6^{th} SEMESTER BOTANY

UNIVERSITY OF CALICUT

PLANT PHYSIOLOGY AND METABOLISM

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BOT6B10T PLANT PHYSIOLOGY AND METABOLISM

Syllabus

Module - 1.

1. Plant cell and Water
Properties of water; water as a solvent; cohesion and adhesion. Diffusion, osmosis, osmotic pressure, concept of water potential, components of water potential, osmotic potential, turgor pressure, imbibition, matric potential.
2. Transpiration. Types and process. Mechanism of guard cell movement. K^+ ion mechanism. Why transpiration? Antitranspirants.
3. Absorption of water by transpiration pull and cohesion of water molecules. Radial movement of water through root. Soil-plant-atmosphere continuum of water.

Module-II

1. The ascent of sap; Transpiration pull and cohesion of water molecules. Merits and demerits of cohesion-tension theory.
2. Plants and inorganic nutrients. Macro and Micro nutrients. Uptake of mineral elements. Difference between passive uptake and active uptake. Simple and facilitated diffusion. Active uptake. Carrier concept. Evidences.

Module - III

1. Photosynthesis in higher plants: Photosynthetic apparatus. Electromagnetic radiation. Absorption of light. Fluorescence and phosphorescene. Organization of light harvesting antenna pigments. Photochemical and chemical phases of photosynthesis and its evidences. Red drop and Emerson enhancement effect. Two pigment systems, components. Redox potentials of the electron carriers. Photosynthetic electron transport and photophosphorylation. Assimilatory powers- ATP and NADPH.

Photosynthetic carbon reduction cycle (PCR), RUBISCO, C3. C4, and CAM pathways. Ecological significance of C4, and CAM metabolism. Photorespiration. Law of limiting factors.
2. Biological nitrogen fixation, symbiotic nitrogen fixation in leguminous plants. Biochemistry of Nitrogen fixation. Export of fixed nitrogen from nodules. Genetics of nitrogen fixation, Ammonia assimilation, assimilation of nitrate. Biosynthesis of amino acids reductive amination and transamination.
3. Translocation and distribution of photo assimilates. Composition of phloem exudates. Mechanism of phloem transport. Phloem loading and unloading; pressure flow hypothesis.

Module - IV

1. Plant growth and development. Auxins, gibberellins, cytokinins, abscisic acid and ethylene, their physiological roles. Photoperiodism and vernalization.
2. Plant movements -Phototropism, gravitropism. Nyctinastic and seismonatic movements.
3. Photomorphogenesis: Phytochrome: chemistry and physiological effects.
4. Seed dormancy and germination.

Module – V

1. Intermediary metabolism: anabolism, catabolism, amphibolic pathways and anapleurotic reactions.
2. Catabolism of hexoses. Glycolysis: Two phases of glycolysis. Overall balance sheet. Fate of pyruvate under aerobic and anaerobic conditions. Citric acid cycle: Formation of acetate, Reaction of citric acid cycle, Anapleurotic reactions of citric acid cycle. Amphibolic nature of citric acid cycle.
3. Oxidation of fatty acids. β oxidation of saturated fatty acids in plants. Glyoxylate cycle.
4. Biosynthesis of saturated fatty acids in plants. Involvement of fatty acid synthase complex and acyl carrier protein.
5. Oxidation of amino acids and entry to TCA cycle.
6. Oxidative phosphorylation: Electron transport reactions in mitochondrion. Electron carriers, redox potential, electron carriers function as multienzyme complexes, ATP synthesis. Chemiosmotic hypothesis. Shuttle systems.

Module 1

1. **PLANT CELL & WATER**

- Water is abundant in cell (95%).
- Structural and functional properties depend upon the chemical and physical properties of water.
- Water is exist in two form
  1. Free- it is solvent for several compounds
  2. Bound form- water is bound with polar molecules

- Properties of water
    - ✓ Colorless, tasteless, odorless and have unique physical and chemical property of which is vital for the maintained of the life.
    - ✓ Water expands during freezing, but most other compounds contract during freezing. So, ice is less dense than water (liquid) so it flows on water surface.
    - ✓ High melting and boiling point.
    - ✓ High specific heat, high tensile strength, high transmission of visible light etc.
- Properties of water significant for biological process.
    1. Water is a polar molecule
        - ✓ Water is not linear but angular.
        - ✓ Asymmetric charge distribution of make the water as polar molecule. So each pole may act as electric dipole which can attract oppositely charged molecules.
        - ✓ Unique properties of water due to hydrogen bond.
    2. Water is a universal solvent
        - ✓ Polar nature of water makes them universal solvent; they can bind with positively and negatively charged molecules.
        - ✓ Hydrogen attracts anions and oxygen attracts cations.
        - ✓ Clustering of water around ions is called hydration of water or solvation.
        - ✓ Water cannot dissolve non-polar compounds like fat and oil.
        - ✓ Water can dissolve organic compounds like alcohol, sugar etc.
        - ✓ Water cause micelle formation in amphipathic molecules.by arranging their hydrophobic regions towards centre and hydrophilic region towards the periphery.
    3. Water is an amphoteric molecule
        - ✓ Water can act as acid and base, which donate proton (acids) accept proton (base).
    4. Dissociating agent
        - ✓ It can dissociate itself and weak electrolyte when diluted with water.
    5. Water has strong forces of inter molecular attraction
        - ✓ Water is hydrate of oxygen with strong forces of attraction like hydrogen bonding, strong affinity with each other and polar molecule, high degree of interaction with other molecules.
    6. High hydrogen bonding powers
        - ✓ The hydrogen bond forms between high electronegative oxygen with electropositive hydrogen atom.
        - ✓ So 5 water molecule arranged in a tetrahedral manner. In liquid the tetrahedral arrangement is dynamic.
        - ✓ In ice the tetrahedral arrangement is ordered and regular. Hydrogen bond can be broken down by thermal agitation.

7. Low power to undergo ionization
    - ✓ The dissociation of water to H+ and OH- ions is very slow (very less concentration). But this small concentration of ions can influence the biological process.
    - ✓ Water adding reaction called hydration and water removing reaction called dehydration.
    - ✓ The H+ ions never exist as Free State but it migrate called migration of proton, which is important for photosynthesis and respiration.
8. High specific heat
    - ✓ High specific heat means the amount of energy required to rise the temperature 1^{o} c of unit mass of substance.
    - ✓ High specific heat provides stable temperature and metabolic rate.

- Biological function of water in plants
    1. It act as solvent for absorption of mineral nutrient from soil. And also transport within plant body.
    2. It act as solvent for ionic and polar molecule.
    3. An ideal median for enzymatic reaction.
    4. It hydrates cellular constituents there by maintain cell shape.
    5. It serves substrate for anabolic reaction ($CO_2 + H_2O \longrightarrow C_6H_{12}O_6$).
    6. Water is a powerful ionizing agent. It can dissociate weak electrolyte into ions.
    7. Water donates hydrogen during photosynthesis.
    8. It promotes cell-elongation.
- Cohesion
    - ✓ It is the attraction between similar molecules.
    - ✓ Here the mutual attraction between water molecules through hydrogen bonding. So water molecule can cling to each other.
    - ✓ High surface tension of water is due to cohesion. H_2O molecules at the surface are strongly attracted by water molecules in the interior than air molecules. Here the surface of water behaves as an elastic membrane. That is the reason why water drops are spherical.
    - ✓ Cohesion is also responsible for tensile strength. Tensile strength is the maximum tension that an uninterrupted column of any material can withstand without breaking.
    - ✓ Cohesion maintains the continuity of water column.
- Adhesion
    - ✓ It is the attraction between dissimilar molecule like glass, cellulose and wood etc.
    - ✓ It is responsible for the capillary rise of water in small distance.
- Absorption & dissipation of heat by water

1. High specific heat
    - ✓ High specific heat due to the hydrogen bonding in water.

- ✓ It enables H_2O to absorb and store heat and dissipate it very slowly. So water is called heat buffer and heat cushion.
- ✓ So large fluctuation of temperature in atmosphere cause only small change of temperature within plant. When external temperature falls low, the dissipation very slowly.

2. High latent heat of vaporization
   - ✓ Latent heat of vaporization is the energy required for the transformation of liquid water into gaseous form.
   - ✓ It helps to cool plants themselves during vaporization.

- Water potential
  - ✓ In any chemical system the free energy called chemical potential.
  - ✓ Here the potential energy of water is called water potential.
  - ✓ The term was first used by Slatyer and Taylor (1960).
  - ✓ Water always moves from region of higher potential to lower potential. So the movement of water will be continues till it attain an equilibrium point.
  - ✓ We can measure water potential in terms of pressure.
    1MPa=10bars
    1bar=0.987 ATM pressure
  - ✓ The potential represented by the Greek letter Ψ (Psi).
  - ✓ Water potential as Ψ_w.
  - ✓ Pure water has the highest water potential (0). Water potential of a solution is less than zero or negative.
  - ✓ Water potential is determines the direction of movement of water.
  - ✓ In plants water potential has an inverse relation with the absorption in plants. ie lower the water potential then higher will be the absorption.
  - ✓ Water will be donated to neighboring desiccating cells due to the higher water potential.
  - ✓ Soil solution is always hypotonic compares to root cells because root contains sugars and metabolites etc. when it attain an equilibrium then water in root cell move to the adjacent cells of root.
  - ✓ Three components influences water potential
    1. Solute potential or osmotic potential (Ψ_s)
       - It is the concentration of solute in a solution. It has an inverse relation with water potential
       - Solute potential depend only the number of solute particle not the charge of particles.
       - Solute potential varies from species to species and also vary during day and night. During day time water content of leaf falls low. So solute potential increases. Whereas during night time water content of leaf falls high so solute potential is low.

2. Pressure potential
    - It is the hydrostatic pressure of water represented by Ψ_{p}.
    - Pressure potential directly proportional to water potential.
    - Turgor pressure is the outwardly directed pressure exerted by wall content on the cell wall or positive pressure develops due to the entry of the water.
3. Gravity potential (Ψ_{g})
    - It is effect of gravity on potential.
    - Gravity has no significant role in water absorption. Water absorption takes place in the opposite direction of gravity.

Water potential, $\Psi_w=\Psi_s+\Psi_p+\Psi_g$

- Matric potential
    - ✓ It is also called imbibition pressure. Imbibition pressure is the inverse pressure created on a surface, when it is immersed in water.
    - ✓ It is significant only for dry plants materials such as seeds, wood and cellulose etc.
    - ✓ The swelling of dry seeds and wood due to matric potential (Ψ_m).
    - ✓ If matric potential exist then

Water potential, $\Psi_w=\Psi_s+\Psi_p+\Psi_m$

Water –plant relation

- Water is essential for plant growth and reproduction.
- Only water molecules enter to plant by cell wall and plasma membrane. Sometimes the constituents of cell wall are not entering water molecule (selectively permeable); in such cases plasmodesmata paly its action.
- Plasma membrane is selectively permeable, it only small permit small amounts of molecule.
- Permeability is the ability to restrict, prevent or permit the entry or movements of ions or molecules across them.
- Permeability depends upon the nature and composition of molecules and plasma membrane
- There are 2 different types of membranes based on their permeability
    1. Semipermeable- it permits the entry of solvent molecules. Eg, Tonoplast
    2. Selectively and differentially permeable- eg., all other membrane except tonoplast.
        a. Freely permeable- freely permeable to some molecule.
        b. Slowly permeable- slowly permeable for some molecules.
        c. Impermeable- not permeable

- Most cases permeability in a plasma membrane is an active process it depends upon energy and takes place against concentration gradient.

Movement of water in plants

- Major steps includes
  1. Flow of water from soil solution to root xylem through root cortex.
  2. Longitudinal movement of water solvent along the xylem of root, stem and leaf.
  3. Movement of water from leaf xylem to evaporate xylem.
  4. Water escape through stomata to atmosphere.
- Mechanisms involves
  - I. Absorption of soil water
    - a. Organ of water absorption
      - Root hairs are the chief water absorption area. Root hairs are close contact with capillary water absorbs easily.
      - Root hairs are present just above the meristematic zone.
      - Root hairs increase the surface area of absorption. It is the extension of epidermis.
      - Root hairs are unicellular. The number of root hairs varying according to species. Angiosperm contains more root hairs than gymnosperms. Some gymnosperms lack root hairs.
      - Root hairs are unicellular, thin delicate, tubular outgrowth of epidermis/ epiblema. They are short living. Cell wall made up of outer pectin and inner cellulose. Cellulosic cell wall is hydrophilic in nature. Root hairs also have thin layer of cytoplasm and a big central vacuole. Nucleus is found at the base.

    - b. Factors affecting water absorption
      1. Availability of soil water
         - Most available water is capillary water.
         - If the capillary water present below permanent wilting percentage, it adversely affect the plant.

      2. Temperature of the soil
         - The temperatures at 20^0c or below 20^0c inhibit absorption. 20 $^{0-}$30 ^{0}c maximum absorption of water takes place.
      3. Concentration of soil solution
         - If the soil solution is hypertonic, exosmosis is takes place. Thereby wilting of plants occurred.

4. Aeration of the soil
   - Poorly aerated soil retards the absorption. Accumulation of co_2 also inhibits absorption.

c. Mechanism of water absorption

It occurs mainly in to two

1. Passive water absorption
   - ✓ It is the absorption of water without the involvement of metabolic energy.
   - ✓ Passive water absorption takes place at high transpiration rate.
   - ✓ Due to the rapid loss of water mesophyll cells have a saturation deficiency which create a succion force. Which will transmit from leaf to the root through xylem.
   - ✓ Three physical process involved in passive absorption.

     a. Imbibition
        - It is the absorption or adsorption of water molecule by the hydrophilic constituent of the cell wall. Such as cellulose, hemicellulose, starch by surface attraction.
        - Water thus absorbed called imbibate. The substance which absorbs water called imbibant.
        - Imbibition involves the movements of water in a concentration gradient.
        - Imbibition differs from diffusion,
          It require an imbibant, no membranes are involved in diffusion.
        - Imbibition requires two conditions.
          Diffusion pressure gradient
          Strong affinity between imbibant and water.
        - When an imbibant is immersed in water it swells up and it has an inward pressure called matric potential. Matric potential is very high in dry seed and wood.
        - During imbibition, some energy lost as heat called heat of swelling/ heat of hydration. That is the reason why water becomes warm when dry seeds are immersed in it.
        - Significance of imbibition
          1. It is the first step of water absorption.
          2. It helps or initiates process of germination in seeds.
          3. It causes swelling of seed coat and breaking of testa during germination.

     b. Diffusion

- Random movement of ions or molecules of a solvent, solute or gas in a concentration gradient.
- It occurs always from a region of higher concentration to lower concentration. It continues till it attains an equilibrium point.

  Eg. When a perfume bottle open at the corner of a room. Fragrance spread at very fast.
- Diffusion pressure- it is the pressure generated by the concentration of its ions or molecules. Higher the number of diffusing molecule higher will be its diffusion pressure.
- Diffusion pressure (DP) is high in pure water, low in hypotonic and lowest in hypertonic solution.
- Diffusion pressure deficit (DPD) is the decrease in rate of diffusion of liquid or any other substances from cell to surrounding medium or surrounding medium to cell.

  Eg. Full fludged cell have DP maximum DPD minimum.
- DPD here represent the difference between diffusion pressure of soil and root hair content.
- The direction of diffusion of one substance is independent to another it occurs in different direction.
- But rate may slow down to collesion of different molecules.
- Significance of diffusion
  1. It helps for the exchange of gases such as CO_2, O_2 during photosynthesis and respiration.
  2. Ions are absorbed by simple diffusion during passive salt uptake.
  3. It helps for the transport of food for a short distance.
- Factors affecting rate of diffusion
  1. Temperature

     Rate of diffusion is directly proportional to temperature.
  2. Density of diffusing substance

     It is inversely proportional to diffusion.
  3. Size of the diffusing molecule

     It is inversely proportional to diffusion.
  4. Concentration of the medium

     It is inversely proportional to diffusion.
  5. Diffusion pressure gradient

     Greater the diffusion pressure gradient greater would be the diffusion.

c. Osmosis

- It is the movement or flow of solvent from hypotonic to hypertonic solution through semipermeable membrane.
- In plants water move from soil to plant through osmosis and also from one cell to another cell by crossing plasmamembrane and tonoplast.
- So 70% of water in vacuole.
- Osmotic movement of water depends on difference in osmotic potential (potential due to solute). So it can draw solvent through osmosis from hypertonic to hypotonic solutions.
- Tonisity –it is the relative concentration of solute in a solution. Osmotic potential directly propotional to tonisity. Water always move from low tonisity to high tonisity.
- Significance of osmosis

  1. It is the major mechanism of water absorption.
  2. It helps for the cell to cell movement of water.
  3. It helps to maintain the turgidity and shape of the cell.
  4. It indirectly involves the movement of organs.

     Eg: sleeping movement

     Opening and closing of stomata.

  5. It provide resistance against drought and frost.

- Plant cell as an osmotic system
  - Water spontaneously move from soil to root by osmosis because soil solution is hypotonic compared to root cells. This entry causes swelling of cells. There by water potential increases solute potential decreases. It causes turgor pressure (TP).
  - Turgor pressure is the intercellular hydrostatic pressure developed within the cell due to entry of water by endosmosis. This turgor pressure is counterbalanced by an equal and opposite pressure exerted by cell wall called wall pressure.
  - When turgor pressure equals to wall pressure osmotic entry of water stops. Turgidity is essential for the mechanical support, normal growth and shape of cell etc.

✓ Factors affecting passive water absorption

a) Water potential

The rhythematic change in water potential cause passive water absorption.

b) Tonisity
c) DPD

2. Active water absorption
   - ✓ When transpiration rate is low, the energy dependent active water absorption takes place. It occurs against the concentration gradient.
   - ✓ Two types of active absorption
     1. Osmotic active water absorption
        - ▪ First cell wall absorbs water by imbibition. Then cell wall allows both solute and solvent. So water enters to cell wall and come in contact with plasma membrane.
        - ▪ Osmotic potential of soil is below 1 atm and that of cell sap is 2-8 atm. So there exists a water potential gradient.
        - ▪ So water move from soil to cell sap.
        - ▪ Water move from cell to cell like this, at last it enters to xylem.

     2. Non-osmotic active water absorption
        - ▪ When the osmotic potential of root hairs is lower. Absorption of water can occurs in normal condition water should move from root to soil (exosmosis).
        - ▪ In such cases water movement occurs against concentration gradient. Energy from respiration is used for this.
        - ▪ Low temperature, lack of oxygen, respiratory inhibitors etc, causes non-osmotic water absorption.

II. Radial conduction of water
   - ➢ Radial conduction means the absorbed water flow from root hair to root xylem through root cortex.
   - ➢ The flow of water takes place in differently.
     1. Vacuolar pathway
        - ▪ Also known as transmembrane pathway.
        - ▪ Vacuole to vacuole pathway.
        - ▪ Here water cross tonoplast, protoplasm, plasmamembrane, cellwall
     2. Symplastic pathway
        - ▪ Cell to cell diffusion of water through the plasmodesmata and plasmamembrane.
        - ▪ Here plasmodesmata serve as free channel.
     3. Apoplastic pathway

- It is the cell wall to cell wall diffusion of water through cell wall and intercellular space.
- It occurs exclusively through cell wall without crossing tonoplast.

III. Ascent of sap

- It is the upward movement of water and dissolved substance through xylem (from root xylem to leaf xylem).
- It occurs against gravitational force and depends on transpiration. So it is also called transpiration stream.
- Since it depends on transpiration. It may vary rapid during day time.
- Three facts about ascent of sap.
  - ✓ Lumen of xylem vessels and tracheids serves as main pathway.
  - ✓ Phloem does not involve or participate in ascent of sap.
  - ✓ Xylem walls have only a minor role.
- Theories of ascent of sap
  1. Vital theory
     - According to vital theory living cells have or plays an important role in ascent of sap.
       a. Relay pump theory / clambering theory of Godlewsky
          - ✓ Ascent of sap takes place due to the pumping activity of living xylem parenchyma.
          - ✓ Living cells of xylem parenchyma shows rhythematic change in osmotic potential. When osmotic potential increases water enters to cell by endosmosis, absorbed water enters lowers osmotic potential. Like ways ascent of sap takes place.
          - ✓ Demerits of relay pump theory
            - o Living parenchyma is not seen in between two xylem elements. But they are found laterally to xylem elements.

       b. Pulsation theory of J. C. Bose
          - ✓ Ascent of sap occurs due to the pulsatory activityof parenchyma of innermost cortical cell, seen just outside to the endodermis.
          - ✓ Expansion and contraction of these cells cause pumbing. He proved these theory by electric probe apparatus.
          - ✓ One side of the apparatus is attached with probe and one side with galvanometer. He introduces the

probe into the stem slowly. When it reached innermost cortical cells galvanometer shows deflection.

- ✓ This pulsation is called as heart beating of plants.
- ✓ This theory has so many drawbacks

2. Root pressure theory
   - It was proposed by Priestley.
   - According to this theory ascent of sap occurs due to root pressure.
   - If a stem cut near it base. Sap is flow out through injured part called bleeding or exudation.
   - Root pressure is a pressure developed in the trachiery elements of xylem due to the entry of water as a result of metabolic activity of root.
   - Root pressure has been found lowest in summer and higher in early morning of spring and rainy season.

3. Physical theory
   - Non-living cells are involved in this.

   a. Capillary theory
      - ✓ Proposed by Boehm.
      - ✓ According to this theory capillary action of trachieds and vessels are responsible for ascent of sap. They act as capillary tube.

   b. Imbibition theory
      - ✓ Imbibition of cell wall of xylem are responsible for ascent of sap.

   c. Transpiration pull / cohesion tension theory
      - ✓ Proposed by Dixon & Jolly.
      - ✓ This theory was most accepted theory for ascent of sap.
      - ✓ Cohesive and adhesive properties of water helps to form continuous and unbroken column of water throughout xylem from root tip to mesophyll cells of leaf.
      - ✓ Thus continuous transpiration generates a pulling force.
      - ✓ Transpiration cause heavy loss of water fromleaves.
      - ✓ Cells of transpiring area become dehydrated.
      - ✓ Dehydration lowers water potential and generates a strong force of osmotic pull in them. It is called transpiration pull.

- ✓ Transpiration pull causes drawing of water to dehydrated cells from nearby hydrated cells.
- ✓ Transpiration pull passes from leaves to root.
- ✓ As a result water is continuously lifted up from root to leaf against gravitational force in the form of continuous water column.
- ✓ Water column is continuous due to adhesion and cohesion of water.
- ✓ Evidences for this theory
    - Osmotic potential of mesophyll cells is 20atm. It is sufficient to raise water up to 200meters.
    - Tensile strength of xylem sap is 25-30atm, which is sufficient to maintain a continuous water column.

2.TRANSPIRATION

- **Transpiration** is the loss of water in the form of vapour through uninjured aerial part of the plant.
- About 99% of water gets eliminated through transpiration.
- Principle organ of transpiration is leaf.
- Types of transpiration
    1. Stomatal type- through leaf stomata
    2. Cuticular type- through cuticle of epidermis
    3. Lenticular type- through lenticel
- **Stomatal transpiration**
    - ✓ Stomatal transpiration is a **two steps** process.
        1. Evaporation of water from saturated mesophyll cell near the sub-stomatal chamber.
        2. Diffusion of this water from saturated sub-stomatal chamber to atmosphere.

    - ✓ In normal case evaporation occurs from saturated mesophyll cell near the sub-stomatal chamber.
    - ✓ But in some cases evaporation occurs from inner surface of the epidermis not from mesophyll cell called **peristomatal transpiration**.
- **Transpiration flux** is the quantity of water transpired by unit area of the leaf surface in a unit time.
- **Structure of stomata**
    - ✓ Stomata is the pores on the epidermis.
    - ✓ Stomata helps for the gaseous exchange and water elimination.
    - ✓ Stomata is surrounded by a pair of kidney shaped or dumb bell shaped cells called guard cells.

- ✓ Guard cell differs from other epidermal cells in having, chloroplast and high concentration of sugars. They control the opening and closing of stomata and there by regulate transpiration and water loss.
- ✓ These guard cells are smaller than other epidermal cells. Hence they are rapidly affected by small change in turgor pressure.
- ✓ These guard cells surrounded by subsidiary or accessory cells.
- ✓ These guard cells have thick wall towards the pore and thin on opposite side. And these are attached or connected to each other in both ends.
- ✓ The cell wall has an elastic property. And guard cell have plasmodesmatal connection with mesophyll cells.

- **Distribution of stomata**
  1. Hypostomatous- stomata more on the lower surface.
  2. Hyper stomatous or epistomatous- stomata more on upper surface
  3. Amphistomatous- stomata seen on both upper and lower surface

- **Different types of stomata**
  1. Photoactive
     - ✓ Activity depends on the light condition.
     - ✓ Open during day time, close during night time.
     - ✓ Characteristic of mesophyte
  2. Scotoactive
     - ✓ Open during night time, close during day time.
     - ✓ Eg. xerophyte
  3. Hydroactive
     - ✓ Open during water is loss and turgidity falls low. They remain closed when water gains and turgidity becomes high.
  4. Pulsatory movement
     - ✓ Regular and rhythmic movement of stomata will cause the opening and closing.

- **Stomatal movement**
- ✓ Stomatal movement is controlled by opening and closing of guard cells.
- ✓ It depends on light intensity, pH, concentration of CO_2 and water.
- ✓ Opening and closing occurs due to change in turgor pressure. During opening guard cells become turgid. Thin wall of the guard cell become extended. And thick wall become concave.
- ✓ During closing guard cell become flassive and reverse back to original position.

- **Mechanism of stomatal movement**
  - ✓ Stomata are turgor operated valves and movement is controlled by light intensity, O_2, H_2O ,CO_2, pH etc.
  - ✓ Stomata open when turgidity falls high, close when turgidity falls low.
  - ✓ Opening of stomata have 2 phases
    1. Tension phase
       During tension phase guard cells, breadth gets increased.
    2. Motor phase
       During motor phase they bend outward.

- ✓ During stomatal opening, the water potential of the guard cells falls low. As a result, their osmotic potential goes high and water enters them. This raises the turgor.
- ✓ At high turgor, the guard cells swell and bend outward, pulling the inner walls of the two cells away from each other. This widens the stomatal pore.
- ✓ During stomatal closing, the water potential of the guard cells goes high. As a result, their osmotic potential falls low and water escapes from them. This lowers their turgor.
- ✓ At low turgor the inner walls of the two guard cells move closer to each other. Fnally the two cells met together, completely closing the stomatal pore.

- **Theories of stomatal movement**

1. . **Starch - sugar interconversion hypothesis of stomata opening and closing.**
   It was formulated by Lloyd (1908), extended and elaborated by Sayre (1923) and Scarth (1932). The theory holds that transpiration is controlled by the reversible starch-sugar interconversion and also by the effect of pH on the enzymes which governs these interconversion.

(a) During daytime: According to this theory, the CO2 released in respiration is utilized in the process of photosynthesis, which makes the medium of the guard cell alkaline. Due to this high pH, the starch produced in the night is converted into sugar in the presence of enzyme phosphorylase. Sugar is soluble in water and consequently increases to the OP of the guard cells. Therefore, the cells become turgid. In this state, the thin outer wall of guard cell stretches outward and opens the stomata.

(b) During the night: During the night, the CO_2 produced in respiration is not utilized and diffuses into the cytoplasm of guard cells. It makes the medium of the guard cells acidic (low pH). At this low pH, the sugar made during daytime is also converted into starch. Starch being insoluble in water reduces the osmotic pressure of the guard cell. Consequently, water moves from guard cells to the attached subsidiary cells. It makes the guard cells flaccid and therefore, stomata close.

2. **Active K^+ Transport or Potassium Pump Theory and Role of Abscisic Acid:**

The concept of K^+ ion transport was given by Fujino. It was supported and elaborated by Levitt & Rashke in 1975 It appears to be an active mechanism which needs ATP. It is based on recent observations and explains the mechanism as follows.

A. Opening of Stomata during Daytime (in presence of light):

Opening of stomata depends upon following conditions:

(a) Presence of light.

(b) Decrease in starch contents of guard cells.

(c) Increased concentration of malic acid in guard cells.

(d) Influx of K^+ ions in guard cells.

(e) Efflux of H^+ ions from guard cells.

(f) Intake of CI ions by guard cells.

(g) Low CO_2 concentration in an around guard cells.

(h) High pH (more than 7) in guard cells (hence, alkaline medium of the cell sap in guard cells).

(i) High T.P. in guard cells due to endosmosis, (turgidity of cells).

(j) TP more towards thin wall of guard cell & stomata open.

Explanation of Levitt Concept:

This is explained as follows:

In the guard cells, starch is converted into malic acid in presence of light (during day time).

$$\text{Starch} + H_2O \longrightarrow \text{Hexose Sugars}$$

$$\underset{\text{Hexose}}{2C_6H_{12}O_6} + 3O_2 \longrightarrow \underset{\text{Malic acid}}{3C_4H_6O_5} + 3H_2O$$

Malic acid then dissociated into Matale anions and protons.

$$\underset{\text{Malic acid}}{[R(COOH)_2]} \longrightarrow \underset{\text{Malate Anions}}{R(COO)_2^-} + \underset{\text{Protons}}{2H^+}$$

Protons (H^+) thus formed are used by the guard cells for the uptake of K+ ions (in exchange for the protons H^+). This is an active ionic exchange and requires ATP energy and cytokinin (a plant hormone). In this way, the concentration of K^+ ions increases in guard cells. At the same time, the concentration of H+ ions decreases in guard cells. The pH of the cell sap in guard cells also increases simultaneously (pH becomes more than 7 and the medium becomes alkaline).

There is also an increased uptake of CI” (anions) by the guard cells to maintain the electrical and ionic balance inside and outside the guard cells. The malate anions formed in the guard cells are neutralized by the K+ ions. This results in the formation of potassium malate.

Malate anions + K^+ →Potassium malate:

Potassium malate enters the cell sap of the guard cells thereby reducing the water potential while increasing the osmotic concentration (and the O.P.) of the cell sap. Hence, endosmosis occurs, guard cells become turgid and kidney-shaped and the stomata opens.

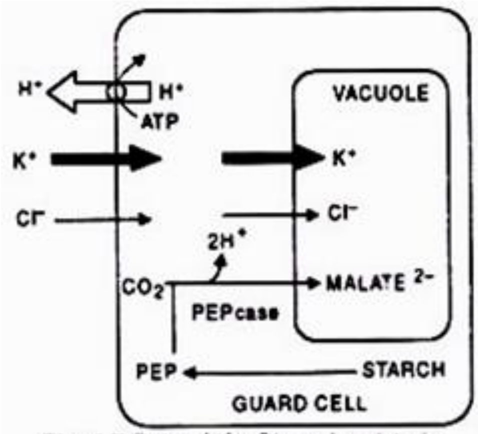


Fig. 4.7 Role of K+, Cl− and malate in increasing osmotic concentration (decreasing water potential) of guard cells.

It is also observed that the CO_2 concentration is low in and around guard ceils during day time. This is due to high photosynthetic utilization of CO_2. It helps in opening of stomata.

B. Closing of Stomata in Absence of Light (Darkness/Night Time):

Closing of stomata depends on following conditions:

(a) Absence of light.

(b) Decreased concentration of malic acid in guard cells.

(c) Efflux of K^+ ions from guard cells.

(d) Influx of H^+ ions in guard cells.

(e) Acidic medium of the cell sap in guard cells.

(f) Loss of Cl^- ions from guard cells.

(g) Increases CO_2 concentration in and around guard cell due to release of CO_2 in respiration combined with the absence of photosynthetic activity in dark.

(h) Presence of plant growth inhibiting hormone abscissic acid (ABA),

(i) Loss of turgidity and loss of kidney-shape by guard cells.

All these conditions represent the reversal of the daytime events. Under these conditions, the guard cells lose water by exosmosis and become flaccid. This causes closing of the stomata.

Role of Plant Hormones in Stomatal Movements:

(i) Presence of Cytokinin (Plant growth regulator) is needed for the active uptake of K^+ ions

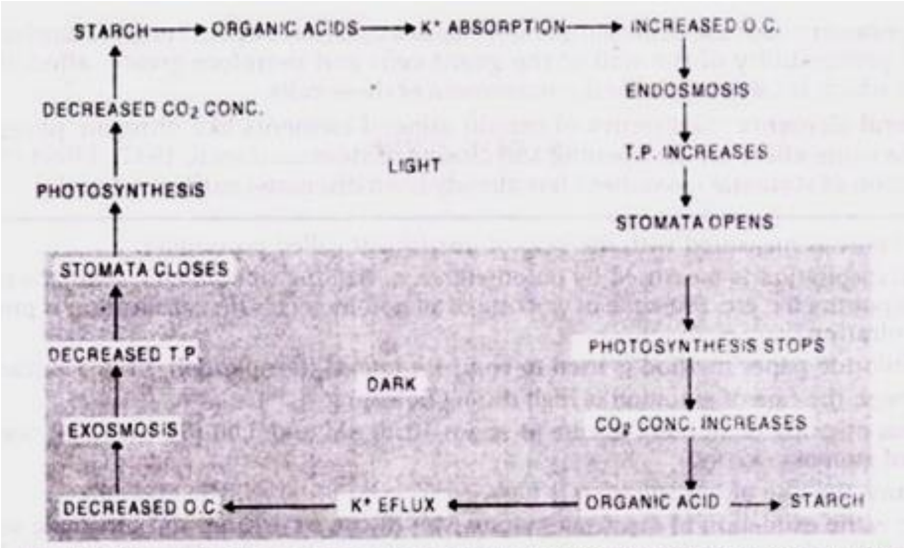


Fig. 4.8 Schematic diagram to explain active potassium ion (K⁺) transport in plants.

(ii) Presence of ABA (abscissic acid, a plant growth inhibiting hormone) favours closing of stomata by blocking uptake of K^+ by guard cells in the dark. It also prevents efflux of H^+ ions from guard cells. ABA and CO2 cone, together help in lowering the pH in guard cells and making the medium acidic. This helps in closing of stomata. ABA act as stress hormone during drought condition.

- Significance of transpiration
    - Advantages
        - ✓ It promote gaseous exchange, respiration and photosynthesis.
        - ✓ Protects plant tissue from excessive water accumulation by eliminating surplus water.
        - ✓ Speed up the passive absorption and passive conduction of soil solution.
        - ✓ Promote the distribution of mineral nutrients.
        - ✓ It maintains favourable temperature and protect leaves.
    - Disadvantages
        - ✓ Heavy loss of water takes place.
        - ✓ It sometimes causes temporary wilting. Internal water deficit or water stress and desiccation also taken place.
        - ✓ Burden of special adaptation.

Guttation

- It is the exudation of liquid drop of water with inorganic solutes through a smsll opening called hydathodes from uninjured xylem endings.
- It occurs through scars and lenticels of stem also.
- It is an adaptation for elimination of extra water in fully turgid plants.

- It particularly occurs at night.
- It is common in tropical herbaceous plants, growing under high humidity, high soil moisture, high water absorption and very low transpiration.
- Root pressure is the major cause of guttation.
- The hydathodes are present over a loosely arranged cells epithem.
- Guttation is less important to plants cause injury by salt deposition. This salt deposition invite pathogenic organisms like bacteria, fungi etc.

Anti transpirants

- Substances sprayed on leaf surface to reduce transpiration without any significant effect in other physiological activity like respiration, photosynthesis etc.
- It prevent excessive transpiration there by prevent wilting.
  Eg. Colourless plastic, silicon oil, low viscosity waxes etc.
- Antitranspirants fall under the following main groups;
  1. Water impermeable substances- eg. Colourless plastic, silicon oil, low viscosity
  2. Substance which can cause partial closure of stomata- eg. Salicylic acid, phenyl mercuric acid.
  3. Metabolic inhibitors – eg. Abscisic acid, aspirin

Factors affecting rate of transpiration

1. External factors like
   a. Atmospheric humidity
   b. Temperature
   c. Wind
   d. Relative humidity
   e. Light
   f. Carbon dioxide concentration
2. Internal factors like
   a. Internal water condition
   b. Structural features
   c. Age of the plants
   d. Root- shoot ratio
   e. Leaf area

Bleeding

- It is the slow exudation of watery sap from incision made on plant.
- There are 4 types of bleeding
  1. Oozing out of xylem sap due to the root pressure
  2. Oozing out of xylem sap due to the local pressure
  3. Oozing out of phloem sap due to the local pressure
  4. Oozing out of milky latex from laticiferous tissue of cortex and pith.

Soil plant atmospheric continuum (SPAC)

- movement of water from the soil through the plant to the atmosphere involves different mechanisms of transport:
- In the soil and the xylem, water moves by bulk flow in response to a pressure gradient
- In the vapor phase, water moves primarily by diffusion, at least until it reaches the outside air, where convection (a form of bulk flow) becomes dominant.
- When water is transported across membranes, the driving force is the water potential difference across the membrane.
- In all of these situations, water moves toward regions of low water potential or free energy.

Module 2: Plants & Inorganic Nutrients

- Energy giving and body building materials are called food constituents or nutrients.
- Plants procure and utilize nutrients is called nutrition.
- Mineral nutrients utilized for
  - ✓ Synthesis of organic compounds.
  - ✓ Structural and functional framework of the plant body.
  - ✓ Complex nutrients serve as body-builders and energy suppliers.
  - ✓ Oxidation of some nutrients releases energy.
- Essential elements are the most essential and indispensable for the growth and development of plants. Others are non-essential.
- Essential elements-C,H,O,N,P,S, Ca, Mg, B, Cl, Cu, Fe, Mo, Mn and Zn.
- Nonessential elements- Na, V, Co, Fe, Se and Si.
- Na, Fe are not essential for many plants, though they are essential for animals.
- Criteria for essentiality of elements
  1. Elements must be inevitable or indispensable for normal growth, development and reproduction and in its absence the plants is unable to complete its normal life cycle.
  2. The biological role of the elements must be specific and not replaceable by other elements. The elements are functionally replaceable by another.
  3. The elements must have a direct nutritional role.
  4. The elements must be able to serve as a structural component or as a functional constituent; more specifically it must be an integral part of an essential plant constituent or a metabolite.
- The essentiality of elements can be determined by water culture experiments or hydroponics.
- Sources of essential elements
  - ✓ Plants obtain essential elements from soil, water and atmosphere.
  - ✓ Non-mineral elements like C, H, O are absorbed from soil, water and atmosphere.
  - ✓ Mineral elements like N etc. are released to the soil by weathering of rocks and are absorbed mainly as inorganic ions.
  - ✓ N can be absorbed from soil as nitrites, nitrates and ammonium.
  - ✓ H obtained in the form of water.

- Overall processes by which mineral nutrients are absorbed from soil, then transported to different parts and finally utilized for the production of organic matter called mineral nutrition.
- Mineral nutrition is completed in three stages like absorption, conduction and assimilation.
- Beneficial elements
    - ✓ Non-essential elements promote growth and some others functionally replace some essential elements.
      Eg: Barium, Strontium, Rubidium, Caesium, and Beryllium.
    - ✓ Sodium- promotes the growth of several plant species (halophytes).
    - ✓ Cobalt- part of vitamin B_{12} & essential for nitrogen fixation.
    - ✓ Silicon- decrease transpiration, provide resistance against several pathogens and reducing toxicity of Fe and Mn by precipitating them.
    - ✓ Barium and strontium- replace calcium in physiological functions.
    - ✓ Caesium and rubidium - replace potassium in physiological functions.
    - ✓ Beryllium can partly replace Mg in some species.
- Microelements and microelements
    - ✓ Based on the relative degree of essentiality or requirements, essential elements of plant nutrition are arbitrarily grouped into macro elements and micro elements.
    - ✓ Macroelements-essential elements needed in large amounts, eg. C,H,O,N,K,Ca, Mg, Fe, P and S.
    - ✓ Microelements are essential elements required only in very small or trace amounts. Eg. B, Cl, Cu, Mn, Mo, Zn etc.
    - ✓ Plants absorb minersl elements from the soil mainly as inorganic ions, either as anionic or as cations known as mineral nutrients.
    - ✓ These mineral nutrients belong to two groups macronutrients and micronutrients.
    - ✓ Primary macronutrients-N,P,K
    - ✓ Secondary macronutrients-Ca, Mg, S etc.
- General functions of essential elements
    1. Form the structural framework of protoplast and cell wall.
    2. Enter into the synthesis of several biologically important molecules such as proteins, enzymes, hormones, nucleic acids, ATP, GTP, chlorophyll and cytochromes etc.
    3. Regulate the pH of the cytoplasm and vacuole sap by serving as pH buffers.
    4. Control the permeability of cell membrane
    5. Mineral ions of the vacuole sap influence the osmotic potential of the cell.
    6. Some mineral elements serve as activators or co-factors of enzymes and thereby play a role in catalytic conversions.
    7. Potassium ions play an active role in the opening and closing of stomata.
- Mineral deficiency and its symptoms
    - ✓ Plants require a critical concentration of mineral nutrients for growth and development.
    - ✓ Critical concentration is the lowest concentration at which plant growth is normal.
    - ✓ Adequate concentration is the concentration above critical level which will have no effect on the growth of the plants.
    - ✓ Deficient range, concentration below critical level it behaves as limiting factor.
    - ✓ There are 2 different type of deficiency
      1. Mild or moderate

2. Extreme or severe

- ✓ Optimum concentration is the highest level of mineral concentration at which plant growth is maxima.
- ✓ Luxury range, just above optimum concentration, which have only neutral effect on plant growth.
- ✓ Toxic range, above to luxury level. Mineral nutrients are toxic to plant.

- Visible symptoms of mineral deficiency called **hunger signs**. Like chlorosis, necrosis etc.
- Some mineral are essential for normal plant growth. There are some deficiency symptoms like stunted growth, necrosis, chlorosis, delayed flowering and fruit maturation etc.
- Absorption of mineral nutrients
  - ✓ Uptake of mineral ions from soil by root system called soil mining.
  - ✓ Piliferous part of the root epidermis helps for mineral uptake. So mineral absorption is independent of water absorption.
  - ✓ The movement of ions through plasma membrane called flux.
  - ✓ Inflow of ions called influx. Out flow of ions called efflux.
  - ✓ Uptake of mineral ions by 2 mechanisms

1. Active
2. Passive

1. Passive

- Without energy utilization.
- Absorption takes place in different methods

a. Passive diffusion
- Energy free diffusion across plasma membrane.
- It occurs in a concentration gradient.
- Diffusion continues till it attains an equilibrium point.

b. Facilitated diffusion
- Energy free diffusion with the help of a carrier proteins such as permeases and translocases**.**
- It operates in a concentration gradient as that of simple diffusion.
- Here ions first reversibly bind with carriers on outer surface. Then move across the PM. They dissociate and carrier molecule returned back to outer surface.

c. Ion exchange
- It is the exchange of mineral ions between the soil solution and cell cytoplasm.
- Ion exchange is mutual or reciprocal, similar charged ions are exchanged. Anions are exchanged with anion and cations with cations.
- In some cases exchange may be unilateral or one sided.
- In flow of one ion accompanied by an oppositely charged ions to maintain electric neutrality.

- **Theory of passive absorption**

1. Mass flow or bulk flow
- Mineral ions move across the PM in large amount along with water under the inspiration of transpiration pull.

- It is the passive absorption without the use of metabolic energy.
- According to this theory mineral absorption is directly related with transpiration.

2. Ion exchange theory

- Exchange of similar charged ions from root cell and soil, cations like K^+, Mg^{2+}, Ca^{2+} exchanged for H^+.
- Anions like SO_4^{2-},Cl^-, NO_2^- exchanged for OH^-

a. Contact exchange theory

- Ions absorbed on the soil particle and cell wall of root can oscillate within a limited space called oscillation volume.
- When oscillation volume of two overlaps each other ion exchange occurred.
- H^+ on root surface and K^+ on soil oscillate in their oscillation volume. When it overlap H^+ transfer to soil and K^+ to root.

b. Carbonic acid exchange theory

- In root CO_2 is continuously released as a result of respiration.
- This CO_2 dissolves in H_2O and form carbonic acid (H_2CO_3). Then H_2CO_3 dissociate and form H^+ and HCO_3^-. This H^+ ions exchange for cations, HCO_3^- for anions.

3. Donnan equilibrium

- There are certain preexisting anions inside the cell, which cannot diffuse outside through PM called fixed or non-diffusable ions.
- In such a condition when further anions enters to cell, it is accompined by an inflow of equal number of cations to keep ionic balance such a diffusion continue till cation and anions inside the cell become equal to soil solution.
- It can be represented as

$$[Ci][Ai] = [Co][Ao]$$

Ci = cation inside

Ai = anion inside

Co = cation outside

Ao = anion inside

2. Active

- Energy dependent.
- Not spontaneous process but an activated process and does not proceed to equilibrium stage.
- Active absorption, ions and molecules transport against concentration gradient.

- It causes the asymmetrical distribution of ions there by creates an ionic gradient for passive absorption.

- Two mechanisms of active absorption
  1. carrier concept
     - With the help of proteins and ATP.
     - To begin with carrier protein activated by utilizing ATP and enzyme known as phosphate kinase.
     - The activated carrier moves to outer surface of the PM.
     - And binds with specific ions called carrier ion complex. This complex moves across the PM. And dissociate ions into cell interior.
     - The free inactivated carrier, then returned back to pick up another ions.
  2. cytochrome pump theory
     - Also called Lundergradh cytochrome pump theory.
     - There is a definite correlation between respiration and anions absorption.
     - when a plant is transfer from water to a salt solution the rate of respiration increases. This increase in rate of respiration over normal respiration has been called anoin respiration or salt respiration.
     - The mechanism of anions absorption and cation absorption is different.
     - Anions are absorbed through cytochrome chain by an active process.
     - Cations are absorbed passively.
     - According to this theory
       1. Dehydrogenation reaction on the innerside give rise to protons and electrons.
       2. Electrons travel over cytochrome chain towards outside the membrane, so that Fe of cytochrome reduced to ($Fe^{3+} \rightarrow Fe^{2+}$)outer surface and oxidized in the inner side.
       3. On the outer surface reduced cytochrome oxidized by releasing an electron and taking an anion.
       4. The electron thus released unites with H+ and oxygen and to form water.
       5. Anion travel over cytochrome towards inside, on the inner side oxidized cytochrome becomes reduced by taking electron and anion release.
       6. As a result of anion absorption cation move passively from outside to inside to maintain electric neutrality.

- conduction of mineral nutrients
  - ✓ From the epidermal cell mineral ion enters into the root xylem through root cortex via apoplasic, symplastic and vacuolar pathway.
  - ✓ Once they reached at root xylem they are lifted upward through transpiration stream or ascent of sap. In the leaf they are used in the synthesis of organic molecule.
- Aquaporins

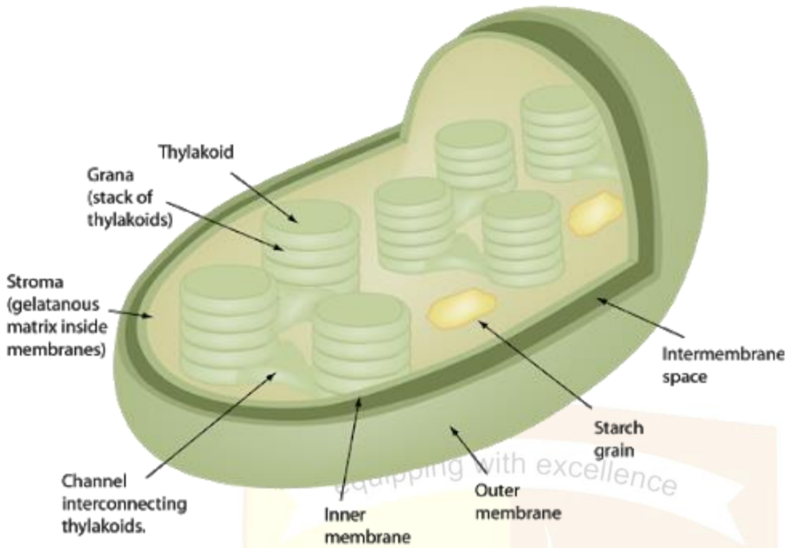
- ✓ They are the integral membrane proteins that form water selective channel across the PM. Water moves faster through this channel than lipid bilayer.
- ✓ These are found in plant and animal cell.

Module 3 : Photosynthesis

- The term photosynthesis derived from Greek word
  Photon=light, synthesis= putting together
- Photosynthesis is an anabolic process by which chlorophyll –bearing autotrophs synthesize carbohydrate and release molecular oxygen, using carbon dioxide, water, light energy and chlorophyll.

  $6CO_2+12H_2O \longrightarrow C_6H_{12}O_6+6H_20+6O_2$
- The produced carbon dioxide used in various metabolic activity.
- Leaf is the principle organ for photosynthesis, it have some definite characters like
  1. Broad area of leaf margin will absorb maximum light.
  2. Efficient gas exchange through stomata.
  3. Well organized transport system present in the leaf.
- In addition to green plants algae like red, green, brown, diatoms, sulphur bacteria, purple bacteria carryout photosynthesis. These organisms are abundant in oceans, so 90% of photosynthesis occurs in oceans.
- Significance of photosynthesis
  - ✓ Photosynthesis maintains more over less equilibrium level of CO2 and O2 in atmosphere.
  - ✓ It provides food for biological world.
  - ✓ Photosynthesis purifies air by taking CO2 and releasing oxygen.
  - ✓ It brings energy fixation and thereby initiate the dynamics of ecosystems.
  - ✓ It serves as a link between plants and animals.
  - ✓ Photosynthesis transformed primitive anaerobic atmosphere to present aerobic atmosphere.
  - ✓ Fossil fuels such as coal, petrol, natural gas are photosynthetic product.

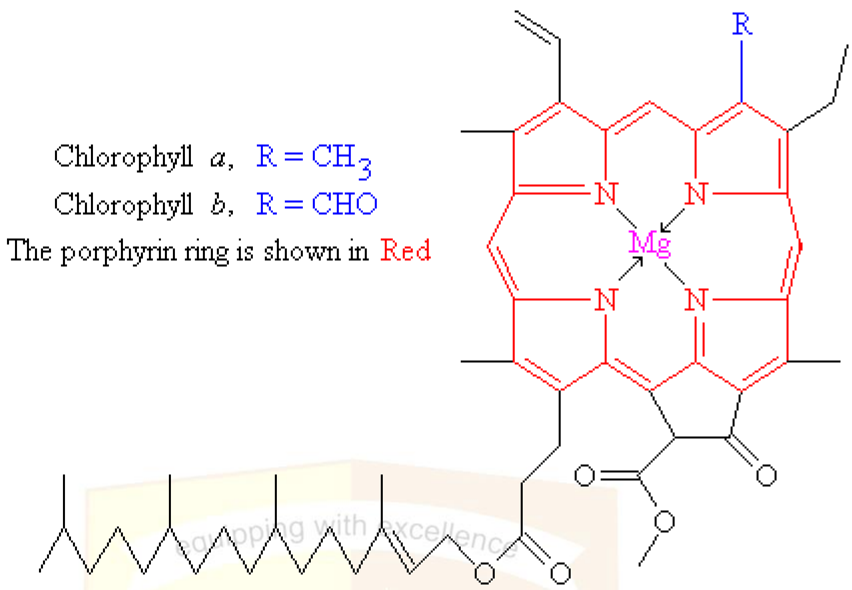
- Chloroplast is the centre of photosynthesis.



- Pigment systems
  - ✓ Pigments are the light sensitive molecule present in the thylakoid membrane. They absorb only specific wavelength of light.
  - ✓ Pigments are classified into
    1. Principal pigment
       - Chlorophyll a (green plants), bacteriocholorophyll (purple and green bacteria), chlorobium chlorophyll (green bacteria), bacterio-rhodopsin.
    2. Accessory pigment
       - Chlorophyll b, c, d, carotenoid (xanthophyll and carotene).

CHLOROPHYLL

- Structure of chlorophyll
  - ✓ They have a porphyrin (4 N_2containing pyrol ring) head and phytol tail. The porphyrin head with a central Mg atom.
  - ✓ Porphyrin is hydrophobic in nature.
  - ✓ This loke haemoglobin, instead of Fe magnesium is present.



- Kinds of pigments
  1. chlorophyll
     I. Chlorophyll a and chlorophyll b
        - Found in higher plants, cyanobacteria and algae.
        - Chlorophyll a has CH_3 in the second pyrol ring instead of CHO in chlorophyll b.
        - Chemical formula of chlorophyll b
          $C_{55}H_{70}O_6N_4Mg$

Chlorophyll a	Chlorophyll b
Principal pigment	Accessory pigment
Blue-green in pure state	It is olive green
$C_{55}H_{72}O_5N_4Mg$	$C_{55}H_{70}O_6N_4Mg$
In the first position side group at the third carbon is CH_3 (2^{nd} ring)	Here it is CHO
Molecular weight is 873.	Molecular weight is 907.

II. Chlorophyll c
- Found in brown algae, diatoms and dianoflegellate (Pinnularia, Noctiluca).
- Chlorophyll c lacks phytol tail.

III. Chlorophyll d
- Found in red algae.
- Instead of CH_2=CH_2 in first ring, O-CHO is present. That is the reason why they appear in green.

2. Carotenoids
   - Red, orange, yellow, brown coloured pigments.
   - They absorbs violet and blue light.
   - It impart autumn colour of leaf and it also gives colour to carrot and tomato.
   - It is lipid soluble hydrocarbon.
   - Those seen along with chlorophyll pigments in chloroplast.
   - Carotenoids are two types

1.Carotene	2.xanthophyll
Red, orange colored pigment.	Brown/ yellow colored pigment
Alpha, beta, gama, delta, lycopyne, phytotene types of carotene.	It is the oxygenated carotene.
Lycopene gives colour to tomato.	Xanthophyll is more abundant than carotene
Beta carotene is immediate precursor of vitamin A.	Leutin, zeaxanthin,fucoxanthin violoxanthin
	Fucoxanthin present in brown algae Alphacarotene → leutin Betacarotene → zeaxanthin

   - Significance of carotenoid
     - ✓ Since it is an accessory pigment, it can absorb light energy and transmit to chlorophyll a by resonance effect.
     - ✓ It protects chlorophyll from photo oxidation by absorbing excess blue light.

3. Phycobilins
   - It is found in red algae and cyanobacteria.
   - They can absorb green light, so they see as in black colour.
   - Accessory pigment.
   - Water soluble pigment. Others are insoluble in water.
   - Structure similar to chlorophyll but it lacks Mg. the tetra pyrol ring arranged linearly. And it side chains are covalently bonded with protein. This protein portion called apoprotein. The tetra pyrol ring portion called chromophore. It can absorb the light.
   - 4 types of phycobilins.
     1. Phycocyanin
     2. Phycoerythrin
     3. Allophycocyanin
     4. phytochromobilins
   - phycoerythrin can absorb dim light from deep ocean.

- Red algae appear as black. Because phycoerythrin and chlorophyll absorbs all light.

PHOTOSYNTHETIC UNIT (PSU)

- Smallest group of light harvesting molecule capable of carrying out photochemical reaction.
- Also called Quantasome.
- PSU has two units
  1. Reaction centre (RC)
     - Consist of 4-6 chlorophyll a
     - These are 3 types

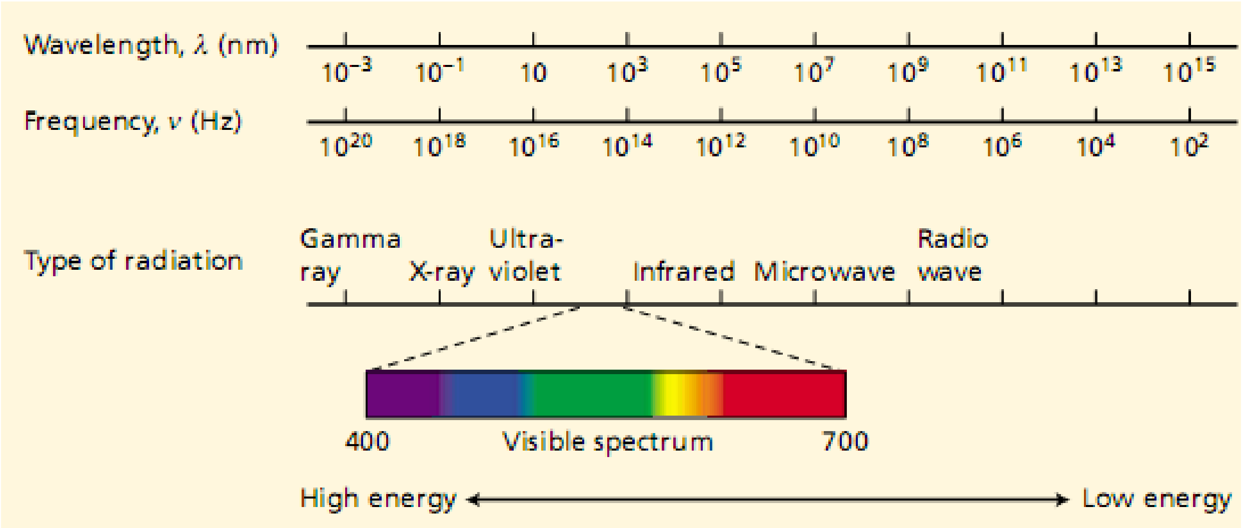
       P_{700}- with absorption maxima is 700nm.

       P_{680}- with absorption maxima is 680nm

       P_{870}- with absorption maxima is 870nm
     - RC is surrounded by LHPM.
  2. Light harvesting pigment molecule (LHPM)
     - LHPM are two type
       1. Core molecule
       2. Antenna molecule
     - LHPM absorb the light energy and transfer to reaction centre (through resonance transfer).
     - Core molecule situated close to reaction centre. Antenna molecule are surrounds the core molecule. Antenna molecule is 200-400 in number.
     - LHPM have carotenoid, chlorophyll c, d etc.
     - A single reaction centre increases in the efficiency in collection and utilization of light energy.

ELECTROMAGNETIC RADIATION

- Solar radiations are electromagnetic in nature are called electromagnetic radiation.
- Radiation enters into the biosphere called solar radiation flux.
- The solar light emitted from the sun called electromagnetic spectrum.

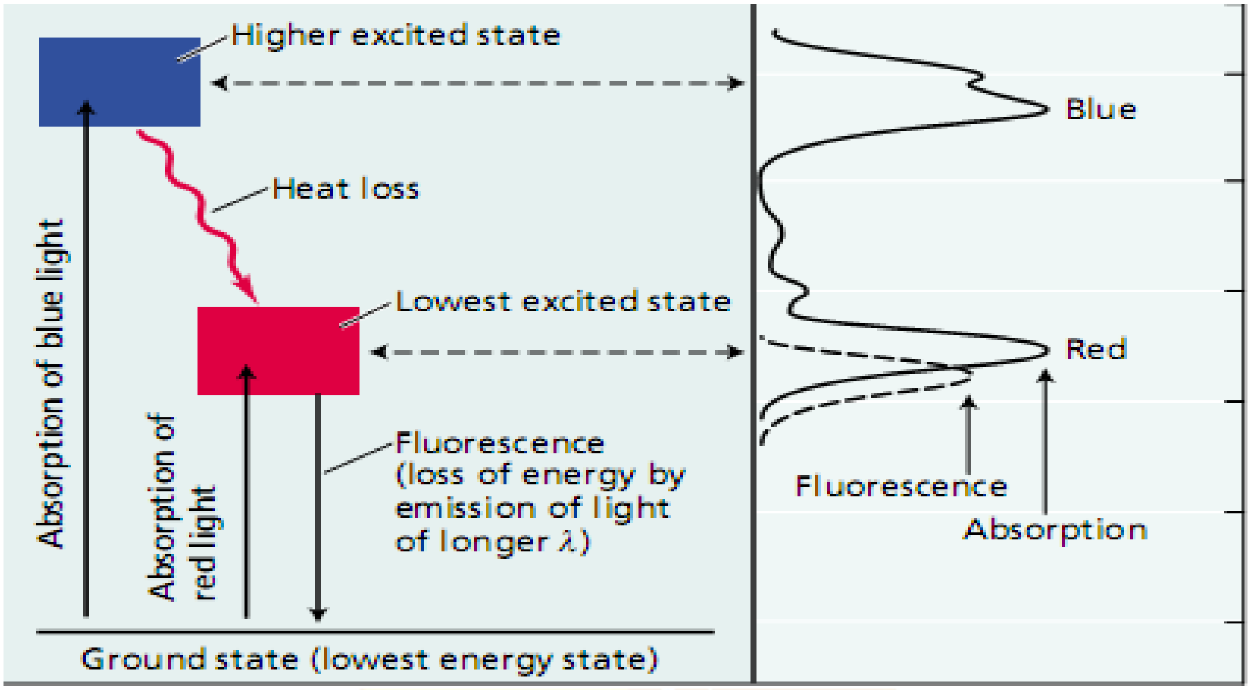


Electromagnetic spectrum

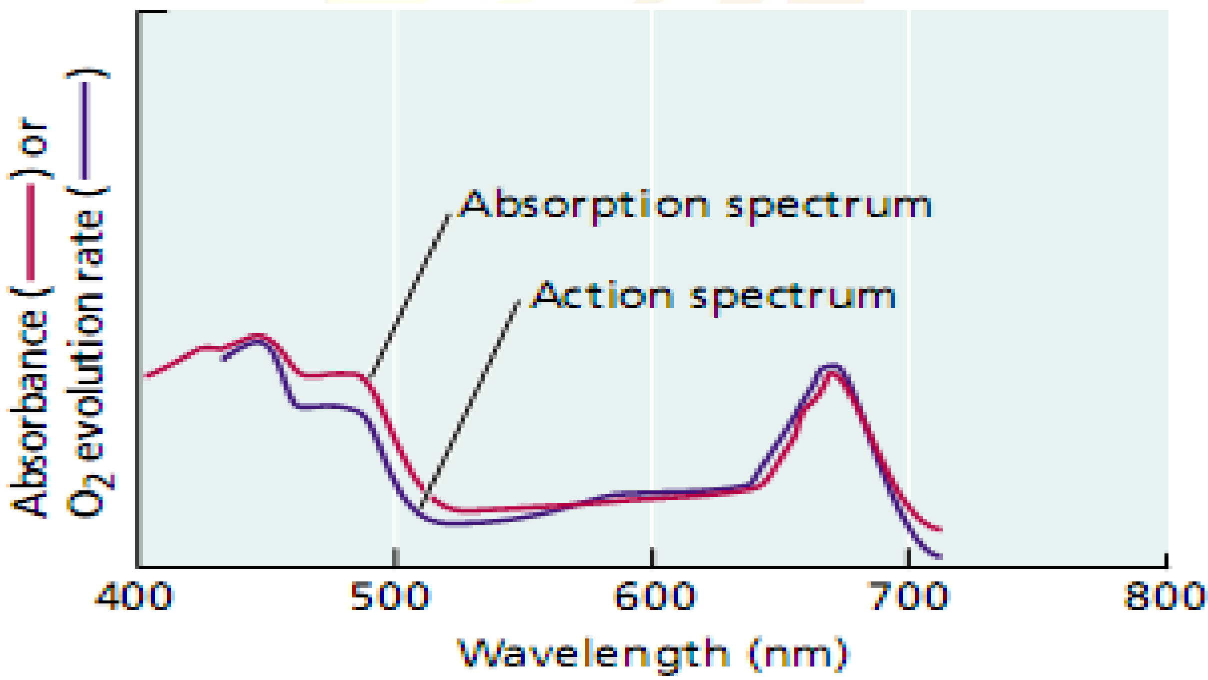
- Photosynthetically active radiation- visible spectrum used for photosynthesis.
- Usually light travel as a tiny or small energy packet called photons.
- The energy contains in a photon called quanta.
  Quanta are inversely propositional to wavelength.
- Photon or quanta required for the production of one molecule oxygen called quantum requirement.
- The smallest number or amount of pigment unit for the production of one quantum called quantasomes.
- Photosynthesis can be measured on the number of oxygen produced called quantum yield.

ABSORPTION & ACTION SPECTRUM

- Pigments are highly specific; chlorophyll a has two absorption peak ie blue and red.
- Carotenoids has also absorption peak on violet and red.
- The amount of light absorbed by a pigment can be plotted. Graphical representation of different wavelength of light absorbed by pigment is called absorption spectra.



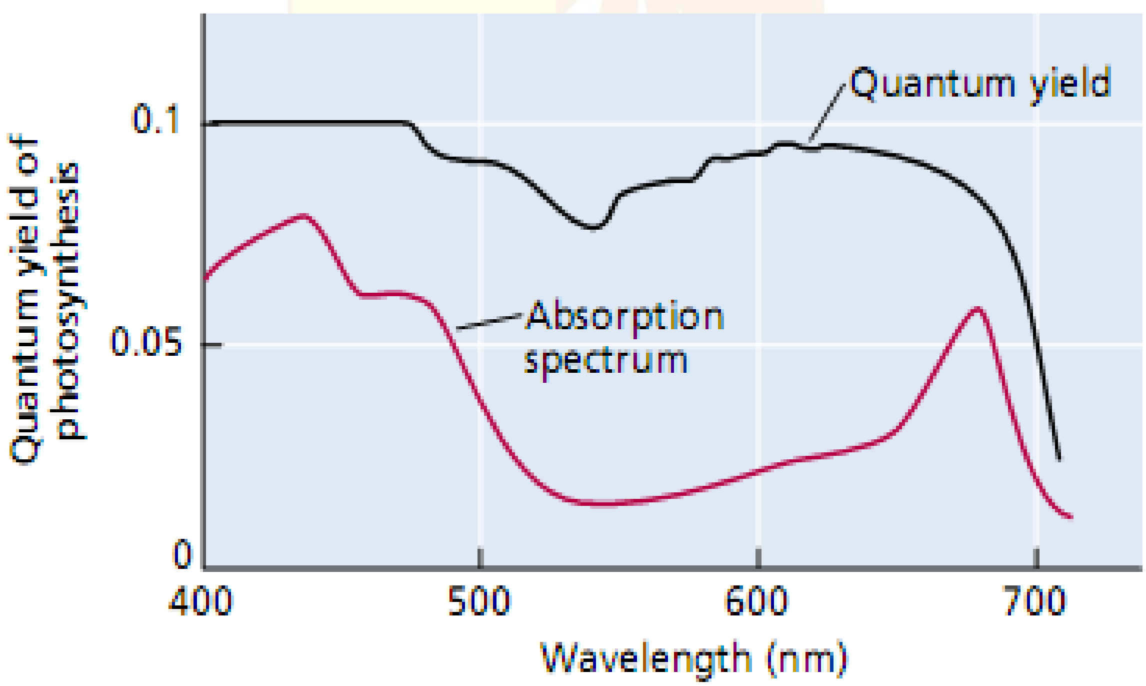
- An action spectrum is the graphical representation of effect of different wavelength of light on photosynthesis.



- Chlorophyll a is the primary trapping molecule.
- Rate of photosynthesis is directly propositional to efficiency to absorb blue and red.
- Certain part of the visible light are not absorbed by chlorophyll and have no role in photosynthesis.

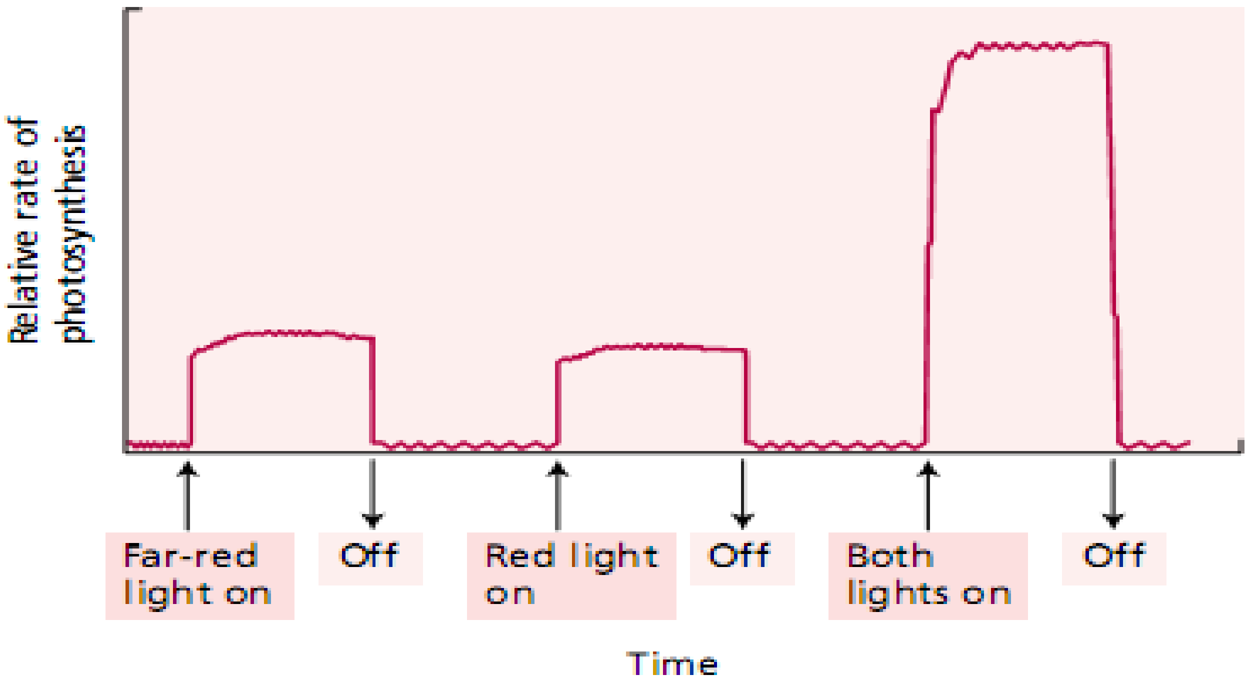
RED DROP AND EMERSON'S ENHANCEMENT EFFECT

- 8 quantum of light is required for the photosynthetic production of 1molecule oxygen and reduction of CO_2 to carbohydrate.
- While studying they exposed chlorella to monochromatic light and measured quantum yield.
- They plotted a graph according to this in terms of oxygen evolution against different wavelength of light.
- It aims to determine a particular wavelength at which oxygen evolution and quantum yield in maximum. But the yield was constant.
- In almost all region except a dip in 440-520nm (blue), it is due to absorption by carotenoids. It was constant till 680nm. But it shows a sudden drop at region above 680nm (far red). This sudden fall in far red region called Emerson red drop.



- The scientist further extended their study. They supply short wavelength along with long wavelength (above and below 680nm).
- The photosynthetic yield was enhanced.
- This enhancement of photosynthetic yield due to combined effect of short and long wavelength of light Emerson's enhancement effect.

- It is an example of synergism; combined effect was much higher than the sum total of their separate effect.
- They concluded that there exist two photosystems-
  -one driven by short wavelength (below 680nm).
  -another one driven by long wavelength (above 680nm).
- Red drop occurs when photosystems drive by shorter wavelength failed to functional beyond 680nm. When both lights are given both pigments started in function.



MECHANISMS OF PHOTOSYNTHESIS

- According to Blackman & Hill photosynthesis includes both light and dark reactions.
- Evidences:
  1. Flashing light experiments
     Warburg exposed one set of chlorella to continuous light and second set to intermitted light (alternating light and dark).
     Total timing of light was same in both, but duration was different. he measured photosynthesis and observed that those set showing intermitted light show high photosynthesis, indicate the efficient light utilization product of light reaction consumed.
     During continuous light the product of light reaction is accumulated.
  2. CO_2 reduction in darkness

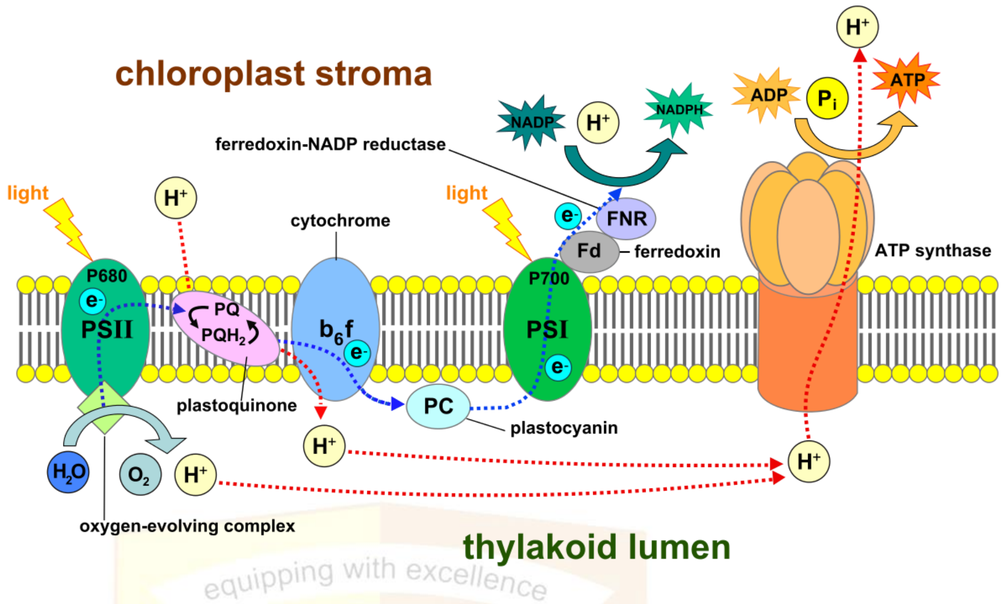
Calvin exposed plants to light in the absence of CO_2. Then it is transferred to darkness and provided $^{14}CO_2$. The reduced carbohydrate contains $^{14}CO_2$ it indicates CO_2 fixation takes place in dark also.

- Two different reaction in photosynthesis
  1. Light reaction- light dependent phase of photosynthesis.
  2. Dark reaction- light independent phase of photosynthesis
- During light reaction ATP & NADPH formed.
- Dark reaction, CO_2 reduced to carbohydrate using ATP & NADPH.

LIGHT REACTION

- It is the light dependent phase, takes place in grana thylakoids of chloroplast.
- Also known as photochemical reaction ie chemical reaction in the presence of light.
- 4 steps in photosynthesis
  - I. Photo excitation of chlorophyll
  - II. Photophosphorylation of ADP to ATP
  - III. Photo-reduction of NADP TO NADPH
  - IV. Photolysis of water
    1. Photo excitation of chlorophyll
       - ✓ Light reaction begins with excitation of chlorophyll.
       - ✓ Once the photons are absorbed by antenna molecules they get excited into a high energy state. This high energy state is unstable and short living. So it have a tendency to return to ground state by transferring the energy of next molecule.
       - ✓ Finally excitation energy reaches to chlorophyll a through resonance transfer.
       - ✓ So now chlorophyll a get excited and transforms to a new energy state. Soon the pigment molecule returns to its low energy and state by emiting high electron from it.
       - ✓ High energy electron emitted from reaction centre would be accepted by primary electron acceptor, the exact chemical nature is not known and it is believed to be pheophytin in PS I.
       - ✓ From the reduced primary electron acceptor electrons travel downhill result a series of redox reaction, these redox reactions are coupled to synthesis of ATP.
       - ✓ PSI – surrounded by chlorophyll a, b carotenoids. Located in stroma thylakoids and non-appressed regions of grana. They can carry out cyclic and non-cyclic photophosphorylations.
       - ✓ PSII – surrounded by chlorophyll a, b, carotenoids located at the appressed regions of grana thylakoid involved only in non-cyclic photophosphorylation.

2. Electron transport and oxidative phosphorylation
   1. Non –cyclic photophosphorylation
      - ✓ Result reduction of NADPH
      - ✓ Formation of ATP
      - ✓ Release of O2
      - ✓ It is also called Z-scheme due to its z shape.
      - ✓ In this PSI,PSII and electron carriers are arranged on thylakoid membrane.
      - ✓ The transport actually begins with the arrival of excitation energy at PSII. So it get excited and passes into primary electron acceptors.
      - ✓ From the primary electron acceptor ions are carried to PSI through 3 ions are carried through 3 ions carriers such as PQ, Cyt $_{b6/f}$ and Pc.
      - ✓ ATP synthesis coupled to electron transport through thylakoid membrane- chemiosmotic hypothesis (Mitchell hypothesis)
      - ✓ It is based upon a fundamental requirements
        1. Energy transducing membranes are impermeable to H^+
        2. Electron carriers are organized asymmetrically in thylakoid membrane.
      - ✓ So, in addition to transporting electrons. Some carriers also serve to translocate protons across the membrane against concentration gradients. It is called proton pumb.
      - ✓ In chloroplast protons are pumbed across the thylakoid membrane, from stroma to lumen. It creates a potential gradient but, low proton conductance of the thylakoid membrane will not allow the proton to simply diffuse back.
      - ✓ In fact, the return of proton of stroma is restricted to highly specific proton lined channels that extends through the membrane, and are part of ATP synthesizing enzyme ATP synthase.
      - ✓ ATP synthase also known as coupling factor or CF_0-$CF_{1,}$ consist of 2 multipeptide complexes ie, CF_0 and CF_1. CF_0 forms H^+ channels across the membrane.
      - ✓ As the energy rich proton gradient collapse through CF_0-CF_1complex, conserved energy is utilized for ATP synthesis.



2. Cyclic photophosphorylation
   - ✓ A continuous ATP supply is required to carry out various metabolic activity of chloroplast, such as
     1. Synthesis of various protein in stroma.
     2. Transport of protein and metabolites across the membranes.
   - ✓ Features
     - Single photosystem PSI is involved.
     - Electron move from P_{700}, first to ferrodoxin, then to cytochrome complex, and plastocyanin(Pc).
     - The transport of electron through cytochrome complex is coupled with the proton pumb across the membrane (stroma to lumen). It creates proton gradient.
     - ATP synthase present on thylakoid membrane produce ATP as proton diffuse back through it from lumen to stroma.
   - ✓ At last de-energized electron return back from Pc to PSI.
   - ✓ No O_2 evolution, No photolysis, No NADPH production.

DARK REACTION

- It takes place in the stroma of thylakoid.
- This is also called biosynthetic phase of photosynthesis or PCR- photosynthetic carbon reduction cycle or Blackman's reaction.
- The synthesis of carbohydrate called CO_2 fixation or carbon assimilation.

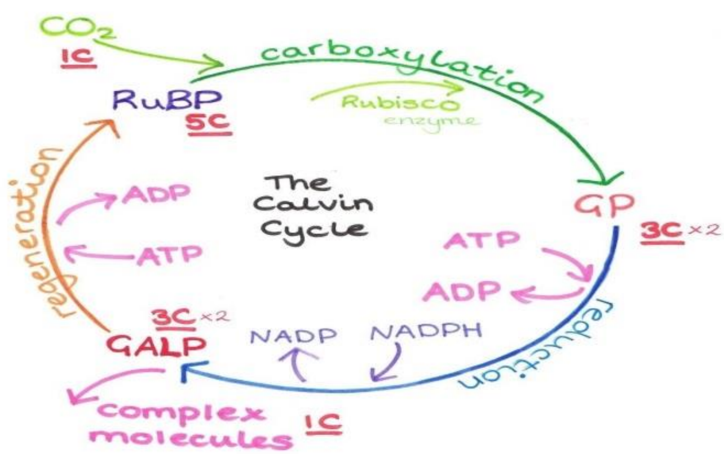
- CO_2 fixed in 4 pathways

1. C_3 cycle
   - It is also called Calvin cycle (Melvin Calvin).
   - The first stable compound is C_3 carbon is 3PGA (3-phosphoglyceric acid).
   - C_3 plants show C_3 cycle.
   - 3 major steps involved in C_3 cycle.

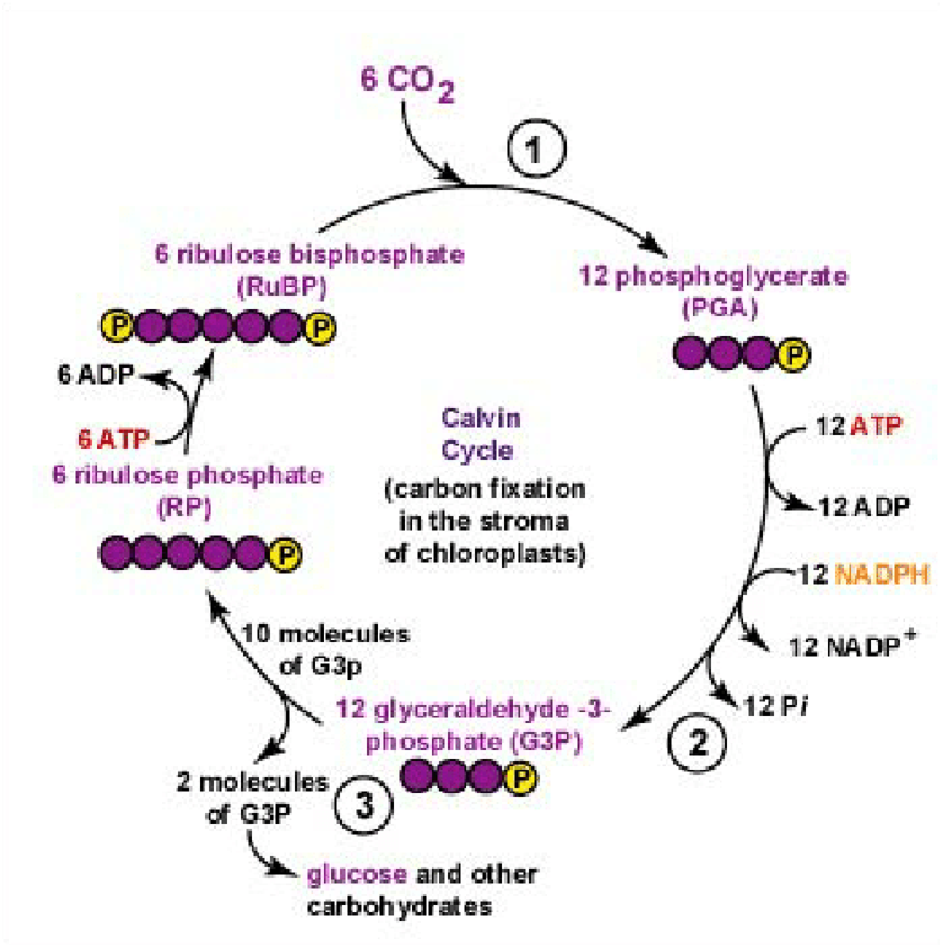
     1.Carboxylation.

     2.Reduction/glycolytic reversal

     3.Regeneration



Calvin cycle is given below:

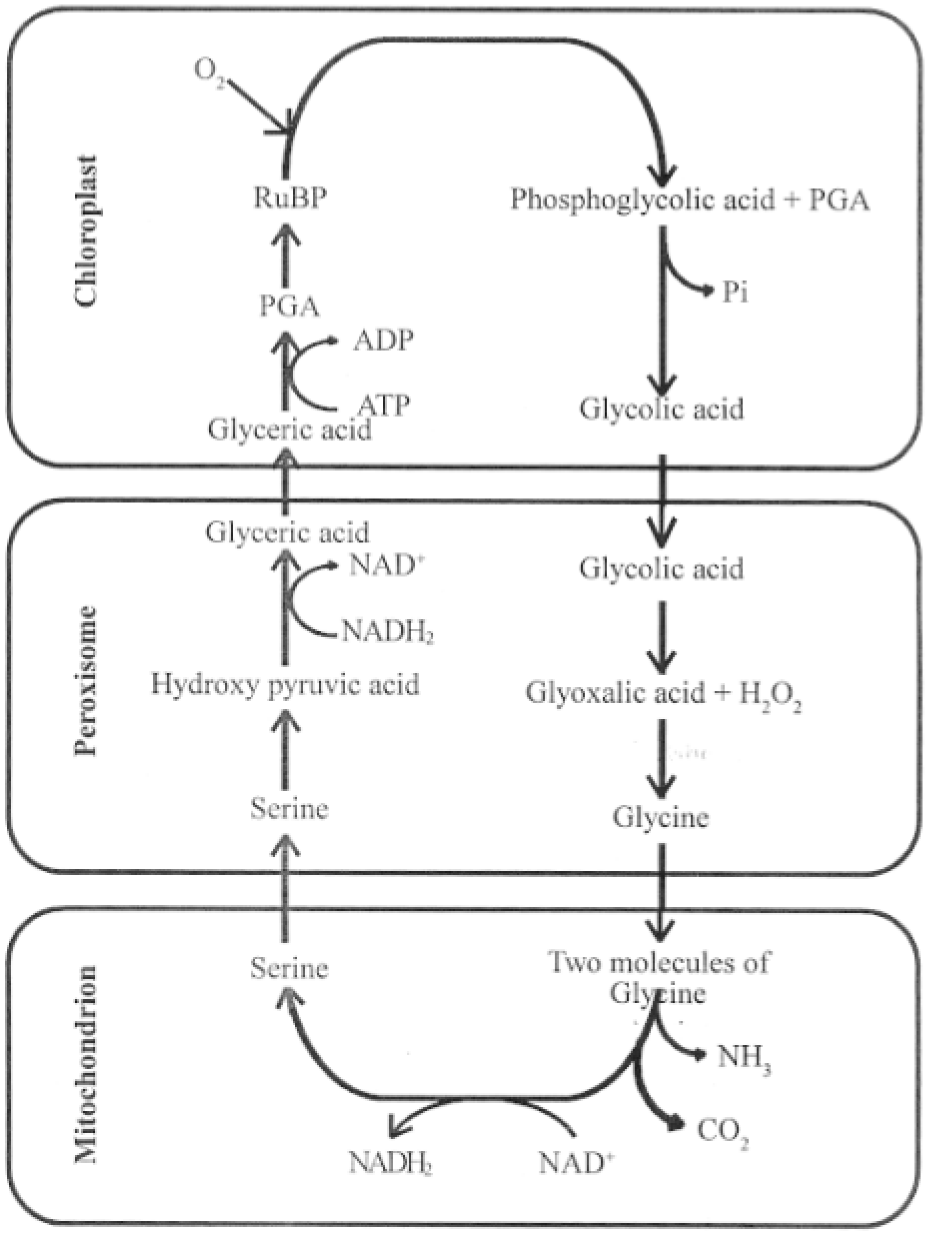


- The overall reaction
  $6RUBP+6CO_2+18ATP+12NADPH \rightarrow 6RUBP+C6H12O_6+18ADP+ 18Ip+$
  12NADP

2. C2 cycle
   - It is the photosynthetic carbon oxidation reaction.
   - It also called **photorespiration**.
   - It takes place in 3 cell organelles
     Chloroplast
     Peroxisome
     Mitochondria
   - It is an alternative pathway of C3 cycle.
   - It may takes place at some condition in C3 plants like

- High oxygen concentration
- High intensity light
- Age of the plant
- High temperature

▪ C3 cycle first discovered by Dicker & Tio.
▪ The first stable compound is 2 carbon compound is Phosphoglycolate.

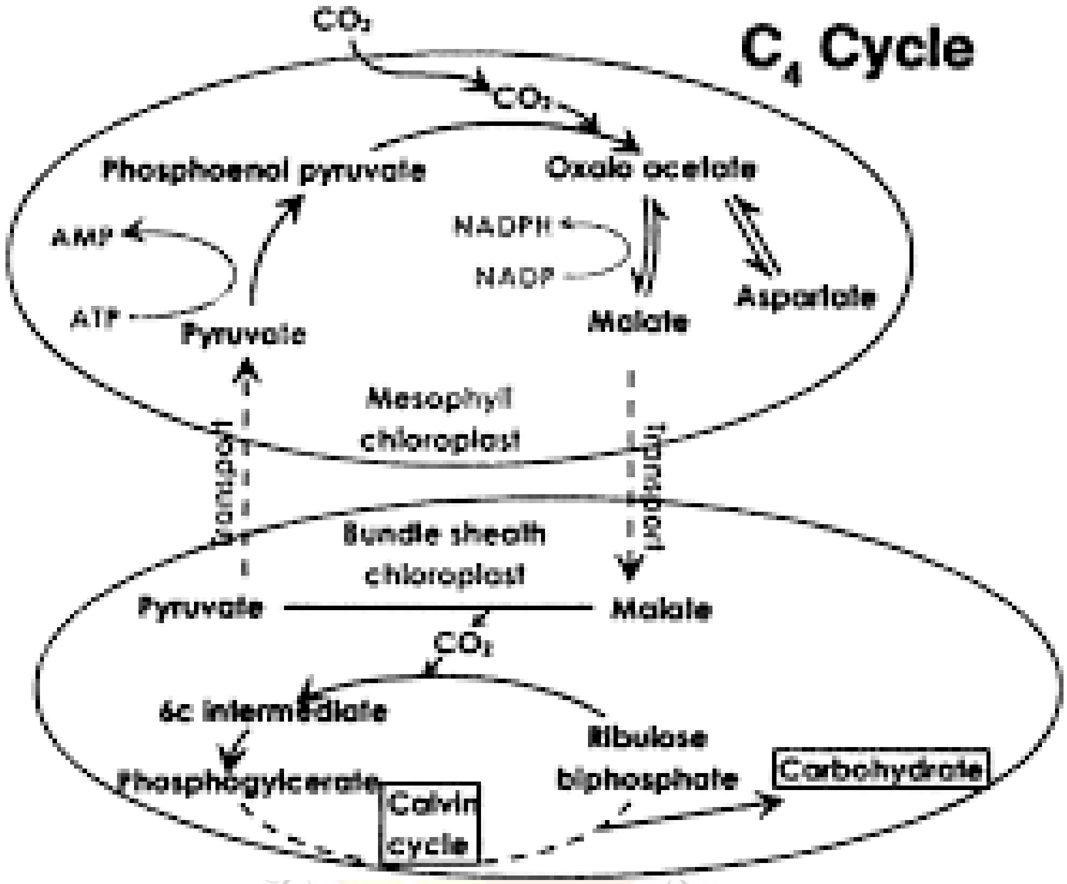


▪ 2 molecule of glycine converted to 1 CO2 and I molecule of serine (3C).

- The ATP and NADPH in C2 is approximately equals to C3. But there is a loss of 1 carbon. So C2 is an inefficient process with respect to energy and CO2.
- But it has scavengers' functions; for each two turn two phosphoglycolate are formed. Of this 4 carbon, one lost as CO2 and other three returned to chloroplast. So it recovers 75% of carbon that would otherwise lost as glycolate.

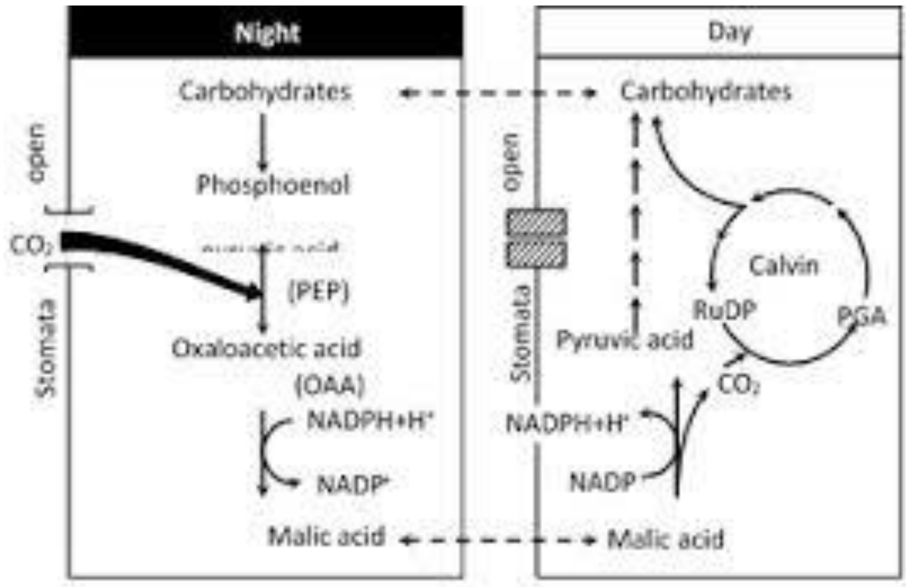
3. C4 cycle
   - C4 plants (Maize, Amaranthus, Sugarcane) are shows C4 cycle.
   - First stable compound is OAA (Oxalo acetic acid). 4 carbon compound.
     It is a dicarboxylic acid. Hence it is called dicarboxylic acid cycle.
   - Bundle sheath cell look like a reeth. It is known as to be Kranz. Hence it is called Kranz anatomy.
   - In C4 plants the cells surrounded the bundle sheath not differentiated into spongy and palisade.
   - Starch grains present in chlorophyll and Rubisco is absent.
   - Bundle sheath surrounded by isodiametric cells. Normal chloroplast is present.
   - Instead of Rubisco, Pepco is present.
   - Bundle sheath cells are large. They have centripetally arranged. In this pepco is absent but Rubisco is present.
   - Steps involved in C4 cycle
     1. Carboxylation of PEP/ fixation of CO2 in mesophyll cells as OAA.
     2. Transport of 4 carbon acid from mesophyll to bundle sheath cells.
     3. Decarboxylation of 4c acid. So concentration of CO2 increases in bundle sheath cells.
     4. Transport of 3 carbons back to mesophyll cell and regeneration of PEP.
   - Advantages and disadvantages
     - ✓ C4 is energetically expensive, it requires 30 ATP (18ATP (C3) + 12ATP (C4)). But it an adaptation to overcome C2. Because C2 causes decrease of 30-40% of photosynthetic yield.
     - ✓ It concentrates CO2 in bundle sheath cells to carryout normal C3. So it serves as CO2 pumb for C3 cycle.
     - ✓ C4 requires 5ATP + 2NADPH/ NADH to fix one CO2. Whereas C3 requires 3ATP+ 2NADPH.
     - ✓ C4 has 2 to 3 times more yield than C3.
     - ✓ C4 can absorb CO2 at very low concentration when C3 fails to absorb it.
     - ✓ C4 can maintain high CO2 fixation under water stress condition.

- ✓ C4 requires high intensity light than C3. So it is better adopted to tropical plants.



4. CAM pathway
   - CAM- Crassulacean acid metabolism
   - First discovered in a Crassulaceae member *Bryophyllum calycinum*.
   - Plants showing CAM is called CAM plants.
   - Here the first stable product is malic acid.
   - It is an adaptation to carryout photosynthesis in xerophytes.
   - In xerophytes, during night CO2 is fixed as malic acid, during day time malic acid under decarboxylation yield CO2. This CO2 is used for C3 cycle.
   - CAM Cycle is significant in 2 aspects.
     - ✓ It build an internal CO2 concentration for C3 cycle.
     - ✓ Internal CO2 causes stomata to open for less time in light/ day time. So it reduces transpiration loss of water.
     - ✓ CAM pathway includes 2 phases
       1. Acidification

2. Deacidification

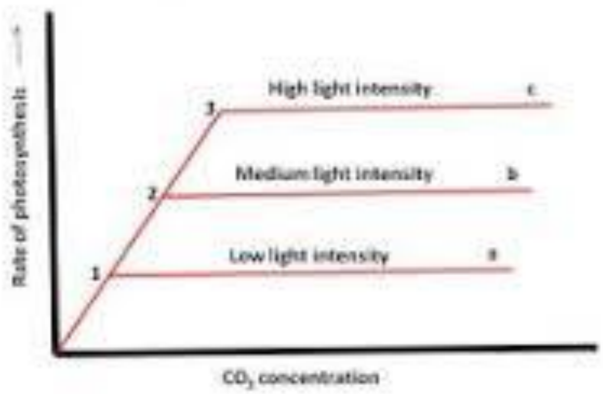


CAM pathway

- Difference with C4 cycle
  1. C4 is separated by special anatomy called Kranz anatomy, whereas CAM was separated by the time.
  2. There is no closed cycle in CAM. And PEP is obtained from stored starch.

LAW OF LIMITING FACTOR

- Sachs proposed 3 cardinal points
  1. There is a maximum temperature, above which photosynthesis fails to occur.
  2. There is a minimum temperature, below which photosynthesis fails to occur.
  3. Optimum temperature which maximum photosynthesis occurs.
- Blackman's law of limiting factors define as when a biological process under the control of several factors, would be determined by any one factor ie, needed in minimum quantity. That is the rate determined by slowest or limiting factor.
- Eg: sunlight, CO2, H2O can be act as limiting factors in photosynthesis. That is, when the availability of CO2, H2O is high and light dim. The light becomes act as limiting factor.



Module 3: biological nitrogen metabolism

- breaking of an exceptionally stable triple covalent bond between two nitrogen atoms to produce ammonia (NH3) or nitrate (NO3)
- *Haber–Bosch process:* Under elevated temperature (about 200°C) and high pressure (about 200 atmospheres), N2 combines with hydrogen to form ammonia
- industrial production of nitrogen fertilizers amounts to more than $80X10^{12}$ g yr^{-1}
- Natural processes fix about $190X10^{12}$ g yr^{-1} of nitrogen (Lightening-8%)
- Lightning converts water vapor and oxygen into highly reactive hydroxyl free radicals,free hydrogen atoms, and free oxygen atoms that attack molecular nitrogen (N2) to form nitric acid (HNO3).
- This nitric acid subsequently falls to Earth with rain.
- Approximately 2% of the nitrogen fixed derives from photochemical reactions between gaseous nitric oxide (NO) and ozone (O_3) that produce nitric acid (HNO_3).
- The remaining 90% results from biological nitrogen fixation, in which bacteria or blue-green algae (cyanobacteria) fix N_2 into ammonium ($NH4^+$).

2.Biological nitrogen fixation

- ✓ The most common type of symbiosis occurs between members of the plant family Leguminosae and soil bacteria of the genera *Azorhizobium*, *Bradyrhizobium*, *Photorhizobium*, *Rhizobium*, and *Sinorhizobium* (collectively called rhizobia).
- ✓ Another common type of symbiosis occurs between several woody plant species, such as alder trees, and soil bacteria of the genus *Frankia*.
- ✓ Still other types involve the South American herb *Gunnera* and the tiny water fern *Azolla*, which form associations with the cyanobacteria *Nostoc* and *Anabaena*, respectively.

Examples of organisms that can carry out nitrogen fixation	
Symbiotic nitrogen fixation	
Host plant	**N-fixing symbionts**
Leguminous: legumes, *Parasponia*	*Azorhizobium, Bradyrhizobium, Photorhizobium,* ` *Rhizobium, Sinorhizobium*
Actinorhizal: alder (tree), *Ceanothus* (shrub), *Casuarina* (tree), *Datisca* (shrub)	*Frankia*
Gunnera	*Nostoc*
Azolla (water fern)	*Anabaena*
Sugarcane	*Acetobacter*
Free-living nitrogen fixation	
Type	**N-fixing genera**
Cyanobacteria (blue-green algae)	*Anabaena, Calothrix, Nostoc*
Other bacteria	
Aerobic	*Azospirillum, Azotobacter, Beijerinckia, Derxia*
Facultative	*Bacillus, Klebsiella*
Anaerobic	
Nonphotosynthetic	*Clostridium, Methanococcus* (archaebacterium)
Photosynthetic	*Chromatium, Rhodospirillum*

✓

- **Symbiotic nitrogen fixation in leguminous plants**

✓ Symbiotic nitrogen-fixing prokaryotes dwell within nodules.

✓ In the case of *Gunnera*, these organs are existing stem glands that develop independently of the symbiont. In the case of legumes and actinorhizal plants, the nitrogen-fixing bacteria induce the plant to form root nodules.

✓ In grasses nitrogen-fixing bacteria seem to colonize plant tissues or anchor to the root surfaces, mainly around the elongation zone and the root hairs

✓ *Acetobacter diazotrophicus* lives in the apoplast of stem tissues in sugarcane and may provide its host with sufficient nitrogen to grant independence from nitrogen fertilization.

✓ Legumes and actinorhizal plants regulate gas permeability in their nodules, maintaining a level of oxygen within the nodule that can support respiration but is sufficiently low to avoid inactivation of the nitrogenase

✓ Gas permeability increases in the light and decreases under drought or upon exposure to nitrate.

✓ The Nodules contain an oxygen-binding heme protein called leghemoglobin.

✓ Leghemoglobin is present in the cytoplasm of infected nodule cells at high concentrations (700 μM in soybean nodules) and gives the nodules a pink color.

✓ The host plant produces the globin portion of leghemoglobin in response to infection by the bacteria the bacterial symbiont produces the heme portion.

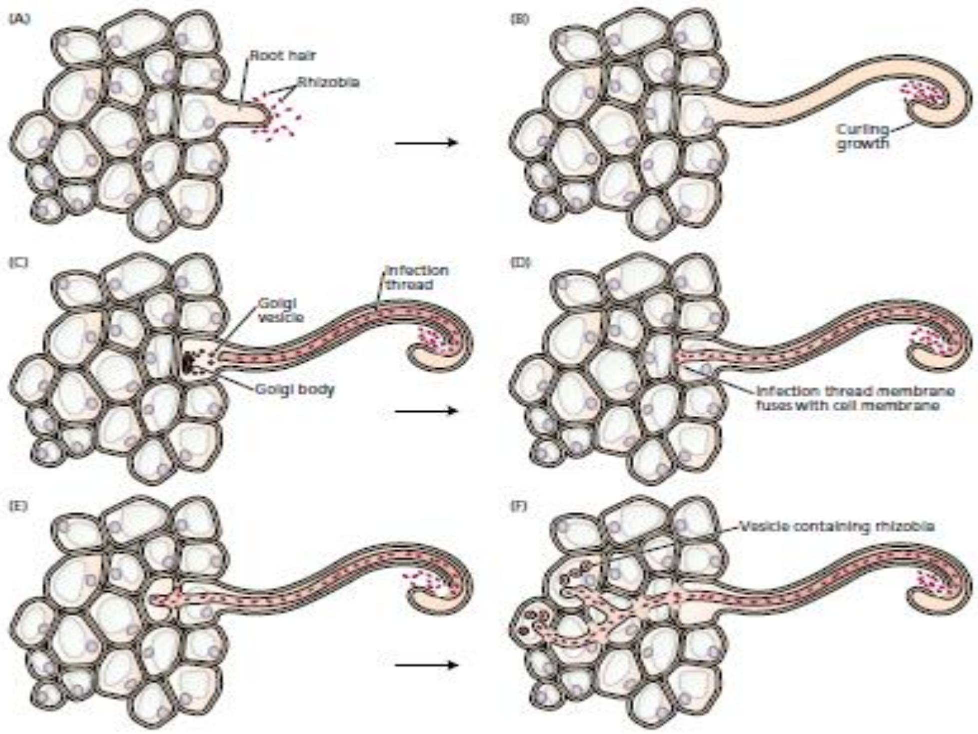
✓ Leghemoglobin has a high affinity for oxygen (a Km of

✓ about 0.01 μM), about ten times higher than the β chain of human hemoglobin.

✓ The infection process during nodule formation

- ➢ (A) Rhizobia bind to an emerging root hair in response to chemical attractants sent by the plant.
- ➢ (B) In response to factors produced by the bacteria, the root hair exhibits abnormal curling growth, and rhizobia cells proliferate within the coils.

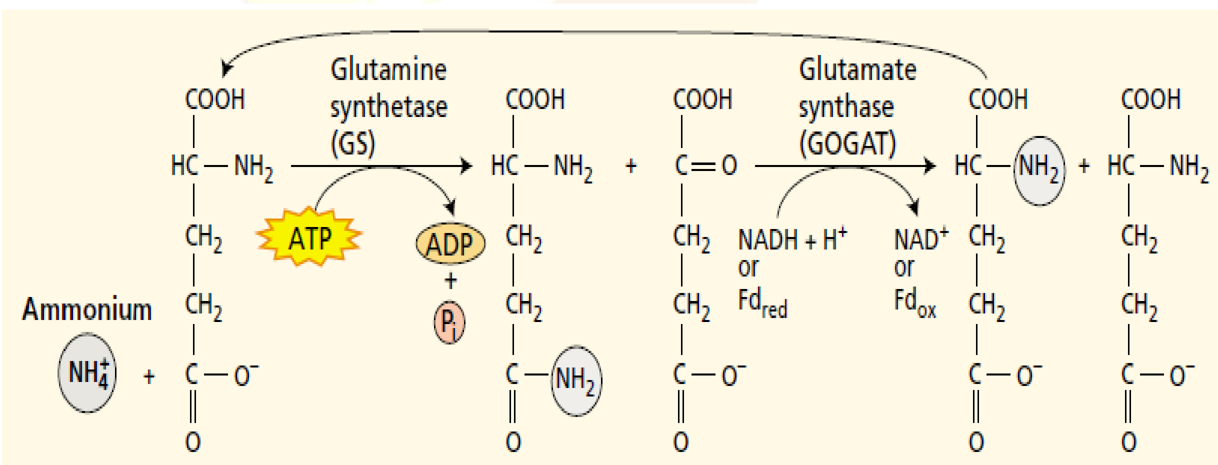
- (C) Localized degradation of the root hair wall leads to infection and formation of the infection thread from Golgi secretory vesicles of root cells.
- (D) The infection thread reaches the end of the cell, and its membrane fuses with the plasma membrane of the root hair cell.
- (E) Rhizobia are released into the apoplast and penetrate the compound middle lamella to the subepidermal cell plasma membrane, leading to the initiation of a new infection thread, which forms an open channel with the first.
- (F) The infection thread extends and branches until it reaches target cells, where vesicles composed of plant membrane that enclose bacterial cells are released into the cytosol.



- **Genetics of nitogen fixation**
  - ✓ Plant genes specific to nodules are called nodulin (*Nod*) genes;
  - ✓ rhizobial genes that participate in nodule formation are called nodulation (*nod*) genes.
  - ✓ The common *nod* genes—*nodA*, *nodB*, and *nodC*—are found in all rhizobial strains;
  - ✓ The host-specific *nod* genes—such as *nodP*, *nodQ*, and *nodH*; or *nodF*, *nodE*, and *nodL*—differ among rhizobial species and determine the host range.
  - ✓ regulatory *nodD*, is constitutively expressed, its protein product (NodD) regulates the transcription of the other *nod* genes.
  - ✓ The first stage is migration of the bacteria toward the roots of the host plant.
  - ✓ This migration is a chemotactic response mediated by chemical attractants, especially (iso)flavonoids and betaines, secreted by the roots.
  - ✓ These attractants activate the rhizobial NodD protein, which then induces transcription of the other *nod* genes.

- ✓ The promoter region of all *nod* operons, except that of *nodD*, contains a highly conserved sequence called the *nod* box. Binding of the activated NodD to the *nod* box induces transcription of the other *nod* genes
- ✓ The *nod* genes activated by NodD code for nodulation proteins, most of which are involved in the biosynthesis of Nod factors.
- ✓ Nod factors are lipochitin oligosaccharide signal molecules, all of which have a chitin β-1→4-linked *N*acetyl- D-glucosamine backbone (varying in length from three to six sugar units) and a fatty acyl chain on the C-2 position of the nonreducing sugar.
- ✓ Three of the *nod* genes (*nodA*, *nodB*, and *nodC*) encode enzymes (NodA, NodB, and NodC, respectively) that are required for synthesizing this basic structure
- ✓ NodA is an *N*-acyltransferase that catalyzes the addition of a fatty acyl chain.
- ✓ NodB is a chitin-oligosaccharide deacetylase that removes the acetyl group from the terminal nonreducing sugar.
- ✓ NodC is a chitin-oligosaccharide synthase that links *N*-acetyl-D-glucosamine monomers
- ✓ A particular legume host responds to a specific Nod factor.
- ✓ The legume receptors for Nod factors appear to be special lectins (sugar-binding proteins) produced in the root Hairs.
- ✓ Nod factors activate these lectins, increasing their hydrolysis of phosphoanhydride bonds of nucleoside di- and triphosphates.
- ✓ This lectin activation directs particular rhizobia to appropriate hosts and facilitates attachment of the rhizobia to the cell walls of a root hair.
- ✓

- **Ammonia assimilation**
  - ✓ Structure and pathways of compounds involved in ammonium metabolism.
    (A) The GS-GOGAT pathway that forms glutamine and glutamate.

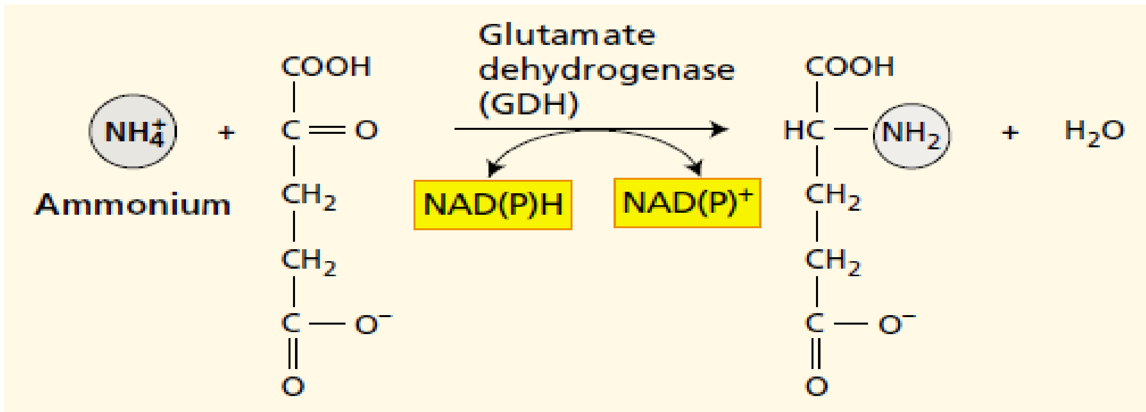


Glutamate Glutamine 2-Oxoglutarate 2 Glutamates

- ✓
- ✓ Conversion of Ammonium to Amino Acids Requires Two Enzymes
  - ✓ Glutamine synthetase (GS) combines ammonium with glutamate to form glutamine
  - ✓ This reaction requires the hydrolysis of one ATP and involves a divalent cation such as Mg2+, Mn2+, or Co2+ as a cofactor

- ✓ Plants contain two types of GOGAT: One accepts electrons from NADH; the other accepts electrons from ferredoxin (Fd):
- ✓ 1st one (NADH type) in non photosynthetic tissues (roots, VB)
- ✓ 2nd type (FD type) in chloroplasts—in photorespiratory N metabolism (is light influenced)

✓ Ammonium Can Be Assimilated via an Alternative Pathway
(B) The GDH pathway that forms glutamate using NADH or NADPH as a reductant.

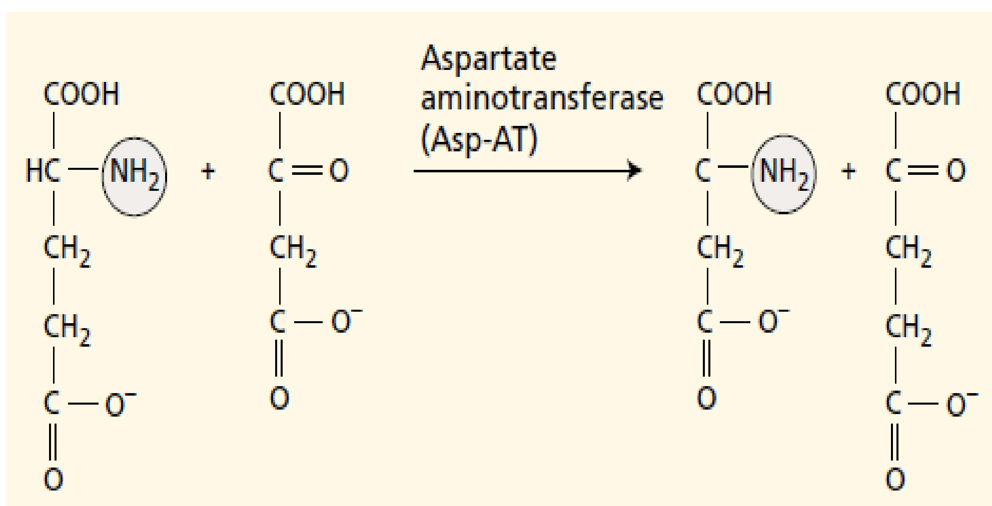


2-Oxoglutarate Glutamate

✓

- ✓ An NADH-dependent form of GDH is found in mitochondria, and an NADPH-dependent form is localized in the chloroplasts of photosynthetic organs.
- ✓ Although both forms are relatively abundant, they cannot substitute for the GS–GOGAT pathway for assimilation of ammonium, and their primary function is to deaminate glutamate

✓ (C) Tranamination reactions: Transfer of the amino group from glutamate to oxaloacetate to form aspartate (catalyzed by aspartate aminotransferase).

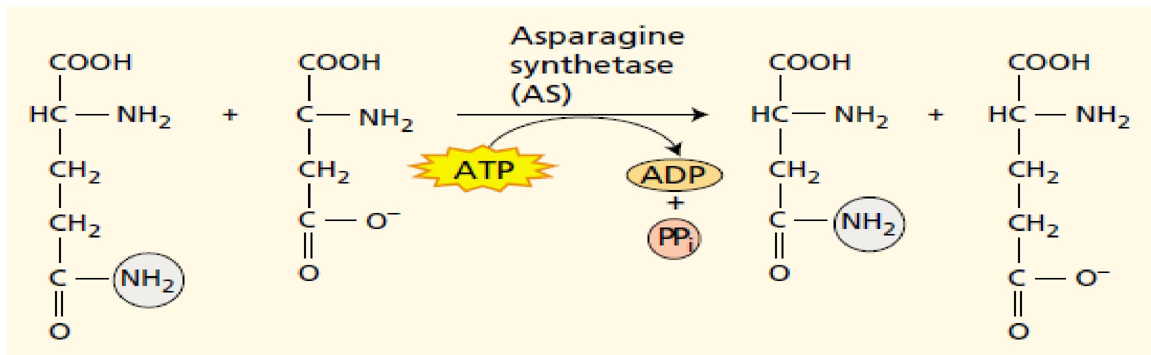


Glutamate Oxaloacetate Aspartate 2-Oxoglutarate

✓

- ✓ Aspartate is an amino acid that participates in the malate–aspartate shuttle to transfer reducing equivalents from the mitochondrion and chloroplast into the cytosol
- ✓ and in the transport of carbon from mesophyll to bundle sheath for C4 carbon fixation.
- ✓ All transamination reactions require pyridoxal phosphate (vitamin B6) as a cofactor.
- ✓ Aminotransferases are found in the cytoplasm, chloroplasts, mitochondria, glyoxysomes, and peroxisomes.

✓ (D) Synthesis of asparagine by transfer of an amino acid group from glutamine to aspartate (catalyzed by asparagine synthesis).



Glutamine Aspartate Asparagine Glutamate

✓

✓ Asparagine synthetase (AS), the enzyme that catalyzes this

✓ reaction, is found in the cytosol of leaves and roots and in

✓ nitrogen-fixing nodules

✓

- **Assimilation of nitrates**
  - ✓ N available to plants: 1) NO_3^- 2) NH_4^+ (available through fixation & microbial decomposition)
  - ✓ NO_3^- ---not bound---washed or leached off
  - ✓ NH_4^+ ---cation---held tightly
  - ✓ NH_4^+ is converted to nitric acid by soil bacteria (nitrification)
  - ✓ Nitric acid disociates to H+ NO_3^-
  - ✓ NO_3^- is absorbed into leaves by transpiration stream

$$NO_3^- + NAD(P)H + H^+ + 2\,e^- \rightarrow NO_2^- + NAD(P)^+ + H_2O$$

- ✓ The enzyme nitrate reductase catalyzes this reaction.
- ✓ The most common form of nitrate reductase uses only NADH as an electron donor;
- ✓ another form of the enzyme that is found predominantly in nongreen tissues such as roots can use either NADH or NADPH
- ✓ The nitrate reductases of higher plants are composed of two identical subunits,
- ✓ each containing three prosthetic groups: FAD (flavin adenine dinucleotide), heme, and a molybdenum complexed to an organic molecule called a *pterin*
- ✓ The FAD-binding domain accepts two electrons from NADH or NADPH.

- ✓ The electrons then pass through the heme domain to the molybdenum complex, where they are transferred to nitrate.
- ✓ $NADH_2$----FAD----$FADH_2$----MO^{6+}---MO^{5+}- --$NO3^-$--- $NO2^-$
- ✓ Nitrate, light, and carbohydrates influence nitrate reductase at the transcription and translation levels
- ✓ Light, carbohydrate levels, and other environmental factors stimulate a protein phosphatase that dephosphorylates several serine residues on the nitrate reductase protein and thereby activates the enzyme.
- ✓ Operating in the reverse direction, darkness and Mg2+ stimulate a protein kinase that phosphorylates the same serine residues, which then interact with a 14-3-3 inhibitor protein, and thereby inactivate nitrate reductase (post translational modulation
- ✓ Nitrate reductase regulated by
    - Light reaction---ATP—transport of stored NO3- from vacuole to cytosol
    - Photosynthsis—carbohydrate--NADH

3.Translocation and distribution of photoassimilates

- In plants transport of organic and inorganic molecules takes from their site of synthesis or reservoir to their consumption or storage.
- Transport are
    1. Long distance
    2. Medium distance
    3. Short distance
- Long distance transport is called **translocation**. Translocation takes place through xylem or phloem.
- Translocation of water, minerals through xylem.
- Translocation of photoassimilate through phloem.
- Transport of photoassimilate is always polar, from source to sink. It occurs in a concentration gradient.
- Composition of phloem sap
    - ✓ Composition of phloem sap varies.
    - ✓ It depends upon age of the plant, physiological factor.
    - ✓ It contains carbohydrates, hormones (auxin, cytokinin, gibberellin), proteins,inorganic anions (phosphate, chlorate).
    - ✓ It also contains enzymes also.
- Direction of translocation
    1. Downward translocation (leaves to stem and root).
    2. Upward translocation (leaves to developing buds, flowers and fruits).
    3. Radial translocation (cells of pith to cortex and epidermis)
    4. Bidirectional translocation (occurs near shoot apex, downward (apex to storage region)+ upward (apex to mature leaves)).
- Mechanism of translocation

- ✓ It occurs by a mass transfer along a hydrostatic pressure gradient between in the source and sink.
- ✓ It completed in three steps
  1. Phloem loading
     - Initial transfer of photoassimilate from mesophyll cell to sieve elements(phloem) at the source end (leaf).
     - Active process.
     - Takes place through symplastic and apoplastic pathway.
  2. Translocation over a long distance (long transport)
  3. Phloem uploading
     - Transfer of solutes from sieve tubes to the sink.
     - Reverse of phloem loading.occurs in concentration gradient in symplastic or apoplastic pathway.

- Theories of translocation
  1. Protoplasmic streaming theory (deVries -1885)
  2. Contractile protein theory (Fenson & Williams -1974)
  3. Diffusion hypothesis
  4. Activated diffusion theory
  5. Electro-osmotic theory
  6. Munch flow hypothesis (Munch –1930, Craft –1938)

Module 4: Plant Growth, Photoperiodism & Vernalization, Plant Movements & Seed dormancy and germination

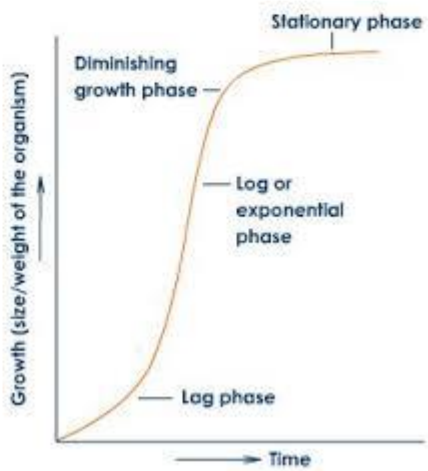
PLANT GROWTH

- It is the irreversible increase in size, mass and weight of the body.
- Plant growth restricted to root and shoot meristems.
- Growth involves an increase in the number and size of cells, called quantitative phenomenon.
- Plant growth
  1. Primary growth- elongation of plant body, due to activity of apical and intercalary meristem.
  2. Secondary growth-thickening of plant body, due to activity of lateral meristem.
- Plant growth involves three genetically programmed events
  1. Cell division
  2. Cell enlargement
  3. Cell differentiation

- Phases of plant growth- different phases in growth.

1. Lag phase
2. Log phase
3. Deceleration phase
4. Stationary phase

- Growth curve
  - ✓ Graphic representation of growth phases of organs or organisma.
  - ✓ S-shaped curve or sigmoid curve or logistic curve.



- Growth hormones or phytohormones
  - ✓ Organic substance synthesized in minute quantities in a part of the plant body and transported to another part where they influence specific physiological processes.
  - ✓ There are natural as well as synthetic growth hormones.

    1. Auxin
    2. Cytokinin
    3.Gibberellins
    4.Ethylene
    5. Abscisic acid
- Abscission
  - ✓ Natural detachment or dislodging of plant organs, such as leaf, flower and leaf etc. from the parent plant.
  - ✓ Abscission restricted to a distinct region, called abscission zone.
  - ✓ Just before abscission, there develops a special layer of cells within the abscission zone, called abscission layer.
  - ✓ Abscission is controlled by a balanced interaction between auxins and abscissic acid.
  - ✓ Auxins inhibit abscission and abscisic acid stimulates abscission. So high level of abscisic acid promote abscission. It includes extreme level of temperature and water, increased respiration, short photoperiods, attacks of parasites and ethylene.

- ✓ Absission is self- pruning process, removes aged and injured organs from the plant body.
- ✓ It helps in disseminating fruits and vegetative propagules.
- ✓ It removes plant part contains waste materials.

- Senescence
  - ✓ Types of senescence
    1. Whole plant senescence
    2. Organ senescence
    3. Shoot senescence
    4. Sequential senescence
    5. Simultaneous senescence

  - ✓ Physiology of senescence- includes different structural and physiological changes
    1. Regression of cells and disorganization of cell organelles by the lysosomal activity of vacuoles. Vacuoles act as lysosomes and release hydrolytic enzymes.
    2. Disintegration of chlorophyll, falls in photosynthetic rate, and decrease in the starch content of the cells.
    3. Synthesis and accumulation of anthocyanins and change in colour of leaves from green to yellow.
    4. Reduction in the protein content of cells due to fall in protein synthetic rate and also due to the increased activity of proteolytic enzymes.
  - ✓ Significance of senescence.
    1. Enables continuous replacement of old and inefficient organs by new and young leaves.
    2. Enables plants to escape from seasonal adversities.
    3. Leaf fall adds leaf litter to the surface layer of soil and increases mineral content in soil.
    4. Leaf fall in winter reduces the transpiratory loss of water.
    5. It enables recovery or withdrawal of nutrients from senescing organs for the rest of the plant.

PHOTOPERIODISM AND VERNALIZATION

Photoperiodism

- Flower initiation begins with the formation of flower primordial (flower bud) in the apical and lateral shoot meristems.
- Flowering is the process mainly controlled by the
  1. Duration, quality, and intensity of day light

2. Temperature.

- A light controlled development and flowering is generally called photomorphogenesis.
- Photoperiodism is the response of a plant to the relative length of day and night. Duration of light period or length of daytime is called photoperiod.
- Plants exhibit photoperiodism called photoperiodic plants.
- Based on the photoperiodic responses flowering plants are classified into three.
  1. Short day plants (SDP) or long night plants
     - ✓ Flowering is induced by exposure to short day length (photoperiod) which is shorter than critical length.
     - ✓ Plants require a cyclic exposure to short light periods and long dark periods eg. Coffee, Cotton, Maize.
  2. Long day plants (LDP) or short night plants
     - ✓ Flowering induced by exposure to long day length, which is longer than the critical length. Eg. Radish, Sugarbeet.
  3. Day- neutral plants (DNP)
     - ✓ Flowering not influenced by the length of day or night. Do not require a specific photoperiod for flowering. Eg. Tomato, Cucumber.
- flowering responses of short day plants
  1. Flowering occurs when dark period is uninterrupted and longer than the critical day length.
  2. No flowering occurs when the duration of dark period and light period is the same.
  3. No flowering occurs when the dark period is shorter than the critical day length.
  4. No flowering occurs if dim light is present during the dark period.
  5. No flowering occurs when the longer dark period is interrupted midway by single flash of bright or dim light.
  6. Flowering occurs when the longer dark period is interrupted by a single flash of light either at its beginning or towards the end.
  7. Flowering occurs in continuous darkness , if sucrose is administered to plants
- flowering responses of long day plants
  1. Flowering occurs when the dark period is uninterrupted and shorter than the critical day length.
  2. No flowering occurs when the dark period is longer than the critical day length.
  3. Flowering occurs even under short-day conditions, if the longer dark period is interrupted mid-way by a brief flash of light.
  4. Flowering occurs under shorter photoperiods, if they are followed by still shorter dark periods in a 24 hour cycle.
  5. Flowering is maximal during continuous or uninterrupted photoperiods.
- Red light inhibit flowering where as far red light induces flowering. This phenomenon is called red-far red reversible photoreaction.
- Flowering responses depends on the quality of the light of the last exposure. If the last exposure is red light, no flowering occurs, if it is far red light, flowering may occur.
- Phytochromes are the pigments involved in the initiation of flowering.
- Phytochromes are photo-reversible bluish biliprotein that can exist in two inter-convertible forms namely Pr and Pfr. Pr is bluish-green colour, absorbs red light and becomes Pfr form. Pfr light green coloured, absorb far red light and becomes Pr.

- Flowering in short-day plants iss promoted by the Pr form and inhibited by Pfr form. In long days plants, flowering is promoted by Pfr form and inhibited by Pr form.
- Some workers suggested that a flower- producing stimulus is formed in the leaves and then conveyed to meristems. Some floral hormones like florigen, is synthesized in the leaves under favourable photoperiodic conditions. These hormones will transmit to flowering regions.
- Flowering may also induced by the ineraction between auxins, gibberilins, cytokinins and ethylene.
- Carbohydrate –nitrate ratio also influence flowering. Very high ratio induces very low vegetative growth and flowering. Very low carbohydrate and nitrate ratio will cause the very low vegetative growth and no flowering.

Vernalization

- Vernalization is the low temperature treatment or cold treatment or chilling treatment of seedlings or germinating seeds to increase the flowering and fruiting abilities of plants.
- It requires three environmental conditions
  1. Low temperature
  2. Free oxygen supply
  3. Sufficient water supply
- It was first noticed by Klippart (1857) in two varieties of wheat, namely winter wheat and spring wheat. Winter wheat is sown in winter and flowering in summer. Spring wheat is sown in spring and flowering in summer. He observed that germinated seeds of winter wheat exposed to low temperature, they can behave as spring wheat. That is winter wheat requires low temperature for subsequent flowering.
- Site of cold stimulus is meristematic regions. Low temperature treatment of seed is effective.
- Induction of early flowering in plants is occurred by the shortening of vegetative growth. Very low temperature induces the formation of flowering hormone vernalin.
- Application of gibberellins can replace the cold treatment or vernalization in many plants.
- Vernalization will
  1. Shortens the period of vegetative growth.
  2. Early flowering and fruiting.
  3. Enhances cold-resistances.
- Cold treatment can be nullified by the immediate treatment with high temperature known to be devernalization.

PLANT MOVEMENTS

- Plant movements are largely the responses to external and internal stimuli.
- A stimuli is an external or internal environmental factor (light, temperature, gravity), mechanical (contact, friction, pressure), chemical and physical.
- Plant movements can be classified into two
  1. Hygroscopic movement
     - ✓ Movements manifested by dead plant parts in response to gain or loss of water.

     a. Hygrochasy – movement due to imbibition of water. eg. Dehiscence of seed vessels, closing of peristome of mosses.

b. Xerochasy- movement due to the loss of water. Eg. Dehiscence of pod and widening of peristome of mosses.

2. Vital movement

✓ Movement manifested by living cells or parts.

- Vital movement classified into different types of movements.

Vital Movement

- Locomotor Movement
  - Autonomic Movement
    - Ciliary Movement
    - Ameboid Movement
    - Gliding Movement
    - Cyclosis
  - Paratonic Movement
    - Phototaxis
    - Thermotaxis
    - Chemotaxis
- Curvature Movement
  - Growth Movement
    - Paratonic Movements
      - Tropic Movement
        - Phototropism
        - Hydrotropism
        - Chemotropism
        - Galvanotropism
        - Aerotropism
        - Geotropism
        - Thermotropism
        - Thigmotropism
        - Rheotropism
      - Nastic Movement
        - Epinasty
        - Hyponasty
        - Photonasty
        - Thermonasty
    - Autonomic Movements
      - Nutation
      - Circumnutation
  - Turgor Movement
    - Rolling Movement
    - Sleep Movement
    - Shock Movement
    - Touch Movement
    - Hydronasty

Traunatropism

SEED DORMANCY AND GERMINATION

- Seed dormancy is inability or failure of seeds to germinate due to internal factors, even at the optimal temperature.
- Factors causing seed dormancy
  1. Due to hard seed coat
     - ✓ Seed coat is formed of a complex mixture of polysaccharides, hemicellulose, fats, waxes and proteins.
     - ✓ During seed ripening, seed coat becomes dehydrated and forms a hard tough protective covering around embryo. It will prevent seed germination.
     - ✓ Seed coat dormancy due to some reasons like
       - ➢ Impermeability of the seed coat to water.
       - ➢ Impermeability of the seed coat to oxygen.
       - ➢ Mechanical resistance of seed coat against embryonic growth.
  2. Due to absence of light
     - ✓ Some seed like photoblastic seeds require light for germination.
  3. Due to absence of low temperature
     - ✓ Seeds of temperate plants require low temperature treatment for germination. So the absence of low temperature cause seed dormancy.
  4. Due to the state of embryo
     - ✓ Dormancy of the embryo due to;
       1. Immature or underdeveloped state of embryo, when seeds are shed. It delays seed germination until embryonic maturation is completed.
       2. Presence of germination inhibitors in the embryo, endosperm and other tissue of seed or fruit like abscisic acid, phenolic acid, parasorbic acid and coumarin.
- Methods to overcome seed dormancy
  1. Exposure to light
     - ✓ A numbers of seeds like photoblastic seeds require light for germination.
     - ✓ There are three categories of such seeds as follows;

       1. Positive photoblastic seeds- single light exposure promote seed germination.

       2. Negative photoblastic seeds- light inhibit seed germination so that seed require complete darkness for germination.

       3. Non-photoblastic seeds- seeds germinate irrespective light or darkness.

  2. Alternating temperature
     - ✓ It is useful in those seeds in which dormancy due to immature embryos.

- ✓ Seed germination promoted by alternating temperature. This difference between alternating temperature should not be more than 10- 20°C.

3. Impaction
    - ✓ Impaction is the treatment of seed by vigorous shaking to remove the plug. In some seeds, water and oxygen are unable to penetrate, because their entry is blocked by a block a cork- like filling in the small opening in the seed coat.
4. Scarification
    - ✓ Softening or weakening the seed coat is known as scarification.
    - ✓ Under natural conditions in the soil, micro-organisms such as fungi and bacteria will decompose seed coat.
    - ✓ Mechanical and chemical treatments are used to promote seed germination. It includes cutting or chipping of the seed coat, storage of seeds at high temperature, and use of organic solvents to remove waxy or fatty compounds. Acidic treatment also recommended.
5. Stratification
    - ✓ Some seeds require well aerated moist conditions under low temperature for weeks or months for germination. Such treatment known as stratification.
    - ✓ Here immature embryo requires some chemical changes for the seed germination.

- Advantages of seed dormancy
    1. Enables the embryo to tide over the unfavourable part of the year.
    2. Enables storage of cereals, millets, pulses to be used later for food or sowing in the next season
    3. Serves as an adaptation to ensure that seed germination occurs only under favourable conditions, and also in the right time and at the right place. In nature dormancy periods always coincide with unfavourable seasons.
- Seed germination
    - ✓ It is the process by which a dormant embryo becomes active, grows out of the seed- coat and develops to a seedling. Embryo grows by absorbing water from outside, and stored food from cotyledons or endosperm.
- Changes during germination
    1. Seed coat becomes permeable to water, oxygen and carbon dioxide.
    2. Intake of water and swelling of seed and rupturing of seed coat.
    3. Hydration of protoplasm, activation of enzymes and resumption of physiological activities.
    4. Enzymatic breakdown of insoluble materials to soluble constituents.
    5. Translocation of soluble food materials to growing parts.
    6. Assimilation of food in the growing organs for growth.
- Different kinds of germination
    1. Hypogeal germination
        - ✓ The cotyledons stay beneath the soil surface or just on the soil surface.
        - ✓ Here radicle emerges first and grow deep into the soil and forms the root system. The epicotyl elongates and forms an arch called epicotyl bent. It pushes plumule upwards outward out of the soil.
        - ✓ Plumule grows fast; leaving the cotyledons in the soil. Cotyledons never becomes green. They dry out and fall.
        - ✓ Most common in monocots like wheat, maize, palms.

2. Epigeal germination
    - ✓ Here hypocotyl elongates rapidly, pushing the cotyledons upward, well above the soil surface.
    - ✓ Here most of the cotyledons become green, flat and leaf like.
    - ✓ In some dicots like castor, cotton and tamarind

- Mechanism of seed germination
    - ✓ Here the dormant embryo within the seed resumes its metabolic activities and grows to a seedling.
    - ✓ It occurs under favourable conditions of water, temperature, nutrients, light etc.
    - ✓ Seed germination involves four major events;
        1. Water imbibition
        2. Resumption of metabolic activities
        3. Mobilization of food reserves
        4. Breaking of seed dormancy
- Factors affecting seed germination
    1. Water
        - ✓ Helps the hydrolysis and transport of the stored food.
    2. Oxygen
        - ✓ For energy yielding aerobic oxidation. Thus seeds cannot germinate under poor oxygenated soil.
    3. Favourable temperature
        - ✓ Moderate temperature needed for seed germination.
        - ✓ It activates enzymes, accelerate metabolism and stimulate germination.
    4. Light
        - ✓ Photoblastic seeds require an appropriate quantity of light for germination.
    5. Nature of the seed coat
        - ✓ Thick, hard and impermeable seed coat inhibits seed germination. Germination occurs only after it is softened, weakened or broken.
    6. Germination inhibiting substances
        - ✓ abscisic acid, phenolic acid, parasorbic acid and coumarin inhibit seed germination.
        - ✓ Industrial wastes and soil pollutants also inhibit seed germination.
- Vivipary
    - ✓ In-situ seed germination in which the seeds germinates inside unshed fruits.
    - ✓ Viviparous plants like *Rhizophora* shed seedlings, not seeds.
    - ✓ Most common in halophytic mangroves plants.
    - ✓ Vivipary is an adaptation to prevent the seeds from being carried away by tides and waves.

Module 5 :Metabolism

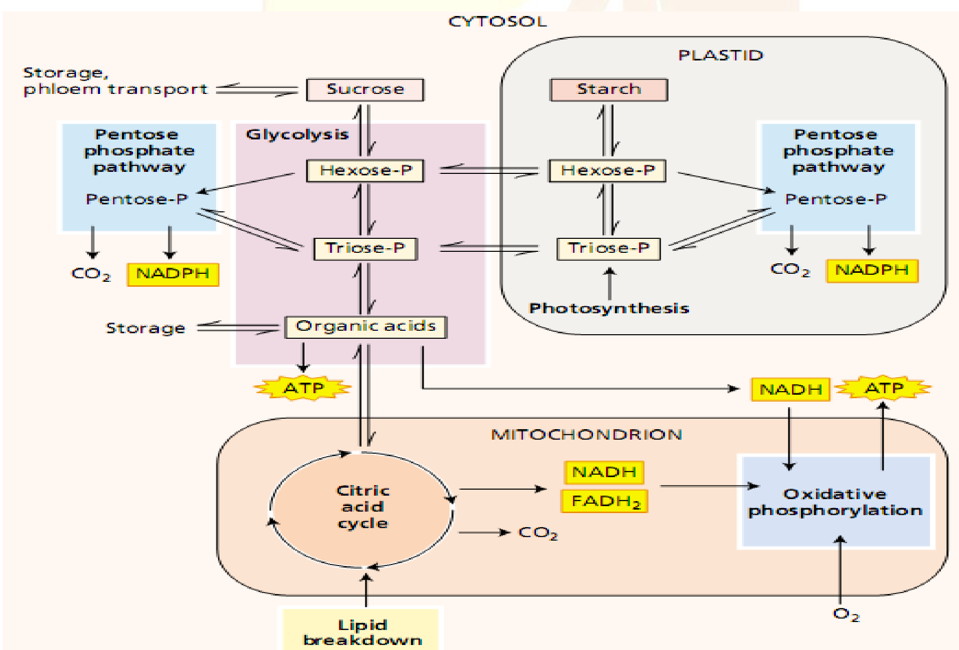
1. Catabolism of hexoses

- Respiration is a chain of chemical reactions that enables all living entities to synthesize energy required to sustain.
- It is a biochemical process wherein air moves between the external environment and the tissues and cells of the species. In respiration, inhalation of oxygen and exhalation of carbon dioxide gas takes place. As an entity acquires energy through oxidising nutrients and hence liberating wastes, it is referred to as a metabolic process.
- **Cellular Respiration**: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$.

Glucose —(Glycolysis, In cytoplasm)→ Pyruvate —(In absence of oxygen, (Yeast) (Fermentation))→ $2C_2H_5OH + 2CO_2 + 38ATP$

Ethanol, Carbon dioxide, Energy

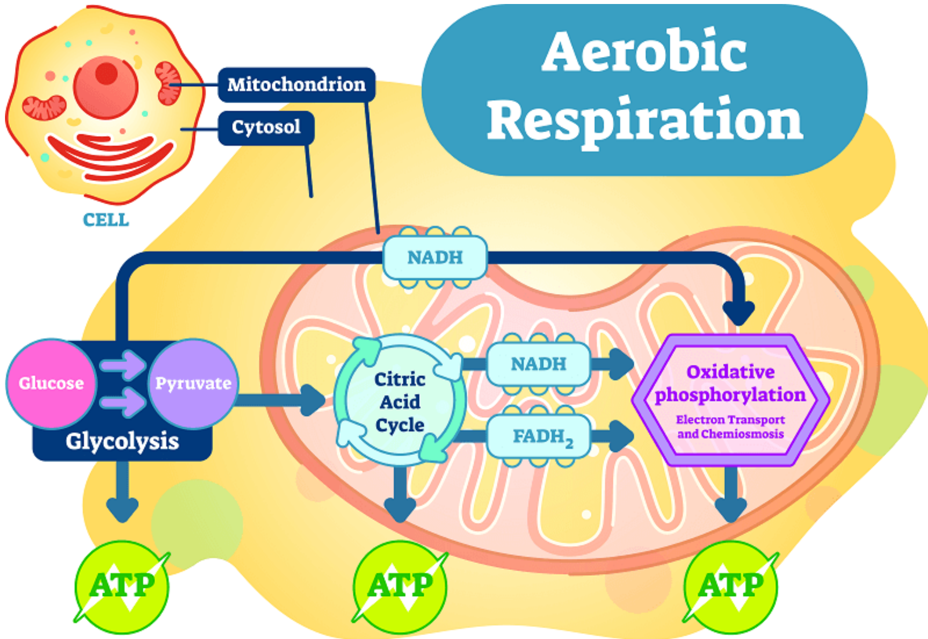
- Respiration



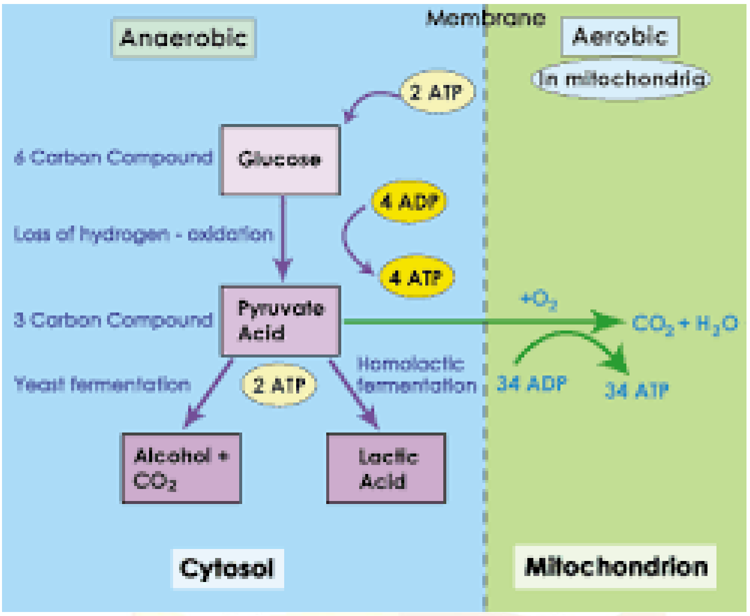
- Types of Respiration

There are two main types of respiration.

1. Aerobic Respiration
   - ✓ This type of respiration takes place in the mitochondria of all eukaryotic entities. Food molecules are completely oxidized into the carbon dioxide, water, and energy is released in the presence of oxygen.
   - ✓ This type of respiration is observed in all the higher organisms and necessitates atmospheric oxygen.



2. Anaerobic Respiration
   - ✓ This type of respiration occurs within the cytoplasm of prokaryotic entities such as yeast and bacteria. Here, lesser energy is liberated as a result of incomplete oxidation of food in the absence of oxygen.
   - ✓ Ethyl alcohol and carbon dioxide are produced during anaerobic respiration.



- **Glycolysis** is the process by which one molecule of glucose is converted into two molecules of pyruvate, two hydrogen ions and two molecules of water. Through this process, the 'high energy' molecules of ATP and NADH are synthesised. The pyruvate molecules then proceed to the link reaction, where acetyl-coA is produced

- Glycolysis and the pentose phosphate pathways in the cytosol and plastid convert sugars to organic acids, via hexose phosphates and triose phosphates, generating NADH or NADPH and ATP.

- The organic acids are oxidized in the mitochondrial citric acid cycle, and the NADH and FADH produced provide the energy for ATP synthesis by the electron transport chain and ATP synthase in oxidative phosphorylation.

- In gluconeogenesis, carbon from lipid breakdown is broken down in the glyoxysomes, metabolized in the citric acid cycle, and then used to synthesize sugars in the cytosol by reverse glycolysis

ANAEROBIC GLYCOLYSIS

- ✓ It is the anaerobic oxidation of hexose sugars or glycogen to pyruvic acid.
- ✓ It occurs in the cell cytoplasm through a chain of enzymatic reactions, absolutely without the participation of oxygen.
- ✓ Some of the free energy released from glycolysis is conserved in the form of ATP.

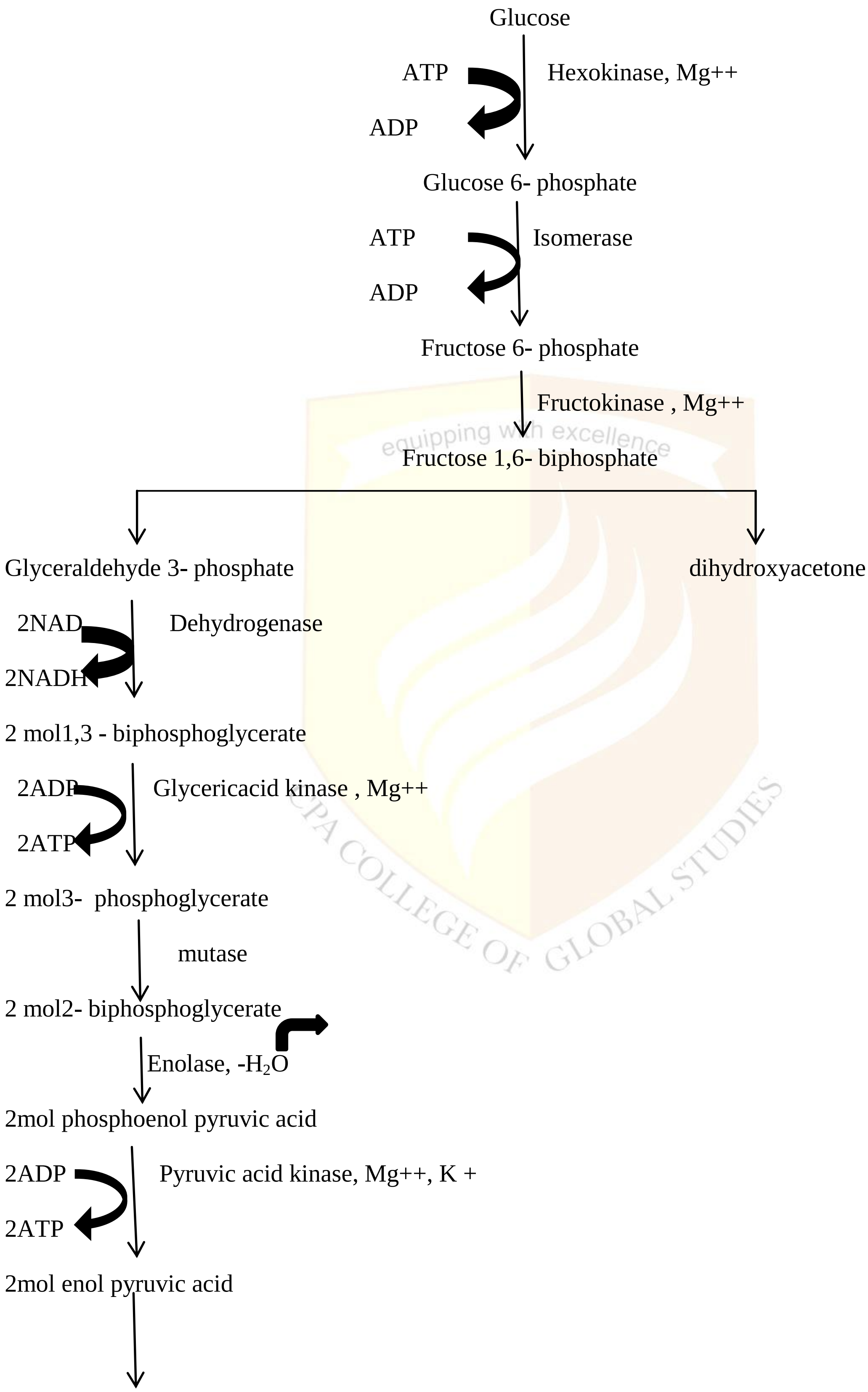
- ✓ The successive steps of glycolytic pathway were elucidated by a German biochemists Embden and Meyerhof and the Russian biochemist Parnas. Hence it is referred as Embden- Meyerhof-Parnas pathway.
- ✓ There are six major kinds of reactions occur in the glycolytic pathway
  1. Phosphoryl transfer.
  2. Phosphoryl shift
  3. Isomerization
  4. Dehydration
  5. Dehydrogenation
  6. Aldol cleavage
- ✓ Major steps of glycolysis

I. Preparatory phase

1. Phosphorylation of glucose to form glucose 6, phosphate, with ATP utilization.
2. Isomerization of glucose 6 phosphate to form fructose 6- phosphate.
3. Phosphorylation of fructose 6- phosphate to fructose 1, 6- biphosphate, utilizing ATP.
4. Cleavage of fructose 1, 6- biphosphate to two triose phosphate molecules, namely glyceraldehyde 3-phosphate and dihydroxyacetone phosphate molecules.
5. Isomerization of dihydroxyacetone phosphate to form a second molecule of glyceraldehyde 3-phosphate molecules are formed.

II. Pay off phase

6. Combined phosphorylation and oxidation of glyceraldehyde 3- phosphate, utilizing inorganic phosphate instead of ATP. This forms 1,3- biphosphoglyceric acid.
7. Transfer of phosphate group from 1,3- biphosphoglyceric acid to ADP and the formation of 3- phosphoglyceric acid and ATP.
8. Isomerization of 3- phosphoglyceric acidto form 2- phosphoglyceric acid.
9. Dehydration of 2- phosphoglyceric acid to form phosphoenol pyruvic acid.
10. Transfer of phosphoryl or phosphate group from phosphoenol pyruvic acid to ADP, forming enol pyruvic acid and ATP.
11. Spontaneous transformation of enol pyruvic acid to keto pyruvic acid.


Glucose
ATP
Hexokinase, Mg++
ADP
Glucose 6- phosphate
ATP
Isomerase
ADP
Fructose 6- phosphate
Fructokinase , Mg++
Fructose 1,6- biphosphate
Glyceraldehyde 3- phosphate
dihydroxyacetone
2NAD
Dehydrogenase
2NADH
2 mol1,3 - biphosphoglycerate
2ADP
Glycericacid kinase , Mg++
2ATP
2 mol3- phosphoglycerate
mutase
2 mol2- biphosphoglycerate
Enolase, -H_2O
2mol phosphoenol pyruvic acid
2ADP
Pyruvic acid kinase, Mg++, K +
2ATP
2mol enol pyruvic acid

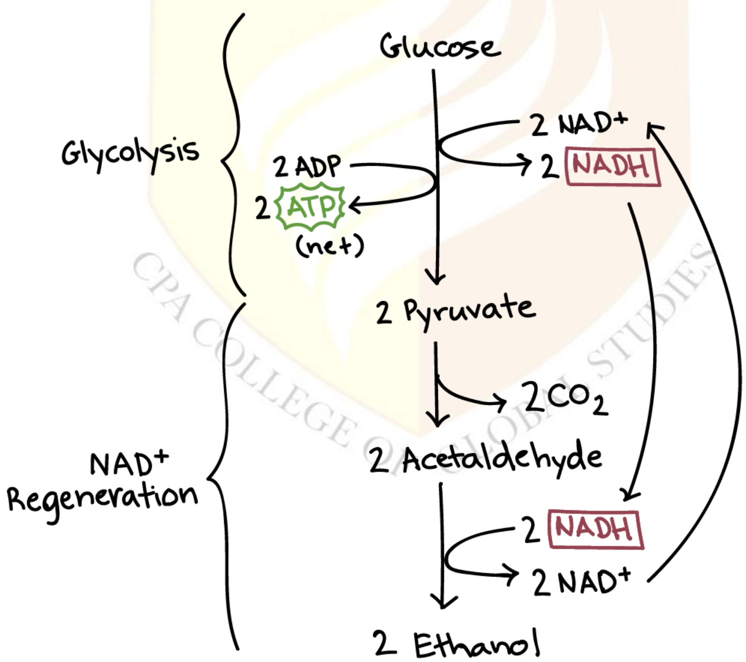
2mol keto pyruvic acid

ANAEROBIC RESPIRATION

- Involves the conversion of glucose to ethanol and CO_2 in alcoholic fermentation or lactic acid fermentation.
- Do not require oxygen.
- Glucose first coverts into pyruvic acid through glycolysis, and later to ethyl alcohol or lactic acid depending upon the organism in which it occurs.
- Complete pathway occurs in cytoplasm.
- Fermentation simply the anaerobic breakdown of glucose or other organic molecule, yielding energy in the form of ATP.
- The anaerobic breakdown of sugars to CO_2 and ethyl alcohol in micro-organism called Pasteur effect.
- Fermentation is 2 types

  1. alcoholic fermentation – produce ethanol from glucose

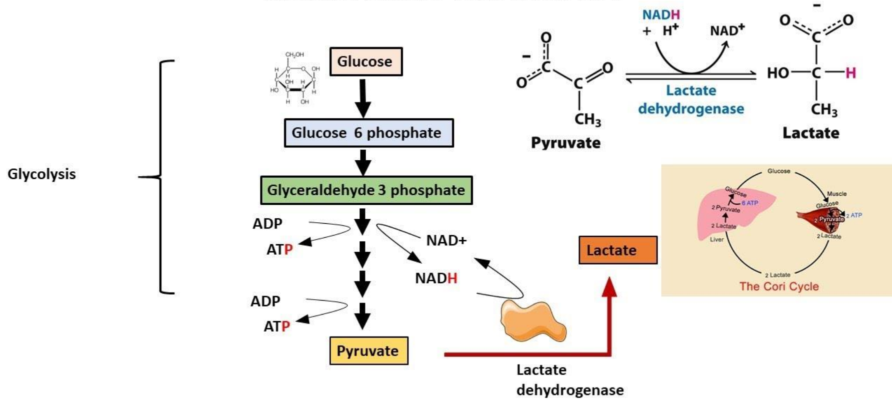
     glucose+ 2Pi+2ADP $\longrightarrow$ 2Ethanol+2ATP+2H_2O+2CO_2



  2. lactic acid fermentation- produce lactic acid

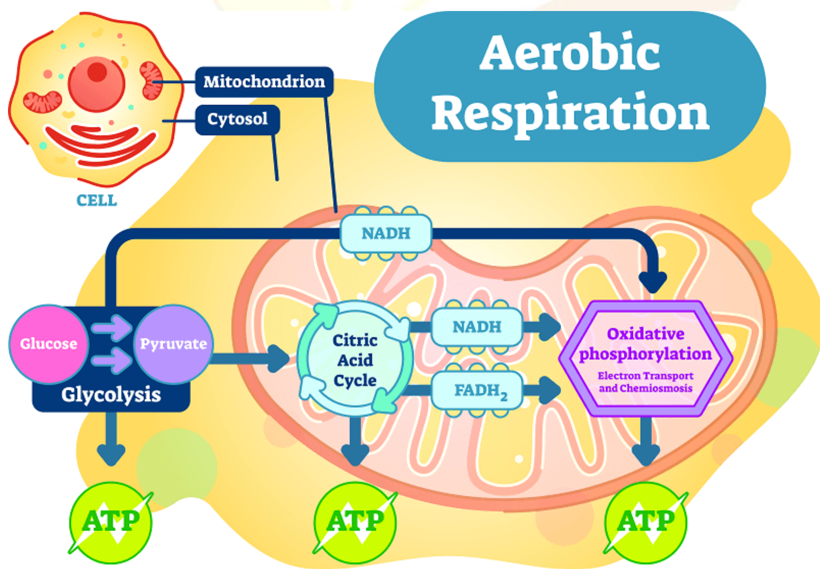
     pyruvic acid+NADH+H^+ $\longrightarrow$ lactic acid+ NAD^+

Lactic acid fermentation : fate of pyruvate under anaerobic condition



AEROBIC RESPIRATION

- Stepwise breakdown of respiratory substrate to carbondioxide and water in the presence of molecular oxygen.
- It involves 4 major events.
  1. Glycolysis- breakdown of glucose to pyruvic acid.
  2. Oxidative decarboxylation of pyruvic acid to Acetyl CoA
  3. Krebs cycle or tricarboxylic acid cycle (TCA cycle)
  4. Terminal oxidation and phosphorylation in the respiratory chain.

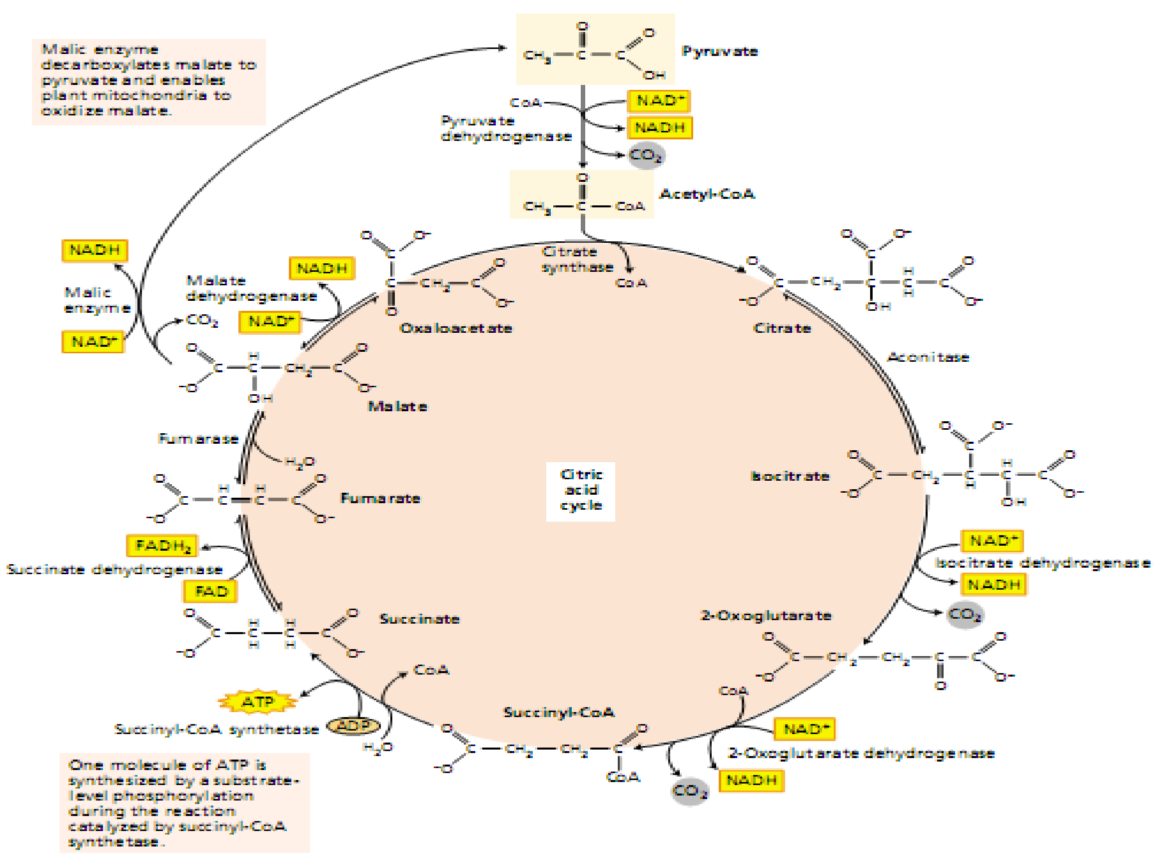


1. Glycolysis taken place and produce pyruvic acid.
2. conversion of pyruvic acid to acetyl CoA
   - ✓ the major steps I this conversions are listed below
     1. Decarboxylation of pyruvic acid using pyruvic acid dehydrogenase.

2. Transfer of acetol group to lipoic acid using lipoyl acetyl transferase.
3. Transfer of acetyl group to CoA and reduction of lipoic acid using acetyl tranferase.
4. Oxidation of dihydrolipoic acid.

3. Krebs cycle or tricarboxylic acid cycle (TCA cycle)

- ✓ The **tricarboxylic acid (TCA) cycle,** also known as the Krebs or citric acid cycle, is the main source of energy for cells and an important part of aerobic respiration. The cycle harnesses the available chemical energy of **acetyl coenzyme A** (acetyl CoA) into the reducing power of nicotinamide adenine dinucleotide (NADH).
- ✓ The TCA cycle is part of the larger glucose metabolism whereby glucose is oxidized to form pyruvate, which is then oxidized and enters the TCA cycle as acetyl-CoA.
- ✓ Half of the intermediates on which the cycle depends are also the origin of pathways leading to important compounds such as fatty acids, amino acids, or porphyrins.
- ✓ If any of these intermediates are thus diverted, the integrity of the cycle is broken and the cycle no longer functions.
- ✓ Production of essential energy can only be resumed if the diverted intermediate or a subsequent intermediate that leads to oxaloacetate can be replenished by *anaplerotic* (refilling) reactions.



- ✓ Biochemical functions of krebs cycle
  1. Energetic functions.
  2. Integrative functions.
  3. Amphibolic functions.

4. Hydrogen-gnerating or donating functions.
5. Regulatory functions

- ✓ Each turn of the TCA cycle brings about the complete oxidation of one molecule of acetate and the total production of 209,000 calories of energy.
- ✓ TCA cycle serves as a common terminal catabolic pathway for the biological oxidation or final breakdown of carbohydrate, lipids, and proteins.
- ✓ TCA cycle serves as the major hydrogen generator for the respiratory chain.

ELECTRON TRANSPORT SYSTEM (ETS)

- Terminal oxidation and phosphorylation in aerobic respiration.
- Electron transport chain, hydrogen carrying chain, oxidation-reduction chain, or respiratory chain is a complex multi enzyme chain, concerned with the terminal oxidation of the respiratory substrate and phosphorylation of ADP in aerobic respiration.
- It transport energized hydrogen or electron from a donor molecule to molecular oxygen by a chain transfer mechanism.
- Involves a series of a redox reaction.
- Overall reaction taken place in mitochondria.

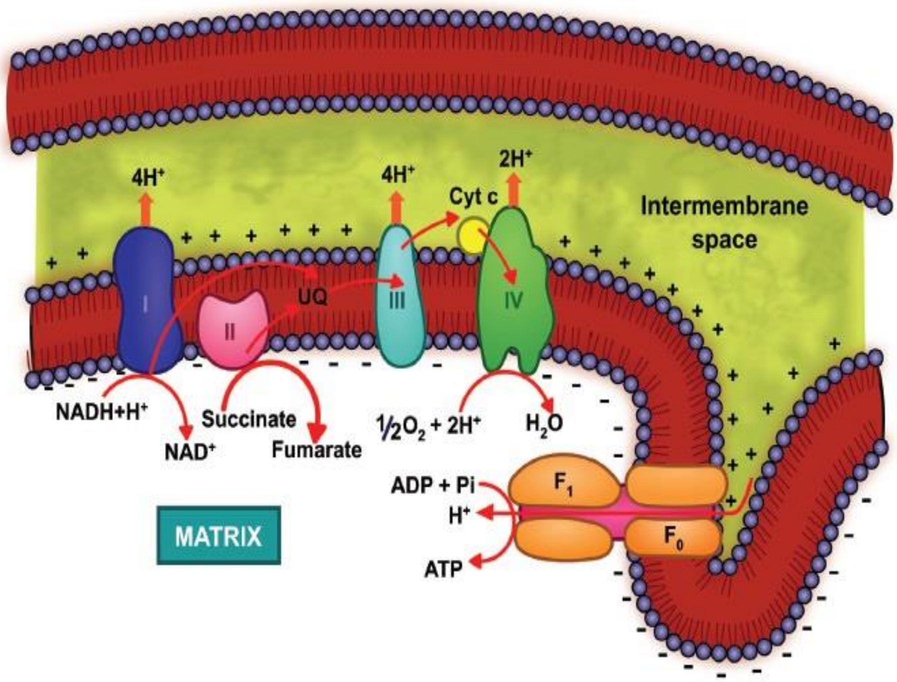


Figure 14.10: Electron Transport Chain and Terminal Oxidation

RESPIRATORY QUOTIENT (RQ)

- Ratio of the volume of the carbon dioxide evolved to the volume of the oxygen consumed during the period of respiration at standard temperature and pressure.

$$RQ = \frac{Volume\ of\ the\ carbondioxide\ evolved}{volume\ of\ the\ oxygen\ absorbed}$$

FACTORS AFFECTING RESPIRATION

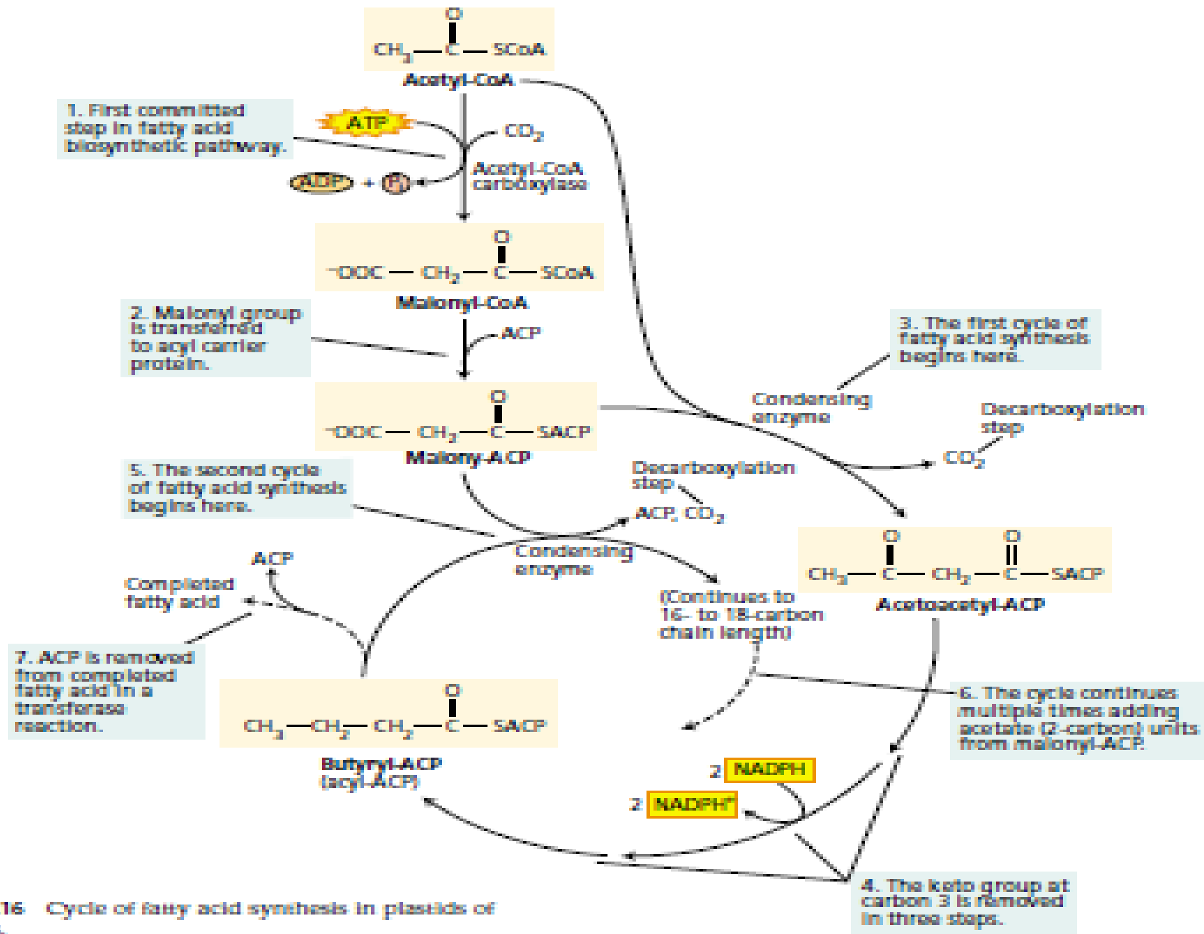
- External factors
  1. Atmospheric temperature
  2. Light intensity
  3. Carbon concentration
  4. Availability of oxygen
  5. Salts
  6. Injuries
- Internal factors
  1. Protoplasmic factors
  2. Concentration of respiratory substrate.

Lipd metabolism

- Lipids represent a more reduced form of carbon than carbohydrates,
- Complete oxidation of 1 g of fat or oil (which contains about 40 kJ, or 9.3 kcal, of energy) can produce considerably more ATP than the oxidation of 1 g of starch (about 15.9 kJ, or 3.8 kcal).
- The fatty acids in plants are usually straight-chain carboxylic acids having an even number of carbon atoms.
- The carbon chains can be as short as 12 units and as long as 20, but more commonly they are 16 or 18 carbons long.
- Fats, which have a higher proportion of saturated fatty acids, are solid at room temperature.
- Triacylglycerols in most seeds are stored in the cytoplasm of either cotyledon or endosperm cells in organelles known as oleosomes (also called *spherosomes* or *oil bodies*)
- Oleosomes have an unusual membrane barrier that separates the triglycerides from the aqueous cytoplasm.
- A single layer of phospholipids (i.e., a half bilayer) surrounds the oil body with the hydrophilic ends of the phospholipids exposed to the cytosol and the hydrophobic acyl hydrocarbon chains facing the triacylglycerol interior.
- The oleosome is stabilized by the presence of specific proteins, called *oleosins*, that coat the surface and prevent the phospholipids of adjacent oil bodies from coming in contact and fusing.

Fatty Acid Biosynthesis Consists of Cycles of Two-Carbon Addition

- Fatty acid biosynthesis involves the cyclic condensation of two-carbon units in which acetyl-CoA is the precursor.
- In plants, fatty acids are synthesized exclusively in the plastids;
- in animals, fatty acids are synthesized primarily in the cytosol.



11.16 Cycle of fatty acid synthesis in plastids of ...ils.

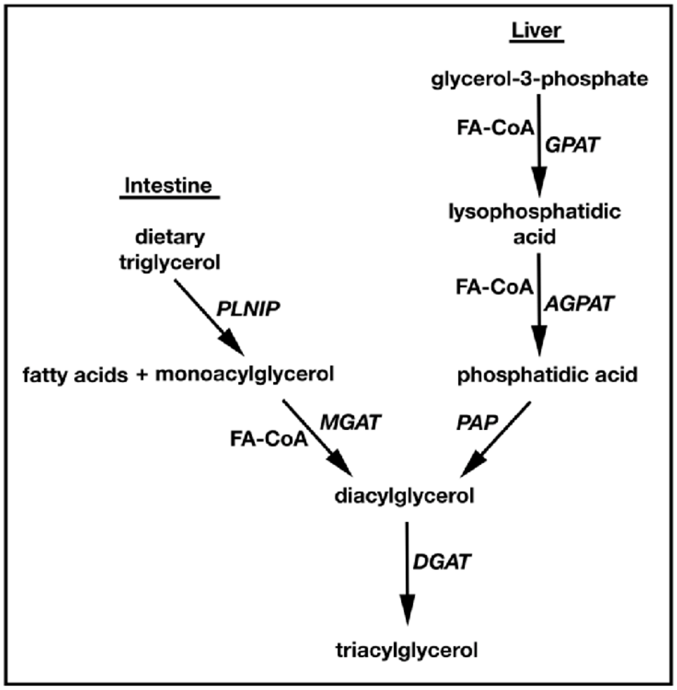
- In the first cycle of fatty acid synthesis, the acetate group from acetyl-CoA is transferred to a specific cysteine of *condensing enzyme* (3-ketoacyl-ACP synthase) and then combined with malonyl-ACP to form acetoacetyl-ACP.
- Next the keto group at carbon 3 is removed (reduced) by the action of three enzymes to form a new acyl chain (butyryl-ACP), which is now four carbons long
- The four-carbon acid and another molecule of malonyl-ACP then become the new substrates for condensing enzyme, resulting in the addition of another two-carbon unit to the growing chain, and the cycle continues until 16 or 18 carbons have been added.
- Some 16:0-ACP is released from the fatty acid synthase machinery, but most molecules that are elongated to 18:0-ACP are efficiently converted to 18:1-ACP by a desaturase enzyme. The

repetition of this sequence of events makes 16:0-ACP and 18:1-ACP the major products of fatty acid synthesis in plastids

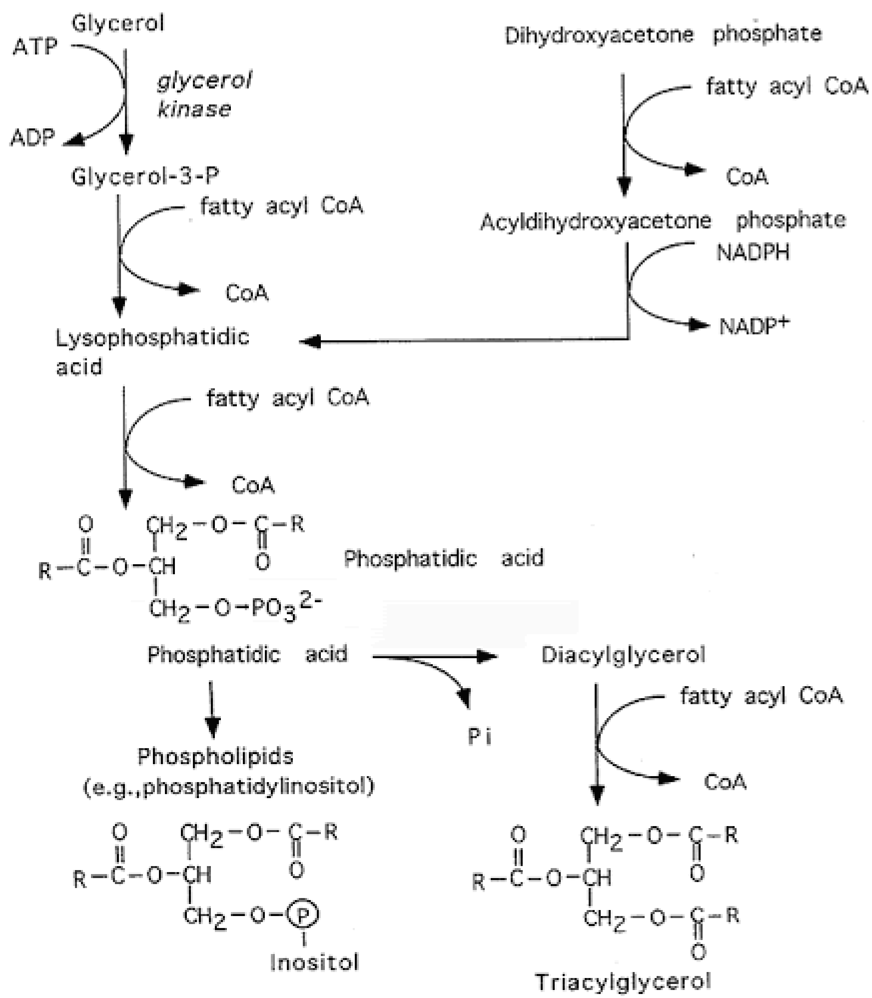
- Fatty acids may undergo further modification after they are linked with glycerol to form glycerolipids.
- Additional double bonds are placed in the 16:0 and 18:1 fatty acids by a series of desaturase isozymes.
- Desaturase isozymes are integral membrane proteins found in the chloroplast and the endoplasmic reticulum (ER).
- Each desaturase inserts a double bond at a specific position in the fatty acid chain, and the enzymes act sequentially to produce the final 18:3 and 16:3 products

Triglyceride biosynthesis

- The overall process of triglyceride (triacylglycerol) biosynthesis consists of four biochemical pathways: fatty acyl-CoA biosynthesis, conversion of fatty acyl-CoA to phosphatidic acid, conversion of phosphatidic acid to diacylglycerol, and conversion of diacylglycerol to triacylglycerol.
- In the direct synthesis of triglycerides alpha glycerol phosphate and fatty acyl CoA are utilized, rather than free glycerol and fatty acids.
- The process occurs in cytoplasm.
- There are two initial pathway in triglyceride synthesis
    1. Glycerol phosphate pathway- glycerol undergo TP –dependent phosphorylation and forms alpha glycerol 3 phosphate.mediated by enzyme glycerokinase.
    2. Dihydroxyacetone phosphate pathway –DHAP undergo NADH dependent reduction and forms alpha glycerol3- phosphate. It is mediated by glycerol 3-phosphate dehydrogenase.



- A flow chart of triglyceride synthesis is given below

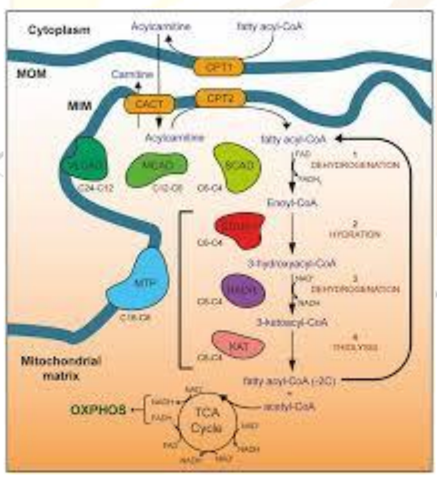


Lipid metabolism

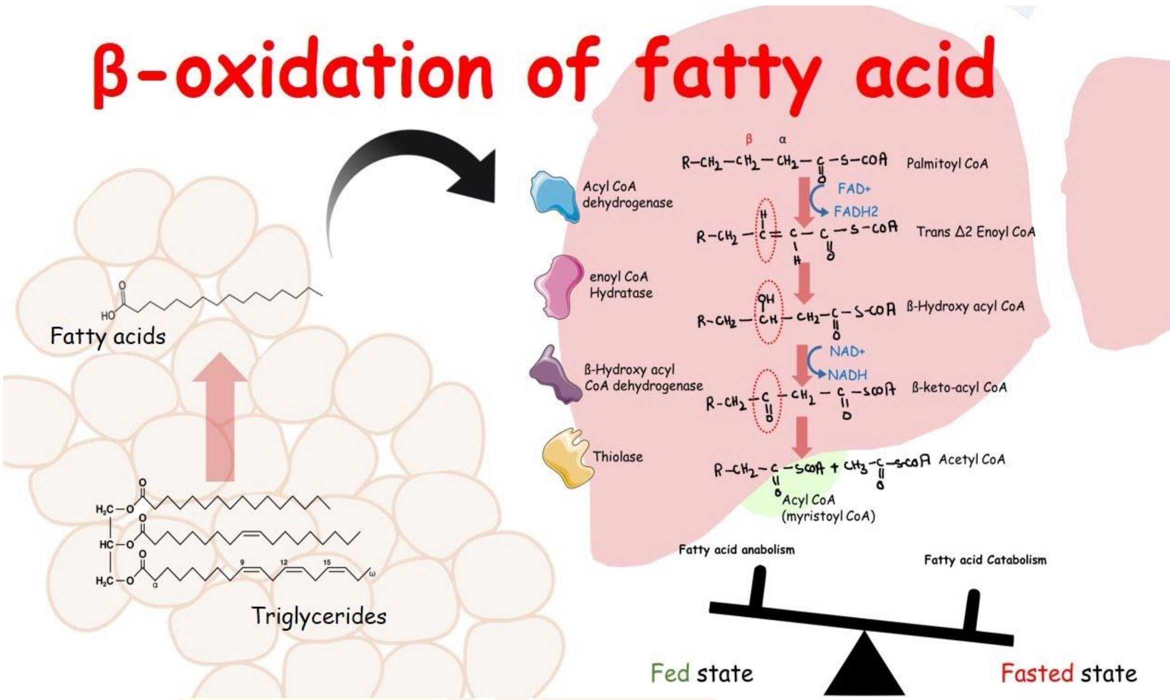
- Metabolism of triglycerides (triacylglycerols).
- Includes catabolic phase includes oxidation of triglycerides and anabolic phase includes the synthesis of fatty acids, triglycerides and cholesterol.
- Oxidation of lipids
  - ✓ Oxidations of fats or triglycerides.
  - ✓ Fats first hydrolyzed into fatty acids and glycerol. Hydrolysis mediated by cellular lipases like triglyceride lipases, diglyceride lipases and monoglyceride lipases.
  - ✓ oxidation of lipids includes oxidation of glycerol and fatty acids
    1. Oxidation of glycerol
       - Produced glycerol have two metabolic fates
       - Utilized for the synthesis of glucose (reverse glycolysis) and rest may undergo oxidation.
       - Under anaerobic condition dihydroxyacetone phosphate enters to glycolytic pathway and transformed into pyruvic acid. Under aerobic conditions, it is oxidized into carbondioxide and water.

- Under anaerobic condition Oxidation of glycerol yield one ATP.
- Under aerobic condition it yields 19 ATP molecules.

2. Oxidation of fatty acid (
   I. Fatty acid with even number of carbon atom
      - Fatty acids with even number ofcarbon atoms follows three principal pathways
        1. Alpha oxidation-successive removal of 1 carbon unit from the carboxyl end of fatty acids. In Endoplasmic recticulam.
        2. Beta oxidation- principal pathway of fatty acid oxidation. Successive separation of 2 carbon units from the beta position of the carboxyl end of fatty acid. Occurs in mitochondrial matrix.
        3. Omega oxidation- occurs the omega carbon of fatty acids, which is far away from carboxyl end. Takes place in Endolasmic recticulum
      - The β-oxidation pathway accomplishes the complete degradation of saturated fatty acids having an even number of carbon atoms. Most fatty acids have such structures because of their mode of synthesis .
      - However, not all fatty acids are so simple. The oxidation of fatty acids containing double bonds requires additional steps.
      - Beta oxidation involve the activation of fatty acid into fatty acyl CoA. And cross the mitochondrial membrane through carnitine shuttle system.



The complete beta oxidation is



II. Fatty acid with odd number of carbon atom

- fatty acids containing an odd number of carbon atoms yield a propionyl CoA at the final thiolysis step that must be converted into an easily usable form by additional enzyme reactions.
- Here propionyl CoA takes an unsual enzymatic route. It get carboxylated to its stereoisomer D-methylmalonyl CoA. It is catalyzed by propionyl CoA carboxylase.
- Later this D-methylmalonyl CoA will undergo epimerization and forms its L- isomers with the help of methyl malonyl epimerases. L-methylmalonyl CoA undergo unusual intramolecular rearrangement and forms succinyl CoA.
- This succinyl CoA enters the TCA cycle for final oxidation.

Aminoacid metabolism

- Catabolic degradation of aminoacids classified under thtee categories

I. Conversion of alpha amino group

✓ Cleavage of an amino group from an aminoacids as NH_3

1. Deamination

✓ Production of free aminoacid and corresponding keto acids or hydroxyl acids.

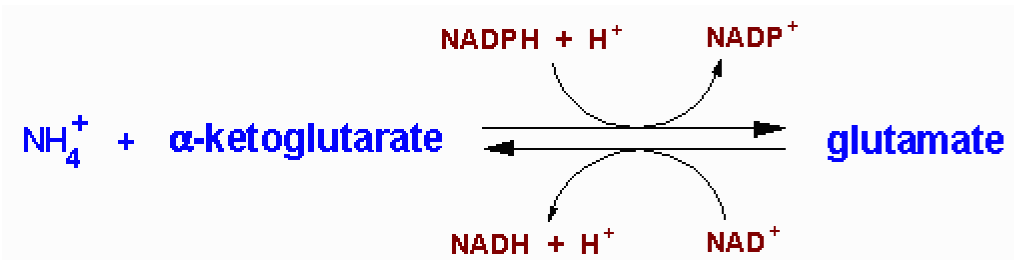
a. Oxidative deamination

b. Reductive deamination

c. Hydrolytic deamination

d. Intermolecular deamination

2. Transamination
   - ✓ Reversible transfer of alpha-amino group from an aminoacid to a keto acid which, in turn, is a derivative of another aminnoacids.
   - ✓ Aminoacids and keto acids interconversion, result the formation of a new amino acid and a new keto acid.
   - ✓ Its ithe process of combined deamination and amination.
   - ✓ Tranamination reaction catalyzed by a group of enzyme called transaminases or aminotranferases.



3. Transdeamination
   - ✓ Tranamination coupled with oxidative deamination.
   - ✓ It occurs in two steps; initially tranamination and the newly formed aminoacid will forms to keto acid and ammonia by oxidative deamination.

II. Degradation of the carbon framework of aminoacids
   - ✓ Hydrocarbon radical of amino acids is broken down and ultimately converted to products that are involved in TCA cycle like acetyl CoA, oxaloacetic acid, fumaric acid and succinyl Co A.

III. Decarboxylation of aminoacids
   - ✓ Enzymatic removal of carboxyl group as CO_2. And production of biogenic amines.
   - ✓ Enzyme decarboxylases catalyses these reaction. Pyrodoxal phosphate acts as a coenzyme.