BREATHING AND EXCHANGE OF GASES

- **Breathing or pulmonary ventilation** occurs in two stages namely, inspiration and expiration.
- During **inspiration** (active process), air enters the lungs from atmosphere and during **expiration** (passive process), air leaves the lungs.
- The term 'breathing' and 'respiration' are not synonymous. Breathing, is the first step of respiration which refers to the movement of air inside and outside of the respiratory organs. **Respiration** is a biochemical process by which organic compounds are oxidised to liberate chemical energy from the food in a step-wise process. The energy released is stored as **ATP molecules.**

RESPIRATORY ORGANS IN ANIMALS

- The mechanism of breathing vary among different groups of animals depending mainly on their habitats and levels of organisation.

Table : Respiratory structures for the exchange of gases in different groups of animals.

	Animal group	Respiratory structure
1.	**Protozoans** (*e.g.*, *Amoeba*, *Paramecium*)	Plasma membrane
2.	**Sponges** (*e.g.*, *Sycon*)	Cell's plasma membrane
3.	**Cnidarians** (*e.g.*, *Hydra*)	Body surface
4.	**Platyhelminthes** (i) Free living (*e.g.*, *Planaria*) (ii) Parasites (*e.g.*, Tapeworm)	 Body surface No exchange of gases (Anaerobic respiration)
5.	**Nemathelminthes** (i) Free living (*e.g.*, *Rhabditis*) (ii) Parasites (*e.g.*, *Ascaris*)	 Body surface No exchange of gases (Anaerobic respiration)
6.	**Annelids** (*e.g.*, Earthworm)	Skin (Cutaneous respiration)
7.	**Arthropods** (i) Prawn, crayfish (ii) Insects, centipedes, millipedes, ticks (iii) Scorpions, spiders (iv) King crab (*Limulus*)	 Gills (Branchial respiration) Tracheae (Tracheal respiration) Book lungs Book gills
8.	**Molluscs**	Ctenidia (gills) and pulmonary sac.
9.	**Echinoderms** (*e.g.*, Starfish)	Dermal branchae, tube feet
10.	**Hemichordates** (*e.g.*, *Balanoglossus*)	Pharyngeal wall
11.	**Chordates** (i) Urochordata (*e.g.*, *Herdmania*) (ii) Cephalochordata (*e.g.*, *Branchiostoma*) (iii) Vertebrata (a) Cyclostomes, fishes (b) Amphibians (c) Reptiles, birds, mammals	 Pharyngeal wall Pharyngeal wall Gills Skin, buccopharyngeal lining, lungs Lungs

HUMAN RESPIRATORY SYSTEM

- Respiratory system of man is located in the thoracic cavity. It consists of lungs and number of small tubes.
- The human respiratory system may be divided into two major components : **respiratory tract** or conducting portion and **respiratory organs.**

Respiratory tract

- Respiratory tract serves as a passageway for the respiratory gases. Gas exchange does not occur here.
- The respiratory tract consists of nostrils, nasal cavity, pharynx, larynx, trachea, bronchi and alveoli.
- **Nostrils (external nares)** are holes of the nose. These are paired openings that open into two nasal cavities. Nasal cavity has special **pseudostratified ciliated epithelium** by which air is filtered (by hair), moistened (by mucus) and warmed (by capillary network) before it enters the lung. **Internal nares** are the posterior openings of the nasal cavities that lead into the nasopharynx.
- **Nasopharynx** is the posterior part of the pharynx. Air has to pass through nasopharynx to enter larynx. **Larynx** (also called as **sound box**) is the cartilaginous structure at the opening of trachea. Larynx is comprised of nine cartilages. It grows larger and becomes prominent in boys during puberty, therefore, it is called **Adam's apple.**
- Larynx opens into the laryngopharynx by a slit like opening called glottis. Glottis bears a leaf like elastic cartilage, the **epiglottis.** Epiglottis closes the opening of glottis during swallowing.
- **Trachea (wind pipe)** runs through the neck in front of oesophagus and extends into the thoracic cavity. It connects lungs to nasopharynx. It has C-shaped rings of **hyaline cartilage** that prevent the collapse of trachea during inspiration. It is lined with ciliated, pseudostratified columnar epithelium that keeps the unwanted particles away from lungs by beating the cilia towards the buccal cavity.
- Trachea divides into a right and left primary **bronchi.** Each bronchus undergoes repeated divisions to form the secondary and tertiary bronchi and bronchioles ending up in very thin terminal **bronchioles.** The tracheae, primary, secondary and tertiary bronchi, and initial bronchioles are supported by incomplete cartilaginous rings. Each terminal bronchiole gives rise to a number of very thin,

irregular-walled and vascularised bag-like structures called **alveoli**. There are **300 millions** of alveoli in two lungs. Due to very intimate contact of blood capillaries with the alveoli, the exchange of gases takes place easily.

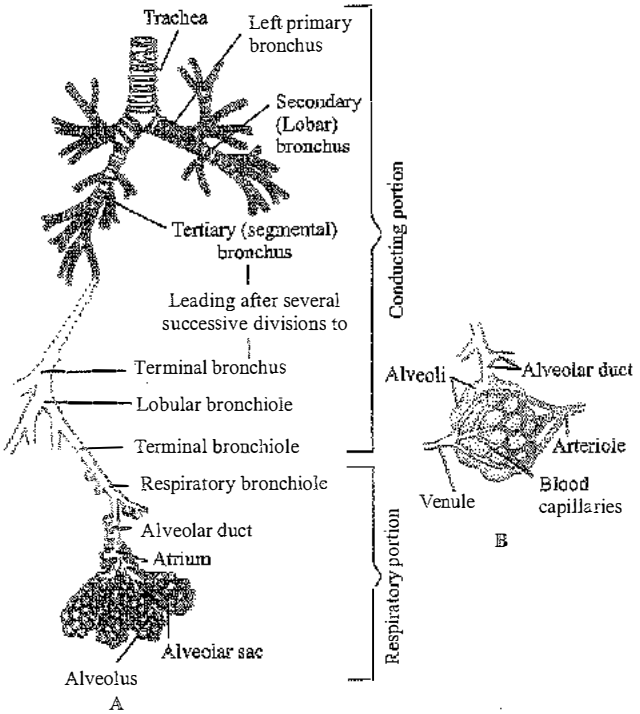


Fig.: A. Branches of trachea, bronchi and their branches.
B. Blood supply in relation to the alveoli

Respiratory organs

- The branching network of bronchi, bronchioles and alveoli comprise the **lungs**. In man, the respiratory organs are a pair of lungs. The lungs lie in the thoracic cavity on the sides of the heart.
- The **left lung** has **two lobes**, separated by oblique fissure. It has **cardiac notch**, a concavity where the heart lies. The **right lung** is bigger and has **three lobes** separated by horizontal fissure and oblique fissure. **Mediastinum** is the partition between the two lungs.
- Each lung is enclosed by two membranes, the **pleurae**. The outer membrane is called **parietal pleura** and the inner membrane is known as **visceral pleura**. A very narrow space exist between the two pleura known as **pleural cavity**.
- The pleural fluid secreted by pleura lubricates it. Lubrication reduces the friction as membranes rub against each other during inspiration and expiration.
- The pleural cavity is air tight and pressure in it remains 3 – 4 mm Hg lower than that in the lungs.
- If the chest wall is ever pierced, say by a stab wound, atmospheric air rushes into the pleural cavity, eliminating the pressure difference across the lung walls. This causes the lungs to collapse. The condition is called **pneumothorax**.

MECHANISM OF RESPIRATION/BREATHING

- Respiration involves the following steps :
  - Breathing or **pulmonary ventilation** by which atmospheric air and 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.
  - Utilisation of O_2 by the cells for catabolic reactions and resultant release of CO_2.
- Each breathing movement has two components : **inspiration** or inhalation and **expiration** or exhalation.
- **Inspiration** is defined as the process of drawing in of fresh air into lungs for gaseous exchange. It is an active process brought about by **diaphragm muscles** and external **intercostal muscles**. **Diaphragm** is a musculotendinous and membranous partition between **abdomen** and **thorax**. Inspiration happens when the **external intercostal muscles contract** and pull the **ribcage upwards and outwards**, away from the spinal column. At the same time the **diaphragm contracts and flattens** pushing down on the abdominal organs. These movements **increase the volume of the thoracic cavity** and therefore **lower the pressure in the thorax**. As the pressure falls below the atmosphere in the thorax, air is forced into the lungs to equalise the pressure.
- **Expiration** is a process of **exhalation** or pushing out of CO_2 emiched foul air from the lungs. It is a passive process, caused by the relaxation of muscles of **diaphragm** and **external intercostal muscles**. With the relaxation of the muscles of diaphragm, the abdominal viscera compressed during inspiration, push the **diaphragm upward**, making it **convex**. **External intercostal muscles also relax**. This brings the ribs and the sternum to their original position and the **thoracic cavity becomes smaller**. The contraction of abdominal muscles presses **the abdominal viscera against the diaphragm**, bulging it further upward. This **shortens the thoracic cavity** vertically. Contraction of internal intercostal muscles moves the **ribs downward and inward**. This reduces the thoracic cavity from front-to-back and also from side-to-side. **The decrease in the volume of thoracic cavity raises the pressure of air in the lungs**. This pressure **pushes out the foul air** from the lungs until the air pressure in the lungs falls to that of the atmosphere.

> Mammals have **negative pressure breathing**, *i.e.* the lungs draw air due to reduction in pressure within them. This allows them to eat and breathe at the same time. If air were to be forced into the lungs, it might carry food particles into the trachea and block it. Negative pressure breathing gently moves air which is less likely to carry food particles into the wind pipe.

Pulmonary volumes and capacities

- The quantities of air the lungs can receive, hold or expel under different conditions are called **pulmonary** (= lung) **volumes**. Combinations of two or more pulmonary volumes are called **pulmonary capacities**. The different types of pulmonary volumes and capacities are discussed under the following table.

Table : Pulmonary volumes and capacities

	Type of pulmonary volume/capacity	Approx. quantity of air (ml)	Characteristic
1.	Tidal volume (TV)	500	It is the volume of air inspired and expired during normal breathing or in each respiratory cycle without any effort. It is contributed by alveolar volume (350 ml) and dead space volume (150 ml).
2.	Alveolar volume	350	The alveolar volume is the air that reaches the respiratory surfaces of alveoli and engages in gas exchange.
3.	Dead space volume	150	Dead space volume or air is that air which does not reach the respiratory surface, it just fills the respiratory passage.
4.	Inspiratory reserve volume (IRV)	2500 -3000	It is an extra amount of air that can be inspired forcibly after a normal inspiration.
5.	Expiratory reserve volume (ERV)	1000-1100	It is an extra amount of air that can be expelled after a normal expiration.
6.	Residual volume (RV)	1100-1200	It is the volume of air that always remain in the lungs even after forcible expiration. It enables the lungs to continue exchange of gases even after maximum exhalation or on holding the breath.
7.	Vital capacity (VC)	4000-4600	It is the total volume of air inspired and expired to a maximum level. It is the sum total of tidal volume, inspiratory reserve volume and expiratory reserve volume. Thus VC = TV + IRV + ERV – The vital capacity is higher in athletes, mountaineers or mountain-dwellers and lower in non-athletes, people living in plains, women, old individuals, cigarette smokers. – Higher the vital capacity, higher is the amount of air exchanged in each breath.
8.	Inspiratory capacity (IC)	3000-3500	It is the total volume of air that can be inhaled after a normal expiration. It includes tidal volume and inspiratory reserve volume (IC = TV + IRV).
9.	Functional residual capacity (FRC)	2100-2300	It is the sum total of residual volume and the expiratory reserve volume (FRC = RV + ERV).
10.	Total lung capacity (TLC)	5100-5800	It is the total amount of air present in the lungs and the respiratory passage after a maximum inspiration. It is the sum total of vital capacity and the residual volume. TLC = VC + RV or TLC = TV + IRV + ERV + RV.
11.	Alveolar ventilation	4200	It is the rate at which the fresh air reaches the alveoli and adjoining areas like alveolar ducts, alveolar sacs and respiratory bronchioles. It is calculated as: Alveolar ventilation per minute = Rate of respiration × (TV – Dead Space volume) = 12 × (500 – 150) = 12 × 350 = 4200 ml/minute

EXCHANGE OF GASES

- **Alveoli are the primary sites of exchange of gases.** Exchange of gases also occur between blood and tissues. O_2 and CO_2 are exchanged in these sites by simple diffusion based mainly on pressure/concentration gradient.

Exchange along the alveolar surface

- The blood that reaches the alveolus (venous blood) has lower pO_2 **(40 mm of Hg)** and higher pCO_2 **(46 mm of Hg)** than the alveolar air **(pO_2 -100 mm of Hg and pCO_2 -40 mm of Hg)**. As a result oxygen diffuses into the blood and carbon dioxide out of the blood into the alveolus.
- By the time blood leaves the alveolus (arterial blood) it has almost the same pO_2 (95 mm of Hg) and pCO_2 (40 mm of Hg) as the alveolar air. The percentage saturation of blood also rises from 75% (venous blood) to 97% (arterial blood).

Exchange of gases in tissues

- In the tissues, exchange of gases occurs between the blood and the tissue cells through tissue fluids that surround the tissue cells. Blood that reaches the tissues has more partial pressure of O_2 (pO_2 = 100 mm Hg), than that in the tissues (pO_2 = 40 mm Hg). Partial pressure of CO_2 is more in tissues (= 46 mm Hg) than in the blood (= 40 mm Hg). Due to these **differences in partial pressure of gases,** O_2 from blood diffuses in the tissues and CO_2 from tissues diffuses into the blood. This exchange of gases occur simultaneously.

- The venous blood goes to the right side of the heart that sends it to lungs *via* pulmonary artery for reoxygenation. The venous blood is 75 % saturated at 40 mm Hg of O_2 and contains 14.4 ml of O_2/100 ml of blood.

TRANSPORT OF GASES

- Blood is the medium of transport for O_2 and CO_2. About 97 per cent of O_2 is transported by RBCs in the blood. The remaining 3 per cent of O_2 is carried in a dissolved state through plasma. Nearly 20-25 per cent of CO_2 is transported by RBCs whereas 70 per cent of it is carried as bicarbonate. About 7 per cent of CO_2 is carried in a dissolved state through plasma.

TRANSPORT OF OXYGEN

- Oxygen is carried by blood in two forms- in solution (plasma) and as oxyhaemoglobin by RBCs.

As oxyhaemoglobin

- RBCs contain a protein called **haemoglobin** which has four polypeptide chains and **four haem groups** attached to it or 4 atoms of **iron in ferrous form** (Fe^{2+}). It can react with **4 molecules** of oxygen to form Hb_4O_8. This is called **oxyhaemoglobin.** This combination process is called **oxygenation.**

$$\underset{\text{Haemoglobin}}{Hb} + O_2 \underset{\text{In tissues}}{\overset{\text{In lungs}}{\rightleftharpoons}} \underset{\text{Oxyhaemoglobin}}{HbO_2}$$

Oxygen-haemoglobin dissociation curve (= Oxygen dissociation curve)

- The percentage of haemoglobin that is bound with O_2 is called **percentage saturation of haemoglobin.**
- The relationship between the partial pressure of oxygen (pO_2) and percentage saturation of the haemoglobin with oxygen (O_2) is graphically illustrated by a curve called **oxygen-haemoglobin dissociation curve** (also called oxygen dissociation curve).

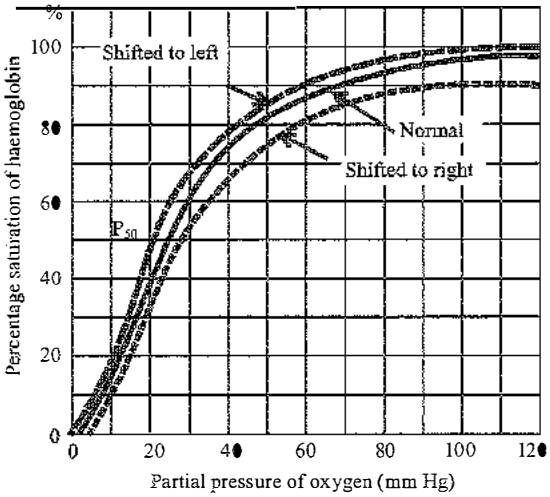


Fig.: Oxygen-haemoglobin dissociation curve

- Under normal conditions, the oxygen haemoglobin dissociation curve is **sigmoid shaped** or **'S' shaped.** The lower part of the curve indicates **dissociation of oxygen** from haemoglobin. The upper part of the curve indicates the **acceptance of oxygen** by haemoglobin.
- When the partial pressure of oxygen is **25 mm Hg** the haemoglobin gets saturated to about **50%.** The partial pressure at which the **haemoglobin saturation is 50%** is called P_{50}. At **40 mm Hg** of partial pressure of oxygen, the saturation is **75%.** It becomes **97%** when the partial pressure of oxygen is **100 mm Hg.**

Haemoglobin does not take up oxygen at low Po_2, but as the oxygenation of pigment occurs its affinity for more O_2 increases. In haemoglobin where 4 sub units are present, acquisition of one molecule of oxygen increases the affinity of neighbouring haems for oxygen. This is known as **co-operativity between active sites.**

Factors affecting oxygen dissociation curve

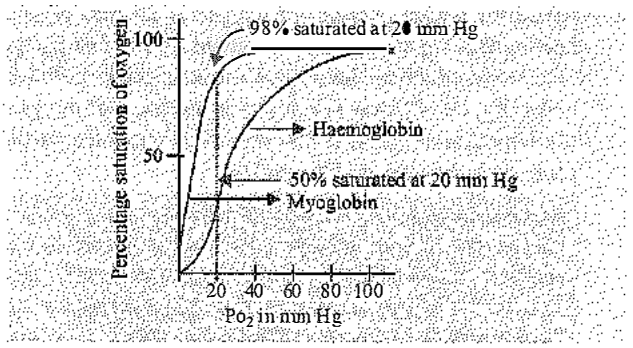
- pO_2 : Decrease in partial pressure of O_2 shifts the curve to right.
- **Temperature :** At higher temperature haemoglobin gives up oxygen more readily and the dissociation curve shifts to the right.
- **pH** : Increase in CO_2 or other acids lowers the pH of plasma and shifts the dissociation curve to the right.
- pCO_2 : CO_2 lowers the oxygen affinity of haemoglobin even if the pH is kept constant. The curve shifts to the right and releases more O_2 with increase in pCO_2
- **2, 3-diphosphoglyceric acid** (2, 3 – DPG) is present in the red cells of adult blood, formed from 3-phosphoglyceric acid. It competes for oxygen binding sites in the haemoglobin molecule.
- The oxygen-haemoglobin dissociation curve is shifted to **left** in the **foetal blood**, because, foetal haemoglobin has more affinity for oxygen than the adult haemoglobin.
- In the **low temperature** and **high pH** the curve shifts to **left.**

Bohr's effect

- Shifting of the oxygen-haemoglobin dissociation curve to the right by increasing partial pressure of carbon dioxide is known as Bohr's effect.
- It is named after the Danish physiologist **Christian Bohr** (1855 - 1911).
- The presence of carbon dioxide decreases the affinity of haemoglobin for oxygen and increases release of oxygen to the tissues.

Oxygen dissociation curve for myoglobin of muscle

The shape of oxygen dissociation curve for myoglobin is hyperbolic because its curve is to the left of the haemoglobin curve. It clearly shows that it has great affinity for oxygen and binding of oxygen to the single polypeptide chain is non-cooperative. It takes up O_2 from the haemoglobin in the blood and releases it only at low pO_2 values. Since pO_2 in the lung capillary bed is 100 mm Hg, myoglobin could effectively load oxygen in the lungs. However, the pO_2 of venous blood is 40 mm Hg. Since myoglobin cannot deliver a large fraction of its bound oxygen even at 20 mm Hg, it cannot serve as an effective vehicle for delivery of oxygen from lungs to peripheral tissues.



TRANSPORT OF CARBON DIOXIDE

- Carbon dioxide in gaseous form diffuses out of the cells into the capillaries, where it is transported in three ways: in **dissolved state,** in the form of **bicarbonate** and as **carbaminohaemoglobin.**
- Due to high solubility, about 7 per cent carbon dioxide gets dissolved in the blood plasma and is carried in solution to the lungs.
- The dissolved carbon dioxide in the blood reacts with water to form **carbonic acid (H_2CO_3).** This reaction occurs very **rapidly inside RBCs** because a zinc containing enzyme, the **carbonic anhydrase** present in RBCs accelerates its rate about 5000 times.
- **About 70% of CO_2,** received by blood from the tissues, enters the RBCs where it reacts with water to form carbonic acid. Almost as rapidly as formed, all carbonic acid of RBCs dissociates into **hydrogen (H^+) and bicarbonate ions (HCO_3^-).**
- In addition to reacting with water, carbon dioxide also reacts directly with **amine radicals (NH_2)** of haemoglobin to **form an unstable compound carbamino haemoglobin.**

$$HHbNH_2 + CO_2 \rightleftharpoons HbNHCOOH + H^+$$

Reduced haemoglobin — Carbamino haemoglobin

Chloride shift

- During transport of CO_2 **exit of bicarbonate ions** considerably changes ionic balance between the plasma and the erythrocytes. To restore the ionic balance, the **chloride ions diffuse** from the plasma into the erythrocytes. This movement of chloride ions is known as chloride shift or **Hamburger's phenomenon.**

RELEASE OF GASES

- At the tissue level, oxygen is released from **oxyhaemoglobin** and carbon dioxide is picked up by plasma and red blood cells.
- At the lung level, carbon dioxide is released from its three states so as to expel it out of the blood to alveoli and oxygen is picked up by haemoglobin.

Haldane effect

- Binding of oxygen with haemoglobin tends to displace carbon dioxide from the blood. This effect is called Haldane effect (J.S. Haldane, a Scotish Physiologist, 1860-1936).
- It is quantitatively far more important in promoting carbon dioxide transport than is the Bohr's effect in promoting oxygen transport.

Haemoglobin acts as a buffer

Addition of hydrogen ions would make the blood acidic. However, most of the hydrogen ions are **neutralized by combination with haemoglobin,** which is negatively charged, forming acid haemoglobin. This reduces the acidity of the blood, and also releases additional oxygen. If the blood becomes too basic, acid haemoglobin dissociates, releasing hydrogen ions. $HHb \rightarrow H^+ + Hb$. Thus, **the haemoglobin also acts as a buffer,** a substance that keeps the pH from fluctuating.

REGULATION OF RESPIRATION

- Humans breathe about **12 to 14 times per minute.**
- It is controlled by nervous system *i.e.* nervous regulation, mechanical control and chemical regulation.

Nervous regulation

- The respiratory centre is composed of several widely dispersed groups of neurons located in the medulla oblongata and pons varolii.
- The respiratory centre can be divided into **dorsal respiratory group, ventral respiratory group, apneustic centre** and **pneumotaxic centre.** These centres are very sensitive to Pco_2 in the arteries and to the pH level of blood.

Dorsal respiratory group (Inspiratory centre)

- It is present in the dorsal part of the **medulla oblongata.** It controls the contraction of **external intercostal muscles** and muscles that flatten the diaphragm to cause **inspiration.**

Ventral respiratory group (Expiratory centre)

- It is present in the ventral part of the medulla oblongata. It issues signals for both inspiration (to diaphragm & external intercostal muscles) and expiration (to internal intercostal muscles and muscles of abdominal wall).

Pneumotaxic centre

- It is present in the dorsal part of the pons varolii and regulates the time of inspiration.

Apneustic centre

- It lies in the lower part of pons varolii and works in collaboration with pneumotaxic centre to control the depth of inspiration.

Mechanical control (Herring-Breuer reflex)

- **Stretch receptors** (slow adapting pulmonary receptors) are located in the walls of bronchi and bronchioles. These are stimulated by overstretching of the lungs. They send impulses through **vagus nerve** fibres to expiratory centre which in tum sends to inspiratory centre for inhibition and causes **expiration.**
- As the thoracic cavity becomes smaller during expiration, stretch receptors are not stimulated and so inhibition is released automatically and new inspiration begins.

Chemical regulation

- A chemosensitive area is situated near respiratory centre in **medulla** where it is bathed with **cerebrospinal fluid.**

- It is highly sensitive to change in CO_2 concentration or change in blood pH.
- The chemoreceptors are present in the **carotid** and **aortic bodies** within carotid arteries and aorta respectively.
- They get stimulated by rise in pCO_2 or H^+ concentration of arterial blood or a decline in its pO_2 concentration and send impulses to chemosensitive area to increase the rate of contraction and relaxation.

The level of CO_2 has more effect on breathing than does the level of oxygen. If the CO_2 content of the blood drops below a certain **critical level**, breathing stops.
In fact, oxygen level does not regulate breathing rate unless it falls dangerously low. Activation of the inspiratory centre due to low oxygen level is a last-ditch effort to increase breathing rate and restore normal oxygen levels.

DISORDERS OF RESPIRATORY SYSTEM

- **Hypoxia** : It is a condition of **oxygen shortage** in the tissues.
- **Asphyxia** : In this **O_2 content falls** whilst the **CO_2 content rises.**
- **Bronchitis** : It is the **inflammation** of the bronchi.
- **Bronchial asthma** : It is an **allergic** attack of **breathlessness** accompanied by **bronchial obstruction** or **spasm.** It is generally caused by **hypersensitivity** of bronchioles to **foreign substances. Coughing** or **difficulty in breathing** are common symptoms of this disease.
- **Pneumonia** : It is an **acute infection** due to **inflammation** of **alveoli of the lung.**
- **Emphysema** : It is **reduction** in **alveolar ventilation** because of **loss of elasticity** and **distension** of alveolar sacs and **bronchioles. Cigarette smoking** and **chronic bronchitis** are the cause of this disease. In this the alveolar sac remains filled with air even after expiration, as a result the **lung size increases.**
- **Occupational lung disease** : Such diseases are common in persons who work in an environment where they are constantly exposed to potentially harmful substances such as gas, fumes or dusts.
- **Silicosis** and **asbestosis** are the common occupational **lung diseases.** These diseases are caused due to **chronic exposure** of **silica** and **asbestos dust.** As a result of chronic exposure, there is **fibrosis** (*i.e.*, proliferation of fibrous connective tissue) of upper part of lung causing inflammation.

CONCEPT MAP