## BREATHING AND EXCHANGE OF GASES

All biological activities require energy which is released by the breakdown of food. So all organisms consume high energy organic molecules in the form of food.

The breakdown of food by the use of oxygen is called oxidation. Cells utilize Oxygen for catabolism and produce energy along with oxygen.

The process of exchange between oxygen from the atmosphere and carbon dioxide produced by the cells is called breathing.

The method by which oxidation of food material occur in the living cells of an organism is called respiration and the term respiration was coined by Dutrochet. During oxidation, stored chemical energy in food is released and is temporarily stored in ATP. The first step in respiration is breathing. The food substance which is involved in respiration is called respiratory substrate. E.g.: Glucose, Amino acids, Fatty acids etc.

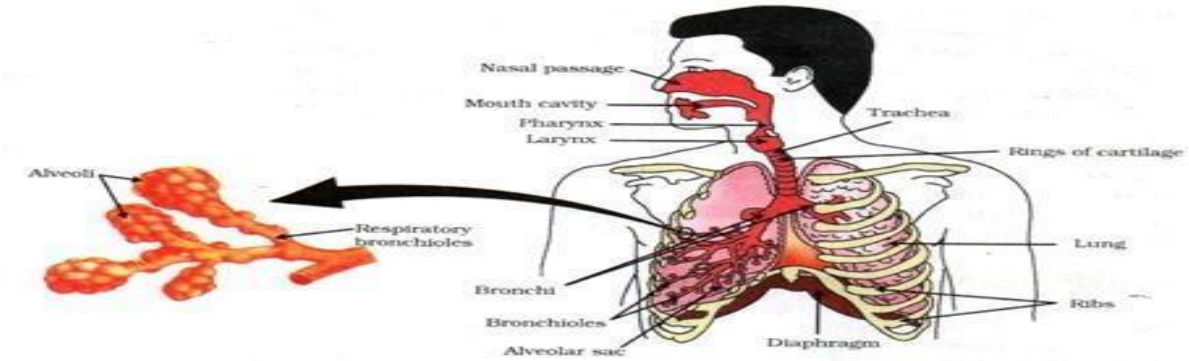
17. 1 **Respiratory Organs:** According to the body structure and habitat, breathing mechanism varies.

| Respiratory Organs | Organisms |
|---|---|
| Moist skin, Lungs | Amphibians |
| Entire Body surface | Sponges, coelenterate, flatworms. |
| Skin | Earthworm. |
| Tracheal system | Insects |
| Gills | Pisces, aquatic arthropods, molluscs |
| Lungs | Mammals. |

**17.1.1 Human respiratory system:** It consists of the external nostrils, nasal cavities, larynx, trachea, bronchi, and bronchioles.

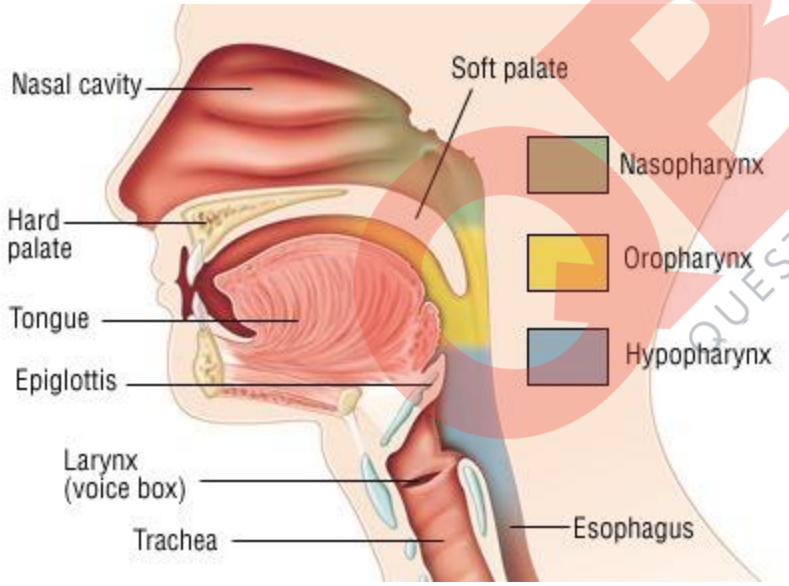
Respiratory system starts with a pair of external nostrils which leads to a nasal chamber through the nasal passage.

The nasal cavities are lined by mucous membrane which secretes mucous. It keeps the nasal cavity moist and traps dust and other foreign particles in the inhaled air. Hairs are also present in the nasal cavity which filters out the dust from the air. The nasal cavities open into the posterior part of the pharynx.




Pharynx is the common passage for respiratory system and digestive system. The part of the pharynx behind the buccal cavity for the passage of food is called oropharynx and the part for air passage is called nasopharynx. The part of the pharynx behind the larynx is called laryngeopharynx. On the floor of the nasopharynx there is a slit like opening called glottis which is guarded by a cartilaginous flap of skin called epiglottis. The epiglottis prevents the entry of food into the trachea while swallowing. Glottis leads to a thin walled tube called trachea or wind pipe which runs through the neck in front of the oesophagus.

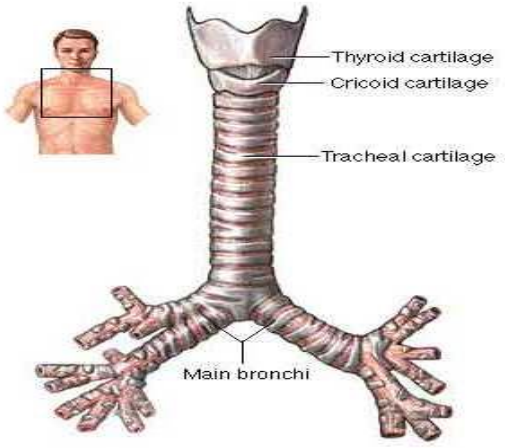
The upper part of the trachea is enlarged to form the larynx or sound box. The wall of the larynx is supported by rings of cartilage such as thyroid cartilage and cricoids cartilage. The thyroid cartilage is the largest and projects externally at the neck region and called as Adam's apple in man. The two folds of mucous membrane stretching across the lumen of the larynx called vocal cords vibrate to produce the sound.



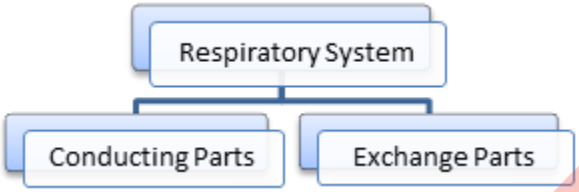

The trachea is protected by C shaped cartilaginous rings which prevent the collapsing of the walls of the trachea when there is less air in it.

Trachea divides in to bronchi and each bronchus enters into each lungs. The bronchi divide to form the bronchiole. Each bronchiole is further divided into a number of small ducts called alveolar ducts. Each alveolar ducts swells up into a thin walled air sacs called alveolus. Groups of alveoli are called infundibulum. Thus each infundibulum looks like a bunch of grapes.

The bronchi, bronchiole and the alveolus comprise the lungs. There are two lungs covered by double layered pleura. Between the pleural membranes is filled with a pleural fluid which reduces friction on the lung- surface.




Outer pleural membrane is in contact with the thoracic lining and the inner pleural membrane with the lung surface.




**Conducting part** –The function of the conducting part is the transport of the atmospheric air to the alveoli. It also prevents the entry of foreign particles, humidifies and brings the air to body temperature.

**Exchange part** - The site of diffusion of $O_2$ and $CO_2$ between blood and atmospheric air.

Lungs are located in the thoracic chamber which is limited dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs and on the lower side by the dome-shaped diaphragm.

Any change in the volume of the thoracic cavity will be reflected in the lung cavity which is essential for breathing.

**The steps involved in respiration are**

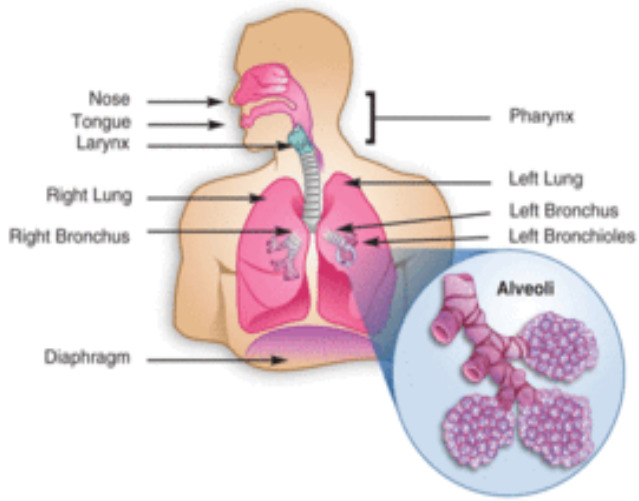
Breathing or pulmonary ventilation (where air is drawn in and $CO_2$ rich alveolar air is released out).

Diffusion of gases ($O_2$ and $CO_2$) across alveolar membrane.

Transport of gases by the blood.

Diffusion of $O_2$ and $CO_2$ between blood and tissues.

Oxygen is utilized by the cells for catabolic reactions and resultant release of $CO_2$ (cellular respiration).




**17.2 Mechanism of breathing:** The inflow and outflow of air between atmosphere and the alveoli of the lungs is called breathing which is affected by the expansion and contraction of lungs.

The lungs are contracted by two processes

- Inspiration
- Expiration.

Both the process is carried out by creating a pressure gradient between lungs and the atmosphere.

**Inspiration:** Includes muscle contraction, and is an active process consuming mechanical energy. It takes place when the pressure within the lungs becomes less than the atmospheric pressure. Lungs are located in the thorax. During inspiration the diaphragm (the muscular partition wall which separates thorax from abdomen) and some of the intercostals muscles (rib muscles between the ribs) contract. This results in pulling of the ribs upwards and outwards which increase the volume of the thoracic chamber. As a result the sternum causes increase in the volume of the thoracic chamber in the dorsoventral axis. If there is an overall increase in the thoracic volume causes an increase in pulmonary volume. An increase in pulmonary volume decreases the intrapulmonary pressure. So fresh air enters through nose and reaches the lungs.

**Expiration:** when the diaphragm and the inter-costal muscles occurs relax, the diaphragm and sternum come back to their normal positions. It reduces the thoracic volume and the pulmonary volume which leads to an increase in intra-pulmonary pressure. It is slightly greater than the atmospheric pressure causing the expulsion of air from the lungs -expiration.

With the help of additional muscles in the abdomen we can increase the strength of inspiration and expiration.

A healthy human breathes **12-16 times/minute** normally with about **10 litres per minute**.

The apparatus used to measure the rate of breathing is **spirometer** or **respirometer**.

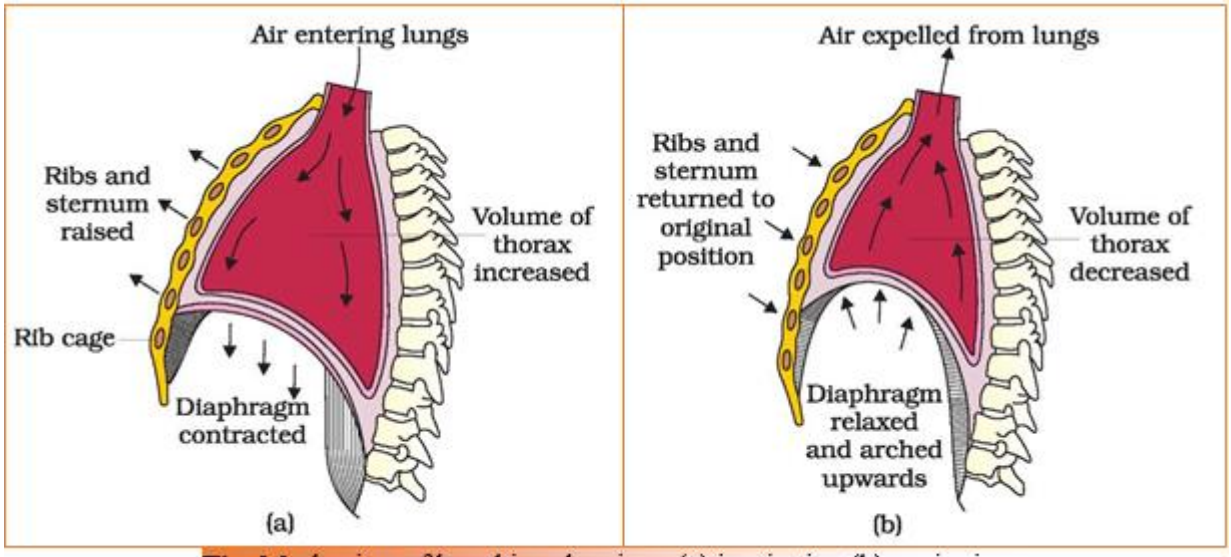



**Fig:** Mechanism of breathing showing : (a) inspiration (b) expiration

### 17.2.1 Respiratory volumes and capacities:

The air that passes into and out of the lungs with each respiration is called **tidal air**.

1. **Tidal volume**: The volume of air inspired or expired during a normal respiration is called tidal volume. In adult man tidal volume is about 500mL. A healthy man can inspire or expire approximately 6000 to 8000 mL of air per minute.
2. **Inspiratory reserve volume**: It is the additional volume of air that can be inspired beyond the normal tidal volume by a forcible inspiration. IRV of normal man is about 2000mL-3000 mL.
3. **Expiratory reserve volume**: It is the additional volume of air that can be expired beyond the normal tidal volume by a forcible expiration. ERV of normal man is about 1100mL off air.
4. **Residual volume**: The volume of air that remains inside the lungs after a forcible expiration is called residual volume. The RV of normal man is about 1100- 1200mL.The residual volume is always present in lungs. So the gaseous exchange continues in the lungs even after a forcible expiration.
5. **Pulmonary capacity**: When any two or more pulmonary volumes considered together, such a capacity is called pulmonary capacity.

The important pulmonary capacities are

**Inspiratory capacity**: The total volume of air a person can take in after a normal expiration is called inspiratory capacity. In it inspiratory reserve volume and tidal volume are included.

IC= TV + IRV

3500 + 500mL=3500mL

**Expiratory capacity**: It is the amount of air a person can expire after a normal inspiration.

EC= TV + ERV.

**Functional Residual Capacity**: The amount of air which remains inside the lungs after normal expiration. It includes expiratory reserve volume and residual volume.

FRC + ERV + RV

2500mL + 1000mL + 1500 mL

**Vital capacity**: It is the amount of air that can be expired with forceful efforts after a deepest inspiration. It includes inspiratory reserve volume, expiratory reserve volume and tidal volume.

VC = IRV + ERV + TV

4500mL= 3000mL + 500mL + 1000mL

**Total Lung Capacity**: The maximum amount of air lungs can hold is the total lung capacity. It includes inspiratory reserve volume, tidal volume, expiratory reserve volume and residual volume.

TLC + IRV + TV + ERV + RV

Or TLC = VC + RV

**17.3 Exchange of Gases:** The primary sites of exchange of gases takes place in the alveoli. The exchange of gases is between blood and tissues. Exchange of gases occurs by simple diffusion based on pressure gradient or concentration gradient. The important factors affecting diffusion are solubility of gases and the thickness of the membrane. Partial pressure is the pressure by an individual gas in a mixture of gases .It is represented as $pO_2$ for oxygen and $pCO_2$ for carbon dioxide.

TABLE 17.1 Partial Pressures (in mm Hg) of Oxygen and Carbon dioxide at Different Parts Involved in Diffusion in Comparison to those in Atmosphere

| Respiratory Gas | Atmospheric Air | Alveoli | Blood (Deoxygenated) | Blood (Oxygenated) | Tissues |
|---|---|---|---|---|---|
| $O_2$ | 159 | 104 | 40 | 95 | 40 |
| $CO_2$ | 0.3 | 40 | 45 | 40 | 45 |

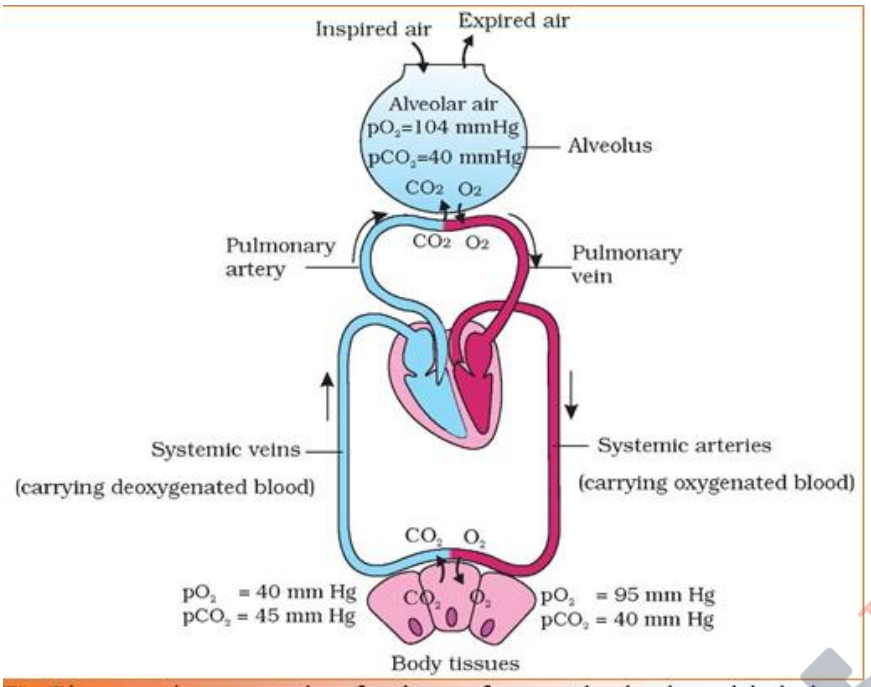



**Fig:** Diagrammatic representation of exchange of gases at the alveolus and the body tissues with blood and transport of oxygen and carbon dioxide

The amount of $CO_2$ which can diffuse through the diffusion membrane is higher than the partial pressure of O2. The diffusion membrane is made up of squamous epithelium of alveoli, the alveolar capillaries endothelium and the basement substance in between them and its total thickness is less than a millimetre. All the various factors of our body favour the diffusion of $O_2$from alveoli to tissues and that of $CO_2$ from tissues to alveoli.

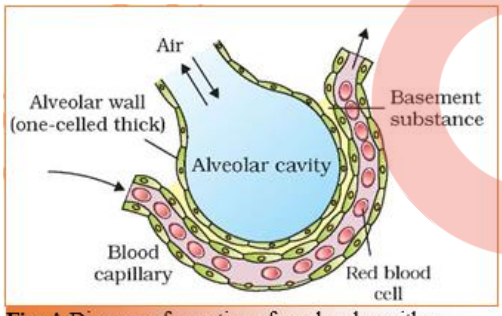



**Fig:** A Diagram of a section of an alveolus with a pulmonary capillary

**17.4 Transport of Gases:** It is through the blood the transport for $O_2$ and $CO_2$ takes place and 97 % of O2 is transported by the RBCs and remaining 3% through the plasma. 20-25 % of $CO_2$ is transported through RBCs and 70 % is carried as bicarbonate. 7 % of $CO_2$ is carried out through plasma.

**17.4.1 Transport of oxygen:** The red coloured iron containing pigment in RBC is haemoglobin and they bond with oxygen to form oxyhaemoglobin and this binding is related to partial pressure of oxygen. Four molecules of oxygen can be carried by a single haemoglobin. Binding is affected by the partial pressure of $CO_2$, hydrogen ion concentration and temperature

When the relationship of haemoglobin with oxygen is expressed by the plotting of oxygen saturation of blood against the pO2 of oxygen, an S shaped curve or sigmoid curve is obtained and is called oxygen dissociation curve or oxygen haemoglobin dissociation curve.

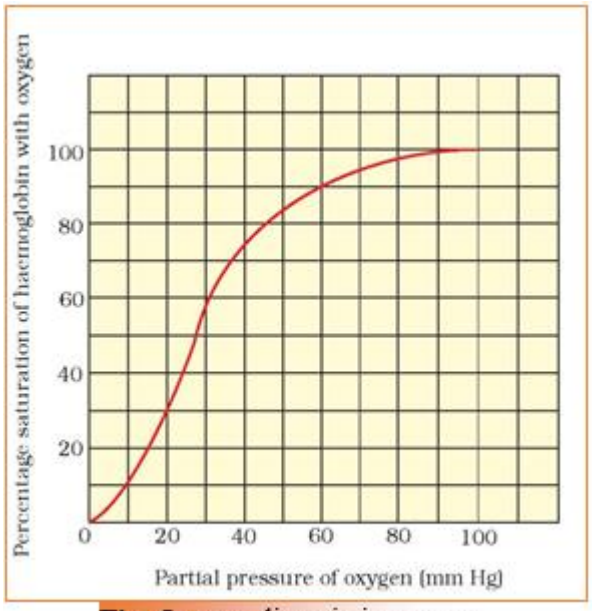



**Fig:** Oxygen dissociation curve

When there is high $pO_2$, low $pCO_2$, lesser $H^+$ concentration and lower temperature, in the alveoli, oxyhaemoglobin is formed. In the tissues, low $pO_2$, high $pCO_2$, high $H^+$ concentration and higher temperature happens, dissociation of oxygen takes place from oxyhaemoglobin. So oxygen binds to haemoglobin on the lung surface and is dissociated in the tissues. Under normal physiological conditions 100 mL of oxygenated blood gives about 5mL of oxygen under normal conditions.

**17.4.2 Transport of Carbon dioxide:** $CO_2$ combines with haemoglobin to form carbamino-haemoglobin and is related to the partial pressure of $CO_2$. Partial pressure of $O_2$ affects the binding up of carbon dioxide with haemoglobin. More binding happens if partial pressure of $CO_2$ is high and partial pressure of $O_2$ is low as in the tissues more carbon dioxide binding occurs. When the $pCO_2$ is low and $pO_2$ is high as in the alveoli, dissociation of $CO_2$ takes place to from carbamino-haemoglobin.

RBCs have high concentration of carbonic anhydrase enzyme .Only very less amount of this enzyme is present in the plasma.

$$CO_2 \xrightleftharpoons{\text{Carbonic anhydrase}} H_2CO_3 \xrightleftharpoons{\text{Carbonic anhydrase}} HCO_3^- + H^+$$

In the tissue the partial pressure of $CO_2$ is high because of catabolism, $CO_2$ diffuses into blood to form $HCO_3$ and H+.

In the alveolus partial pressure of $CO_2$ is low, $CO_2$ and $H_2$ are formed. The carbon dioxide is trapped as bicarbonate. It is transported from the tissue to the alveoli and carbon dioxide is released out. For every 100 ml of deoxygenated blood, 4 mL of carbon dioxide are delivered approximately.

**17.5 Regulation of respiration:** The process of respiration or respiratory rhythm is controlled by the nervous system. The rate of respiration is changed as per Oxygen demand of the body. The regulatory centre for respiration is known as the respiratory centre. It consists of a number of neurons located bilaterally in the medulla oblongata of the brain. There are three groups of respiratory centres- respiratory rhythm centre, pneumotaxic centre and chemosensitive area.

**Respiratory rhythm centre**: It is the group of neurons located in the dorsal portion of medulla oblongata. It is a specialized centre which is responsible for the regulation of respiration. This group of neurons produces the basic respiratory rhythm. The nervous signals released from the neurons of respiratory rhythm centre are transmitted to the diaphragm which is the primary inspiratory muscle. These signals cause the inspiratory muscle or diaphragm to contract and bring about inspiration.

**Pneumotaxic centre**: It is a group of neurons located dorsally in the upper pons of the brain. It can moderate the functions of the respiratory rhythm centre.

The signal from the neurons of pneumotaxic centre determines the number and depth of breaths. A strong signal from the pneumotaxic centre causes increased rate of breathing due to the shortening of both inspiration and expiration. The neural signals from pneumotaxic centre can also reduce the duration of inspiration and thereby alter the respiration rate.

**Chemo sensitive centre**: This is an area situated adjacent to the respiratory rhythm centre which is highly sensitive to CO2 and hydrogen ions. The concentration of hydrogen ions and CO2 cause an increase in the inspiratory signal and expiratory signal. Oxygen has no direct effect on respiratory signals. The increased concentration of CO2 and Hydrogen ions in the chemo sensitive area activates this centre and chemo sensitive area transmit signals to the respiratory rhythm centre and make adjustments in the respiratory process by which these substances can be eliminated.

Receptors associated with aortic arch and carotid artery recognize the changes in the concentration of CO2 and hydrogen ions .They send necessary signals to the respiratory rhythm centre for immediate control actions.

**17.6 Disorders of the respiratory system**: Respiratory systems of humans is affected by many respiratory diseases and are called respiratory disorders.

Common disorders are asthma, emphysema, and occupational respiratory disorders.

**Asthma**: The difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles is called asthma.

**Emphysema**: It is a chronic obstructive disease of lungs. It is an inflation or abnormal distension of the alveolar wall resulting in the loss of elasticity of their walls. The alveolar walls degenerate and alveoli combine to form large alveoli. The alveoli remain fully filled with air even during expiration. This will lead to increase in lung size and the major cause of emphysema is cigarette smoking.

**Occupational respiratory disorders**: The pulmonary disease caused due to the exposure of potentially harmful substances like gas, fumes, or dusts, present in the working environment of a person are called occupational respiratory disorders. The common examples are silicosis (caused in workers employed in mining industry, quarry etc due to chronic exposure to silica dust from rocks or stones) and asbestosis (in workers employed in asbestos factory due to chronic exposure to asbestos dust).

FAST TRACK REVISION:

Cells use oxygen to produce energy from the nutrient metabolism and also produce waste products which are harmful in nature to the cells.

Animals have several methods for the exchange of gases between the air and body tissues through blood.

There is a respiratory system which exchange gases for the body through several processes occurring in sequential order.

The start of this process is through breathing in which the atmospheric air is taken in and alveolar air is thrown out.

The exchange of oxygen and carbon dioxide between deoxygenated blood and alveoli, transport of all the nutrients along with gases are the events that occur.

Inspiration and expiration are the two mechanism of respiration. It is carried out by creating pressure gradients between the atmosphere and alveoli. Volumes of air that are involved during respiration can be estimated with the help of spirometer and have clinical significance.

The diffusion of gases is dependent on the partial pressure of oxygen and carbon dioxide, their solubility as well as thickness of the diffusion surface.

All these factors work together to diffuse the oxygen from the alveoli to the deoxygenated tissues and Carbon dioxide from the deoxygenated tissues to the blood.

Oxygen forms oxyhaemoglobin when comes in contact with the haemoglobin.

Respiratory rhythm is regulated from the medulla oblongata which is the respiratory centre in the brain.