

Unit - I

Plant - Water Relations

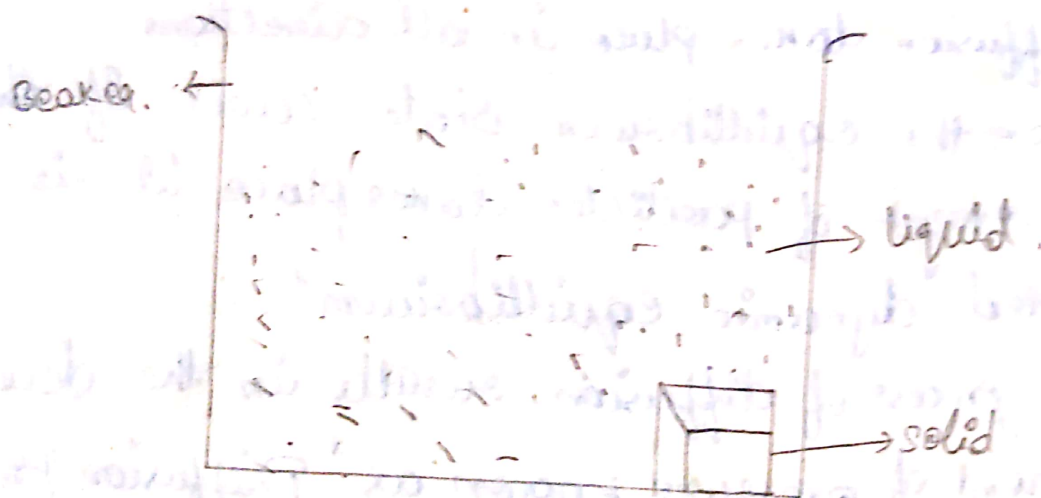
Diffusion :-

- Diffusion is the movement of molecules of gases, liquids & solutes from high concentration to low concentration until the molecules reached to the equilibrium state
- It is the important property of gases, liquids, solutes etc.
- Diffusion takes place in all directions
- Even the equilibrium state occurs if the movement of particles takes place it is called "dynamic equilibrium"
- The process of diffusion results in the development of pressure known as 'Diffusion Pressure'
- Diffusion phenomenon is controlled by the factors like density, temperature, pressure gradient, Concentration of the medium.

Role of Diffusion in plant life:-

- Exchange of gasses during photosynthesis and Respiration.
- During ions Absorption.
- Transpiration (a) At the time of transpiration.
- Translocation of solutes inside the cell at lower distances.

Diffusion of Solid in water:-



- Taking of water & swelling of colloidal substances is called imbibition.
- It is the physical as well as a biological process.

- If a few seeds with a permeable seed coat are soaked in water, within few hours they swell up. The amount of water that enters into the seed is too large when compared with dry seeds.
- There seems to be a specific force of attraction between water molecule and imbibent molecule.
- It can be observed that some pressure is created inside the seed due to imbibition pressure.

$$DPD = IP - TP$$

DPD = Diffusion pressure deficit

IP = Imbibition pressure.

TP = Turgor pressure.

Role of Imbibition in plant life :-

- It plays a key role in germination of seeds.
- Absorption of water through imbibition is the initial step.
- It assists the movement of water from cell to cell.

- Water moves into ovules which are ripening into seeds by imbibition.

Osmosis:-

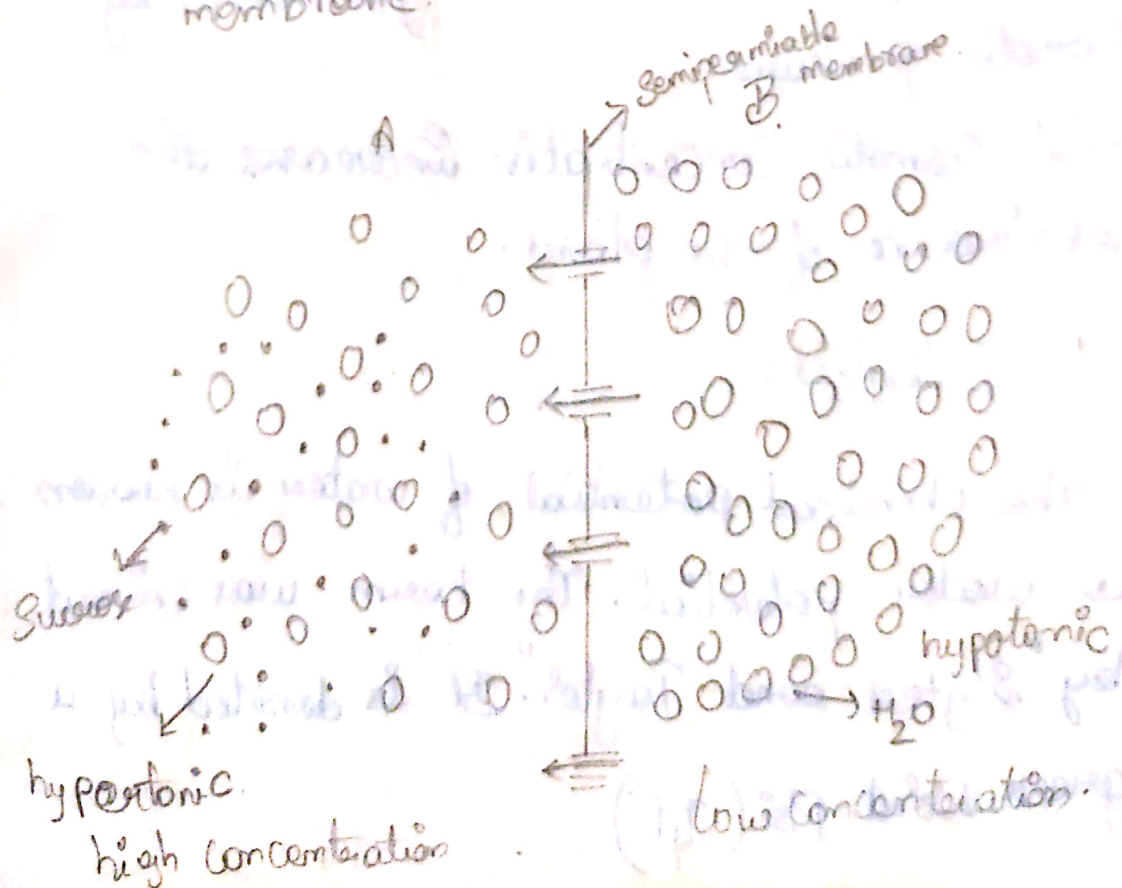
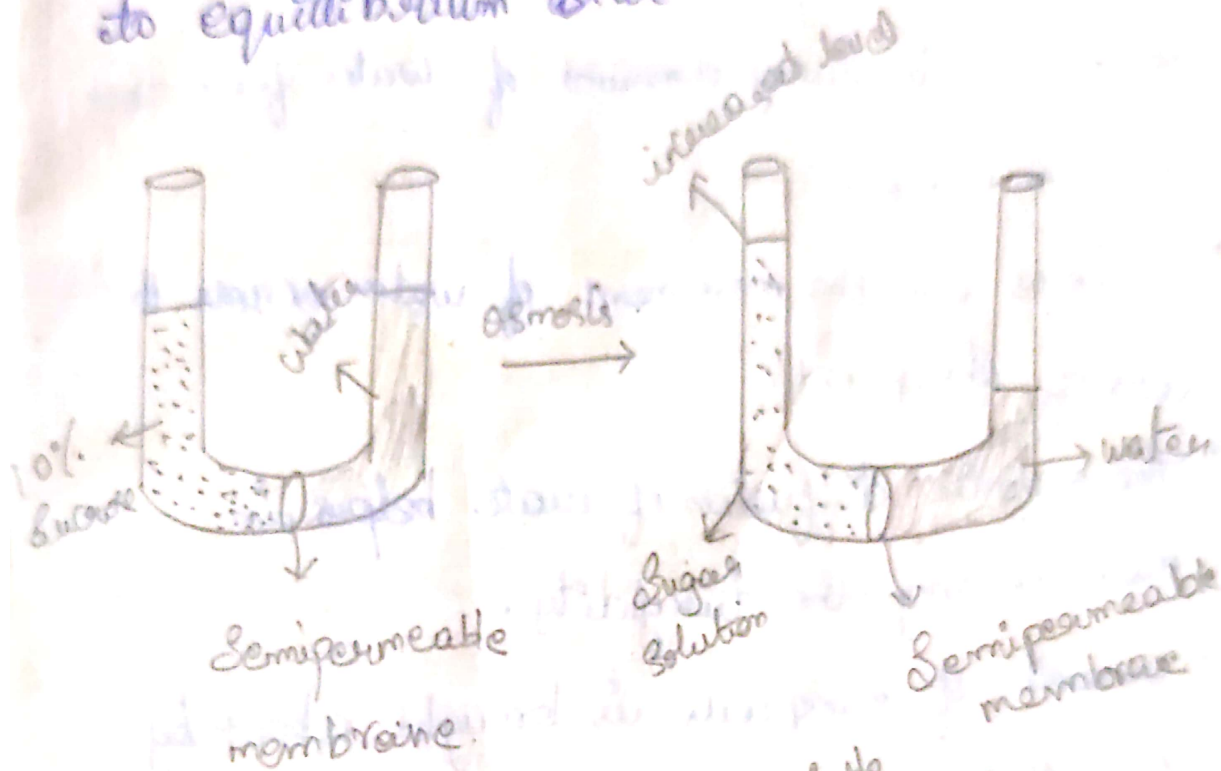
- when the solution of Different Concentrations are separated by semipermeable membrane, the diffusion of water or solvent from the solution of lower concentration to the solution of higher concentration until the state of equilibrium is known as Osmosis.
- Osmosis is against the concentration gradient. It is first observed by Abbe & Nollet.

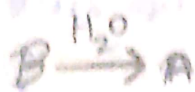
Experiment:-

- A semipermeable membrane is fixed between water, 10% Sugar solution.
- These are kept in U-tube
- Water can move through semipermeable membrane until the equilibrium state occurs.

→ After some time of incubation water molecules move to semipermeable membrane and the level of sucrose solution increases due to osmosis.

→ This phenomenon occurs until the solution reached to equilibrium state.





Semipermeable membrane.

Applications :-

- plants Absorb large amount of water from soil through Osmosis.
- It helps in the movement of water across the cells of the plant.
- The osmotic diffusion of water helps in maintaining the turgidity.
- Growth of young cells is brought about by Osmotic pressure.
- High Osmotic Concentration increases the resistance of the plant.

4M

* Water Potential :-

The chemical potential of water is known as water potential. The term was coined by "Slyter and Taylor". It is denoted by a Greek word Psi (Ψ)

→ The free energy of pure water is more when any solute dissolved in pure water its free energy decreases.

→ For pure water the water potential is "Zero".

→ The water movement takes place from higher water potential (less negative) to a region of lower water potential (more negative).

$$\psi_w = \psi_m + \psi_s + \psi_p$$

ψ_w = Water potential.

ψ_m = matrix potential.

ψ_s = Solute potential

ψ_p = pressure potential.

Matrix potential (ψ_m):-

It is the force of absorption in which some water is held over the surface of the plant cell.

It is about -0.1 atm (negligible)

Solute Potential (ψ_s):-

It is also known as Osmotic Potential.

→ The free energy of water is decreased

by the addition of solute particles. It is equal to the maximum Osmotic Pressure.

→ The value of solute potential is always negative.
Pressure Potential (ψ_p): -

→ The hydrostatic pressure which develops in a plant due to inward flow of water is called pressure potential. It is also known as wall pressure or Turgor pressure.

Significance :-

→ Water potential is an important force which determines the water status of a plant.

→ The absorption of water is depends on water potential.

→ The air dried seeds and spores are able to permeate due to very low water potential

(-60 to -100 atm)

Absorption of water :-

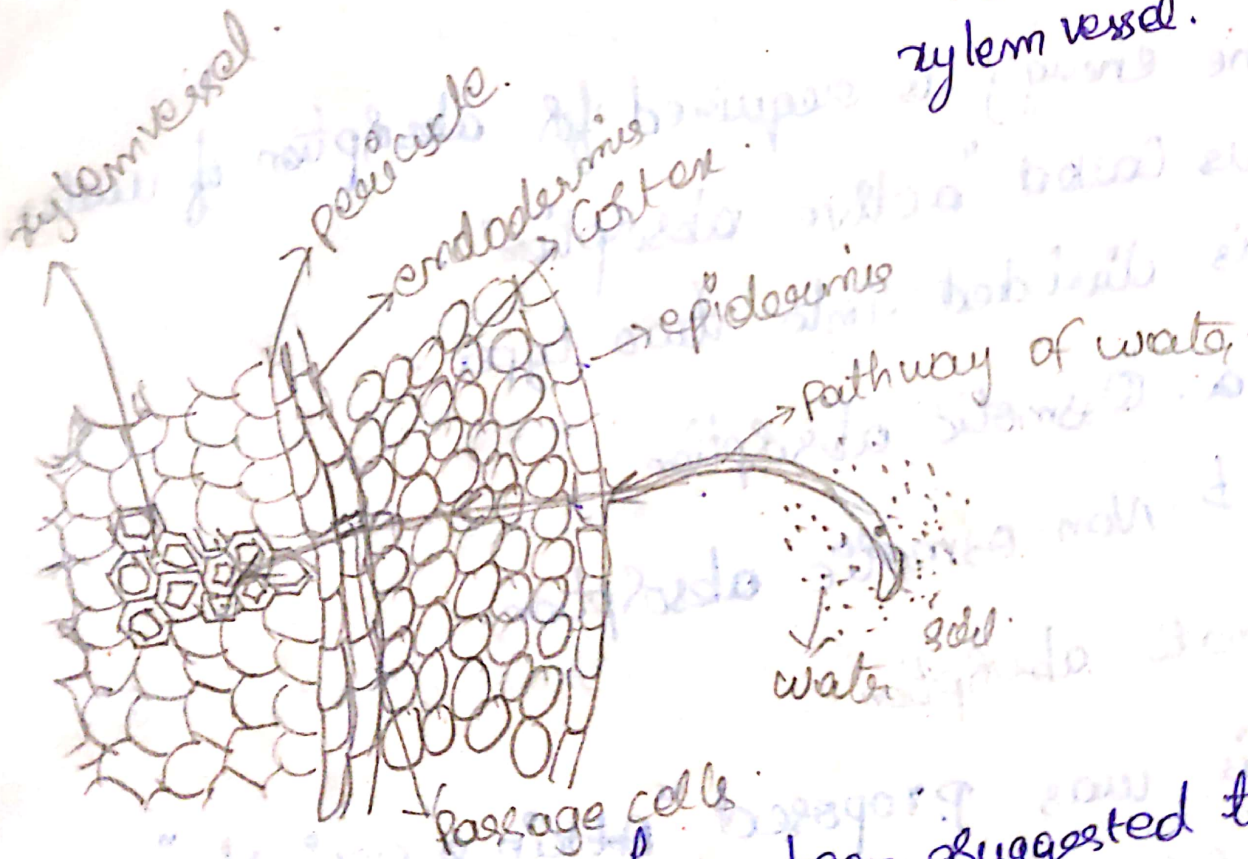
→ Water is absorbed by the plant through root hair, epidermis, cortex, Endodermis (passage cells), pericycle, xylem vessel.

Pathway of Water Absorption.

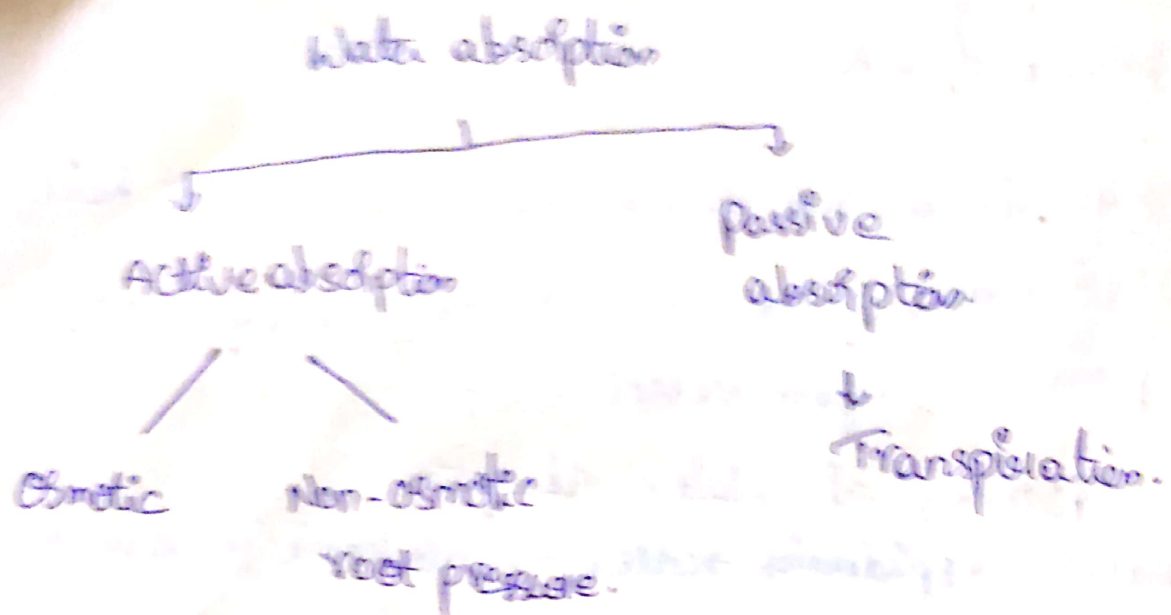
Water → Epidermis → cortex → Endodermis (passage cells)

↓
pericycle.

↓
xylem vessel.



Two types of theories have been suggested to explain the absorption of water mechanism.



Active Absorption:-

- If the energy is required for absorption of water, it is called "active absorption".
- It is divided into two types.
 - a. Osmotic absorption.
 - b. Non-osmotic absorption.

a. Osmotic absorption:-

- This was proposed "Atkin & Priestly".
- According to this theory, there is a gradient of "diffusion pressure deficit" (DPD) created between Soil and the xylem.
- The value of the osmotic pressure in the root hair is generally 2-8. Against it a

Soil solution the osmotic pressure is 1 atm.

→ Then the water is entered into the root hair through endosmosis.

2nd Root Pressure:-

The hydrostatic pressure created in the root due to osmotic absorption of water is called Root Pressure.

Root pressure is enough for herbs but it is not applicable to larger trees.

3rd Bleeding:-

When well watered plant is cut at the stump near to the soil some water exudation occurs this is called Bleeding. Bleeding is due to "Root Pressure".

b. Non-Osmotic Absorption:-

→ This was explained by "Thimann and Krammer".

→ Absorption of water takes place when the osmotic potential is more in the surroundings than the plant should acquire energy from respiration.

→ It is experimentally proved that if oxygen decreases due to low respiration rate the absorption of water also decreases.

→ Respiratory inhibitors Inhibit the absorption of water.

Respiration & Absorption of water

Passive Absorption :-

- Here water Absorption takes place from roots without input of energy.
- Transpiration pulling takes place at the time of Absorption.

Factors Affects On Water Absorption :-

Rate of Transpiration :-

When transpiration increases automatically the absorption of water also increases.

Root System :-

Deep rooted plants can absorb more water than surface rooted plants.

Soil Composition & Soil water Content :-

The absorption of water depends on availability of water in the Soil. At the same time also depends on Soil Composition.

Temperature:-

low temperature inhibits the absorption and
high temperature increases the Absorption.

4M

Apoplast & Symplast:-

→ Munch first proposed Apoplast and Symplast.

Apoplast:-

→ Apoplast is the part of the plant which include
cell wall and Intercellular spaces.

→ They are all interconnected and forming a
continuous non living ^{space} outflow system known
as Apoplast

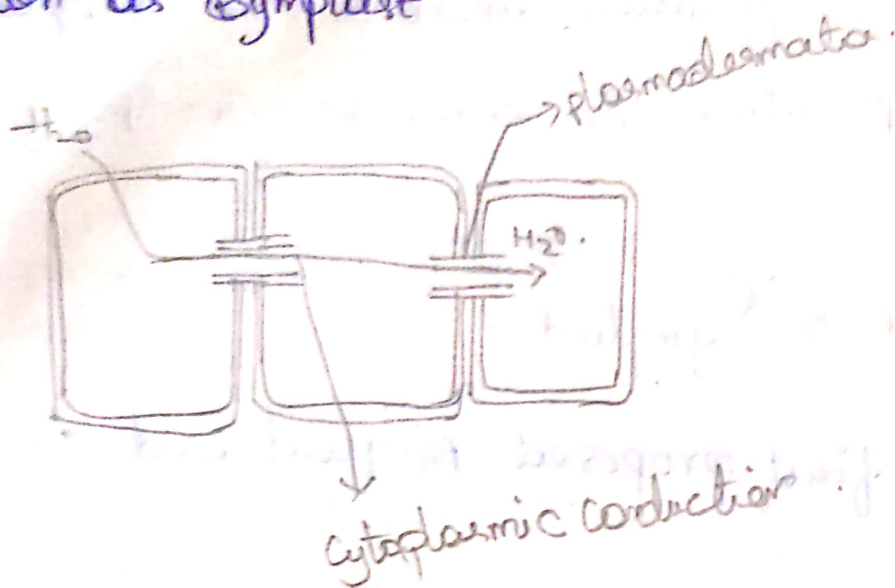


Symplast:-

→ Symplast is the part of the plant includes
cytoplasm of all cells. Connected through plasmodesmata.

→ all living parts of living cells are interconnected

by forming a continuous living inner space known as symplast.



xx 10M Ascent of Sap.

"The upward movement of water through xylem vessels from roots to all over the parts of the plant is called 'Ascent of Sap'."

→ There are many theories to explain Ascent of Sap.

i. Girdling experiment - Malpighi.

ii. Relay pump theory - Crookshanks.

iii. Pulsating theory - J.C. Bose.

iv. Transpiration pulling theory - Dixon & Jolly.

v. Root pressure $\rightarrow$ Stephen Hales

vi. Physical theories.

Girdling Experiment (&) Ringing Experiment :-

$\rightarrow$ This was proposed by "Malpighi".

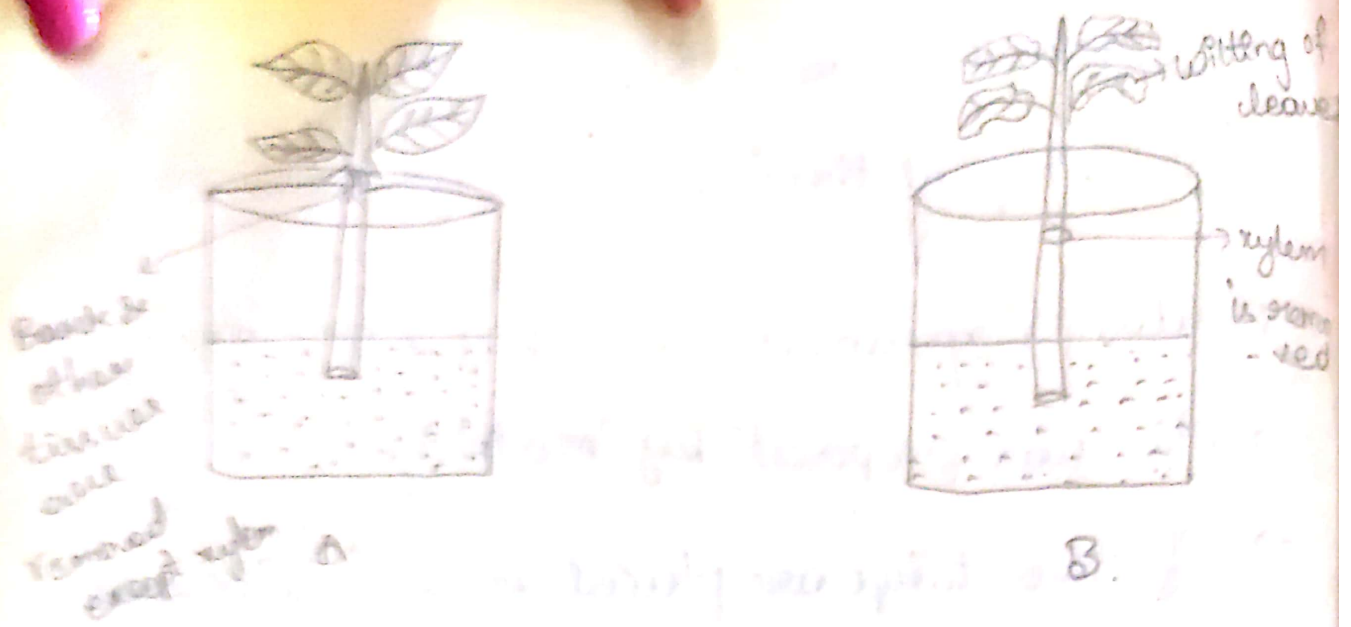
$\rightarrow$ If two twigs are placed in two different beakers (A, B) and supplied with the dye 'eosin'

$\rightarrow$ In beaker A except xylem the outer bark and all tissues are removed

$\rightarrow$ In beaker B the xylem is carefully removed from the twig. After the incubation period the twig present in beaker 'A' is having fresh leaves due to continuous supply of water through xylem.

$\rightarrow$ The twig present in beaker 'B' is wilted due to insufficient supply of water because of the absence of xylem.

$\rightarrow$ Through this experiment Malpighi concluded that "xylem vessel is essential for Ascent of Sap".



Grindling experiment / Ringing experiment.

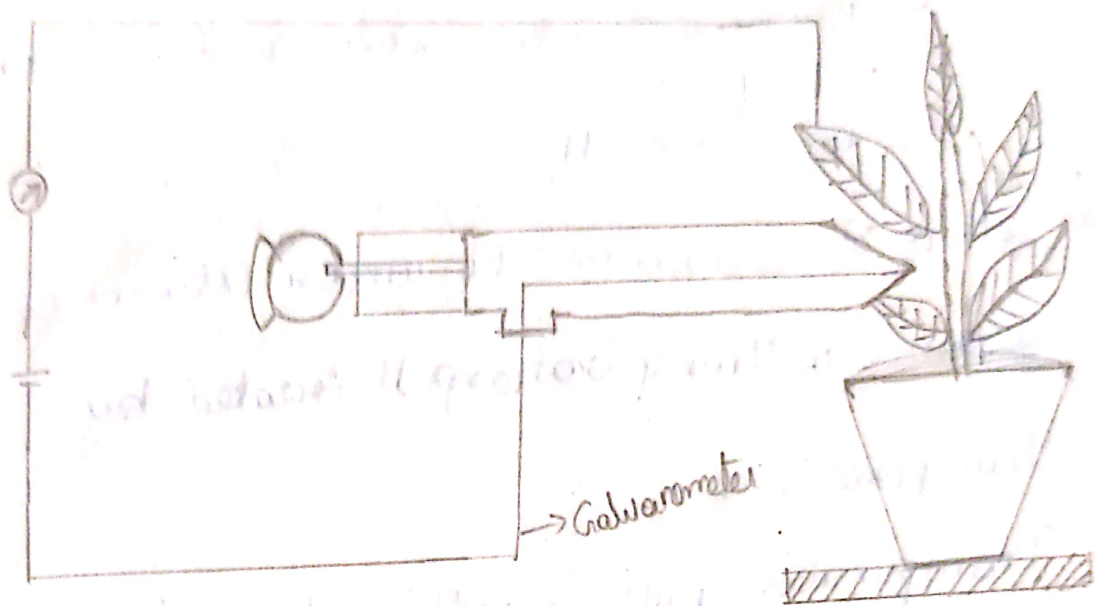
Relay Pump theory:-

- This was explained by "Goldswicky".
- He proposed that xylem vessels and tracheids can act as osmometers and the surrounding tissues pump water in an upward direction.
- Variation in the osmotic concentration draw them to allow water into the xylem vessels.

Pulsating theory:-

- It was explained by J.C Bose.
- In his galvanometer experiments, he observed pulsatory activities exhibited by the cortical cells. In absorption of water from outside.

- Pump water finally enters into the xylem vessels, ultimately the upward transport takes place.



Root pressure theory: -

- It was proposed by "Stephen Hales."
- The hydrostatic pressure generated in roots due to accumulation of absorbed water is called 'Root pressure'.
- Root pressure is mainly due to Osmosis.
- Root pressure magnitude is normally below 2 atm. Can lift water upto 20-21 meters height. So Root pressure theory can't explain Ascent of Sap in tall trees and shrubs.

Cohesion - Tension Theory.

- This was explained by "Dixon and Joly".
- Cohesion means attraction between the water



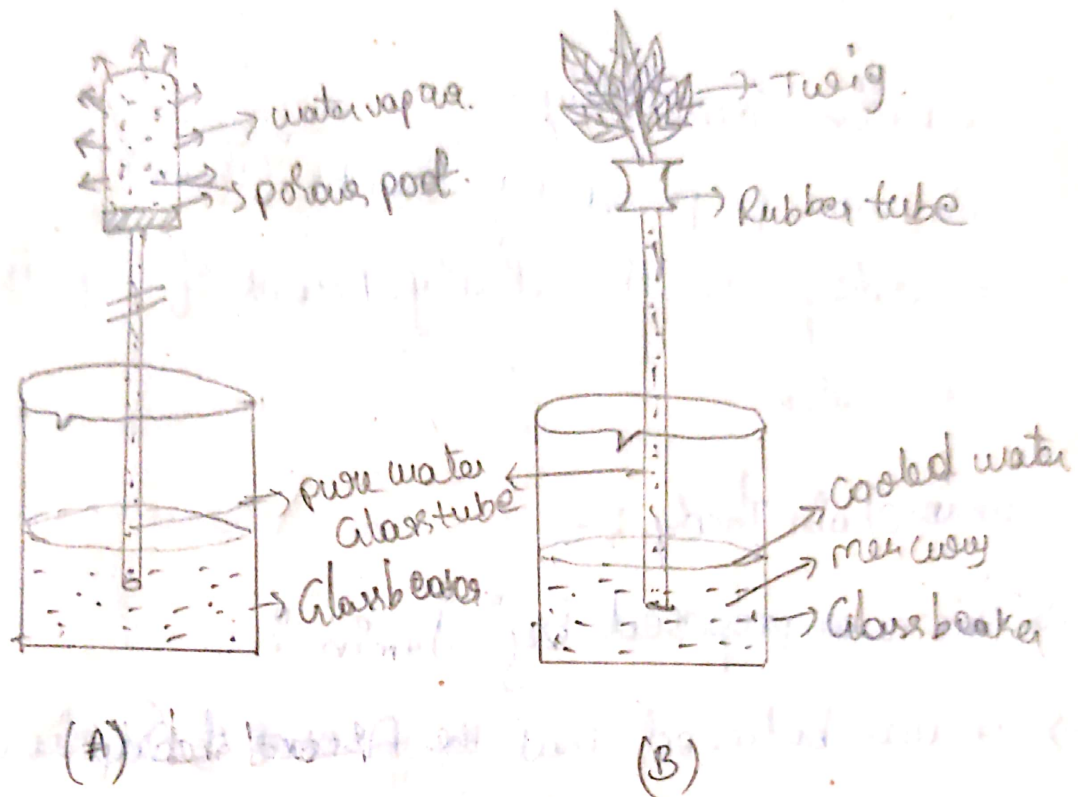
- Tension is created on the water columns on account of Transpiration pull created by Transpiration.

- Transpiration pull is nothing but the Suction force linked to DPD gradient.
- The estimated magnitude required for Ascent of Sap in tallest trees is only 9-10 atm.
- Cohesive force, transpiration pulling involved in Ascent of Sap.

System - A :-

- Glass tube, porous pot filled with water is dipped in the beaker containing mercury & water.
- In the porous pot is released into the outer atmosphere by evaporation.

→ When the continuous water in the glass tube is pulled into the porous pot.



System-B :-

→ Same experiment was conducted like System-A.
→ But porous pot is replaced by twig in System-B.

Observation = Absorption = Transpiration/Evaporation

Physical Theories :-

1. Capillary force theory :-

→ It was proposed by "Boem".

- According to this Ascent of Sap takes place by Capillary action of roots, but it is not applicable to tall trees.

Imbibition force theory :-

- This was proposed by "Sachs" (1878).
- According to this theory Ascent of Sap is due to Imbibition.

Jamin's chain theory :-

- This was proposed by "Jamin".
- It was believed that the Ascent of Sap is due to air expanded in xylem vessel moved up carrying water along with air.

Transpiration

- Water is the abundant molecule in plant cell.
- plants absorb water about 99% and 90% water is lost through stomata, 10% is lost through Cuticle
- Stomata are the major parts for transpiration

❖

Definition:

Loss of water through stomata by evaporation is called transpiration.

Structure of Stomata:

→ Stomata are tiny pores present in the epidermis of leaves

→ Stomata are enclosed by ^{Bean} shaped guard cells in which cellulose microfibrils for retaining water, stretching.

→ The pore wall is thick and the opposite wall is thin.

→ Guard cells are surrounded by subsidiary cells which are used for contraction and relaxation of guard cell.

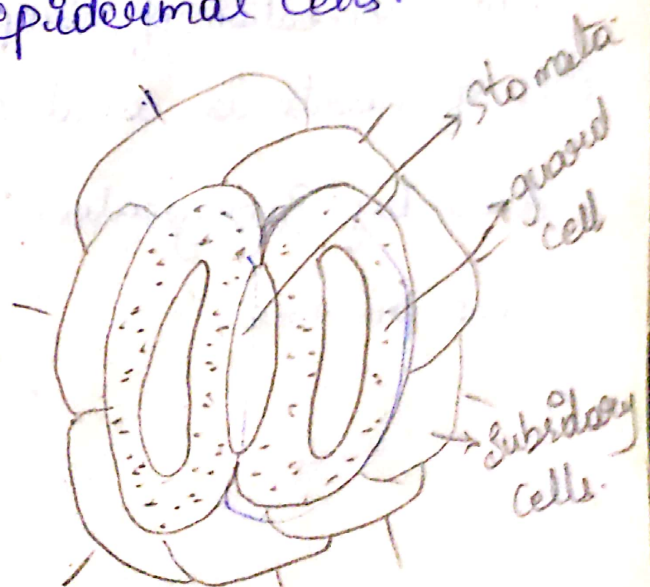
→ These are modified epidermal cells.

→ Advantage:-

→ Transpiration

→ Respiration

→ photosynthesis



Structure of Stomata

Theories to explain the mechanism of Stomatal movement :-

- Leuit hypothesis / potassium ion pump theory.
- vonmohl theory.
- lloyd theory.
- Steward theory.
- Sayre hypothesis.

These are the theories which explains the mechanism of opening and closing movements of stomata.

^{or}
Guttation:-

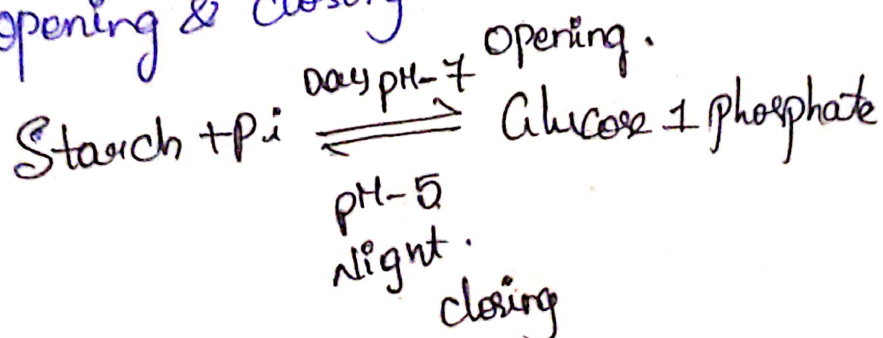
The secretion of droplets of water from the pores of plants is called Guttation. This term was coined by "Burgessstein". It is caused by root pressure.

Vonmohl theory:-

- He first suggested the opening & closing of stomata are due to photosynthetic activity of guard cells.
- During day time osmotically active substance are synthesised in the guard cells. This leads to Endosmosis.
- Then due to Turgidity stomata are opens

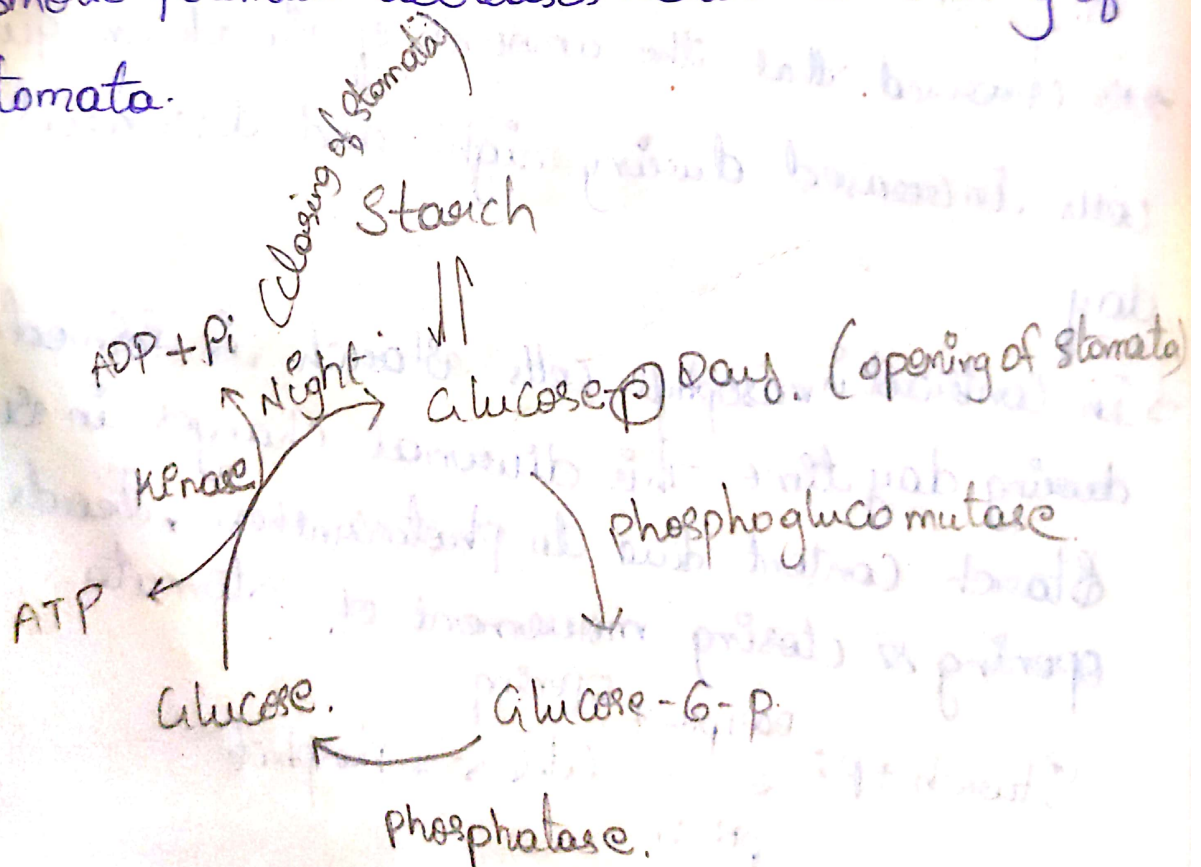
Lloyd hypothesis:-

- He observed that the amount of starch in guard cells increased during night and decreased during day.
- In contrast in mesophyll cells starch is formed during day time. This diurnal changes in sugar-starch content due to photosynthesis, leads to opening & closing movement of stomata.



Steward theory:

- He proposed that in presence of light Glucose-6-phosphate is formed by phosphoglucomutase.
- Glucose is dissolved to create osmotic potential leads to Endosmosis. These events occurs during day time.
- In contrast, during night time Glucose is converted into Glucose-1-phosphate in presence of exokinase and ATP.
- Osmotic Potential decreases leads to closing of Stomata.



Sayre hypothesis:-

- He proposed that pH of guard cells causes stomatal movement.
- Stomata open at low carbon dioxide level, as a result of photosynthesis causes high pH in which glucose production increases and creates more osmotic potential leads to opening of stomata.
- During night time at high carbon dioxide level pH decreases, low level of glucose leads to closing of stomata.

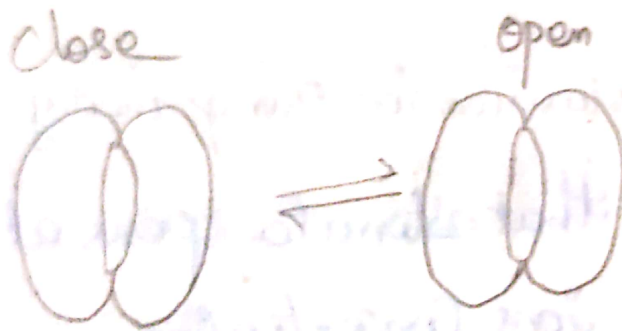
Levitt hypothesis / potassium ion pump theory:-

- Fujino observed that stomata opens at day time at more K^+ ions concentration.
- Levitt proposed that the movement of stomata depends on active absorption of K^+ ions into guard cells.
- potassium ion pump is responsible for transport of K^+ ions into guard cells.
- Light initiates the electro transport of K^+ ions into guard cells and removal of H^+ ions leads to opening of stomata.

→ During night time high carbon dioxide concentration leads to inhibit the entry of K^+ ions eventually closing of stomata occurs.

Modern plant physiologist Ziegen studied guard cell physiology in *Vicia faba*.

Guard cells are highly sensitive to light, humidity, temperature, plant water status, CO_2 , phytohormones etc...



high CO_2 — low
low pH — high ($\neq$)
exit Cl^- — entry.
exit K^+ — entry.
low $O.P$ — high.
entry H^+ — exit.

Ion Absorption:-

Various views regarding mineral salt absorption are studied especially.

i. Passive absorption.

ii. Active absorption.

Passive absorption:-

→ It is a physical process in which metabolic energy is not used.

→ In this different mechanisms are observed.

a. Diffusion

b. Facilitated Diffusion.

c. Mass flow

d. Ion exchange (contact & exchange)

e. Donnan equilibrium.

Diffusion:-

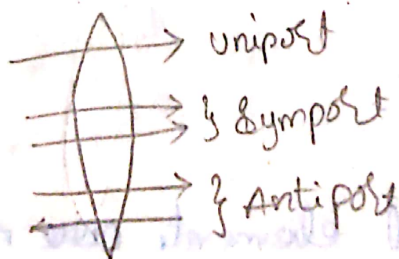
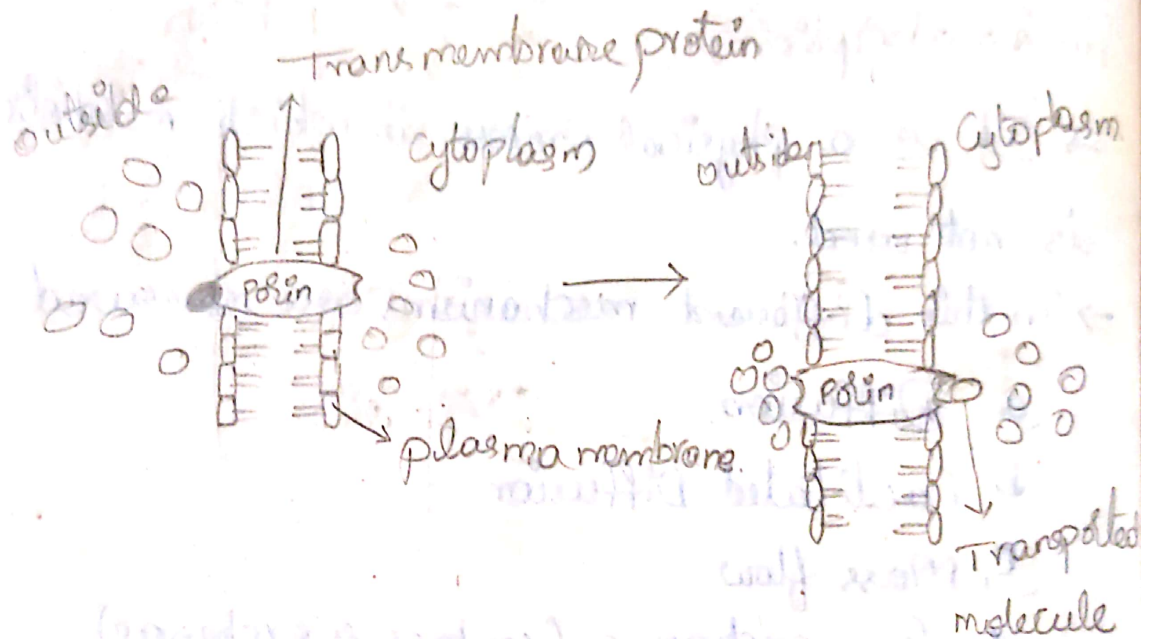
→ The concentration of mineral elements are more in soil solution than that of root cell.

→ The absorption of these elements done by the physical process called Diffusion.

→ This is mainly occurs due to Concentration gradient.

Facilitated Diffusion :-

- In this Diffusion Special transmembrane proteins helps in the movement of ions along the concentration gradient. It depends on solubility in lipids.
- Example of transmembrane protein is porin



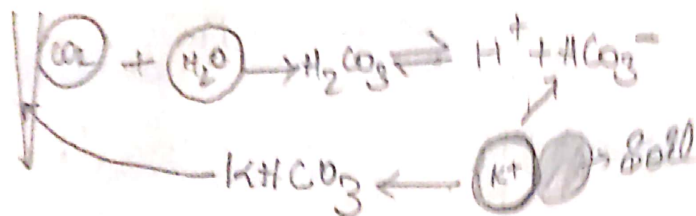
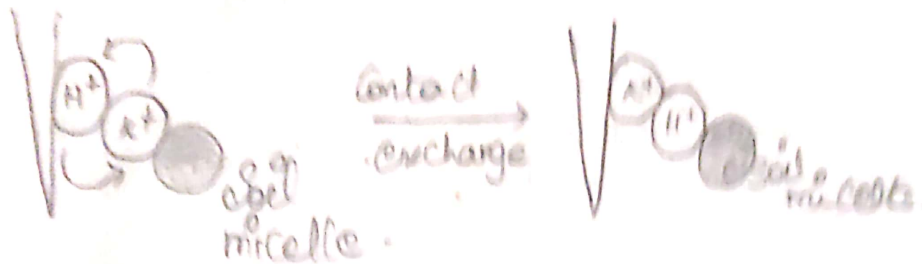
Mass flow :-

- According to Kramer & Russel, ion absorption taken up by roots with mass flow of water through the influence of Transpiration.

Ion exchange theory/contact exchange theory:

→ In this contact exchange theory cation is absorbed by the contact and exchange mechanism.

contact exchange



Donnan's equilibrium:-

→ This effect is applicable to fixed & Indiffusible ions.

→ Suppose the membrane is separating the cell from the external medium that is permeable to some ions not others. On the inner side of this membrane there is a concentration of anions to which the membrane is impermeable.

→ If this membrane is permeable to the cation then the cations moves until the equilibrium

is reached.

→ In Donnan equilibrium there is no expenditure of energy.

Active	Inside	outside.
	$K^+ - 100$	$100 - K^+$
	$Cl^- - 50$	$50 - Cl^-$
	$Pr^- - 50$	
	(fixed ions)	
		↓
		Donnan's equilibrium

	Inside	outside
	$K^+ - 115$	$85 - K^+$
	$Cl^- - 65$	$35 - Cl^-$
	$Pr^- - 50$	

Active absorption:-

→ Active absorption refers to the ions are absorbed by the expenditure of metabolic energy.

There are two concepts to explain active absorption.

i. Carrier Concept.

ii. ATPase pump.

i, Carrier pumps :-

→ There are two mechanisms are observed in Carrier concept

a. Ion pump

b. ATP Carrier Concept.

a. Ion pump :-

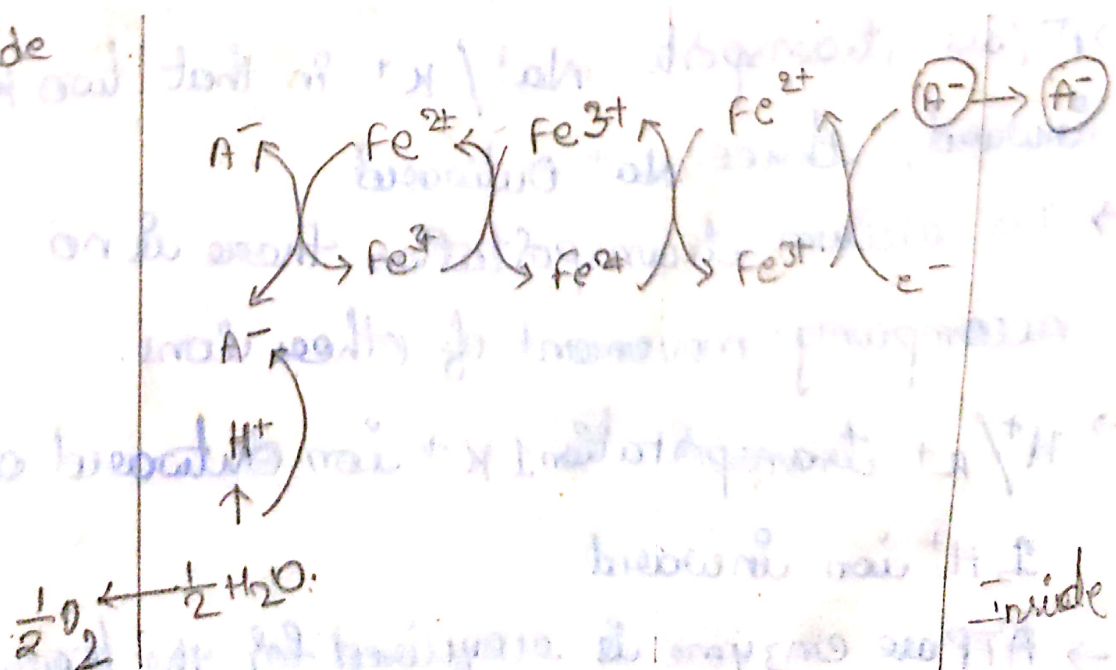
→ "Lundbergardh" proposed cytochrome pump theory

→ Anion absorption is independent and is carried through cytochromes

→ Cytochromes are the Anion Carriers and is mediated by Cytochrome Oxidase.

→ Cytochrome is oxidised by using an electron and picking up an Anion

outside



inside

b, ATP Carrier Concept:-

→ It was explained by Wilkins & Robertson.

→ They observed that 2,4 D (dinitrophenol) inhibits salt absorption by retarding the formation of ATP without affecting respiration.

Ex:- "Lecithin is the phospholipid" picks up ions on the outer surface and releases them on hydrolysis into inner surface

→ According to this the phosphate group in the lecithin is the active site for both Anions and Cations.

Hence it is called "Amphoteric Carrier"

ii, ATPase pump :-

→ ATPase transports Na^+/K^+ in that two K^+ ions inward, three Na^+ outward

→ For Calcium transportation there is no accompany movement of other ions.

→ H^+/K^+ transportation 1 K^+ ion outward and 1 H^+ ion inward

→ ATPase enzyme is required for the transportation of Cations.

* Factors Effects on Enzyme Activity:

→ The influence of various factors upon enzyme activity is studied *in vitro*.

→ There are various factors like

i, Substrate Concentration.

ii, Enzyme Concentration.

iii, Temperature

iv, pH

v, Concentration of End products.

vi, Inhibitors.

i, Substrate Concentration:-

→ The enzyme molecule is much larger than the substrate molecules and has several active sites on the surface.

→ Enzyme activity increases with increasing in Concentration of Substrate.

→ Further increase in the substrate will have no effect, because it becomes a limiting factor.

→ If the enzyme active sites are saturated there is no use with addition of substrate.

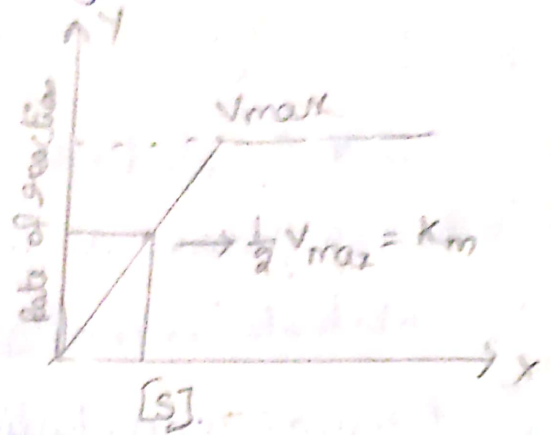
→ If the graph is plotted between Substrate

Concentration on x-axis. Rate of reaction on

y-axis. straight line is obtained but

for Allosteric enzymes. Sigmoid curve obtained

$$K_m = \frac{1}{2} V_{max}$$

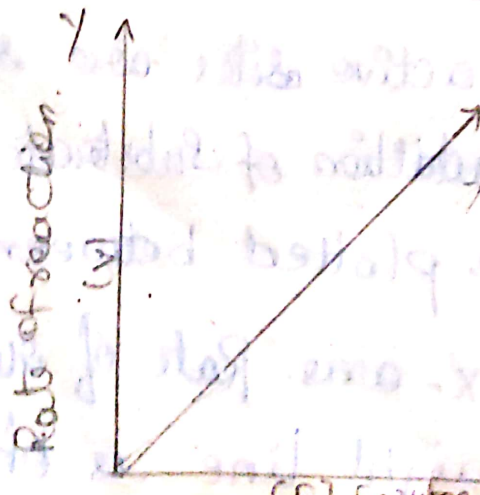


2nd Michelis menten Constant:-

The substrate Concentration where the rate of reaction is half of its maximum value is denoted as Michelis Menten Constant.

ii) Enzyme Concentration:-

- The rate of enzyme activity reaction increases by increasing the enzyme concentration but enzyme concentration increases beyond the substrate they may be a constant rate of reaction.
- If the graph is plotted between enzyme concentration on x-axis, rate of reaction on y-axis, a straight line is obtained



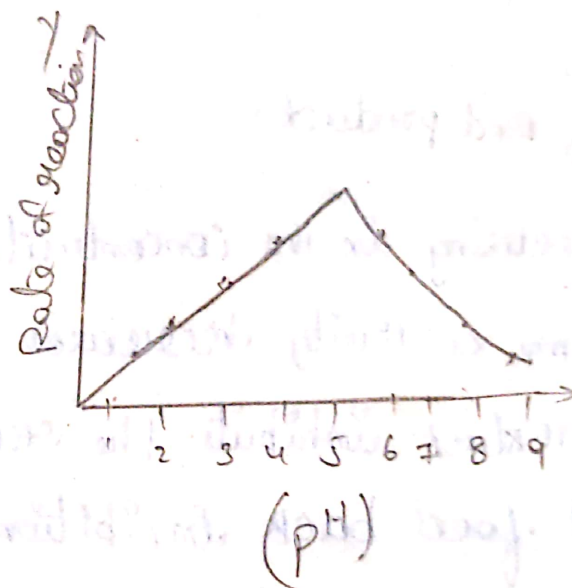
iii) pH :-

- Enzymes function effectively at particular pH which is called "Optimum pH."
- Any changes towards acidic or basic enzyme activity decreases.
- There are some enzymes whose activity lies at acidic range

ex:- pepsin - pH-2

- Some enzymes work best at alkaline range

ex:- Alkaline phosphatase - pH-8.5 to 10.0

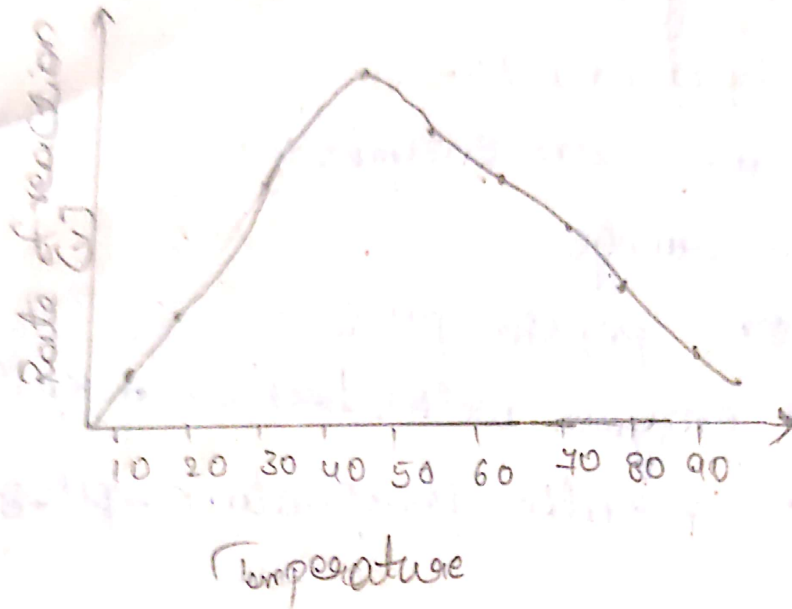


iv) Temperature :-

- Temperature influences the rate of reaction.
- The rate of enzyme activity increases 2 times for every 10°C rise of temperature upto 25°C this is called Temperature coefficient (Q_{10})
- The optimum temperature for enzyme activity is $35-45^{\circ}\text{C}$. Beyond & below these temperatures

the enzyme activity decreases.

→ Bell shaped curve is obtained between temperature and rate of reaction.



v. Concentration of end product:-

→ Gradual increasing in the concentration of end product enzyme activity decreases.

→ If the end product inhibits the reaction rate it is called feed back inhibition.

vi. Inhibitors:-

There are three types of inhibitors.

a. Competitive Inhibitors:-

when inhibitors are structural analogs of substrate and inhibit enzyme activity.

eg: monalonic. structural analog of

Succinic acid and inhibit the formation of lipoic acid.

b, Non Competitive.

Some metal ions binds the active site of enzymes and inhibits the reaction rate.

eg:- mercury, Arsenic.

Feed back inhibitors :-

Feed back inhibitors are nothing but end products may inhibit the reaction rate.

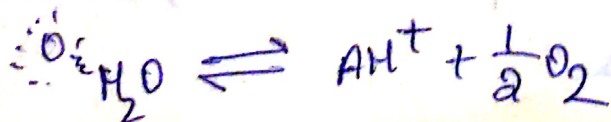
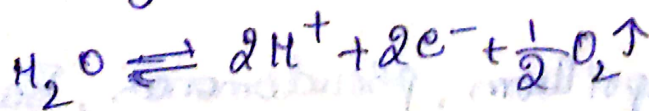
Hill reaction :-

Robin Hill (1931) proposed.

→ In presence of light water molecule is dissociated and forms two electrons & 2 protons & $2H^+$, $\frac{1}{2}O_2$.

→ Hill observed that oxygen is liberated only from H_2O not from CO_2 .

→ He is used hydrogen acceptor such as ferric Oxalate acts as electron acceptor and CO_2 is fixed into carbohydrate.



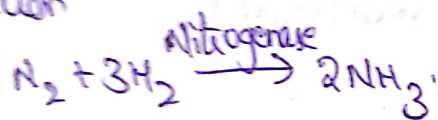
Biological Nitrogen Fixation :-

Nitrogen is the abundant (78.45%) gas present in the atmosphere. It is not available to higher plants

(It is not utilised)

due to absence of nitrogenase

"The utilization of atmospheric nitrogen ($N \equiv N$) as a source of cell nitrogen by the reduction to ammonia by a biological organism is called Biological Nitrogen fixation



The nitrogen fixation is of 3 types.

i. ~~Non~~ - Symbiotic nitrogen fixation :-

→ This is independent or free living nitrogen fixation through some micro organisms.

ex:- Azotobacter, Azomonas, Azotococcus

ii, Associative Symbiotic nitrogen fixation :-

In this type the nitrogen fixation takes place at

Rhizosphere

ex:- Azospirillum, pseudomonas, Bacillus, Klebsiella

iii, Symbiotic nitrogen fixation :-

Here bacteria is directly associated with the plant .

ex ☆ :- Through nodule formation in legume

ex :- pea plant - *Rhizobium leguminosarum*

2. Through nodule formation in non-legumes.

ex:- *Casuarina*, *Alnus*, *Frankia* .

3. Without nodulation.

ex:- *Anabaena* - *Azolla*, *Guineea-Nostoc*

Process of nodule formation in legume by *Rhizobium* bacteria :-

Enzyme Action (or) Activity of Enzyme:-

There are different mechanisms to explain the activity of an enzyme.

- i. Lock and Key theory
- ii. Induced fit theory.
- iii. MS Sequential model / Concerted model.
- iv. Michaelis menten model.

Lock and key model:-

→ It was proposed by Emil Fisher (1894).

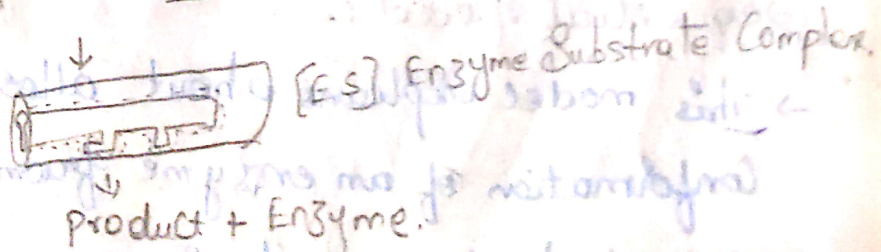
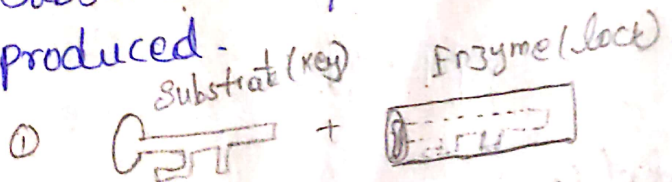
→ Substrate binds to the active site of enzyme.

→ Active site is the specific site of enzyme which combines with the substrate.

→ The active site has unique geometric shape i.e., complementary to the geometric shape of a substrate.

→ Enzyme specifically binds to only specific substrate

→ Only the correct key opens particular lock like that specific enzyme acts only on specific substrate and particular product will be produced.





Due to variation in enzyme structure, complex formation is inhibited.

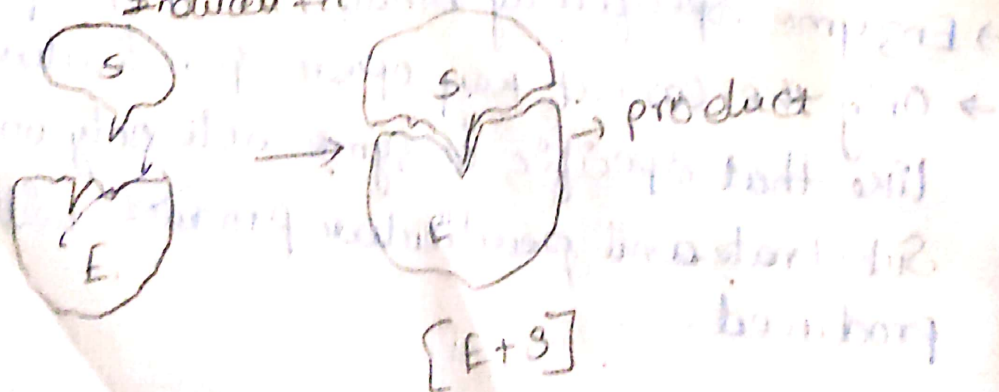
↓
No product.

Induced fit theory:-

- This theory was proposed by Daniel Koshland (1958).
- Formation of E.S complex results in the interaction between the substrate and a flexible active site.
- The substrate produces changes in the conformation of the enzyme. This property changes groups in the enzyme.
- It allows better binding & catalytic effects.

ex:- Adenylate kinase.

Induced fit



Sequential Model:-

- This model explains about allosteric changes of conformation of an enzyme from 'T' structure to 'R' structure and vice versa.

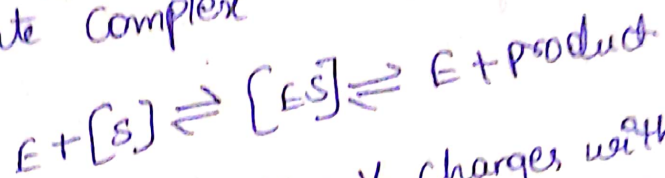
→ In the concerted model all the subunits that are from the allosteric protein change conformation at once.

Michaelis-Menten model:-

- It is related to the kinetics of an enzyme.
- It describes the relationship between concentration of substrate and enzyme velocity.

Enzyme Kinetics:-

Enzymes bind to substrate to form Enzyme Substrate Complex



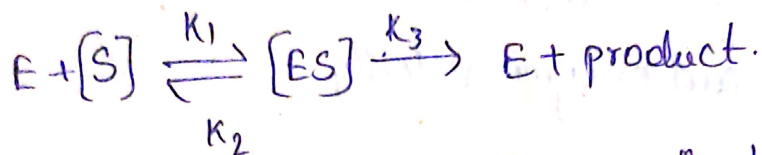
Rate of enzyme reaction V_0 changes with substrate concentration, the initial rate of the reaction is proportional to the substrate concentration.

→ when substrate concentration is increased further the proportional increase in V_0 is less. So further increase in substrate concentration the rate of reaction is constant, at a maximum value called V_{max} .

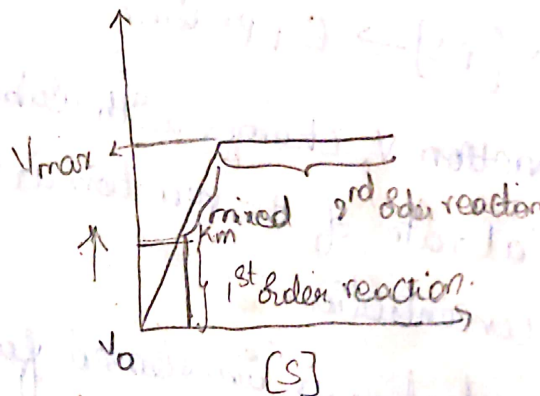
→ In 1913 the general theory of enzyme kinetics was proposed by Michaelis-Menten.

→ According to this theory the enzyme combines with substrate to form a necessary intermediate called $[ES]$

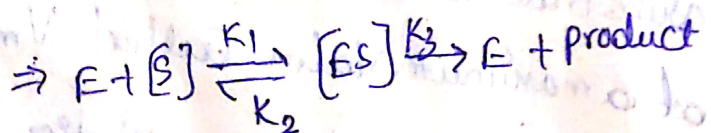
- The rate constant for the formation of $[ES]$ is k_1 .
- It can dissociate back to form substrate and free enzyme with rate constant k_2 .
- It can proceed to form product with rate constant k_3 .



- when the rate of reaction v_0 is plotted against $[S]$, it gives a rectangular hyperbolic curve.
- All enzymes can obey Michaelis-Menten theory.



$$v_0 = \frac{V_{\max} [S]}{K_m + [S]}$$



$$K_m = \frac{k_1 + k_2}{k_3}$$

$$\text{If } v_0 = \frac{1}{2} V_{\max}$$

$$K_m = [S]$$

$$\frac{1}{2} V_{max} = \frac{V_{max} [S]}{K_m + [S]}$$

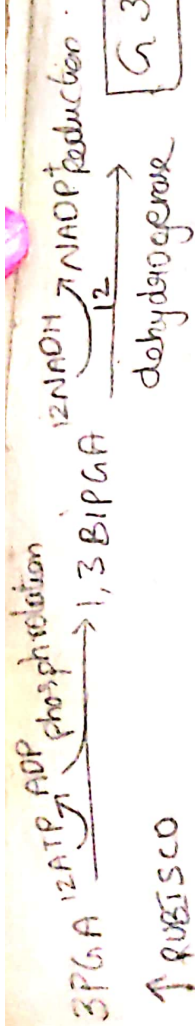
$$K_m + [S] = 2[S]$$

$$K_m = 2[S] - [S]$$

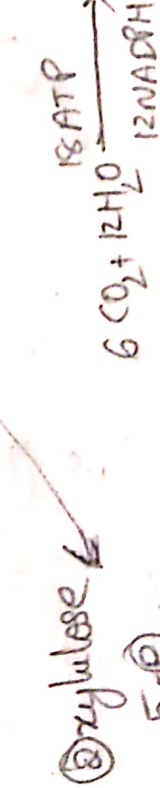
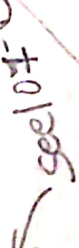
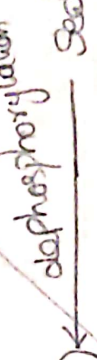
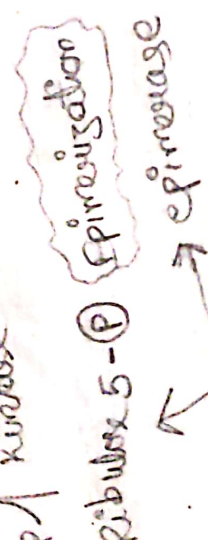
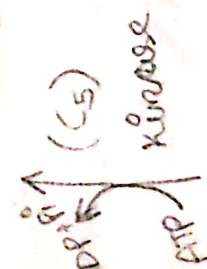
$$\boxed{K_m = [S]}$$

Michaelis menten Constant (K_m):-

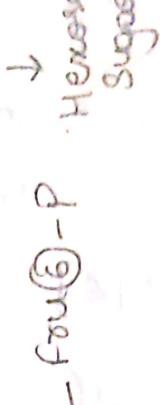
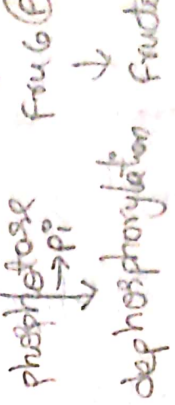
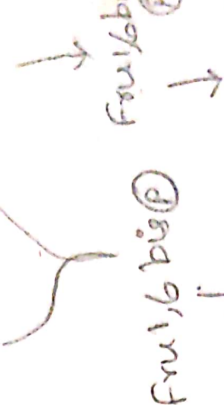
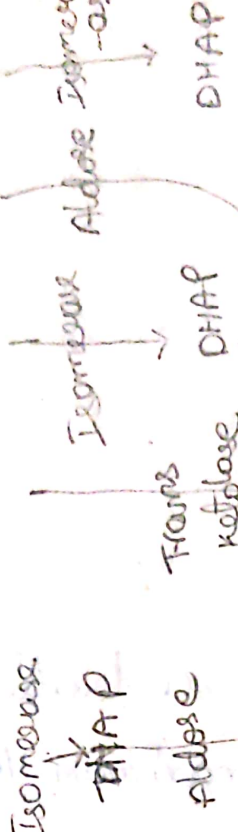
K_m is expressed as the substrate concentration (moles/litre) to produce half of its maximum velocity in an enzyme catalyzed reaction.



↑ RUBISCO



$\text{G3-P} \rightarrow \text{G3P} \rightarrow \text{G3P} \rightarrow \text{G3P} \rightarrow \text{G3P}$



C₃ Cycle

C₄ Cycle

→ This pathway is also called as β -carboxylation pathway (or) Hatch & Slack pathway.

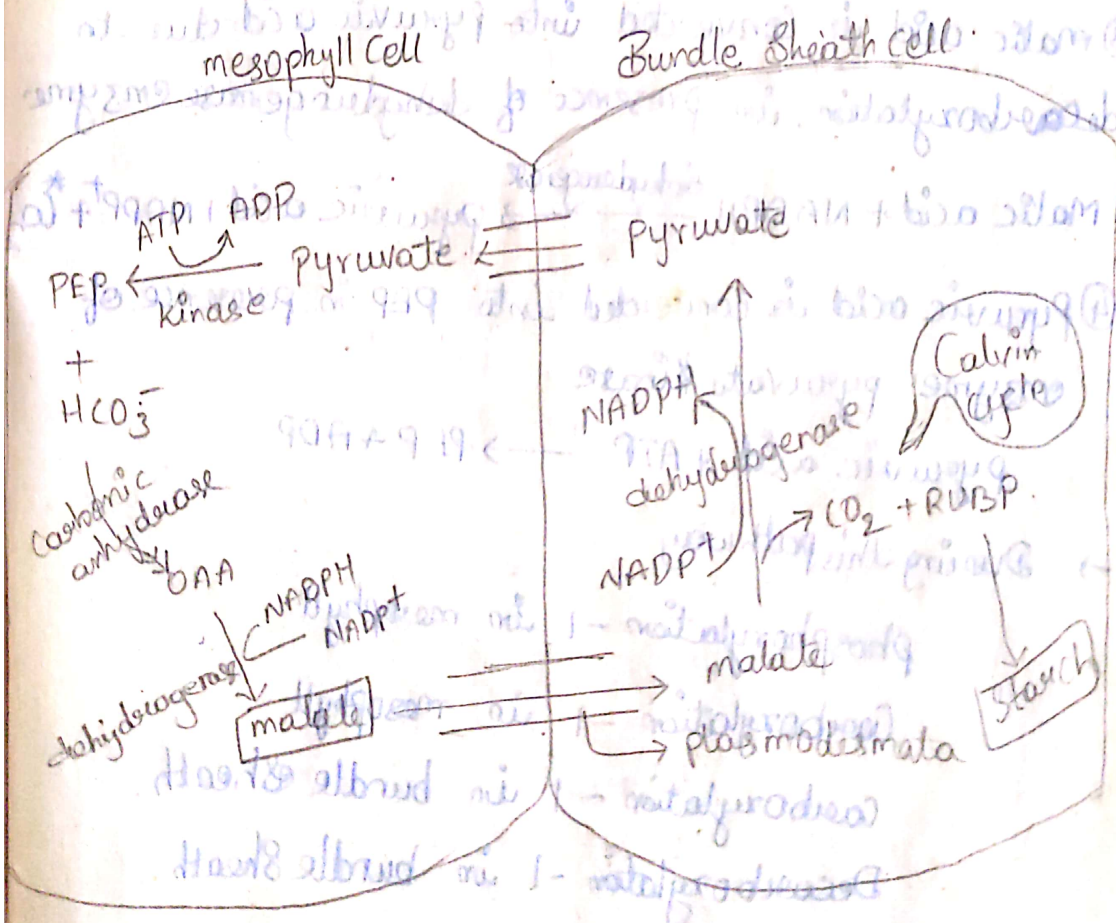
→ V.S. Rama Das — did research in C₄ plants.

→ The first formed product in this cycle is (4-C) Compound is called malic acid. Hence the name C₄-Cycle.

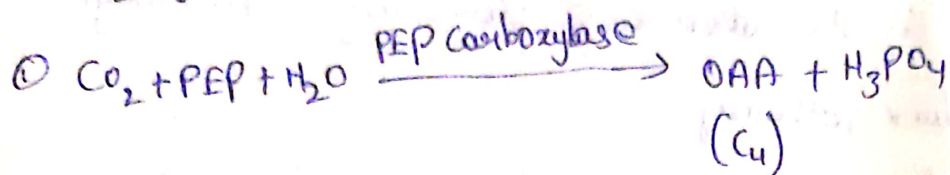
→ C₄ plants are — maize, sugarcane, sorghum, pearl millet, Amaranthus.

Structure of C₄ leaf :-

Anatomy of leaf is called Kranz (wreath) anatomy.

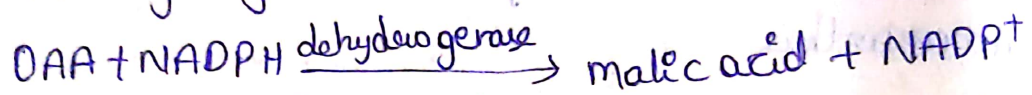


Carboxylation:-



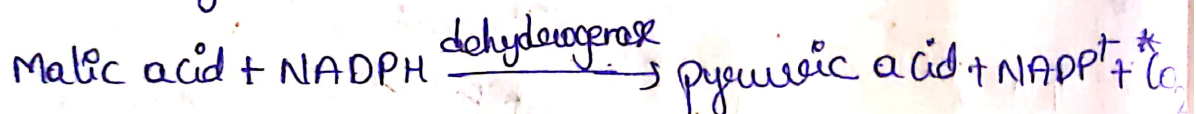
PEP is added with CO_2 & forms oxaloacetic acid. it is a C_4 compound.

② OAA is reduced and forms malic acid in presence of malic dehydrogenase



Reactions in Bundle Sheath cell $\rightarrow$ malic acid enters into Bundle Sheath cell.

③ malic acid is converted into pyruvic acid due to decarboxylation, in presence of dehydrogenase enzyme



④ Pyruvic acid is converted into PEP in presence of enzyme pyruvate kinase.



$\rightarrow$ During this pathway

phosphorylation - 1 in mesophyll

Carboxylation - 1 in mesophyll.

Carboxylation - 1 in bundle sheath.

Decarboxylation - 1 in bundle sheath.

$\rightarrow$ To Synthesize 1 mole of Glucose in C_4 plants.

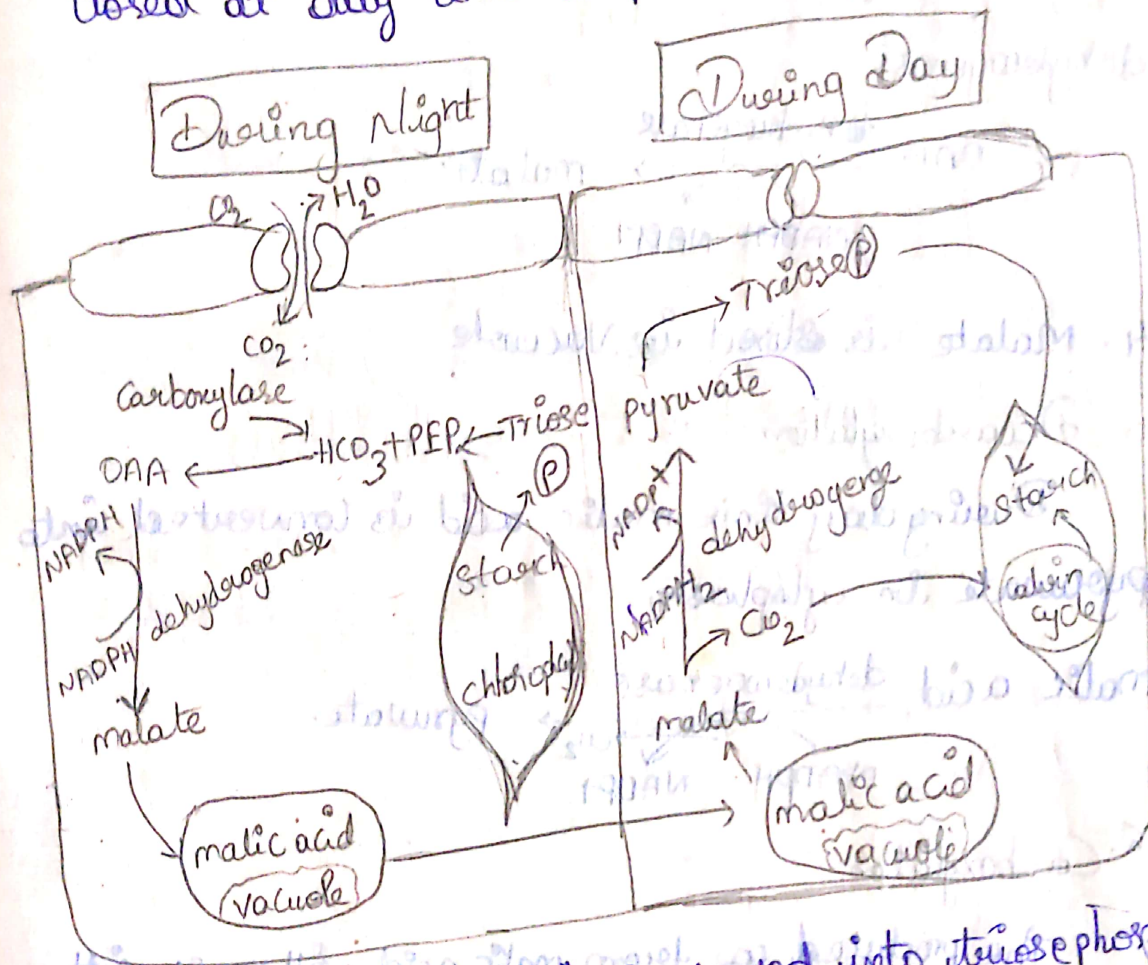
utilizes $\rightarrow$ 30 ATP
12 NADPH.

CAM

- Crassulacean acid metabolism also called as CAM.
- It is CO_2 fixation seen in some plants

ex:- Cactaceae, Crassulaceae

- They are adapted to arid conditions.
- In CAM plants stomata opens at night time and closed at day time to prevent loss of H_2O .



- During night time starch is converted into triose phosphate
- Triose phosphate is converted into pyruvate

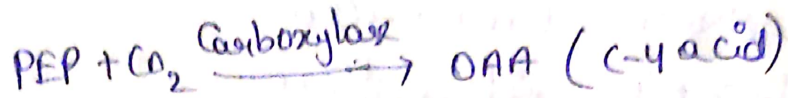
Reactions same as in C_4 cycle.

- CAM cycle occurs in some cell, but at different time period.

- ① During night time CO_2 enters into cell through stomata.

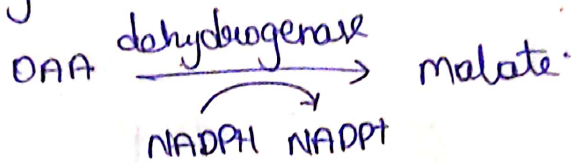
2. Carboxylation:-

CO_2 reacts with PEP in presence of Carboxylase
convert into OAA.



3. Dehydrogenation/oxidation:-

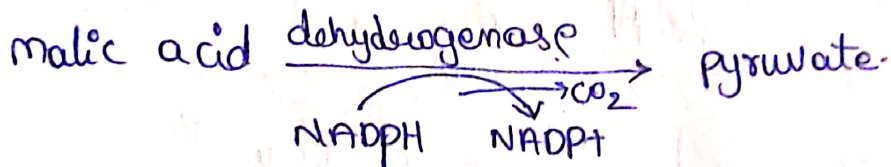
OAA is converted into malate in presence of dehydrogenase.



4. Malate is stored in vacuole.

5. Decarboxylation.

During day time malic acid is converted into pyruvate in cytoplasm



6. Carboxylation:-

The produced CO_2 from malic acid will react with RUBP and went to C_3 cycle for the formation of sugar.

→ Total 30 ATP, 12 NADPH₂ required to fix 1 mole of Glucose.

Factors effect on photosynthesis:-

1. Light :-

- 680nm
- 700nm

↑ photosynthesis - Red, blue ↓ - green

photosynthesis is mainly depends on light, because light energy is converted into assimilatory power.

→ most absorbable wavelength of chlorophyll a is 700 nm.
most absorbable wavelength of chlorophyll b is 680 nm.

2. CO_2 :- C_3 -RUBP C_4 -PEP (C₂ acceptor)

Under normal conditions an increase in the amount of CO_2 causes an increase in photosynthesis.

3. Temperature :-

The effect of temp on photosynthesis depends on species and environmental conditions.

→ Desert plants can carry on photosynthesis at 55°C.
→ Optimum temperature for photosynthesis is 15-35°C.

C_3 plants → 15-35°C

C_4 plants → 30-40°C

CAM plants → 35°C

→ Rate of photosynthesis doubles at every increasing in 10°C temperature until reached.

→ The optimum temperature beyond that photosynthesis is attored.

4. Oxygen:-

- O_2 is a by product of photosynthesis but high O_2 concentration will inhibit photosynthesis.
- This inhibition of photosynthesis by high O_2 concentration in C_3 plants and algae is called "Wolberg effect".
- Photosynthesis shows a high rate if O_2 concentration is low.

5. Water:- photolysis $\rightarrow O_2$

Water is one of the raw material required for photosynthesis. The amount of water needed by a plant is very small (1%). So water hardly be a limiting factor. Water deficiency cause closure of stomata results in decreasing the photosynthesis.

6. Internal factors:-

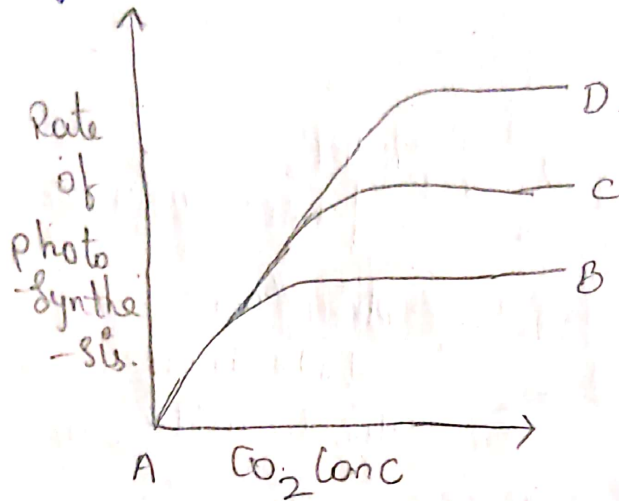
1. Chlorophyll Content.
2. Leaf Anatomy.
3. Age of the leaf.
4. Proper hydration of protoplasm.

(5m)

→ F.F. Blackman proposed law of limiting factors. He explained about the effect of CO_2 and light on photosynthesis.

→ The rate of photosynthesis may increase as CO_2 concentration increases. But a point will be reached when further increase in CO_2 concentration will not be increased.

→ Light energy is insufficient and hence light becomes limiting factor.



10M.

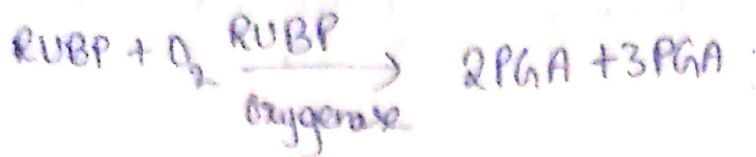
Photorespiration / C₂ cycle :-

- In plants, respiration occurs in light as well as darkness.
- Decker named that respiration occurs in presence of light is called photorespiration.
- Here respiration occurs in photosynthetic tissue in presence of light is called photorespiration.
- photorespiration occurs in chloroplast, peroxisomes and mitochondria.
- C_3 plants show photorespiration more than that of C_4 plants.

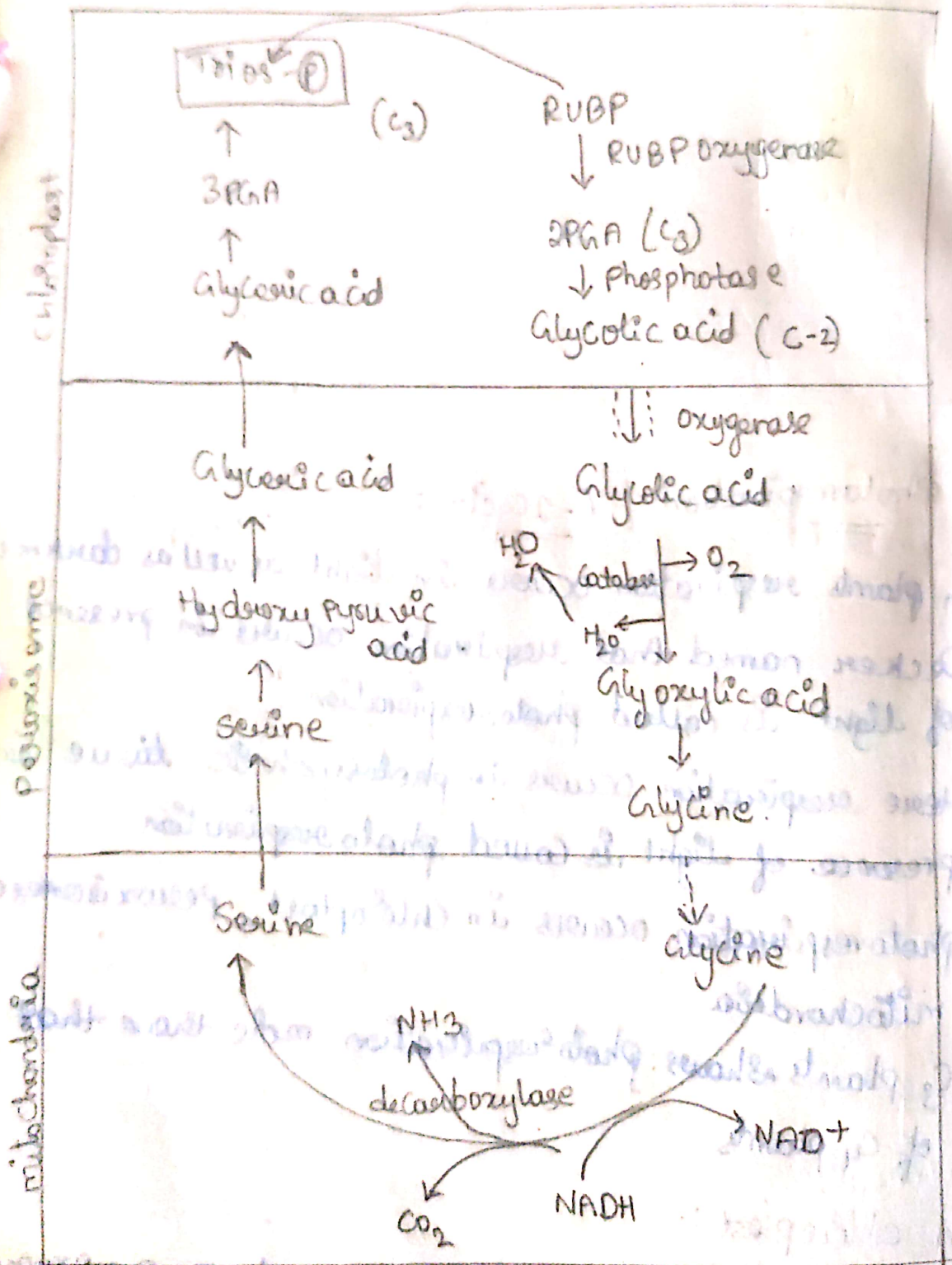
In chloroplast :-

① RUBP reacts with O_2 in presence of RUBP oxygenase

and produces (2-PGA, 3PGA)



② 2PGA is converted into glycolic acid in presence of phosphatase.



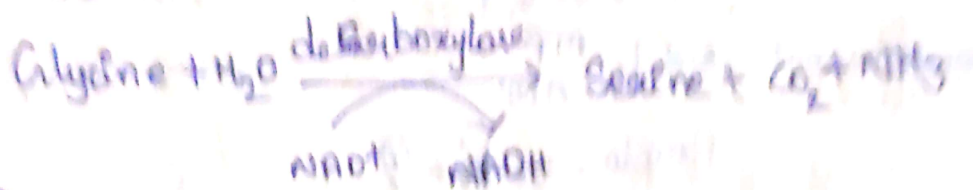
① Glycolic acid enters into peroxisomes



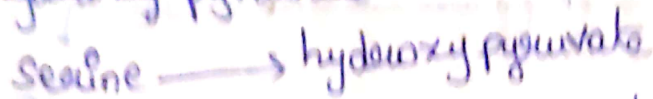
② Glyoxylic acid is converted into amino acid glycine in presence of transaminase:



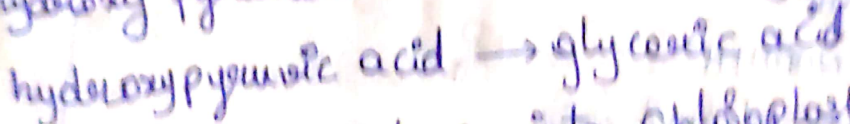
③ Glycine enters into mitochondria and is converted in Serine:



④ Serine enters into Peroxisome and is converted into hydroxy pyruvate



⑤ hydroxy pyruvate is converted into glyceric acid



⑥ Glyceric acid enters into chloroplast and is converted into 3PGA:



→ The formation of 3PGA from glycolic, glyoxylic, glycine is called glycolate pathway.

Glycolysis

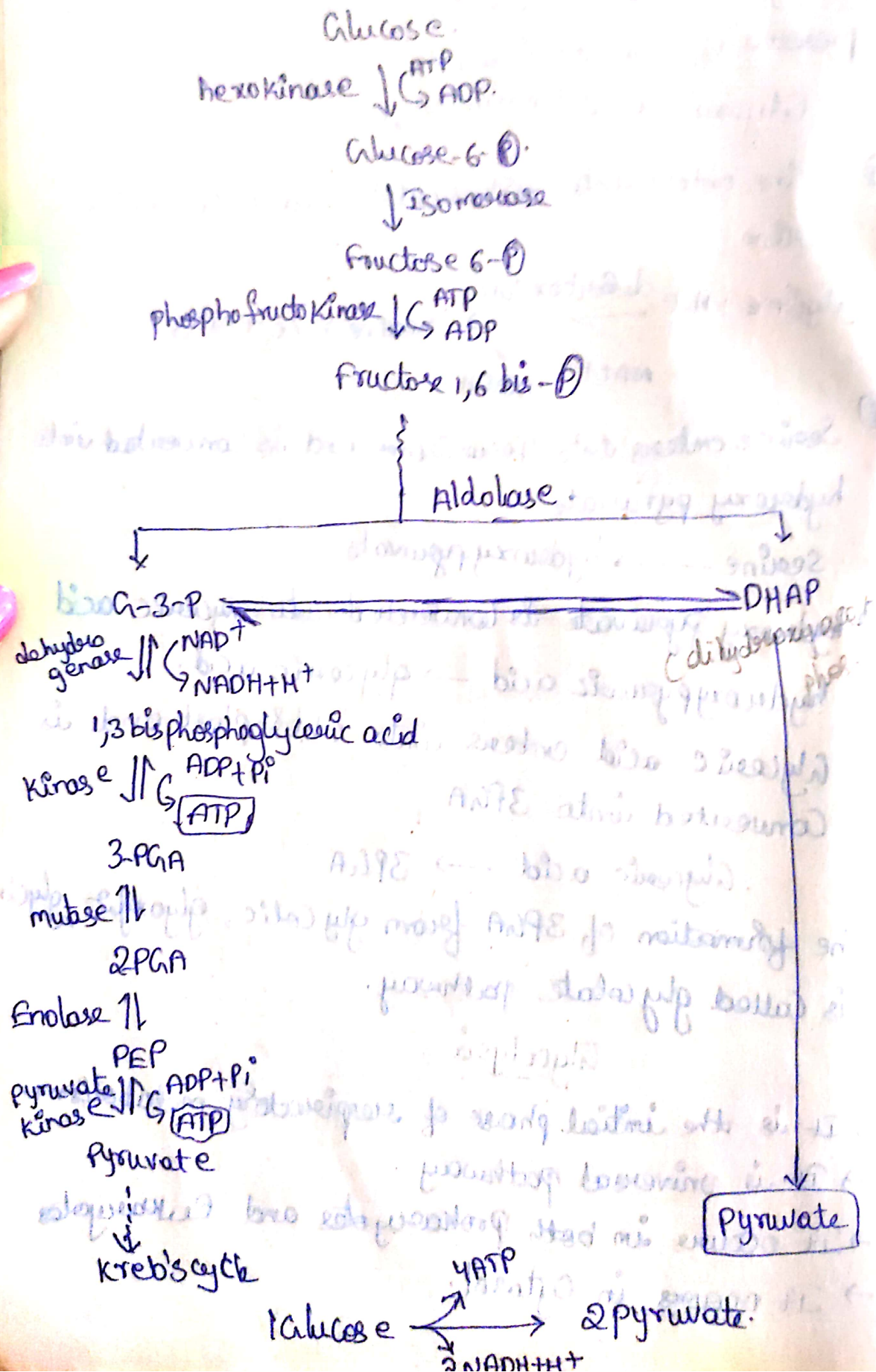
→ It is the initial phase of respiratory metabolism

→ It is universal pathway

→ It occurs in both prokaryotes and eukaryotes

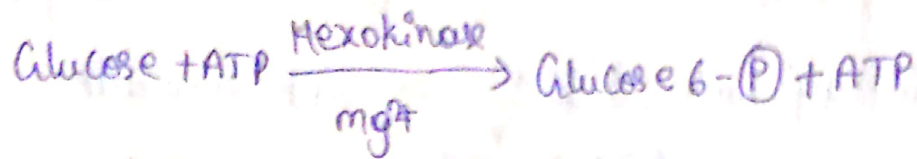
→ It occurs in cytosol

→ This pathway is called EMP pathway - Embden, Meyerhof, Parinas contributed that.

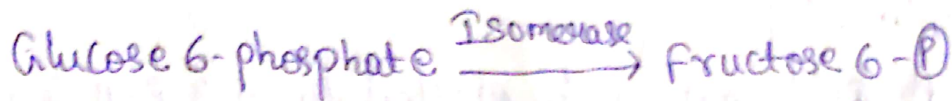


1. Phosphorylation:-

Glucose is converted to Glucose 6-P in presence of enzyme hexokinase.

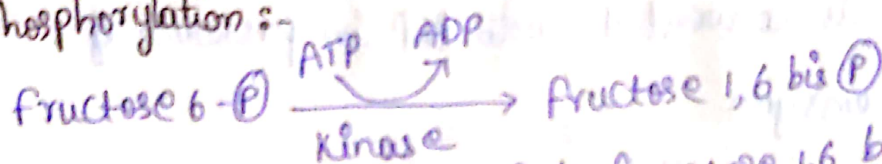


2. Isomerisation:-



Glucose 6-P is converted into fructose 6-P in presence of isomerase.

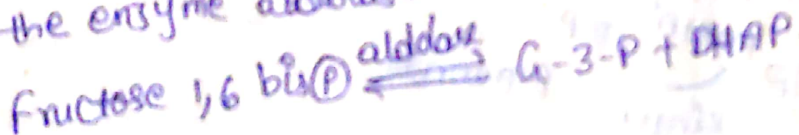
3. phosphorylation:-



Fructose 6-P is converted into fructose 1,6 bis P in presence of kinase.

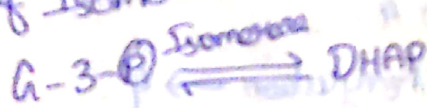
4. Cleavage:-

Fructose 1,6-bis P is converted into G3P and DHAP by the enzyme aldolase.



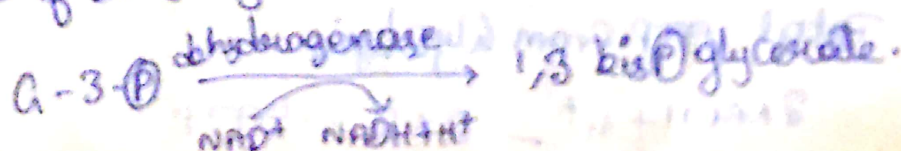
5. Isomerisation:-

Glyceraldehyde 3-P is converted into DHAP in presence of isomerase.



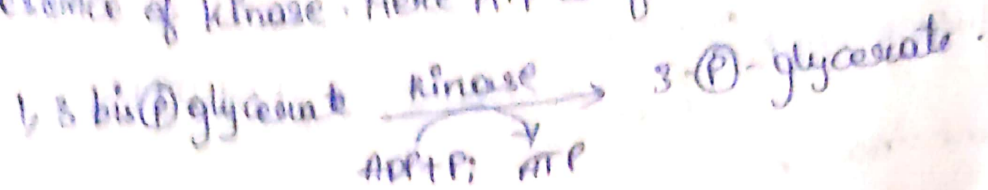
6. Oxidation:-

G-3-P is converted into 1,3 bis P glycerate in presence of dehydrogenase.



7. Substrate level phosphorylation:-

1,3 bis(P) glycerate is converted into 3(P) glycerate in presence of kinase. Here ATP is formed.

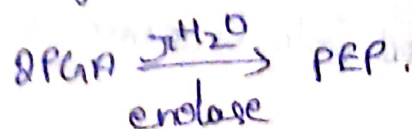


8. Molecular Shift:-

The phosphate molecule is shifted from 3-PGA to 2-PGA in presence of the enzyme Mutase.

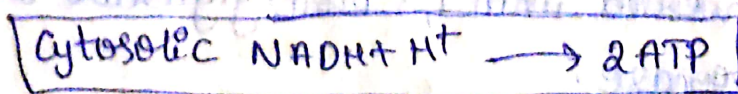
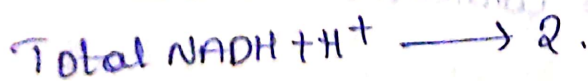
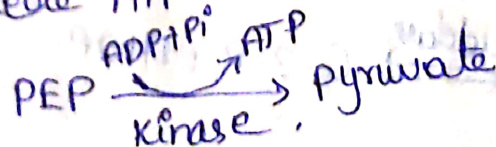
9. Dehydration:-

2-PGA is converted into PEP in presence of Enolase enzyme.

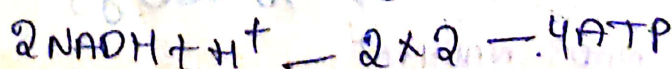


10. Substrate level phosphorylation:-

PEP is converted into Pyruvate in presence of kinase. Here ATP is formed.



Total ATP from Glycolysis



ATP — 4.

Total ATP $\rightarrow$ 8 ATP.

utilised ATP — 2 ATP

6 ATP

Kreb's cycle

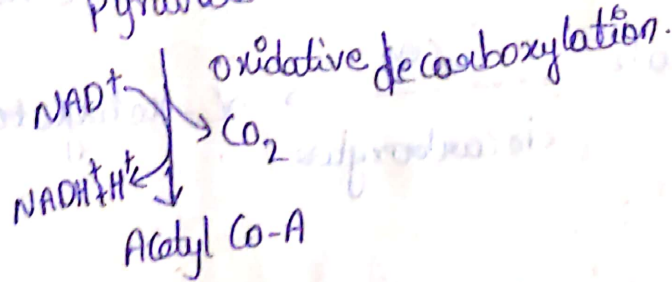
Pyruvate is formed from glycolysis undergoes oxidative

Pho Decarboxylation and produces Acetyl-CoA.

$\rightarrow$ Acetyl-CoA enters into Kreb's cycle.

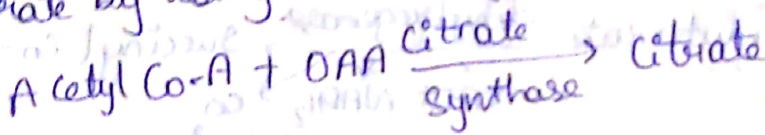
$\rightarrow$ This linked reaction occurs in mitochondria.

Pyruvate



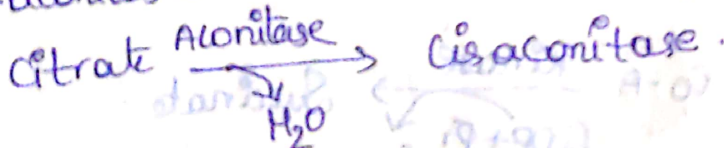
1. Hydration:-

Acetyl Co-A is added with oxaloacetic acid and produces citrate by using Citrate Synthase. $\text{Acetyl Co-A} + \text{OAA}$



2. Dehydration:-

Water is removed citrate is converted into cis-aconitase.



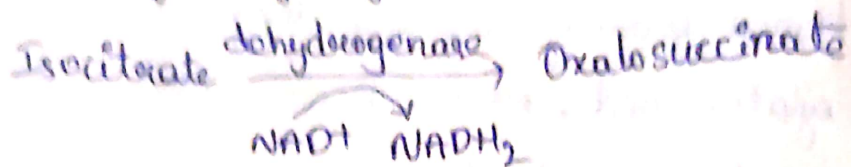
3. Hydration:-

Cis-aconitase is converted into Isocitrate in presence of aconitase.

Cis-aconitase $\xrightarrow{H^+}$ Isocitrate
Aconitase

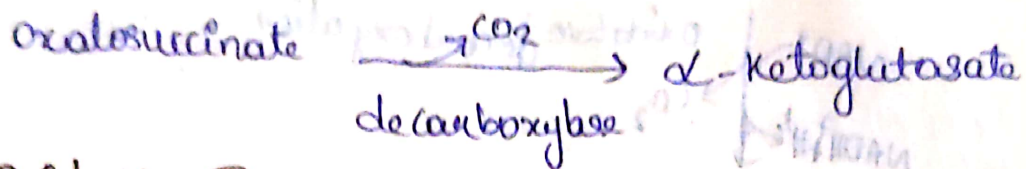
4. Oxidation-I :-

Isocitrate is converted into oxalosuccinate in presence of dehydrogenase.



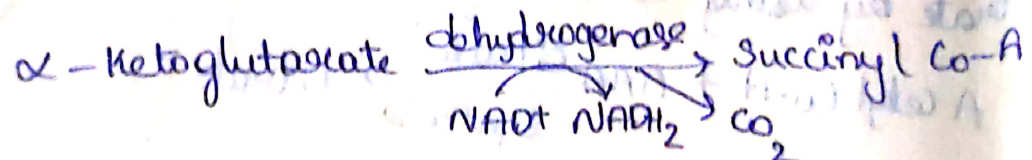
5. Decarboxylation :-

oxalosuccinate is converted into α -ketoglutarate.



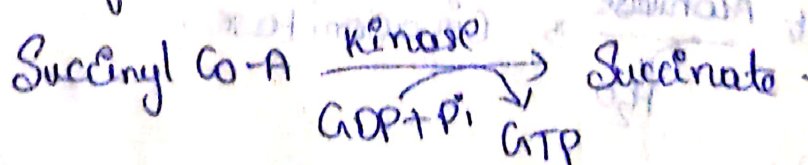
6. Oxidation-II :-

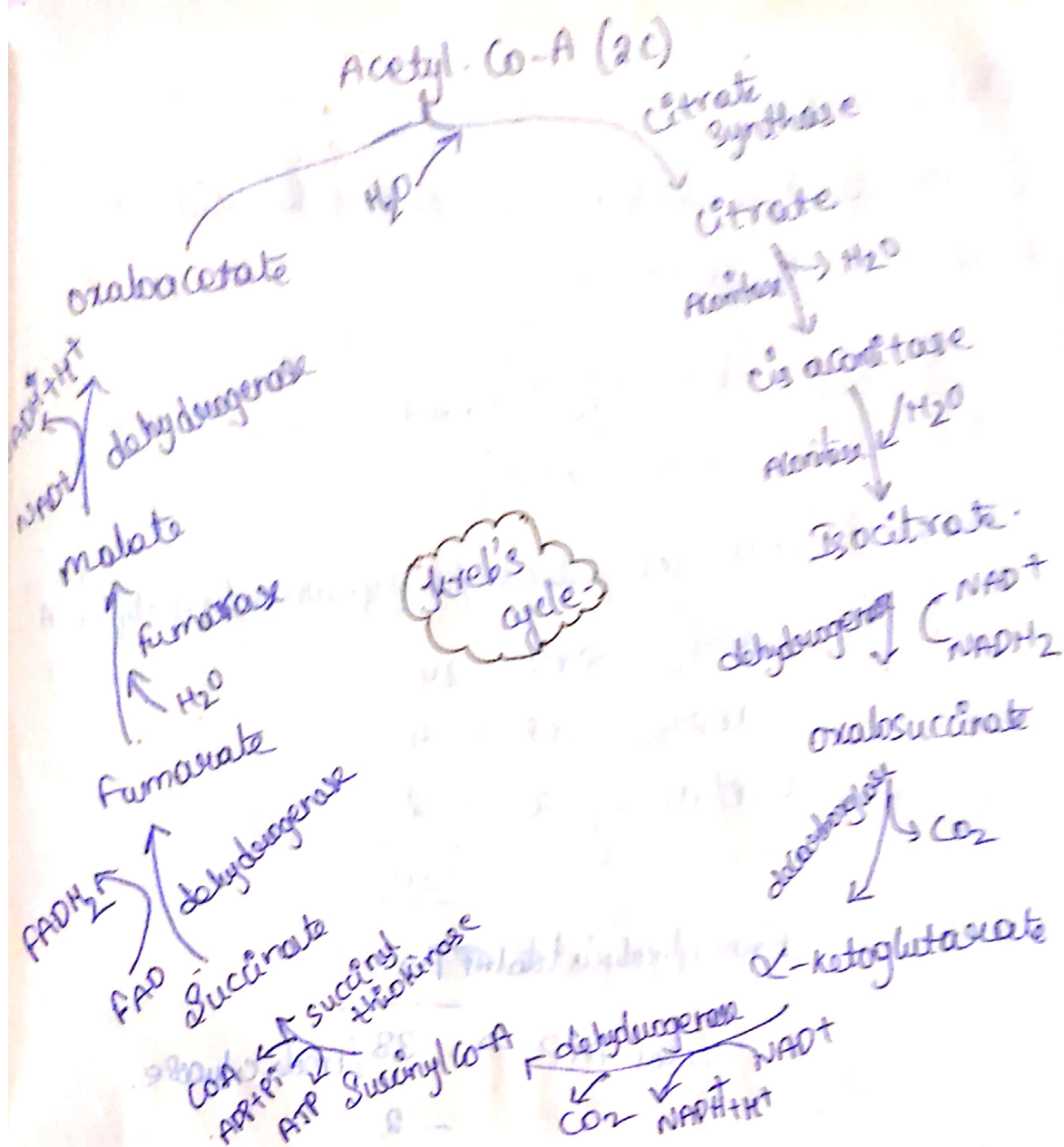
α -ketoglutarate is converted into Succinyl Co-A in presence of dehydrogenase.



7. Substrate level phosphorylation :-

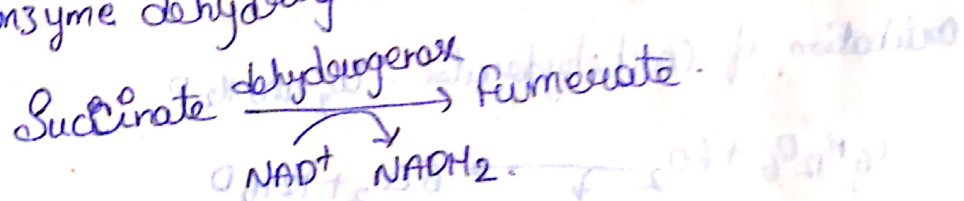
Succinyl Co-A is converted into succinate in presence of kinase.





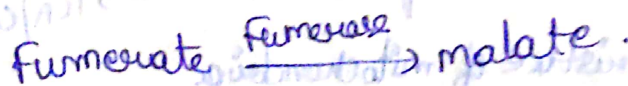
8. Oxidation - II :-

Succinate is converted into fumarate in presence of enzyme dehydrogenase.



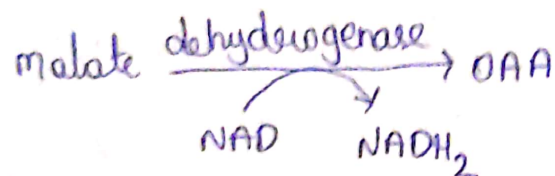
9. Hydration :-

Fumarate is converted into malate in presence of fumarase, here water molecule is added.



10. Oxidation - IV

malate is converted into malic acid in presence of dehydrogenase.



In kreb's cycle for 1 Glucose / 2 Pyruvate / 2 Acetyl Co-A

$$\text{NADH}_2 - 8 \times 3 = 24$$

$$\text{FADH}_2 - 2 \times 2 = 4$$

$$\text{GTP/ATP} - 2 = 2$$

$$\underline{30}$$

From glycolysis total ATP $\rightarrow 8$

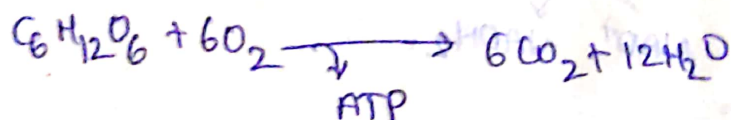
$$\text{Total ATP} \rightarrow 38 / \text{mole glucose.}$$

$$\underline{- 2}$$

$$\text{Net ATP } \underline{36}$$

Respiration

Oxidation of carbohydrates - CO_2 and H_2O



1. Glycolysis - Cytoplasm - EMP
2. Kreb's cycle - matrix of mitochondria $\rightarrow$ TCA / citric acid cycle
3. ETC - cristae of mitochondria
4. Oxidative phosphorylation - Cristae of mitochondria.

Electron transport chain.

→ After Completion of kreb cycle NADH_2 , FADH_2 enters into electron transport chain.

→ Electron transport Chain occurs in cristae of mitochondria (inner membrane foldings of mitochondria)

→ There are 5 complexes in ETC.

Complex - I

→ It contains NADH dehydrogenase and it has Flavoprotein (FMN) associated with Iron Sulphur protein (Fe-S).

→ This complex is responsible for passing electrons from NADH to Ubiquinone.

→ For every 2 electron transport four protons are translocated from matrix to perimembranous space.

Complex - II

→ It consists of Succinate dehydrogenase.

→ It contains Flavoprotein (FAD), prosthetic group is Iron Sulphur protein (Fe-S)

→ This complex receives electron from Succinic acid to Ubiquinone.

Complex - III

→ It consists of Cytochrome c reductase. It

contains electron carriers namely cytochrome b

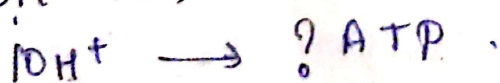
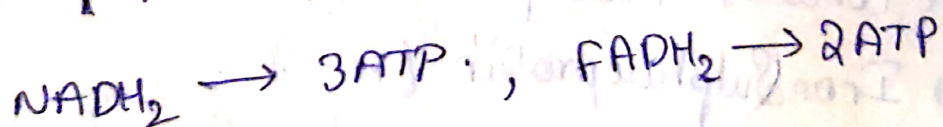
- and cytochrome c and contains one Fe-S protein
- It helps in the oxidation of Ubiquinone and transports electrons to cytochrome c, Coenzyme Q
 - Cytochrome c is a small protein attaches to the outersurface of the inner membrane.

Complex - IV

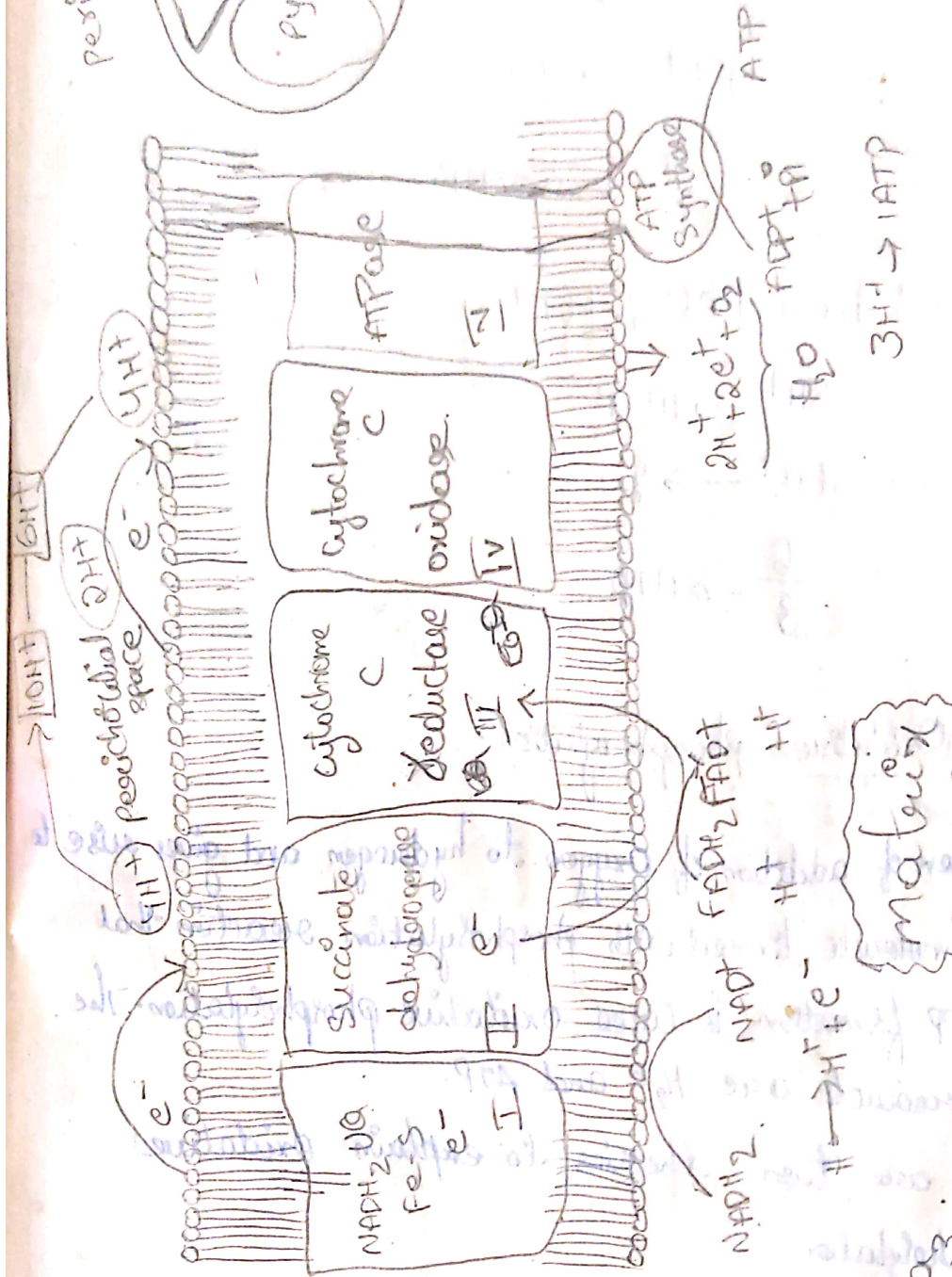
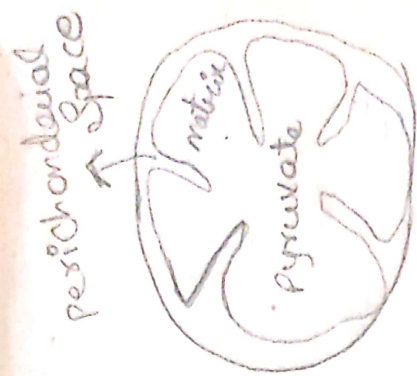
- It consists of cytochrome c oxidase and it contains cytochrome a and a₃ with copper ions!
- This complex receives electrons from cytochrome c and passes them to $\frac{1}{2} O_2$.
- This is called Endoxidation and leads to the formation of Water (H_2O)

Complex - V

- It consists of ATP Synthase or F_0F_1 ATPase
- stem is F_0 , loop is F_1 and has catalytic activity. that catalyses the conversion of ADP ~~and~~ P_i to ATP.



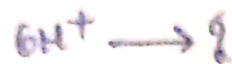
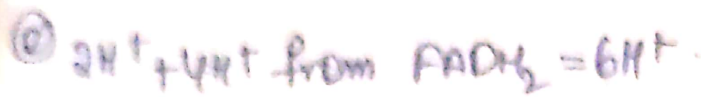
$$\frac{10}{3} = 3ATP$$



Iron-Sulphur
↓
Ubiquinone
↓
Fe-S protein
↓
Cytochrome b
↓
Cytochrome c
↓
Cytochrome c⁺
↓
Cytochrome c⁺
↓
Cytochrome c⁺



$$\frac{10}{3} = 3.3ATP$$



$$\frac{6}{3} = 2ATP$$

Oxidative Phosphorylation

→ The process of addition of Oxygen to hydrogen and gives rise to water molecule linked with phosphorylation reaction that is ATP formation is called oxidative phosphorylation. The end products are H_2O and ATP.

→ There are two theories to explain oxidative phosphorylation.

1. Chemiosmotic theory - Peter Mitchell.

2. Conformational coupling theory - Paul Boyer

↳ Chemiosmotic theory:-

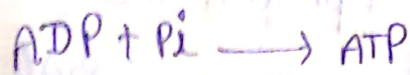
→ This was proposed by Peter Mitchell.

→ The electrons and protons are released from $NADH_2$ and

FADH_2 . They are carried to another surface through intermembrane space. Due to high concentration of protons in perimitochondrial space results in the development of proton motive force.

→ This proton motive force drives the protons across the membrane via ATPase.

→ ATP Synthase drives the phosphorylation

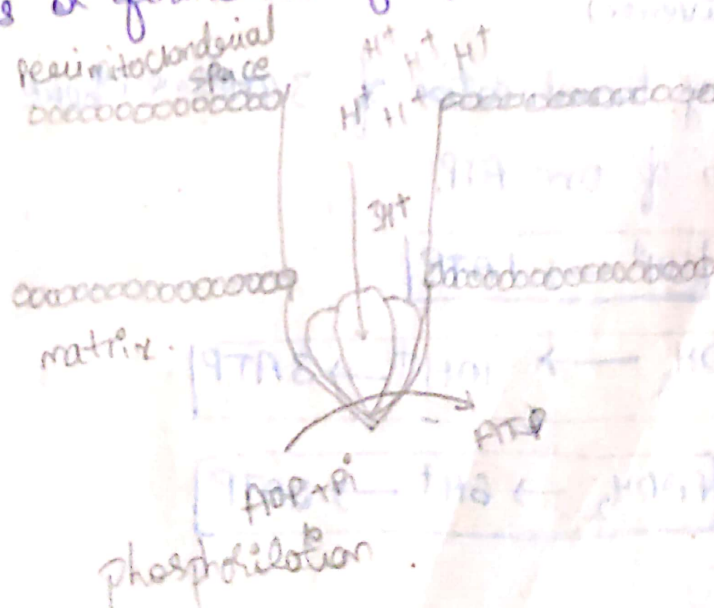


→ Formation of ATP is dehydration reaction.

→ when artificial proton gradient is imposed across membrane ATP is formed in absence of electron transport.

Ex: 2,4-D prevent ATP formation but electron transport continues and the cell membrane is permeable to all protons and proton gradient is absent.

→ there is a formation of H_2O but not ATP



2. Conformational Coupling hypothesis:-

- This theory was explained by "Paul Boyer".
- This is also known as binding change mechanism.
- F_0, F_1 , ATPase enzyme contains F_0 -tail, F_1 -head.
- ATPase is multisubunit transmembrane protein.
- ATPase was discovered by "Ephraim Racker".
- F_0 is a water insoluble transmembrane protein containing 8 different types of subunits ($\gamma, \epsilon, \alpha, \beta, \delta$).
- F_1 is water soluble protein.
- F_1 contains C ring terminal, F_0 contains $\gamma, \epsilon, \alpha, \beta, \delta$ subunits.
- ADP and P_i binds to the 'L' site (Loose site).
- The free energy ATP is synthesized at 'T' site (Tight site).
- ATP is dissociated from 'O' site (Open site).
- Here ATPase can act as motor (Smallest motor in the universe).
- For every translocation of 3 protons there is a formation of one ATP.

