Respiratory Gas Exchange

⇒ The ~~gols~~ goals of respiration are to provide oxygen to the tissues and to remove Carbon dioxide. To achieve these goals respiration can be divided into 4 major functions:-

1) Pulmonary ventilation, which means the inflow and outflow of air b/w the atmosphere and the lung alveoli.
2) Diffusion of oxygen and Carbon dioxide between the alveoli and the blood
3) transport of O_2 and Co_2 in the blood and body fluids to and from the body's tissue cells.
4) Regulation of ventilation and other facets of respiration.

Respiration:→ is a biochemical process by which organic compounds are oxidised to liberate chemical energy from the food in a step-wise process. The organic compounds are carbohydrates, fats and proteins and the energy released is stored as the ATP molecules (adenosine triphosphate).

⇒ Animals prey energy out of food molecules using the biochemical process called **cellular respiration**. Cellular respiration is the use of oxygen and production of carbon dioxide at the cellular level.

Types of Respiration

Anaerobic Respiration

⇒ When food is oxidised without the use of molecular oxygen, it is called anaerobic respiration, the organisms undergoing this type of respiration are termed as **anaerobes**. Examples are:- anaerobic bacteria, yeasts, many parasitic animals such as Taenia, fasciola and Ascaris. In micro-organisms this respiration is termed as fermentation and this is termed after the name of the product they form, such as alcoholic fermentation and lactic acid fermentation

⇒ Alcoholic fermentation occurs in yeasts, where they oxidise glucose to ethyl alcohol and Co_2.

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + \text{Energy}$$

⇒ Lactic acid fermentation occurs in some bacteria where glucose is metabolized to lactic acid.

$$C_6H_{12}O_6 \longrightarrow 2CH_3CHO\text{-}HCOOH + \text{Energy}.$$
(lactic acid)

⇒ In muscles and RBC, glucose is metabolised to form lactic acid which enters the blood and reaches the liver, where it is converted to glycogen aerobically for further use.

⇒ Accumulation of lactic acid in muscles causes fatigue.

Aerobic Respiration

⇒ When oxygen is used for the oxidation of food it is termed as aerobic respiration and the organisms undergoing this process are termed as aerobes. It is high energy yielding process. It is of two types:-

(i) Direct respiration:→ It is the exchange of environmental molecular O_2 with the Co_2 of the body cells without any special respiratory organ and blood. It is found in aerobic bacteria, protists, plants, sponges, Coelenterates, flatworms, round worms and most arthropods.

(ii) Indirect respiration:→ In this exchange of gases take place through special respiratory organs such as skin, gills, buccopharyngeal cavity and lungs. It needs blood (fluid) for transporting O_2 and Co_2 after the exchange.

⇒ The respiration through organs are termed according to their names eg:- Skin - cutaneous, Gills:- branchial, buccopharyngeal cavity:- buccopharyngeal and lung:- pulmonary respiration.

⇒ The indirect respiration occur in 2 phases external and internal respiration. These are preceded by a preliminary phase called breathing (Ventilation)

Breathing :→ refers to the movement that send fresh air or water to the respiratory organs and remove foul air or water from them.

(1) **External respiration** :→ It is the intake of O_2 by the blood from water or air in the respiratory organs and elimination of Co_2.

(2) **Internal respiration** :→ It involves four processes :–

⇒ uptake of O_2 by tissue cells from the blood via tissue fluid.

⇒ Storage of energy from oxidation in the phosphate bonds of ATP.

⇒ Release of Co_2 by tissue cells into the blood via tissue fluid.

⇒ Oxidation of food in the tissue cells by the action of oxidising enzymes producing Co_2, water and energy. This is also termed as **cell respiration**

∴ **Differences between breathing and respiration** :–

Breathing	Respiration
1) It is simply an intake of fresh air and removal of foul air.	1) It is an oxidation of food to form Co_2, water and energy.
2) It is a physical process	2) It is a biochemical process.
3) No energy is released, rather used.	3) Energy is released in the form of ATP.
4) It occurs outside the cells, hence it is an extracellular process.	4) It occurs inside the cells, hence it is an intracellular process.
5) No enzymes are involved in this process	5) A large number of enzymes are involved in the process.
6) It is confined to certain organs.	6) It occurs in all cells of the body.

Respiratory Surface :→ The surface at which exchange of gases (Co_2 and O_2) occurs is termed as respiratory surface. This surface must have enough area of gas exchange to meet the metabolic needs of the organism.

⇒ For the exchange to be efficient, respiratory surface should have the following features :–

1) It should be thin, large and moist.
2) It should be permeable to respiratory gases.
3) It should be highly vascular.
4) It must be directly or indirectly in contact with source of oxygen (that is either air or water).

Respiratory Medium :→ Air or water may serve as the source of oxygen for the animals. The source of oxygen is called respiratory medium. The respiratory medium supplies oxygen to the body at the body's respiratory surface.

Respiratory Structures for the exchange of Gases in different groups of animals:- (Page 2)

Animal Group	Respiratory Structure
1) Protozoans (e.g. Amoeba, Paramecium)	Plasma membrane.
2) Sponges (e.g. Sycon)	cell's plasma membrane.
3) Chidarians (e.g. Hydra)	Body surface.
4) Platyhelminthes	
(A) Free living (e.g. Planaria)	Body surface.
(B) Parasites (e.g. ~~Ascaris~~ Tapeworm)	No exchange of gases (anaerobic respiration)
5) Nemathelminthes	
(A) Free living (e.g. Rhabditis)	Body surface
(B) Parasites (e.g. Ascaris)	No exchange of gases (anaerobic respiration)
6) Annelids (e.g. earthworm)	Skin (cutaneous respiration)
7) Arthropods	
(A) Prawn, Crayfish	Gills (Branchial respiration)
(B) Insects, centipedes, millipedes, Ticks.	Tracheae (Tracheal respiration)
(C) Scorpions, Spiders	Book lungs.
(D) King crab (Limulus)	Book gills.
8) Molluscs	
(A) Unio	Two ctenidia (gills).
(B) Pila	one ctenidium (gill) and one pulmonary sac.

Animal Group	Respiratory Structure
9) Echinoderms. (e.g. Starfish)	Dermal branchae, tube feet.
10) Hemichordata. (e.g. - Balanoglossus)	Pharyngeal wall.
11) Chordata.	
A) Urochordata (e.g. Herdmania)	Pharyngeal wall.
B) Cephalochordata. (e.g. Branchiostoma)	pharyngeal wall.
C) Vertebrata	
(i) Cyclostomes, fishes	Gills.
(ii) Amphibians	skin, Buccopharyngeal lining, lungs
(iii) Reptiles, birds, Mammals.	Lungs.

Problems of water-breathing:- water-breathing animals face the following problems in ventilating their respiratory surfaces (gills):→

⇒ water contain much less oxygen than air.

⇒ oxygen diffuses through water far more slowly than through the air. Therefore a large quantity of water is required to be passed over the gills to fullfill the oxygen need.

⇒ water is about 800 times denser than air so that the fish has to make a great muscular effort to maintain water flow.

⇒ At a higher temp^n an animals needs more supply of O_2 because rise in temp^n ↑↑ their metabolic rate, but less O_2 is available to them in warmer H_2O, as warmer H_2O holds less O_2.

Problems of Air-Breathing:- → Land animals for breathing are face the following difficulties:-

⇒ They have to protect their respiratory surface from drying out. ⇒ Respiratory surface must be kept moist as gases passes through liquid medium.

⇒ They loose their precious water through evaporation from their respiratory surface.

Diffusion of Gases:- → Diffusion of gases taker place due to difference in the partial pressure of O_2 (P_{O_2}) and partial pressure of Co_2 (P_{CO_2}) in the surrounding medium and the animal.

⇒ The gases always move from higher partial pressure to lower partial pressure.

⇒ All land vertebrates have internal sacs called lungs for respiration. They develop as sac like outgrowths of the pharynx and are present in all air breathing vertebrates. The respiration by lungs is called pulmonary respiration.

Human Respiratory System:- → Respiratory system of man is located in the thoracic cavity. It has number of small tubes and lungs. Lungs are spongy organs protected by ribs and the floor of the thoracic cavity is formed by the muscular diaphragm.

⇒ The human respiratory system begins with external nares or nostrils, the paired openings that open into the nasal chambers or nasal cavity. The structure, location and function of various components of respiratory system are as follows:-

Parts of Respiratory System	Location	Importance and function.
1) Nasal Cavity.	At the back of nostrils, just above the mouth cavity.	⇒ Nasal cavity is divided into 2 chambers and each chamber in turn has 3 chambers:- Vestibular, respiratory and olfactory. The 3 bony ridges:- the superior, middle and inferior nasal conchae arise from the wall of each nasal chamber to increase the surface area of nasal chamber. Nasal cavity has Special pseudostratified ciliated epithelium by which air is filtered (by hairs), moistened (by mucus) and warmed (by capillary network) before it enters the lung. detected ⇒ Mucus traps the dust and other fine particles. Odours in the air are also ↑
2) Naso-pharynx	Posterior part of the pharynx.	⇒ Air enters naso pharynx through two internal openings. The air is free from dust particles and is moist and warm. Air has to pass through nasopharynx to enter larynx.
3) Larynx. (also called Voice box)	Cartilagenous structure at the opening of trachea.	⇒ Larynx is comprised of nine cartilages. Three are single and 3 are paired. Unpaired cartilages are:- 1> epiglottis 2> thyroid (support it from front) 3> Cricoid Consists of Hyaline cartilage. Paired cartilage are:- 1> Arytenoid (hyaline and elastic type) 2> Corniculate (elastic type) 3> Cuneiform (elastic) ** These 9 cartilage forms voice box.

Part of Respiratory System	Location	Importance And Functions
		⇒ Inside the larynx are the vocal cords. These are 2 pairs of folds of mucous membrane that extend into the lumen from the sides. The upper pair are called false vocal cords and the lower pair are termed true vocal cords. ⇒ The vocal cords are composed of yellow elastic tissue covered by stratified squmous epithelium. The true ~~for~~ vocal cords have cord like free margins which enclose a passage named rima glottidis. The latter puts the larynx in communication with the laryngopharynx above. ⇒ Sound is produced by the true vocal cords. ⇒ For the production of sound, the vocal cords are brought parallel and closer to each other by the action of the pharyngeal muscles. ⇒ Now a current of air is passed through them under pressure from the lungs. This sets the vocal cords into vibration, which results in the production of sound. The quality of sound is altered by vibration in the tensions of the vocal cords. The buccal cavity, soft palate, tongue, and lips assist the larynx in producing articulate human speech.
4) Glottis	Slit-like opening to pharynx.	⇒ Above the larynx opens into the laryngopharynx by glottis.
5) Epiglottis	A triangular flap of cartilage present at the glottis.	⇒ It is a leaf like elastic cartilage. Since pharynx is the common passage for both food and air, epiglottis closes the opening of glottis during swallowing. It is a reflex action that prevents the passage of food into trachea.
6) Trachea (wind pipe)	Runs through the neck in front of oesophagus and extends into the thoracic cavity.	⇒ Connects lungs to nasopharynx. ⇒ Has C-shaped rings of hyaline cartilage that prevent the collapse of trachea during inspiration. The open part of C is towards the oesophagus. ⇒ Lined with ciliated pseudostratified columnar epithelium that keeps the unwanted particles away from lungs by beating the cilia towards the buccal cavity. ⇒ Mucus secreted by Goblet cells of epithelium traps dust particles and microbes. ⇒ It divides into two primary bronchi as it enter the thoracic cavity. Each bronchus has rings of cartilage. Further branches may have irregular cartilage thickening.

Parts of Respiratory System	Location	Importance And Function
7) Right and left bronchi	Right bronchus enters the right lung and left bronchus the left lung.	⇒ Each primary bronchus divides into secondary and tertiary bronchi, which also have cartilaginous rings. Right bronchus divides into three bronchi which enter into three lobes of lungs and left bronchus divides into two bronchi that enter the two lobes of left lung.
8) Bronchioles		⇒ Each tertiary bronchus divides many times and forms a network of bronchioles. Network of branching tubes is lung. # Some wider bronchioles with inner diameter > 1mm have cartilaginous rings but finer branches have only smooth muscle, connective tissue and lining of ciliated epithelium. # Carry air to and from the alveoli.
9) Respiratory bronchioles.		Bronchiole branch into respiratory bronchioles. ⇒ Finest and smallest tubes, only about 0.5 mm in diameter. They lack cartilaginous rings and epithelium lacks mucus cells.
10) Alveolar tubes.		⇒ Each respiratory bronchiole divides repeatedly into number of alveolar tubes, each alveolar tube leads into number of air sacs or alveoli. They are lined with cuboidal epithelium.
11) Alveoli		⇒ These are extremely thin walled lobulated structures, surrounded by capillary network. they are site of gaseous exchange. ⇒ Have thin, simple squamous, non-ciliated epithelium. ⇒ There are about 300 million alveoli in the two lungs having a combined surface area of about $70m^2$ (surface area of skin is only about $1.6m^2$) ⇒ A film of lecithin lines these alveoli, which lowers the surface tension and keeps the alveoli open. In some newborn babies this film of lecithin may not be present, which may be fatal to the baby due to collapsing of lungs.
12) Lungs.		⇒ Spongy, elastic, roughly paired triangular bags consisting of bronchi, bronchioles, respiratory bronchioles, alveolar tubes and alveoli. ⇒ The most upper portion of lung is called the apex and most inferior portion is called base. The left lung is smaller than the right lung. The left lungs has two lobes superior lobe and inferior lobe separated by oblique fissure. The right lung is bigger and has three lobes superior, middle and inferior lobe which is separated by horizontal and oblique fissure. Mediastinum is the partition between the two lungs. Left lung has cardiac notch, a concavity where the heart lies.

Parts of Respiratory system	Location	Importance And Function
13) Pleural cavity		⇒ Both the lungs are enclosed in a pleural cavity. ⇒ The pleural cavity is lined by two pleural membranes. The outer membrane is called parietal pleuron and inner membrane is known as visceral pleuron. The inner pleuron is tightly attached to the lung surface and the outer one lines the wall of thorax and diaphragm. ⇒ The pleural cavity contains a pleural fluid which lubricates the pleura and reduces the friction as the membranes rub against each other during inspiration and expiration.
14) Diaphragm		⇒ It is a muscular shelf at the base of lungs that separates thoracic and abdominal cavity. When relaxed (during expiration) it is dome shaped and on contraction become flattened (during inspiration).

Mechanism of Pulmonary Respiration (Lung Respiration)

→ Pulmonary respiration involves a number of steps:-

1) Breathing or pulmonary ventilation which involves two phases inspiration and expiration.
2) Exchange of gases between alveolar air and lung capillaries.
(3) Transport of gases in blood.
(4) Release of gases at the tissue and lung level.
(5) Regulation of breathing.

Pulmonary Ventilation:- → Lungs are passive in the process of breathing as they have little musculature and cannot expand and contract of their own. Breathing in man is brought by alternate expansion and contraction of the thoracic cavity.
⇒ These breathing movements lead to intake of fresh air into the lungs called inspiration and removal of foul air from the lungs called expiration.

Inspiration:- It is the process by which fresh air enters into the alveoli of the lungs. It is an active process and is brought about by activity of inspiratory muscles. The main muscles of inspiration in normal quiet breathing are the external intercostal muscles and phrenic or radial muscles of diaphragm. During difficult or deep breathing (forced inhalation) they are assisted by the muscles of abdomen.

Expiration:- → It is the process by which foul air is expelled out of the lungs. Expiration is normally a passive process and involves the relaxation of inspiratory muscles. But during forced exhalation, expiratory muscles (abdominal muscles and internal intercostal muscles) become active, making expiration an active energy consuming process.

Inspiration :→

(1) **Diaphragm** :→ when relaxed the diaphragm is a dome-shaped structure, which separates the thoracic cavity from the abdominal cavity.
⇒ Phrenic or radial muscles extend from diaphragm to ribs and vertebral column. When these muscles contract diaphragm become flat, thus increasing the thoracic-cavity antero-posterior. These are the principle inspiratory muscles and play about 75% role in inspiration, other muscles play only 25% role in inspiration.

2) **External intercostal muscles** :→ They occurs between the ribs. These are 11 pair of muscles extending between 12 pairs of ribs. Their contraction pulls the ribs and sternum upward and outward thereby increasing the thoracic cavity dorso ventrally and laterally.

3) **Abdominal muscles** :→ These muscles relax and allow compression of abdominal organs by diaphragm.

⇒ Due to the simultaneous contraction of inspiratory muscles volume of thoracic cavity increases in all directions.
⇒ As the lungs are held tightly against thoracic wall, enlargement of thoracic cavity results in expansion of the lungs.
⇒ This decreases the intrapulmonary pressure than the atmospheric pressure by −2 to −6 mm Hg.
⇒ As it is the property of gases, that they move from the place of their higher pressure to the place of their lower pressure, fresh air rushes through respiratory passage into the lungs to equalize the pressure.
⇒ This movement of fresh air into the lungs is called Inspiration.

Expiration :→

(1) **Diaphragm** :→ when muscles of diaphragm relax it again becomes dome-shaped, decreasing the thoracic cavity.

(2) **External intercostal muscle** :→ when these muscles relax, sternum and ribs come to their original position. This also decreases the thoracic cavity.

(3) **Abdominal muscles** :→ Contraction of abdominal muscles presses the abdominal viscera against the diaphragm, bulging it further upward and thus decreasing the thoracic cavity more vertically.

(4) **Internal intercostal muscles** :→ Contraction of these muscles moves the ribs downward and inward and reduces the thoracic cavity laterally and dorsoventrally. The abdominal and internal intercostal muscles are called expiratory muscles.

⇒ Due to the action of above muscles the overall volume of thoracic cavity decreases and the intra pleural pressure increase by +3 to +4 mm Hg, due to this increased pressure in lungs foul air is given out of them.
⇒ One breath includes one inspiration and one expiration.
⇒ The respiratory rate is the number of breaths taken per minute. For a person breathing normally at rest, it is equal to 12-14 breaths per minute.
⇒ Breathing through nose is healthier as it gets filtered and conchae of nose warm up the air.
⇒ Mammals have a negative pressure breathing as it allows them to eat and breath at the same time and in human female thoracic breathing is more predominant.

Some important terms :-
1) Hypercapnia :→ Excess of CO_2 in the body.
2) Cyanosis :- Blueness of skin because of excessive amount of deoxygenated Hb.
3) Atelectasis :→ Means collapse of alveoli.

Respiratory Quotient: → The ratio of volume of CO_2 produced to the volume of O_2 used in a unit time is called respiratory quotient.

⇒ It varies with different foods utilized in the respiration. ⇒ Glucose has RQ = 1 as $RQ = 6CO_2/6O_2 = 1$.

⇒ Fats has about 0.7 and proteins have about 0.85. ⇒ Organic acids have about 1.30 or 1.4.

⇒ R.Q is determined by Ganong's respirometer.

Pulmonary Air volumes and Capacities: → Spirometry is the process of recording the changes in the volume movement of air into and out of lungs and the instrument used for this purpose is called Spirometer or respirometer. The graph showing the changes in the pulmonary volumes and capacities under different conditions of breathing is called spirogram.

⇒ The quantity of air the lungs can receive, hold or expel under different conditions are called pulmonary volumes.

⇒ Combinations of two or more pulmonary volumes are called pulmonary capacities.

Type of Pulmonary Volume / Capacity	Quantity of air	Characteristic
1) Tidal Volume (TV)	500ml	⇒ 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 (150ml).
2) Alveolar volume (AV)	350 ml.	⇒ The alveolar volume is the air that reaches the respiratory surfaces of alveoli and engages in gas exchange.
3) Dead space volume	150 ml.	⇒ Dead space volume of air is that air which does not reach the respiratory surface, it just fills the respiratory passage.
4) Inspiratory Reserve Volume (IRV)	2000-2500ml.	⇒ It is an extra amount of air that can be inspired forcibly after a normal inspiration.
5) Expiratory reserve volume (ERV)	1000-1500ml	⇒ It is an extra amount of air that can be expelled after a normal expiration.
6) Residual Volume (RV)	1500ml	⇒ It is the volume of air that always remain in the lungs after forcible expiration, it enables the lungs to continue exchange of gases even after maximum exhalation or on holding the breath.

Type of pulmonary volume / Capacity	Quantity of air.	Characteristic
7) Vital Capacity (VC)	(3500-4500 ml)	⇒ 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. VC = TV + IRV + ERV. (i) The vital capacity is higher in athletes, mountaineers or mountain-dwellers and lower in non-athletes, people living in plains, women, old individual, cigarette smokers. (ii) Higher the vital capacity, higher is the amount of air exchanged by each breath.
8) Inspiratory Capacity (IC)	(2500-3000 ml)	⇒ It is the total volume of air that can be inhaled after a normal expiration. It includes sum of tidal volume and inspiratory reserve volume (IC = TV + IRV)
9) Functional Residual Capacity (FRC)	(2500-3000 ml)	⇒ It is the sum total of residual volume and the expiratory reserve volume. (FRC = RV + ERV)
10) Total lung Capacity (TLC)	(5000-6000 ml)	⇒ 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 ml.	⇒ 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 :→ Composition of alveolar air :→ In the alveoli of lungs some air is already present that is about 3000 ml (Residual volume + Expiratory reserve volume). The air that is inspired in and reaches the lungs (350 ml) gets mixed with it. As it gets mixed, the composition changes and is not the same as the inspired air.

Gas	Inspired air	Alveolar air	Expired air.
O_2	20.95%	13.8%	16.4%
CO_2	0.04%	5.5%	79.6%
N_2	79.01%	80.7%	79.6%

Exchange along the alveolar Surface: → Each alveolus consists of a single layer of flattened Squamous epithelium and is highly permeable and thin.

⇒ The capillaries that form a network also have a layer of squmous epithelium.

⇒ The barrier between the alveolar wall and alveolar capillaries is extremely thin and hence diffusion of gases takes place from higher partial pressure to lower partial pressure.

⇒ The blood that reaches the alveolus (venous blood) has lower P_{O_2} (40mm of Hg) and higher P_{CO_2} (46 mm of Hg) than the alveolar air (P_{O_2} 100 mm of Hg) and P_{CO_2} (40mm 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 P_{O_2} (95mm of Hg) and P_{CO_2} (40mm of Hg) as the alveolar air.

⇒ The % saturation of blood also rises from 70% (venous blood) to 95% (arterial blood), the composition of alveolar air remain relatively unchanged.

⇒ Partial pressure of N_2 is same in air of alveoli and in the blood present in blood capillaries. This position is maintained because N_2 is a gas which is not used up by the body.

Exchange of gases in tissue: → In the tissues exchanges of gases occur 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 (P_{O_2} = 100mmHg), than that in the tissues (P_{O_2} = 40mmHg). Similarly partial pressure of CO_2 is more in tissue (P_{CO_2} = 45 mmHg) than in the blood (P_{CO_2} = 40mmHg).

⇒ Due to these differences in partial pressure of gases O_2 from blood diffuses into the tissues and CO_2 from tissues diffuses into the blood.

⇒ This exchange of gases occurs 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 95% saturated at 40 mm Hg of O_2, and contains 14.4 ml of O_2 / 100 ml of blood.

Transport of Gases In Blood

(I) Transport of Oxygen: → O_2 is carried by blood in two forms in solution (plasma) and as oxyhaemoglobin by RBC.

(A) In Solution: → O_2 is soluble in plasma to a small extent under normal conditions of temperature and pressure. Hence most of it is carried by RBC. About 3% of O_2 is transported by blood in dissolved form in plasma of blood.

(B) As oxyhaemoglobin: → RBC's contain a protein called haemoglobin. It has 4 poly peptide chains and 4 haem groups attached to it at 4 atoms of iron in ferrous form (Fe^{2+}) thus it can react with 4 molecules of O_2 to form HbO_8. This is called oxyhaemoglobin, this combination process is called oxygenation.

⇒ On an average 15 gm of haemoglobin (Hb) is present in 100 ml of blood. 1 gm Hb can combine with 1.34 ml of O_2. Thus 100 ml of blood carries approximately 20 ml of O_2 (19.4 ml to be exact).

⇒ But when blood reaches the tissues, its O_2 concentration reduces gradually to 14.4 ml which is collected by venules and veins. Thus 5 ml of O_2 is transported by 100 ml of blood under normal conditions.

$Hb_4 + 4O_2$ ⇌ Hb_4O_8 (high P_{O_2} in lungs; low in tissues)

(haemoglobin) (oxygen) (oxyhaemoglobin)

⇒ Haemoglobin has high affinity for oxygen and this affinity is increased by fall in P_{CO_2} of blood.

Respiratory pigments	Description and animals containing it.
⇒ Haemocyanin	– A copper containing blue pigment occurs in plasma of crustaceans, snails and cephalopods.
⇒ Chloro-cruorin	⇒ It is an iron containing green pigment occur in plasma of annelids, polychaete (Sabella, Serpula).
⇒ Pinna-globin	⇒ It is manganese containing brown pigment occurs in blood fluid of some molluscs (Pinna)
⇒ Echino-chrome	⇒ Contains iron and occurs in the coelomic fluid of sea urchin (echinoderm).
⇒ Vanadium	⇒ Contain vanadium (rare metal found in sea water) Present in the blood of tunicates (Urochordates). Ciona contains vanadium in plasma and Ascidia contains in green blood corpuscles (Vanadocytes)
⇒ Myoglobin	⇒ Haemoglobin of muscle.
⇒ Molpadin	⇒ occur in Molpadia (Echinodermata)

⇒ At the alveolus in lungs, venous blood has low O_2 and is exposed to low P_{CO_2} of alveolus, thus O_2 diffuses into RBC and form oxyhaemoglobin (bright red). As CO_2 diffuses from blood to alveolus, blood P_{CO_2} falls increasing the further uptake of O_2.

⇒ Oxyhaemoglobin remain unchanged till it reaches the tissues where it dissociates readily to release oxygen.

Oxygen-haemoglobin dissociation curve (or O_2 dissociation curve): ⇒ the % of haemoglobin that is bound with O_2 is called percentage saturation of haemoglobin.

⇒ The relationship between the partial pressure of oxygen (P_{O_2}) and percentage saturation of the haemoglobin with (O_2) is graphically illustrated by a curve called oxygen haemoglobin dissociation curve (also called oxygen dissociation curve).

⇒ Under normal conditions the oxygen haemoglobin dissociation curve is sigmoid shaped or 's' shaped. The lower part of the curve indicates the dissociation of O_2 from haemoglobin.

⇒ The upper part of the curve indicates the acceptance of O_2 by haemoglobin. When the partial pressure of O_2 is 25 mmHg the haemoglobin gets saturated to about 50%, it means the blood contains 50% oxygen.

⇒ The partial pressure at which the haemoglobin saturation is 50% is called P_{50}. At 40 mmHg of partial pressure of O_2, the saturation is 75%. It becomes 95% when the partial pressure of O_2 is 100 mmHg.

⇒ Haemoglobin does not take up oxygen at low P_{O_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 O_2 increases the affinity of neighbouring haems for oxygen. This is known as Cooperativity between active sites.

Factors affecting oxygen dissociation curve:→

1) P_{O_2}:→ Decrease in partial pressure of O_2 shifts the curve to right.

2) Temperature:→ At higher temperature haemoglobin gives up O_2 more readily and the dissociation curve shifts to the right. This is of physiological importance because increased temperature means higher metabolic rate or higher oxygen requirement.

3) pH:→ Increase in Co_2 or other acids lowers the pH of plasma and shifts the dissociation curve to right. At high Co_2 concentration more O_2 is given up at any given O_2 pressure.

4) 2,3-diphosphoglyceric acid (2,3-DPG):→ is present in the RBC of adult blood, formed from 3-phosphoglyceric acid (a product of glycolysis via Embden-Meyerhof pathway).

⇒ It competes for O_2 binding sites in the haemoglobin molecule. As it binds the β-Chain of HbA (especially deoxy HbA) it causes the right shift of dissociation curve resulting in higher P_{50}. Each tetramer of haemoglobin (adult) binds with one molecule of 2,3 DPG. $HbO_2 + 2,3\text{-DPG} \rightleftharpoons (Hb\text{-}2,3\text{-DPG}) + O_2$ thus an increase 2-3 DPG Concentration shifts the reaction to right causing more unfolding of O_2 in tissues.

⇒ ATP binds to deoxyhaemoglobin to a lesser extent and some organic phosphates bind to minor degree.

⇒ Increase in P_{O_2}, lower Co_2 concentration, lower body temp^n, lower 2,3-DPG lower the P_{50}, and the curve moves to the left. In such a case, lower P_{O_2} is required bind a given amount of O_2. These play significant roles in oxygenation of blood in the lungs and its dissociation in the tissue.

Bohr effect:→ Shifting of the O_2 haemoglobin dissociation curve to the right by increasing Co_2 partial pressure is known as Bohr effect, it is named after the Danish physiologist Christian Bohr. (1855-1911).

⇒ The presence of Co_2 decreases the affinity of haemoglobin for O_2 and increases release of O_2 to the tissues.

⇒ The pH of the blood falls as its Co_2 content increases so that when the P_{Co_2} rises the curve shifts to the right and P_{50} rises.

Factors influencing Bohr effect:— all the factors which shift the O_2 haemoglobin dissociation curve to the right (mentioned above) increases the Bohr's effect.

Biological importance of Bohr's effect:→ In the tissue P_{O_2} is between 10 and 40 mm Hg and P_{Co_2} is high around 46 mm of Hg. So an active tissue will have high P_{Co_2}, low pH, and raised temperature leading to the dissociation of oxyhaemoglobin. Oxygenated blood passing through inactive cells does not give up O_2 even if the P_{O_2} is low but in active cells it readily gives O_2 as P_{Co_2} is very high.

(I) **Transport of Carbon dioxide**:→ CO_2 in gaseous form diffuses out of the cells into the capillaries, where it is transported in 3 ways.

(A) **In dissolved state**:→ Because of its high solubility, about 7% CO_2 gets dissolved in the blood plasma and is carried in solution to the lungs.

⇒ Deoxygenated (venous) blood and oxygenated (arterial) blood carry about 2.7 ml and 2.4 ml of CO_2 per 100 ml of blood in dissolved state in plasma respectively.

(B) **In the form of bicarbonate**:→ This dissolved CO_2 in the blood reacts with H_2O to form Carbonic acid. This reaction is very slow in blood plasma but occurs very rapidly inside RBC's because a zinc containing enzyme the Carbonic anhydrase present in RBC's, accelerates its reaction about 5000 times.

⇒ Due to this about 70% of CO_2 (about 2.5 ml / 100 ml of blood), recieved by blood from the tissues, enters the RBCs where it reacts with the water to form Carbonic acid (H_2CO_3).

⇒ Carbonic anhydrase is exclusively found in RBCs. All other tissues contain it in traces except stomach and pancreas which has considerable amount.

⇒ This enzyme not only speeds up the formation of H_2CO_3 but also rapidly converts it back to CO_2 and H_2O when blood reaches the lungs.

⇒ Almost as rapidly as formed all Carbonic acid of RBCs dissociates into (H^+) and bicarbonate ions (HCO_3^-).

⇒ The most of bicarbonate ions (HCO_3^-) formed within the RBCs diffuse out into the blood plasma along the concentration gradient.

⇒ Exit of bicarbonate ions, considerably change ionic balance between the plasma and the erythrocytes (RBCs). To restore the ionic balance, the chloride ions diffuse from the plasma into erythrocytes. This movement of chloride ions is called Chloride shift (Hamburger's phenomenon).

$$CO_2 + H_2O \longrightarrow H_2CO_3$$
$$H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

⇒ The chloride ions (Cl^-) inside RBC combine with potassium ion (K^+) to form potassium chloride (KCl), whereas bicarbonate ions (HCO_3^-) in the blood plasma combine with Na^+ to form Sodium hydrogen Carbonate ($NaHCO_3$).

(C) **As Carbaminohaemoglobin**:→

⇒ In addition to reacting with water, CO_2 also reacts directly with amine radicals (NH_2) of haemoglobin to form an unstable compound Carbamino-haemoglobin. This is a reversible reaction.

⇒ A small amount of CO_2 also react in the same way with the plasma protein. About 23% CO_2 is transported in combination with haemoglobin and plasma proteins.

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

Reduced haemoglobin — Carbamino haemoglobin.

Release of Gases at the tissue and the lung level:→ At the tissue level, O_2 is released from oxyhaemoglobin and CO_2 is picked up by plasma and RBC.

⇒ At the lung level, CO_2 is released from its three states so as to expel it out of the blood to alveoli and O_2 is picked up by haemoglobin.

(i) Release of O_2 from Oxyhaemoglobin at tissue level :-

$$HbO_2 \longrightarrow Hb + O_2$$

⇒ The dissociation of oxyhaemoglobin gives off its O_2 more readily in presence of increased P_{CO_2} or CO_2. It actually lowers the pH value (by increasing acidity) because of formation of carbonic acid. An active cell has high P_{CO_2} and low P_{O_2} and so get more O_2 than an inactive cell even if it has low P_{O_2}.

(ii) Release of CO_2 from all the 3 States at the lung level :-

⇒ At the lung alveolus the situation is just reverse of what it is at tissue level. The blood capillaries are subjected to high O_2 and low CO_2 concentrations. As a result there is speedy reversal of chemical events relasing of CO_2 and picking up O_2 simultaneously.

$$H_2CO_3 \xrightarrow[\text{anhydrase}]{\text{Carbonic}} H^+ + HCO_3^-$$

$$HbNHCOOH \rightleftharpoons HbNH_2 + CO_2$$

$$2NaHCO_3 \rightleftharpoons Na_2CO_3 + H_2O + CO_2$$

Haldane effect :- Binding of O_2 with Hb tends to displace CO_2 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 CO_2 transport than is the Bohr effect is promoting O_2 transport.

Haemoglobin acts as a buffer :- Addition of H^+ ions would make the blood acidic. However, most of the H^+ ions are neutralized by combination with Hb, which is negatively charged, forming acid haemoglobin. This reduces the acidity of the blood, and also releases additional O_2. If the blood becomes too basic, acid haemoglobin dissociates releasing H^+ ions :-

$$HHb \longrightarrow H^+ + Hb.$$

⇒ Thus the haemoglobin also acts as buffer, a substance that keeps the pH from fluctuating.

⇒ The haemoglobin of a foetus has a higher affinity for O_2 than the mother's haemoglobin. After birth, the foetal haemoglobin is gradually replaced by adult haemoglobin.

Regulation of Breathing :-

⇒ Human breathe about 12 to 14/minute.

⇒ It is regulated by 3 methods :- nervous regulation, mechanical control and chemical regulation.

(A) Nervous Regulation :-

⇒ The respiratory centre is composed of several widely dispersed groups of neurons located in the medulla oblongata and pons varolii.

⇒ The neurons are responsible for normal breathing which is rhythmic and automatic like the beating of heart. Unlike the beating of heart, breathing may be brought under voluntary and automatic control within limits.

⇒ The voluntary control system is located in the cerebral cortex and send impulses to the respiratory motor neurons via the corticospinal tracts.

⇒ The automatic system is located in the pons and medulla and the efferent output from this system to the respiratory motor neurons is located in the lateral and ventral portion of spinal cord.

⇒ The respiratory centre can be divided into a dorsal respiratory group and a ventral respiratory group in the medulla, an apneustic centre in the lower and mid-pons and a pneumotaxic centre in the dorsal most part of the pons. These centres are very sensitive to P_{CO_2} in the arteries and to the pH level of blood.

⇒ The medulla oblongata reacts to both Co_2 and pH levels which triggers the breathing process so that more O_2 can enter the body to replace the O_2 that has been utilized.

⇒ The medulla oblongata sends neural impulses down through the spinal cord and into the diaphragm and at the same time there is a message sent to the chest muscles to expand causing a partial vacuum to be formed in the lungs. The partial vacuum will draw air into the lungs.

(i) Dorsal respiratory group (Inspiratory centre) :→

⇒ It is present in the dorsal part of the medulla oblongata, and control the contraction of external intercostal muscles and muscles that flatten the diaphragm to cause inspiration.

⇒ The neurons of inspiratory centre are active for 2 seconds and then rest for 3 seconds.

(ii) Ventral respiratory group (expiratory centre) :→ It is present in the ventral part of the medulla oblongata and issues signals for both Inspiration (to diaphragm and external intercostal muscles) and expiration (to internal intercostal muscles and muscles of abdominal wall).

(iii) Pneumotaxic Centre :→ It is present in the dorsal part of the pons varolii and regulates the time of inspiration.

(iv) Apneustic centre :→ It lies in the lower part of pons Varolii and works in collaboration with pneumotaxic centre to control the depth of inspiration.

(B) Mechanical Control (Herring-Breuer reflex) :→

⇒ Stretch receptors (slow adapting pulmonary receptors) are located in the walls of bronchi and bronchioles and these are stimulated by overstretching of the lungs and these send impulses through vagus nerve fibres to expiratory centre which in turn 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.

(C) Chemical Control :→

⇒ A chemosensitive area is situated near respiratory centre in medulla where it is bathed with CSF.

⇒ Since the CSF lacks blood's ability to buffer pH changes, dissolved Co_2 changes the pH of CSF more than that of blood. 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 which detect the change in pH and Co_2 concentration.

⇒ They get stimulated by rise in P_{Co_2} or H^+ conc^n of arterial blood or a decline in the P_{O_2} conc^n and send impulses to chemosensitive area to increase the rate of contraction and relaxation (raise the inspiratory centre).

⇒ The level of Co_2 has more effect on breathing than does the level of O_2. If the Co_2 content of the blood drops below a certain critical level breathing stops.

⇒ In fact, O_2 level does not regulate breathing rate unless it falls dangerously low. Activation of the inspiratory centre due to low O_2 level is a last-ditch effort to increase breathing rate and restore normal O_2 levels.

⇒ Sudden Infant Death Syndrome (SIDS) in which a baby dies while asleep, may be caused by a failure of the chemoreceptors in major arteries and/or the brains respiratory centres to respond to low O_2 levels in arterial blood.

(Page 9)

Respiratory Disorders :→

1) Asphyxia :→ It is a condition caused by increase in CO_2 concentration in tissues that paralysed the respiratory centre. Breathing stops and death occurs.

2) Hypoxia :→ A term for lack of O_2 supply to the tissue.

A) Hypoxic hypoxia :→ The arterial Po_2 is low.

B) Anaemic hypoxia :→ The amount of O_2 carrying haemoglobin is reduced either by anaemia or because haemoglobin binding sites are already full.

C) Stagnant hypoxia :→ Caused by either intense local vasoconstriction or a poor cardiac output. The blood emerges from the vascular bed almost completely desaturated, although arterial blood may have a normal Po_2.

D) Artificial hypoxia :→ It results from shortage of O_2 in the air as at high altitudes.

Terms associated with breathing :→

1→ Eupnea :→ Normal breathing
2→ Hypopnea :→ Slow breathing
3) Hyperpnea :→ Rapid breathing.
4) Apnea :→ No breathing.
5) Dyspnea :→ Difficult breathing.
6) orthopnea :→ Painful breathing except in upright position
7) Tachypnea :→ Rapid shallow breathing.

3) Pulmonary Disorders :→

(i) Emphysema :→ A situation of 'short breath' due to breakdown of alveolar wall and reduction of respiratory area due to Smoking.

(ii) Asthma :→ Difficult breathing due to spasm in bronchial muscles and narrowing of bronchi.

(iii) Sleep Apnoe Syndrome :→ Person with snoring habit because respiratory tract closes.

(iv) Pneumonia :→ Infection of lung by Streptococcus pneumoniae and leads to an accumulation of mucus and lymph in alveoli impairing gas exchange.

(v) Whooping cough or pertussis :→ An infectious disease caused by Brodetella pertussis.

(vi) Pharyngitis :→ Attack of bacteria in the pharynx producing its inflammation.

(vii) Rhinitis :→ Infection in nasal chambers.

(viii) Sinusitis :→ Infection in sinus.

(ix) Bronchitis :→ Infection in bronchioles.

(x) Laryngitis :→ Infection in larynx.

(xi) Pleurisy :→ Inflammation of pleural membrane.

(xii) Tuberculosis :→ A disease of respiratory tract caused by Mycobacterium tuberculosis.

4) Occupational lung diseases :→ Persons working in industries involving grinding or stone breaking or stone etc. suffer from these diseases Sillicosis and asbestosis are the common occupational lung diseases.

5) Carbon monoxide poisoning :→ CO combines with haemoglobin far more readily than O_2 forming a relatively stable compound Carboxy haemoglobin, this reduces the amount of free haemoglobin available for carrying O_2 and starves the tissues of O_2.
⇒ Deficiency of O_2 causes headache, dizziness, nausea, paralysis and even death.

6) Diphtheria :→ It is caused by Corynebacterium diphtheriae resulting enlarged mucous membranes of the oropharynx, nasopharynx and larynx.
⇒ It may obstruct airways and cause death from asphyxiation.

7) Coryza (= common cold) :→ hundreds of viruses can cause coryza or the common cold, but a group of viruses called rhinovirus is responsible for about 40% of all colds in adults. Its symptoms include sneezing, excessive nasal secretion, dry cough and congestion. The uncomplicated common cold is not usually accompanied by a fever.

8) Influenza (flu) :→ It is also caused by a virus. Its symptoms include chills, fever, headache and muscular pain. Cold like symptoms appear as the fever subsides.

9) SARS (Severe Acute Respiratory Syndrome) :→
⇒ The first patient of SARS was reported on Feb 26/2003 in china. In India first patient of SARS was Prasheel Verde of Goa.
⇒ It is caused by Human Coronavirus (HCV) It is a new member of Influenza virus family which is considered as a mutant form of Influenza virus.
⇒ Human Corona virus has 2-10 days incubation period.