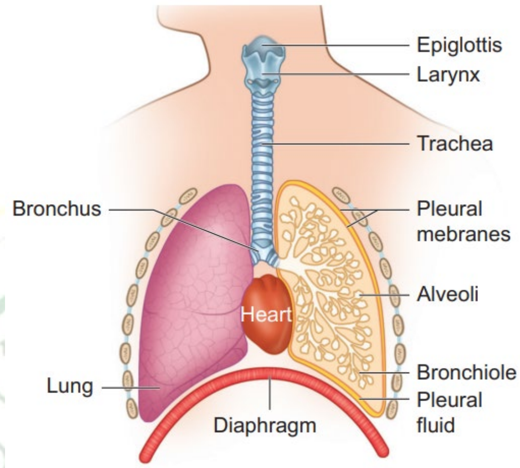
Respiration

1. Human Respiratory System

Our respiratory system consists of organs like trachea, bronchus and lungs which are responsible for exchange of air between the atmosphere and the blood.



The nose

We inhale air through the nostrils, which lead to the nasal cavity. The inner surface of this cavity is lined with cilia and mucous producing cells, which make it sticky and moist. The cilia and mucous trap dust and germs to prevent them from going deeper into the respiratory tract. The blood vessels in the nose help to warm the inhaled air.

The windpipe

After passing through the nasal cavity, the air enters the pharynx. Then it goes into the trachea or the windpipe which is an elastic tube extending down the length of the neck and partly into the chest cavity. Between the pharynx and the trachea lies a small air passage called the larynx commonly known as the **voice box**. The larynx has fold of tissue which vibrate with the passage of air to produce sound.

Bronchi

The trachea divides into two branches called **bronchi (Singular: bronchus)**. Each bronchus leads to a lung, where it divides and redivides to finally form air passages called bronchioles.

Lungs

The lungs are the organs present in the chest cavity that allow our body to exchange gases (oxygen and carbon dioxide). The lungs are two spongy elastic bags, on each side of the thoracic cavity. The thoracic cavity is bound dorsally by the vertebral column and ventrally by the sternum, laterally by the ribs and on the lower side by the dome shaped diaphragm. The left lung is slightly smaller than the right lung (allows room for the heart). Within the lungs, each bronchiole leads to a bunch of air sacs called alveoli (Singular: Alveolus).

Alveoli

Alveoli are tiny air sacs in the lungs that are located at the end of bronchial tubes, which is microscopic in nature. It is meant for the exchange of oxygen and carbon dioxide.

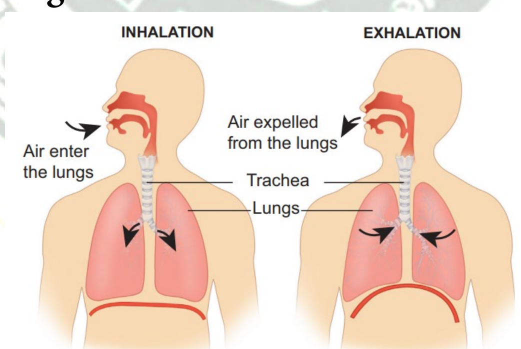
Characteristic features of respiratory surface:

Surface area must be very large and richly supplied with blood vessels
Should be extremely thin and kept moist
Should be in direct contact with the environment
Should be permeable to respiratory gases

The steps involved in respiration are

The exchange of air between the atmosphere and the lungs.
The exchange of O2 and CO2 between the lungs and the blood.
Transport of O2 and CO2 by the blood.
Exchange of gases between the blood and the cells.
Uptake of O_2 by the cells for various activities and the release of CO_2.

2. Mechanism of Breathing



Inspiration (Inhalation)

The process of taking air into the lungs is called **inspiration** or inhalation. During inspiration, the sternum is pushed up and outward and the diaphragm is pulled down. This increases the volume of the thoracic cavity and thus the pressure decreases. The air outside the body flows into the lungs. Here exchange of gases takes place between the air and the blood.

Expiration (Exhalation)

The process of expelling air from the lungs is called **expiration or exhalation.** Upon exhalation, the lungs recoil to force the air out of the lungs. The inter costal muscles relax, returning the chest wall to its original position. During exhalation, the diaphragm also relaxes, moving higher into the thoracic cavity. This increases the pressure within the thoracic cavity relative to the environment. Air rushes out of the lungs due to the pressure gradient. This movement of air out of the lungs is a passive event.

Exchange of gases in the Alveoli

The content of oxygen in the inhaled air in alveoli is more than the blood flowing through the capillaries. So, the oxygen moves into the blood by simple diffusion. Haemoglobin in the blood combines with oxygen to form oxyhaemoglobin. The blood carrying oxygen reaches the heart through blood vessels. The heart pumps it to all the tissues in the body. The tissues release carbon dioxide which is carried back to alveoli by the blood. Carbon dioxide diffuses from the blood to the air in the alveoli and is sent out of the body when the air is exhaled.

Difference between inhalation and exhalation

Inhalation	Exhalation
The muscles of the diaphragm contract.	The muscles of the diaphragm relax.
The diaphragm goes downward.	The diaphragm goes upward.
The ribs move upwards and outwards.	The ribs move downwards.
The volume of thoracic (chest) cavity increases.	The volume of thoracic (chest) cavity decreases.
Air enters the lungs through the nose.	Air goes out of the lungs through the nose.

OR

Inspiration	Expiration
Respiratory centre initiates the stimuli during inspiration. The diaphragm and exspiratory muscles contract. The thoracic volume increases as the chest wall expands. The intra pulmonary pressure is reduced. The alveolar pressure decreases than the atmospheric pressure Air is taken inside due to expansion of alveoli. Air flows into the alveoli until the alveolar pressure equalizes the atmospheric pressure and the alveoli get inflated.	Respiratory centre terminates the stimuli during expiration. The diaphragm relax but internal intercostal muscles contract. The thoracic volume decreases as the chest wall contracts. The intra pulmonary pressure is increased. The alveolar pressure increases than the atmospheric pressure. Air is sent out due to the contraction of alveoli. Air flows out of the alveoli until the alveolar pressure equalizes the atmospheric pressure and the alveoli get deflated.

3. Regulation of Respiration

A specialised respiratory centre present in the medulla oblongata of the hind brain called respiratory rhythm centre is responsible for this regulation. Pneumotaxic centre present in pons varoli region of the brain moderates the function of the respiratory rhythm centre to ensure normal breathing. The chemosensitive area found close to the rhythm centre is highly sensitive to CO_2 and H^+. And H^+ are eliminated out by respiratory process. Receptors associated with the aortic arch and carotid artery send necessary signals to the rhythm centre for remedial action. The role of O_2 is insignificant in the regulation of respiratory rhythm.

4. Disorders of the Respiratory system

1. Asthma – It is characterized by narrowing and inflammation of bronchi and bronchioles and difficulty in breathing. Common allergens for asthma are dust, drugs, pollen grains, certain food items like fish, prawn and certain fruits etc.

2. Emphysema – Emphysema is chronic breathlessness caused by gradual breakdown of the thin walls of the alveoli decreasing the total surface area of a gaseous exchange. i.e., widening of the alveoli is called emphysema. The major cause for this disease is cigarette smoking, which reduces the respiratory surface of the alveolar walls.

3. Bronchitis – The bronchi when it gets inflated due to pollution smoke and cigarette smoking, causes bronchitis. The symptoms are cough, shortness of breath and sputum in the lungs.

4. Pneumonia – Inflammation of the lungs due to infection caused by bacteria or virus is called pneumonia. The common symptoms are sputum production, nasal congestion, shortness of breath, sore throat etc.

5. Tuberculosis – Tuberculosis is caused by Mycobacterium tuberculae. This infection mainly occurs in the lungs and bones. Collection of fluid between the lungs and the chest wall is the main complication of this disease.

5. Occupational respiratory disorders

The disorders due to one's occupation of working in industries like grinding or stone breaking, construction sites, cotton industries, etc. Dust produced affects the respiratory tracts.

Long exposure can give rise to inflammation leading to fibrosis. Silicosis and asbestosis are occupational respiratory diseases resulting from inhalation of particle of silica from sand grinding and asbestos into the respiratory tract. Workers, working in such industries must wear protective masks.

6. Cyclic Photophosphorylation and Cyclic Photophosphorylation

Cyclic Photophosphorylation	Cyclic Photophosphorylation
1. PS I only involved	1. PS I and PS II involved
2. Reaction centre is P700	2. Reaction centre is P680

3. Electrons released are cycled back	3. Electron released are not cycled back
4. Photolysis of water does not take place	4. Photolysis of water takes place
5. Only ATP synthesized	5. ATP and NADPH + H^+ are synthesized
6. Phosphorylation takes place at two places	6. Phosphorylation takes place at only one place
7. It does not require an external electron donor	7. Requires external electron donor like H_2O or H_2S
8. It is not sensitive to di chloro di methyl urea (DCMU)	8. It is sensitive to DCMU and inhibits electron flow

7. Factors affecting Photosynthesis

External factors

1. Light

Energy for photosynthesis comes only from light. Photooxidation of water and excitation of pigment molecules are directly controlled by light. Stomatal movement leading to diffusion of CO_2 is indirectly controlled by light.

a. Intensity of Light:

Intensity of light plays a direct role in the rate of photosynthesis. Under low intensity the photosynthetic rate is low and at higher intensity photosynthetic rate is higher. It also depends on the nature of plants. Heliophytes (Bean Plant) require higher intensity than Sciophytes (Oxalis).

b. Quantity of Light:

In plants which are exposed to light for longer duration (Long day Plants) photosynthetic rate is higher.

c. Quality of light:

Different wavelengths of light affect the rate of photosynthesis because pigment system does not absorb all the rays equally. Photosynthetic rate is maximum in blue and red light.

Photosynthetically Active Radiation (PAR) is between 400 to 700 nm. Red light induces highest rate of photosynthesis and green light induces lowest rate of photosynthesis.

2. Carbon dioxide

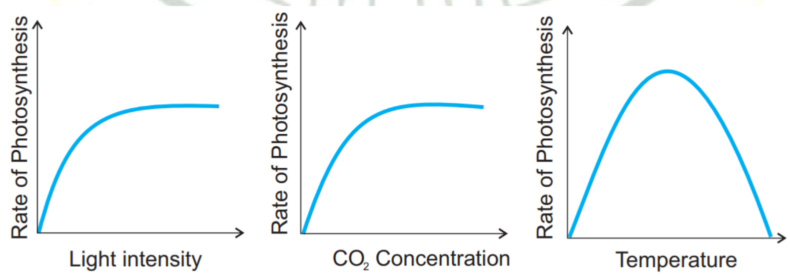
CO_2 is found only 0.3 % in the atmosphere but plays a vital role. Increase in concentration of CO_2 increases the rate of photosynthesis (CO_2 concentration in the atmosphere is 330 ppm). If concentration is increased beyond 500ppm, rate of photosynthesis will be affected showing the inhibitory effect.

3. Oxygen

The rate of photosynthesis decreases when there is an increase of oxygen concentration. This Inhibitory effect of oxygen was first discovered by Warburg (1920) using green algae Chlorella.

4. Temperature

The optimum temperature for photosynthesis varies from plant to plant. Temperature is not uniform in all places. In general, the optimum temperature for photosynthesis is 25° C to 35° C. This is not applicable for all plants. The ideal temperature for plants like Opuntia is 55o C, Lichens 20° C and Algae growing in hot spring photosynthesis is 75° C. Whether high temperature or low temperature it will close the stomata as well as inactivate the enzymes responsible for photosynthesis.



5. Water

Photolysis of water provides electrons and protons for the reduction of NADP, directly. Indirect roles are stomatal movement and hydration of protoplasm. During water stress, supply of $NADPH + H^+$ is affected.

6. Minerals

Deficiency of certain minerals affect photosynthesis e.g. mineral involved in the synthesis of chlorophyll (Mg, Fe and N), Phosphorylation reactions (P), Photolysis of water (Mn and Cl), formation of plastocyanin (Cu).

7. Air pollutants

Pollutants like SO_2, NO_2, O_3 (Ozone) and Smog affects rate of photosynthesis.

Internal Factors

1. Photosynthetic Pigments

It is an essential factor and even a small quantity is enough to carry out photosynthesis.

2. Protoplasmic factor

Hydrated protoplasm is essential for photosynthesis. It also includes enzymes responsible for Photosynthesis.

3. Accumulation of Carbohydrates

Photosynthetic end products like carbohydrates are accumulated in cells and if translocation of carbohydrates is slow then this will affect the rate of photosynthesis.

4. Anatomy of leaf

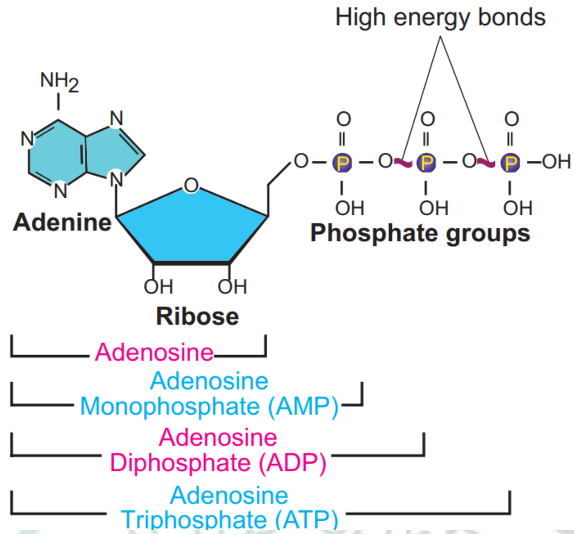
Thickness of cuticle and epidermis, distribution of stomata, presence or absence of Kranz anatomy and relative proportion of photosynthetic cells affect photosynthesis.

5. Hormones

Hormones like gibberellins and cytokinin increase the rate of photosynthesis.

8. Structure of ATP

Respiration is responsible for generation of ATP. The discovery of ATP was made by Karl Lohman (1929). ATP is a nucleotide consisting of a base-adenine, a pentose sugar-ribose and three phosphate groups. Out of three phosphate groups the last two are attached by high energy rich bonds. On hydrolysis, it releases energy (7.3 K cal or 30.6 KJ/ATP) and it is found in all living cells and hence it is called universal energy currency of the cell. ATP is an instant source of energy within the cell. The energy contained in ATP is used in synthesis carbohydrates, proteins and lipids. The energy transformation concept was established by Lipman (1941).

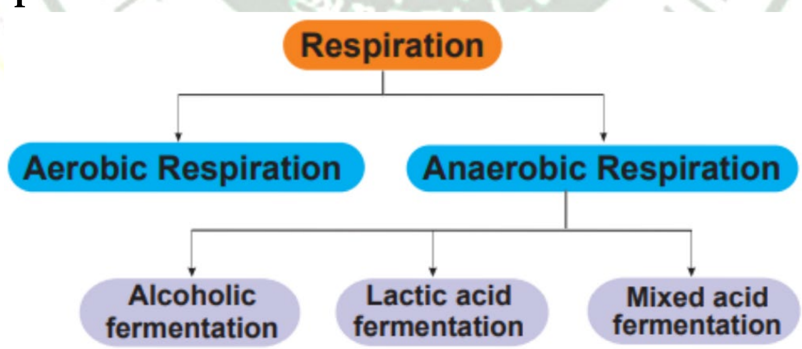


Redox Reactions

When NAD^+ (Nicotinamide Adenine Dinucleotide-oxidised form) and FAD (Flavin Adenine Dinucleotide) pick up electrons and one or two hydrogen ions (protons), they get reduced to $NADH + H^+$ and $FADH_2$ respectively. When they drop electrons and hydrogen off they go back to their original form. The reaction in which NAD^+ and FAD gain (reduction) or lose (oxidation) electrons are called redox reaction (Oxidation reduction reaction). These reactions are important in cellular respiration.

$$NAD^+ + 2e^- + 2H^+ \longrightarrow NADH + H^+$$
$$FAD + 2e^- + 2H^+ \longrightarrow FADH_2$$

9. Types of Respiration



Aerobic respiration

Respiration occurring in the presence of oxygen is called aerobic respiration. During aerobic respiration, food materials like carbohydrates, fats and proteins are completely oxidised into CO_2, H_2O and energy is released. Aerobic respiration is a very complex process and is completed in four major steps:

1. Glycolysis
2. Pyruvate oxidation (Link reaction)
3. Krebs cycle (TCA cycle)
4. Electron Transport Chain (Terminal oxidation).

Anaerobic respiration

In the absence of molecular oxygen glucose is incompletely degraded into either ethyl alcohol or lactic acid. It includes two steps:

1. Glycolysis
2. Fermentation

Stages of Respiration

1. Glycolysis-conversion of glucose into pyruvic acid in cytoplasm of cell.
2. Link reaction-conversion of pyruvic acid into acetyl coenzyme-A in mitochondrial matrix.
3. Krebs cycle-conversion of acetyl coenzyme A into carbon dioxide and water in the mitochondrial matrix.
4. Electron transport chain to tranfer electrons remove hydrogen ions and tranfer electrons from the products of glycolysis, link reaction and Krebs cycle It takes place in mitochondrial inner membrane to release ATP with water molecule by terminal oxidation

10. Glycolysis

(Gr: Glykos 5 Glucose, Lysis 5 Splitting) Glycolysis is a linear series of reactions in which 6-carbon glucose is split into two molecules of 3-carbon pyruvic acid. The enzymes which are required for glycolysis are present in the cytoplasm. The reactions of glycolysis were worked out in yeast cells by three scientists Gustav Embden (German), Otto Meyerhoff (German) and J Parnas (Polish) and so it is also called as EMP pathway. It is the first and common stage for both aerobic and anaerobic respiration. It is divided into two phases.

Preparatory phase or endergonic phase or hexose phase (steps 1-5).

Pay off phase or oxidative phase or exergonic phase or triose phase (steps 6-10).

1. Preparatory phase

Glucose enters the glycolysis from sucrose which is the end product of photosynthesis. Glucose is phosphorylated into glucose-6- phosphate by the enzyme hexokinase, and subsequent reactions are carried out by different enzymes. At the end of this phase fructose-1, 6 - bisphosphate is cleaved into glyceraldehyde-3-phosphate and dihydroxy acetone phosphate by the enzyme aldolase. These two are isomers. Dihydroxy acetone phosphate is isomerised into glyceraldehyde-3-phosphate by the enzyme triose phosphate isomerase, now two molecules of glyceraldehyde 3 phosphate enter into pay off phase. During preparatory phase two ATP molecules are consumed in step-1 and step-3.

2. Pay off phase

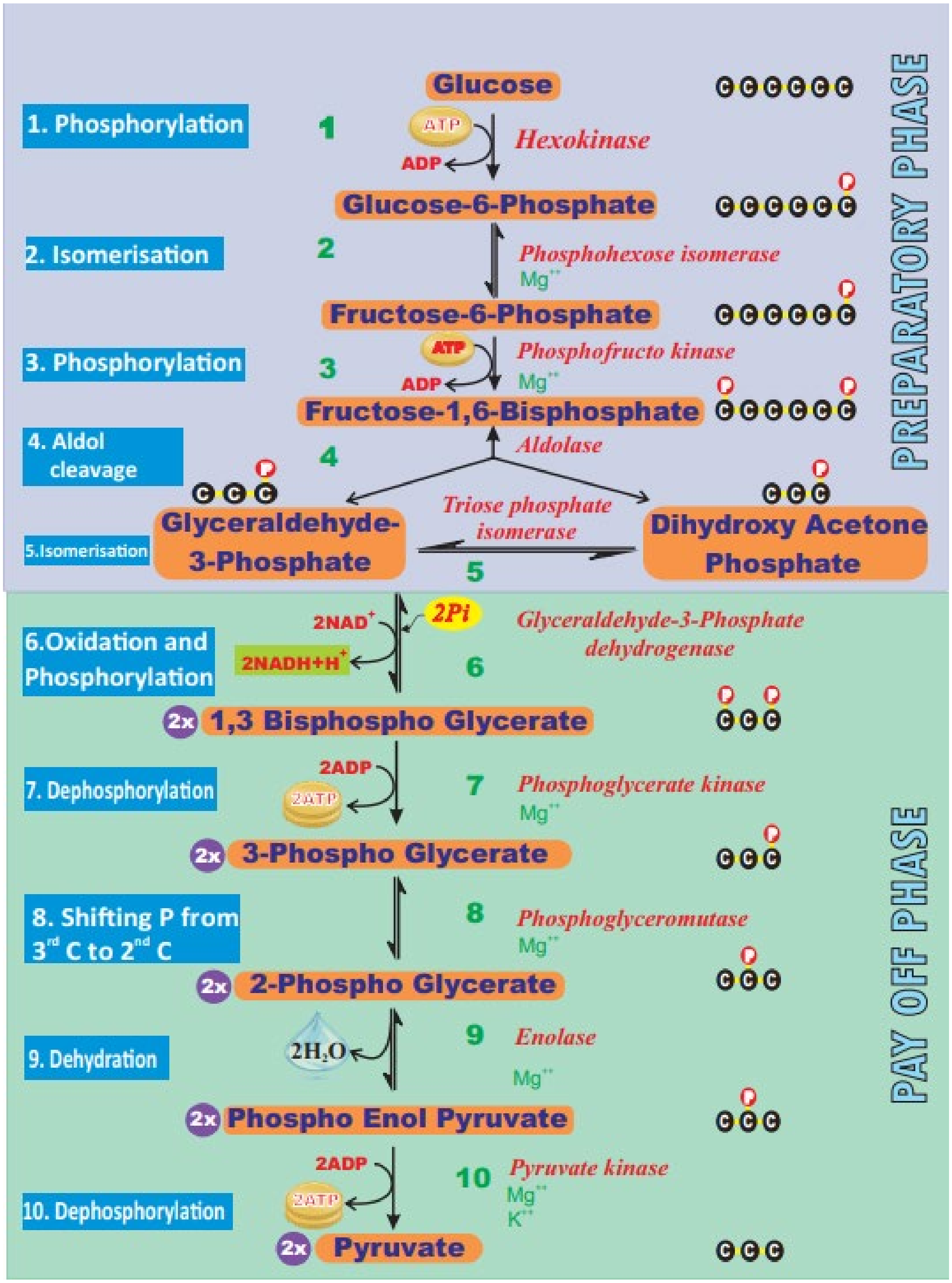
Two molecules of glyceraldehyde-3- phosphate oxidatively phosphorylated into two molecules of 1,3 - bisphospho glycerate. During this reaction $2NAD^+$ is reduced to $2NADH + H^+$ by glyceraldehyde- 3- phosphate dehydrogenase at step 6. Further reactions are carried out by different enzymes and at the end two molecules of pyruvate are produced. In this phase, 2ATPs are produced at step 7 and 2 ATPs at step10. Direct transfer of phosphate moiety from substrate molecule to ADP and is converted into ATP is called substrate phosphorylation or direct phosphorylation or trans phosphorylation. During the reaction at step 9, 2 phospho glycerate dehydrated into Phospho enol pyruvate. A water molecule is removed by the enzyme enolase. As a result, enol group is formed within the molecule. This process is called Enolation.

3. Energy Budget

In the pay off phase totally 4ATP and $2NADH + H^+$ molecules are produced. Since 2ATP molecules are already consumed in the preparatory phase, the net products in glycolysis are 2ATPs and $2NADH + H^+$.

The overall net reaction of glycolysis

$$C_6H_{12}O_6 + 2ADP + 2Pi + 2NAD^+ \downarrow 2x\,CH_3COCOOH + 2ATP + 2NADH + 2H^+$$



11. Pyruvate Oxidation (Link reaction)

Two molecules of pyruvate formed by glycolysis in the cytosol enters into the mitochondrial matrix. In aerobic respiration this pyruvate with coenzyme A is oxidatively decarboxylated into acetyl CoA by pyruvate dehydrogenase complex.

This reaction is irreversible and produces two molecules of $NADH + H^+$ and $2CO_2$. It is also called transition reaction or Link reaction. The reaction of pyruvate oxidation is

$$2x\ CH_3COCOOH + 2NAD^+ + 2CoA \xrightarrow[\text{complex/ } Mg^{++}]{\text{Pyruvate dehydrogenase}} 2xCH_3CO.CoA + 2NADH + 2H^+ + 2CO_2\uparrow$$

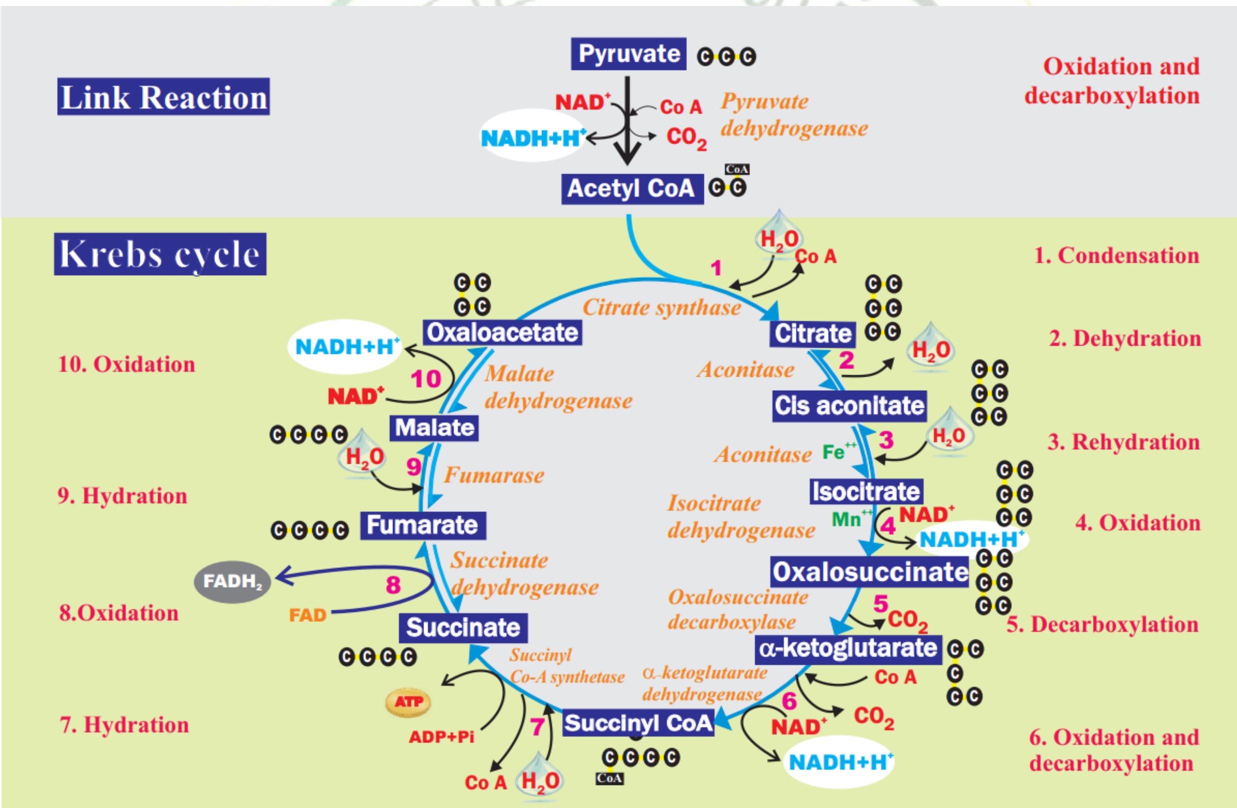
12. Krebs cycle or Citric acid cycle or TCA cycle:
Two molecules of acetyl CoA formed from link reaction now enter into Krebs cycle. It is named after its discoverer, German Biochemist Sir Hans Adolf Krebs (1937). The enzymes necessary for TCA cycle are found in mitochondrial matrix except succinate dehydrogenase enzyme which is found in mitochondrial inner membrane. TCA cycle starts with condensation of acetyl CoA with oxaloacetate in the presence of water to yield citrate or citric acid. Therefore, it is also known as Citric Acid Cycle (CAC) or Tri Carboxylic Acid (TCA) cycle. It is followed by the action of different enzymes in cyclic manner. During the conversion of succinyl CoA to succinate by the enzyme succinyl CoA synthetase or succinate thiokinase, a molecule of ATP synthesis from substrate without entering the electron transport chain is called substrate level phosphorylation. In animals a molecule of GTP is synthesized from GDP + Pi. In a coupled reaction GTP is converted to GDP with simultaneous synthesis of ATP from ADP + Pi. In three steps (4, 6, 10) in this cycle NAD^+ is reduced to $NADH + H^+$ and at step 8 where FAD is reduced to $FADH_2$.
The summary of link reaction and Krebs cycle in Mitochondria is

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

Two molecules of pyruvic acid formed at the end of glycolysis enter into the mitochondrial matrix. Therefore, Krebs cycle is repeated twice for every glucose molecule where two molecules of pyruvic acid produces six molecules of CO_2, eight molecules of $NADH + H^+$, two molecules of $FADH_2$ and two molecules of ATP.

Significance of Krebs cycle:

1. TCA cycle is to provide energy in the form of ATP for metabolism in plants.
2. It provides carbon skeleton or raw material for various anabolic processes.
3. Many intermediates of TCA cycle are further metabolised to produce amino acids, proteins and nucleic acids.
4. Succinyl CoA is raw material for formation of chlorophylls, cytochrome, phytochrome and other pyrrole substances.
5. α-ketoglutarate and oxaloacetate undergo reductive amination and produce amino acids.
6. It acts as metabolic sink which plays a central role in intermediary metabolism.



Amphibolic nature

Krebs cycle is primarily a catabolic pathway, but it provides precursors for various biosynthetic pathways there by an anabolic pathway too. Hence, it is called amphibolic pathway. It serves as a pathway for oxidation of carbohydrates, fats and proteins. When fats are respiratory substrate they are first broken down into glycerol and fatty acid. Glycerol is converted into DHAP and acetyl CoA. This acetyl CoA enter into the Krebs cycle. When proteins are the respiratory substrate they are degraded into amino acids by proteases. The amino acids after deamination enter into the Krebs cycle through pyruvic acid or acetyl CoA and it depends upon the structure. So respiratory intermediates form the link between synthesis as well as breakdown. The citric acid cycle is the final common pathway for oxidation of fuel molecules like amino acids, fatty acids and carbohydrates. Therefore, respiratory pathway is an amphibolic pathway.

13. Electron Transport Chain (ETC) (Terminal oxidation)

During glycolysis, link reaction and Krebs cycle the respiratory substrates are oxidised at several steps and as a result many reduced coenzymes NADH + H^+ and $FADH_2$ are produced. These reduced coenzymes are transported to inner membrane of mitochondria and are converted back to their oxidised forms produce electrons and protons. In mitochondria, the inner membrane is folded in the form of finger projections towards the matrix called cristae. In cristae many oxysomes (F_1 particles) are present which have electron transport carriers. According to Peter Mitchell's Chemiosmotic theory this electron transport is coupled to ATP synthesis. Electron and hydrogen (proton) transport takes place across four multiprotein complexes (I-IV).

They are

1. Complex-I (NADH dehydrogenase). It contains a flavoprotein (FMN) and associated with non-heme iron Sulphur protein (Fe-S). This complex is responsible for passing electrons and protons from mitochondrial NADH (Internal) to Ubiquinone (UQ).

$$NADH + H^+ + UQ \rightleftharpoons NAD^+ + UQH_2$$

In plants, an additional NADH dehydrogenase (External) complex is present on the outer surface of inner membrane of mitochondria which can oxidise cytosolic NADH + H^+. Because mitochondrial inner membrane cannot allow NADH molecules directly into the matrix.

Ubiquinone (UQ) or Coenzyme Quinone (CoQ) is a small, lipid soluble electron, proton carrier located within the inner membrane of mitochondria.

2. Complex-II (Succinic dehydrogenase) It contains FAD flavoprotein is associated with non-heme iron Sulphur (Fe-S) protein. This complex receives electrons and

protons from succinate in Krebs cycle and is converted into fumarate and passes to ubiquinone.

$$\text{Succinate} + \text{UQ} \rightarrow \text{Fumarate} + \text{UQH}_2$$

3. Complex-III (Cytochrome bc1 complex) This complex oxidises reduced ubiquinone (ubiquinol) and transfers the electrons through Cytochrome bc_1 Complex (Iron Sulphur center bc1 complex) to cytochrome c. Cytochrome c is a small protein attached to the outer surface of inner membrane and act as a mobile carrier to transfer electrons between complex III to complex IV.

$$\text{UQH}_2 + 2\text{Cyt c}_{\text{oxidised}} \rightleftharpoons \text{UQ} + 2\text{Cyt c}_{\text{reduced}} + 2\text{H}^+$$

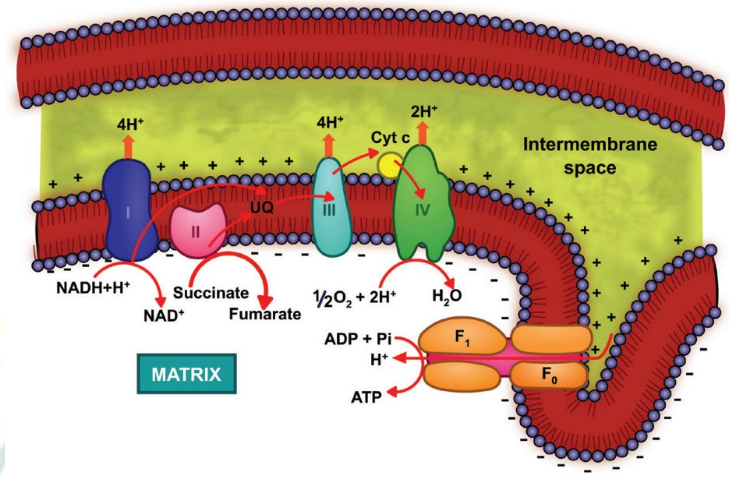
4. Complex IV (Cytochrome c oxidase)

This complex contains two copper centers (A and B) and cytochromes a and a_3. Complex IV is the terminal oxidase and brings about the reduction of 1/2 O_2 to H_2O.Two protons are needed to form a molecule of H_2O (terminal oxidation).

$$2\text{Cyt c}_{\text{oxidised}}\ 1\ 2\text{H}^1\ 1\ 1/2\ \text{O}_2 \rightleftharpoons 2\text{Cyt c}_{\text{reduced}}\ 1\text{H}_2\text{O}$$

The transfer of electrons from reduced coenzyme NADH to oxygen via complexes I to IV is coupled to the synthesis of ATP from ADP and inorganic phosphate (Pi) which is called Oxidative phosphorylation. The F_0F_1-ATP synthase (also called complex V) consists of F_0 and F_1. F_1 converts ADP and Pi to ATP and is attached to the matrix side of the inner membrane. F_0 is present in inner membrane and acts as a channel through which protons come into matrix.

Oxidation of one molecule of NADH 1 H^1 gives rise to 3 molecules of ATP and oxidation of one molecule $FADH_2$ produces 2 molecules of ATP within a mitochondrion. But cytoplasmic NADH 1 H^1 yields only two ATPs through external NADH dehydrogenase. Therefore, two reduced coenzyme (NADH 1 H^1) molecules from glycolysis being extra mitochondrial will yield 2 3 2 5 4 ATP molecules instead of 6 ATPs (Figure 14.10). The Mechanism of mitochondrial ATP synthesis is based on Chemiosmotic hypothesis. According to this theory electron carriers present in the inner mitochondrial membrane allow for the transfer of protons (H^1). For the production of single ATP, 3 protons (H^1) are needed. The terminal oxidation of external NADH bypasses the first phosphorylation site and hence only two ATP molecules are produced per external NADH oxidised through mitochondrial electron transport chain. However, in those animal tissues in which malate shuttle mechanism is present, the oxidation of externl NADH will yield almost 3 ATP molecules.



Complete oxidation of a glucose molecule in aerobic respiration results in the net gain of 36 ATP molecules in plants as shown in table 14.2. Since huge amount of energy is generated in mitochondria in the form of ATP molecules they are called 'power house of the cell'. In the case of aerobic prokaryotes due to lack of mitochondria each molecule of glucose produces 38 ATP molecules.

Net Products gained during aerobic respiration per glucose molecule.

Stages	CO_2	ATP	Reduced NAD[1]	Reduced FAD	Total ATP Production
Glycolysis	0	2	2 (2x 2= 4)	0	6
Link reaction	2	0	2 (2x 3= 6)	0	6
Krebs cycle	4	2	6 (6 x3 =18)	2 (2x 2= 4)	24
Total	**6**	**4 ATPs**	**28 ATPs**	**4 ATPs**	**36 ATPs**

14. Respiratory Quotient (RQ)

The ratio of volume of carbon dioxide given out and volume of oxygen taken in during respiration is called Respiratory Quotient or Respiratory ratio. RQ value depends upon respiratory substrates and their oxidation.

$$RQ = \frac{\text{Volume of } CO_2 \text{ liberated}}{\text{Volume of } O_2 \text{ consumed}}$$

1. The respiratory substrate is a carbohydrate, it will be completely oxidised in aerobic respiration and the value of the RQ will be equal to unity.

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

$$\text{RQ of glucose} = \frac{6 \text{ molecules of } CO_2}{6 \text{ molecules of } O_2}$$

$$= 1 \text{ (unity)}$$

2. If the respiratory substrate is a carbohydrate it will be incompletely oxidised when it goes through anaerobic respiration and the RQ value will be infinity.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow 2CO_2\uparrow + \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + \text{Energy}$$

$$\left.\begin{matrix}\text{RQ of glucose}\\ \text{Anaerobically}\end{matrix}\right\} = \frac{2 \text{ molecules of } CO_2}{\text{zero molecule of } O_2}$$

$$= \infty \text{ (infinity)}$$

3. In some succulent plants like Opuntia, Bryophyllum carbohydrates are partially oxidised to organic acid, particularly malic acid without corresponding release of CO2 but O2 is consumed hence the RQ value will be zero.

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

$$\begin{matrix}\text{RQ of glucose}\\ \text{in succulents}\end{matrix} = \frac{\text{zero molecule of } CO_2}{3 \text{ molecules of } O_2}$$

$$= 0 \text{ (zero)}$$

4. When respiratory substrate is protein or fat, then RQ will be less than unity.

$$\underset{\text{Tripalmitin(Fat)}}{2(C_{51}H_{98}O_6)} + 145O_2 \longrightarrow 102CO_2\uparrow + 98H_2O + \text{Energy}$$

$$\text{RQ of Tripalmitin} = \frac{102 \text{ molecules of } CO_2}{145 \text{ molecules of } O_2}$$

$$= 0.7 \text{ (less than unity)}$$

5. When respiratory substrate is an organic acid the value of RQ will be more than unity.

$$\underset{\text{Malic acid}}{C_4H_6O_5} + 3O_2 \longrightarrow 4CO_2\uparrow + 3H_2O + \text{Energy}$$

$$\text{RQ of malic acid} = \frac{4 \text{ molecules of } CO_2}{3 \text{ molecules of } O_2}$$

$$= 1.33 \text{ (more than unity)}$$

Significance of RQ

RQ value indicates which type of respiration occurs in living cells, either aerobic or anaerobic.

It also helps to know which type of respiratory substrate is involved.

15. Anaerobic Respiration

Fermentation

Some organisms can respire in the absence of oxygen. This process is called fermentation or anaerobic respiration. There are three types of fermentation:

1. Alcoholic fermentation

The cells of roots in water logged soil respire by alcoholic fermentation because of lack of oxygen by converting pyruvic acid into ethyl alcohol and CO_2. Many species of yeast (Saccharomyces) also respire anaerobically. This process takes place in two steps:

$$\text{(i) } \underset{\text{Pyruvic acid}}{2CH_3COCOOH} \xrightarrow[\text{TPP}]{\text{Pyruvate decarboxylase}} \underset{\text{Acetaldehyde}}{2CH_3CHO} + 2CO_2\uparrow$$

$$\text{(ii) } \underset{\text{Acetaldehyde}}{2CH_3CHO} + 2NADH + 2H^+ \xrightarrow{\text{Alcohol dehydrogenase}} \underset{\text{Ethyl alcohol}}{2CH_3CH_2OH} + 2NAD^+$$

Industrial uses of alcoholic fermentation:

1. In bakeries, it is used for preparing bread, cakes, biscuits.
2. In beverage industries for preparing wine and alcoholic drinks.
3. In producing vinegar and in tanning, curing of leather.
4. Ethanol is used to make gasohol (a fuel that is used for cars in Brazil).

2. Lactic acid fermentation

Some bacteria (Bacillus), fungi and muscles of vertebrates produce lactic acid from pyruvic acid.

$$\underset{\text{Pyruvic acid}}{2CH_3COCOOH} + 2NADH + 2H^+ \xrightarrow{\text{Lactate dehydrogenase}} \underset{\text{Lactic acid}}{2CH_3CHOHCOOH} + 2NAD^+$$

3. Mixed acid fermentation

This type of fermentation is a characteristic feature of Enterobacteriaceae and results in the formation of lactic acid, ethanol, formic acid and gases like CO_2 and H_2.

Characteristics of Anaerobic Respiration

- Anaerobic respiration is less efficient than the aerobic respiration.
- Limited number of ATP molecules is generated per glucose molecule.
- It is characterized by the production of CO_2 and it is used for Carbon fixation in photosynthesis.

Stage	Substrate level ATP production	Reduced NAD^+	Total ATP
Glycolysis	2	2*	8
Anaerobic respiration	2	2 reduced NAD^+ re-oxidised	2

*One reduced NAD1 equivalent to 3 ATPs