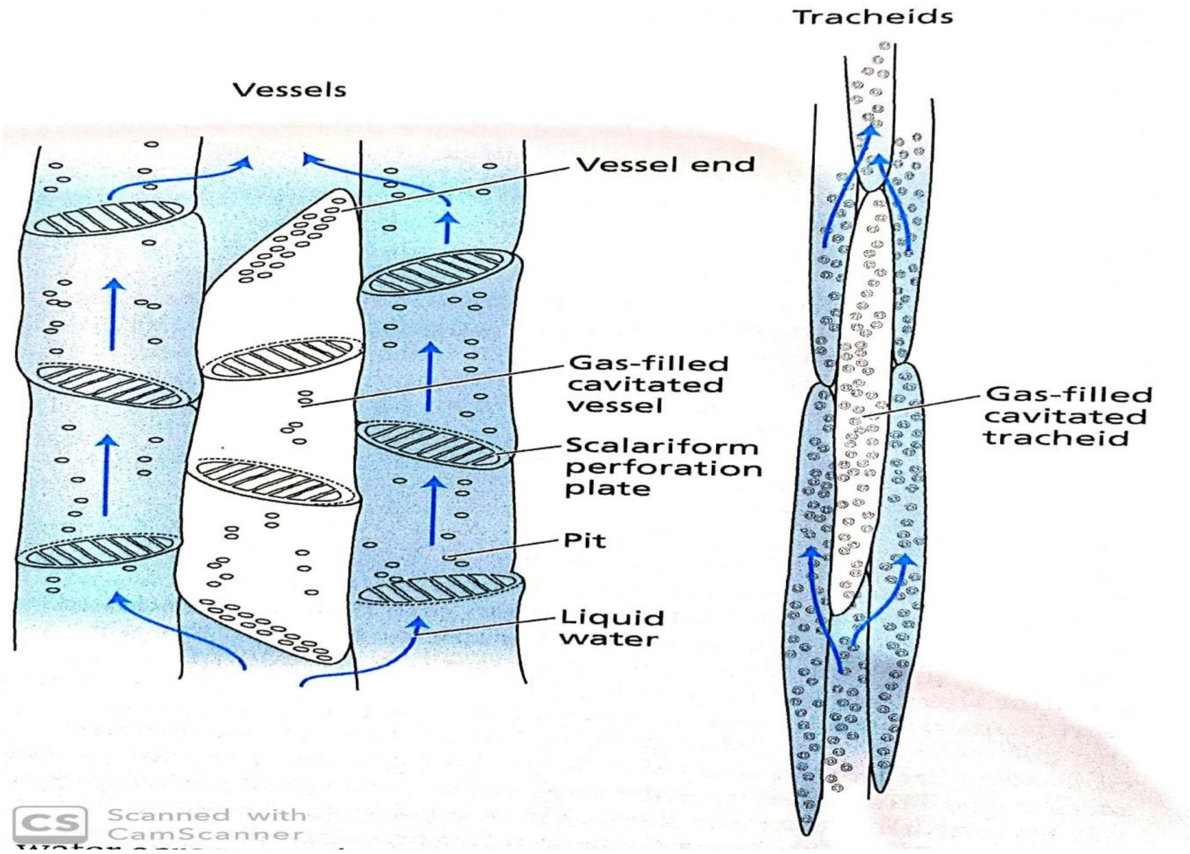


The magnitude of this force is very high, therefore the continuous water column in the xylem cannot be broken easily due to the force of gravity or other abstractions offered by the internal tissues in the upward movement of water.

The **adhesive** properties of water i.e. attractions between the water molecules and the containers walls (here the walls of xylem) further ensure the continuity of water column in xylem.

When transpiration takes place in the leaves at the upper parts of the plant, water evaporates from the intercellular spaces of the leaves to the outer atmosphere through stomata. More water is released into the intercellular spaces from mesophyll cells. In turn, the mesophyll cells draw water from the xylem of the leaf.

Due to all this, a tension is created in the xylem elements of the leaves. This tension is transmitted downward to water in xylem elements of the root through the xylem of petiole and stem and the water is pulled upward in the form of continuous unbroken water column to reach the transpiring surfaces up to the top of the plant.



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C_4 Cycle

or

Hatch and Slack Pathway

In C_4 cycle, the first formed stable compound is a 4 carbon compound viz., oxaloacetic acid. Hence it is called **C4 cycle.**

The path way is also called as Hatch and Slack as they worked out the pathway in 1966 and it is also called as **C_4 Dicarboxylic Acid Pathway.**

This pathway is commonly seen in many grasses, sugar cane, maize, sorghum and amaranthus. The C_4 plants show a different type of leaf anatomy.

The chloroplasts are dimorphic in nature. In the leaves of these plants, the vascular bundles are surrounded by bundle sheath of larger parenchymatous cells.

These bundle sheath cells have chloroplasts. These chloroplasts of bundle sheath are larger, lack grana and contain starch grains. The chloroplasts in mesophyll cells are smaller and always contain grana. This peculiar anatomy of leaves of C4 plants is called **Kranz anatomy.** The bundle sheath cells are bigger and look like a ring or wreath.

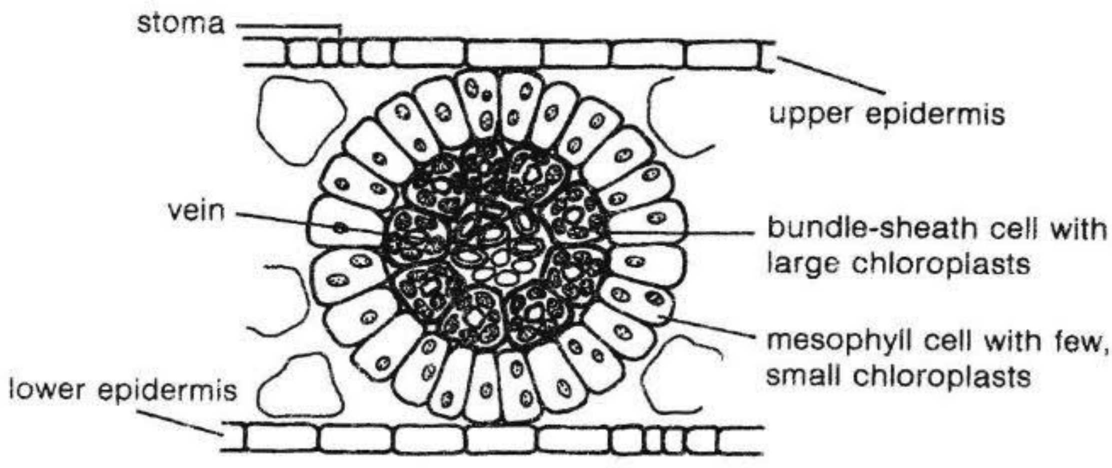
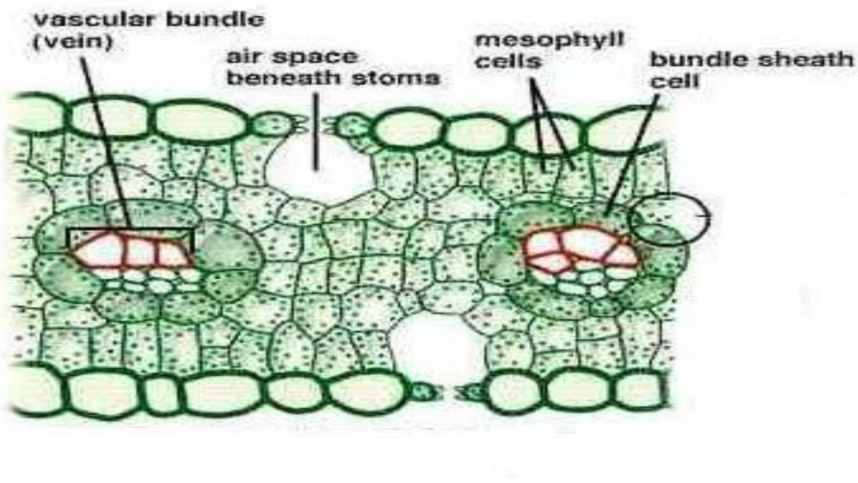


Fig 1. KRANZ ANATOMY



Kranz in German means wreath and hence it is called **Kranz anatomy.** The C_4 cycle involves two carboxylation reactions, one taking place in chloroplasts of mesophyll cells and another in chloroplasts of bundle sheath cells.

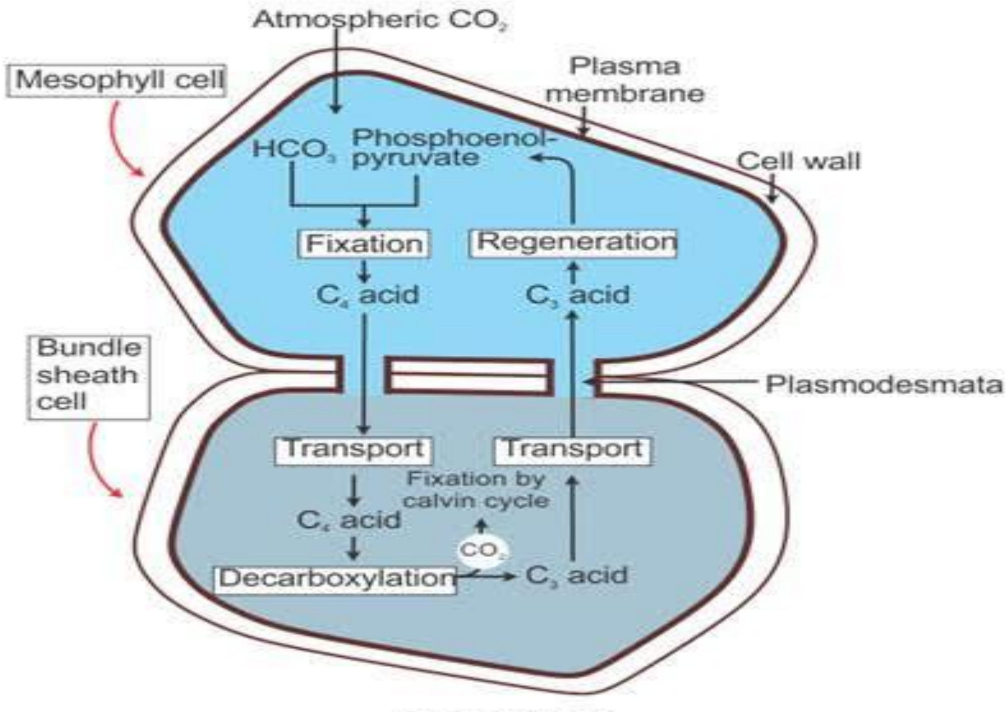
There are four steps in Hatch and Slack cycle:

1. Carboxylation

2. Breakdown

3. Splitting

4. Phosphorylation



C4 Pathway

1. Carboxylation

It takes place in the chloroplasts of mesophyll cells. Phosphoenolpyruvate, a 3 carbon compound picks up CO2 and changes into 4 carbon oxaloacetate in the presence of water. This reaction is catalysed by the enzyme, phosphoenol pyruvate carboxylase

2. Breakdown

Oxaloacetate breaks down readily into 4 carbon malate and aspartate in the presence of the enzyme, transaminase and malate dehydrogenase. These compounds diffuse from the mesophyll cells into sheath cells.

3. Splitting

In the sheath cells, malate and aspartate split enzymatically to yield free CO_2 and 3 carbon pyruvate. The CO_2 is used in Calvin's cycle in the sheath cell

The second Carboxylation occurs in the chloroplast of bundle sheath cells. The CO_2 is accepted by 5 carbon compound ribulose diphosphate in the presence of the enzyme, carboxy dismutase and ultimately yields 3 phosphoglyceric acid. Some of the 3 phosphoglyceric acid is utilized in the formation of sugars and the rest regenerate ribulose diphosphate

4. Phosphorylation

The pyruvate molecule is transferred to chloroplasts of mesophyll cells where, it is phosphorylated to regenerate phosphoenol pyruvate in the presence of ATP. This reaction is catalysed by pyruvate phosphokinase and the phophoenol pyruvate is regenerated.

In Hatch and Slack pathway, the C_3 and C_4 cycles of carboxylation are linked and this is due to the Kranz anatomy of the leaves. The C_4 plants are more efficient in photosynthesis than the C_3 plants. The enzyme, phosphoenol pyruvate carboxylase of the C_4 cycle is found to have more affinity for CO_2 than the ribulose diphosphate carboxylase of the C_3 cycle in fixing the molecular CO_2 in organic compound during Carboxylation.

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Crassulacean Acid Metabolism (CAM) Cycle

OR

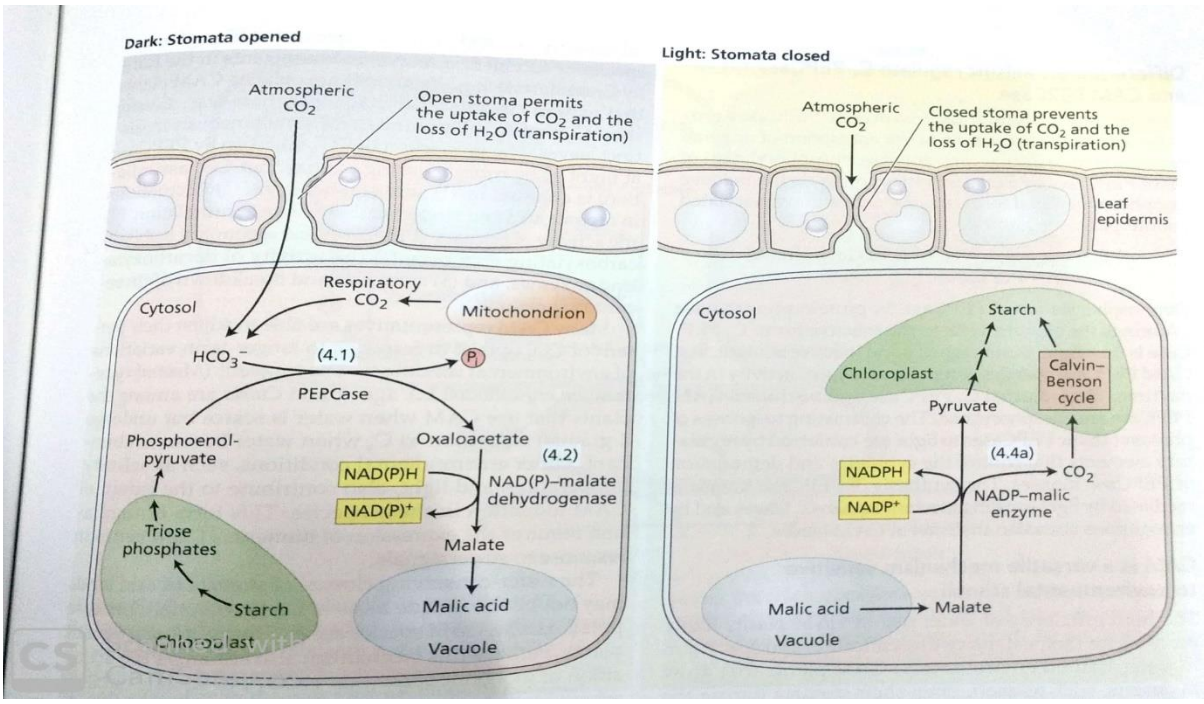
The Dark Fixation of CO_2 in Succulents

CAM is a cyclic reaction occurring in the dark phase of photosynthesis in the plants of Crassulaceae. It is a CO_2 fixation process wherein, the first product is malic acid. It is the third alternate pathway of Calvin cycle, occurring in mesophyll cells. The plants exhibiting CAM cycle are called **CAM plants**.

Most of the CAM plants are succulents e.g., Bryophyllum, Kalanchoe, Crassula, Sedium, Kleinia etc. It is also seen in certain plants of Cactus e.g. Opuntia, Orchid and Pine apple families.

CAM plants are usually succulents and they grow under extremely xeric conditions. In these plants, the leaves are succulent or fleshy. The mesophyll cells have larger number of chloroplasts and the vascular bundles are not surrounded by well defined bundle sheath cells.

In these plants, the stomata remain open during night and closed during day time. The CAM plants are adapted to photosynthesis and survival under adverse xeric conditions. CAM plants are not as efficient as C_4 plants in photosynthesis. But they are better suited to conditions of extreme desiccation.



CAM involves two steps:

1. Acidification 2. Deacidification

1. Acidification

In darkness, the stored carbohydrates are converted into phophoenol pyruvic acid by the process of Glycolysis. The stomata in CAM plants are **open in dark** and they allow free diffusion of CO_2 from the atmosphere into the leaf. Now, the phosphoenolpyruvic acid carboxylated by the enzyme phosphoenol pyruvic acid carboxylase and is converted in to oxalaoacetic acid.

The oxaloacetic acid is then reduced to malic acid in the presence of the enzyme malic dehydrogenase. The reaction requires $NADPH_2$ produced in Glycolysis.

The malic acid produced in dark is stored in the vacuole. The malic acid increases the acidity of the tissues.

2. Deacidification During day time, when the stomata are closed, the malic acid is decarboxylated to produce pyruvic acid and evolve carbon dioxide in the presence of the malic enzyme. When the malic acid is removed, the acidity decreases the cells. This is called **deacidification.** One molecule of $NADP^+$ is reduced in this reaction.

The pyruvic acid may be oxidized to CO_2 by the pathway of Kreb's cycle or it may be reconverted to phosphoenol pyruvic acid and synthesize sugar by C_3 cycle. The CO_2 released by deacidification of malic acid is accepted by ribulose diphosphate and is fixed to carbohydrate by C_3 cycle. CAM is a most significant pathway in succulent plants. The stomata are closed during day time to avoid transpiration loss of water.

As the stomata are closed, CO_2 cannot enter into the leaves from the atmosphere. However, they can carry out photosynthesis during the day time with the help of CO_2 released from organic acids.

During night time, organic acids are synthesized in plenty with the help of CO_2 released in respiration and the CO_2 entering from the atmosphere through the open stomata. Thus, the CO_2 in dark acts as survival value to these plants

Oxidative phosphorylation and Electron Transport Chain

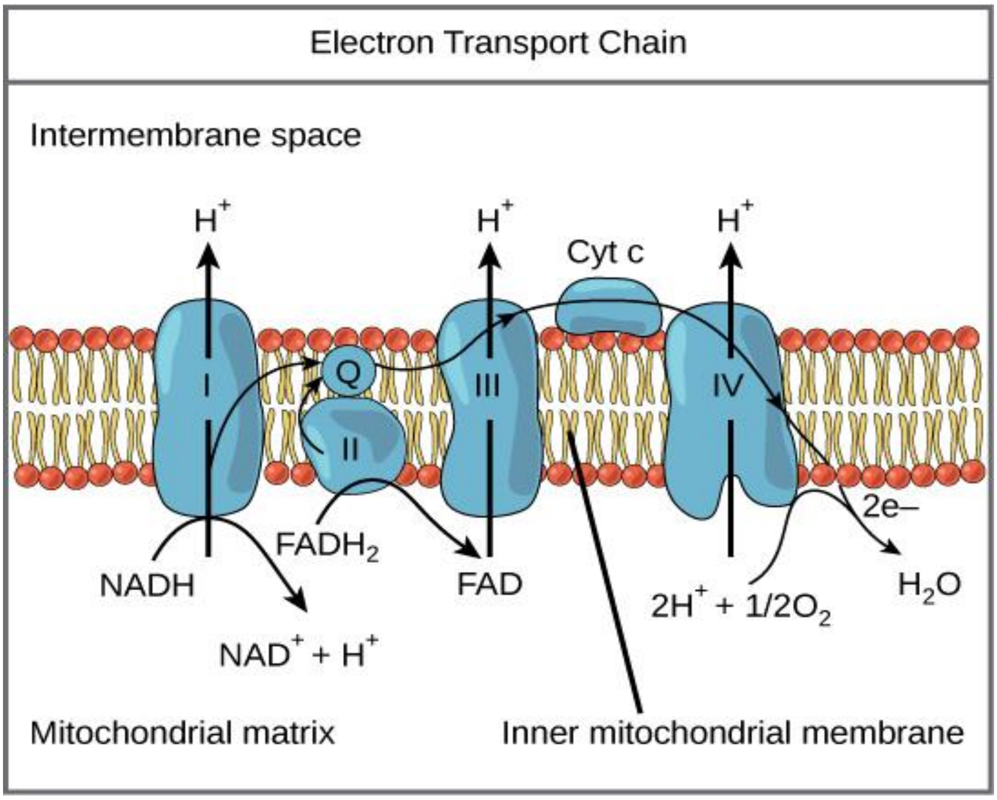
- Oxidative phosphorylation is the metabolic pathway in which electrons are transferred from electron donors to electron acceptors in redox reactions; this series of reactions releases energy which is used to form ATP.
- There are four protein complexes (labelled complex I-IV) in the electron transport chain, which are involved in moving electrons from NADH and $FADH_2$ to molecular oxygen.
- Complex I establish the hydrogen ion gradient by pumping four hydrogen ions across the membrane from the matrix into the intermembrane space.
- Complex II receives $FADH_2$, which bypasses complex I, and delivers electrons directly to the electron transport chain.
- Ubiquinone (Q) accepts the electrons from both complex I and complex II and delivers them to complex III.
- Complex III pumps protons through the membrane and passes its electrons to cytochrome c for transport to the fourth complex of proteins and enzymes.
- Complex IV reduces oxygen; the reduced oxygen then picks up two hydrogen ions from the surrounding medium to make water.

Oxidative phosphorylation is a highly efficient method of producing large amounts of ATP, the basic unit of energy for metabolic processes. During this process electrons are exchanged between a molecule, which creates a chemical gradient that allows for the production of ATP. The most vital part of this process is the electron transport chain, which produces more ATP than any other part of cellular respiration.

Electron Transport Chain

The electron transport chain is the final component of aerobic respiration and is the only part of glucose metabolism that uses atmospheric oxygen. Electron transport is a series of redox reactions that resemble a relay race. Electrons are passed rapidly from one component to the next to the endpoint of the chain, where the electrons reduce molecular oxygen, producing water. This requirement for oxygen in the final stages of the chain can be seen in the overall equation for cellular respiration, which requires both glucose and oxygen.

A complex is a structure consisting of a central atom, molecule, or protein weakly connected to surrounding atoms, molecules, or proteins. The electron transport chain is an aggregation of four of these complexes (labelled I through IV), together with associated mobile electron carriers. The electron transport chain is present in multiple copies in the inner mitochondrial membrane of eukaryotes and the plasma membrane of prokaryotes.



The electron transport chain: The electron transport chain is a series of electron transporters embedded in the inner mitochondrial membrane that shuttles electrons from NADH and $FADH_2$ to molecular oxygen. In the process, protons are pumped from the mitochondrial matrix to the intermembrane space, and oxygen is reduced to form water.

Complex I

To start, two electrons are carried to the first complex aboard NADH. Complex I is composed of flavin mononucleotide (FMN) and an enzyme containing iron-sulphur (Fe-S). FMN, which is derived from vitamin B_2 (also called riboflavin), is one of several prosthetic groups or co-factors in the electron transport chain. A prosthetic group is a non-protein molecule required for the activity of a protein. Prosthetic groups can be organic or inorganic and are non-peptide molecules bound to a protein that facilitate its function.

Prosthetic groups include co-enzymes, which are the prosthetic groups of enzymes. The enzyme in complex I is NADH dehydrogenase, a very large protein containing 45 amino acid chains. Complex I can pump four hydrogen ions across the membrane from the matrix into the intermembrane space; it is in this way that the hydrogen ion gradient is established and maintained between the two compartments separated by the inner mitochondrial membrane.

Q and Complex II

Complex II directly receives $FADH_2$, which does not pass through complex I. The compound connecting the first and second complexes to the third is ubiquinone (Q). The Q molecule is lipid soluble and freely moves through the hydrophobic core of the membrane. Once it is reduced to QH_2, ubiquinone delivers its electrons to the next complex in the electron transport chain.

Q receives the electrons derived from NADH from complex I and the electrons derived from $FADH_2$ from complex II, including succinate dehydrogenase. This enzyme and $FADH_2$ form a small complex that delivers electrons directly to the electron transport chain, bypassing the first complex.

Since these electrons bypass, and thus do not energize, the proton pump in the first complex, fewer ATP molecules are made from the $FADH_2$ electrons. The number of ATP molecules ultimately obtained is directly proportional to the number of protons pumped across the inner mitochondrial membrane.

Complex III

The third complex is composed of cytochrome b, another Fe-S protein, Rieske center (2Fe-2S center), and cytochrome c proteins; this complex is also called cytochrome oxidoreductase. Cytochrome proteins have a prosthetic heme group.

The heme molecule is similar to the heme in hemoglobin, but it carries electrons, not oxygen. As a result, the iron ion at its core is reduced and oxidized as it passes the electrons, fluctuating between different oxidation states: Fe^{2+} (reduced) and Fe^{3+} (oxidized).

The heme molecules in the cytochromes have slightly different characteristics due to the effects of the different proteins binding them, which makes each complex. Complex III pumps protons through the membrane and passes its electrons to cytochrome c for transport to the fourth complex of proteins and enzymes. Cytochrome c is the acceptor of electrons from Q; however, whereas Q carries pairs of electrons, cytochrome c can accept only one at a time.

Complex IV

The fourth complex is composed of cytochrome proteins c, a, and a_3. This complex contains two heme groups (one in each of the cytochromes a and a_3) and three copper ions (a pair of Cu_A and one Cu_B in cytochrome a_3).

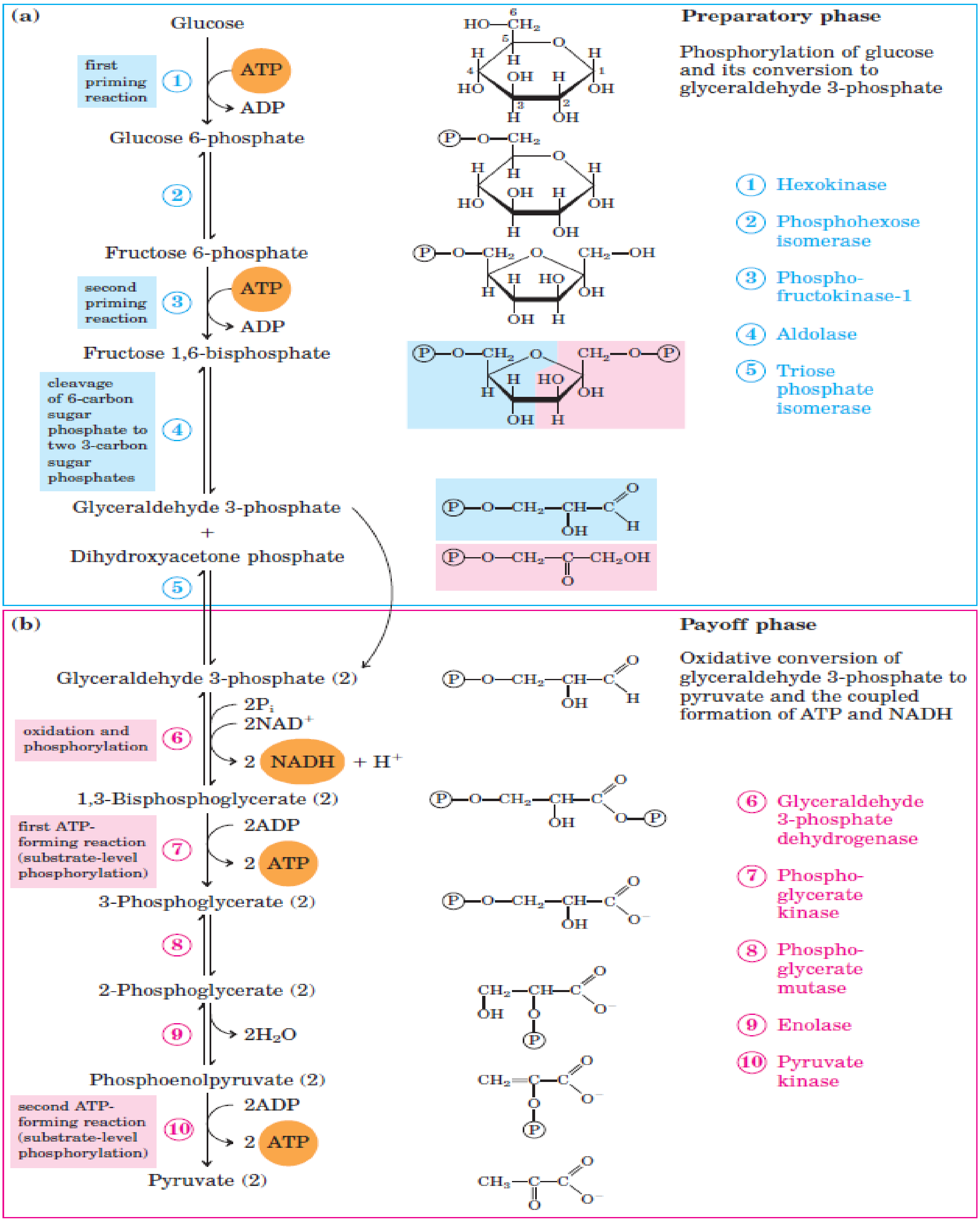
The cytochromes hold an oxygen molecule very tightly between the iron and copper ions until the oxygen is completely reduced. The reduced oxygen then picks up two hydrogen ions from the surrounding medium to produce water (H_2O). The removal of the hydrogen ions from the system also contributes to the ion gradient used in the process of chemiosmosis.

GLYCOLYSIS / EMBDEN – MEYER HOF – PARANAS (EMP) PATHWAY

Glycolysis can take place even in the absence of O_2.

One molecule of the **6** carbon compound, glucose is broken down through a series of enzyme reactions into two 3-carbon compounds, **the pyruvic acid.**

Glycolysis takes place in the **cytoplasm** and it does not require oxygen. Hence it is an anaerobic process.



Steps:

1. Glucose molecules react with ATP molecules in the presence of the enzyme hexokinase to form glucose -6- phosphate.

   Glucose + ATP → Glucose -6- phosphate + ADP

2. Glucose-6-phosphate is isomerised into fructose-6-phosphate in the presence of phospho hexose isomerase.

   Fructose + ATP → Fructose -6- phosphate + ADP

3. Fructose-6-phosphate reacts with one molecule of ATP in the presence of phospho hexo kinase forming fructose 1, 6-disphosphate.

   Fructose – 6- phosphate + ATP → Fructose -1,6- biphosphate + ADP

4. Fructose 1, 6 diphosphate is converted into two trioses,
   3-phospho glyceraldehyde and dihydroxy acetone phosphate in the presence of aldolase.

   Fructose -1,6- biphosphate → 3-phospho glyceraldehyde+ DHAP

5. 3-phosphoglyceraldehyde reacts with H_3PO_4 and forms 1,3-diphosphoglyceraldehyde where, the reaction is non –enzymatic.

6. 1, 3-Diphosphoglyceraldehyde is oxidized to form 1,3- diphosphoglycerate in the presence of triose-phosphate dehydrogenase and coenzyme NAD+.
   The NAD+ acts as hydrogen acceptor and reduced to NADH+ + H+ in the reaction.

   Glyceraldehde -3- phosphate + NAD + Pi → 1,3- diphosphoglycerate + NADH

7. 1, 3-Diphosphoglycerate reacts with ADP in the presence of phosphoglyceric transphorylase (kinase) to form 3 phosphoglyceric acid and ATP

   1,3- diphosphoglycerate + ADP → 3, Phosphoglycerate + ATP

8. 3, Phosphoglycerate → 2, Phosphoglycerate acid is isomerized into 2 phosphoglyceric acid in the presence of the enzyme, phospho glycero mutase.

3, Phosphoglycerate $\rightarrow$ 2, Phosphoglycerate

9. 2 phosphoglyceric acid is converted into 2-phosphoenolpyruvic acid in the presence of enolase.

2, Phosphoglycerate $\rightarrow$ Phosphoenol pyruvate + H2O

10. 2 phospho enol pyruvic acid reacts with ADP to form one molecule each of pyruvic acid and ATP in the presence of pyruvate kinase.

Phosphoenol pyruvate + ADP $\rightarrow$ Pyruvate + ATP .

Glycolysis or EMP pathway is common in both aerobic and anaerobic respiration

The overall glycolytic process can be summarized as follows

$C_6H_{12}O_6$ + 2ATP + 2NAD + 4ADP+2H_3PO_4

$$\Downarrow$$

2 $CH_3COCOOH$ + 2ADP + 2$NADH_2$ + 4 ATP
Pyruvic acid

- Thus there is a gain of 4-2 = 2 ATP molecules per hexose sugar molecule oxidized during this process.
- Besides this, 2 molecules of reduced coenzyme NADH2 are also produced per molecule of hexose sugar in glycolysis.
- During aerobic respiration, these two $NADH_2$ are oxidized via the electron transport chain to yield 3 ATP molecules each. Thus **6** ATP molecules are formed.

Krebs Cycle

Or

Tricarboxylic Acid (TCA) Cycle

Or

The citric Acid Cycle

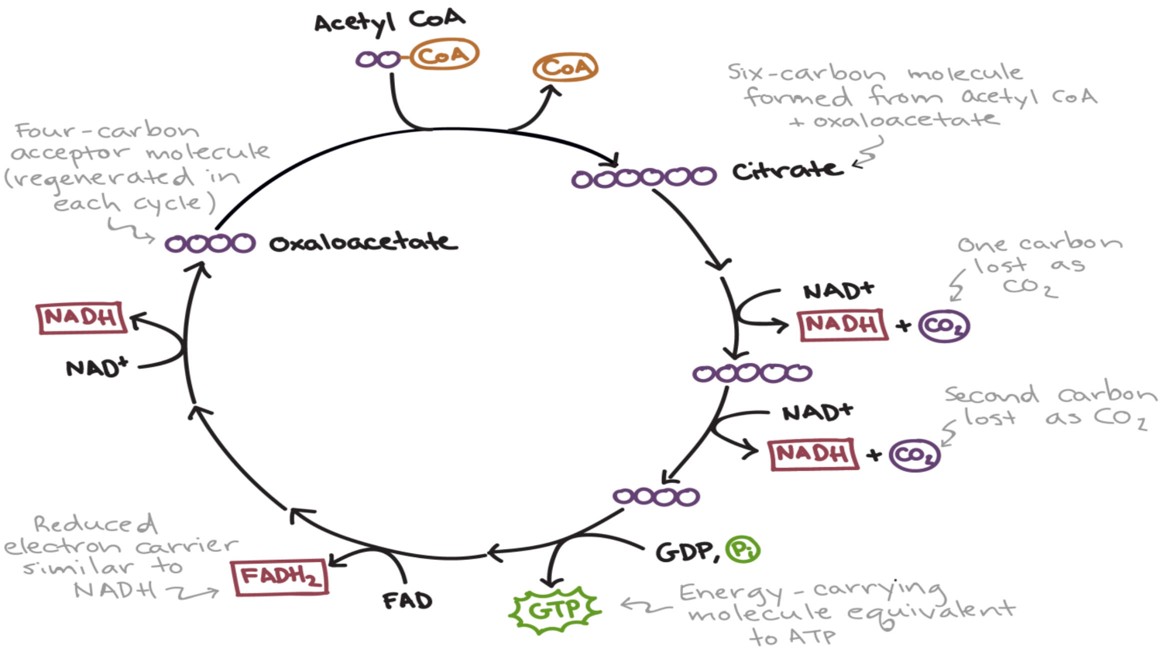
If the molecular oxygen is available, aerobic respiration takes place and the **pyruvate** produced in **glycolysis** in **cytosol** enters into **mitochondria** for further oxidation through Krebs cycle.

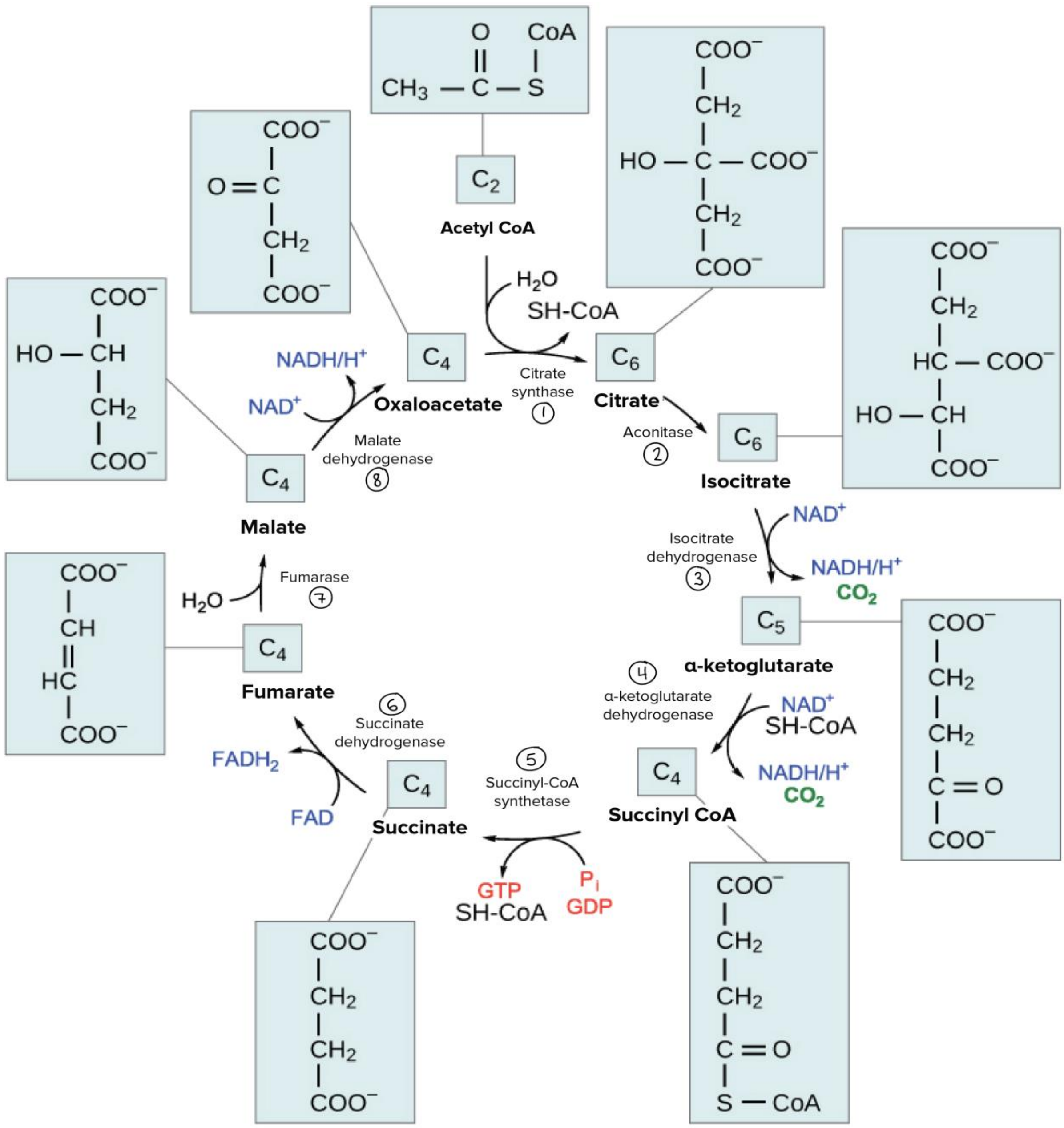
Krebs cycle is also known as Citric acid cycle or TCA because **citric acid** is an early intermediate of this cycle which contains **three carboxylic groups**.

Krebs cycle is so named after its discoverer **Hans A Krebs** who discovered this cycle in 1937 and was awarded the Nobel Prize in 1953 in Physiology category.

Overview of the citric acid cycle

In eukaryotes, the citric acid cycle takes place in the matrix of the mitochondria, just like the conversion of **pyruvate** to **acetyl CoA**. In prokaryotes, these steps both take place in the cytoplasm. All enzymes necessary for TCA cycle are found in **matrix** region of mitochondria. However, the enzymes **Succinate dehydrogenase** is present on the inner mitochondrial membrane.





Krebs Cycle

Steps of the citric acid cycle or Krebs cycle

Step 1. In the first step of the citric acid cycle, **acetyl CoA** joins with a four-carbon molecule--- **oxaloacetate**, releasing the CoA group and forming a six-carbon molecule called **citrate.**

Step 2. In the second step, **citrate** is converted into its isomer, **iso-citrate.** This is actually a two-step process, involving first the removal and then the addition of a water molecule, which is why the citric acid cycle is sometimes described as having nine steps—rather than the eight listed here.

Step 3. In the third step, isocitrate is oxidized and releases a molecule of carbon dioxide, leaving behind a **five**-carbon molecule—**α-ketoglutarate.** During this step, **NAD^+** is reduced to form **NADH.** The enzyme catalyzing this step, **isocitrate dehydrogenase**, is important in regulating the speed of the citric acid cycle.

Step 4. The fourth step is similar to the third. In this case, it's α-ketoglutarate that's oxidized, reducing NAD^+ to NADH and releasing a molecule of carbon dioxide in the process. The remaining four-carbon molecule picks up **Coenzyme --A,** forming the unstable compound **succinyl CoA.** The enzyme catalyzing this step, **α-ketoglutarate dehydrogenase**, is also important in regulation of the citric acid cycle.

Step5. In step five, the CoA of **succinyl CoA** is replaced by a phosphate group, which is then transferred to ADP to make ATP. In some cells, GDP—guanosine diphosphate—is used instead of ADP, forming GTP—guanosine triphosphate—as a product. The four-carbon molecule produced in this step is called **succinate.**

Step 6. In step six, succinate is oxidized, forming another four-carbon molecule called **fumarate.** In this reaction, two hydrogen atoms—with their electrons—are transferred to FAD, producing $FADH_2$. The enzyme that carries out this step is embedded in the inner membrane of the mitochondrion, so $FADH_2$ can transfer its electrons directly into the electron transport chain.

Step 7. In step seven, water is added to the four-carbon molecule fumarate, converting it into another four-carbon molecule called **malate.**

Step 8. In the last step of the citric acid cycle, **oxaloacetate**—the starting four-carbon compound—is regenerated by **oxidation of malate.** Another molecule of NAD^+ is reduced to NADH in the process.

Products of the citric acid cycle

Tracing the fate of the carbons that enter the citric acid cycle and counting the reduced electron carriers—NADH and $FADH_2$ and ATP produced.

In a single turn of the cycle,

- **Two carbons** enter from acetyl CoA and **two molecules** of carbon dioxide are released;
- **Three** molecules of NADH and one molecule of $FADH_2$ are generated; and
- **One** molecule of ATP or GTP is produced.

These figures are for one turn of the cycle, corresponding to one molecule of acetyl CoA. **Each glucose** produces **two acetyl CoA** molecules, so we need to multiply these numbers by 2 if we want the per-glucose yield.

Two carbons—from acetyl CoA—enter the citric acid cycle in each turn, and two carbon dioxide molecules are released. However, the carbon dioxide molecules don't actually contain carbon atoms from the acetyl CoA that just entered the cycle.

Instead, the carbons from **acetyl CoA** are initially incorporated into the intermediates of the cycle and are released as carbon dioxide only during later turns. After enough turns, all the carbon atoms from the acetyl group of acetyl CoA will be released as **carbon dioxide.**

Where's all the ATP?

Output of the citric acid cycle seems pretty unimpressive. All that work for just one ATP or GTP?

It's true that the citric acid cycle doesn't produce much ATP directly. However, it can make a lot of ATP indirectly, by way of the NADH and $FADH_2$ it generates. These electron carriers will connect with the last portion of cellular respiration, depositing their electrons into the electron transport chain to drive synthesis of ATP molecules through **oxidative phosphorylation.**

Mechanism of Photosynthesis

Photosynthesis: It is the process by which green plants and certain bacteria such as blue green algae can make their own food in the presence of sunlight using water and CO_2 as raw material.

Photosynthesis is a complex process of synthesis of organic food materials. It is a complicated **oxidation- reduction** process where water is oxidized and CO_2 is reduced to carbohydrates.

The mechanism of photosynthesis consists of two parts.

1. Light reaction / Primary photochemical reaction / Hill's reaction/ Arnon's cycle

2. Dark reaction / Black man's reaction / Path of carbon in photosynthesis.

1. Light reaction or Primary photochemical reaction or Hill's reaction:

In Light reaction, **ATP and $NADPH_2$** are produced.

In the Dark reaction, **CO_2** is reduced with the help of ATP and $NADPH_2$ to produce **glucose**.

The light reaction is called **PRIMARY PHOTOCHEMICAL REACTION ----**as it is induced by light.

OR

Light reaction is also called as **Hill's reaction** as Hill proved that chloroplast produce O_2 from water in the presence of light.

OR

It is also called as **Arnon's cycle** because Arnon showed that the **H^+ ions** released by the break **-**down of water are used to reduce the coenzyme NADP to NADPH.

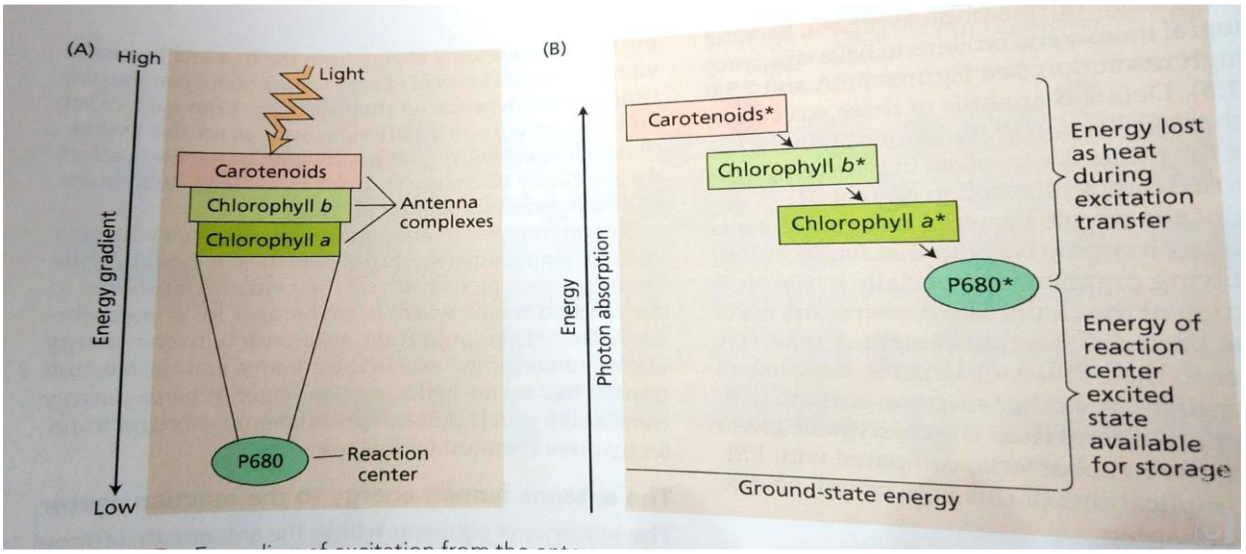
Process of light Reaction

Light reaction includes photophosphorylation as ATP is synthesized in the presence of light. The reaction takes place only in the presence of light in **Grana** portion of the **Chloroplast** and it is **faster** than dark reaction.

The chlorophyll absorbs the light energy and hence the chlorophyll is called **as photosystem or pigment system.** Chlorophylls are of different types and they absorb different wavelengths of light.

Chlorophylls exist in **two** photo systems----------- **Photosystem I (PSI)** and **Photosystem II (PS II).**

Both photo systems (PSII &PS I) are affected by light with wavelengths **shorter** than 680nm, while PS I is affected by light with wavelengths **longer** than 680nm.



The light reaction can be studied under the following headings.

A) Absorption of light energy by chloroplast pigments :

Different chloroplast pigments absorb light in different regions of the visible part of the spectrum.

B) Transfer of light energy from accessory pigments to chlorophyll a.

All the photosynthetic pigments except **chlorophyll a** are called as **accessory or antenna pigments.** The light energy absorbed by the accessory pigments is transferred by resonance to chlorophyll a which alone can take part in photochemical reaction. Chlorophyll a molecule can also absorb the light energy directly.

In pigment system **I**, the photoreaction centre is **P700** and in pigment system **II--** it is **P680**.

C). Activation of chlorophyll molecule by photon of light.

When P700 or P680 forms of chlorophyll a receives a photon (quantum) of light, becomes an excited molecule having more energy than the ground state energy.

After passing through the unstable second singlet state and first singlet stage the chlorophyll molecules comes to the meta stable triplet state. This excited state of chlorophyll molecule takes part further in primary photochemical reaction.

D). Photolysis of water and O_2 evolution (oxidation of water).

These processes are associated with pigment system II and are catalyzed by Mn^{++} and Cl^- ions. When pigment system II is active ----it receives the light.

The water molecules split into OH^- and H^+ ions (Photolysis of water).

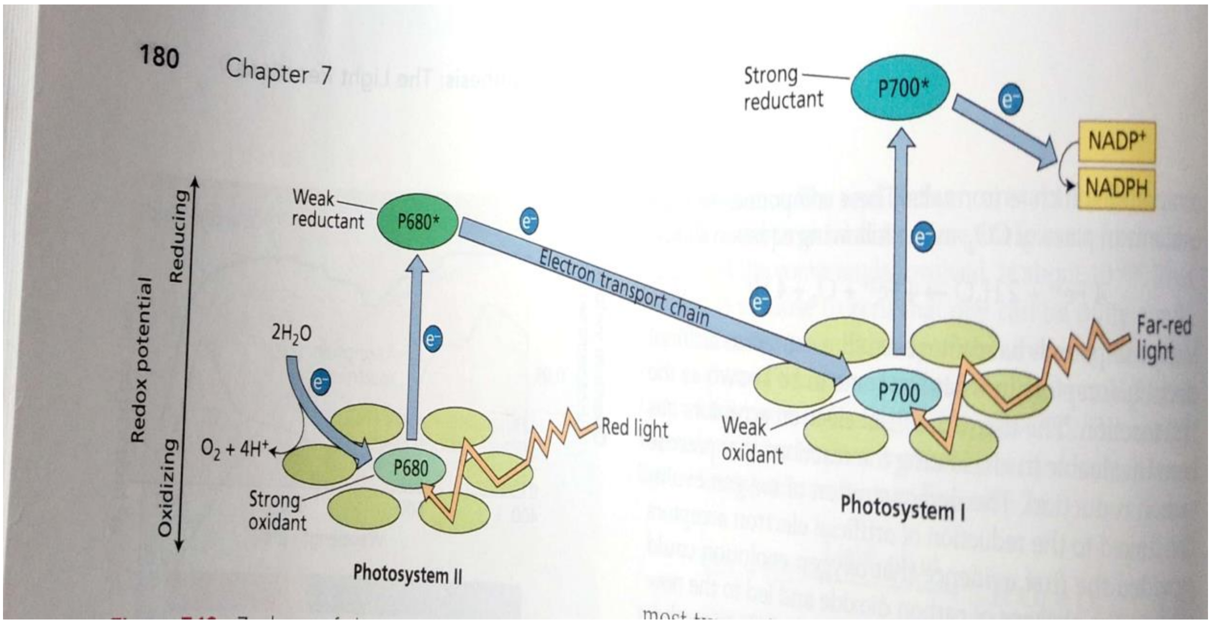
The OH^- ions unite to form some water molecules again

Release O_2 and electrons.

E). Electron transport and production of assimilatory powers ($NADPH_2$ and ATP).

It has already been observed that when chlorophyll molecule receives the photon of light, an electron is expelled from the chlorophyll a molecule along with extra energy. This electron after traveling through a number of electron carriers is utilized for the production of $NADPH_2$ from NADP and also utilized for the formation of ATP molecules from ADP and inorganic phosphate (Pi).

The transfer of electrons through a series of coenzymes is called **ELECTRON TRANSPORT** and the process of formation of ATP from ADP and Pi using the energy of electron transport is called as **PHOTOSYNTHETIC PHOSPHORYLATION OR PHOTOPHOSPHORYLATION**.



Phloem Loading and Unloading in Plants

Translocation of organic solutes such as **sucrose** (i.e. photosynthetic) takes place through sieve tube elements of phloem from **supply end** (or source) to **consumption end** (or sink).

But, before this translocation of sugars could proceed, the soluble sugars must be transferred from mesophyll cells to sieve tube elements of the respective leaves.

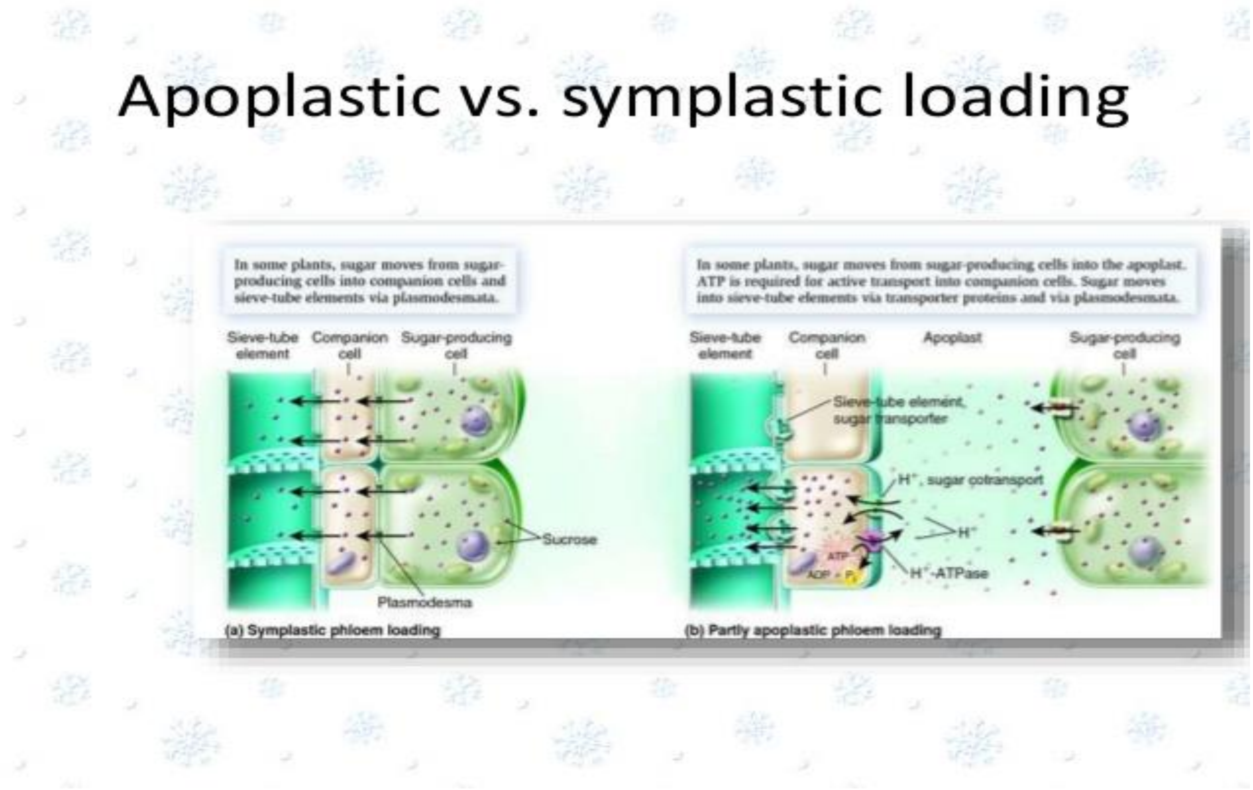
This **transfer** of sugars (photosynthetic) from **mesophyll cells** to **sieve tube** elements in the leaf is called as **phloem loading.**

On the other hand, the transfer of sugars (photosynthetic) from sieve tube elements to the receiver cells of consumption end (i.e., sink organs) is called as **phloem unloading.**

Both are **energy** requiring processes.

As a result of photosynthesis, the sugars such as **sucrose** produced in mesophyll cells move to the sieve tubes of smallest veins of the leaf either directly or through only 2-3 cells depending upon the leaf anatomy. Consequently, the concentration of sugars increases in sieve tubes in comparison to the surrounding mesophyll cells.

The movement of sugars from mesophyll cells to sieve tubes of phloem may occur either through **symplast** (i.e., cell to cell through plasmodesmata, remaining in the cytoplasm) or the sugars may enter the **apoplast** (i.e., cell walls outside the protoplasts) at some point en route to phloem sieve tubes.



Apoplast movement---In this process, sugars are actively loaded from apoplast to sieve tubes by an energy driven transport located in the plasma membrane of these cells.

The mechanism of phloem loading in such case has been called as **sucrose-H^+ symport or cotransport mechanism.**

According to this mechanism -----protons (H^+) are pumped out through the plasma membrane using the energy from **ATP** and an **ATPase** carrier enzyme, so that concentration of **H^+** becomes higher outside (in the apoplast) than inside the cell.

Spontaneous tendency toward equilibrium causes protons to diffuse back into the cytoplasm through plasma membrane coupled with transport of sucrose from apoplast to cytoplasm through sucrose -H^+ symporter located in the plasma membrane.

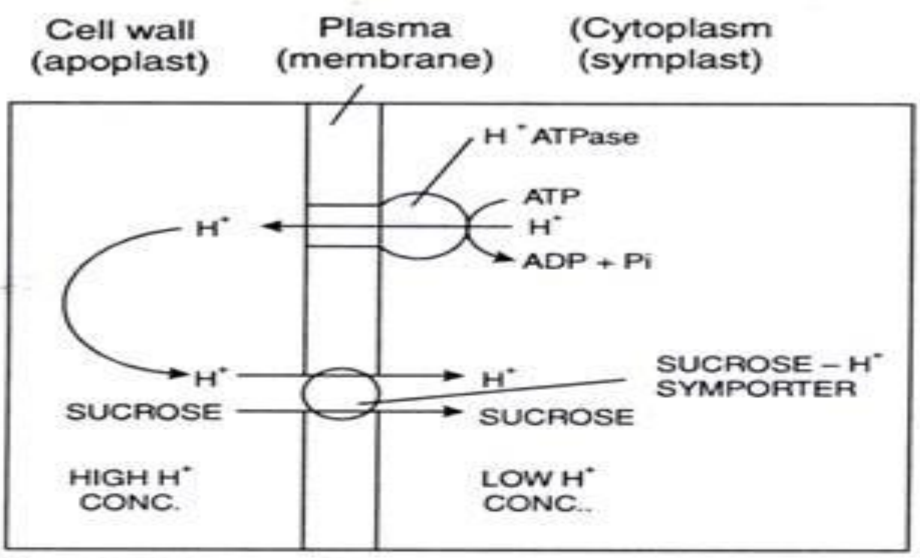


Fig. 15.5. Sucrose –H^+ symport or cotransport mechanism.

The mechanism of the transfer of sugars (sucrose) from mesophyll cells to apoplast is however, not known.

Phloem loading is specific and selective for transport sugars. Both symplastic and apoplastic pathways of phloem loading are used in plants but in different species.

In some species however, phloem loading may occur through both the pathways in the same sieve tube element or in different sieve tube elements of the same vein or in sieve tubes in veins of different sizes.

Table 15.1 Patterns in apoplastic and symplastic phloem loading.

	Apoplastic loading	Symplastic loading
Type of sugar transported	Sucrose	Sucrose + other oligosaccharides
Type of companion cells in the small veins	Ordinary or transfer cells	Intermediary cells
Number of plasmodesmata connecting the sieve tubes (including companion cells) to surrounding cells	Fewer	Abundant

Phloem Unloading:

It occurs in the consumption end or sinks organs (such as developing roots, tubers, reproductive structures etc.)

Sugars move from sieve tubes to receiver cells in the sink involving following steps:

(i) Sieve element unloading:

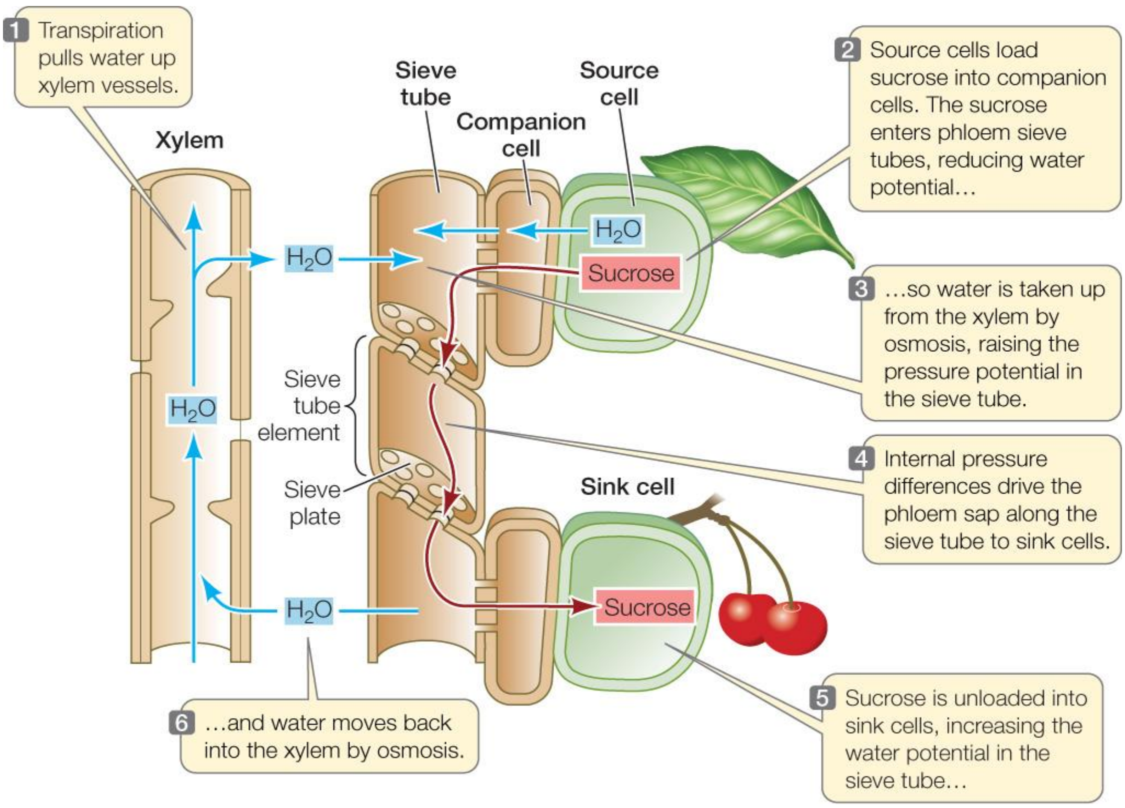
In this process, sugars (imported from the source) leave sieve elements of sink tissues.

(ii) Short distance transport:

The sugars are now transported to cells in sink by a short distance pathway which has also been called as **post-sieve element transport.**

(iii) Storage and metabolism:

Finally, sugars are stored or metabolized in the cells of the sink.



Photorespiration
Or
C2 Cycle
Or
Photosynthetic Carbon Oxidation Cycle (PCO-Cycle)
Or
Glycolytic Metabolism Cycle

The excessive respiration that takes place in green cells in the presence of light is called as **photorespiration.**

Decker (1955) discovered the process and it is also called as **C_2 cycle** as the 2 carbon compound **glycolic acid** acts as the substrate in photorespiration.

In general, respiration takes place under both light and dark conditions. However in some plants, the respiration is more in light than in dark. It is 3-5 times higher than the rate of respiration in dark.

Photorespiration is carried out only in the presence of light. But the normal respiration is not light dependent and it is called dark respiration.

In photorespiration, temperature and oxygen concentration play an important role. Photorespiration is very high when the temperature is between 25 and 30 ºC. The rate of photorespiration increases with the increase in the concentration of oxygen.

Three cell organelles namely ***chloroplast, peroxisome and mitochondria*** are involved in the photorespiration. This kind of respiration is seen in plants like cotton, pulses, capsicum, peas, tomato, petunia soybean, wheat, oats, paddy, chlorella etc and it is absent in grasses.

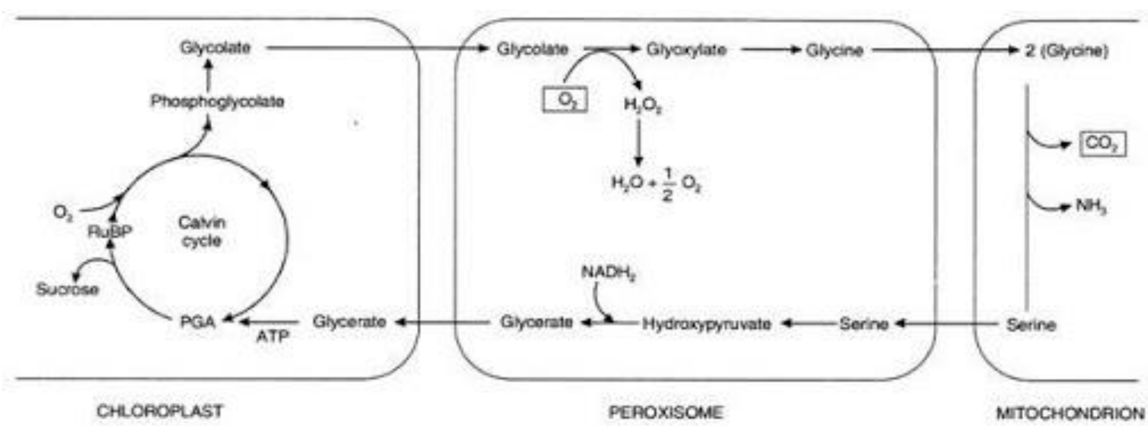
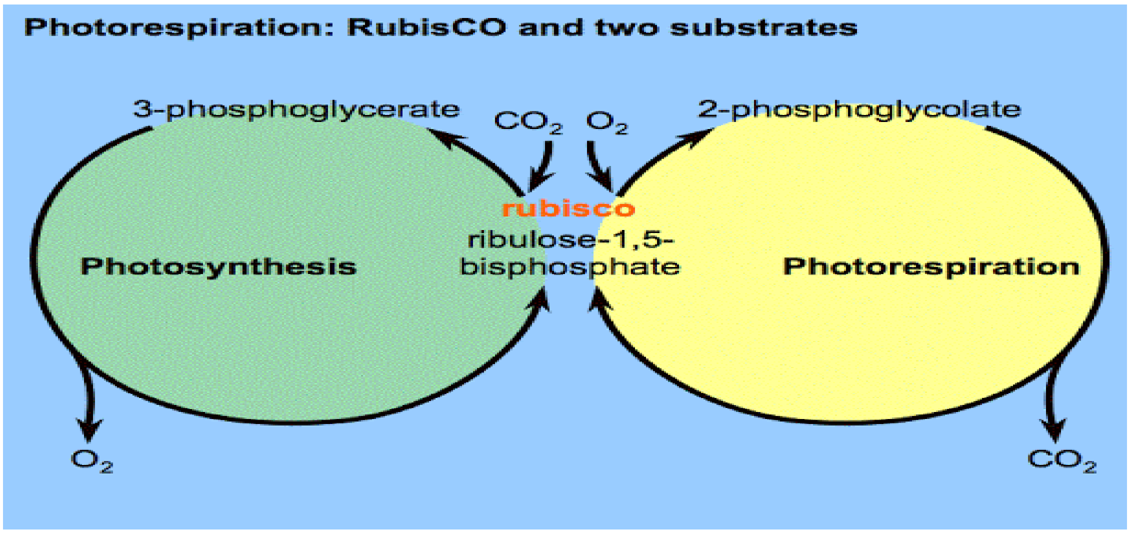


Fig. 11.26. Glycolate metabolism during photorespiration (see text for details).

Mechanism

1. In the presence of excess oxygen and low CO_2 , ribulose 1,5 diphosphate (RuBP) produced in the chloroplast during photosynthesis is split into **2 phospho glycolic** acid and **3 phospho glyceric** acid by the enzyme**, (Rubisco) ribulose 1,5 diphosphate oxygenase.**



2. The 3 phospho glyceric acid enters the Calvin cycle.

3. In the next step, phosphate group is removed from **2 phosphoglycolic acid** to produce **glycolic acid (Glycolate)** by the enzyme, **phosphatase.**

4. Glycolic acid then it come out of chloroplast and enter the peroxisome.

Here, it combines with **oxygen** to form **glyoxylic acid (Glycoxlate)** and hydrogen peroxide. This reaction is catalyzed by the enzyme, **glycolic acid oxidase**.

Hydrogen peroxide (**H_2O_2)** is toxic and it is broken down into **water and oxygen** by the enzyme, **Catalase.**

Photorespiration is an oxidation process. In this process, **glycolic acid** is converted into **carbohydrate** and **CO_2** is released as the by product.

As glycolic acid is oxidized in photorespiration, it is also called as **glycolate metabolism**.

5. The **glyoxylic acid** converted into **glycine** by the addition of **one amino group** with the help of the enzyme, **amino transferase.**

Now, the glycine is transported from the **peroxisome** into the **mitochondria.**

6. In the mitochondria, two molecules of glycine condense to **form serine** and liberate carbon dioxide and ammonia.

7. Amino group is removed from serine to form hydroxyl pyruvic acid in the presence of the enzyme, transaminase.

8. **Hydroxy pyruvic acid** undergoes reduction with the help of NADH to form **glyceric acid** in the presence of enzyme **alpha hydroxyl acid reductase.**

9. Finally, regeneration of **3 phosphoglyceric acid** occurs by the phosphorylation of glyceric acid with **ATP.** This reaction is catalyzed by the enzyme, **Kinase.**

10. The **3 phosphoglyceric acid** is an intermediate product of Calvin cycle.

If it enters the chloroplast, it is converted into carbohydrate by photosynthesis.

Thus, starting from intermediates of Calvin cycle with the synthesis of glycolate, serine is formed which is agin converted into intermediates of Calvin cycle and completing the glycolate cycle.

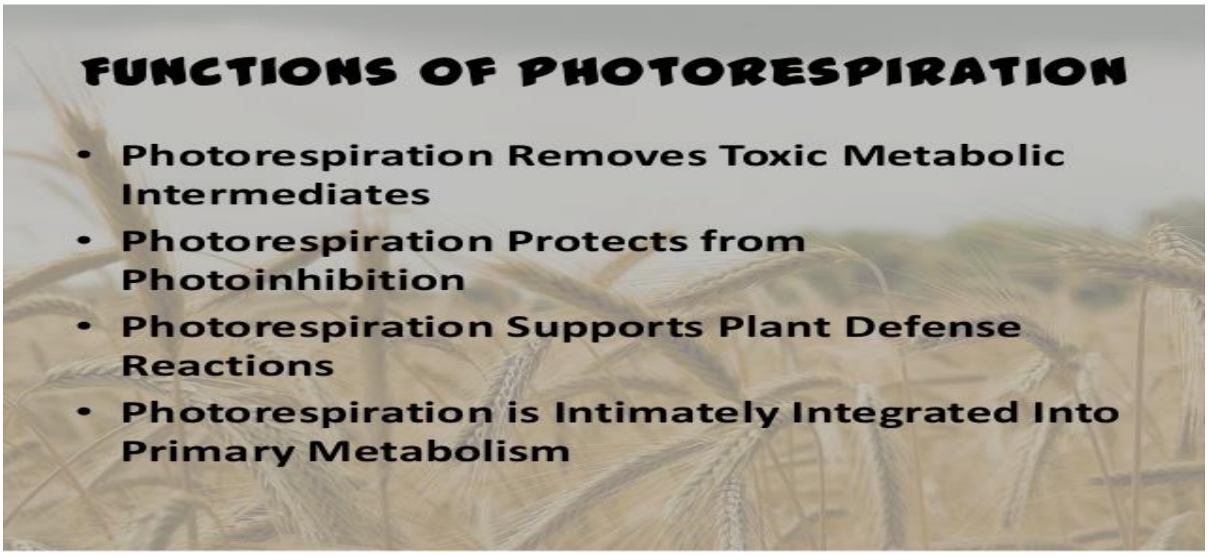
Significance of photorespiration

1. Photorespiration helps in classifying the plants, Generally, photorespiration is found in C_3 plants and absent in C_4 plants.

2. Carbon dioxide is evolved during the process and it prevents the total depletion of CO2 in the vicinity of chloroplasts

3. Photorespiration uses energy in the form of ATP and reduced nucleotides, but normal respiration yields ATP and reduced nucleotides.

4. It is believed that photorespiration was common in earlier days when CO2 content was too low to allow higher rates.



Anil Kumar Dogra

Assistant Professor (Botany)

Red Drop and Emerson's Enhancement Effect

Robert Emerson noticed a sharp decrease in quantum yield at wavelength greater than **680 nm**, while determining the quantum yield of photosynthesis in **Chlorella** using monochromatic light of different wavelengths. Since this decrease in quantum yield took place in the red part of the spectrum, the phenomenon was called as **Red Drop.**

Later, they found that the inefficient far-red light beyond 680 nm could be made fully efficient if supplemented with light of **shorter wavelength.** The quantum yield from the **two** combined beams of light was found to be **greater than** the sum effects of both beams used separately. This enhancement of photosynthesis is called as **Emerson's Enhancement.**

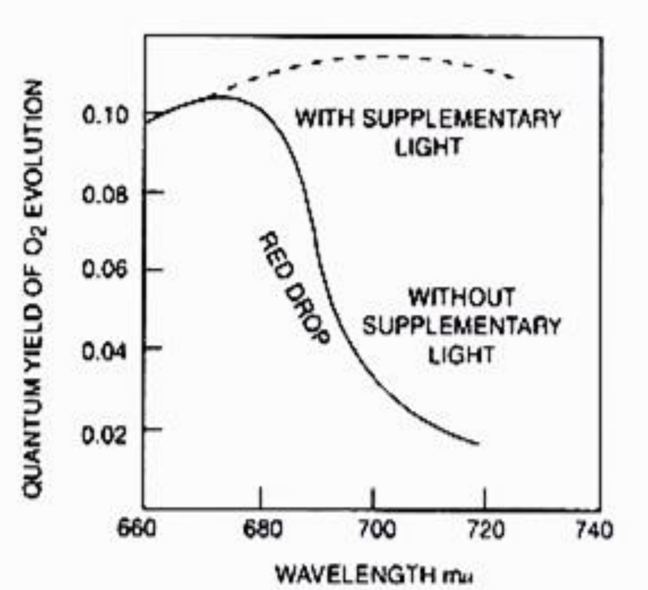


Fig. 6.6 Red drop effect and Emerson's enhance ment effect.

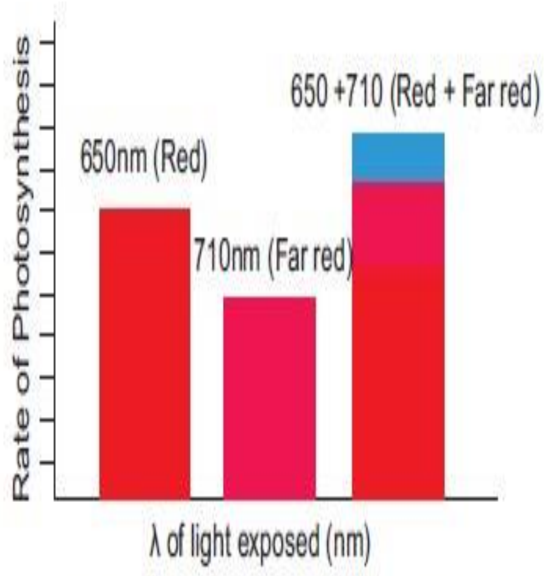
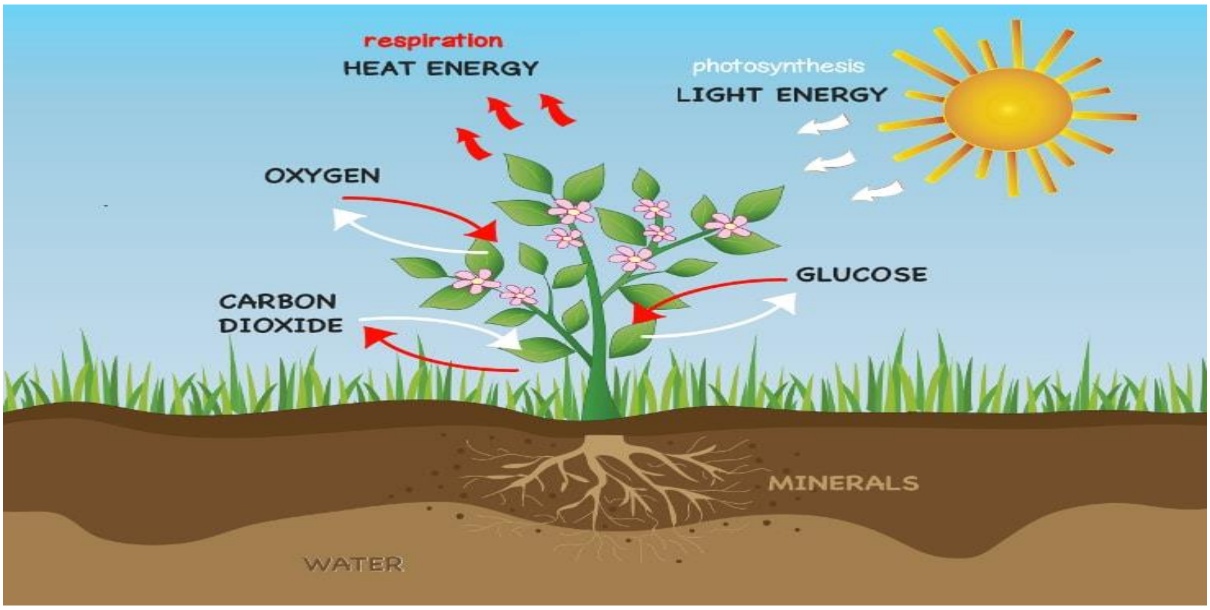


Figure 13.9: Emerson's Enhancement Effect

RESPIRATION IN PLANTS



The cellular oxidation or break down of carbohydrates into CO_2 and H_2O and release of energy is called as **respiration.**

It is a **reverse** process of photosynthesis.

In respiration, the oxidation of various organic food substances like **carbohydrates, fats, proteins** etc, may take place. Among these, **glucose** is the commonest.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy (686 kcal)}$$

This oxidation process in not so **simple** and does not take place in one step. Breakdown of glucose involves many steps releasing energy in the form of **ATP** molecules and also forming a number of carbon compounds (intermediates).

Respiration is a vital process that occurs in all living cells of the plant and the most actively respiring regions are floral buds, vegetative buds, germinating seedlings, stem and root apices.

Types of Respiration

Degradation of organic food for the purpose of releasing energy can occur with or without the participation of oxygen.

Hence, respiration can be classified into two types:

1. Aerobic Respiration

2. Anaerobic Respiration

1. Aerobic Respiration

Aerobic respiration takes place in the presence of **oxygen** and the respiratory substrate gets completely oxidized to carbon dioxide and water as end products.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy (686 kcal)}$$

Glucose

2. Anaerobic Respiration

It takes place in the absence of **oxygen** and the respiratory substrate is incompletely oxidized. Some other compounds are also formed in addition to carbon dioxide. This type of respiration is of rare occurrence but, common among microorganisms like yeasts.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 56 \text{ kcal}$$

Glucose Ethanol

Respiratory Substrate

A respiratory substrate is an organic substance which can be degraded to produce energy which is required for various activities of the cell. The respiratory substrates include **carbohydrates, fats, organic acids, protein** etc.

Carbohydrates: The carbohydrates constitute the most important respiratory substrate and the common amongst them are starch, sucrose, glucose and fructose. The complex carbohydrates are first hydrolyzed to simple sugars and then they are utilized.

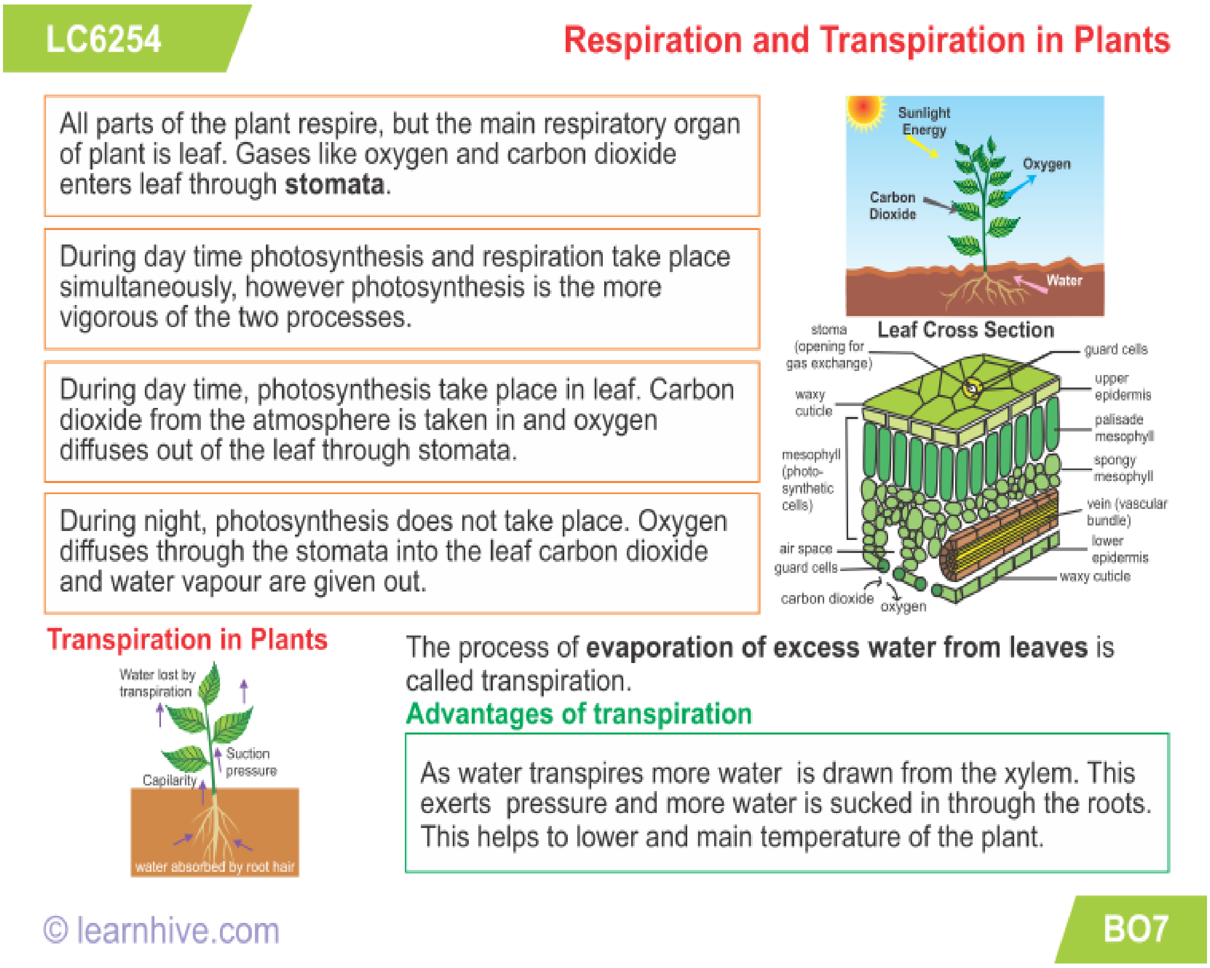
$$\text{Starch} \rightarrow \text{Disaccharides} \rightarrow \text{Hexoses}$$

Fats: The fats are important storage food in seeds. Nearly 80 per cent of the angiosperms have fats as the main storage food in their seeds. At the time of seed germination, large amount of fats are converted into carbohydrates while the remaining fats are utilized in respiration.

Fats are first broken down to **glycerol** and **fatty acids**. The fatty acids are broken down to **acetyl coenzyme** by **β-oxidation**. The acetyl coenzyme enters **Kreb's cycle** for further degradation and releases energy. Glycerol can directly enter the respiratory channel via glyceraldehyde.

Organic acids: Organic acids normally do not accumulate in plants to any appreciable extent except in the members of the family, Crassulaceae. Organic acids are oxidized under aerobic conditions to carbon dioxide and water.

Proteins: Under normal conditions, proteins are used up as respiratory substrate only in seeds rich in storage proteins. In vegetative tissues, proteins are consumed only under starvation. The proteins are hydrolyzed to form amino acids. Later, the amino acids undergo deamination forming organic acids and the organic acids can enter Kreb’s cycle directly.



Mechanism of Respiration

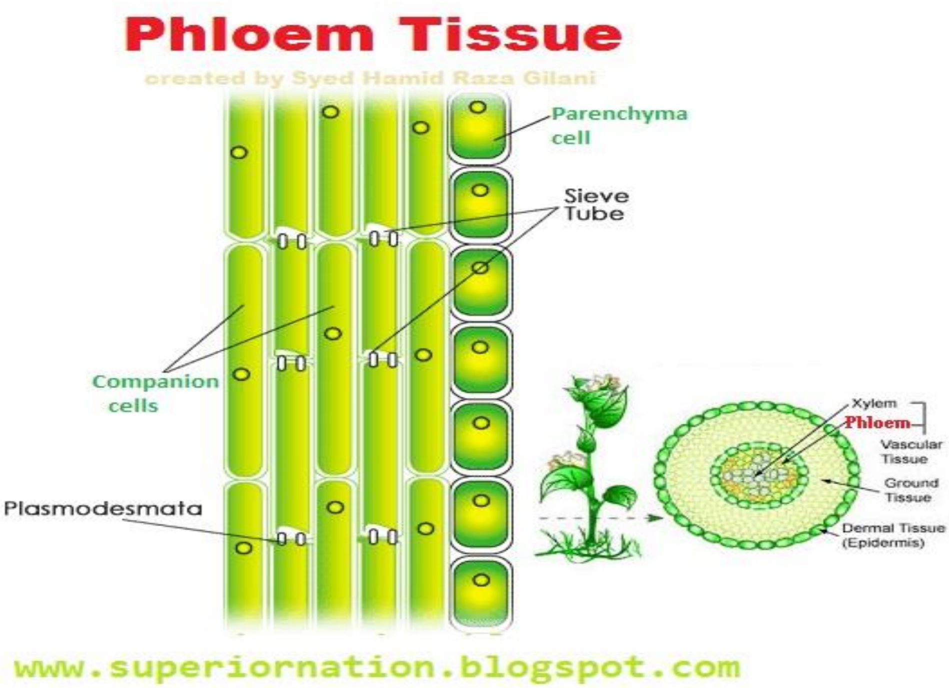
1. Glycolysis

2. Aerobic breakdown of pyruvic acid (Kreb’s cycle)

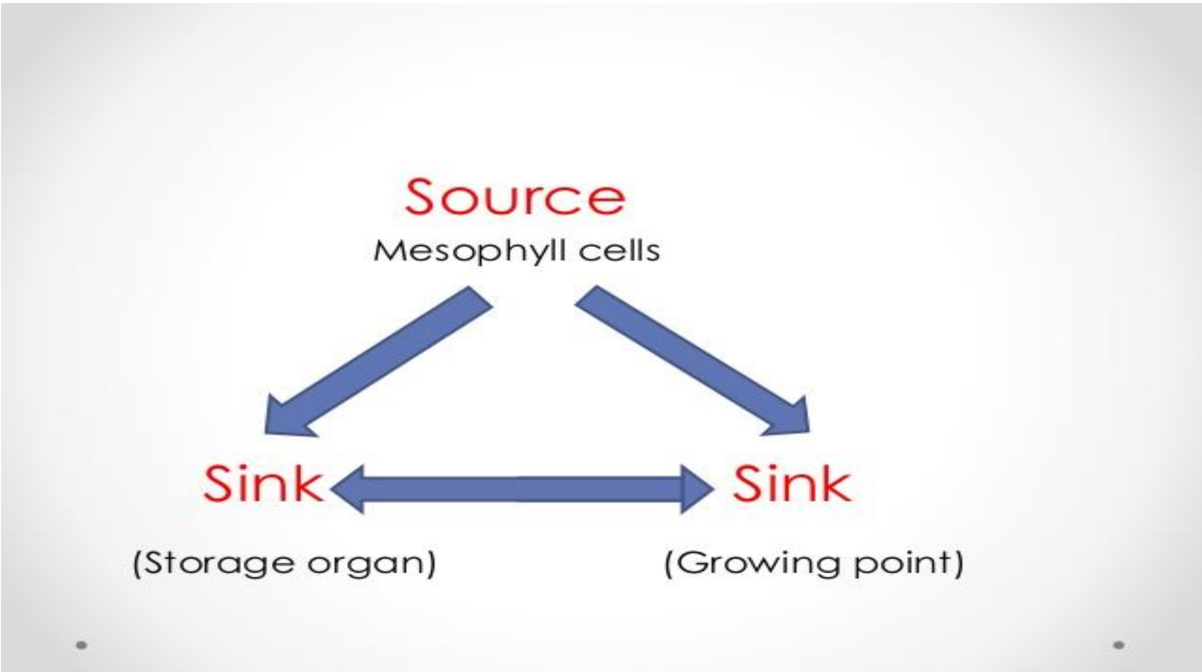
3. Electron Transport System/ Terminal oxidation / oxidative phosphorylation

4. Pentose phosphate pathway.

Translocation in Phloem: Girdling Experiment and Pressure Flow Model



Translocation in phloem is the long distance movement of organic substances from the source or supply end (region of manufacture or storage) to the region of utilization or sink. But the source and sink may be reversed depending on the season or need of the plants.



Sugar stored in roots may be mobilised to become a source of food in the early spring when the buds of trees act as **sink** and require energy for their growth and development. Since the source-sink relationship is variable, the direction of movement of organic solutes in phloem can be upwards or downwards i.e., bidirectional.

Directions of Translocation of Organic Solutes:

Translocation of organic solutes can occur in the following directions:

1. Downward Translocation:

It is the most common mode of translocation. The leaves manufacture food in excess of their own requirement. The excess food comes out of leaves and is trans-located in the downward direction to stem (for storage, metabolism, maintenance of its cells and secondary growth, if any) and root system (for storage, growth, metabolism and maintenance).

2. Upward Translocation:

In deciduous plants renewal of growth and development of new foliage are dependent upon upward transport of food from reserves present in the roots and stems. Growth of the stem apices, formation of flowers, fruits, etc. require the movement of assimilates from leaves in an upward direction.

3. Lateral Translocation:

It is little except when source and sink lie on the opposite sides.

4. Bidirectional Translocation:

Rabideau and Burr (1945) found that labelled carbohydrates moved out of the leaves in both upward and downward directions. The two types of translocation are believed by many workers to occur in different sieve tubes.

Pathway of Translocation:

The most common organic nutrient trans-located in plants is **sucrose.** The channels of transport are sieve tubes (in flowering plants) and sieve cells (in non-flowering vascular plants) of phloem. It was proved for the first time by **Czapek (1897).**

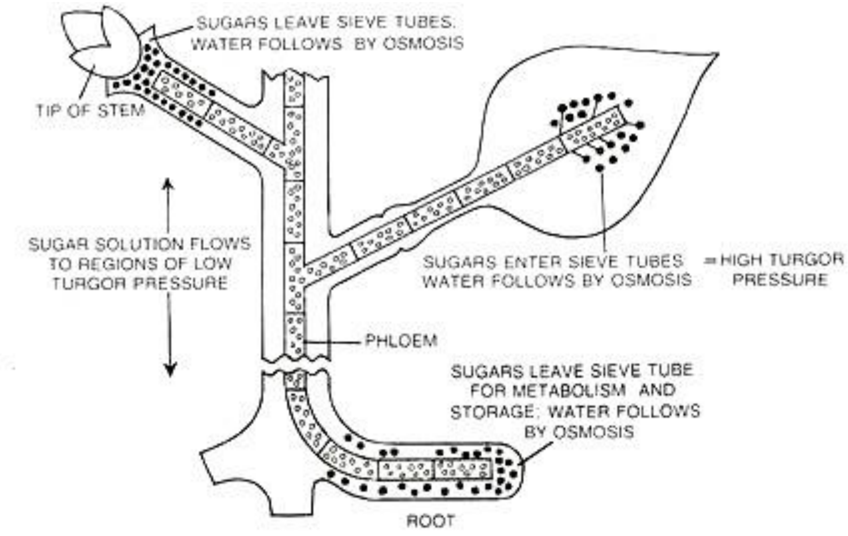


Fig. 11.41. Pathway and mechanism of phloem translocation.

The evidences are as follows:

1. There are only two paths for long distance translocation, tracheary elements and sieve tubes. The former are dead while the latter are living. Translocation of organic solutes seems to be through sieve tubes because it is inhibited by steam girdling which kills living cells.

Girdling or Ringing Experiment

2. In girdling or ringing experiment, a **ring of bark** is **cut** from the stem. It also removes **phloem.** Nutrients collect above the ring where the bark also swells up and may give rise to adventitious roots. Growth is also vigorous above the ring.

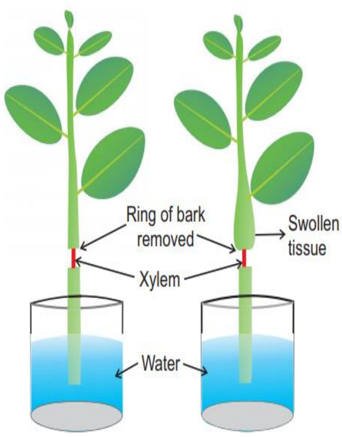


Figure 11.20: Ringing experiment

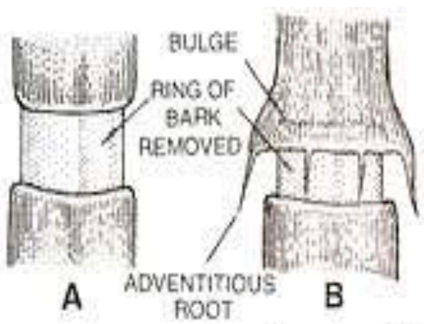


Fig. 11.40. Girdling of tree trunk to show that organic nutrients accumulate in the bark above the girdle where a bulge is also produced.

The tissues below the ring not only show stoppage of growth but also begin to shrivel (Roots can be starved and killed if the ring is not healed after some time. Killing of roots shall kill the whole plant, clearly showing that bark or phloem is involved in the movement of organic solutes which occurs in one direction, i.e., towards root.

Girdling experiments are performed in fruit trees to make more food available to fruits. However, the rings are kept narrow and cambium is not touched so that the incision heals up after some time.

(Girdling experiments cannot be carried out in monocots and dicots with bi-collateral bundles because of the absence of a single strip of phloem).

Mechanism of Phloem Translocation:

Several theories have been put forward to explain the mechanism of translocation of organic nutrients through the phloem e.g., diffusion, activated diffusion, protoplasmic streaming, interfacial flow, elect osmosis, trans cellular strands, contractile proteins, mass flow.

Mass flow hypothesis is the most accepted one.

Mass Flow or Pressure Flow Hypothesis:

It was put forward by **Munch (1927, 1930).** According to this hypothesis, organic substances move from the region of **high osmotic pressure** to the the **region of low osmotic pressure** in a mass flow due to the development of a gradient of turgor pressure.

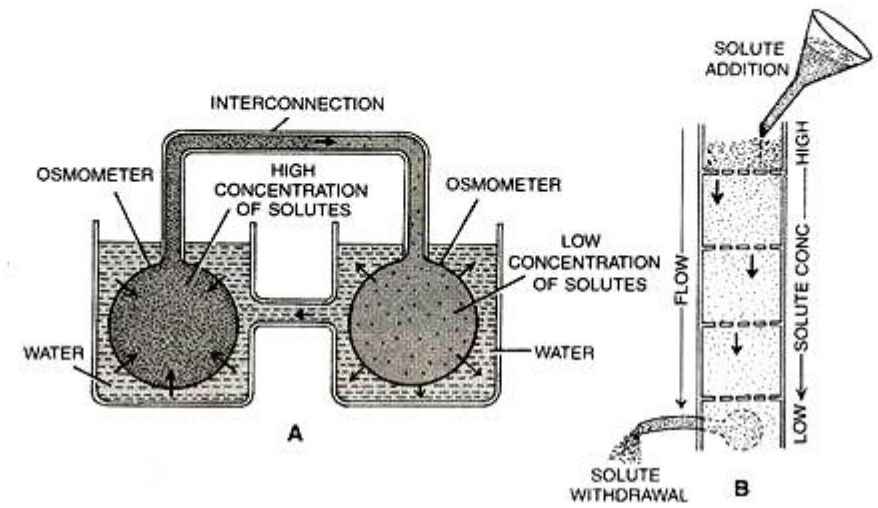


Fig. 11.42. A, mass flow or pressure flow of fluids from high to lower osmotic or turgor pressure. B, diagrammatic representation of continuous flow of solutes in one direction.

This can be proved by taking two interconnected osmometers, one with high solute concentration and the other with little osmotic concentration.

The two osmometers of the apparatus are placed in water. More water enters the osmometer having high solute concentration as compared to the other.

It will, therefore, come to have high turgor pressure which forces the solution to pass into the second osmometer by a mass flow.

If the solutes are replenished in the donor osmometer and immobilised in the recipient osmometer, the mass flow can be maintained indefinitely.

Sieve tube system is fully adapted to mass flow of solutes. Here the vacuoles are fully permeable because of the absence of tonoplast. A continuous high osmotic concentration is present in the source or supply region, e.g., mesophyll cells (due to photosynthesis).

The organic substances present in them are passed into the sieve tubes through their companion cells by an active process.

A high osmotic concentration, therefore, develops in the sieve tubes of the source. The sieve tubes absorb water from the surrounding xylem and develop a high turgor pressure.

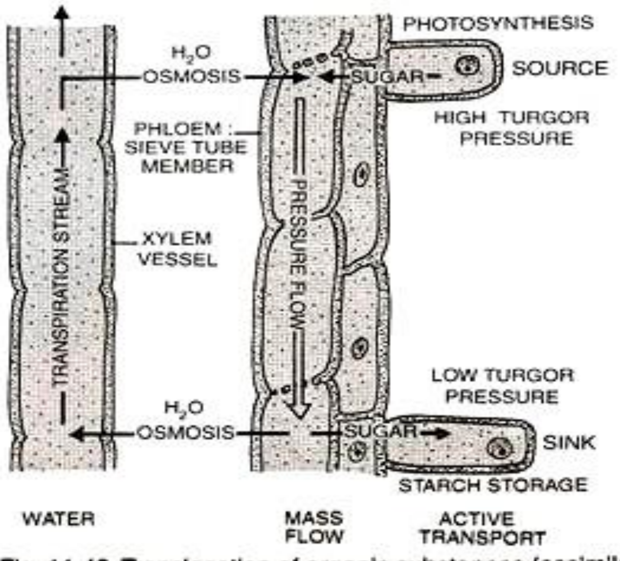


Fig. 11.43. Translocation of organic substances (assimilates) according to mass flow or pressure flow hypothesis.

It causes the flow of organic solution towards the area of low turgor pressure. A low turgor pressure is maintained in the sink region by converting soluble organic substances into insoluble form. Water passes back into xylem.

WATER POTENTIAL

INTRODUCTION OF WATER POTENTIAL

Most organisms are comprised of at least 70% or more water. Some plants, like a head of lettuce, are made up of nearly 95% water. When organisms go dormant, they loose most of their water.

For example, seeds and buds are typically less than 10% water, as are desiccated rotifers, nematodes and yeast cells. Earth is the water planet (that's why astronomers get so excited about finding water in space). Water is the limiting resource for crop productivity in most agricultural systems

LEARN MORE ABOUT WATER POTENTIAL • In general, water always moves down its water potential gradient from areas of higher water potential to areas of lower water potential.

- Water potential is typically measured as the amount of pressure needed to stop the movement of water.
- The unit used to express this pressure is the megapascal (MPa). The three factors that most commonly determine water potential are

WHAT IS WATER POTENTIAL?

Water potential is the potential energy of water relative to pure free water (e.g. deionized water) in reference conditions. It quantifies the tendency of water to move from one area to another due to osmosis, gravity, mechanical pressure, or matrix effects including surface tension.

Water potential is measured in units of pressure and is commonly represented by the Greek letter (Psi).

This concept has proved especially useful in understanding water movement within plants, animals, and soil.