Breathing and Exchange of Gases

DISCLAIMER

Breathing and Exchange of Gases

- A normal human being experiences an involuntary inward and outward flow of air through their nose all the time. This breathing movement is continuous irrespective of other activities been performed by human beings.
- Human beings are multicellular organisms. Every living cell of our body requires energy to carry out its **metabolic processes.** This energy is derived by the oxidation of assimilated food in the cells (cellular respiration).
- Out of all the gases present in the atmospheric air, **oxygen** is required for cellular respiration whereas **carbon dioxide** is produced as a waste product during respiration.
- Oxygen cannot directly diffuse into every cell in human body, since all the cells are not in immediate contact with the atmospheric air.
- Hence, to fulfil the oxygen requirement of every living cell inside the body, the atmospheric air is taken in through a specialized organ system called as the respiratory system.
- Once the atmospheric air reaches a suitable exchange surface within the **respiratory system**, the oxygen is diffused into the blood which carries it further to every cell of the body.

Definition

Breathing: The mechanical process of movement of atmospheric air in and out of the lungs is called breathing.

Definition

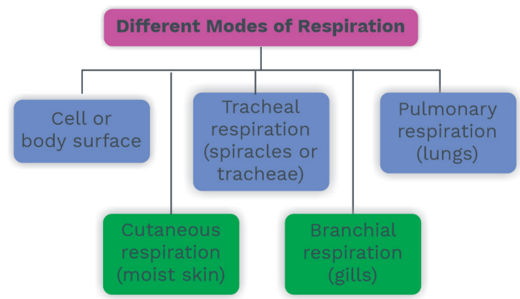
Cellular respiration: It is an enzyme catalysed process involving complete oxidation of organic nutrients present in a cell in the presence of oxygen to release energy.

Table. Difference between Breathing and Cellular Respiration

Breathing	Cellular Respiration
Mechanical process	Biochemical process
Not catalysed by enzymes	Enzyme catalyzed process
Energy is consumed	Energy is released
Extracellular	Intracellular

MODES OF RESPIRATION IN ORGANISMS

- Based on the habitats and levels of organisation, different animals have different modes of respiration:



Gaseous Exchange from Cell Surface

- Exchange of gases occurs between the cell or (organism) and its surrounding environment directly through the cell surface e.g., in **free-living acellular protists, poriferans, cnidarians and flatworms** oxygen dissolved in water passes into the cells through simple diffusion while carbon dioxide diffuses out of the cells into the surrounding water through the cell surface.

Cutaneous Respiration

- Skin functions as respiratory surface as in **earthworm, leech, *Nereis*, frog,** etc. In frog, along with pulmonary respiration, cutaneous respiration also occurs. In *Nereis* and earthworm, cutaneous respiration is the sole mode of respiration.

Tracheal Respiration

- It is a mode of gaseous exchange where a network of tubes called tracheae (singular trachea) connect the living tissues with the external air through lateral openings called spiracles e.g., terrestrial insects like **cockroach.**

Branchial Respiration

- Branchial respiration occurs with the help of gills. Gills are highly vascularized for exchange of gases. **Young tadpole, newt, axolotl larva, nymphs** of **dragonfly** exchange gases via external gills. Aquatic arthropods **(prawn),** aquatic molluscs **(*Unio*), fish** exchange gases through internal gills.

Pulmonary Respiratory System

- Pulmonary respiratory system consists of lungs e.g., **amphibians, reptiles, birds, mammals.**

Rack your Brain

Respiration in insects is regarded as direct. Why?

HUMAN RESPIRATORY SYSTEM

Functionally, the human respiratory system is divided into two parts:

- **The conducting zone:** It moistens, filter and warm the air before conducting it into the lungs.
  It includes nose, pharynx, larynx, trachea, bronchi, bronchioles, and terminal bronchioles.
- **The respiratory or exchange zone:** It is the main site for gaseous exchange between alveoli and pulmonary capillaries.
  It includes the respiratory bronchioles, alveolar ducts, alveolar sacs and the alveoli.

Nose

- The external portion of the nose (external nose) which is visible on the face is supported by frontal bone, nasal bone, maxillae, and hyaline cartilage which are covered with muscle and skin and also lined by a mucous membrane.

Definition

Human Respiratory System: It is the passage that carries atmospheric air to the site of gaseous exchange in the lungs.

Keywords

- Pharynx
- Trachea
- Bronchi
- Bronchioles
- Alveoli

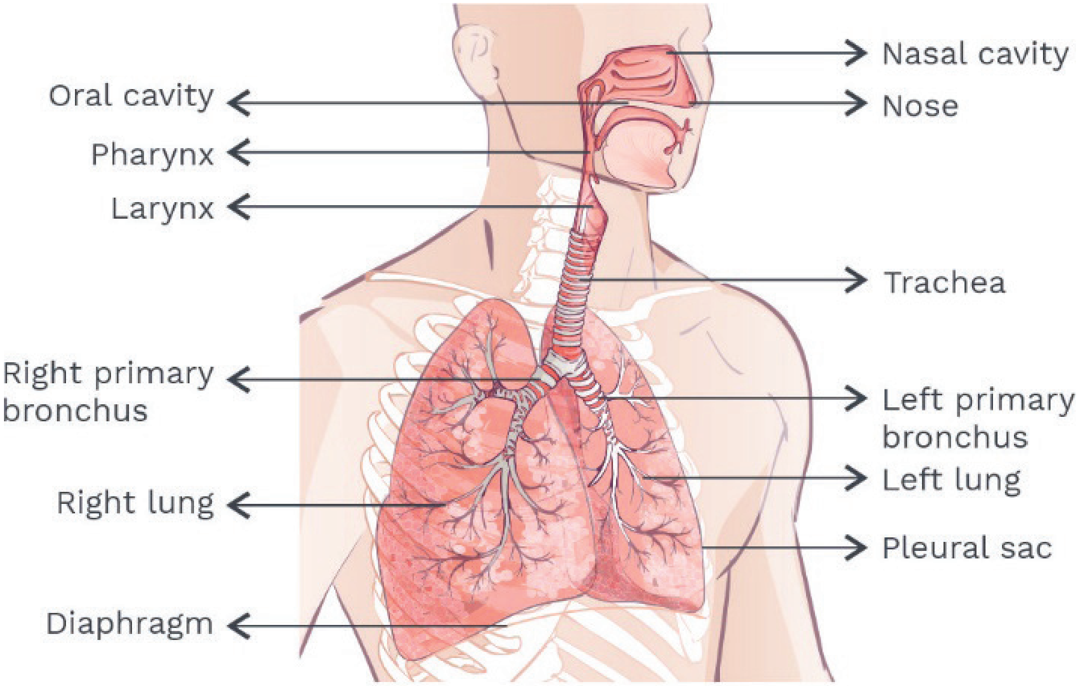


FIG. HUMAN RESPIRATORY SYSTEM

- There are two openings on the undersurface of external nose called as **external nares** or external nostrils which open into the nasal cavities.
- The entire nasal cavity contain **mucous membrane**. Mucus secreted by mucous membrane moistens and filters the air.
- Mucous membrane consists of **pseudo-stratified ciliated columnar epithelium** and numerous blood capillaries. The cilia move mucus containing trapped dust particles towards nasopharynx which is then spitted or swallowed whereas the blood capillaries warm the inhaled air.

Gray Matter Alert!!!

Nasal vestibule is the anterior portion of the nasal cavity just next to the external nostrils. The nasal cavity is divided into right and left sides by a vertical partition called as nasal septum. Nasal vestibule is lined by skin having coarse hairs called vibrissae which filters the incoming air.

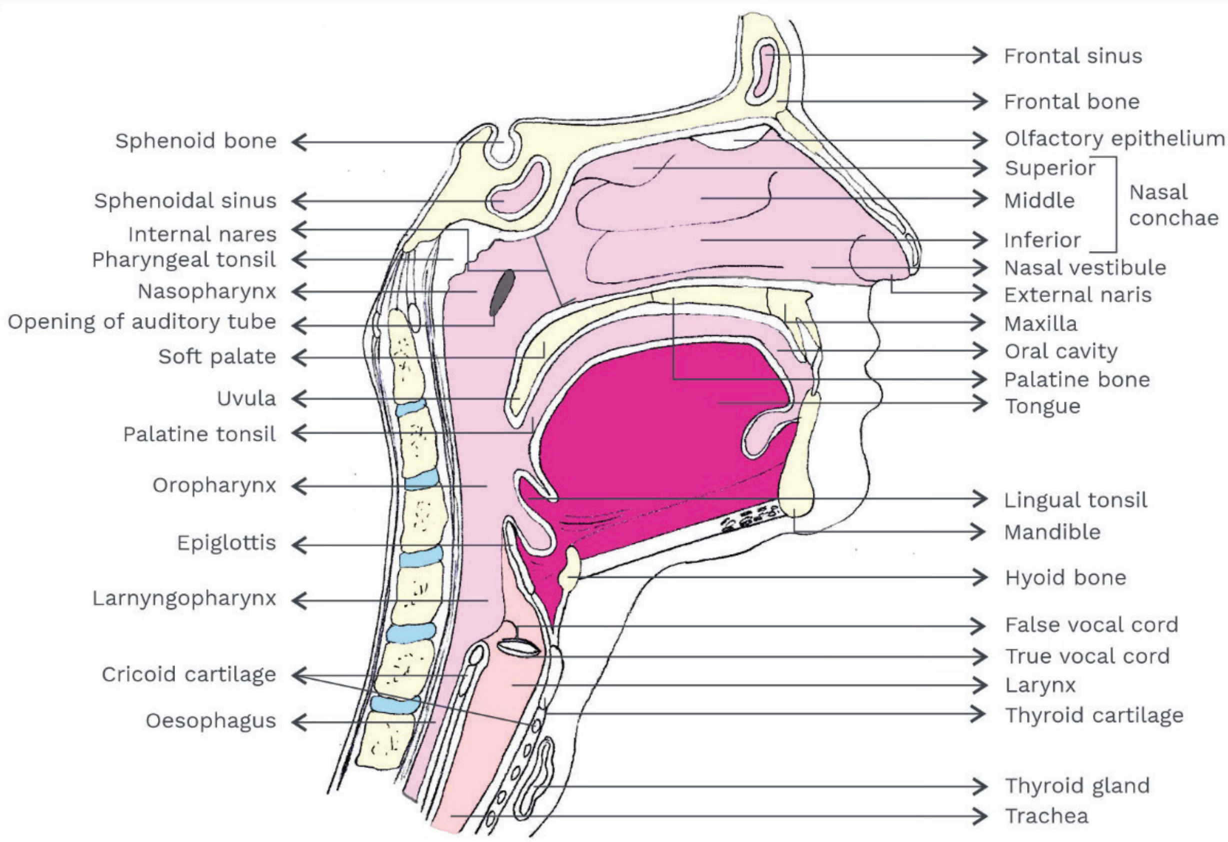
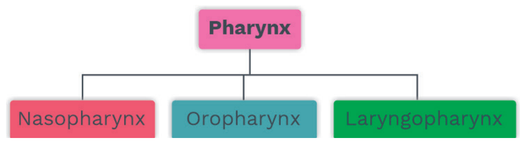


FIG. SAGITTAL VIEW OF HUMAN HEAD AND NECK DISPLAYING VARIOUS RESPIRATORY STRUCTURES

Pharynx

- Pharynx or throat (about 13 cm) lies just anterior to cervical vertebrae, just posterior to the nasal and buccal cavities and superior to the larynx and oesophagus.
- It serves as a common passageway for swallowed materials and air. Therefore, it is the most common site of infection.
- Pharynx is an important site for immunological reactions against foreign bodies as it houses the tonsils.
- The wall of pharynx is composed of skeletal muscles which help in **deglutition** (swallowing).



Pharynx is divided into three parts:

Nasopharynx

- It lies posterior to the nasal cavity, just after the internal nares and extends to the soft palate.
- Nasopharynx consists of a total of five openings: two openings of internal nares, two openings of eustachian tubes or auditory tubes or pharyngotympanic tubes (which exchange air between pharynx and middle ear to equalize air pressure) and the opening into the oropharynx.

Oropharynx

- It lies posterior to the oral cavity.
- Both air and swallowed materials (food and drinks) pass through the oropharynx.
- Paired palatine tonsils and paired lingual tonsils are present in the oropharynx.

Laryngopharynx

- Laryngopharynx or hypopharynx starts at the level of **hyoid bone.**
- At its end, laryngopharynx opens into posteriorly placed oesophagus (food pipe) and anteriorly placed larynx (voice box).

Larynx

- Larynx lies anterior to oesophagus between the fourth and sixth cervical vertebrae.

Definitions

- **Eustachian tubes:** Tubes connecting nasopharynx to the cavity of middle ear.
- **Glottis:** The opening of larynx.

Gray Matter Alert!!!

- Nasopharynx is lined with pseudo-stratified ciliated columnar epithelium.
- Pharyngeal tonsils called as adenoids are also present in its posterior wall.
- Oropharynx and laryngopharynx is also lined with non-keratinized stratified squamous epithelium as it is subjected to damage because of receiving site for air, food and drinks.

- Its mouth is called as the glottis.
- Hyoid bone is placed just above the larynx.
- Its wall consists of nine pieces of cartilage: Paired cartilages include arytenoid, cuneiform and corniculate cartilage whereas thyroid cartilage, epiglottis and cricoid cartilage occur singly.

Gray Matter Alert!!!

Arytenoid cartilage influence changes in position and tension of the true vocal cords.

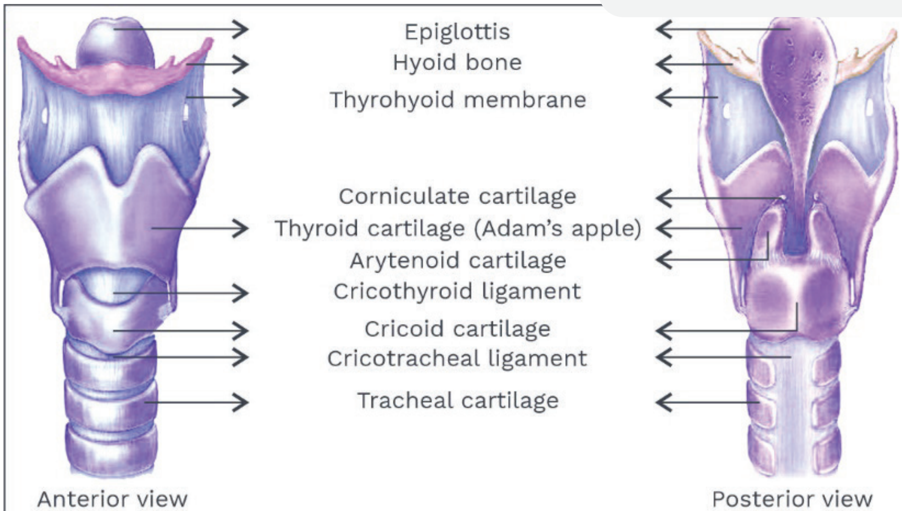


FIG. LARYNX

Thyroid cartilage

- It is formed by the fusion of two plates of hyaline cartilage.
- It is the largest among the laryngeal cartilages.
- Thyroid cartilage is connected to hyoid bone by thyrohyoid membrane (ligament).

Epiglottis

- It is leaf-shaped, elastic cartilage which is attached to the anterior rim of thyroid cartilage and hyoid bone.
- Its broad leaf-like part is free and covers the glottis to close the larynx during swallowing and thus provides a route to food and liquid into the oesophagus.

Definition

Adam's apple: Subcutaneous outgrowth of thyroid cartilage in males during puberty under the influence of male sex hormones.

Cricoid cartilage

- It is a ring of hyaline cartilage which is placed lower to thyroid cartilage and connects with the thyroid cartilage by cricothyroid ligament. It also connects with the first cartilaginous ring of trachea by cricotracheal ligament.

Arytenoid cartilage

- Located at the posterior, superior border of the cricoid cartilage are two triangular pieces of arytenoid cartilages which are mostly made up of hyaline cartilage.

Corniculate cartilage

- Corniculate cartilages are also called the cartilages of Santorini.
- They are two horn-shaped pieces made from elastic cartilage that are located at the apex of each arytenoid cartilage.

Cuneiform cartilage

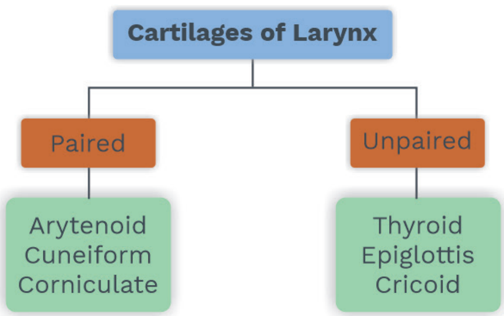
- They are two club-shaped, elastic cartilages anterior to corniculate cartilage and support the vocal folds. They connect arytenoid cartilage and epiglottis.
- Larynx consists of two pairs of folds of the mucous membrane: Ventricular folds or **false vocal cords** and vocal folds or **true vocal cords**.
- Larynx helps in sound production and hence, it is called sound box.
- vocal cords is called **rima glottidis**.

Trachea

- Trachea is located anterior to the oesophagus. It is about **12 cm long** and **2.5 cm wide.**
- It runs from the posterior end of larynx to the fifth thoracic vertebra, where it divides into the right and the left primary bronchi.
- The inner lining of the tracheal mucosa is made up of pseudo stratified ciliated columnar epithelium.

Gray Matter Alert!!!

Cricoid cartilage is the main site for tracheotomy i.e. for making an emergency airway.



Previous Year's Question

Arytenoid cartilage is found in
(1) hyoid
(2) sternum
(3) larynx
(4) nose

- Stacked one above the other are 16-20 incomplete, **C-shaped** hyaline cartilaginous rings that surround the trachea and are connected by dense connective tissue. Open part of the C-shaped cartilage rings faces posteriorly towards the oesophagus and makes the trachea non-collapsible.

Bronchi

- At the superior border of the fifth thoracic vertebra, trachea divides into right primary bronchus and left primary bronchus.
- The right primary bronchus is shorter (about 2.5 cm), wider and more vertical and enters the right lung.
- The left primary bronchus is longer (about 5 cm), narrower, bent and enters the left lung.
- Primary bronchi also contain incomplete cartilage rings and are lined by pseudostratified ciliated columnar epithelium.
- In the right lung, right primary bronchi divide into three secondary or lobar bronchi (superior, middle, inferior lobar bronchi) and in the left lung, left primary bronchi divide into two lobar bronchi i.e. one lobar bronchus for each lobe (superior and inferior lobar bronchi).
- Inside the lungs, lobar (secondary) bronchi divides into segmental (tertiary) bronchi which supply segments of both the lungs called as bronchopulmonary segments.
- Each such segment consists of many lobules which are surrounded by elastic connective tissue and a lymphatic vessel, an arteriole, a venule and a branch of lobular bronchiole.
- Lobular bronchioles divide further into terminal bronchioles which later form respiratory bronchioles. These respiratory bronchioles also contain some alveoli and in turn subdivide into several alveolar ducts (about 2-11).
- Alveolar ducts open in expanded areas called the

Rack your Brain

Why does an aspirated foreign particle more likely to enter in the right lung?

Gray Matter Alert!!!

Carina is an internal ridge area formed by the projection of the last tracheal cartilage and marks the point where trachea divides into primary bronchi. Carina is the most sensitive area for triggering a cough reflex.

Gray Matter Alert!!!

The diameter of the trachea is subject to change during the in and out flow of air. This is because of the presence of transverse smooth muscle fibres called trachealis muscle and elastic connective tissue in the fibromuscular membrane between the cartilage rings.

atria which leads into alveolar sacs. Alveolar sacs open into alveoli.

- An alveolus is lined by simple squamous epithelium which is supported by an elastic basement membrane.
- Numerous **type I alveolar cells** form a major part of simple squamous epithelium of the alveoli and forms the main site for gaseous exchange.
- **Type II alveolar cells** or septal cells are found between Type I alveolar cells which secrete alveolar fluid containing a mixture of lipoproteins and phospholipids called as **surfactant**.
- The surfactant reduces the tendency of alveolar collapse by reducing the surface tension of alveolar fluid.
- Alveolar wall also consists of dust cells or alveolar macrophages which phagocytise dust particles from alveolar spaces.
- Dense network of blood or alveolar capillaries having a single layer of endothelial cells and basement membrane is present on the outer surface of alveoli.
- The alveolar walls and the blood capillary walls form the respiratory membrane where gaseous exchange occurs between alveoli and the blood by the process of diffusion.
- The **respiratory membrane** is only 0.5 µm thick and consist of:
    - o A layer of surfactant.
    - o Alveolar wall which consists of type I and II alveolar cells along with alveolar macrophages.
    - o Basement membrane underlying alveolar wall.
    - o Thin interstitial space.
    - o Capillary basement membrane.
    - o Capillary endothelium.

Note: Between the cells of the alveoli are present minute spaces called Kohn pores (2-13 µm) which helps in communicating with adjacent alveoli.

Gray Matter Alert!!!

Cartilaginous rings are absent in bronchioles. They are present only till tertiary bronchi and initial bronchioles. As the cartilage rings decrease the amount of smooth muscles increase.

Rack your Brain

Which type of alveolar cells secrete surfactant?

Gray Matter Alert!!!

- Surfactant comprises of 80% phosphatidylcholine (PC), of which dipalmitoyl-PC, palmitoyl-myristoyl-PC and palmitoyl-palmitoleoyl-PC together are 75%.
- Lungs contain about 300 million alveoli. These alveoli provide a large surface area for gases exchange.

Lungs

- Lungs are the principal respiratory organs of human body.
- A pair of lungs is situated along the median line in the air-tight thoracic chamber which is enclosed by sternum (ventrally), ribs (laterally), thoracic vertebrae (dorsally) and diaphragm (posteriorly).
- Lungs lie against the ribs and extend from just above the clavicles to the diaphragm. They have a narrow apex to the medial one-third of the clavicles and a broad, concave inferior base that extends from the sixth costal cartilage, anteriorly to the tenth thoracic vertebra posteriorly that fits over the convex upper surface of the diaphragm.
- The costal surface of the lungs matches with the rounded curvature of the ribs. Blood vessels, nerves, lymphatic vessels and branches of trachea communicate with the lungs through a concave region called the **hilum**, present at their medial surface which is close to the **mediastinum**. These structures associated with the hilum constitute the root of the lungs and are held together by the pleura and connective tissue.
- Medially, a concavity is present in the left lung and is called as the **cardiac notch** which carries the lower and narrow apex of the heart.
- The lungs are covered by a double-layered serous membrane called as the **pleural membrane** (pleural sacs).
- The outer, superficial layer is called the parietal pleura which lines the wall of the thoracic cavity.
- The inner layer is the visceral pleura which covers the lungs. Anteriorly, the pleura extends about 5cm below the base of the lungs from the sixth costal cartilage and posteriorly to the twelfth rib.
- Pleural cavity or intrapleural space is a small (20 µm thick) space present between the parietal and visceral pleurae which is filled with a lubricating fluid called as the pleural fluid, secreted by the pleural membranes.

Definition

Mediastinum: The space or cavity in the thorax enclosed by the right and the left pleurae (laterally) and by sternum (ventrally) and by vertebral column (dorsally). It consists of heart, thoracic duct, oesophagus, thymus, trachea, cardiac and phrenic nerves.

Gray Matter Alert!!!

Anatomically, the right lung is shorter than the left lung since the diaphragm is placed higher on the right side below the right lung. This arrangement is to accommodate the liver that lies on the right side of the abdominal cavity and lower to the diaphragm.

Previous Year's Question

Lungs are enclosed in
(1) periosteum
(2) perichondrium
(3) pericardium
(4) pleural membrane

The pleural fluid

- Allows easy sliding movement of the two pleural membranes during breathing by reducing friction between them.
- Due to surface tension, it keeps the two pleural membranes adhered to each other.
- Absorbs any sudden jerk or shock.
- Maintains moisture in the lungs.
- Keeps the lungs pulled against the thoracic walls (expanded) due to the **negative pressure** present in it.
- The right lung has an oblique fissure which divides it into a superior lobe and an inferior lobe. It also has a **horizontal fissure** creating a middle lobe. Thus, the middle lobe is bordered superiorly by the horizontal fissure and inferiorly by the **oblique fissure**.
- The superior lobe and inferior lobe in the left lung are separated by an oblique fissure.

Pleural Membrane
- Visceral pleura
- Parietal pleura

Gray Matter Alert!!!

Pleural fluid is under a negative pressure of 4mmHg because of its siphoning by the lymphatics.

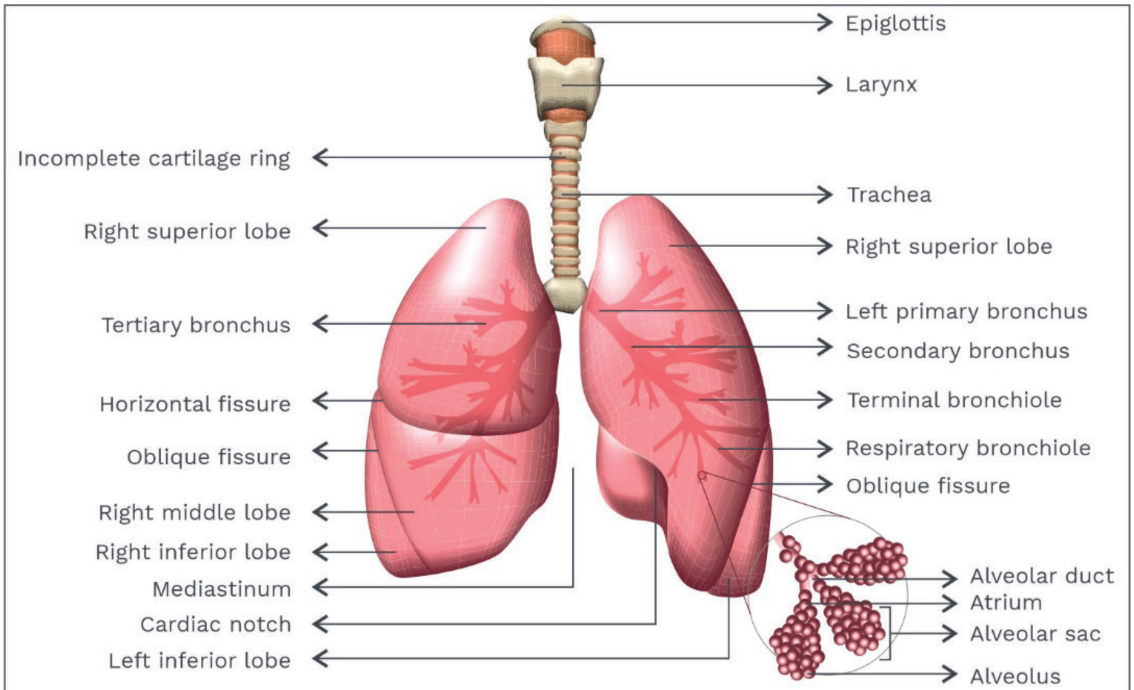
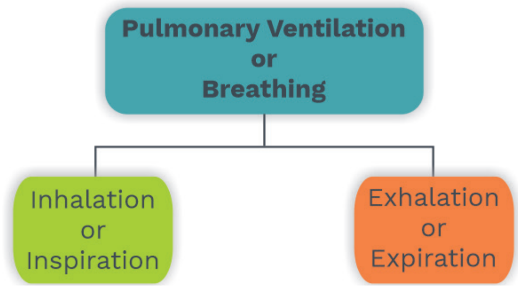


FIG. TRACHEA, LUNGS AND BRONCHIAL TREE

MECHANISM OF BREATHING

The process of respiration has the following steps:

- **Pulmonary ventilation or breathing**
  - It involves exchange of gases between atmosphere and alveoli by the process of inspiration and expiration.
- **External respiration or pulmonary respiration**
  - Gaseous exchange between alveoli and alveolar capillaries through the respiratory membrane.
  - Transport of gases by the blood.
- **Internal respiration**
  - Gaseous exchange between blood capillaries of systemic circulation and tissue cells.
  - Internal respiration provides oxygen to the cells for cellular respiration (breakdown of glucose to generate energy for other metabolic processes).



Inspiration

- Inspiration or inhalation is breathing in air.
- It is an **active process** which is carried out by increasing the size of the lungs caused by contraction of the inspiratory muscles.
- The movement of air into and out of the lungs is carried out by creating a pressure gradient between the lungs and the atmosphere.
- For this, the lungs must be expanded to increase their volume, which will in turn decrease the pressure in the lungs (intra-pulmonary pressure), i.e., there is a negative pressure in the lungs with respect to atmospheric pressure below the atmospheric pressure.
- Diaphragm is the most important muscle of inspiration. Diaphragm is a **dome-shaped** skeletal muscle which separates the thoracic cavity from the abdominal cavity. It is supplied by phrenic nerves. As the diaphragm contracts, its dome or convexity lowers which increases the vertical

Keywords

- Inspiration
- Expiration
- Diaphragm
- External intercostal muscles
- Internal intercostal muscles
- Elastic recoil

Gray Matter Alert!!!

Just before inhalation, the air pressure inside the lungs is 1 atmospheric pressure (1 atm = 101325 Pascals), or 760 mmHg which is equal to the pressure of atmospheric air. To bring atmospheric air into the lungs, the pressure inside the lungs should be less than the atmospheric pressure.

diameter of thoracic cavity (anterior-posterior axis). This increases the volume of the thoracic chamber.

- On contraction, the external intercostal muscles elevate the ribs, i.e. the ribs and the sternum move upward and outward, thereby increasing the antero-posterior and lateral diameters of chest cavity. This causes an increase in the volume of thoracic chamber in the dorso-ventral axis.

Note: During normal breathing, the intrapleural pressure or the pressure between the two pleural layers in the pleural cavity is always sub-atmospheric i.e. **756 mmHg** (atmospheric pressure is **760 mmHg**). Parietal pleural membrane is in contact with the thoracic wall. Parietal and visceral pleura normally adhere tightly due to sub-atmospheric pressure between them and due to the surface tension created by their moist adjoining surfaces.

- On simultaneous contraction of diaphragm and external intercostal muscles, the volume of thoracic cavity increases as the parietal pleura is pulled outward in all directions which in turn increases the volume of pleural cavity (as visceral pleura and lungs are pulled along with the parietal pleura) and thus decreases the intrapleural pressure to about **754 mmHg.**
- This increases the volume of lungs and thus, the alveolar (intra-pulmonary) pressure decreases from **760** to **758 mmHg.**
- Thus, a pressure difference is established between the alveoli and the atmosphere. The atmospheric air from outside (air at higher pressure, 760 mmHg) moves into the lungs (intra-intrapulmonary pressure, **758 mmHg**).
- On an average, a healthy person breathes **12-16 times in a minute.**

Gray Matter Alert!!!

Abdominal Breathing: During quiet inhalation, contraction of diaphragm is responsible for about 75% of the air that enters in the lungs.

Note: During normal inhalation, contraction of diaphragm produces a pressure difference of 1-3 mmHg and this leads to inhalation of about 500 ml of air.

During strenuous inhalation (heavy exercises) diaphragm contracts to produces a pressure difference of 100 mmHg resulting in inhalation of 2-3 liters of air.

Gray Matter Alert!!!

About 25% of the air that enters the lungs during normal quiet breathing is because of contraction of external intercostal muscles.

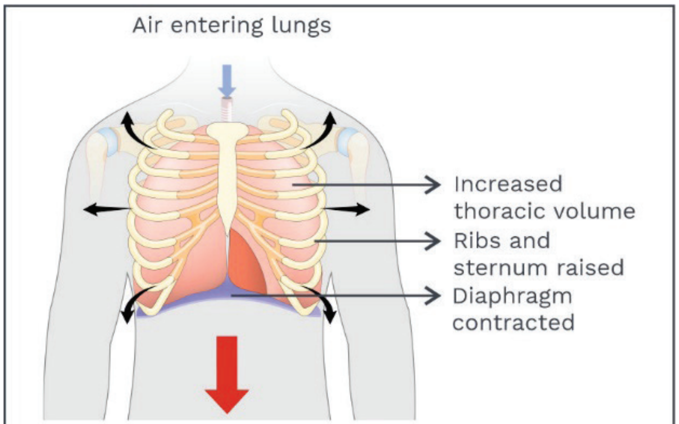


FIG. MECHANISM OF BREATHING (INSPIRATION)

Expiration

- Expiration or exhalation is breathing out air. Normal quiet exhalation is a passive process since there is no muscular contract involved.
- It simply is a result of **elastic recoil** (natural tendency to spring back after getting stretched) of the thoracic wall and lungs. This elastic recoil is because of recoil of stretched elastic fibres and inward pull of surface tension due to the alveolar fluid film.
- Exhalation begins with relaxation of inspiratory muscles. Diaphragm relaxes and because of its elasticity it moves superiorly back to its convex position.
- Relaxation of external intercostal muscles causes depression in the ribs. Thus, the vertical, antero-posterior and lateral diameter of thoracic cavity decreases, in turn, decreasing the lung volume. As a result, the alveolar pressure (intra-pulmonary pressure) increases upto about 762 mmHg, forcing the air to move from alveoli (with high pressure) to outside the body (with lower pressure).

Previous Year's Question

Pulmonary ventilation movements are due to
(1) costal muscles
(2) diaphragm
(3) wall of lungs
(4) costal muscles and diaphragm

Gray Matter Alert!!!

Forceful inspiration: During forceful inspiration, contraction of accessory muscles of inspiration magnifies the whole process of inhalation. These muscles include i.e. sternocleidomastoid muscles which elevate the sternum, the scalene muscles which elevate the first two ribs and pectoralis minor muscles that help in elevation of the third through fifth ribs.

Previous Year's Question

At the time of expiration, diaphragm becomes
(1) oblique
(2) normal
(3) flattened
(4) dome-shaped

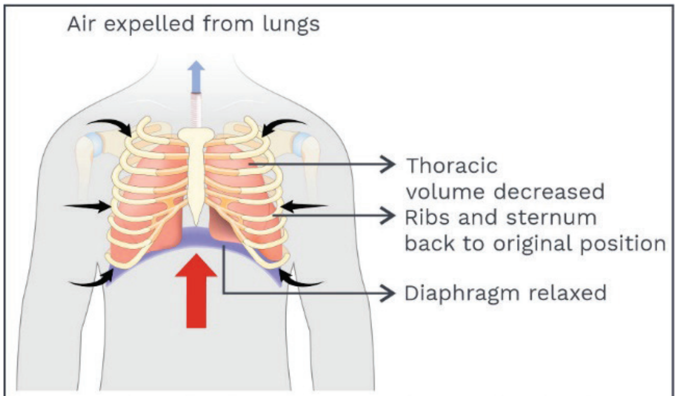


FIG. MECHANISM OF BREATHING (EXPIRATION)

Note : Breathing in Pregnant Females

Breathing in pregnant females is called **thoracic breathing**. During pregnancy, the breathing rate increases. Since the foetus grows in the uterus growing below the diaphragm, complete downward movement of diaphragm is restricted. Thus, the diaphragm can contribute only about 60% in ventilation. To compensate this, the work of external intercostal muscles increases to about 40% because of which thoracic movement becomes clearly visible (thoracic breathing).

Gray Matter Alert!!!

- **Hiccupping:** Irritation of the sensory nerve endings of the gastrointestinal tract stimulates spasmodic contraction of the diaphragm followed by a spasmodic closure of the rima glottidis, thus producing sharp sound on inhalation.
- **Sneezing:** An irritation of the nasal mucosa can stimulate spasmodic contraction of muscles of exhalation that forcefully expels air through the nose and mouth.

Previous Year's Question

The ventilation movements of the lungs in mammals are governed by

(1) muscular walls of lung
(2) diaphragm
(3) costal muscles
(4) both (2) and (3)

Gray Matter Alert!!!

Forceful expiration:
Only during forceful exhalation, there is contraction in the muscles of exhalation i.e. the abdominal and internal intercostal muscles which increases the pressure in the abdominal region and thorax. The contracted abdominal muscles move the inferior ribs downward and compress the abdominal viscera, thus, forcing the diaphragm to move upwards. Also, the ribs are pulled inferiorly because of the contraction of internal intercostal muscles.

RESPIRATORY VOLUMES

Physical capacity of lungs is measured by an instrument called as a spirometer. It measures the air which is blown out of the lungs. Air taken in or not blown out is not measured by the **spirometer.**

- **Tidal volume (TV):** It is the amount of air inspired or expired during normal breathing. Its value for a human is about **500 ml**. Whole inspired air does not reach up to lungs.
- **Inspiratory Reserve Volume (IRV):** It is the maximum amount of air inspired over tidal volume by deepest (forcible) inspiration. Its value is about **2500-3000 ml**.
- **Expiratory Reserve Volume (ERV):** It is the amount of air expired over tidal volume by most forceful expiration. Its value is about **1000-1100 ml**.
- **Residual Volume (RV):** It is the amount of air that remains inside lungs after forceful expiration. Residual volume cannot be exhaled out of lungs. Its value is about **1100-1200 ml**.

Respiratory Capacities

- **Inspiratory capacity (IC): IC = IRV + TV**

  It is the amount of air one can inspire by maximum distension or expansion of the lungs. It includes Inspiratory Reserve Volume and Tidal Volume (IC = IRV + TV). Its value is about **3500 ml** (3000 ml + 500 ml).
- **Expiratory capacity (EC): EC = ERV + TV**

  It is the amount of air expired after a normal tidal inspiration. It includes Expiratory Reserve Volume and Tidal Volume (EC = ERV + TV). Its value is nearly **1600 ml** (1100 ml + 500 ml).
- **Functional Residual capacity (FRC): FRC = ERV + RV**

  It is the amount of air that normally remains inside lungs after a normal expiration. It includes Expiratory Reserve Volume and Residual Volume

Rack your Brain

Which volume of air cannot be directly measured by a spirometer?

Gray Matter Alert!!!

The portion of air which remains in the respiratory track is called **anatomical dead-space.** Its value for a human is about 150 ml.

Previous Year's Question

Residual volume is

(1) lesser than tidal volume

(2) greater than inspiratory volume

(3) greater than vital capacity

(4) greater than tidal volume

(FRC = ERV + RV). Its value is about **2300 ml** (1100 ml + 1200 ml).

- **Vital capacity (VC): VC = IRV + ERV + TV**
  The maximum volume of air a person can breathe in after a forced expiration or the maximum volume of air a person can breathe out after a forced inspiration. It determines the efficiency of lungs. It includes Inspiratory Reserve Volume, Expiratory Reserve Volume and Tidal Volume (VC = IRV + ERV + TV). Its value is nearly **4600 ml** (3000 ml + 1100 ml + 500 ml).
- **Total lung capacity (TLC):**
  TLC = IRV + TV + ERV + RV
  Total volume of air accomodated in the lungs at the end of a forced inspiration. It includes Inspiratory Reserve Volume, Tidal Volume, Expiratory Reserve Volume and Residual Volume (TLC = IRV + TV + ERV + RV). Its value is **5800 ml** (3000 ml + 500 ml + 1100 ml+ 1200 ml).

Previous Year's Question

When 1500 ml air is in the lungs, it is called
(1) Residual Volume
(2) Inspiratory Reserve Volume
(3) Vital Capacity
(4) Tidal Volume

Rack your Brain

What is the reason for continuous gaseous exchange in the lungs even after a normal expiration?

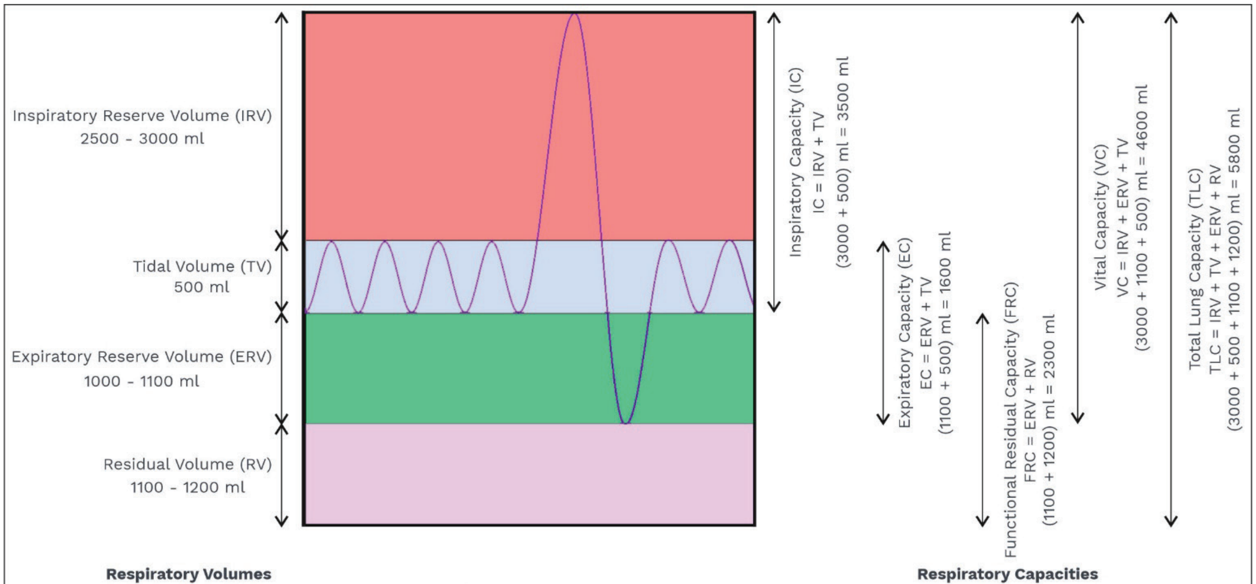


FIG. RESPIRATORY VOLUMES AND RESPIRATORY CAPACITIES

EXCHANGE OF GASES

It occurs at two levels: External respiration and internal respiration.

- **External respiration or pulmonary gas exchange**
  - It occurs between alveolar air and alveolar capillaries across the respiratory membrane.
  - Oxygen (O_2) present in the alveolar air has a pO_2 of 104 mmHg. It diffuses in the blood of pulmonary capillaries where pO_2 is only 40 mmHg (at rest).
  - This happens as a gas passively diffuses across a permeable membrane from the area where it has greater partial pressure to the area where its partial pressure is low. The greater the difference in partial pressure, the faster is the rate of diffusion.
  - Similarly, pCO_2 of alveolar capillaries is 45 mmHg at rest and pCO_2 of alveolar air is 40 mmHg and this makes CO_2 diffuse from deoxygenated blood of alveolar capillaries into the alveoli until the pCO_2 of blood lowers to 40 mmHg.
  - After inspiration and external respiration, the blood from alveolar capillaries that leaves the lungs and enters the left atrium has pO_2 = 95 mmHg and pCO_2 = 40 mmHg. This blood is transported to different cells of the body through aorta which continues with systemic arteries and finally systemic capillaries.
- **Internal respiration or systemic gas exchange**
  - It occurs between systemic capillaries and tissue cells throughout the body.
  - At rest, the pO_2 in systemic capillaries is 95 mmHg and pO_2 in tissue cells is 40 mmHg (due to the utilization of O_2 during cellular respiration to produce ATP).
  - Thus, O_2 diffuses in the tissue cells from the systemic blood capillaries. As a result, the pO_2 in systemic blood capillaries changes to 40 mmHg.

Previous Year's Question

The exchange of gases in the alveoli of the lungs takes place by

(1) passive transport
(2) active transport
(3) osmosis
(4) simple diffusion

Definition

Diffusing capacity: It is the volume of a gas that diffuses across per unit membrane area per minute when the partial pressure difference is 1 mmHg.

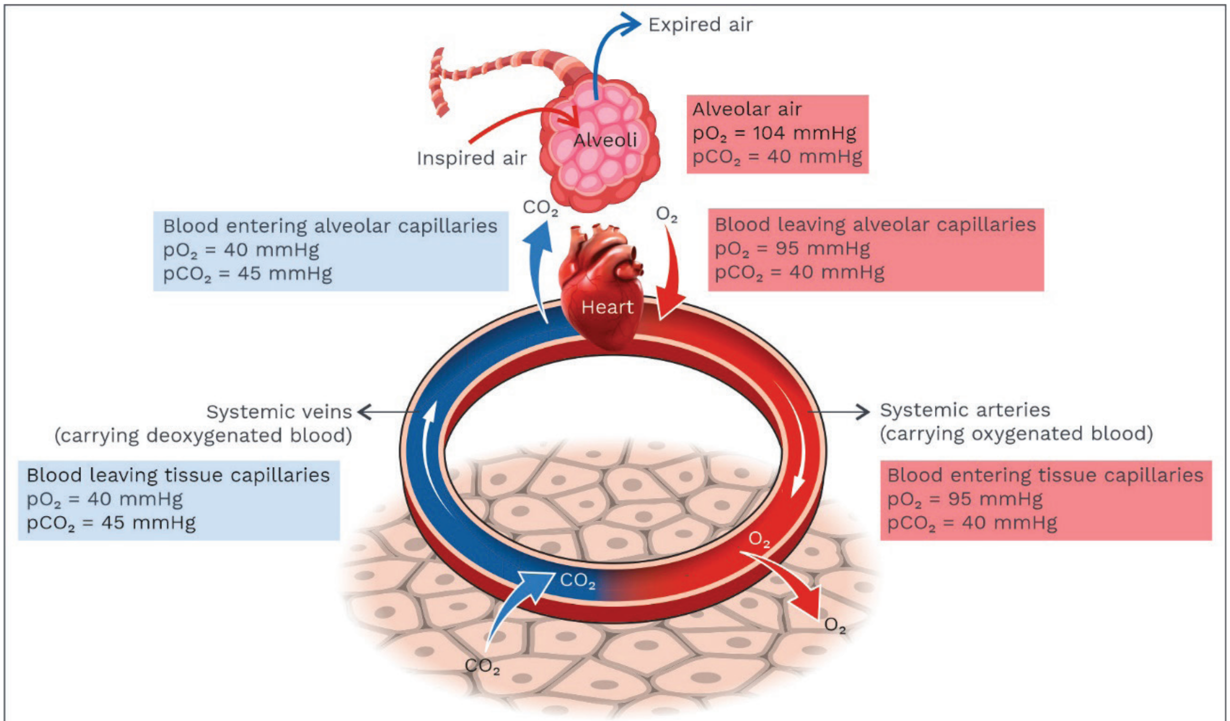


FIG. EXCHANGE OF GASES AT ALVEOLAR LEVEL AND BODY TISSUE LEVEL

- The pCO_2 in tissue cells is 45 mmHg due to continuous CO_2 production in the cells as a waste product of cellular respiration whereas pCO_2 in the systemic blood capillaries is 40 mmHg.
- As a result, CO_2 diffuses from the tissue cells into the systemic blood capillaries changing the pCO_2 to 45 mmHg in systemic veins.

Factors affecting the rate of internal and external respiration

- **Partial pressure difference of the gases**
  - The rate of diffusion of gases is directly proportional to the partial pressure difference of the gases across a semipermeable membrane.
  - At rest, the pO_2 is higher in the alveoli (104 mmHg) and lower in the alveolar capillaries (40 mmHg). Thus, O_2 diffuses in the alveolar blood.

Gray Matter Alert!!!

At rest, the tissue cells in a person, on an average, uses only 25% of the O_2 present in oxygenated blood. That means, deoxygenated blood retains 75% of the O_2 diffused in it during external respiration.
While exercising, more O_2 can be diffused from the blood into the cells. This lowers the O_2 content of deoxygenated blood below 75%.

- Similarly, during normal breathing, pCO_2 is higher in the alveolar capillaries (45 mmHg) and lower in the alveoli (40 mmHg). So, CO_2 simply diffuses in the alveoli through the respiratory membrane. Carbon dioxide has a volume share of 0.04% in the atmosphere.
- During exercise, the differences between pO_2 and pCO_2 in alveolar air and pulmonary blood capillaries increases.
- The larger partial pressure differences accelerate the rates of gas diffusion.

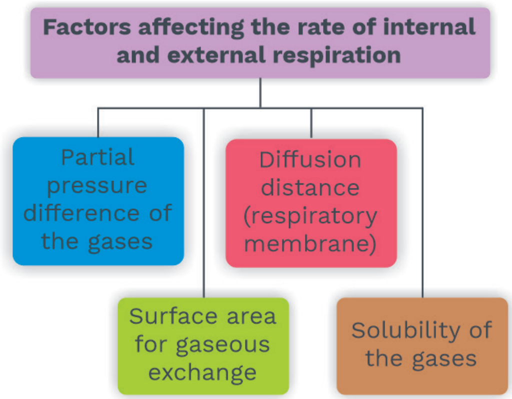


Table. Partial Pressures (in mmHg) of Oxygen and Carbon dioxide at different parts of the body Involved in Diffusion in Comparison to those in Atmosphere

Respiratory Gas	Atmospheric Air	Alveoli	Deoxygenated Blood	Oxygenated Blood	Tissues
O_2	159	104	40	95	40
CO_2	0.3	40	45	40	45

- At high altitudes, the atmospheric pressure decreases and so does the pO_2 in the alveoli. Thus, oxygen diffuses slowly into the blood at high altitude (high altitude sickness) resulting in headache, nausea, dizziness, fatigue, shortness of breath.

- **Surface area for gaseous exchange**
  - The greater the surface area of respiratory membrane, the greater is the rate of external respiration.
  - This explains the huge surface area of alveoli (about 750 square feet) and presence of numerous capillaries surrounding each alveolus such that about 900 mL of blood can participate in gaseous exchange at any given time.

Gray Matter Alert!!!

Drugs like morphine slow down the ventilation, thereby decreasing the pO_2 and pCO_2 in the alveoli and thus, lowering the gaseous exchange.

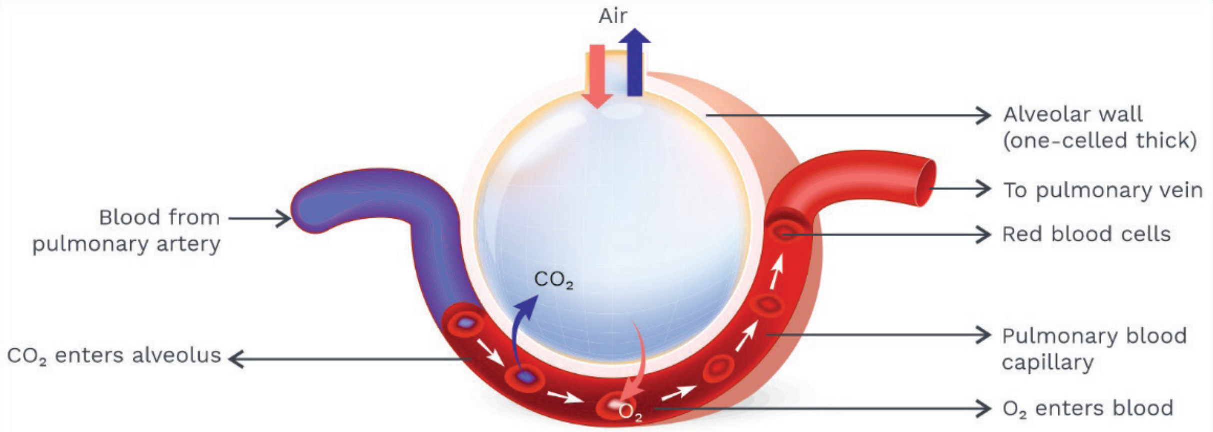


FIG. DIAGRAMMATIC REPRESENTATION OF GASEOUS EXCHANGE BETWEEN ALVEOLUS AND ALVEOLAR CAPILLARY

- **Diffusion distance**
  - The lesser the thickness of respiratory membrane, the quicker is the diffusion of gases. In addition to this, the narrow capillaries allow only a single line of RBCs to pass through them which further reduces the diffusion distance.
  - The respiratory membrane (0.5 mm) through which gaseous exchange occurs consists of:
    - Alveolar endothelium (inner wall of alveolar capillaries)
    - Endothelial basement membrane of alveolar endothelium
    - Interstitial space
    - Epithelial basement membrane of alveolar epithelium
    - Alveolar epithelium (inner membrane of alveoli)
- **Solubility of the gases**
  - O_2 is expected to diffuse across the respiratory membrane about 1.2 times faster because of its lower molecular weight. But the solubility of CO_2 in plasma is 20-25 times higher than that of O_2. So, the net outward CO_2 diffusion occurs 20 times faster than net inward O_2 diffusion.

Gray Matter Alert!!!

Alveoli are highly vascularized (presence of numerous blood capillaries) for maximum gaseous exchange.

Previous Year's Question

In lungs, the air is separated from the venous blood through

(1) transitional epithelium + tunica externa of blood vessel
(2) squamous epithelium + endothelium of blood vessel
(3) squamous epithelium + tunica media of blood vessel
(4) none of the above

Note: Diver's Paralysis or Caisson Disease or Bends Disease:

Caisson disease or **decompression sickness** is experienced by deep sea divers (SCUBA-Contained Underwater Breathing Apparatus, diving) in case of a rapid ascent from a deep dive. Atmospheric air contains about 78% of nitrogen gas. When we inhale atmospheric air, we inhale nitrogen along with it.

At atmospheric pressure (above sea level), nitrogen is insoluble in water. Therefore, nitrogen does not diffuse through the respiratory membrane in the alveoli and is exhaled out.

At a depth of more than 10,000 feet (high pressure), nitrogen (present in the diver's cylinder) becomes soluble in water (Henry's Law). As its solubility increases, its diffusing capacity also rises. Thus, nitrogen inspired along with the air present in the diver's cylinder diffuses across the respiratory membrane and gets dissolved in the blood.

If the diver comes up quickly, the nitrogen dissolved in the blood will again become insoluble and create nitrogen bubbles causing air embolism (blockage of blood supply by air bubbles in the blood vessels).

Additional information:

Rapid and shallow breathing is more efficient during exercise than slow and deep breathing

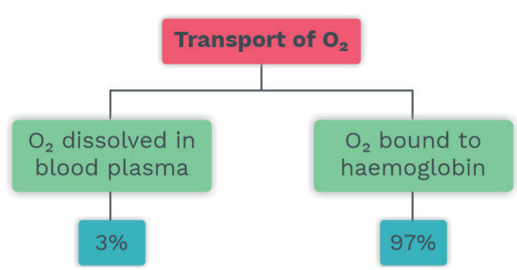
Partial pressure of oxygen in the alveolar blood capillaries carrying deoxygenated blood is 40 mmHg, whereas in the alveoli it is 104 mmHg. If there would have been a stable equilibrium across the respiratory membrane, then pO_2 equal to 72 mmHg should have been established in both the alveoli and the blood capillaries. But the exchange of gases across the respiratory membrane shows a dynamic equilibrium. It is known that the effect of frequency is more than the effect of amplitude to perform more work in less time i.e. faster the frequency, faster is the work done. Thus, exercises will be efficiently performed with rapid and shallow breathing rather than with slow and deep breathing.

TRANSPORT OF GASES

Transport of Oxygen

O_2 is transported by blood in two ways:

- **Oxygen dissolved in blood plasma**
  - O_2 does not easily dissolve in water. Only about 3% of inhaled O_2 gets dissolved in blood plasma.
- **Oxygen bound to haemoglobin**
  - About 97% of O_2 diffused in blood gets bound to haemoglobin (respiratory pigment) in red



blood cells to form oxyhaemoglobin (HbO_2). Haemoglobin has a heme (iron) part which has four atoms of iron and a protein or globin part.

- The iron is in the form of Fe^{2+} (ferrous) ions and each atom of iron is capable of binding to a molecule of O_2. Thus, a haemoglobin molecule can bind to four molecules of oxygen to form oxyhaemoglobin. This reaction is reversible.

$$\underset{\text{Reduced haemoglobin}}{Hb} + \underset{\text{Oxygen}}{O_2} \underset{\text{In systemic capillaries}}{\overset{\text{In alveolar capillaries}}{\rightleftharpoons}} \underset{\text{Oxyhaemoglobin}}{HbO_2}$$

- Oxyhaemoglobin is weakly acidic. It binds to potassium ions to form $KHbO_2$.
- Normally, 1 gram of haemoglobin (Hb) binds with 1.34 ml of O_2 and a normal person has about 15 grams of haemoglobin in 100 ml of blood. Thus, on an average 100 ml of blood in the pulmonary veins carry about 20 ml (19.4 ml i.e. 97% bound to haemoglobin and 0.6 ml i.e. 3% dissolved in blood plasma) of O_2.
- At the tissue level, only 25% oxygen is unloaded from the 20 ml oxygen carried by 100 ml of blood. In other words, 5 ml of oxygen is transported to tissues by 100 ml of blood (Oxygen unloading).
- This means, that the deoxygenated blood from the tissues are sent to the heart via systemic veins that carries 15 ml of O_2 in 100 ml of blood which are then sent to the lungs. Thus, in the lungs, only 5 ml of O_2 is loaded in 100 ml of blood (oxygen loading).
- During exercise, the cells utilise more O_2. Thus, the pO_2 at the tissue level decreases. The blood at tissue level has only 4.4 ml of O_2 per 100 ml of blood. About 15 ml of O_2 is transported by haemoglobin during exercise.

- **The Relationship between Haemoglobin and**

Previous Year's Question

Haemoglobin is a type of
(1) carbohydrate
(2) respiratory pigment
(3) vitamin
(4) skin pigment

Gray Matter Alert!!!

Carbon monoxide (CO) poisoning: CO gas is found in tobacco smoke, exhaust fumes automobiles, space heaters and gas furnaces. It has over 200 times higher affinity with haemoglobin as compared to oxygen. Exposure of Hb to CO at a concentration of only 0.5 mmHg reduces the oxygen carrying capacity of blood by 50% causing carbon monoxide poisoning by the formation of carboxyhaemoglobin.

Partial Pressure of Oxygen (pO_2)

- Combination of haemoglobin with O_2 is directly proportionally to the pO_2.
- Higher the pO_2, higher is the binding between O_2 and haemoglobin.
- The haemoglobin is said to be fully saturated with O_2, when reduced haemoglobin is completely converted into oxyhaemoglobin (HbO_2).
- Partially saturated haemoglobin consists of a mixture of haemoglobin and oxyhaemoglobin.
- When haemoglobin binds with four molecules of O_2, it is said to be 100% saturated, whereas 50% saturation of haemoglobin denotes that each haemoglobin molecule has bound two molecules of O_2.
- Thus, percent saturation of haemoglobin is an expression of the average saturation of haemoglobin with O_2.

• **Oxygen-haemoglobin dissociation curve**
  - Oxygen-haemoglobin dissociation curve illustrates the relationship between the percent saturation of haemoglobin and pO_2 i.e. it represents the rate of saturation of haemoglobin w.r.t. partial pressure of O_2. Here, the percentage saturation of haemoglobin is plotted against pO_2 in mmHg which gives an S-shaped oxygen dissociation curve or sigmoid curve. Since the relationship between oxygen and haemoglobin is not shown by a straight line, it means this rate is not uniform.
  - One haemoglobin molecule binds with four oxygen molecules.
  - The given figure shows the relationship between pO_2 and the percent saturation of haemoglobin.

Definition

Carboxyhaemoglobin: It is a stable compound formed due to a reaction between carbon monoxide and haemoglobin.

Rack your Brain

Which form of iron is found in haemoglobin?

Previous Year's Question

Haemoglobin is having maximum affinity with
(1) CO_2
(2) CO
(3) O_2
(4) NH_3

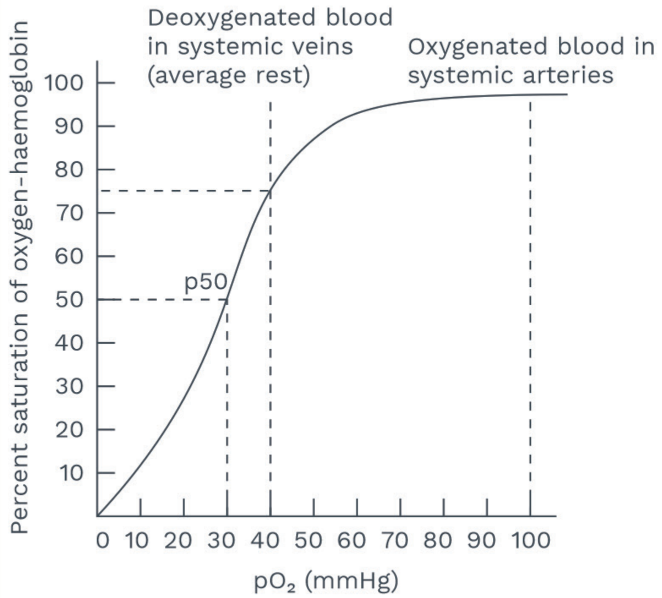


FIG. OXYGEN-HAEMOGLOBIN DISSOCIATION CURVE

- Haemoglobin readily binds with O_2 in the pulmonary or alveolar capillaries as the pO_2 becomes high.
- In the tissue capillaries, the pO_2 is low. Thus, the percent saturation of haemoglobin with O_2 is low.
- At high pO_2 of about 100 mmHg and above, haemoglobin gets almost 100% saturated with O_2.
- At pO_2 of 40 mmHg (average pO_2 of tissue cells in a person at rest) haemoglobin is 75% saturated with O_2. Thus, only 25% of the O_2 in tissue capillaries gets unloaded from haemoglobin and is used by cells, when the body is at rest.
- When pO_2 is between 60-100 mmHg, haemoglobin is more than 90% saturated with O_2.
- This shows that even at pO_2 60 mmHg, the blood is nearly fully loaded with O_2.
- At a pO_2 of 40 mmHg, the haemoglobin is about 75% saturated with O_2.

Note: When oxygen molecule starts to join with haemoglobin molecule, the first, second and third molecules of oxygen join very fast (accelerated joining) i.e. upto 25%, 50% and 75% saturation of haemoglobin.

This is due to an increase in pO_2 as we move along the X-axis (as O_2-Hb affinity is directly proportional to pO_2). But from 75% to 97% saturation of haemoglobin, i.e. the joining of fourth molecules of oxygen is decelerated. This is because the valence shell electron pair of the fourth oxygen molecule experience repulsion from the valence shell electron pairs of the rest three oxygen molecules. Even though slow, the fourth molecule of oxygen finally joins the haemoglobin as oxygen-haemoglobin affinity is more than the valence shell electron pair repulsion.

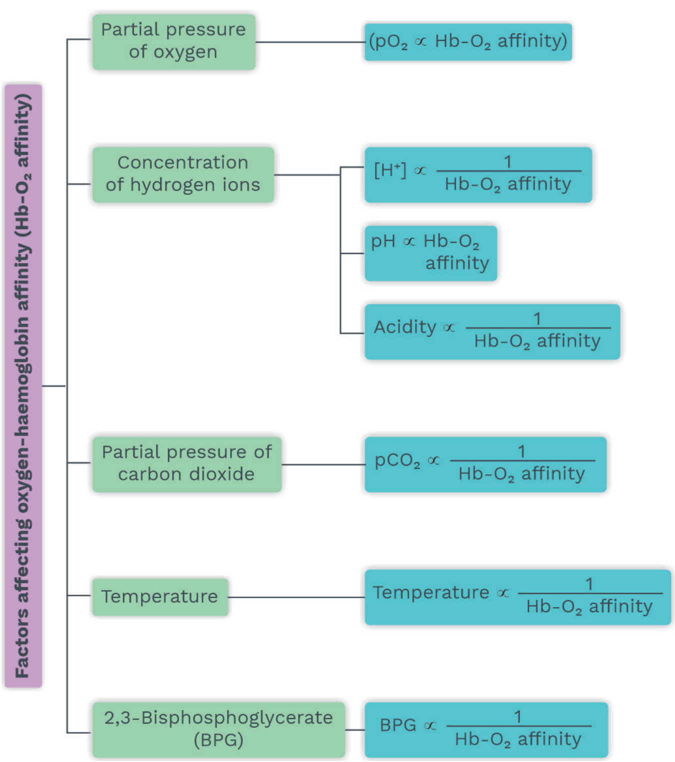
Gray Matter Alert!!!

100% saturation of haemoglobin with oxygen is rare. The maximum haemoglobin saturation is 95%.

- At pO_2 of 30 mmHg, only 50% saturation is present (p50) and at further lower pO_2 of 20 mmHg, O_2 saturation of haemoglobin lowers to 35%.
- This shows that between 40 to 20 mmHg, large amount of O_2 is released from haemoglobin as occurs in tissue cells.

Factors Affecting the Affinity of Haemoglobin for Oxygen:

- Along with pO_2, many other factors also affect the affinity with which haemoglobin binds to O_2.
- These factors shift the entire oxygen dissociation curve to either left (higher affinity of haemoglobin for oxygen) or right (lower affinity of haemoglobin for oxygen).



- **Partial pressure of Oxygen**
  - As the pO_2 increases, the affinity of haemoglobin for O_2 also increases and O_2

Rack your Brain

Why are people able to perform well even at higher altitudes?

Rack your Brain

Why athlete training camps are set at higher altitudes?

binds readily with haemoglobin. Thus, a decrease in the pO_2 will shift the curve to right.

- **Acidity (pH)**
  - An increase in acidity (i.e., a lower value of pH or high concentration of H^+ ions) decreases the haemoglobin's affinity for O_2 and thus, O_2 dissociates more rapidly from haemoglobin. The main acidic products of metabolism in tissues are lactic acid and carbonic acid.
  - At any given pO_2, the oxygen haemoglobin dissociation curve will shift to the right if the pH decreases.
- **Partial pressure of Carbon Dioxide**
  - As pCO_2 rises, haemoglobin releases O_2 more readily, i.e., shifts the curve to the right.
  - The pH and pCO_2 are related factors. When CO_2 enters the blood, it is temporarily changed to carbonic acid (H_2CO_3) by a biochemical reaction catalysed by carbonic anhydrase enzyme.

Previous Year's Question

Reduction in pH of blood will

(1) reduce the rate of heartbeat

(2) reduce the blood supply to the brain

(3) decrease the affinity of haemoglobin with oxygen

(4) release bicarbonate ions by the liver

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \xrightleftharpoons{\text{Carbonic anhydrase}} \underset{\text{Carbonic acid}}{H_2CO_3} \xrightleftharpoons{\text{Carbonic anhydrase}} \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

  - In the blood, carbonic acid (H_2CO_3) dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO^-_3) and as concentration of H^+ ions increases, the pH of blood decreases.
  - Therefore, increase in pCO_2 causes an increase in H^+ ion concentration in blood and thus decrease the blood pH. Under these conditions, O_2 is released from haemoglobin.

Bohr Effect

- It is described by Christian Bohr (Danish physiologist) in 1904.
- Bohr Effect explains the dissociation of CO_2 from haemoglobin due to an increase in the pCO_2 in blood.
- At the tissue level, CO_2 is produced in the cells

Previous Year's Question

Oxygen binding to haemoglobin in blood is

(1) directly proportional to the concentration of CO_2 in the medium

(2) inversely proportional to the concentration of CO_2 in the medium

(3) directly proportional to the concentration of CO in the medium

(4) independent of the concentration of CO in the medium

because of cellular respiration. The pCO_2 in the cells is 45 mmHg. This CO_2 diffuses in the blood capillaries present in close proximity to the tissue cells as the pCO_2 in the capillaries is 40 mmHg.

- As CO_2 enters the plasma and RBCs, it reacts with water to form carbonic acid which readily dissociates to form H^+ ions and bicarbonate ions.
- When H^+ ions bind to amino acids in haemoglobin, they alter its structure slightly, thereby decreasing its oxygen-carrying capacity. Thus, lowered pH (increased H^+ ions concentration) makes more O_2 available for tissue cells.
- Increase in the concentration of CO_2 and H^+ ions in the blood capillaries makes the O_2 dissociate from Hb. This is Bohr effect, the free O_2 then enters in the tissue cells.

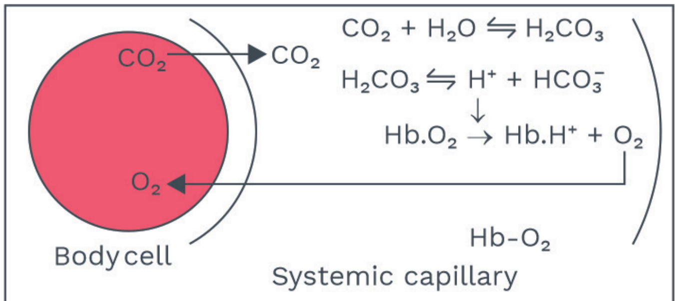


FIG. BOHR EFFECT

- **Temperature**
  - Within a limited increase in temperature, there is an increase in dissociation of haemoglobin with O_2.
  - Contraction or working of muscle fibres (during exercise) generates heat as a by-product which increases the body temperature slightly. Metabolically active cells use more O_2 and liberate more acids and heat.
  - This O_2 is utilized by dissociation of oxyhaemoglobin. The released O_2 is utilised by active cells.
  - Thus, increase in temperature shifts the

Keywords

- Bohr Effect
- Haldane Effect
- Double Bohr Effect
- Chloride Shift
- Foetal Haemoglobin

Previous Year's Question

Left shift of oxyhaemoglobin curve is noticed under
(1) normal temperature and pH
(2) low temperature and high pH
(3) low pH and high temperature
(4) low pH and low temperature

oxygen dissociation curve to the right.

- **BPG-(2,3-bisphosphoglycerate)**
  - Previously called DPG (or 2,3-diphosphoglycerate), the BPG is found in RBCs and it decreases the affinity of haemoglobin for O_2 and thereby helps in unloading O_2 from haemoglobin.
  - BPG is a by-product of glycolysis (breakdown of glucose in cells to produce ATP).
  - The bond between heme group of haemoglobin and O_2 becomes less tight when BPG binds with the terminal amino groups of the two b globin chains of haemoglobin.
  - A greater level of BPG shifts the curve to the

Gray Matter Alert!!!

People living at higher altitudes have higher levels of BPG.

Additional information: Foetal Haemoglobin

Partial pressure of oxygen (pO_2) in the maternal blood is 104 mmHg whereas in the foetal blood is 80 mmHg.

The partial pressure of carbon dioxide (pCO_2) in the maternal blood is 40 mmHg and that in the foetal blood is 45 mmHg. Thus, carbon dioxide diffuses from the region of its high concentration (foetal blood) to the region of its low concentration (maternal blood). This increase in the concentration of carbon dioxide in the maternal blood causes a decrease in the oxygen-haemoglobin affinity so that one molecule of oxygen detaches from the maternal haemoglobin and diffuses in the foetal blood (**Bohr effect**).

Foetal haemoglobin has two alpha subunits and two gamma subunits which give it greater affinity for oxygen as compared to the affinity of adult haemoglobin with oxygen (At lower pO_2, foetal haemoglobin can carry up to 30% more O_2 than maternal haemoglobin).

Oxygen binds with foetal haemoglobin (HbF) in the foetal blood to form foetal oxyhaemoglobin ($Hb\text{-}O_2F$). And this blood reaches the foetal tissues.

In the foetal tissues, carbon dioxide from the cells diffuses out in the systemic capillaries down its concentration gradient. Again, due to Bohr effect, CO_2 displaces O_2 from the foetal blood and forms **foetal carbamino-haemoglobin**. The displaced oxygen in turn diffuses in the cells.

Thus, in the foetus, dissociation of oxygen occurs twice (first at placental level and second at the tissue level). This is called **Double Bohr Effect**. Foetal oxyhaemoglobin shifts the oxygen haemoglobin dissociation curve to the left.

right.

Reason for the shift of oxygen dissociation curve

- Conditions like increased pCO_2, decreased pH, increased H^+ and increased temperature in the blood lowers the oxygen-haemoglobin affinity. To achieve the same saturation values, the body requires more pO_2 values. Thus, with the increase in pO_2, the oxygen-haemoglobin affinity also increases. So, whatever loss of oxygen-haemoglobin affinity has occurred due to any of the above conditions will be compensated for by the increase in the pO_2 w.r.t. the original curve i.e. the curve shifts to the right side.

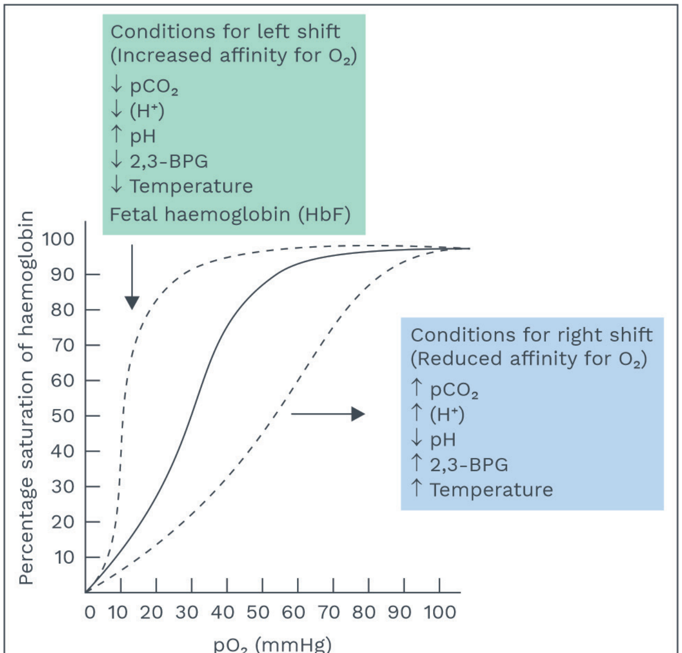


FIG. FACTORS AFFECTING OXYGEN DISSOCIATION CURVE

Transport of Carbon Dioxide

- CO_2 is a gaseous waste product produced during cellular respiration at the tissue level.
- From the tissue cells, CO_2 diffuses in the blood via the interstitial space.
- Every 100 ml of deoxygenated blood delivers

Previous Year's Question

The haemoglobin of a human foetus

(1) has only 2 protein subunits instead of 4

(2) has a higher affinity for oxygen that that of an adult

(3) has a lower affinity for oxygen than that of the adult

(4) its affinity for oxygen is the same as that of an adult

Previous Year's Question

Oxy-haemoglobin dissociates into oxygen and deoxy-haemoglobin at

(1) low O_2 pressure in tissue

(2) high O_2 pressure in tissue

(3) equal O_2 pressure inside and outside tissue

(4) all times irrespective of O_2 pressure

approximately 4 ml of CO_2 to the alveoli.

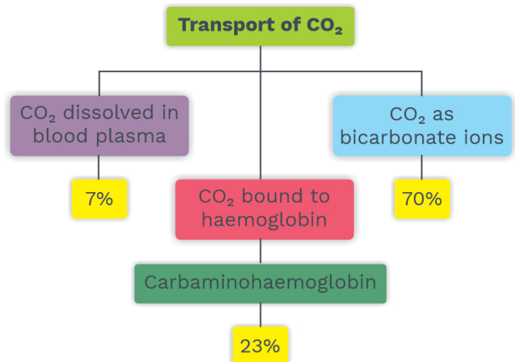
- It is transported in the blood in three main forms:
- **Dissolved Carbon dioxide**
  - About 7% of CO_2 is dissolved in blood plasma and it diffuses into alveoli upon reaching the lungs.
- **Carbamino compounds**
  - About 23% of CO_2 combines with the amino groups of amino acids (22%) and proteins in blood (1%, majorly haemoglobin) to form carbamino compounds.
  - CO_2 mainly binds to the terminal amino acids in the 2a and 2b-globin chains of haemoglobin.
  - Haemoglobin bound to carbon dioxide is called carbamino-haemoglobin ($HbCO_2$).

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{Carbon dioxide}}{CO_2} \rightleftharpoons \underset{\text{Carbamino-haemoglobin}}{HbCO_2}$$

  - This reaction is highly influenced by pCO_2.
  - Formation of $HbCO_2$ is promoted in the tissue capillaries, as the pCO_2 is high in tissues, whereas there is relatively low pCO_2 in alveolar capillaries. So, CO_2 readily splits apart from globin and diffuses into alveoli.
- **Bicarbonate ions**
  - About 70% of CO_2 is transported as bicarbonate ions (HCO_3^-).
  - After diffusing out from the cells, the CO_2 enters the RBCs of systemic capillaries and reacts with water to form carbonic acid (H_2CO_3) in the presence of carbonic anhydrase (containing zinc in its active site). Carbonic acid further dissociates into hydrogen ions and bicarbonate ions.

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \underset{\text{Zn}}{\overset{\text{Carbonic anhydrase}}{\rightleftharpoons}} \underset{\text{Carbonic acid}}{H_2CO_3}$$

$$\underset{\text{Carbonic acid}}{H_2CO_3} \underset{\text{Zn}}{\overset{\text{Carbonic anhydrase}}{\rightleftharpoons}} \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$



Previous Year's Question

During respiration CO_2 is transported in the form of

(1) dissolved plasma
(2) sodium carbonate
(3) $KHCO_3$
(4) partly dissolved in plasma and partly in the form of sodium and potassium bicarbonate

Previous Year's Question

In mammals how much CO_2 is transported as bicarbonates of sodium and potassium in the blood

(1) 5-10%
(2) 10-90%
(3) 70-72%
(4) 90-95%

- Oxyhaemoglobin dissociates to release oxygen in the systemic blood capillaries and at the same time, H^+ ions released by dissociation of carbonic acid replace potassium ions from haemoglobin and form haemoglobinic acid.

$$KHbO_2 \rightleftharpoons KHb + O_2$$

$$KHb + H^+ \rightleftharpoons Hb - H + K^+$$

- Some of the HCO_3^- ions move out from RBCs and enter in the blood plasma. In exchange, Cl^- ions move from plasma into RBCs to maintain electrical balance between cytoplasm of RBC and plasma of blood (chloride shift).

Chloride shift

- It explains the exchange of bicarbonate ions (HCO_3^-) and chloride ions (Cl^-) across the membrane of red blood cells.
- Carbon dioxide produced in the cells diffuses in the blood plasma and RBCs, where it is changed to carbonic acid (H_2CO_3) by the enzyme carbonic anhydrase. Carbonic acid spontaneously breaks into HCO_3^- ions and H^+ ions.
- Thus, the concentration of bicarbonate ions is more in the RBCs as compared to blood plasma.

Note: Some HCO_3^- ions move out into the plasma, down its concentration gradient. But this movement occurs along with the exchange for chloride ions from the plasma through an **anion exchange protein (Band 3)** present in the cell membrane of RBCs to maintain the electrical balance between blood plasma and RBC cytosol.

- This exchange of bicarbonate ions for chloride ions through the RBC membrane is called as chloride shift.
- The chloride ions combine with potassium ions in the RBCs to form potassium chloride whereas bicarbonate ions combine with sodium ions in

Previous Year's Question

The majority of carbon dioxide produced by our body cells is transported to the lungs as
(1) attached to haemoglobin
(2) dissolved in the blood
(3) as bicarbonates
(4) as carbonates

Gray Matter Alert!!!

Chloride shift is also known as Hamburger phenomenon or Lineas phenomenon. It is named after a Dutch physiologist Hartog Jacob Hamburger.

Definition

Anion exchange proteins: Transport proteins present in the cell's plasma membrane which are involved in exchange of anions in and out of the cell.

the blood plasma to form sodium bicarbonate.

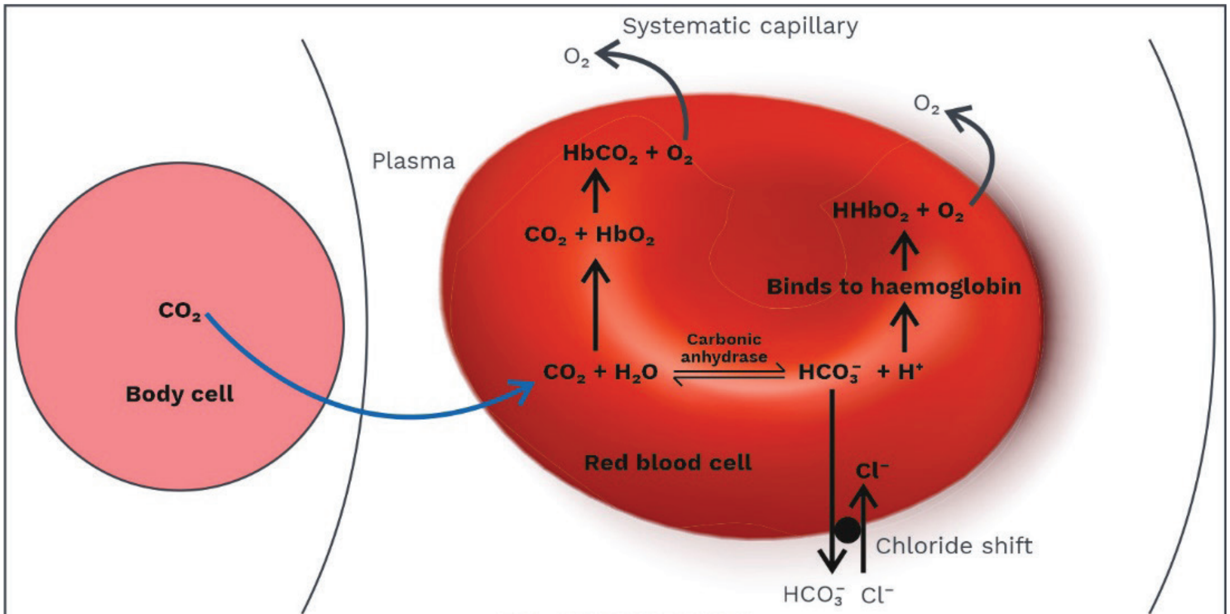


FIG. CHLORIDE SHIFT

$K^+ + Cl^- \rightleftharpoons$ KCl (in RBCs)

$Na^+ + HCO_3^- \rightleftharpoons NaHCO_3$ (in plasma)

- When the blood reaches the alveolar capillaries, all these reactions are reversed to release CO_2 into alveoli.
- Out of the total carbon dioxide in the alveolar blood, **7%** dissolved in blood plasma directly diffuses in the alveoli.
- Carbon dioxide bound to haemoglobin (as carbamino-haemoglobin) dissociates and this releases **23%** of carbon dioxide out of RBCs which later diffuses in the alveoli.

$HbCO_2 \rightleftharpoons Hb + CO_2$

- In the RBCs, as oxygen binds with haemoglobin in the alveolar capillaries, hydrogen of haemoglobinic acid is released.

Previous Year's Question

Chloride shift occurs in respond to

(1) H^+
(2) K^+
(3) HCO^-_3
(4) Na^+

$$HHb \rightleftharpoons Hb + H^+$$

$$Hb + O_2 \rightleftharpoons HbO_2$$

- In the plasma, sodium bicarbonate dissociates into sodium ions and bicarbonate ions and at the same time potassium chloride in the red blood cells dissociates into potassium ions and chloride ions.

$$NaHCO_3 \rightleftharpoons Na^+ + HCO_3^-$$

$$KCl \rightleftharpoons K^+ + Cl^-$$

- Bicarbonate ions enter the RBCs and to maintain the ionic balance of the blood, chloride ions move out of the RBCs in the plasma of blood.
- In the RBCs, bicarbonate ions and hydrogen ions bind to form carbonic acid which dissociates into carbon dioxide and water (Bicarbonate ions act as a **buffer** at the level of lungs).

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

- Thus, in the alveolar capillaries binding of O_2 with haemoglobin (formation of oxyhaemoglobin) displaces CO_2 from the haemoglobin, thus facilitating the CO_2 transport from alveolar blood into the alveoli. This is called **Haldane Effect** (first described by John Scott Haldane).
- If the concentration of oxyhaemoglobin increases, the affinity of CO_2 with haemoglobin decreases.
- This dissociates CO_2 from haemoglobin which later releases H^+ ions bound to it. Hence, oxyhaemoglobin also acts as a strong acid in lungs.

Gray Matter Alert!!!

Haemoglobin acts as a buffer at tissue level as it binds with H^+ ions and as a strong acid in lungs as it donates H^+ ions.

Definition

Buffer solution: A solution which resists the change in pH even by addition of a small amount of acid or base.

Rack your Brain

How does oxyhaemoglobin act as an acid in the lung capillaries?

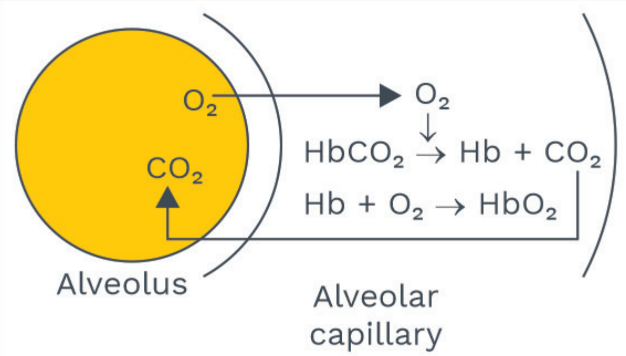


FIG. HALDANE EFFECT

CONTROL OF RESPIRATION

- The regulation of breathing is controlled by the respiratory centre of the neural system.
- The respiratory centre is a collection of clusters of neurons, bilaterally located in the **medulla oblongata** and **pons varolii** of the brain stem.
- Respiratory centre has a medullary rhythmicity area and a pneumotaxic area
- **Medullary rhythmicity area** controls the basic hythm of respiration. It consists of inspiratory areas and expiratory areas.
- **Pneumotaxic area** is located dorsally in the upper pons varolii and transmits inhibitory impulses to the inspiratory area to turn it off before the lungs overfill with air. In other words, it limits inspiration or shortens the duration of inspiration.

Gray Matter Alert!!!

Consumption of O_2 per minute by the body cells varies depending on their metabolic demand.
At rest, about 200 ml of O_2 is taken up by body cells per minute. It increases to 15-20 times during exercise and about 30 times in an athlete.

Gray Matter Alert!!!

Higher activation of pneumotaxic area corresponds to higher breathing rate.

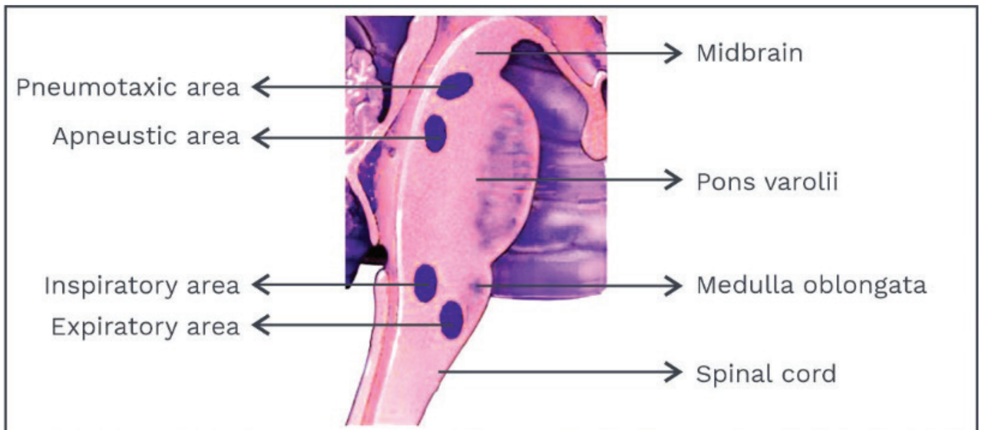


FIG. SAGITTAL SECTION OF BRAIN STEM SHOWING RESPIRATORY CENTER

- It helps to set up the number and depth of breaths.

Note: **Apneustic area** is also located dorsally in the lower pons. It sends activation stimuli to the inspiratory area for prolonged inhalation resulting in long, deep inspiration. On activation, pneumotaxic area overrides the nerve impulses of the apneustic area.

- Regulation of respiration is also performed by **chemoreceptors**.
- **Central chemoreceptors** present near the medulla oblongata are sensitive to the changes in concentration of H^+ ions or pCO_2 or both in cerebrospinal fluid.
- **Peripheral chemoreceptors** which include **aortic bodies** (clusters of chemoreceptors located in the wall of the aortic arch) and the **carotid bodies** (oval nodules in the wall of left and right common carotid arteries), are sensitive to changes in concentration of pCO_2, H^+ ions and pO_2.
- Normally, the pCO_2 in arterial blood is 40 mmHg. Even a slight increase in pCO_2 stimulates the central chemoreceptors which respond vigorously to the resulting increase in H^+ ions level. The peripheral chemoreceptors are stimulated by both the high pCO_2 and the rise in H^+. The peripheral chemoreceptors also respond to a deficiency of O_2. When pO_2 in arterial blood falls from a normal level of 104 mmHg but is still above 50 mmHg, the peripheral chemoreceptors are stimulated.

Note: The inspiratory centre is more strongly stimulated when pCO_2 is rising above normal than when pO_2 is falling below normal. As a result, people like swimmers who hyperventilate voluntarily and cause hypocapnia can hold their breath for an unusually long period.

Chemoreceptors Regulating Respiration

- Central
  - Medulla oblongata
- Peripheral
  - Aortic arch (aortic bodies)
  - Carotid arteries (carotid bodies)

Rack your Brain

Why is an external control of carotid labyrinth and aortic body required in human body?

Gray Matter Alert!!!

The chemoreceptors participate in a negative feedback system to regulate the levels of CO_2, O_2, and H^+ in the blood. Increased pCO_2, decreased pH or decreased pO_2 input from the central and peripheral chemoreceptors cause the inspiratory area to become highly active, and the rate and depth of breathing increase. Hyperventilation (rapid and deep breathing) allows the inhalation of more O_2 and exhalation of more CO_2 until pCO_2 and H^+ are lowered to a normal level.

Additional information:

The inflation Reflex or the Hering-Breuer Reflex:

It is an emergency reflex arc. In a condition where the pneumotaxic area fails to switch off the inspiratory area, the lungs will continue to get filled up with air and the alveoli may expand and burst.

To avoid this condition, stretch receptors or baroreceptors in the walls of bronchi and bronchioles (which are innervated by the vagus nerve endings), send inhibitory signals to the inspiratory area which further inhibits apneustic areas.

This starts exhalation which deflates the lungs so that the stretch receptors are no longer stimulated. Thus, the inspiratory and apneustic areas are no longer inhibited, and a new inhalation begins.

This reflex, referred to as the inflation (Hering-Breuer) reflex, is mainly a protective mechanism for preventing excessive inflation of the lungs.

DISORDERS OF RESPIRATORY SYSTEM

- **Asthma**
  - Asthma is characterized by chronic airway inflammation, hypersensitivity to a variety of stimuli and airway obstruction due to smooth muscle spasms in the walls of smaller bronchi and bronchioles, oedema of the mucosa of respiratory tract, increased mucus secretion by goblet cells (obstruct the airflow) and epithelial damage. Bronchospasms decrease the lumen of bronchi and bronchioles, thereby, increasing the resistance to the flow of air.
  - Expiration is active due to squeezed bronchi.
  - It can be triggered by an allergen such as pollen, dust, molds, a particular food or by non-allergen sources like emotional upset, aspirin, sulfiting agents and cigarette smoke.

Definitions

- **Hypersensitivity:** Exaggerated immune response where mast cells rupture to release histamine.
- **Muscle spasm:** Involuntary sustained contraction of a muscle.
- **Oedema:** Accumulation of fluid in a body part causing swelling.

- Symptoms include wheezing, coughing, chest tightness, difficulty in breathing, fatigue, tachycardia and anxiety.
- There is no permanent treatment for asthma. However, symptomatic treatment can be given by using inhalers (relax the smooth muscles of bronchi) and bronchodilators. Temporary relief can be given by using antihistamine drugs and steroids.

- **Emphysema**
  - Emphysema occurs due to irreversible degenerative changes in the wall of alveoli.
  - Long-term exposure to cigarette smoke, polluted air, industrial dust causes damage to the septa present in the wall of the alveoli, which decreases the internal surface area through which gaseous exchange occurs, thereby, decreasing the efficiency of lungs.
  - As the damage in the alveolar wall increases over time, lung elastic recoil decreases due to loss of elastic fibres and an increased amount of air remains trapped in the lungs at the end of exhalation. This increases the size of chest cage, resulting in a barrel chest.
  - There is no treatment for emphysema. Cessation of smoking, using bronchodilators and oxygen therapy may help in retarding its progress.
- **Occupational Respiratory Disorders**
  - Occupations respiratory disorders include lung diseases caused by long-term exposure to harmful substances from the place of work of an individual. Accumulation of toxic materials in the lungs over time results in pneumoconiosis leading to proliferation of fibrous connective tissue of the upper respiratory tract (fibrosis).
  - Taking precautions in the work area is the best treatment. Compulsory use of masks, short duty hours, regular health check-ups can be some of the precautionary measures.

Previous Year's Question

Increased asthmatic attacks in certain seasons are related to
(1) hot and humid environment
(2) eating fruits preserved in tin containers
(3) inhalation of seasonal pollen
(4) low temperature

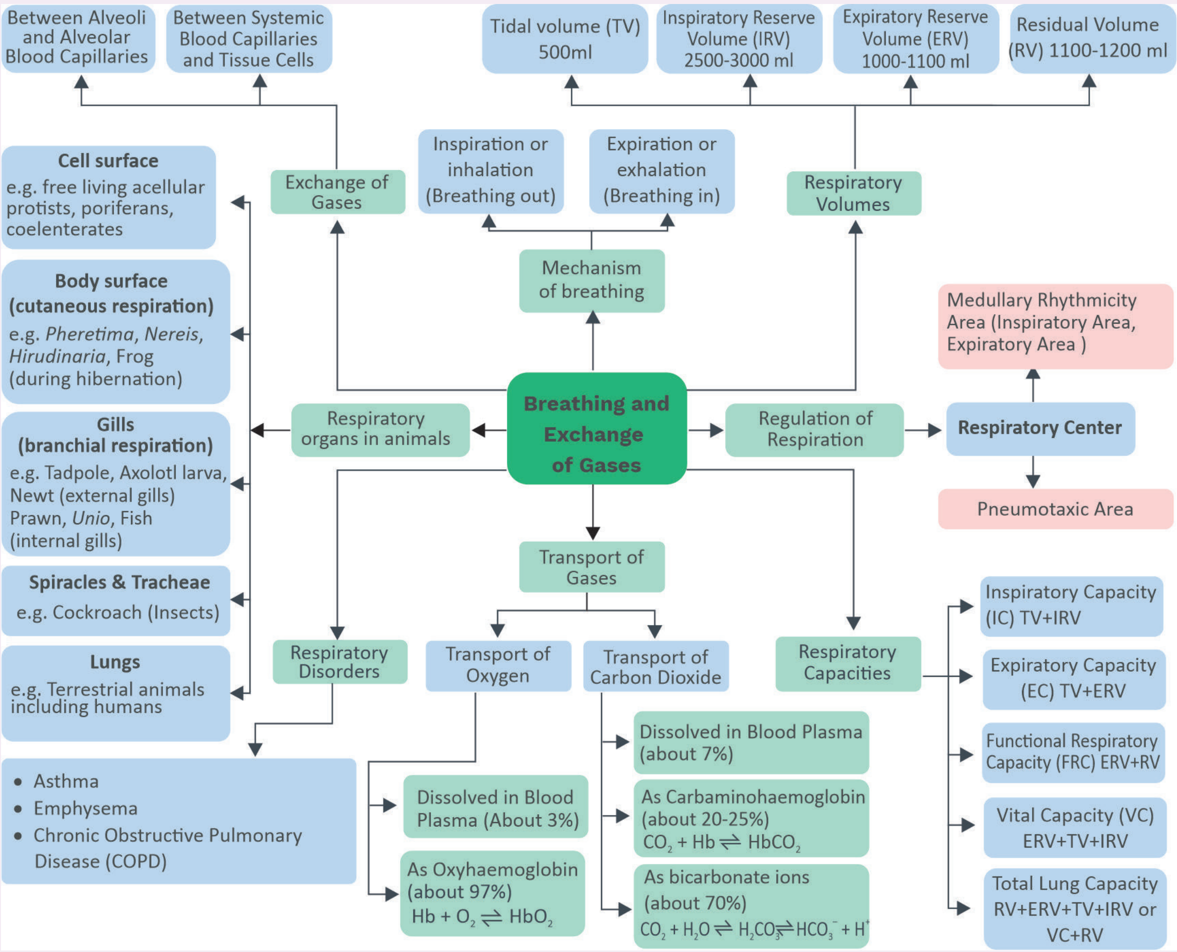
Gray Matter Alert!!!

Depending on the pollutant, pneumoconiosis can be silicosis (exposure to silica), asbestosis (exposure to asbestos dust), siderosis (exposure to iron particles), byssinosis (exposure to cotton dust), bagassosis (inhalation of bagasse dust in sugar mills), anthracosis (accumulation of carbon present in coal dust).

Previous Year's Question

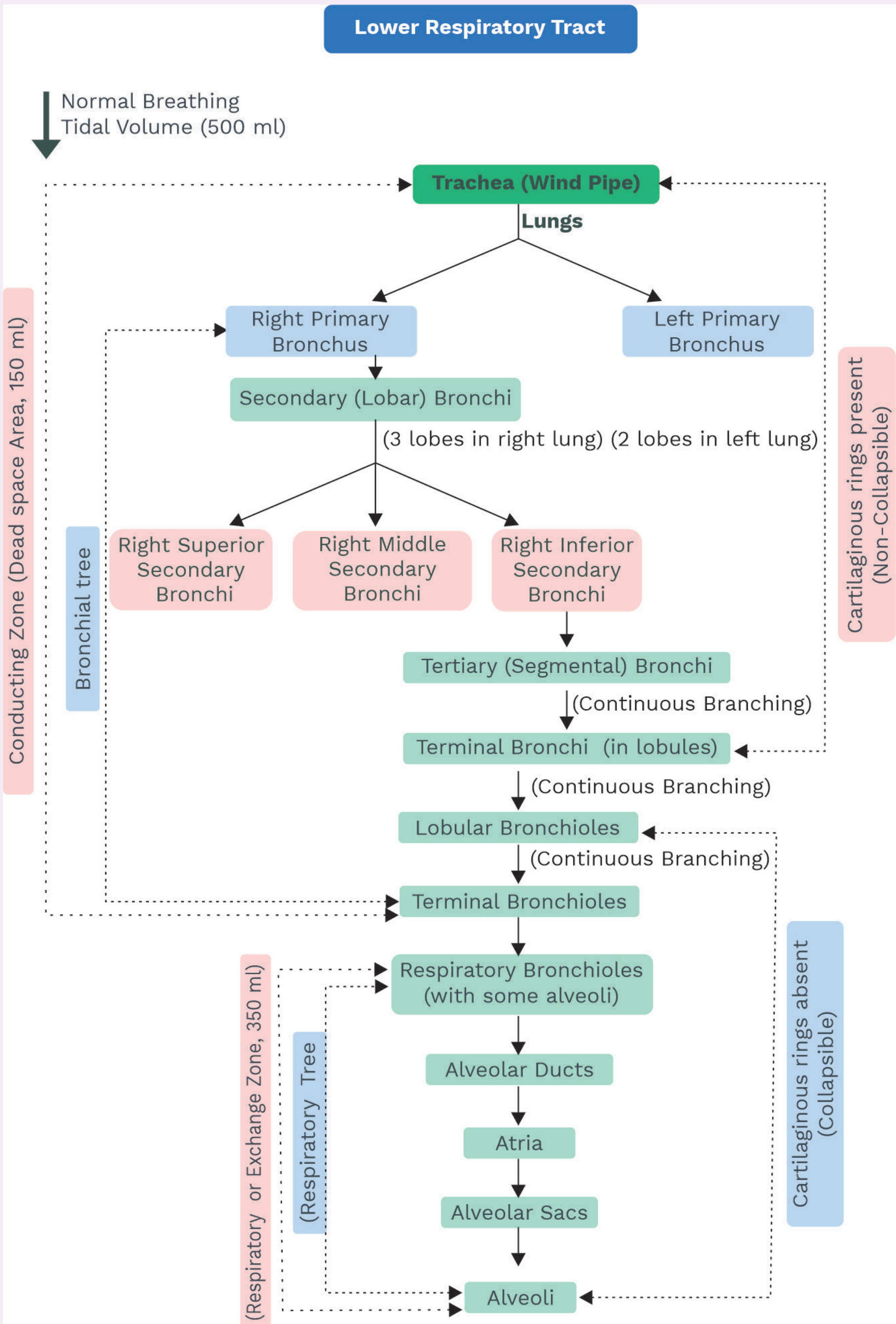
Name the pulmonary disease in which alveolar surface area involved in gas exchange is drastically reduced due to damage in the alveolar walls
(1) bronchitis
(2) asthma
(3) pneumonia
(4) emphysema

Summary



Breathing and Exchange of Gases

Summary



Lower Respiratory Tract

Summary

Mechanism of Breathing

Normal Quiet Breathing (Involuntary)

	Inhalation or Inspiration	Exhalation or Expiration
	Active Process	Relatively Passive Process
Diaphragm	Contract (75% contribution to inspiration)	Relax
External Intercostal Muscles	Contract (25% contribution to inspiration)	Relax
Volume of Thoracic Cavity	Increase (Antero-posteriorly by diaphragm and dorso-ventrally by external intercostal muscles)	Decrease
Volume of Lung (Pulmonary Volume)	Increase	Decrease
Lungs	Expand	Elastic Recoil
Intrapulmonary Pressure	Decrease	Increase
Intra-alveolar Pressure	Decrease (Less than Atmospheric Pressure, 758 mm Hg)	Increase (More than Atmospheric Pressure, 762 mm Hg)
Abdominal muscles	Relax	Relax
Internal Intercostal Muscles	Relax	Relax
Rib Cage	Moves outward and upward	Moves downward and inward
Sternocleidomastoid muscles	Relax	Relax
Scalene muscles	Relax	Relax
Pectoralis minor muscle	Relax	Relax
Atmospheric Air	Drawn in	Released out

Forced Breathing (Voluntary)

	Inhalation or Inspiration	Exhalation or Expiration
	Active Process	Active Process
Diaphragm	Contract	Relax
External Intercostal Muscles	Contract	Relax
Volume of Thoracic Cavity	Increase	Decrease
Volume of Lung (Pulmonary Volume)	Increase	Decrease
Lungs	Expand	Elastic Recoil
Intrapulmonary Pressure	Decrease	Increase
Intra-alveolar Pressure	Decrease (Less than Atmospheric Pressure)	Increase (More than Atmospheric Pressure)
Abdominal muscles	Relax	**Contract**
Intra-abdominal pressure	Decrease	**Increase**
Internal Intercostal Muscles	Relax	**Contract**
Rib Cage	Moves outward and upward	Moves downward and inward
Sternocleidomastoid muscles	**Contract**	Relax
Scalene muscles	**Contract**	Relax
Pectoralis minor muscle	**Contract**	Relax
Atmospheric Air	Drawn in Forcefully	Released out Forcefully

Mechanism of Breathing

Summary

Steps of Normal Breathing

Normal Inspiration

Diaphragm Contracts → Vertical Diameter of Thoracic chamber increases

External Intercostal Muscles Contract → Transverse diameter of Thoracic chamber increases

↓

Chest Expand

↓

Parietal Pleura carried away from visceral pleura in all directions

↓

Vacuum starts to develop in pleural cavity

↓

Intra pleural pressure decreases

↓

Compressed lungs start to decompress (Expansion of Lungs or Elastic recoiling of lungs)

↓

Alveoli Expand

↓

Intra-alveolar pressure decreases

↓

Intra-alveolar pressure less than atmospheric pressure

↓

Air moves from highest pressure area (Atmospheric Pressure) to second lowest pressure area (alveoli)

↓

Air moves in the body (Inspiration)

Normal Expiration

Diaphragm Relax → Vertical Diameter of Thoracic chamber decreases

External Intercostal Muscles Relax → Transverse diameter of Thoracic chamber decreases

↓

Chest moves downward and backward

↓

Parietal Pleura come close to visceral pleura in all directions

↓

Intra pleural pressure Increases

↓

Decompressed lungs start to compress

↓

Alveoli compress

↓

Intra-alveolar pressure increases

↓

Intra-alveolar pressure more than atmospheric pressure

↓

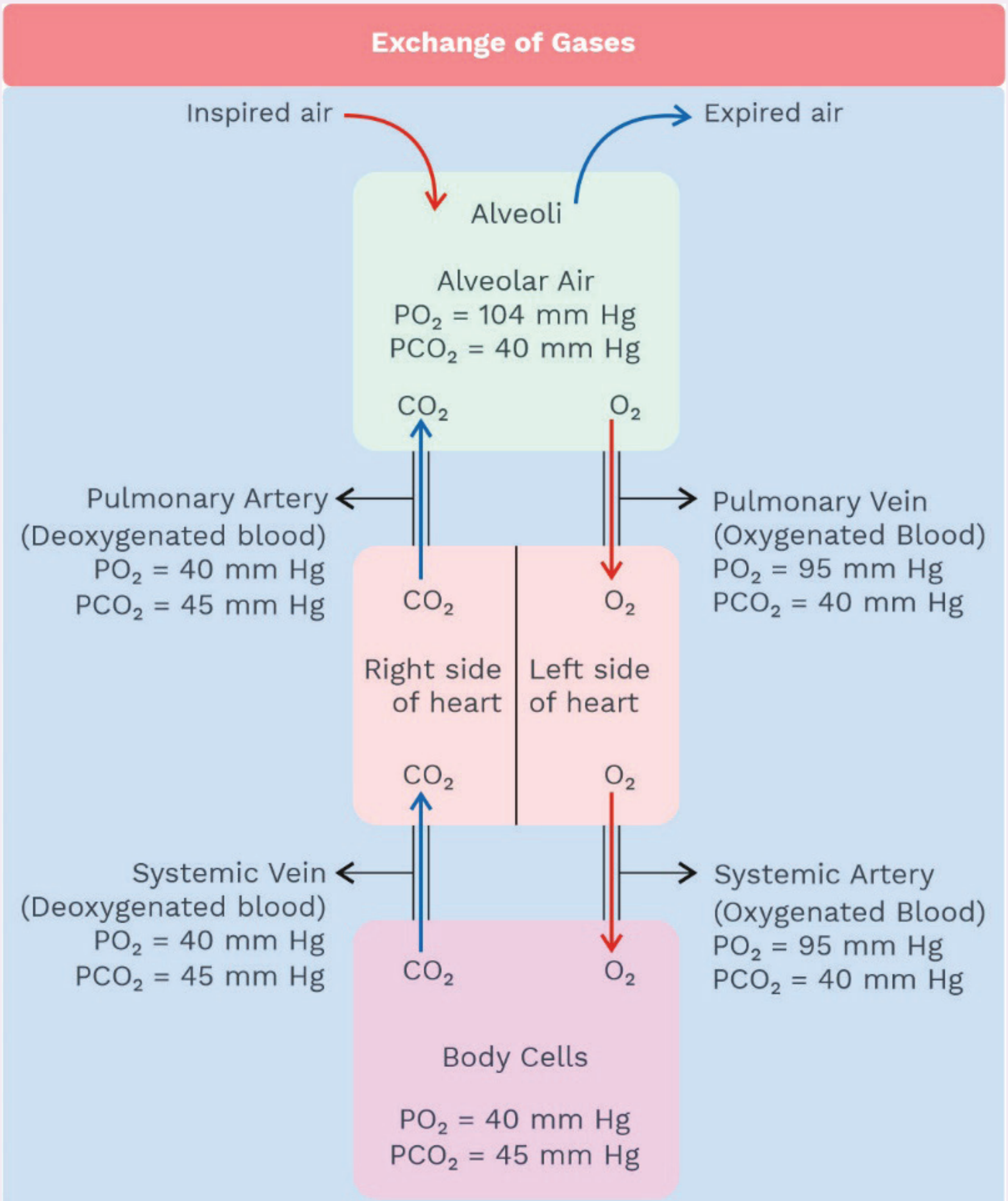
Air moves out from second highest pressure area (alveoli) to lowest pressure area (Atmospheric pressure)

↓

Air moves out of body (Expiration)

Steps of Normal Breathing

Summary



Exchange of Gases

SOLVED EXERCISE

Q1 **Which of the following is not correct about pleural fluid?**

(1) Pleural fluid reduces friction between the pleural membrane.
(2) Pleural fluid has a positive pressure of 4 mmHg.
(3) Pleural fluid acts as a shock absorber.
(4) Pleural fluid causes the pleural membranes to adhere to each other.

A1 **(2)**
Pleural fluid is under a negative pressure of 4 mmHg which keeps the lungs pulled against the chest wall.

Q2 **Club-shaped cartilage of larynx is**

(1) cuneiform cartilage **(2) corniculate cartilage**
(3) arytenoid cartilage **(4) cricoid cartilage**

A2 **(1)**
The paired cuneiform cartilages are club-shaped elastic cartilages.

Q3 **Eustachian tube opens in**

(1) oropharynx **(2) buccal cavity**
(3) nasopharynx **(4) laryngopharynx**

A3 **(3)**
Openings of eustachian tubes are present in the nasopharynx.

Q4 **The primary bronchi divide to form**

(1) lobar bronchi **(2) segmental bronchi**

(3) bronchial tree **(4) terminal bronchioles**

A4 **(1)**

Primary bronchi divide to form secondary or lobar bronchi.

Q5 **Select the correct statement from the following.**

(1) Right lung is divided by a single fissure.

(2) Type II alveolar cells are called septal cells.

(3) The intrapleural pressure increase just before breathing.

(4) Surface tension exerted by alveolar fluid coat results in elastic recoil of lungs during inspiration.

A5 **(2)**

Horizontal fissure and oblique fissure divide the right lung into superior, middle and inferior lobe.

The intrapleural pressure decreases below atmospheric pressure just before breathing.

Surface tension exerted by alveolar fluid coat results in elastic recoil of lungs during exhalation.

Q6 **Vital capacity (VC) is**

(1) TV + IRV **(2) ERV + TV + IRV**

(3) RV + ERV + TV + IRV **(4) TV + ERV**

A6 **(2)**

Vital capacity (VC) is the maximum volume of air a person can breathe in after a forced expiration. It includes Expiratory Reserve Volume (ERV), Tidal Volume (TV) and Inspiratory Reserve Volume (IRV).

Q7 **Partial pressure of oxygen (pO_2) in the systemic arteries is**

(1) 40 mmHg **(2) 95 mmHg** **(3) 45 mmHg** **(4) 104 mmHg**

A7 **(2)**

In the systemic arteries, the partial pressure of O_2 (pO_2) is 95 mmHg.

Q8 **Which of the following will shift the oxygen dissociation curve towards right?**

(1) Decreased body temperature.

(2) Increased pH.

(3) Increase in partial pressure of CO_2.

(4) Decrease in H^+ ion concentration.

A8 **(3)**

The oxygen dissociation curve shifts to right due to an increase in pCO_2, increase in H^+ ion concentration, decrease in pH and increase in temperature.

Q9 **The basic rhythm of breathing is established by**

(1) pneumotaxic area **(2) inspiratory area**

(3) apneustic area **(4) expiratory area**

A9 **(2)**

Inspiratory area generates nerve impulses to initiate inhalation.

Q10 **Which of the following is not a disorder of respiratory system?**

(1) Emphysema **(2) Bronchitis** **(3) Pneumonia** **(4) Acromegaly**

A10 **(4)**

Acromegaly occurs due to deficiency of growth hormone after puberty.