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Breathing and Exchange of Gases

Metabolism is an essensial function of all living organisms. Catabolism takes place to produce energy which is used for all activities. Cellular respiration is a part of catabolism where generally glucose is oxidised through glycolysis, Tri carboxilic acid cycle (TCA) and oxidative phosphorylation. During these processess CO_2 is produced which is toxic to cell, hence it becomes a compultion to cell to remove it. Same way for oxidative phosphorylation cell has neccesity to get oxygen, thus for removal of CO_2 and to go in O_2 special system is required which is possible through respiratory system. This system has two major paths : inspiration and expiration, where O_2 is accepted and CO_2 is released respectively. Such exchange of gases should be done at two surfaces : Cellular surface and pulmonary surface. Entire process comes under the heading 'Respiration'. Cells need a continous supply of oxygen to carry out activities for their existance. Many of these activities release carbon dioxide. There are the circulatory system and the respiratory system to supply O_2 and eliminate CO_2. Let us see first the role of respiratory system along with its structure. The respiratory system consists of organs that exchange gases between atmosphere and blood. Blood tranports gases between lungs and cells. The overall exchange of gases between atmosphere, blood and cell is called respiration in general.

Respiratory system : The respiratory system of human consists organs like nose, pharynx, larynx, trachea, bronchi and lungs.

Nose : The nose has an external portion jutting out from the face and an internal portion lying hidden inside the skull. It is divided into external nares, nasal chamber and internal nares.

External nares Or Nostrils : On the under surface of the external nose two openings called the external nares or nostrils are present. The two nostrils are separated by the septum.

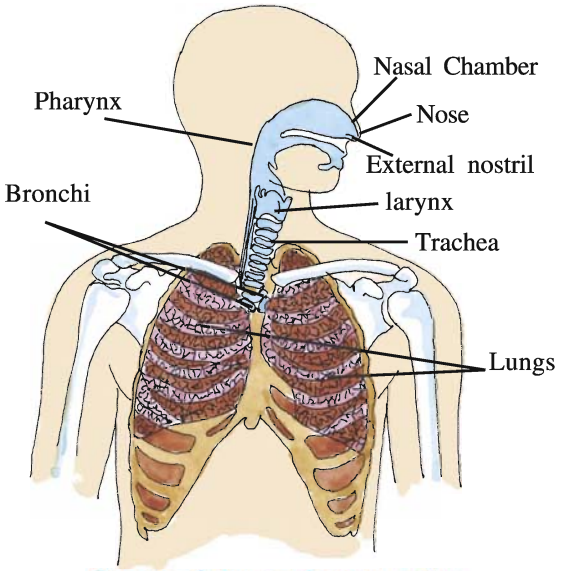
Nasal Chamber : The internal region of nose is a large cavity within the skull. Anteriorly it opens through external nares and posteriorly it communicates with the pharynx through internal nares. The two nasal chambers are also separated by the nasal septum. Each nasal chamber is divided into three regions lower vestibular, middle respiratory and upper olfactory.

Pharynx : The pharynx is a tube about 12.5 cm long, serving as a passage way for air and food. Pharynx is divided into three parts :

(i) **Nasopharynx :** The upper most portion of the pharynx.

(ii) **Oropharynx :** The second portion of the pharynx, lies behind the buccal cavity.

(iii) **Laryngopharynx :** The lowest portion of the pharynx. It extends downward and empties into oesophagus posteriorly and into the larynx (Voice-box) anteriorly.



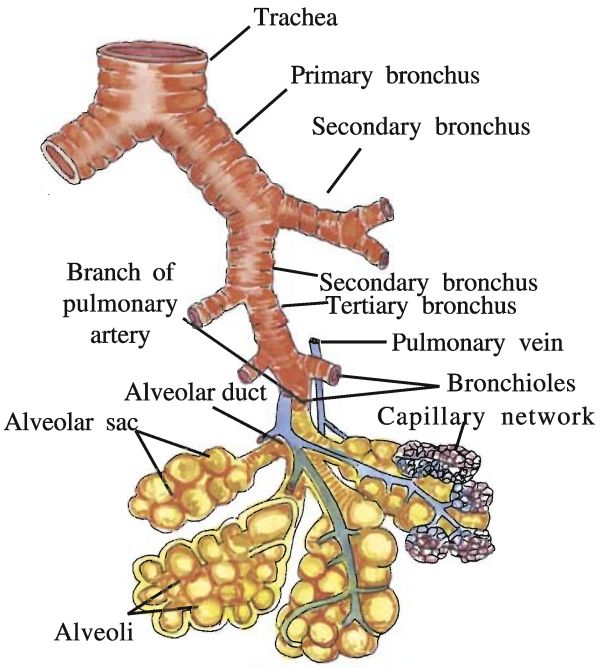
Organs of the respiratory system

Larynx : Larynx is a passage that connects the pharynx with the trachea. The leaf-shaped piece of cartilage called glottis is always remains open except during swallowing. The mucous membrane of the larynx contains vocal cords. It has ability to vibrate. This ability allows us to speech.

Trachea (Windpipe) : Trachea is about 12cm in length and 2.5cm in diameter. It extends from the larynx to the middle of the thoracic cavity, where it divides into right and left primary bronchi. It is a tubular passageway for air.

The trachea is divided into right primary bronchus, which enters the right lung and left primary bronchus, which enters the left lung. The right primary bronchus is more vertical, shorter and wider than the left. Along the length in the trachea and bronchi at short distances'C' shaped incomplete, cartilagenous rings occur. They keep the respiratory passage open and prevent it from blockage.

When Primary bronchi enter into lungs, divide to from smaller bronchi, called secondary bronchi, one for each lobe of the lung. The secondary bronchi continue to branch, forming still smaller bronchi, called tertiary or segmental bronchi. These bronchi divide into bronchioles. Bronchioles divide into smaller tubes, called terminal bronchioles and ended into alveoli of lung. There are millions of alveoli in each lung. Each alveolus is sac-like structure surrounded by pulmonary cells and enveloped by a network of blood capillaries.



Bronchial tree

The continous branching of the trachea into primary bronchi, secondary bronchi, tertiary bronchi, bronchioles and terminal bronchioles is commonly referred to as the 'bronchial tree'.

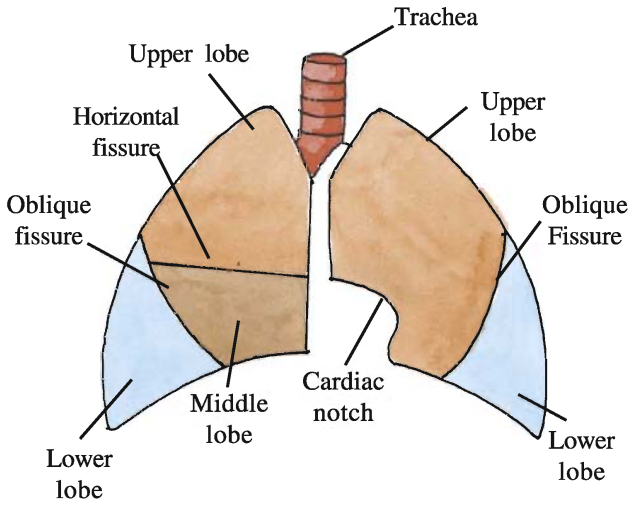
Lungs : The lungs are paired, cone-shaped organs lying in the thoracic cavity. It is protected by rib-cage. The diaphragm is placed under them. The left lung is slightly smaller and lighter than the right one. Two layers collectively called the pleural membrane covers each lung. The outer layer is attached with the wall of thoracic cavity. The inner layer covers, the lungs themselves. The space between two layers contains a lubricating fluid secreted by the membranes. This fluid protects lungs against shock.

The right and left lungs have some structural differences :

Right lung	Left lung
1. It is thicker, broader, longer and heavier	1. It is thinner, narrower, shorter and lighter
2. It has three lobes (Upper, lower and middle lobes) which are demarcated by two fissures (One oblique and one horizontal).	2. It has two lobes (Upper and lower lobes) Which are demarcated by one fissure (oblique)
3. Cardiac notch in which the heart lies is not present.	3. Cardiac notch is present.

Mechanism of Respiration : The principal purpose of respiration is to supply oxygen (O_2) to cells of the body and to remove carbon dioxide (CO_2) produced by cells. The process of drawn in air from the atmosphere towards lungs is called inhalation and the process of exportation of air from lungs into the atmosphere is called exhalation. Both activities occur alternately which is called breathing.

Diaphragm and ribs play an important role in breathing. The 'dome-shaped' diaphragm separates the thoracic cavity and abdominal cavity. It is attached anteriorly with sternum and at its posterior side, it remains attached to the vertebral column. Intercostal muscles are associated with the ribs.



External Structure of Lungs of Human

Inspiration : Inspiration takes place when the volume of the thoracic cavity is increased and the air pressure is decreased. The following steps simultaneously occur during inspiration :

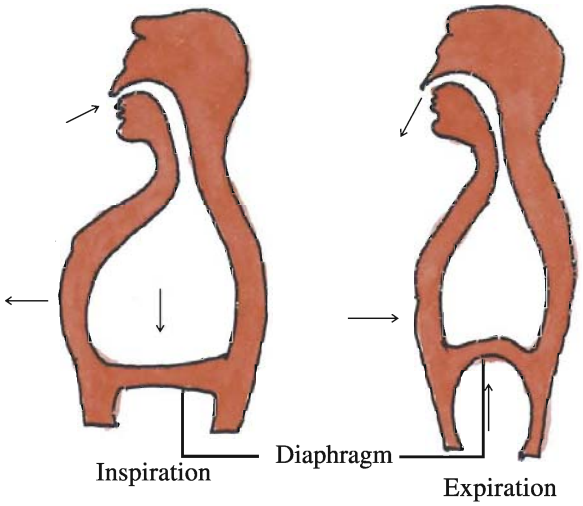
(i) When muscles of diaphragm contract, the diaphragm is pulled down-wards.

(ii) As a result the size of thoracic cavity increases.

(iii) The partial pressure of air in lungs is reduced.

(iv) As a result air from atmosphere moves into lungs through the external nostrils upto equalize the outer and inner pressure.

(v) In the lungs, air reaches alveoli where O_2 diffuses into the alveoli and CO_2 diffuses out of it. When all alveoli receive air, the lungs expand.



Breathing mechanism in human boty

Expiration : Expiration takes place when the volume of the thoracic cavity is decreased. The following steps simultaneously occur during expiration :

(i) When the muscles of diaphragm relax, the diaphragm moves upwards.

(ii) As a result, the size of thoracic cavity reduces.

(iii) As a result lungs becomes compressed and the pressure in them increases.

(iv) Under such pressure the air within the lungs goes out into the atmosphere.

Above mentioned processes of inspiration and expiration occur under normal resting phase.

Respiratory Volumes and Capacities : Many factors effect respiratory capacity viz : person's age, size, sex and physical condition. Let us understand the volumes and capacities :

(1) Tidal Volume (TV) : Normal quiet breathing moves approximately 500 ml of air into and out of the lungs with each breath. This volume is referred as a tidal volume (TV).

(2) Inspiratory Reserve Volume (IRV) : The amount of air that can be inhaled forcibly over the normal (tidal) volume is the IRV. Normally IRV is between 2500 ml to 3000 ml.

(3) Expiratory Reserve Volume (ERV) : The amount of air that can be forcibly exhaled after a normal (tidal) expiration is known as ERV. The ERV is approximately 1000 ml to 1100 ml.

(4) Residual Volume (RV) : It is the amount of air remain in the lungs after a forcible expiration. The approximately RV is 1100 ml to 1200 ml.

(5) Inspiratory Capacity (IC) : It is the total volume of air which can be inhaled by a person after normal expiration i.e. IC is a sum of TV and IRV. It is about 3000 ml to 3500 ml.

(6) Expiratory Capacity (EC) : It is the total volume of air which can be exhaled by a person normal inspiration. i.e. EC is a sum of TV and ERV. It is about 1500 ml to 1600 ml.

(7) Functional Residual Capacity (FRC) : It is a volume of air that will remain in the lungs after normal expiration. FRC is the sum of ERV and RV. FRC is about 2100 ml to 2800 ml.

(8) Vital Capacity (VC) : It is the total volume of air which can be breathe by a person. The VC is the sum of TV, IRV and ERV. VC is about 4000 ml to 4600 ml.

(9) Total Lung Capacity (TLC) : It is the amount of air in the lungs and respiratory passage after a maximum inspiration. The TLC is the sum of TV, IRV, ERV and RV or VC+RV. TLC is about 5100 ml to 5800 ml.

Exchange of gases : As soon as the lungs fill with air, oxygen moves from the alveoli to the blood, through the interstitial fluid and finally to the cells. Carbon dioxide moves in just the opposite direction : From cells, through interstitial fluid to blood and to alveoli. Oxygen and carbon dioxide are exchanged in these sites by simple diffusion mainly based on pressure or concentration gradient. The partial pressures (in mm Hg) of O_2 and CO_2 at different parts is compared with atmosphere as under.

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

Transport of respiratory gases

Transport of O_2 in the Blood : Oxygen (O_2) is transported in the blood by two ways : Nearly 97 % O_2 is transported through RBCs. The remaining O_2 is transported through blood plasma.

Haemoglobin, a respiratory pigment, present in RBCs is responsible for transport of O_2. Each RBC transports around one billion molecules of O_2.

At the respiratory surface, haemoglobin in RBC of blood acts as haemoglobinic acid. It reacts with oxygen and forms oxyhaemoglobinic acid.

$$H + Hb \longrightarrow H.Hb \quad \text{(Haemoglobinic acid)}$$

$$H.\ Hb + O_2 \longrightarrow H.Hb\ O_2 \text{ (Oxyhaemoglobinic acid)}$$

Oxyhaemoglobinic acid (H. Hb O_2) reacts with potassium bicarbonate ($KHCO_3$) of RBC and produce $KHbO_2$ along with H^+ and HCO_3^-. H^+ and HCO_3^- again react to form H_2CO_3 (Carbonic acid)

$$H.Hb\ O_2 + KHCO_3 \longrightarrow KHbO_2 + H^+ + HCO_3^-$$

$$H^+ + HCO_3 \longrightarrow H_2CO_3$$

Thus, O_2 is transported in a form of potassium oxyhaemoglobin ($KHbO_2$). Near tissue surface $KHbO_2$ splits to release K^+, haemoglobin and oxygen.

$$KHbO_2 \longrightarrow K^+ + Hb + O_2 \uparrow \text{ (Near tissue surface)}$$

The Transport of CO_2 in blood : CO_2 produced through cellular respiration in cells diffuses into the blood within the capillaries. It is transported in two forms :

(i) In a form of physical solution :

About 10% of CO_2 combines chemically with water of plasma forming carbonic acid

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

Any increase in its concentration causes the dissociation of H_2CO_3 into hydrogen ion and bicarbonate ion

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

If all amount of CO_2 is transported by blood stream, pH of blood would be lowered from its normal level i.e. 7.4 to about 4.5. This would be instantly fatal. Therefore, only about 10 % of the CO_2 produced by the tissue is actually transported in this fashion.

(ii) As chemical compounds :

(A) Carbamino Compounds : About 20 % of total blood CO_2 is transported along with haemoglobin

$$CO_2 + Hb.\ NH_2 \longrightarrow Hb.NH.COOH$$

(Carbaminohaemoglobin)

(B) Bicarbonates : About 70% CO_2 is carried as bicarbonates in the blood.

(i) In the Erythrocytes (RBC) :

CO_2 from the plasma enters in RBC and combines with water within the cell. There action is catalyzed by carbonic anhydrase and produced carbonic acid, which soon dissociates.

$$CO_2 + H_2O \xrightarrow[\text{anhydrase}]{\text{Carbonic}} H_2CO_3$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

In RBC haemoglobin combines with potassium and forms KHb. KHb combines with H_2CO_3 to form $KHCO_3$ and HHb.

$$K + Hb \longrightarrow KHb$$

$$H^+ + HCO_3^- + KHb \longrightarrow KHCO_3 + H.Hb$$

(Potassium haemoglobin) (Haemoglobinic acid)

(ii) In the plasma : Plasma transports CO_2 by three different processes :

(a) By Phosphate buffers : Alkaline phosphates combine with carbonic acid in the plasma and form sodium bicarbonates.

$$Na_2HPO_4 + H_2CO_3 \longrightarrow NaHCO_3 + NaH_2PO_4$$

(Bi-sodium hydrogen phospate) (Sodium bicarbonate) (Sodium dihydrogen phosphate)

(b) By plasma proteins : Proteins of the plasma mostly remain combined with Na (sodium) and form sodium-protein complex. Now this complex react with carbonic acid and form bicarbonate of sodium.

$$Na^+ + Pr. \longrightarrow Na.\ Pr\ Complex$$

$$Na.\ Pr. + H_2CO_3 \longrightarrow NaHCO_3 + H.\ Pr$$

(Proteinic acid)

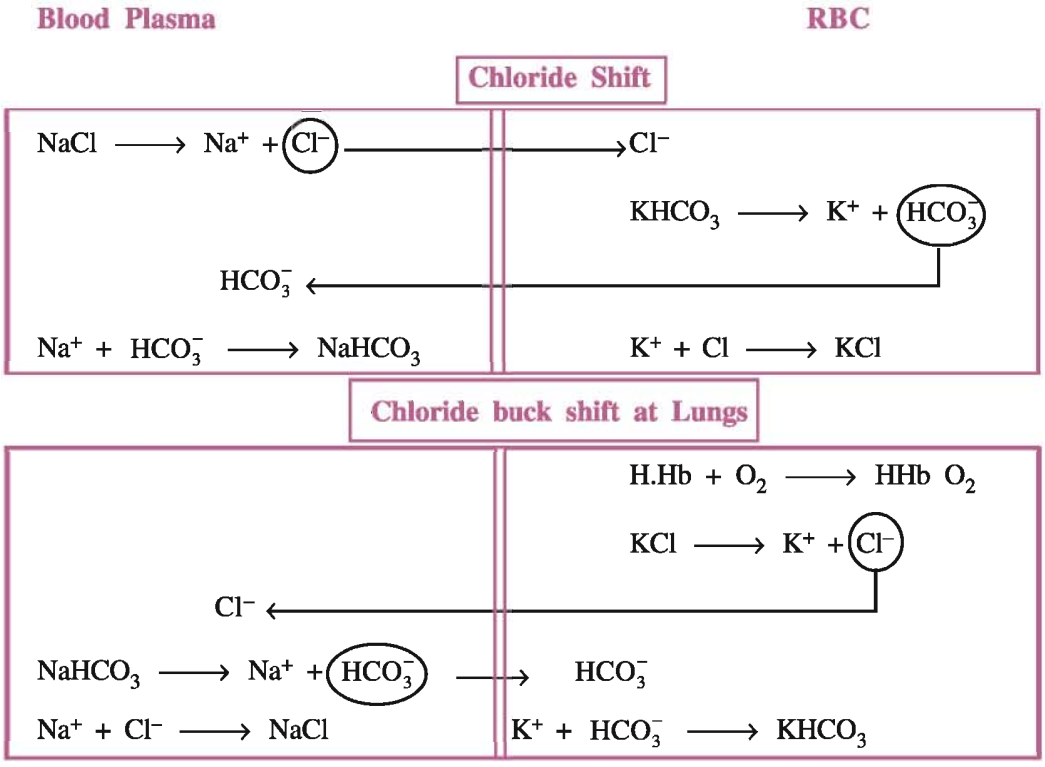
By Chloride Shift : CO_2 released from tissue enters into the RBC. It reacts with water to form carbonic acid.

$$CO_2 + H_2O \xrightarrow[\text{anhydrase}]{\text{Carbonic}} H_2CO_3$$

The carbonic acid is buffered by the intracellular potassium haemoglobin (K.Hb) and form potassium bicarbonate ($KHCO_3$) and haemoglobinic acid (H.Hb)

$$H_2CO_3 + K.Hb \longrightarrow KHCO_3 + H.Hb$$

Under normal conditions the wall of the RBC acts as permeable membrane to anions (Cl^-, HCO_3^-) but virtually impermeable to cations (Na^+, K^+). Under these circumstances, chloride (Cl^-) ions obtained by dissociation of NaCl diffuse into RBC from the blood plasma and react with $KHCO_3$. $KHCO_3$ dissociates into HCO_3^- and K^+. The bicarbonate ions (HCO_3^-) which diffuse out of the RBC into the blood plasma, where as Cl^- is neutralized by K^+ in the RBC. In the blood plasma, HCO_3^- combines with Na^+ and forms $NaHCO_3$ (Sodium bicarbonate). This phenomenon is known as chloride shift.



All reactions related to chloride shift become reversible at the surface of lungs. $NaHCO_3$ is present in blood plasma and KCl and H.Hb are present in RBC At the lungs surface O_2 diffuses into blood from atmosphere where it reacts with H.Hb in RBC to form $H.HbO_2$. Now Cl^- is released from KCl and diffused back into blood plasma. This phenomenon is known as chloride back shift. This Cl^- reacts with Na^+ released from $NaHCO_3$ in blood plasma and forms NaCl and HCO_3^-. Now HCO_3^- reenter into RBC and react with K^+ and forms $KHCO_3$.

Release of CO_2 at the respiratory surface (lungs)

Carbonic acid and bicarbonates of sodium and potassium are carried to the lungs where they are broken down and liberate free CO_2

$$H_2CO_3 \longrightarrow H_2O + CO_2 \uparrow$$
$$2KHCO_3 \longrightarrow K_2CO_3 + H_2O + CO_2 \uparrow$$
$$2NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2 \uparrow$$
$$\text{Hb. NH. COOH} \longrightarrow \text{Hb. } NH_2 + CO_2 \uparrow$$

Regulation of Respiration

The regulation of respiration are of two types :

(i) Nervous regulation and (ii) Chemical regulation.

(i) Nervous regulation : According to one concept it is controled by nervous impulses ordered from respiratory center passing through the vagus nerve (10^{th} Cranial nerve) to the diaphragm and the intercostal muscles. Respiratory centre is present in a medulla oblongata.

According to other concept the respiratory centre has two-folds, consisting of inspiratory and expiratory centres which act reciprocally. These respiratory centres are scattered in the brain stem and are constantly giving off rhythmical stimuli to the respiratory muscles in virtue of their inherent rhythm, causing inspiration and expiration.

Whatever view is correct, the respiratory center or centres receive impulses through nerves distributed in the substance of the lungs.

(ii) Chemical regulation : The chemical regulation of respiration is controlled by level of CO_2 in the arterial blood and cerebro-spinal fluid. Chemoreceptors in the brain, aortic arch and carotid sinus detect the CO_2, pH and O_2 levels in the blood and pass information to the brain's rhythmicity centres. This rhythmicity centers transmit the appropriate signals to respiratory muscles.

Disorders of respiratory system

Bronchitis : Bronchitis is the inflammation of bronchi. It is caused by an infection. It may also be caused by smoking. The typical symptom is regular coughing with thick and large amount of phlegm which is secreted out as cough. It appears yellowish or greenish. It reflects severe burning sensation in trachea. Avoiding exposure to smoke, chemical and pollutants can prevent bronchitis. This disease is treated with suitable antibiotics.

Asthma : It is an allergic disease. The muscles wall of tracheal branches remain constantly agitated and undergo spasmic contraction. The aerial allergens are responsible for it. The symptoms are : repeated coughing out of phlegm, difficulty in breathing mainly during expiration and suffocation of tracheal passage. Avoiding the foreign substance or allergens is the best prevention of it. This is treated with suitable antibiotic, antihistamine drugs.

Emphysema : Emphysema is chronic obstructive disease of lung. Where alveoli loss their elasticity. As a result the alveolar sac remains filled with air even after expiration. It is mainly caused by smoking and chronic bronchitis. The symptoms are : difficulty in breathing, cough and suffocation and as a side effect the heart and brain do not get enough O_2 and hence, their functions are damaged. It can be prevented to avoiding of smoking and pollutants. Once it occurs, the elasticity of alveoli is lost and therefore, there is no permanent treatment for it but relief can be obtained through the use of antibiotics and tracheal dialatory drugs.

Pneumonia : Pneumonia is an acute infection of the alveoli of the lungs. It is caused through bacteria *Streptococcus pneumoniae.* The alveoli of lungs becomes filled with fluid and dead WBCs. Such areas become defunct. Wider is the area, greater is the spread of the disease. Children, old individuals and AIDS patients are more susceptible to this disease. It can be treated with antibiotics.

Occupational Lung Disease : As the name indicates, it happens due to the occupation of an individual. These are caused by the exposure of harmful substances like gases, dusts (antigens) etc. The common examples of such diseases are Silicosis and Asbestosis.

Summary

Cells of body need continous supply of O_2 to carry out metabolic activity and CO_2 must be released. For that circulatory and respiratory systems play important role. The respiratory system helps to exchange gases between atmosphere and blood. From their, O_2 travels towards cells and CO_2 toward lungs. This entire process comes under the heading 'respiration'.

The respiratory system of human consists organs like nose, pharynx, larynx, trachea, bronchi and lungs, by which inspiration and expiration like mechanism of respiration take place.

O_2 moves from alveoli ® blood ® interstitial fluid ® cell, while CO_2 moves in the opposite direction. O_2 and CO_2 are exchanged in these sites by simple diffusion which is mainly based on pressure or concentration gradient.

Transport of O_2 in the blood by two way : through RBCs and through blood plasma. Haemoglobin present in RBCs is responsible for it. The transport of CO_2 occurs through physical solution and as chemical compounds viz : carbamino compound, bicarbonate etc. The CO_2 transported is through bicarbonate by RBCs, and blood plasma. Blood plasma transports CO_2 by phosphate buffers by plasma proteins and by chloride shift.

The respiration is regulated by nervous system and chemicals.

Exercise

1. Put a dark colour in a given circle for correct answer :

(1) The length of pharynx is...

(a) 12 cm ○ (b) 12.5 cm ○

(c) 14 cm ○ (d) 15 cm ○

(2) Which part of respiratory system allows us to speech ?

(a) Oropharynx ○ (b) Trachea ○

(c) Vocal cords ○ (d) Nose ○

(3) The diameter of trachea is...

(a) 1.5 cm ○ (b) 2.5 cm ○

(c) 3.5 cm ○ (d) 0.5 cm ○

(4) Residual volume (RV) in human is... ml.

(a) 1000 to 1100 ○ (b) 3000 to 3500 ○

(c) 1100 to 1200 ○ (d) 1500 to 1600 ○

(5) How much partial pressure (in mm Hg) of O_2 in alveoli ?

(a) 159 ○ (b) 104 ○

(c) 40 ○ (d) 45 ○

(6) How much O_2 is transported through RBCs ?

(a) 90% ○ (b) 97% ○

(c) 3% ○ (d) 10% ○

(7) Normal pH of blood is...

(a) 7.4 ○ (b) 7.3 ○

(c) 6.5 ○ (d) 7.0 ○

(8) Complete the following reaction.

$2NaHCO_3$® ..... + H_2O + CO_2

(a) $NaCO_3$ ○ (b) $2NaCO_3$ ○

(c) Na_2CO_3 ○ (d) $NaHCO_3$ ○

(9) Vagus is the .... number cranial nerve.

(a) 8^{th} ○ (b) 7^{th} ○ (C) 9^{th} ○ (d) 10^{th} ○

(10) Which of the following is the allergic respiratory disease.

(a) Bronchitis ○ (b) Asthma ○

(c) Emphysema ○ (d) Pneamonia ○

2. Do as directed :

(1) Nose as a part of respiratory system : Describe

(2) Give the differences between right and left lung.

(3) Explain exchange of gases.

(4) Transport of O_2 in the blood-describe

(5) Describe - Regulation of respiration

3. Write short note on :

(1) Lungs

(2) Inspiration

(3) Expiration

(4) Respiratory volumes and capacities

(5) Chloride shift and back shift

(6) Emphesema

(7) Bronchitis