TOPICS WE LEARN...

- *Do Plants Breathe?*
- *Glycolysis*
- *Fermentation*
- *Aerobic Respiration*
- *The Respiratory Balance Sheet*
- *Amphibolic Pathway*
- *Respiratory Quotient*

INTRODUCTION

- **Def.- Respiration** is the biochemical process in which the cells of an organism obtain energy by combining oxygen and glucose, resulting in the release of carbon dioxide, water, and **ATP** (the currency of energy in cells).
- Living organisms require energy- life process
- Energy required – oxidation of macromolecules (food)
- Green plants & Cyanobacteria- *Photosynthesis* (autotrophs)
- Animals- Heterotrophs: directly from plants (*Herbivore)* indirectly (*Carnivore)*
- *Saprophytes*- Dead & decaying matter (Fungi)

- Green plants- Photosynthesis (only in cells with chloroplasts)- translocation occurs in non green parts

Outline of Photosynthesis & Respiration:

- Occurs within Chloroplasts- organic compound
- Breakdown of molecules to yield energy (C-C)- cytoplasm & mitochondria- **Respiration**
- Compounds oxidised- **Respiratory substrates**- Carbohydrate, proteins, fats & organic acids
- Oxidation- step wise reaction & controlled by enzymes, energy trapped as chemical energy **ATP**
- ATP- energy currency
- Carbon skeleton produced during respiration- synthesis of biomolecules

MECHANISM OF EXCHANGE OF GASES

- Plants require O_2 for respiration- no specialized organs for gaseous exchange but have *Stomata & lenticels*

Reasons why plants don't need Respiratory organs:

1. Each plant part takes care of its own gas-exchange needs. There is very little transport of gases from one plant part to another.
2. Plants do not present great demands for gas exchange. Respiration in plants is far low than animals. So O_2 requirement will be met by photosynthesis where O_2 will be directly released into cells
3. Diffusion of gases- less; living cells- located close to the surface of plants; Eg.- Thick woody stems- living cells are organised as thin layer beneath bark, opening- *lenticels*; Most cells or part- contact with air; loose packing of parenchyma cells in leaves, stems and roots- provide an interconnected network of air spaces.

- Energy- complete combustion/ catabolism of glucose

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

- Catabolism of glucose- several small steps & energy released is coupled to synthesise ATP
- All organism -Catabolism (oxidation) of glucose retains enzymatic machinery which partially oxidise glucose without the help of oxygen to pyruvic acid- **glycolysis.**

AEROBIC RESPIRATION	ANEROBIC RESPIRATION
• Oxygen is used for the process. • Takes place in the cells of all the higher plants and animals • Glucose is completely oxidized • The end products are carbon dioxide and water • Complete oxidation of one molecule of glucose yields 38 ATP molecules • Process takes place in both cytoplasm and mitochondria of the cell	• Oxygen is not utilized for the process. • Takes place in some bacteria, fungi and certain endoparasites. • Glucose is partially oxidized • The end products are carbon dioxide and either ethyl alcohol or lactic acid • Partial oxidation of one molecule of glucose yields only 2 ATP molecules. • Takes place only in cytoplasm of the cell

Anaerobic respiration

Anaerobic respiration is one in which glucose is partially oxidised without using oxygen to yield lactic acid or ethyl alcohol and energy.

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + ENERGY$
(alcoholic fermentation)

Glucose ($C_6H_{12}O_6$) -------→ 2CH3CHOHCOOH +2ATP (Lactic acid fermentation)

Fermentation is actually anaerobic respiration by microorganisms. Examples of fermentation are alcohol, lactic acid, acetic acid fermentation.

In this process stored food is oxidised to certain compounds instead of CO_2 and water.

Aerobic respiration

- Stored food gets completely oxidised to CO_2 and water with release of some energy.
- $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ +686kcal
- Aerobic respiration is one in which molecular oxygen is used for the complete oxidation of glucose to yield CO_2, H_2O and 38 ATP molecules .

Respiratory quotient

Formulae- $\frac{\text{vol. of } CO_2 \text{ evolved}}{\text{vol. of } O_2 \text{ absorbed}}$

R.Q. of some organic compounds –

Carbohydrates- 1 Citric acid- 1.33

Fats – 0.7 Oxalic acid- 4

Malic acid- 1.33 Tartaric acid- 1.6

Aerobic respiration has 3 steps –

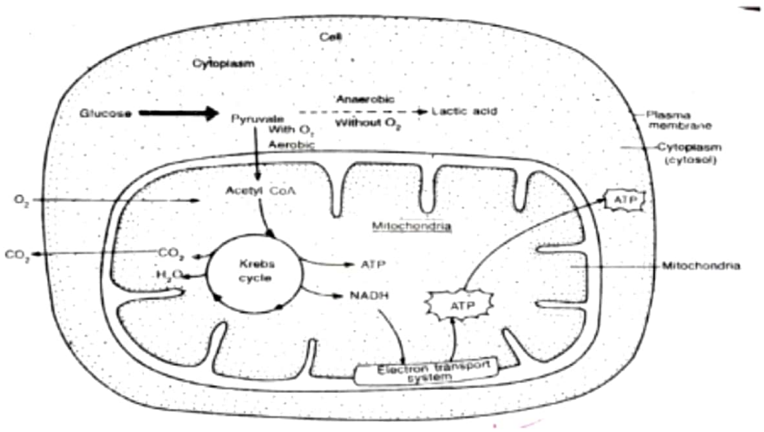
- Glycolysis
- Krebs cycle
- Electron transport system

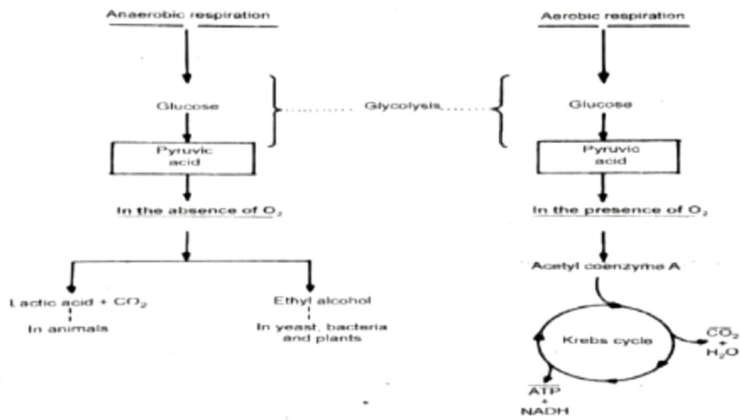
Aerobic respiration

- It need oxygen and occurs in mitochondria where glucose is completely broken down to carbon dioxide and water.
- It occurs in higher plant because of efficient to produce large amount of ATP molecules.
- Aerobic respiration completed in twp phases:

1. Anaerobic phase or glycolysis (i.e. take place inn cytoplasm where glucose molecules into two molecules of pyruvic acid)
2. Aerobic phase (i.e. take place in mitochondria where pyruvic acid are completely broken down to carbon dioxide and water.

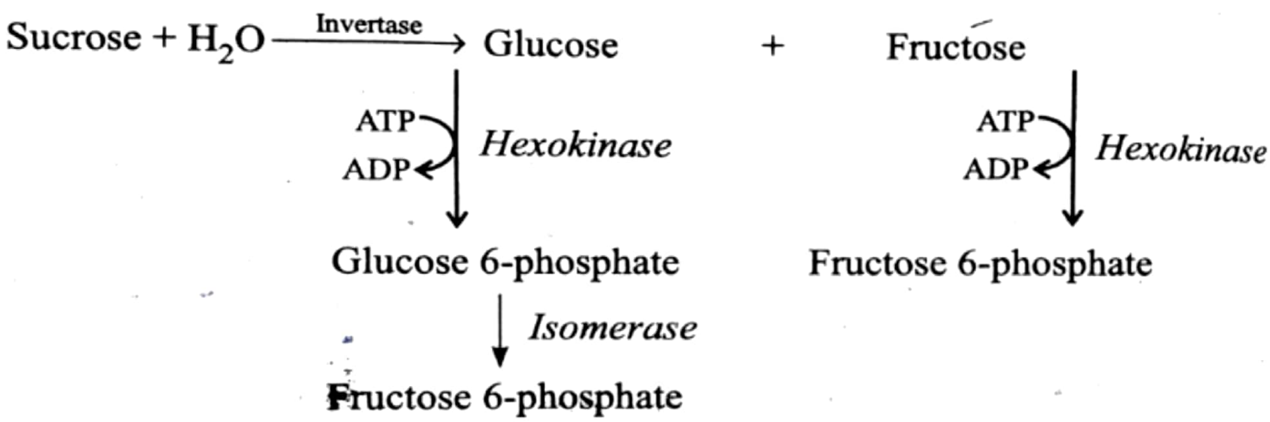
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 38ATP$$





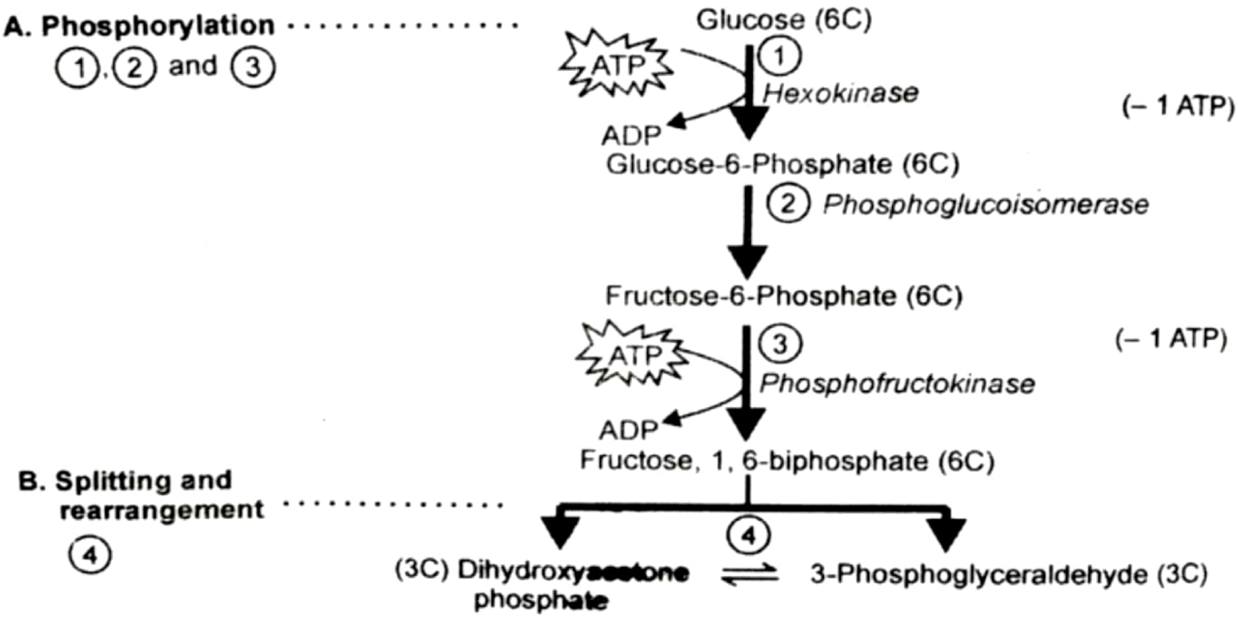
Glycolysis

- It is most common pathway for aerobic and anaerobic respiration and takes place in cytoplasm of the cell and does not require oxygen.
- In partial oxidation of glucose occurs and 2 molecules of pyruvic aid is formed.
- In in plant sucrose is end product of photosynthesis so it act as starter molecules for respiration in leaves.
- Sucrose hydrolyzed into two monosaccharide's by enzyme invertase and then these monosaccharide phosphorylated by enzyme hexokinase .



Splitting and rearrangement of molecules

- In this fuctose-1,6-bisphosphate is split into two molecules of 3-phosphoglyceraldehyde (PGA) and dihydroxyacetone phosphate.



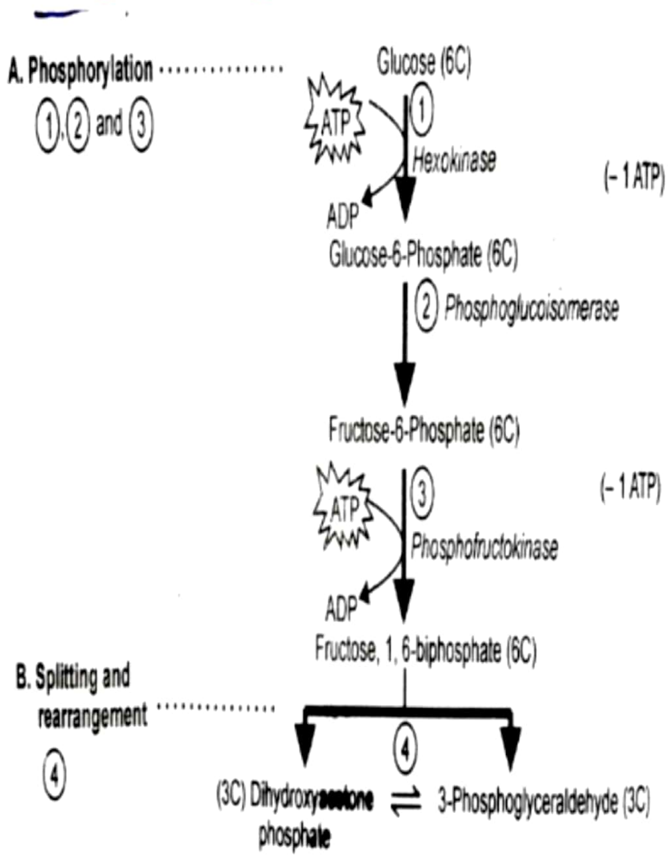
Main steps of Glycoslysis

- Glycolysis involve a sequence of steps that can be grouped into following reactions:

1. **Phosphorylation (Step 1-3)**
2. **Splitting and rearrangement of molecules (step 4)**
3. **Energy harvesting reaction (step 5-9)**

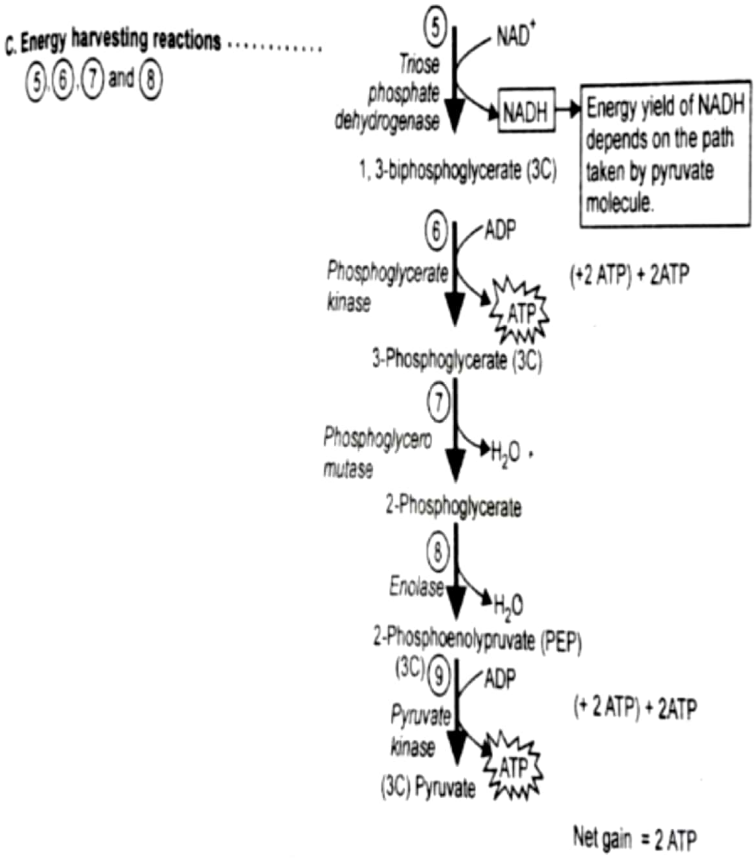
Phosphorylation:

1. It begin with phosphorylation of glucose by ATP through enzyme hexokinase which results glucose - 6 – phosphate.
2. G-6-P isomerise into fructose -6 – phosphate by enzyme phosphoglucoisomerase.
3. F-6-P is phosphorylated and fructose 1,6-phhosphate is formed



Energy harvesting reactions

- It is series of reaction in which sugar phosphate is converted to pyruvate with the involvement of following enzyme triose **phosphate dehydrogenase**, **phosphoglycerate kinase**, **phosphoglyceromutase** and **puyruvate kinase** enzyme respectively.



Formation of ATP molecules and net gain of glcolysis

- In glycolysis the ATP molecule is formed by following two ways:
- Direct transfer of phosphate to ADP molecules.
- By oxidation of NADH (1 NADH = 3 ATP).
- The over all equation of glycolysis is :

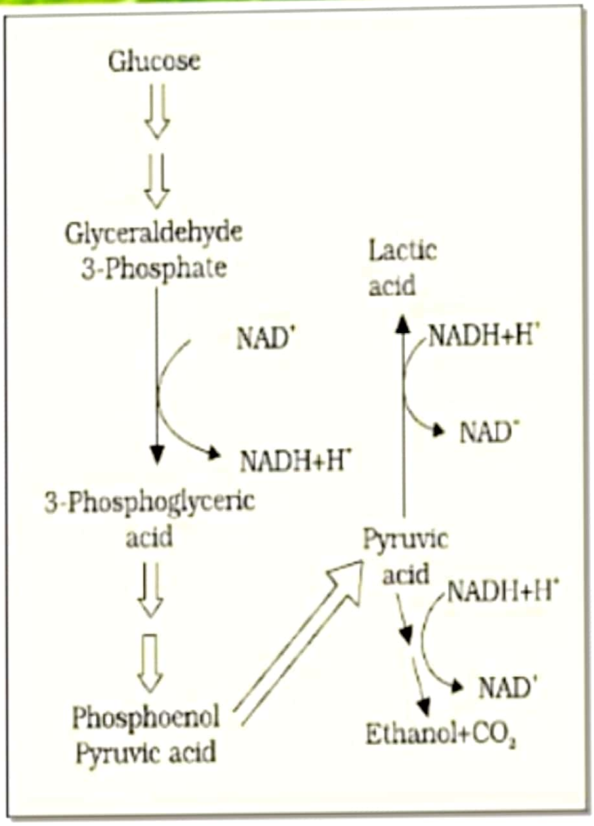
$$C_6H_{12}O_6 \rightarrow 2C_3H_4O_3 + NADH + 2ATP$$

- In gycolysis 4 ATP is produce but 2 ATP are spent during phosphorylation of glucose (i.e. in the conversion of glucose to fructose 1, 6 –bisphosphate) so net gain of ATP is 2 ATP.

FERMENTATION

- There are three major ways in which different cells handle pyruvic acid produced by glycolysis:

1. Lactic acid fermentation.
2. Alcoholic fermentation.
3. Aerobic respiration.



LACTIC ACID FERMENTATION

- Pyruvic acid converted into lactic acid.
- It takes place in the muscle in anaerobic conditions.
- The reaction catalysed by lactate dehydrogenase.
- NADH + H^+ is reoxidised into NAD^+.

ALCOHOLIC FERMENTATION

•Incomplete oxidation of glucose- anaerobic

•Sets of reactions where pyruvic acid is converted into CO_2 and ethanol.

•The enzyme *pyruvic acid decarboxylase* and *alcohol dehydrogenase* catalyze these reactions.

•NADH + H^+ is reoxidised into NAD^+.

•Energy release- less than 7% of energy in glucose

•Yeast poisons to death when concentration of alcohol reaches about 13 peecent

AEROBIC RESPIRATION

- Complete oxidation of glucose & energy extraction- synthesize ATP
- Common in higher organisms & takes place within mitochondria
- requires O_2 and releases CO_2, water and a large amount of energy present in the substrate.

AEROBIC RESPIRATION

- Pyruvic acid enters into the mitochondria.
- Two main event of process:

i. Complete oxidation of pyruvate by the stepwise removal of all the hydrogen atoms, leaving three molecules of CO_2 - Matrix of mitochondria.

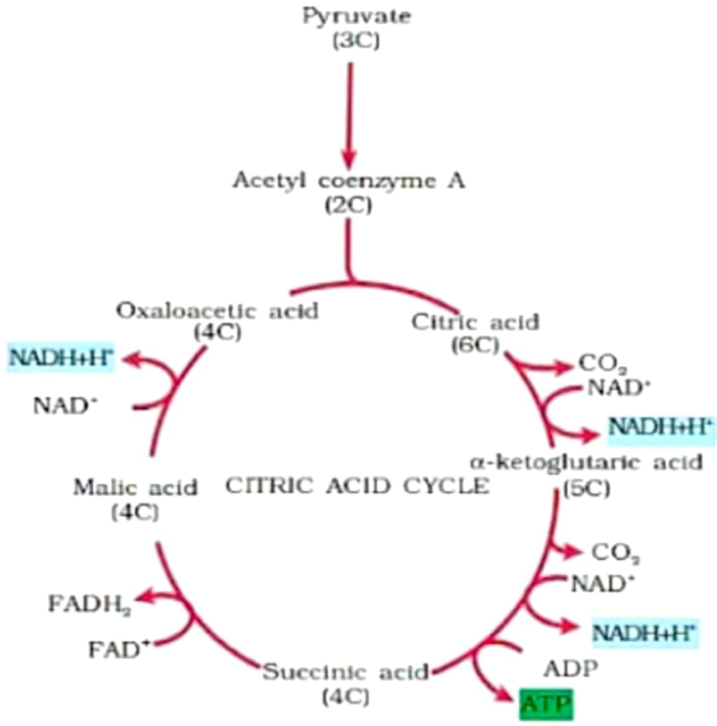
ii. The passing on the electrons removed as part of the hydrogen atoms to molecular oxygen (O_2) with simultaneous synthesis of ATP- inner membrane of mitochondria.

- Pyruvate enters from cytosol to mitochondrial matrix & undergoes oxidative decarboxylation- *Pyruvic dehydrogenase, coenzyme A & NAD*$^+$ - 2 NADH produced from one molecule of glucose

$$\text{Pyruvic acid} + \text{CoA} + \text{NAD}^+ \xrightarrow[\text{Pyruvate dehydrogenase}]{Mg^{2+}} \text{Acetyl CoA} + CO_2 + \text{NADH} + H^+$$

TRICARBOXYLIC ACID CYCLE

- *Condensation* of acetyl group with oxaloacetic acid and water- citric acid- *citrate synthase.*
- *Isomerisation* of Citrate to form isocitrate.
- *Decarboxylation* for two successive steps, leading to formation of α-ketoglutaric acid and then succinyl-CoA.
- *Oxidation* of succinyl CoA into oxaloacetic acid.



- During conversion of succinyl CoA to succinic acid there is synthesis of one GTP molecule.
- In a coupled reaction GTP converted to GDP with simultaneous synthesis of ATP from ADP.
- During Krebs cycle there production of :
  - 2 molecule of CO_2 3 $NADH_2$ 1 $FADH_2$ 1 GTP.

$$\text{Pyruvic acid} + 4NAD^+ + FAD^+ + 2H_2O + ADP + Pi \xrightarrow{\text{Mitochondrial Matrix}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

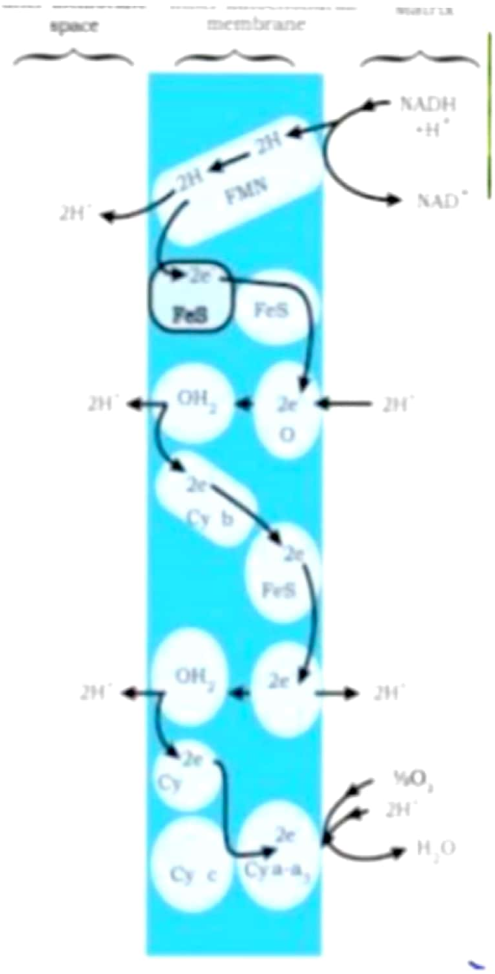
- During the whole process of oxidation of glucose produce:
- CO_2 10 $NADH_2$ 2 $FADH_2$ 2 GTP.(2 ATP)

3. The reduced ubiquinone is then oxidized wi
cytochrome *c* via cytochromes *bc1* complex.

4. Cytochrome c is small protein attached to tl
inner membrane and acts as a mobile carrier
complex III and complex IV.

5. When electrons transferred from one carrie
to IV in the electron transport chain, they are (
(complex V) for the synthesis of ATP from AD

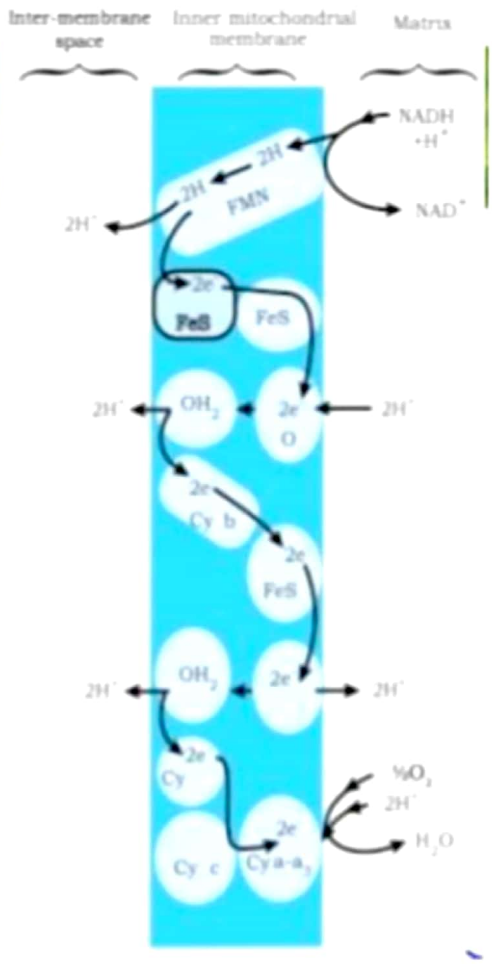
- One molecule of $NADH_2$ gives rise to 3 ATP.
- One molecule of $FADH_2$ gives rise to 2ATP.
- Oxygen plays a vital role in removing electror production of H_2O.
- Phosphorylation in presence of oxygen is cal phosphorylation.



ELECTRON TRANSPORT SYST OXIDATIVE PHOSPHORYLATI

- The metabolic pathway, through which the carrier to another, is called **Electron trans**
- it is present in the inner mitochondrial mem
- ETS comprises of the following:
  - Complex I – NADH Dehydrogenase.
  - Complex II – succinate dehydrogenase.
  - Complex III – cytochromes bc1
  - Complex IV – Cytochromes $a\text{-}a_3$(cytoch
  - Complex V – ATP synthase.

1. $NADH_2$ produced in citric acid cycle oxidize *Dehydrogenase*- electrons are then transfe in the inner membrane.
2. $FADH_2$ is oxidized by *succinate dehydroger* electrons to ubiquinone



RESPIRATORY BALANCED SHEET

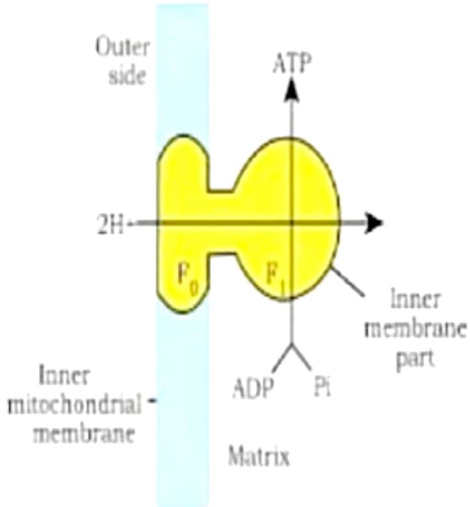
- These calculations can be made only on certain assumptions that:

1. There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another.
2. The NADH synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.
3. None of the intermediates in the pathway are utilised to synthesise any other compound.
4. Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

- Net gain of 36 ATP molecules during aerobic respiration of one molecule of glucose.

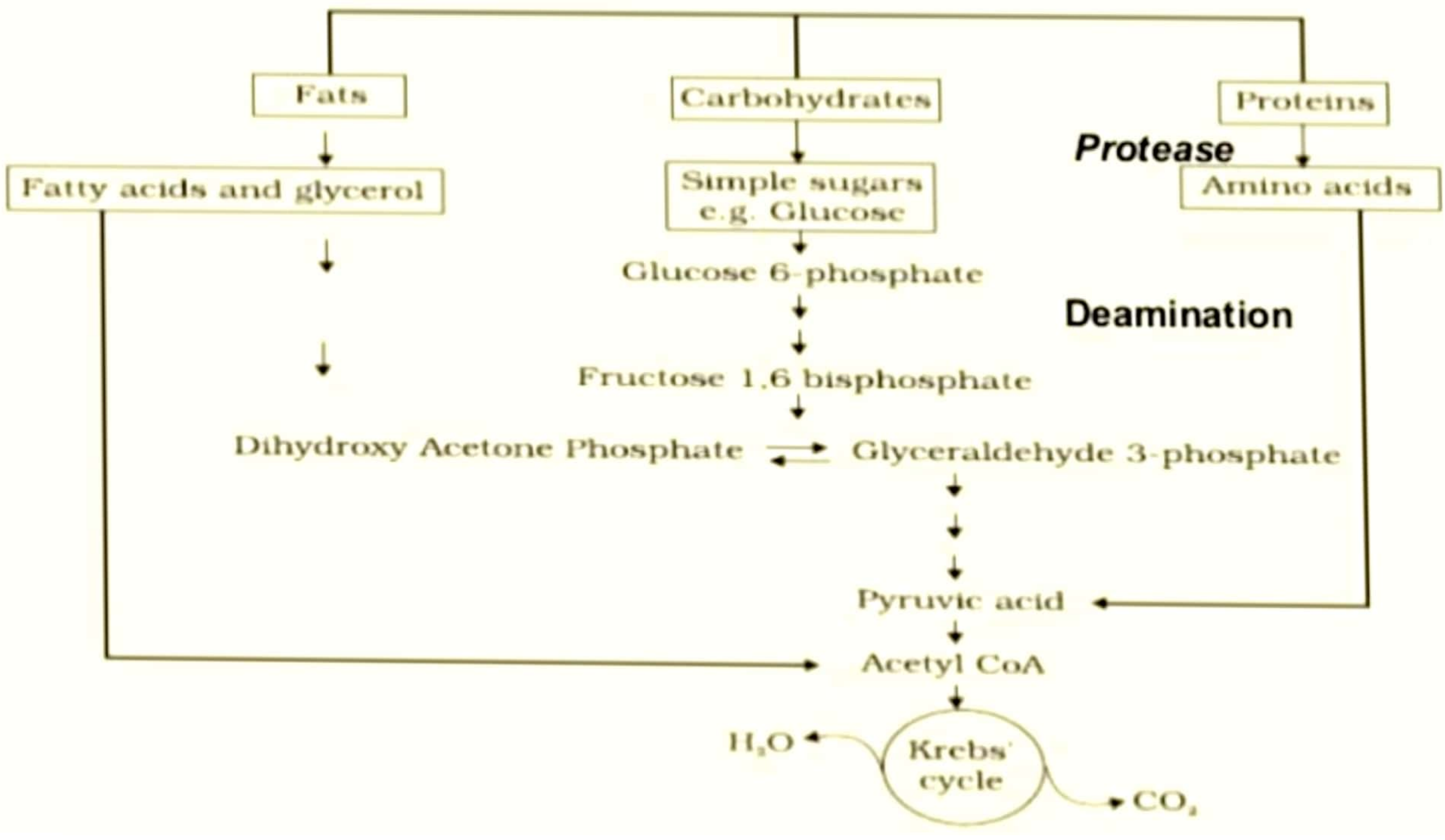
STRUCTURE OF ATP SYNTHASE

- Energy released utilised in synthesising ATP with the help of ATP synthase (complex V).
- Complex consists of two major components, F1 and F0; F1 headpiece is a peripheral membrane protein complex and contains the site for synthesis of ATP from ADP & Pi.
- F0 is an integral membrane protein complex that forms the channel through which protons cross the inner membrane.
- The passage of protons through the channel is coupled to the catalytic site of the F1 component for the production of ATP.
- For each ATP produced, 2H+ passes through F0 from the intermembrane space to the matrix down the electrochemical proton gradient



1. Fermentation accounts for only a partial breakdown of glucose whereas in aerobic respiration it is completely degraded to CO2 and H2O.
2. In fermentation there is a net gain of only two molecules of ATP for each molecule of glucose degraded to pyruvic acid whereas many more molecules of ATP are generated under aerobic conditions.
3. NADH is oxidised to NAD+ rather slowly in fermentation, however the reaction is very vigorous in case of aerobic respiration.

AMPHIBOLIC PATHWAY



RESPIRATORY QUOTIENT

- The ratio of the volume of CO2 evolved to the volume of O2 consumed in respiration is called the **respiratory quotient** (RQ) or respiratory ratio.

$$RQ = \frac{\text{volume of } CO_2 \text{ evolved}}{\text{volume of } O_2 \text{ consumed}}$$

- Depends on respiratory substrates
- Carbohydrate: Completely oxidised, RQ= 1, CO2 & O2- equal amount evolved & consumed

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy} \qquad RQ = \frac{6CO_2}{6O_2} = 1.0$$

- Fats: RQ= less than 1

$$\underset{\text{Tripalmitin}}{2(C_{51}H_{98}O_6)} + 145O_2 \longrightarrow 102CO_2 + 98H_2O + \text{energy} \qquad RQ = \frac{102CO_2}{145O_2} = 0.7$$

- Proteins: RQ= 0.9

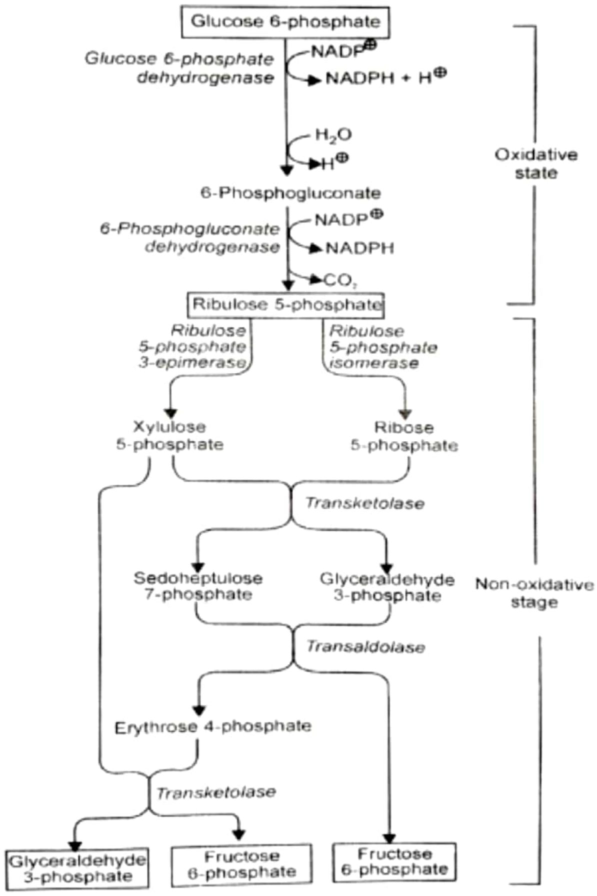
Pentose Phosphate Pathway

- Some organism have another pathway (PPP) for glucose metabolism and it is alternate pathway to release energy.
- In this the glucose is phosphorylated and converted into glucose -6-phosphate (i.e. which enter into the Pentose phosphate pathway).
- It has two important functions:

1. **Generation of NADPH**
2. **Formation of ribose- 5- phosphate.**

- PPP occurs actively in tissue that synthesis fatty acid or steroids (i.e. liver, adipose tissue, mammary glands etc) and consume large amount of pentose phosphate pathway.

Mechanism of pentose phosphate pathways



- It occurs in the cytoplasm of the cell and completed into two phase:

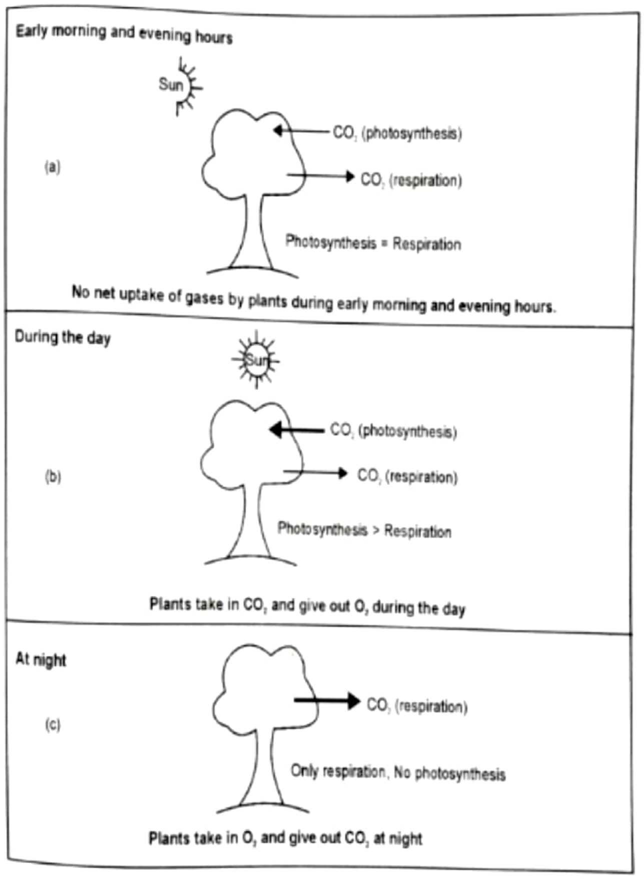
Oxidative phase:

- In this glucose – 6 – phosphate or other photosynthates that produce during photosynthesis are oxidiesd into 6-phosphogluconate and generate NADPH.
- 6-phosphogluconate further oxidiszed by enzyme 6-phopsphogluconate dehydrogenase and results the formation of ribulose – 5- phosphate, carbon dioxide, and NADPH.

Non-oxidative stage:

- In this ribolose -5-phosphate undergo many changes and converted into glycolysis intermediates (i.e. fructtose-6-phosphate, glyceraldehyde-3-phosphate) which further metabolised by glycolysis.

Compensation point



1. Light compensation point:

- It refer to light intensity at which the rate of photosynthesis and rate of respiration are equal in plants.
- In plant both photosynthesis and respiration takes place simultaneously and the rate of photosynthesis differ according to the intensity of light during day.
- During the photosynthesis plants takes Co_2 and release O_2 while during respiration plant takes O_2 and release Co_2 .

2. Co_2 compensation point:

- When light is not the limiting factors then concentration of Co_2 at which rate of photosynthesis is equal to rate of respiration is called Co_2 compensation point (i.e. uptake of Co_2 at which rate of photosynthesis is equal to the rate of respiration is called Co_2 compensation point (i.e. uptake off carbon dioxide is equal to that generated through respiration).
- It can be also define as the concentration of carbon dioxide at which there is no net fixation of photosynthesis or photosynthesis is zero.

  Photosynthesis = respiration or net photosynthesis = 0
- C_3 plant have higher Co_2 compensation point than C_4 plants.