



**Animal**



**physiology**



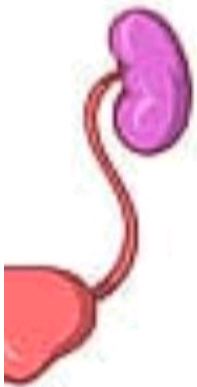
**Topic-**



**respiration**



**By-Bsc 2nd**



**year**



## 1. Exchange of Gases:

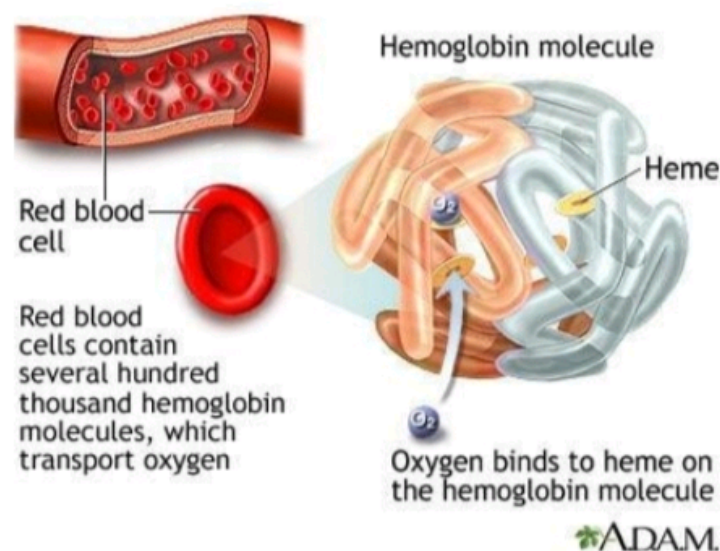
Almost all the living organisms require oxygen ( $O_2$ ) to break down various food substances like carbohydrates, fats and proteins to derive energy for performing various functions. During this oxidation of nutrients, a harmful gas carbon dioxide ( $CO_2$ ) is also released. Therefore, an adequate supply of  $O_2$  must be continuously provided to the cells and  $CO_2$  produced by the cells must be eliminated out. This process of exchange of  $O_2$  from the atmosphere with  $CO_2$  produced by the cells is called breathing.

In general, overall respiration involves the following steps:

- 1) Breathing or gaseous exchange by which atmospheric air ( $O_2$ ) is drawn in and  $CO_2$  rich alveolar air is released out.
- 2) Diffusion of gases ( $O_2$  and  $CO_2$ ) across alveolar membrane.
- 3) Transport of gases by the blood.
- 4) Diffusion of  $O_2$  and  $CO_2$  between blood and tissues.
- 5) Cellular respiration that utilizes  $O_2$  for the breakdown of glucose to oxidize it to  $CO_2$  and  $H_2O$ , and produces energy for daily life functioning

## 2. Oxygen Transport through blood:

Oxygen once reached to the lung through breathing, it diffuses across the alveolar membrane and is further transported via blood to the different cells of the body where it is consumed. Approximately 1.5% of the oxygen transported by the blood is dissolved directly in the blood plasma. However, most of the oxygen (~ 98.5) is transported from the lungs to the tissues by binding with a protein called haemoglobin (Hb).



Haemoglobin is a globular protein molecule and its primary function is to transport oxygen from lung to tissues and to carry  $CO_2$  from tissues to the lung. Haemoglobin is found in red blood cells (RBC) and is made up of four protein chains (globin): two  $\alpha$ -subunits (141 amino acids) and two

$\beta$ -subunits (146 amino acids). Each polypeptide chain is attached to a prosthetic group “heme”, which is an iron ( $\text{Fe}^{2+}$ )-porphyrin compound that binds to the one oxygen molecule. Therefore, each haemoglobin molecule can carry maximum four oxygen molecules.

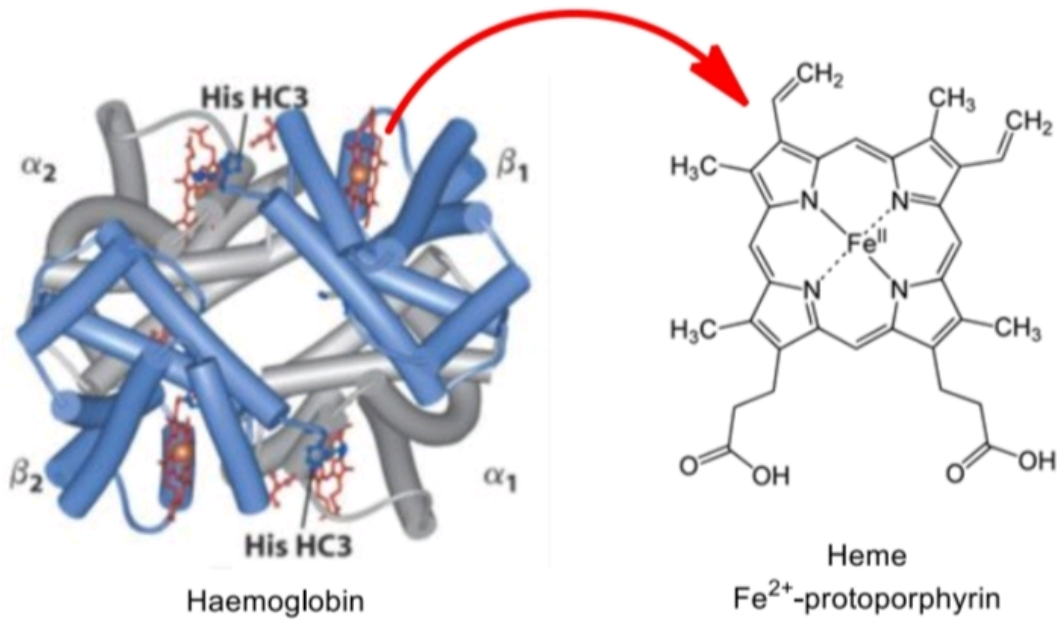


Fig. Structure of Haemoglobin

The binding of oxygen and its dissociation from Haemoglobin is principally governed by the partial pressure of oxygen. Pressure contributed by an individual gas in a mixture of gases is called partial pressure and is represented as  $PO_2$  for oxygen and  $PCO_2$  for carbon dioxide. The higher the  $PO_2$  greater is the binding.

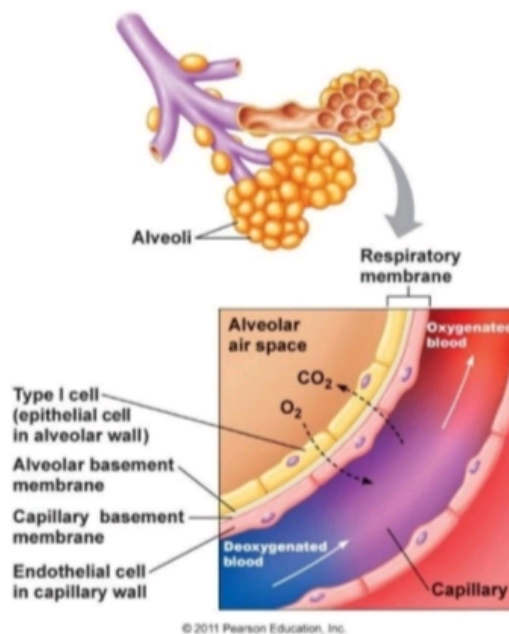
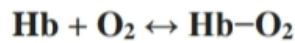


Fig. Gaseous exchange in lung

The oxygen rich air when reaches the alveoli, it has  $PO_2 \sim 100$  mm Hg and that of  $PCO_2$  is 40 mm Hg. Therefore, oxygen moves down the pressure gradient and diffuses across the membrane from the alveoli to the blood capillary. Inside capillaries, it enters the red blood cells and binds with haemoglobin to form oxyhaemoglobin ( $Hb-O_2$ ). Oxyhaemoglobin is a bright red-colored molecule that gives oxygenated blood a bright red color. Oxygen binds reversibly to the haemoglobin, as a result; it can readily dissociate from the heme to give deoxygenated haemoglobin, which is dark red in color.



The tissues have a lower partial pressure of oxygen ( $PCO_2 \sim 40$  mm Hg) because of oxygen utilization and a higher carbon dioxide concentration because of carbon dioxide production. Oxygenated blood when reaches to the tissues, oxygen dissociates from Hb to diffuse out to the tissues, whereas  $CO_2$  gas binds to Hb.

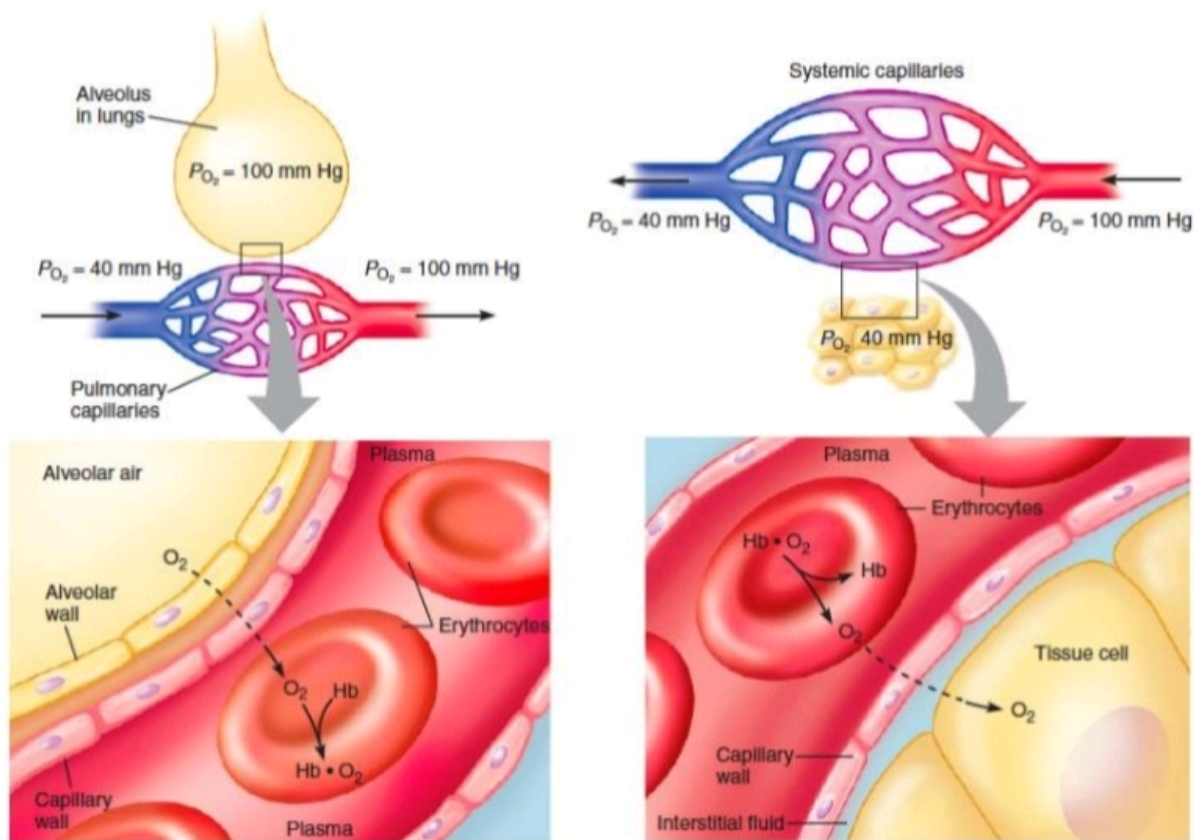


Fig. Transport of oxygen by binding with haemoglobin

## 2.1 The mechanism of oxygen binding to Haemoglobin:

Haemoglobin binds with oxygen in a cooperative manner to form oxyhaemoglobin i.e. binding of one molecule of oxygen to one heme increases the oxygen binding affinity within the remaining heme groups of Hb. When one molecule of oxygen binds to heme group, the shape of globin chain is altered, leading to overall change in the quaternary structure of Hb. This structural

transition of Hb protein, further facilitates the binding of successive oxygen molecules until all four heme groups are occupied. Cooperative behaviour is also observed in dissociation: as the first oxygen molecule dissociates and is released at the tissues, the next oxygen molecule dissociates more readily. When all four heme sites are occupied, the haemoglobin is said to be saturated.

In fully deoxygenated haemoglobin, the molecule's quaternary structure is described as the 'T' or 'tense' form in which the crevices are small, making it difficult for oxygen to gain access to the heme. As each successive oxygen binds to the molecule, the structural changes described above result in the molecule relaxing, enlarging the crevice on adjacent globin chains and increasing their oxygen affinity. When fully oxygenated with four oxygen molecules, the haemoglobin achieves its 'R' or 'relaxed' quaternary structure.

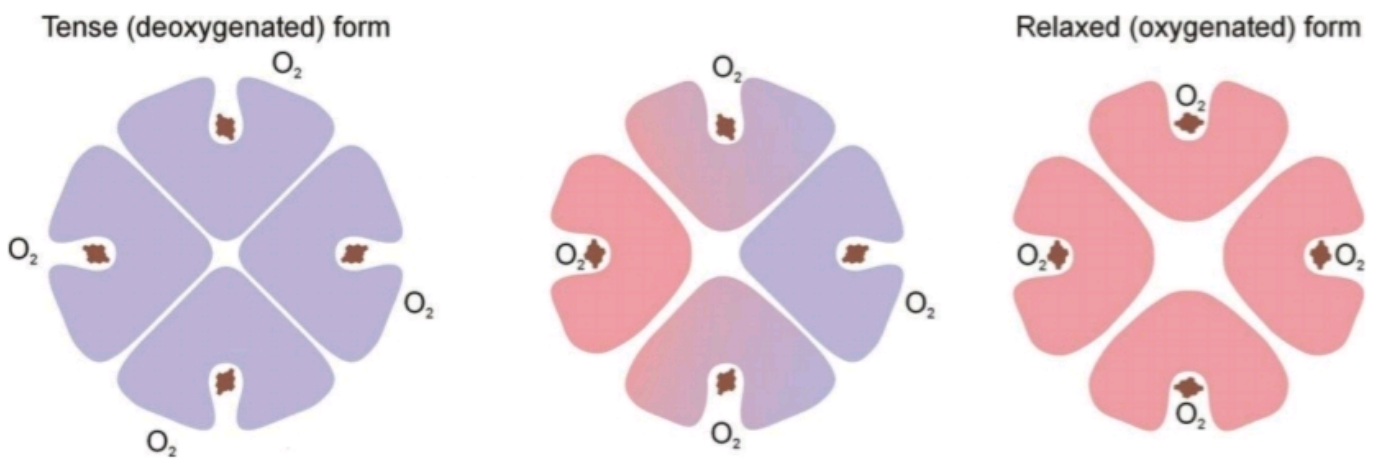
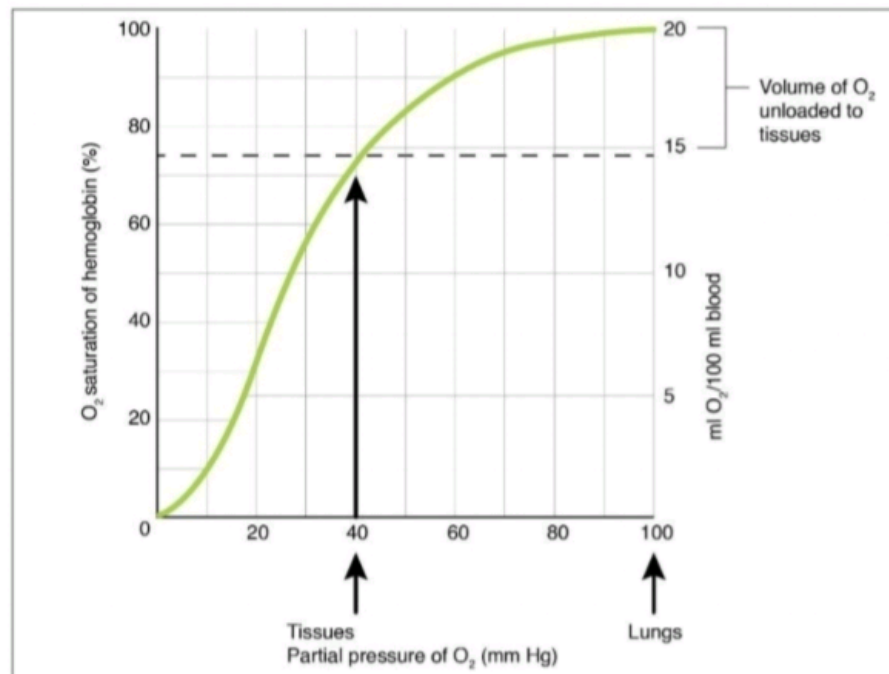


Fig. Cooperative binding of oxygen to haemoglobin

## **2.2 Oxygen-haemoglobin Dissociation curve:**

An oxygen–haemoglobin dissociation curve is a graph that describes the relationship of partial pressure to the binding of oxygen to heme and its subsequent dissociation from heme. This graph of percent saturation of haemoglobin as a function of  $PO_2$  is sigmoid-shaped, which is due to cooperative binding of oxygen to the haemoglobin. At very low partial pressure when most of the haemoglobin is in deoxyhaemoglobin state (tense form), the affinity for oxygen is the lowest. This results in a small increase in percent saturation. With increasing  $PO_2$  most of the haemoglobin acquires at least one oxygen molecule. This causes haemoglobin to undergo conformational changes such that, each subsequent oxygen molecule binds to haemoglobin more easily. Hence, cooperativity leads to steep rise in curve gradient ( $PO_2$  from ~15 to 70 mm Hg). With further increase in  $PO_2$  (Above 70 mm Hg),  $O_2$  binds to haemoglobin and only fewer binding sites become available so the curve starts to levels off again. 100 percent  $O_2$  saturation of haemoglobin means that every heme unit in all RBCs of body is bound to oxygen. In a healthy

individual, at 100 mm Hg the haemoglobin saturation generally ranges from 95 percent to 98 percent.



(a) Partial pressure of oxygen and hemoglobin saturation

Fig. Oxygen-haemoglobin Dissociation curve

Image credit: <https://opentextbc.ca/anatomyandphysiology/chapter/22-5-transport-of-gases/>

### 3. Myoglobin:

Like haemoglobin, myoglobin is also a globular protein which is composed of single  $\alpha$ -helical protein chain that is attached to a prosthetic group heme moiety. Due to presence of only one binding site (heme group), myoglobin can carry just one oxygen molecule. Heme consists of a protoporphyrin ring co-ordinated to central iron ion in  $Fe^{2+}$  state.

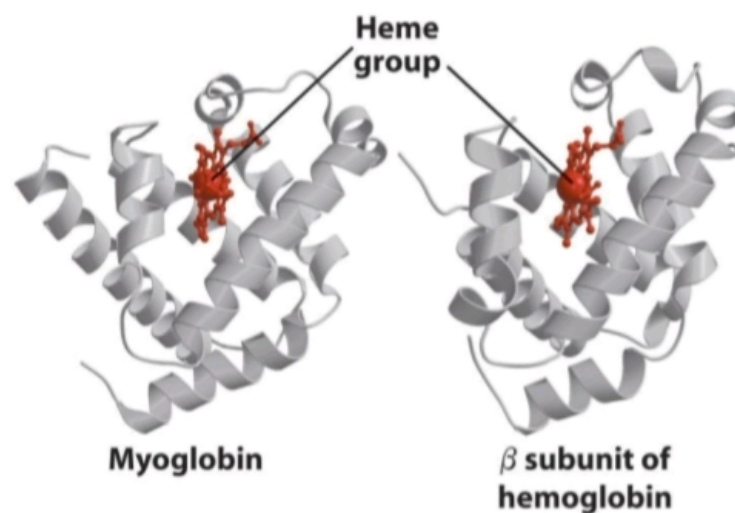


Fig. Structure of myoglobin

Myoglobin is the oxygen storage protein of the muscle, which serves as a reserve supply of oxygen for muscle functioning. Myoglobin grabs oxygen from haemoglobin in tissues, where oxygen  $PO_2$  is low and releases it in the muscle cells. In comparison to haemoglobin, myoglobin absorbs or releases an oxygen molecule at a much lower partial pressure. The muscles of aquatic mammals, such as whales and dolphins, are particularly rich in myoglobin, which allows them to be submerged for long periods of time.

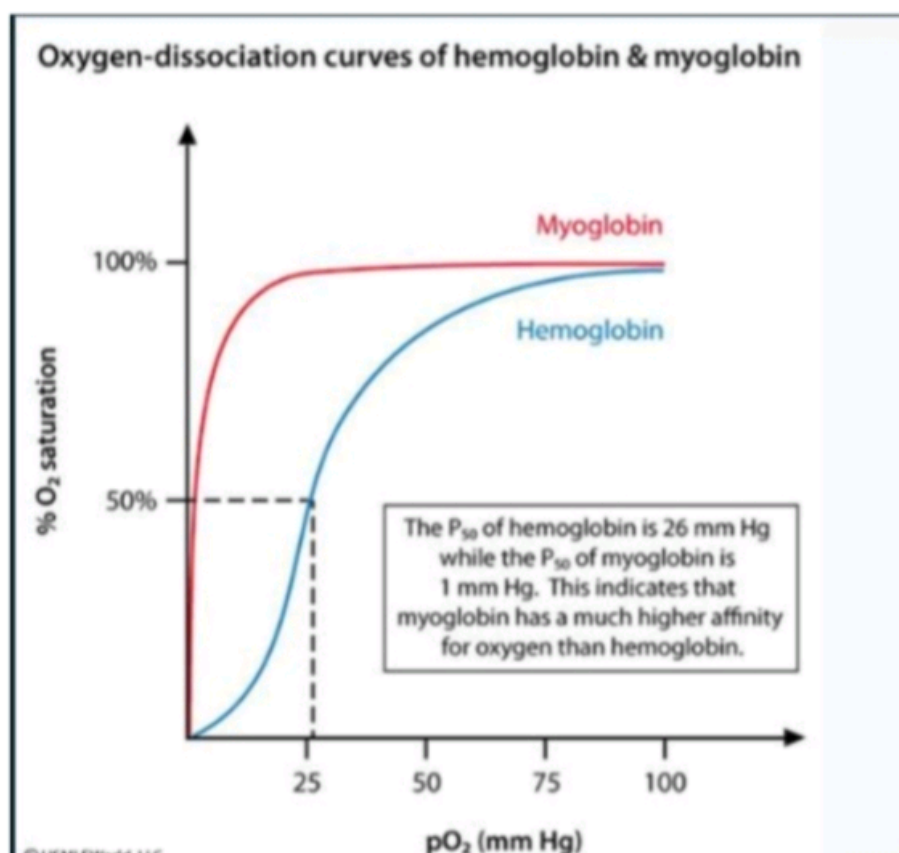


Fig. Oxygen Dissociation curve for haemoglobin and myoglobin

In contrast to haemoglobin, the oxygen-dissociation curve for myoglobin is hyperbolic that rises sharply then levels off as it reaches the maximum saturation. The half-saturation, the point at which half of the myoglobin is bound to oxygen, is 1 mm Hg for myoglobin whereas it is ~26 mm Hg for haemoglobin. This shows that myoglobin has a strong affinity for oxygen. Therefore, it can accept oxygen from haemoglobin at the tissues where  $PO_2$  is 40 mm Hg. The hyperbolic curve also reflects that since myoglobin's oxygen binding affinity is quite high it will release an oxygen molecule only when  $PO_2$  falls below 5 mm Hg. Thus, myoglobin delivers oxygen to muscles only during emergency situation when oxygen level depletes completely.

Overall, myoglobin is less efficient oxygen carrier than haemoglobin, because Hb loses its affinity for oxygen as the pressure goes down and releases the oxygen into the tissues, while myoglobin's strong affinity for oxygen keeps the oxygen bound to it instead of releasing it into the tissues.





**4.2.2 Lactic acid Fermentation:** This occurs in muscle cells, when due to rigorous exercising body cannot supply enough oxygen to the muscles. Under anaerobic conditions muscle can continue to produce ATP by partial oxidation of glucose. Lactic acid is produced in muscle that causes the burning sensation, pain and fatigue.

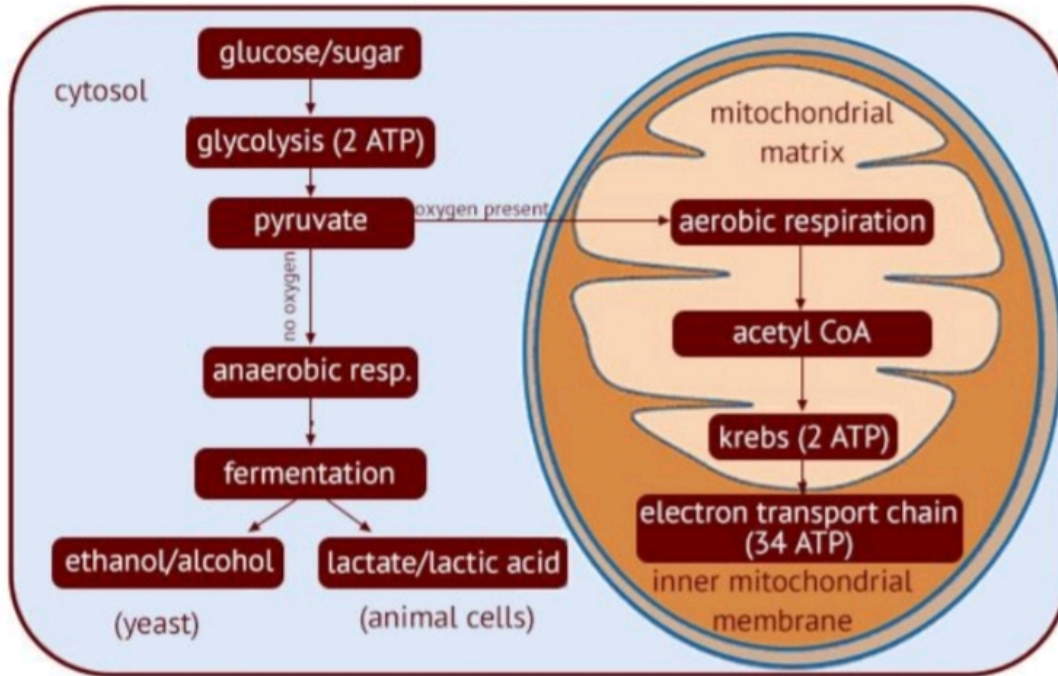
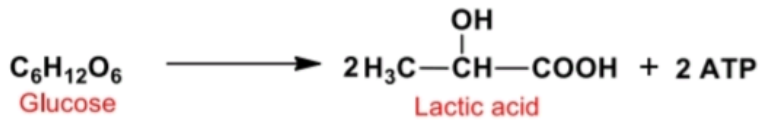


Fig. Schematic representation of Cellular Respiration

Image credit: <https://www.philpoteducation.com/mod/book/view.php?id=782&chapterid=1130#/>

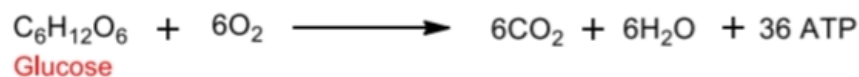
## 5. Respiratory Quotient:

Respiratory quotient, also known as the respiratory ratio (R.Q.), is defined as the volume of carbon dioxide released over the volume of oxygen absorbed during respiration. The volume of carbon dioxide released, and the volume of oxygen consumed by the cell during respiration depends upon the kind of respiratory substrate utilized. Therefore, RQ is a measure of efficiency of combustion of food substrate in the process of respiration to release energy.

$$\text{R.Q.} = \frac{\text{Volume of CO}_2 \text{ released}}{\text{Volume of O}_2 \text{ absorbed}}$$

It is calculated for a particular substrate i.e., carbohydrates, organic acid, fat, and protein. Carbohydrates are oxidized through aerobic respiration resulting in an equal ratio of CO<sub>2</sub> release and O<sub>2</sub> consumption. Therefore, for carbohydrates RQ is always 1. Subsequently, the R.Q. for fat and protein is 0.7 and 0.8, respectively. In anaerobic respiration, since oxygen is not involved, hence R.Q. is infinity.

### For Carbohydrate:



$$\text{R.Q.} = \frac{\text{Volume of CO}_2 \text{ released}}{\text{Volume of O}_2 \text{ absorbed}} = \frac{6 \text{ CO}_2}{6 \text{ O}_2} = 1$$

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### For Fat:



$$\text{R.Q.} = \frac{102 \text{ CO}_2}{145 \text{ O}_2} = 0.7$$

The cells of the body consume an average 250 ml of oxygen per minute and produce about 200 ml of carbon dioxide per minute. Hence, the average human respiratory quotient is 0.8.