Plant Physiology

Unit: One Introduction

1.1 The science of plant physiology

Green plants in general and higher vascular plants in particular have played a very crucial role in existence and survival of mankind on land. Human life as we know it perhaps would have been impossible but for plant; because, the three basic necessities of life namely food, shelter, and clothing is provided by plants. They supply O_2, we breathe in,
Obtain fibres: Clothing
Forage for livestock
Wood for shelter and furnishing and medicines to alleviate our elements.
Besides these, many items used in everyday life such as paper, rubber, oils, species

- Non-alcoholic beverages: Tea, Coffee, Cocoa and
- Alcoholic beverages: Wine, beer, whisky, and vodka.

In fact, we are completely and absolutely dependent on higher vascular plants. Thus in order to beneficial from plant life makes imperative that a through knowledge of their growth, development and function is necessary. It is this knowledge that can help us to make attempt towards improvement of plant life. Thus, the branch of Botany that deals with various functional aspects of plants is called plant physiology. It is concerned with the process & functions and also responses of plants to their environment, namely growth, development and reproduction.
The processes studied in plant physiology are
Photosynthesis, respiration, transpiration, growth and development, reproduction
To summaries the following are the main objectives of plant physiology:

- To describe and explain the function of various level of organization,
- To explain the function of chemical constituents present in plants,
- To explain the effect of environment as process and function in plant,
- To emphasis the interrelationship and interdependence on various process and function so as to understand life process group in plant.

Plant physiology as a science

The science of plant physiology is concerned with the study of life processes and functions (at molecular, cell, tissue organ and organism level), the response of plants to changes in the environment, and growth and development that result from responses.
Process means natural containing sequence of events for example: photosynthesis, respiration, ion absorption, translocation, stomatal opening & closing, assimilation, transpiration flowing and frurting . So, to describe and explain the process is 1st taple of photosynthesis

2. Functions: refers to natural activity of things, whether, cell, tissue, organ, chemical substance.
2. To describe and explain the function or each lemid of cell, tissue, organ

Because the processes and functions are dependent and modified response to external environment such as light, temperature. The 3rd importance of plant physiology is to describe and explain how process and functions response to change in environment. The overall goal of plant physiology is to elevate the detailed and comprehensive knowledge of all natural phenomenon that in living plant and to the nature of growth, development and movement.

In order to realize the above objective, plant physiology describe the help from physics, chemistry, math and statistics. In fact the role of physical science is greater in plant physiology than biological science. It has helped in unraveling the secrets of many important physiological processes in plants.

It is realized that process and function can't be understood properly unless something is known about structure; therefore the knowledge of plant anatomy seems essential.

Tools and technique used in plant physiology:

Traditionally used physics, chemistry, anatomy as well as many-sophisticated technique such as chromatography, E.M. Scanning electrophoresis, Tracer techniques, spectrophotometer, man spectroscopy, radioactive tracer technique.

The study of plant physiology is necessary only from theoretical point of view (to understand the basic functions un plant) but also from point of view to understand the application of knowledge if plant physiology for human welfare in agronomy, horticulture, forestry, floriculture, plant breeding, plant pathology, and pharmacology are source of the applied fields.

Mechanism of opening and closing of stomata

The opening and closing of stomata depend upon the turgid and flaccid state of guard cell.

- If guard cell is turgid, stomata is open.
- If guard cell is flaccid, stomata are closed.

The turgidity of guard cell is due to radiation in osmotic pressure of guard cell. When osmotic pressure of guard cell is higher than epidermal cell endosmosis take place and guard cell become turgid leading to the opening of stomata. When osmotic pressure of guard cell become lower than that of adjoining cells, there is exosmosis of guard cell thus making guard cell flaccid; as a result stomata closes.

The variation in osmotic of guard cell is discussed by different workers:

1. Starch Sugar interconverson theory (Lioyd: 1908)

Active to this theory,

Amount of starch high in darkness (night) while low in day (Light).

The reverse is true for sugar content of guard cell. The starch-sugar interconversion is responsible for opening & closing of stomata.

Sayer (1926: Change in P^H of the medium in guard cell decides interconverson of starch sugar.)

If P^H high – stomata open and take place in light.

If P^H low – stomata closes and decrease in night.

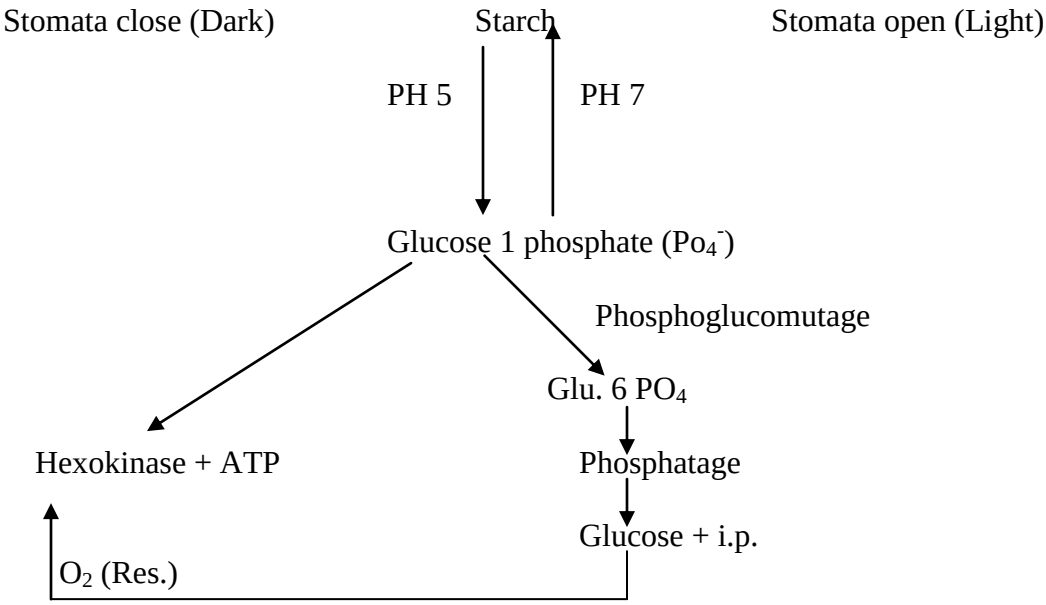
Actually during daytime utilization of Co_2 during photosynthesis increases P^H resulting in conversion of starch-sugar as osmotically active.

In dark Co_2 accumulated in intercellular spaces (due to photosynthesis) and increases H^+ and decreases P^H promoting conversion of sugar into starch.

Yuing Tun (1948) & Willis (1954) : observed

$$\text{Starch} + \text{i.p.} \xrightarrow{P^H\ 7\ \text{Light}} \text{Glucose 1 Po}_4 \xrightarrow[\text{ATP}]{P^H\ 5} \text{Starch}$$

Scheme



Objections

- ❖ Monocots don't have starch in guard cell.
- ❖ There is no evidences to show presence of sugar in time when starch disappear when stomata closes.
- ❖ Often stomata close in midday without any change in starch content.
- ❖ Energy is evolved during closing of stomata but doesn't require for opening.

2. Active K^+ Transport Mechanism (Fujino, 1959, 1967)

When leg is exposed to light Malic acid appear in guard cell.

This malic acid Dissociated → Malate $^-$

H^+ Exchange K^+ i.e.

H+ leave the guard cell and K+ inter the guard cell. This malation → Potassium malate & enter the racuose of guard cell.

In presence of K malali in guard cell water from the epidermal cell enter in guard cell & turgid pressure increases and stomata open.

i.e. Light → formation of malic acid in guard cell → Dissociation of malic acid → $Malate^-$ + H^+

❖ Influx of K+ & Eflux of H+ ⟶ formation of potassium malate in vacuole ⟶ Endosmosis of H2O take place in guard cell ⟶ increase turgid pressure ⟶ stomata open.

The closer of stomata believe to be caused by the passive movement of K+ from guard cell into epidermal cell i.e., active reabsorption of K+ into epidermal cell by Zeigher & Raseloke.

4.1 Mechanism of Ascent of Sap

The various theories have been put forwarded to explain the mechanism of Sap in plants. These are broadly divided under:

4.1.1 Vital force theory: According to this theory, xylem through it happen to be the path of ascent of sap doesn't play role, instead living cells of stem with their vital energy play important role in ascent of sap. The supporters of this theory are as follows.

(a) **Westermeir (1884):** Opinion that the force for upward conduction of water is provided by xylem parenchyma cells the tracheids & vessels simply acts as a water reservoir.

(b) **Goldlewsky (1883):** According to him, the upward movement of water was due to the pumping activity of cells of parenchyma and medullary rays and brought about by periodic change in their osmotic pressure.

He assumed that xylem parenchyma cell absorb water from xylem vessel due to their high osmotic pressure in lower region. The water rises upwardly in parenchymatous cells due to the air pressure. However towards upper end, the osmotic pressure of living cells decreases and water lost to xylem vessel. The same water is now picked up by upper parenchyma cell to repeat the cycle. Thus there is a rhythmic change of osmotic pressure in vasculature between vessel, parenchyma and medullary rays.

(c) **Pulsation theory of Bose (J.C. Bose 1887**): Opened that is a constant pulsatory activity by the enner most cortical cells just outside the endodermis. He believed that these cortical cells absorb water from outside and pump the same into the vessel. The alternating contraction and expansion of these cells forces water into xylem. To prove it he invented an instrument called cresograph, which consists of electric probe connected to Galvanometer. When a fine needle of probe was pierced in to the cortex there was minor oscillation.

When the probe reached in inner cortical cell the oscillation of galvanometer indicator become violent and continuous.

Bose believed that these cells expand when they absorb water from outer cortical cells and after passing the water into xylem they contracted.

Bose theory was supported by Molisch (1929) observed electric activity of inner cortical cells increased when treated with certain chemicals.

Objection: Shull, Mae Dognal and other believed that pulsation activity of inner cortical cells has no relation to ascent of Sap became in order to account for rate of ascent of Sap pulsation rate must be higher than what is demonstrated by Bose.

❖ Benediots (1927) showed rate of ascent of water is 8000 to 30,000 time higher than pulsation rate as shown by Bose.

❖ Strass bergor (1891) demonstrated that living cells are not responsible for ascent of Sap. To prove it he kept a base of 75 yrs old Oak tree in picric acid (poisonous to cell). Picric acid slowly ascended and killed the living cells on its way. Further Eosine dye added to picric acid Eosine also reached to top of the plant showing that living cells are no more responsible for ascent of Sap.

2. **Root Pressure Theory**: It was first observed by Josheph priestly and explained by Stephen Hales (1927). He attached a cut end of stump with rubber tube and noticed rise of water up to 6ft. This is due

to the pressure built up by accumulated water. The water absorbed by root reach to endodermis via cortex, where it meets resistance for its smooth flow. As the water continues to be absorbed, a hydrostatic pressure is built up which forces water into xylem resulting it in upward flow. This is called root pressure. Root pressure can be defined as the positive hydrostatic pressure built up by water in the outer boundary of stele due to continuous absorption of water. Stephen Hales observed a pressure of 1 atmos in root (= 10 ft).

The phenomenon of root pressure may be demonstrated by attaching mercury manometer to cut end of stump within a short time level of Hg rises indicating upward movement of Sap due to root pressure.

Factors affecting root pressure – Respiratory poison and depleted oxygen supply affect root pressure inhibiting the supply of biological energy.

Root pressure phenomenon is concerned with metabolic activity of cells. Inhibition of carbohydrates metabolism and obstruction of mineral salt absorption also known to affect root pressure. These factors largely affect energy supply through respiration rather than affecting the permeability of protoplasm.

In view of stocking (1956) root pressure is an active process and defined a pressure developing in tracheary elements of xylem as a result of metabolic activities of root.

Objection: Root pressure is not a universal phenomenon but ascent of Sap is. In Gymnosperm, which includes some tallest plant, ascent of Sap is high but little or no root pressure is observed.

- ❖ Ascent of Sap is continuing even in absence of root.
- ❖ Magnitude of root pressure is not sufficient to account for ascent of Sap in such tallest tree like Eucalyptus and Sequaia.
- ❖ An important objection delink root pressure and ascent of sap is that the latter can takes place even in absence of living cells while root pressure is a active process linked by supply of energy.

3. **Atmospheric Pressure Theory**: The fact that xylem is vertically elongated and water rises up in tube made people to think that atmospheric pressure is responsible for upward movement of water. But water move up in xylem vessel to fill up the drop in atmospheric pressure caused due to loss of water during transpiration i.e., water rises up in xylem vessel to fill up the gap in pressure provided atmospheric pressure act on water from below.

Objection:

- ❖ For operation of atmospheric pressure the lower end of column should be free. But this is not occur in plant, xylem element don't directly open into soil water.
- ❖ There is not vacuum at upper end of plant, even if vacuum is created at transpiring end, the maximum height to which water can rises in just over 30 ft (10m). As no vacuum is demonstrable in plant hence maximum rise is below 10 metres.

4. **Physical force theory:**

Capillary force theory: Water rises up in narrow tube due to force of surface tension. This phenomenon is observed commonly when a straw pipe is dipped in a cann of soft drink. As the xylem vessels are narrow and comparable to the straw, Boehen (1863) urge that capillary force is responsible for Ascent of Sap.

Objection:

- ❖ Capillary force is inversely proportional to diameter, larger the diameter lower will be height to which water can rise is not applicable to all plants.
- ❖ Vessels don't have uniformity on account of various thick rings.
- ❖ Soil water is not directly connected with xylem vessel.

5. **Imbibitional Theory of Ascent of Sap:**

The wall of xylem element has hydrophilic colloids and can imbibe large quantity of water. Hence many physiologist like Sachs (1978), Unger (1868) opened that imbibitional force is responsible of Ascent of Sap. Water travel upward in the wall of the xylem vessel and trachieds by imbibition as they contains hydrophilic colloids. But the movement of water via hydrophilic colloids is very slow as they hold water very firmly. Therefore movement of water is very slow and negligible. Further water rises up through Lumen and not through wall.

However this theory was discarded as it become evidence that water can rise through the wall due to imbibitional pressure up to a certain height but it move rapidly and rise up through the lumen of xylem elements rather its wall.

6. Transpiration pull and cohesive tension theory

The model for cohesion theory of ascent of sap was developed by Henri Dixon and John Jolly a physicist and was supported by Askanasy in 1895.

The main features of this theory are as follows:

- There is continuous column of water from root through the stem in to leaf. This is called hydrostatic system.
- The leaf cells lose water in transpiration. These cells therefore with draw water from neighboring of adjacent cell due to increased DPD (i.e. the amount by which diffusion pressure of a solution is lower than that of solvent. The latter in their turn get the same water from xylem sap of leaf.
- Due to continuous with drawal of water from xylem vessel by transpiration cell (leaf). The whole water column of the plant comes to the tension or strain. This is called transpiration pull or transpiration tension. Its maximum value is about 20 Atmosphere.
- Transpiration pull/water tension produced due to transpiration is unable to break the continuity of hydrostatic is system because of strong cohesive force of water molecule through their hydrogen bounding. The water molecules also don't break its connection with xylem tube because of adhesive force between two.
- On account of tension created by transpiration water column of the plant is pulled up passively from below to the top of plant like rope.

  The cohesion theory is based upon numerous physical and biological experiments and considered to be most satisfactory theory of Ascent of sap. This together with root pressure theory can possibly account for all observations with ascent of sap.

  This theory is based upon the two remarkable properties of water cohesion and adhesion. Theoretical consideration show that cohesion force of water are very high (10,000 bar) which is high enough to support pull required to loft sap (water) in tallest tree.

Evidences in support of Dixon theory:

The phenomenon of absorption lag clearly indicates that ascent of sap follow closely the rate of transpiration and hence closely related to it.

- It is purely a physical process, which doesn't require metabolic energy. Even if required it is negligible because for hundred meter (100m) rise of one (1) ml water only 0.5calorie energy is needed.
- Osmotic pressure of mesophyll cells has been recorded up to 20 atm., which is quite sufficient for ascent of sap.
- Osmotic pressure of leaf shows diurnal variation. It is maximum in noon when the water content of leaf is minimum. Such condition indicates that it is connected with upward movement of sap water.
- Different workers have reported the value of osmotic pressure of cell sap in different plants in order of Tree>Shrubs>Herbs.

- **Objection**: The only one major objection of this theory is the variation of temperature during day and night and in vessel of longer diameter. There is a fair chance of gas bubbles interring in water column form soil or, due to pressure of dissolved gas due to cavitation.

Absorption of Mineral nutrients by plants

Beside water, mineral salts are also absorbed by plants from soil in inorganic form. Formerly it was believed that elements are taken in to the plant with water that inters via root hairs and translocated to different part due to transpiration pull. It is now known that a plant of the root that evolves in minerals absorption is not the root hair region but the region of elongation zone and cell formation zone.

As many as 60 different elements are found in plant body. Some of them are taken in gaseous form (O2, CO2) but most of them are taken from soil by root uniform of slat or ions of different salts. Some most common salts are:

Anaions: P, B, S, Cl^- etc while

Cations: K, Mg, Mn, Ca, Fe, Zn, Cu, CO.

Mechanism of Ion uptake: The absorption of water and absorption of salt takes place simultaneously and quite independent phenomenon. However like that of water absorption, absorption of solutes can take place either passively or actively.

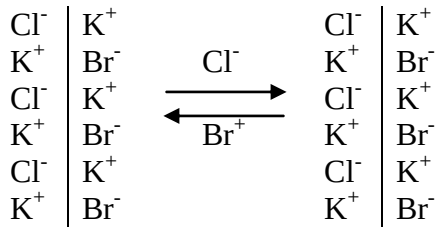
In passive absorption the solute move in to the call along their chemical potential gradient without any expenditure of metabolic energy by cell. While in active absorption movement may occur against the chemical potential gradients but requires energy.

3.2 Theories of passive absorption includes:

1. **Diffusion:** Diffusion is the movement of substances from the region of their higher concentration to the region of lower concentration. When a plant tissue that has been immersed in to the relatively concentration solution is transferred to a dilute salt solution. Some of the ions already absorbed by immersed tissue diffuse rapidly out into external solution. If the tissue id replaced into concentration salt ions will rapidly back in to the tissue. It is thus evident that diffusion of ion can occur freely between external solution and certain parts of tissue, which is caked free space. A plant root dipped in a dilute solution if transfers to concentration solution, the rate of absorption increase providing that absorption is a diffusion process.
2. **Ionic exchange theory:** According to this theory ions from the external solution in which tissue are immersed may be exchanged with the ions absorbed on surface of cell wall of root.

   Two types of ionic forms of elements are found inside the root of cell sap. Out of which cations carry +Ve and anions carry –Ve electric change. The total electric change inside root sap is balanced by total electric change of external solution. When a particular ion present outside is required to be taken inside, another ion bearing similar change has to come out to maintain the balance. This exchange of ions of equal charge between the cell and external solution is termed as ionic exchange. For example H^+ & OH^- are readily available from water and are always remain

absorbed on the surface cell membrane of root. Thus K^+ may exchange with H^+ and Cl^- may exchange with OH^- of Br^- i.e. one cations (+ve) exchange with another cation & is called cationic exchange and one anion exchange another anion is called anionic exchange



3. **Mass flow**: According to this theory Ions are taken up by root along with mass flow of water under the influence of transpiration taking place in aerial surface of leaves. This return causes rapid absorption of water, which can also drive the salt taken in mass along with it.
4. **Donnan Equilibrium: (F.G., Donnan, 1927):** According to this theory presence of certain fixed or undiffusible ion within the cell would require to be balanced by ions of another charge.

   This theory is applicable to a situation when certain non-diffusible anions (protein) are present in one side of membrane and can't diffuse in or out due to large size. Non diffusible ion are termed as fixed ion when excess of protein in present in inner side of membrane it will allow the inward diffusion of cations until an equilibrium called Donnan equilibrium is achieved. At this stage the ratio of cation to anions on innerside of membrane is equal to the ratio of cations and anions outside.

$$\frac{Cl^- \text{ (outside)}}{Cl^- \text{ (inside)}} = \frac{K^+ \text{ (inside)}}{K^+ \text{ (outside)}}$$ i.e. ratio of no, of Cl^- ion

Outside to that inside the cell is equal to the ratio of K^+ inside to that outside the cell.

3.3 Active Ion Uptake

An though passive absorption account for rapid exchange and accumulation of Anion & Cations within the plant call, it was observed that many ions continue to enter the tissue at considerably slow rates long after the initial phase of free diffusion is over. Such ions enter the cytoplasm and accumulate in vacuoles from which they can't radily pass back in to external solution and seems to require metabolic energy because when metabolic activity is inhibited, the rare of ion uptake is also inhibited. The necessary energy require to do this job is derived from respiration (i.e.ATP). Experiment showed that greater the rate of respiration, the faster is the accumulation of inorganic salt uptake. Because if respiration is stopped the salt uptake is also inhibited.

Carrier ions uptake (Carrier Mechanism)

Not all ions or molecules are permeable to plasma membrane of cell. Ions once move inside the vacuole can't push back in to free space of cell because it is assumed that the cytoplasm form the permeability barrier across which ions must pushed using metabolic energy supplied by respiration. The mechanism by which ions pass through the cytoplasm and accumulates the vacuole is analogus to enzyme action. As enzyme molecules first bind with substrate molecule at outer side to form carrier-ion complex in first stage and subsequently release them other side (innerside). Just like the constitutes of cell membrane act as a carrier and besides the ions/molecules at one side of that and release them to opposite sides and again become ready to receive fresh mechanism. The whole process requires energy in each step.

Res P Res Q

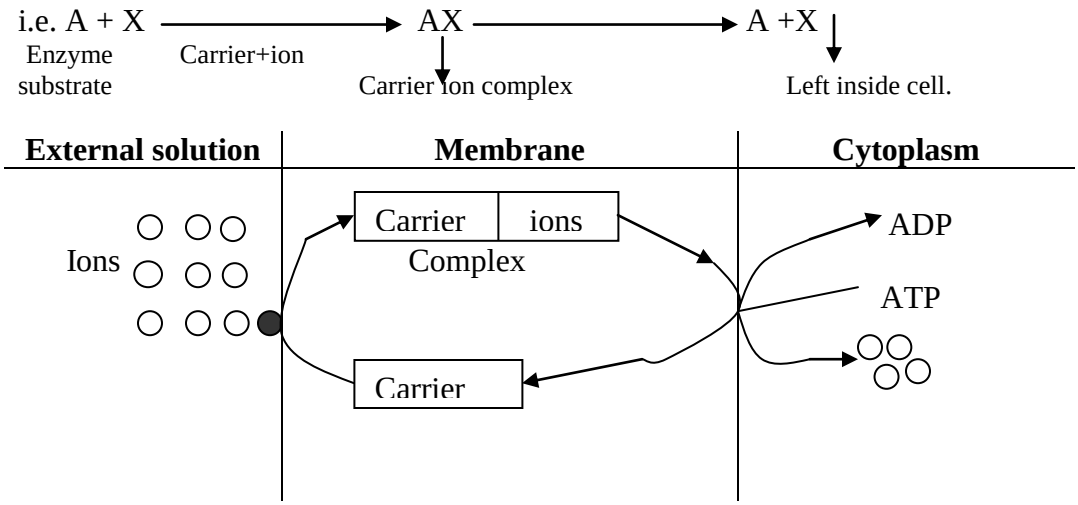


Fig: Concept of carrier mechanism

Cytochrome pump System:

This concept is proposed and modified by Undergrad (1955). According to him uptakes of anions was linked to respiration while that of cations was a passive process.

He further proposed that in cytochrome pump of electron transport system (ETS) are involved in anions transport. According to him, the cytochrome at outer surface of membrane is oxidized (Fe^{+2}) while that on inner side is reduced (Fe^{+2}). At outer side when it goes to oxidation losses an electron and pick up an anion (-ve) in exchange of electron. The released electron combines with proton (+ve) i.e., H+ and oxygen combine to form water. At inner surface oxidized iron of cytochrome is reduced by picking up an electron, which has been released by the action of dehydrogenase involved in respiration.

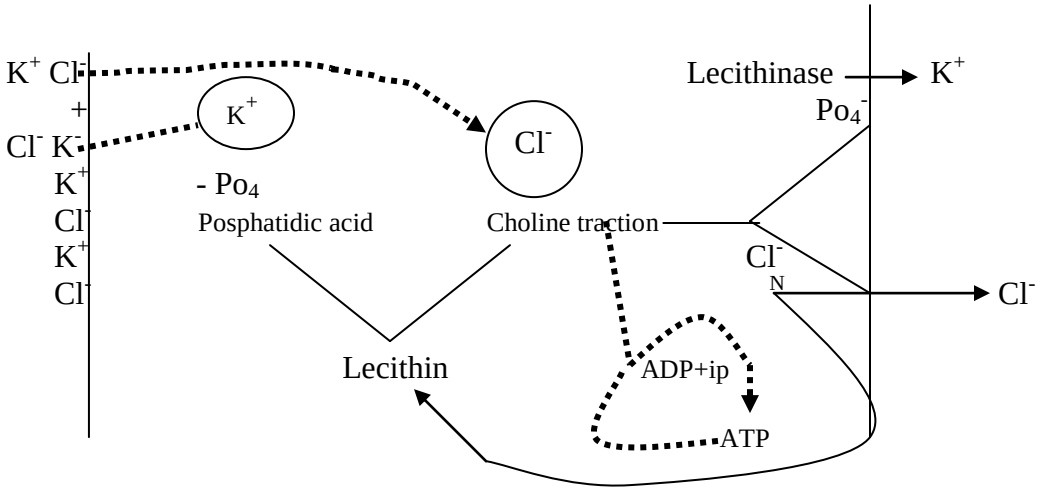
The most important evidences in favour of Lundegardh's hypothesis was the observation that the rate of respiration increased when the plant was transferred from water to salt respiration or anion respiration on it was observed in salt solution and was linked to anion uptake. However this hypothesis couldn't stand against the several other experiments.

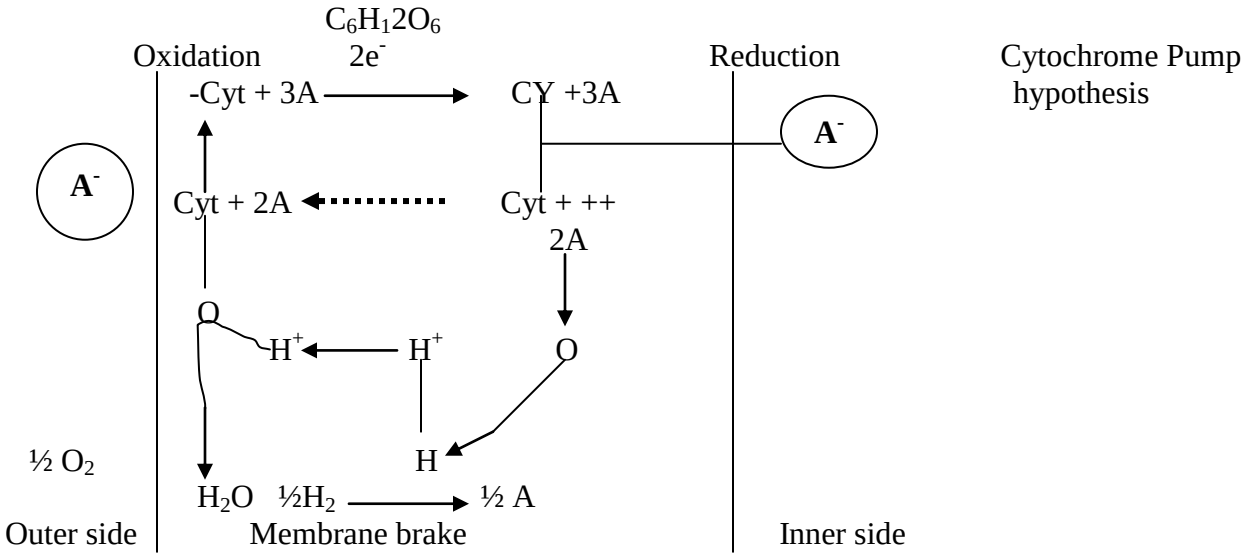
- **Objection:** There is certain objection to electron transport theory. Lundegardh theory is applicable only to anion transport.
- Selectively in ion absorption can't explained.
- This theory explains only one mechanism electron transport of anion but doesn't explain the different rates of anion absorptions.
- Such an electron transport mechanism is absent in many analrobically respiring organisms.

Lecithine Cycle (Protein Lecithin carrier)

Bennet clark (1956) proposed that there is a regular cycle synthesis and hydrolysis of Lecithine in cell membrane. Lecithin is an important phospholipid, which is made up of two components choline and phosphatidic acid. Choline has net positive charge while phosphatidic acid as net –ve charge. The two components release their ions. Sooner in presence of ATP choline and phosphatidic acid reunite and give rise to Lecithin. Lecithin pick up the ions on outer membrane cations (+ve) attach with phosphatidic acid. Anions (-Ve) get attached with choline.

On inner surface Lecithin break and release their ions. Sooner after this both components choline and phosphatidic group reunite together at an expense of ATP and forms Lecithin.





3.1 Absorption of water by plants

Water is required by the plant for the manifestation of its various vital function such as normal activities of cells, absorption of water and minerals, translocation of food material, maintaining turgidity of the cells, as a raw materials for photosynthesis and various other metabolic activities.

Soil complex as related to absorption of water constitute, mineral matters 40% by volume, rganic matter 10%, soil water 25%, soil atmosphere 25% and soil organism to some extent.

The aquatic plant like Algae, fungi absorb water through external surface, epiphytes like moss, fern, orchids through specialized organs from air. While most of the higher plants absorb water through well-developed root system. Usually the terminal parts of root branches or root tap are physiologically active in absorbing water.

The terminal part of root shows four (4) zones, i.e.

Root cap: Present at apex of root as protective layer.

Meristematic zone: A region of cell division.
Elongation Zone: Cell elongation and enlargement lies behind growing point, and partially differentiated in to primary xylem and primary phloem and meant for increase in length of root.
Root hair zone: The zone of elongation is followed by root hair zones where xylem and phloem are fully differentiated. It has thousand of tubular extensions of outer wall (epiblema) having a diameter of 10 µm and 0.05-1.5 mm length in continuation with parent cells, a root hair cavities, central vacuoles, filled with cell sap and cytoplasm. Its wall is permeable. The outer wall contains pectin & inner wall cellulosic. It helps in retaining water in surface of root.

Root is the important center of water absorption. The rate of root hair varies from 0.2-4 cubic micron of water per square micron of surface per minute.

The cell sap is an aqueous solution of mineral salt, organic and inorganic acid. Because of the presence of sugar and, the osmotic pressure of cell sap is higher than osmotic pressure of the soil solution. The osmotic pressure of sap of root hair is 3-5 atmospheres while that of the soil solution in well-watered soil is less than 1 atmosphere.

Mycorrhiza

The term mycorrhiza literally means the fungus root designated a symbiotic association between the root of higher plants and fungal species. The fungal hyphae of mycorrhiza form a mental outside the root and penetrate into epidermal cells of roots. Some plant possesses mycorrhiza instead of root hairs. The fungal hyphae of mycorrhiza absorb water and mineral salts from the soil and handover the same to the root of host.

Mycorrhizal fungi have an important role in ecosystem in soil having low mineral content. In such ecosystem most of the minerals are present in dead organic matters lying above the soil. The mycorrhiza brings about direct recycling of minerals due to percolation of water through the soil is reduced to minimum. In Angiosperm it has been found that nearly 80% of the higher plants absorb water & minerals through mycorrhizal association.

Translocation of organic solutes

The movement of assimilates from the place of manufacture to the other parts of plant through special conducting or transporting tissue is called translocation of organic solutes.

According to classical concept the inorganic solute substances are carried in xylem vessel along with ascending sap of water in the transpiration stream where as phloem is considered as the downward translocation of organic solutes.

Radio autograph have conformed that assimilates to incorporated radioactive C^{14} travel towards the storage region through phloem.

Analysis of sieve tube exudates obtained from anaesthetized proboscis of aphid acting as a micropippate, consider of mainly sucrose. It thus supports the classical view of translocation of organic solute through the sieve tube of phloem. The sieve tube of phloem is considered as sole path of down ward translocation of solute.

Experiment with radio active carbohydrates incorporated with C14 conducted by Burr.et.al further prove that upward translocation of organic solute takes place in phloem.

Thus it can be safely said that the longitudinal translocation of organic solute in stem with upward and downward translocation takes place in phloem.

Translocation in Lower plants

According to Pasker et al trumpet hyphea of Brown algae apparently resemble to sieve tube of higher plant. The algae like Acetabularid protoplasmic sheathing is considered responsible for translocation. In Bryophytes like polytrichum commune, Leptoid cell are responsible for translocation.

Translocation of solute in higher plants

Following hypothesis have been put formulated to explain the mechanism of phloem conduction.

1. **Diffusion hypothesis:** Translocation of food from supply end to consumption end is governed by diffusion as supply end is considered having higher concentration where as consumption is considered having lower concentration of food. Phloem transport is depends upon metabolic energy. Thus this physical theory of diffusion is not at all considered responsible for phloem transport.
2. **Activated diffusion process**: According to Mason & Phillis there is an activation of diffusion process inside the phloem because

⇒ Cell to cell movement of organic compound from phloem tube into sink is enhanced by supply of ATP.

⇒ Assimilates move from mesophyll cell in to sieve tube against concentration gradient and sieve plate inhibit mass flow.

According to them protoplasm of sieve tube accelerates diffusion of solutes by

(a) Utilizing metabolic energy.
(b) By activating diffusion molecules of sieve tube, and
(c) By decreasing the resistance offered by protoplasm of sieve tube.

Due to lack of experienced evidence this theory was discarded.

3. **Protoplasmic Streaming theory**: This theory was proposed by Hugo Devries and supported by Curties (1935). According to this theory movement of organic solute is caused combination of both diffusion and cytoplasmic streaming. Protoplasmic streaming is observed in several cells including sieve element is responsible for movement of organic solutes. After reaching one end of sieve tube the organic molecule migrate to other sieve tube across the intervening cross wall through pore by diffusion. Thus solute translocation is a combination of both diffusion and protoplasmic streamina. According to some physiological protoplasmic streaming is continuous from sieve tube to another sieve tube through sieve pores. In such cases two substances can move in the sieve elements in opposite direction depending upon their own concentration gradient.

Objection: Protoplasmic streaming id not observed in matured sieve tube

⇒ Fluorescent dye injected in to sieve tube doesn't show movement in up and down direction as it showed be move according to their own concentration gradient and protoplasmic streaming.

⇒ The maximum rate of protoplasmic streaming in higher plant is 5 cm/hr while the rate of translocation of organic solute is 150 cm/hr.

4. **Transcellular stremds**: According to Thain sieve tube posses tubular strands which are continuous from oue sieve tube to another sieve tube through sieve pore. Translocation of solutes takes place in these stands by a sort of peristaltic movement. Metabolic energy is use for this purpose.

   According to wooding (1969) transcellular strands are actually microfibrics and are protenaceous in nature and suited to the function of transport as showing rhythmic contraction and expansion. However electron microscope has failed to spot transcellular strands.

5. **Electro osmotic theory:** It was proposed independently by Fensom (1957) and Spanner (1958). Diffusion of water and salt across the membrane is subjected to different electrical potentials is called electro-osmosis. This theory suggests that an electrical mechanism may account for translocation of sugar in sieve tube. According to then sieve tube membrane is porus with fixed electric change and electrical potential across the sieve plate, which brings about the migration of solutes. Active transport of K^+ in to sieve plate and secretion of some (K^+) on other side of the plate produce circulatory pathway. K+ ions are pumped in to sieve tube at the expense of ATP, sugar molecules adhere to K^+ are carried across the sieve plate coupled with K^+ which generate the electrical gradient due to their circular movement between companion sieve tube.

Munch Mass/ Pressure flow hypothesis

The physiological basis of mass or pressure flow hypothesis of organic solute has been put forwarded by Munch (1930) and modified by Crafts (1938) on the assumption that turgor pressure gradient exist between the supply (source) and receiving end (sink).

According to this hypothesis organic solute move from a source (point of manufacture of organic food) to sink (region of consumption) in a mass flow of solution, which is caused by the entry of water in the source due to osmosis and resulting in increased turgor pressure i.e. organic solute move in solution along turgor pressure gradient.

The principal outline of this theory is very simple. Let us assume that A and B are two osmometer permeable only to water.

1. Osmometer A- contains concentration solution and is ≡ to source.
2. Osmometer B- contains dilute solution (water) ≡ Sink.
3. Both A & B are connected by means of Tube T ≡ Sieve tube.
4. Both the osmometer is dipped in water reservoir in a closed system.
   Osmometer A ≅ Source of manufacture ≅ Mesophyll cell (supply).
   Osmometer B ≅ Sink (Consumption end) ≡ root cell.
   Tube T ≡ Phloem element (Sieve tube)

5. Outer vessel having water correspond to xylem.

Figure:

If we supply the above system in plant, A would represent Mesophyll cells leaf and B represent receiving cell of plant (root). The connecting link between osmometer & water container would represent sieve tube & xylem duct respectively. Hence according to this hypothesis, higher osmotic concentration. This osmotic pressure will cause continuous flow of solution from leaf cell to leaf cell through sieve tube through plasmodesmata. Once the conventional flow enters the sieve tube the function of sieve tube become passive allowing the solution under pressure to pass through it. The water from xylem bring about high turgor pressure in leaves and thus causes flow in solution through sieve tube to consumption end. At this consumption end osmotic system is reduced and thus water only return to xylem via cambium.

Objection:

1. Mass flows account for only in unidirectional movement.
2. Bi-directional movement of solute can occur in same sieve tube, which is impossible under mass flow.
3. Osmotic pressure supply & consumption end doesn't always assure the +ve gradient.
4. Rate of movement of water & solute should be similar according to mass flow but actually they are different.
5. Vacuoles of the adjacent sieve tube cell are not continuous.

Unit: 5

PHOTOSYNTHESIS

Photosynthesis is an oxidation-reduction process in which water is oxidizing and carbon dioxide is reduced to carbohydrate level, the water and oxygen being by products. The reduction of CO_2 to carbohydrate level needs assimilatory powers such as ATP and NADPH + H+. Reduction of CO_2 occurs in dark but the production of assimilatory powers is light dependent. Hence, the process of photosynthesis consists of two phases-one light-dependent phase (light reaction or Hill reaction) and other light-independent phase (dark reaction or Blackman's reaction). Emerson and Arnold (1932) carried out the flashing light experiment and showed the existence of light and dark reaction.

1.1 Mechanism of Photosynthesis

Light Reaction

Complicated process & discussed undr,

1. Red drop Emerson effect & Two pigment system

Emerson & Lewis (1943)- Working on quantum field of photosynthesis n monochromatic light at different wavelength $\xrightarrow{obs}$ Sharp decline in quantum field at an wave length greater than 680nm at red zones called red drop.

Emersion etal (1957,58): Red drop could be brought back to full efficiency of applied light of shorter wavelength.

This increased in photosynthetic activity in successive application of beam of different wavelength is called Emersion effect.

2. With discovery of red drop & Emersion effect, it is concluded that at least 2 pigment system are involved in photosynthesis.

Pigment System I (PS I) ⟶ Chlorophyll, caroleneid, p700 (reaction leatre) Cytochrome b, b6, FRS, ferrodoxine, Iron, Cu, NADP.

Pigment System II (PS II) ⟶ Chlorophyll, chl b, phycobillin, phycocrythron, Carotenoids, p680 (reaction center), electron accepton, & PQ, Cytochromes.

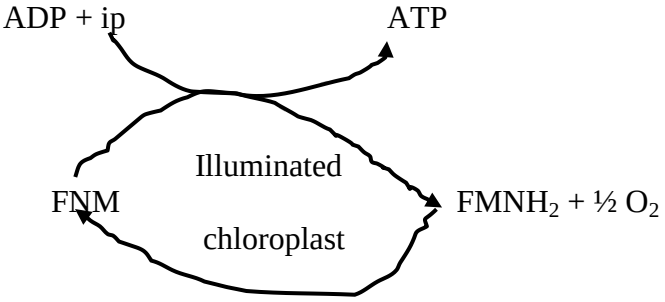
PSI: associated ē reduction of NADP ⟶ $NADPH_2$

PSII: associated ē photol of water & to berate ox

3. Cyt.b_6: Cyt.f complex – non-pigment complex associated ē oxido-reductage activity in the transfer of electron (ETS) and formation of energy rich ATPase from ADP.

4. Photophosphorylation
   - Cychic ⟶ Lower plants (Algae)
   - Non cyclic ⟶ Higher plants
   - Psendocyclic ⟶ Oxygen dependent photophosrylation catalyzed by FMN with the help of light & chlorophyll which oxidized FMN ⟶ FMN H_2 and O2 to form water

2.2



Pseudo cyclic photophosphorplation

The simplest equation o photosynthesis can be

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{hv} C_6H_{12}O_6 + 6O_2 \uparrow$$

Ruben etal working on photosynthesis demonstrated the source of liberated O2 is water and not the CO2. The equation may be corrected:

$$6CO_2 + 12H_2O^{\otimes} \xrightarrow[\text{chlorophyll}]{hv} C_6H_{12}O_6 + 6H_2O + 6O_2^{\otimes} \uparrow$$

Light of Hill reaction of photolysis of water is defined as the phenomenon of breaking up of water into H_2 & O_2 in the illuminated chloroplast by using sunlight to regenerate enzyme complex "Z" connected with photolysis. The water dissociated in to H^+ & OH^- ion in presence of enzyme complex Z the OH- loose their electron and combine to form H_2O & O_2 + Mn

The reaction is

$$4H_2O \xrightarrow{hv} 4H^+ + 4OH^-$$

$$4OH^- + 2z \longrightarrow 2z(OH)2 + 4ē \uparrow$$

$$2z(OH)_2 \longrightarrow 2z + 2H_2O + O_2$$

Scheme: The electron so produced during breaking downs of water pass through 2 pigment system, named PSII & PS I.

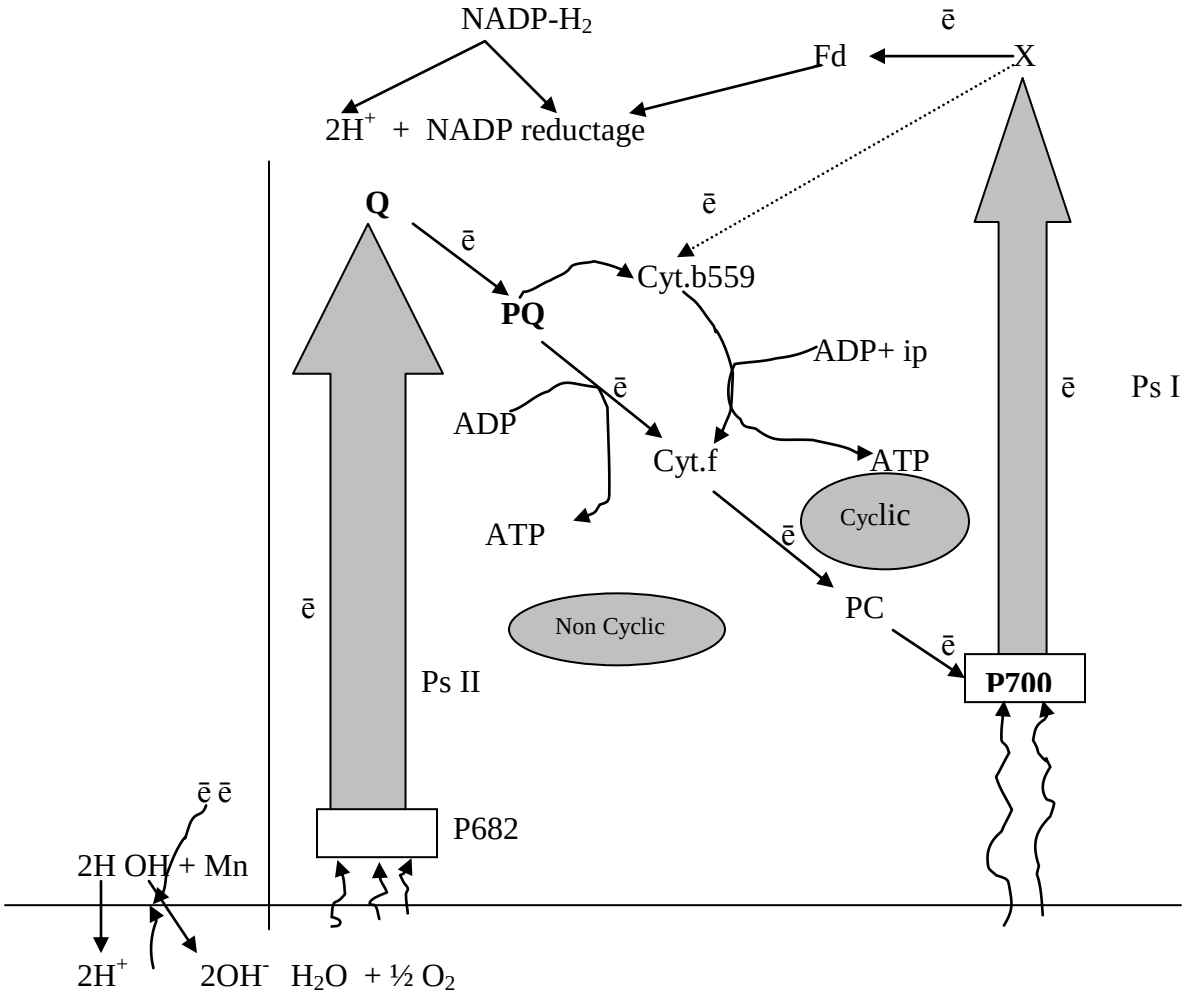


Fig: Z Scheme of non cyclic photophosphorylation, Q= Quinone, PQ= plstoquinone, Cyt.f = cytochrome f, PC= plasto cyanin, fd= ferredoxin

i.e. $4H_2O \longrightarrow 4H^+ + 4OH^- + 4\bar{e}$

$4OH^- \longrightarrow 2H_2O_2 \longrightarrow 2H_2O + O_2 \uparrow$

Dark Reaction or Black mand's reaction

It is only……..the leaves and reduced through a series of reaction to form carbohydrates. The term dark reaction implies that the reaction is independent of light. This processes is also known as carbon fixation. There are three (3) modes of carbon fixations.

1. Calvin Benson Cycle, 2. C_4 dicarboxylic Cyclic, and 3. CAM pathway.

The plants exhibiting these pathways are respectively known as C_3 plant. C_4 plant and CAM plants. There is no taxonomic importance of these pathways since different species of the same genus may be performing different modes of CO_2 fixation.

Calvin-Beson Cycle: Melvin Calvin explained the mechanism of CO_2 fixation during photosynthesis in his monumental work "the path of carbon is photosynthesis ". For this work he received the Nobel prize in 1961. Calvin experimented in Algae Chlorella and used CO_2 labelled with radioactive isotope carbon (C^{14}) and detected an intermediate compound during the process of CO_2 fixation. He concluded that

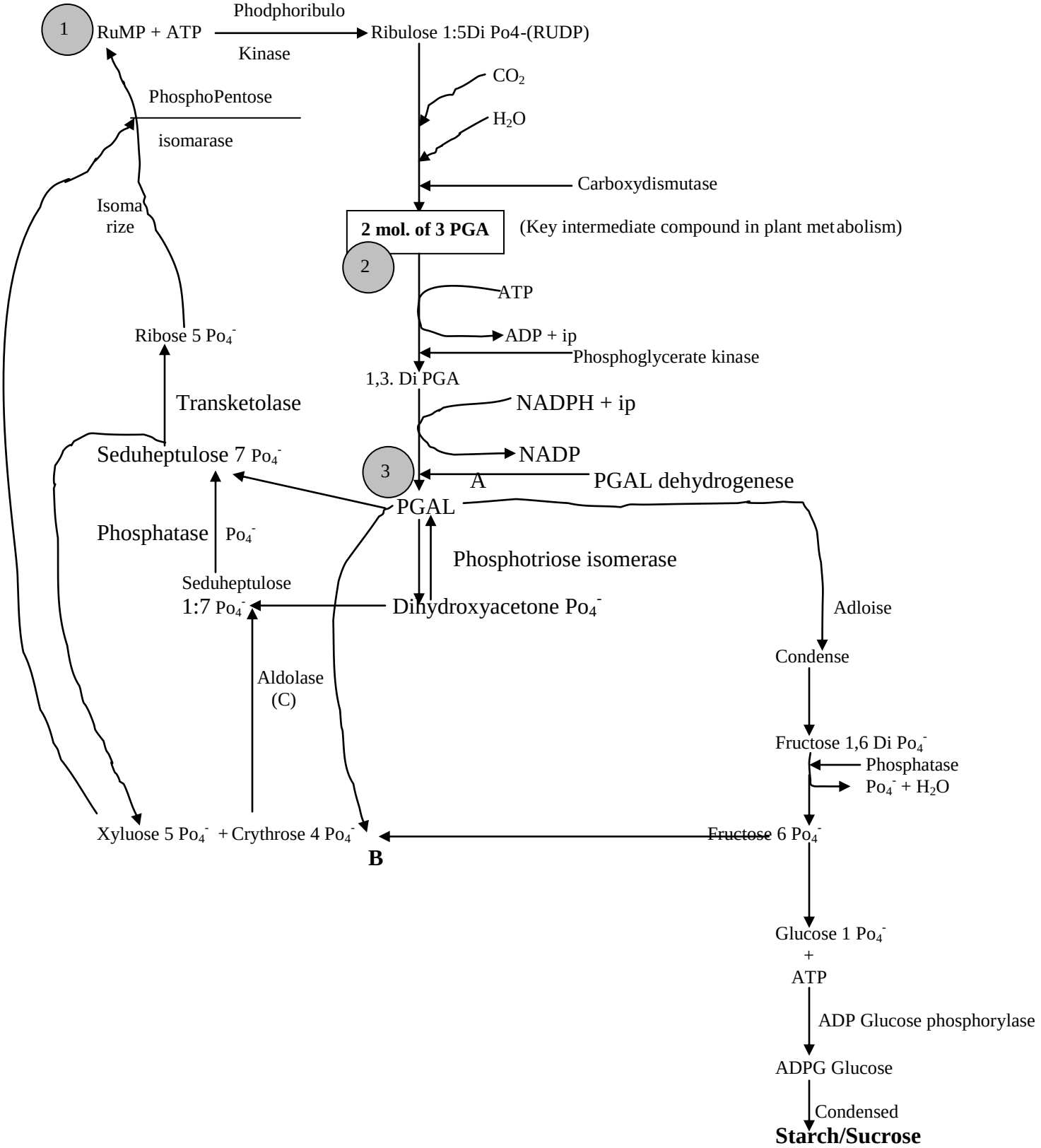
during the course of reduction of CO_2 to form carbohydrates. These reactions operate in cyclic manner and the process is popularly known as Calvin cycle.

In Calvin cycle CO_2 is first inter into 5-carbon compound ribulose 1-5 di $Po4^-$ (RUDP) and first form compound is a 3-carbon compound called 3 PGA. Hence the Calvin cycle is also known as C_3 cycle or pentose phosphate path (PP pathway). The plants where these cycles opera are called C_3 plants.

Calvin Cycle (Phosphate Pentose Cycle of Dark reaction (C_3 plants)
Dark Reaction of photosynthesis as per Calvin occurs cyclic sequence of 4 phases

1. Carbosylation leading to fixation of CO_2 and production of PGA.
2. Reduction or production of PGAL.
3. Formation of hexose of sugar and
4. Regeneration of RUDP.

Plant Physiology



Overall Reaction

$6CO_2 + 18\ ATP + 12\ NADPH_2 \longrightarrow C_6H_{12}O_6 + 18ADP + 18ip + 12\ NADP$

18 ATP+12 NADPH2 carrbout about 791.4 kacl energy (18×8.9 +12× 52.6) which is sufficient to add 686 k cal synthesis of am moles of glucose form CO_2 & water.

C4 – DICARBOXYLIC ACID PATHWAY

Kortschak et. al 1965 AD while tracing the path of carbon in sugarcane leaves observed the formation of compound oxaloacetic acid. Lateron Hatch & slack (1971) observed that it is regular pathway of CO_2 fixation and named it C_4 plants.

It is observed in many monocot & Dicot families; Graminae, cyperaceae, chenopodiaceae, compositae, etc.

Fig: C4 leaf showing mesophyll And bundle sheath chloroplast

Fig: Structure of typical Bundle sheath chloroplast.

Morphological peculiarities and importance of C_4 plants:

- ⇒ They are tropical plants which generally live under xerophytic habitats,
- ⇒ The most distinguishable anatomical features of leaves of C_4 plant are the presence of bundle sheath cell chloroplast,
- ⇒ The bundle sheath cell may also lacus grana in their chloroplast while mesophyll cells have well developed grana & chloroplast,
- ⇒ The arrangement of chloroplast containing bundle sheath cells around vascular bundles is another characteristics feature of C_4 plant.
- ⇒ The kranztype (wreath: twisted) type arrangement of mesophyll cell around bundle sheath cells is significant in C_4 plant. (Concentric arrangement of mesophyll cell),
- ⇒ Bundle sheath cells generally have abundant starch grains as compound to mesophyll cells.

Significance of C4 plants:

- ⇒ The plant operating C4 dicarboxylic acid path can perform normal photosynthesis even in low CO_2 concentration and higher intensity of light.
- ⇒ They are able to trap CO2 both from outside and that released internally due to respiration because of highly efficient PEP carbosylase.
- ⇒ Effect of water stress are minimized the C4 plants because bundle sheath cells lies close to the surface of water supply.
- ⇒ It is found that C4 plants mostly live in area having excess salts, high temperature or low water availability.

⇒ Because of their higher photosynthetic capacity and adoptability to adverse environmental conditions, some of the C4 plants are serious weeds. For example, *Amaranthus, Salsols* etc.

⇒ The concentric arrangement of Tissues provides small surface area in relation to volume. This geometry reduce transpiration surface and allow better utilization of available water.

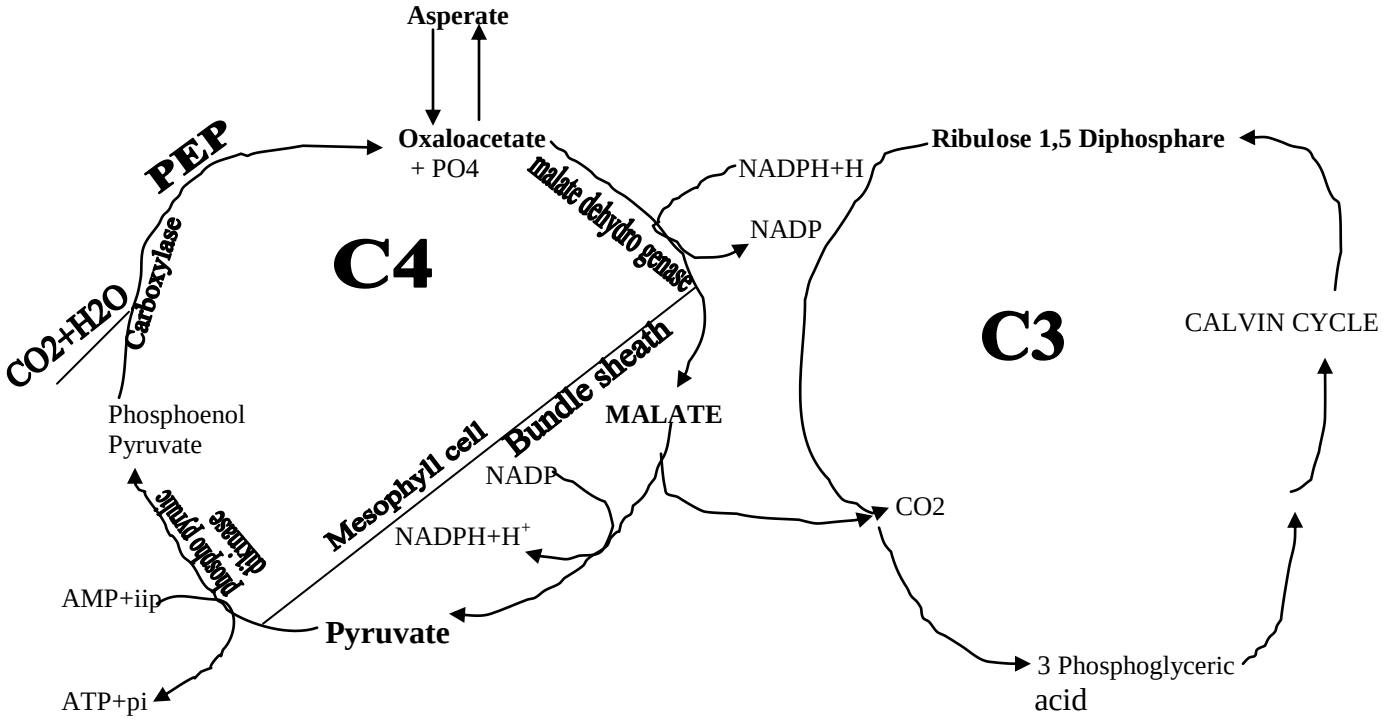


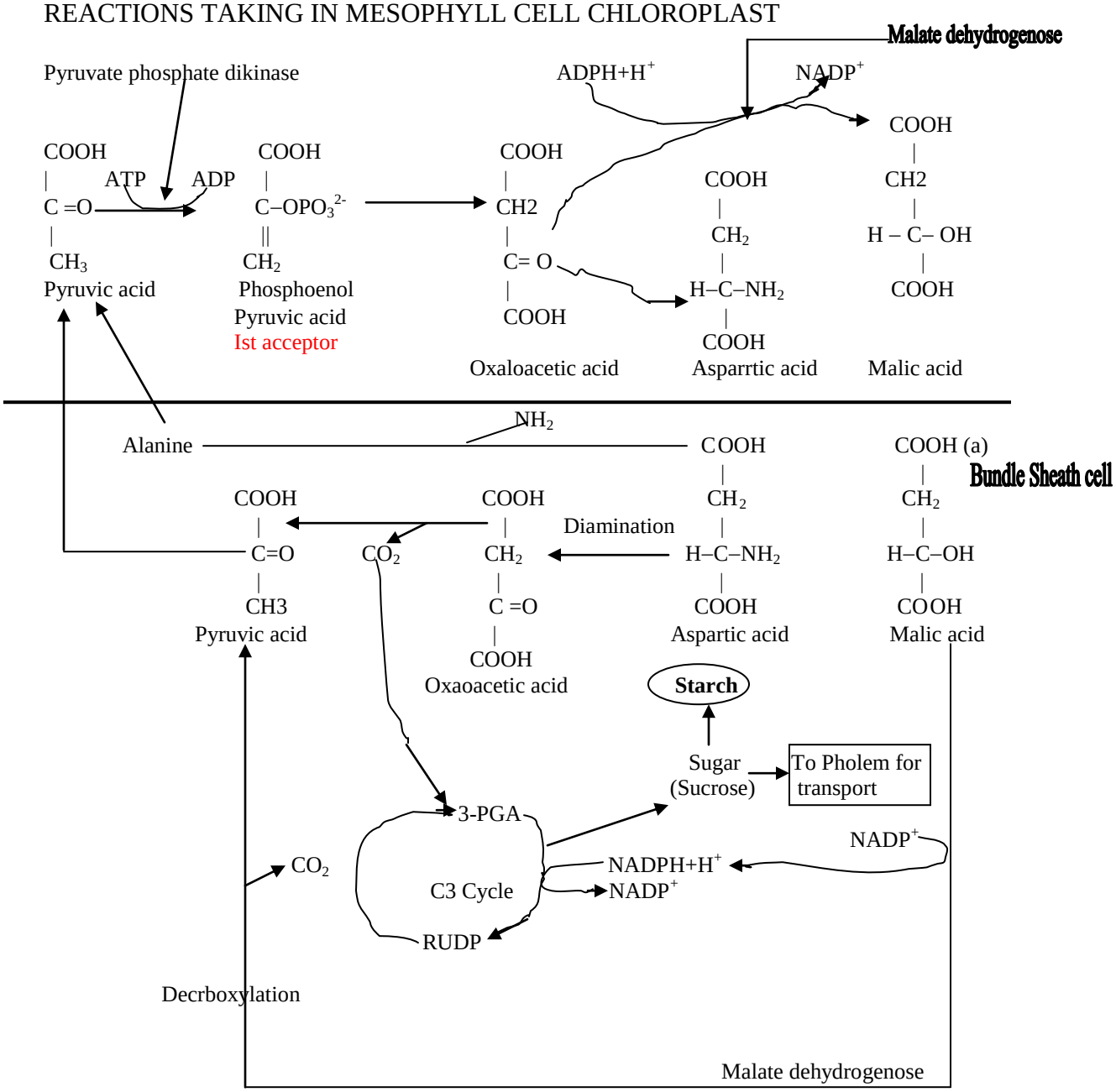
Fig: CO_2 fixation in C_4 dicarbosylic acid pathway

Difference between C_3 and C_4 plants:

Character	C_3 Plants	C_4 Plants
1. CO_2 acceptor	Ribulose 1,5 Diphosphate	Phosphophoenol pyruvic acid
2. First stable products	PGA(Phosphogliyceric acid)	Oxaloacetice acid.
3. Types of chloroplast	One type	Diomorphic; bundle sheath & mesophyll.
4. Leaf system	Normal	Bundle sheath chloroplast lack grana Kranz type anatomy
5. Pigment system	Both PSI & PSII	Bundle sheath chloroplast lack
6. Enzyme for C_3 pathway	Found in mesophyll cell.	In bundle sheath cell.
7. CO_2 Compensation point	50-150 ppm	0-10 ppm.
8. Photorespiration	Present	Absent
9. Saturation intensity	1000-4000 fte.	Different to reach saturation
10. Bundle sheath cell	Not prominent	Very prominent kranz like
11. CO2 fixation	C3 pathway	Both C3 and C4 pathway
12. Optimum temperature	10-25^{0}C	30-45^{0}C
13. High conc. Of O_2	Inhibit photosynthesis	No effect on photosynthesis
14. ATP requirement for 1 mol of Glucose	18 ATP	30 ATP
15. Net rate of photosynthesis in full sunlight	15-35 mg/dm^2/hr	40-80 mg/dm^2/hr

Mechanism of C_4 Cycle

REACTIONS TAKING IN MESOPHYLL CELL CHLOROPLAST



⇒ C4 plant differ from C3 plant in initial fixation of CO2 which is carried out in cytoplasm of mesophyll cell and it begins with fixation of CO2 by PEP on C-3 compound as acceptor.

Reaction Taking in Bundle sheath Chloroplast

⇒ C_4 plants have a higher requirement of ATP for CO_2 assimilation. Here 1 mol. of CO_2 requires 5 ATP (+2NADPH2) in contrast to 3 ATP (+2NADPH2) requirement for C_3 plant. It is possible that extra ATP id supplied through cyclic phisphorylation especially bundle sheath chloroplast where well-developed grana is less abundant. Greater synthesis of ATP also explains the higher light requirement for C_4 plants.

⇒ Depending upon the product transferred to bundle sheath cells from mesophyll cell and its further fate, Chollet and Ogren (1975) recognized 3 categories of C_4 plants

1. Malate is passed in to bundle cell where it is decarboxylated to CO_2 and pyruvate. Pyruvate is transported back to mesophyll cell to regenate PEP in presence of ATP. Exp- Maize & sugarcane.
2. Mesophyll cell transport aspirate to bundle sheath cell, where it is deaminated to form oxaloacetate, which is then changed to pyruvate and CO_2. Pyruvate passed back to mesophyll cell to regenerate PEP. Exp: Panicum maxicum & Chloris.
3. Asperate is transferred from mesophyll and transported to bundle sheath cell where it is transaminated, then dicarboxylated to form CO_2 + Pyruvate. Exp: Atriplex spongiosa.
4. In C_4 plants there are two carboxylation, one by atm. CO_2 that form dicarbosylic acid and next by internally generated CO_2 entering C_3 cycle (RUDP) ie C_4 plant have both C_3 and C_4 pathway. Because of two carboxylation at two sites the pathway is known as Dicarboxylation pathway.

Unit: 6
RESPIRATION

Respiration may be defined as the biological oxidation of prepared food materials i.e. carbohydrates, proteins and fats, to release CO_2 water and energy.

The subrates, which are, break down in respiration for release of energy may be carbohydrates, proteins of fat. Proteins and fats used as a substrate only in absence of carbohydrates. According top Blackman, if carbohydrates is used as a respiratory substrate it is called floating respiration.

If protein used as a respiration substrate ⟶ Protoplasmic respiration. Fat and protein used as a respiration substrate only after their hydrolysis into simpler substances i.e. carbohydrate. For example: In case of fat it ⟶ (hydrolyzed) Fatty acid and Glycerol, and subsequently in to Glucose.
Similarly in case of protein ⟶ Amino acid ⟶ Glucose.

It is a catabotic process in which complex substrates are broken down in to simpler one and finally CO2 & H2O id librated. During oxidation certain amount of energy is released, a part of which lost as a heat and part of this trapped in form of energy rich AYP. The energy trapped informs of ATP is utilized in further metabolic process related to growth & development.

There are two pathway of oxidation of organic compound

1. Common pathway and
2. Pentose pathway

Common pathway is common to both Aerobic and Anaerobic. It consists of (a) Glycolysis, (b) Krebs' cycle/Fermentation, and (c) Terminal oxidation.
Glycolysis is common to both Aerobic and Anaerobic respiration. Krebs' cycle operate aerobic condition in side mitochondria while fermentation is used as 2^{nd} steps under an aerobic condition. Terminal oxidation occurs only in aerobic respiration.

GLYCOLYSIS

The breakdown of hexose sugar in to pyruvic acid through sequential series of reactions modulated under specific enzymes is called Glycolysis. This pathway is known as EMP pathway as 3 German scientists namely Embedon, Mayor Hof, and Paranus found out various steps reaction in the formation of pyruvic from glucose. Hence this pathway is called EMP pathway.

It is accomplished in cytoplasm and is common to both Aerobic and Anaerobic respiration. In EMP pathway a molecule of glucose, fructose etc is oxidized to form 2 molecule of pyruvic acid with released of 4 H^+.

i.e. $C_6H_{12}O_6 \longrightarrow 2 \text{ mol. } C_3H_4O_3 + 4[H^+]$

The above breakdown takes place in series of steps each catalysed by specific enzymes. These all reactions can be broadly grouped under the following headings (1) Phosphorylation of Sugar, (2) Formation of Glyceral dehyde 3 PO_4, (3) Oxidation of Glyceral dehyde 2-PO_4 and (4) Formation of pyruvic acid (2 mol. $C_3H_4O_3 + 4H^+$).

Mechanism/ Glycolysis Pathway (EMP Pathway)

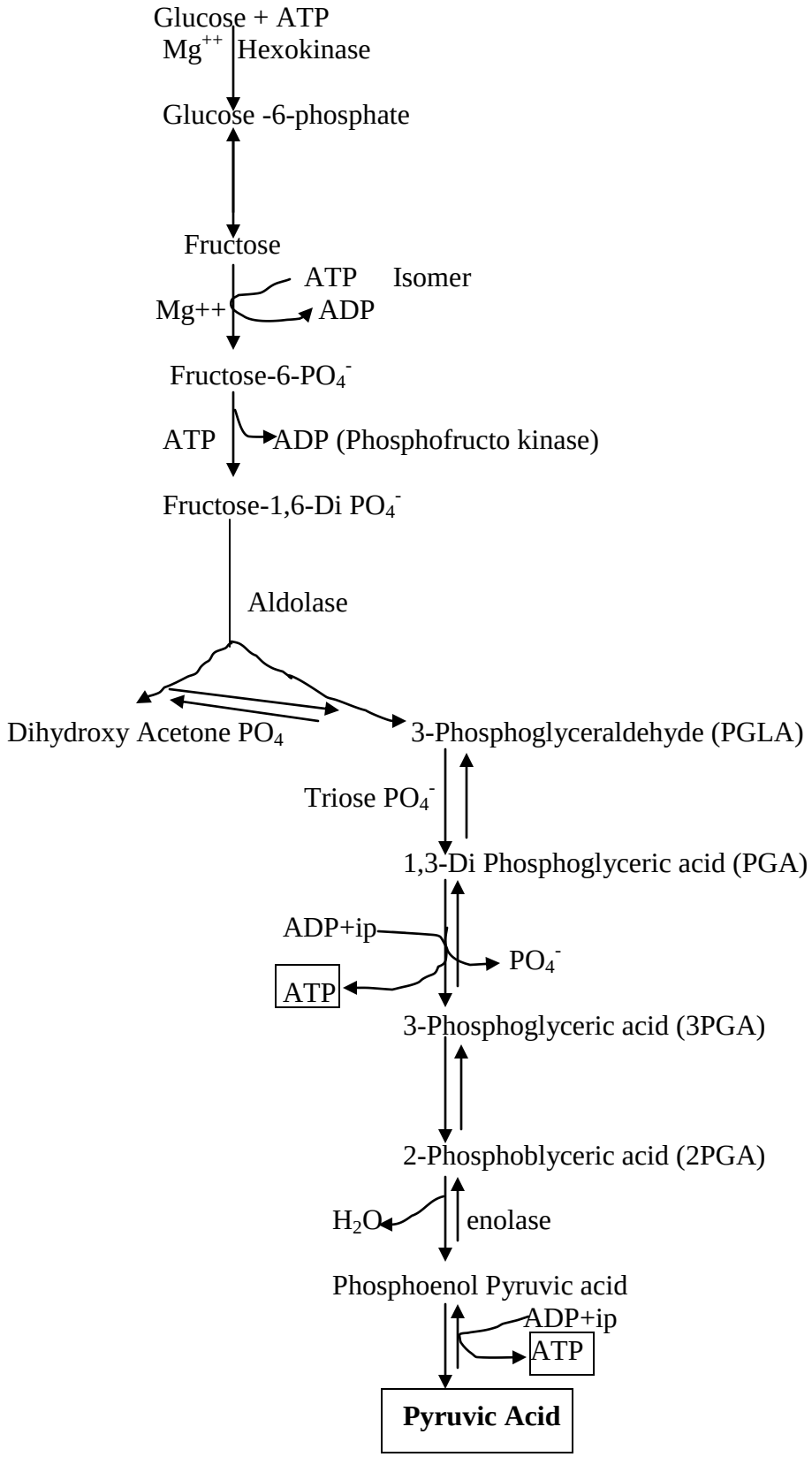


Fig: Schematic representation of glycolysic.