CHAPTER-17

BREATHING AND EXCHANGE OF GASES

INTRODUCTION

This process of exchange of O_2 from the atmosphere with CO_2 produced by the cells is called breathing, commonly known as respiration.

Oxygen (O2) is utilized by the organisms to indirectly break down nutrient molecules like glucose and to derive energy for performing various activities.

Carbon dioxide (CO_2) is released during the above catabolic reactions.

RESPIRATORY ORGANS

Lower invertebrates like sponges, exchange O_2 with CO_2 by simple diffusion over their entire body surface.

Earthworms use their moist cuticle and insects have a network of tubes (tracheal tubes) to transport atmospheric air within the body.

Special vascularised structures called gills are used by most of the aquatic arthropods and molluscs.

Vascularised bags called lungs are used by the terrestrial forms for the exchange of gases.

Amphibians, like frogs, can respire through their moist skin also.

Mammals have a well-developed respiratory system.

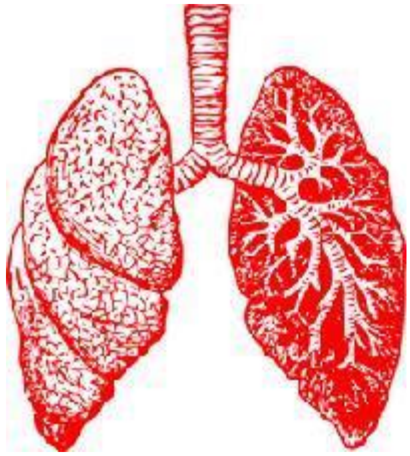


Fig. Lungs

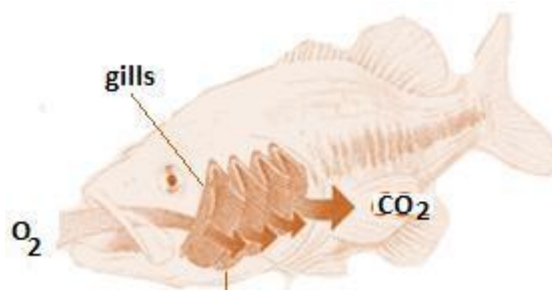


Fig. Gills

HUMAN RESPIRATORY SYSTEM

A pair of external nostrils opens out above the upper lips, which leads to a nasal chamber through the nasal passage, and the nasal chamber opens into the nasopharynx, which is a portion of the pharynx.

The nasopharynx opens through the glottis of the larynx region into the trachea.
The larynx is a cartilaginous box which helps in sound production and hence called the soundbox.

During swallowing, glottis can be covered by a thin elastic cartilaginous flap called

The trachea is a straight tube extending up to the mid-thoracic cavity, which divides at the level of 5th thoracic vertebra into a right and left primary bronchi.
Each bronchus undergoes repeated divisions to form the secondary and tertiary bronchi and bronchioles ending up in very thin terminal bronchioles.

The tracheae, primary, secondary and tertiary bronchi, and initial bronchioles are supported by incomplete cartilaginous rings.

Each terminal bronchiole gives rise to several very thin, irregular walled and vascularised bag-like structures called alveoli.

The branching network of bronchi, bronchioles, and alveoli comprise the lungs.

Two lungs are covered by a double-layered pleura, with pleural fluid between them.

The outer pleural membrane is in close contact with the thoracic lining, whereas the inner pleural membrane is in contact with the lung surface.

The external nostrils up to the terminal bronchioles constitute the conducting part, whereas the alveoli and their ducts form the respiratory part.

The conducting part transports the atmospheric air to the alveoli, clears it from foreign particles, whereas the exchange part is the site of actual diffusion of O_2 and CO_2 between blood and atmospheric air.

The lungs are situated in the thoracic chamber, formed dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs, and on the lower side by the dome-shaped diaphragm.

Respiration involves the following steps:

Breathing or pulmonary ventilation by which atmospheric air is drawn in and CO_2 rich alveolar air is released out.

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

Transport of gases by the blood.

Diffusion of O_2 and CO_2 between blood and tissues.

The utilization of O_2 by the cells for catabolic reactions and resultant release of CO

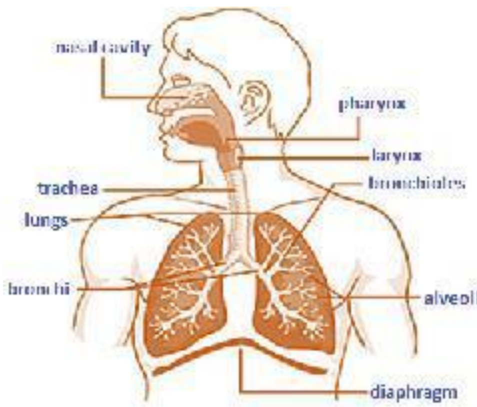


Fig. Human respiratory system

A healthy human breathes 12-16 times/minute.

The volume of air involved in breathing movements can be estimated by using a spirometer.

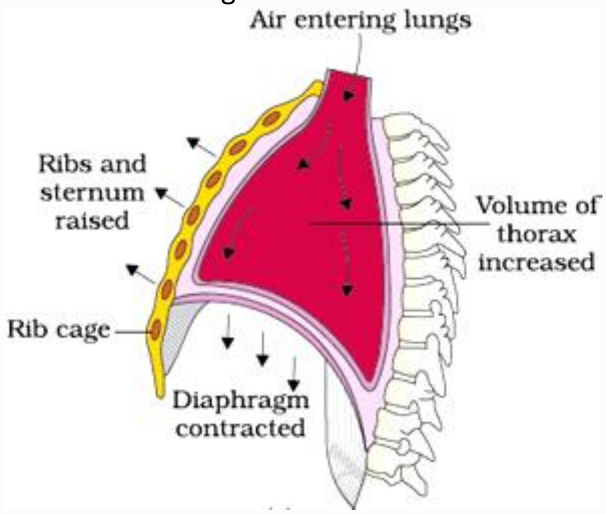
Mechanism of Breathing

Breathing involves inspiration and expiration. During inspiration atmospheric air is drawn in and during expiration, alveolar air is released out.

Movement of air in and out takes place due to difference in pressure gradient.

Inspiration occurs when the pressure inside the lung is less and expiration occurs when pressure is more in the lungs than outside.

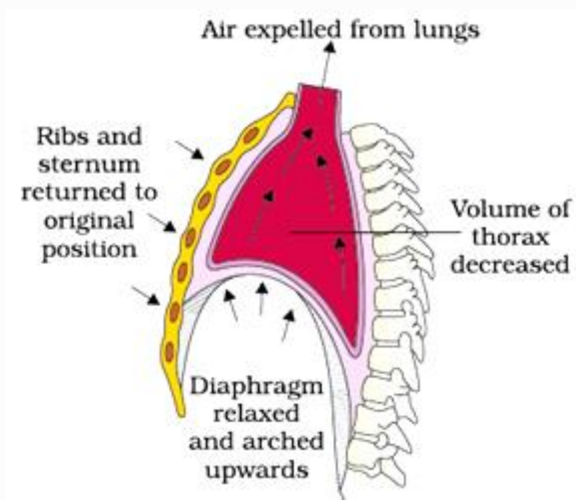
The diaphragm and external and internal intercostal muscles between the ribs help in developing pressure gradient due to changes in volume.



The contraction of intercostal muscles lifts the ribs and sternum causing an increase in the volume of the thoracic cavity that results in a decrease in pressure than the atmospheric pressure. This causes inspiration.

Relaxation of the diaphragm and intercostal muscles reduce the thoracic volume and increase the pressure causing expiration.

The volume of air involved in breathing movements is estimated by using a spirometer for clinical assessment of pulmonary functions.



RESPIRATORY VOLUMES AND CAPACITIES

Tidal Volume (TV): Volume of air inspired or expired during normal respiration, which is approx. 500 mL.

Inspiratory Reserve Volume (IRV): Additional volume of air, a person can inspire by a forcible inspiration, which averages 2500 mL to 3000 mL.

Expiratory Reserve Volume (ERV): Additional volume of air, a person can expire by a forcible expiration, which averages 1000 mL to 1100 mL.

Residual Volume (RV): Volume of air remaining in the lungs even after a forcible expiration, which averages 1100 mL to 1200 mL.

Inspiratory Capacity (IC): Total volume of air a person can inspire after a normal expiration, which includes tidal volume and inspiratory reserve volume (TV+IRV).

Expiratory Capacity (EC): Total volume of air a person can expire after a normal inspiration, which includes tidal volume and expiratory reserve volume (TV+ERV).

Functional Residual Capacity (FRC): Volume of air that will remain in the lungs after a normal expiration, which includes ERV+RV.

Vital Capacity (VC): The maximum volume of air a person can breathe in after a forced expiration, which includes ERV, TV, and IRV.

Total Lung Capacity: Total volume of air accommodated in the lungs at the end of a forced inspiration, which includes RV, ERV, TV, and IRV.

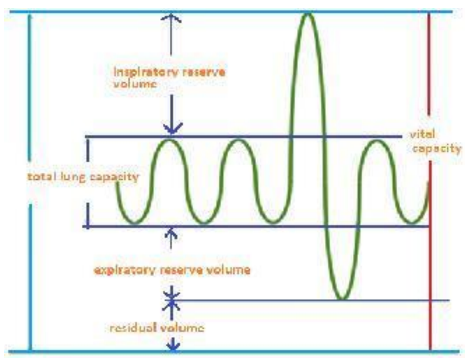


Fig. Respiratory volumes

EXCHANGE OF GASES

Alveoli are the primary sites of the exchange of gases.

O_2 and CO_2 are exchanged in these sites by simple diffusion mainly based on pressure/concentration gradient.

Pressure contributed by an individual gas in a mixture of gases is called partial pressure and is represented as pO_2 for oxygen and pCO_2 for carbon dioxide.

A gradient is present for CO_2 in the opposite direction, i.e., from tissues to blood and blood to alveoli.

As the solubility of CO_2 is 20-25 times higher than that of O_2, the amount of CO_2 that can diffuse through the diffusion membrane per unit difference in partial pressure is much higher compared to that of O_2.

The diffusion membrane is made up of three major layers

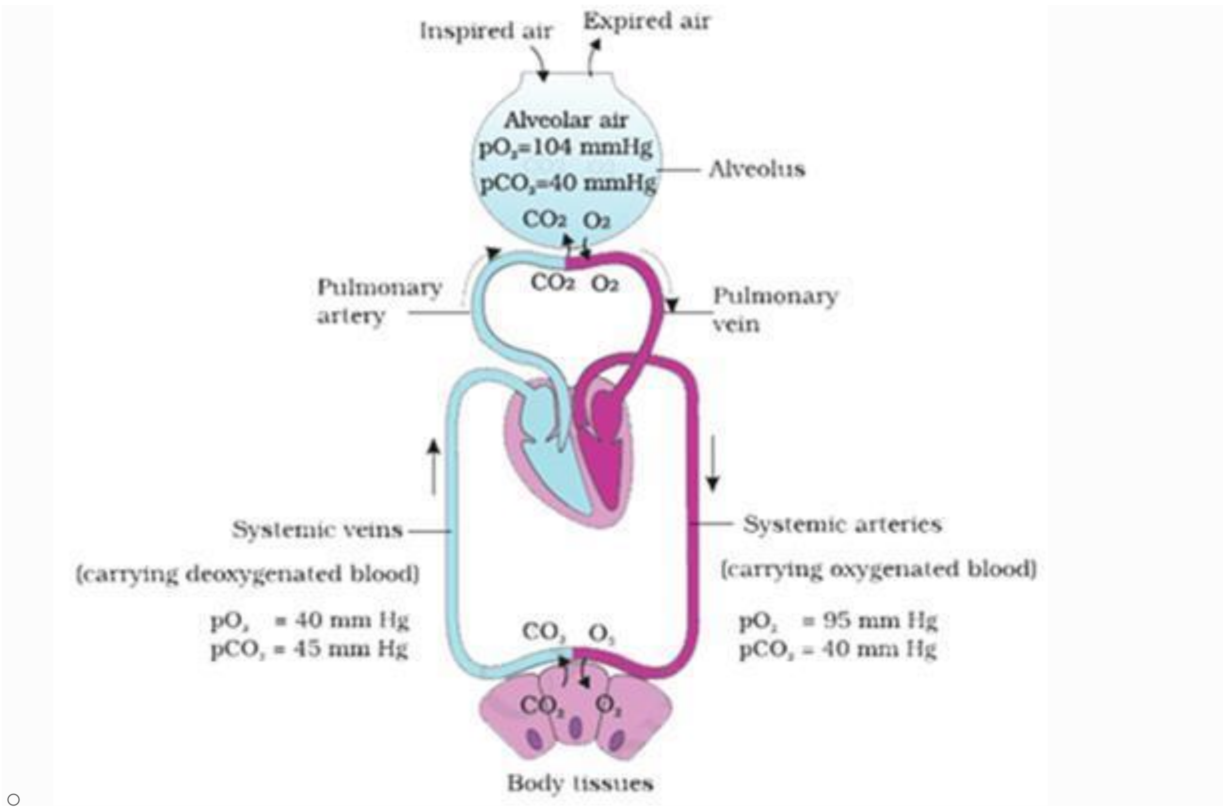
the thin squamous epithelium of alveoli,

the endothelium of alveolar capillaries

the basement substance in between them.

All the factors in our body are favourable for the diffusion of O_2 from alveoli to tissues and that of CO_2 from tissues to alveoli.

Residual Volume.



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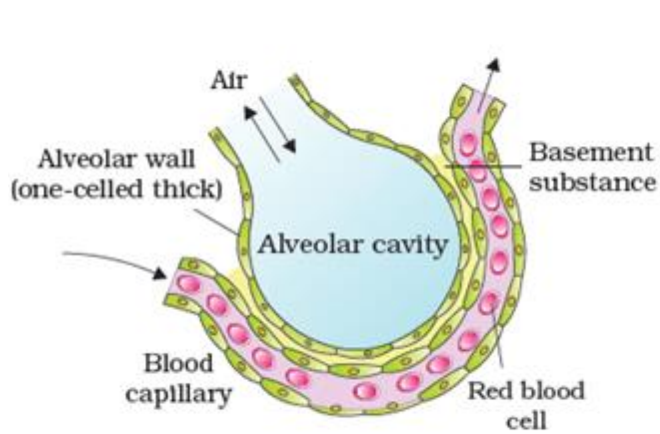

Fig. Diffuson membrane of alveoli

TRANSPORT OF GASES

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

Transport of oxygen

Haemoglobin is a red coloured iron-containing pigment present in the RBCs.
O_2 can reversibly bind with haemoglobin to form oxyhemoglobin.
Binding of oxygen with haemoglobin is primarily related to the partial pressure of O_2 and partial pressure of CO2, hydrogen ion concentration and temperature are the other factors which can interfere with this binding.
A sigmoid curve is obtained when the percentage saturation of haemoglobin with O_2 is plotted
against the pO_2 and the curve is called the oxygen dissociation curve.
pCO2, H^+ concentration has an effect on the binding of O_2 with haemoglobin.
In the alveoli, where there is high pO_2, low pCO_2, lesser H^+ concentration, and lower temperature, the factors are all favourable for the formation of oxyhemoglobin, and where low pO_2, high pCO_2, high H^+ concentration, and higher temperature exist, the conditions are favourable for dissociation of oxygen from the oxyhemoglobin.
Every 100 ml of oxygenated blood can deliver around 5 ml of O_2 and each haemoglobin molecule can carry a maximum of four molecules of O_2.

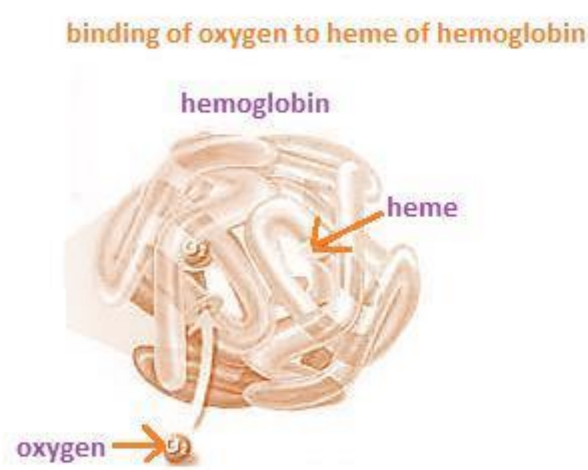

Fig. formation of haemoglobin

Transport of carbon dioxide

CO_2 is carried by haemoglobin as carbamino-haemoglobin, which is related to the partial pressure of CO_2.
When pCO_2 is high and pO_2 is low as in the tissues, more binding of carbon dioxide occurs whereas, when the pCO_2 is low and pO_2 is high as in the alveoli, dissociation of CO_2 from carbamino-haemoglobin takes place.

Functions of Respiration–

1. Energy production
2. Maintenance of acid-base balance.
3. Maintenance of temperature
4. Return of blood and lymph.
5.

REGULATION OF RESPIRATION

A specialized centre present in the medulla region of the brain called the respiratory rhythm centre is primarily responsible for this regulation.
Another centre present in the pons region of the brain called the pneumatic centre can moderate the functions of the respiratory rhythm centre.

The neural signal from this centre can reduce the duration of inspiration and thereby alter the respiratory rate.

A chemosensitive area is situated adjacent to the rhythm centre which is highly sensitive to CO_2 and hydrogen ions.
Receptors associated with the aortic arch and carotid artery also can recognize changes in CO_2 and H^+ concentration and send necessary signals to the rhythm centre for remedial actions.

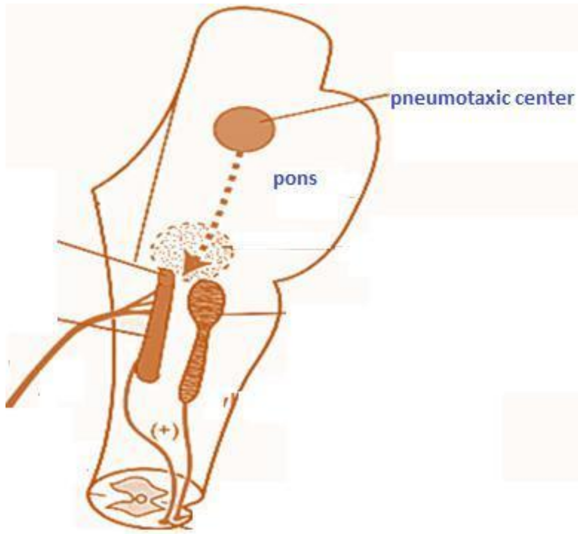

Fig. Pneumotaxic centre

DISORDERS OF RESPIRATORY SYSTEM

Asthma is a difficulty in breathing causing wheezing due to inflammation of the bronchi and bronchioles.

Emphysema is a chronic disorder in which alveolar walls are damaged due to which respiratory surface is decreased.

Occupational respiratory disorders include lung damage due to inflammation, which ultimately leads to fibrosis.

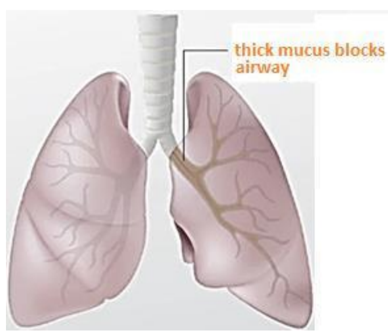

Fig. Fibrosis