Did You Know?

Rate of breathing in aquatic organisms is much faster than that seen in terrestrial organisms.

Knowledge Cloud

- The Indian climbing perch *Anabas testudineus* has accessory respiratory organs for breathing air.
- In some turtles, cloaca is used as respiratory organ.

Example 1 : *Which is the respiratory organ of earthworm?*

Solution : Moist cuticle is used by earthworm as respiratory organ.

Example 2 : *Write the term used for respiratory organs of insects.*

Solution : Trachea

Try Yourself

1. Name two group of animals that respire via gills?
2. Write the respiratory organ of tadpole larva of frog.
3. What is the main characteristic of gills?
4. Which group of animals have well-developed respiratory system?

Human Respiratory System

It is a system consisting of respiratory passage and respiratory organs. Respiratory organs are a pair of lungs.

Respiratory passage : It is a passage that takes air from outside to the respiratory surface of lungs. It consists of a pair of nostrils, nasal cavity, a pair of internal nares, pharynx, larynx, trachea, bronchi and their branches and the respiratory surface of lungs, *i.e.*, alveoli.

Structures involve in respiratory passage

1. **External nostrils :** A pair of external nostrils represent the first part of respiratory passage. These are the holes of our nose opening out above the upper lips. These lead into nasal chamber of nasal cavity through the nasal passage.
2. **Nasal cavities :** These are also two in number. The epithelial lining of cavities is known as respiratory epithelium. It has pseudostratified ciliated columnar, non-ciliated brush border columnar, cuboidal and goblet cells. The epithelium also possesses glands. It is richly supplied with blood vessels. Mucus is produced by goblet cells.

   Functions

   - Mucus from goblet cells and glands makes the surface sticky for trapping dust particles present in the inspired air.
   - Moisture from the epithelium also makes the air humid.
   - It brings the temperature of the incoming air, upto the body temperature.

3. **Internal nares :** These are the posterior openings of the nasal cavities that lead into the nasopharynx.

4. **Nasopharynx :** Internal nares open into a part of pharynx known as nasopharynx. It is a portion of pharynx which is common passage for food and air. It opens into the trachea through glottis of larynx region. Glottis is the opening at the upper part of larynx.

5. **Larynx :** It is also known as sound/voice box because it helps in the production of sound. It is made up of cartilage, present at the upper part of trachea. Its upper part has an opening, *i.e.*, glottis. During swallowing this glottis can be covered by epiglottis which is a leaf-shaped cartilaginous structure made up of elastic cartilage. Epiglottis is the covering or lid of glottis to prevent the entry of food into the larynx during swallowing.

   (i) **Thyroid cartilage** is the most prominent, C-shaped, incomplete dorsally, called as **Adam's apple** as it is apple shaped and more prominent in male.

   (ii) **Cricoid cartilage** lies below the thyroid cartilage, and its shape is like a signet ring

   (iii) **Arytenoid cartilages** are two roughly pyramid shaped cartilages forming posterior wall of the larynx

   (iv) **Corniculate -** These are two conical nodules of elastic fibro-cartilage which lie at the apices of arytenoid cartilages.

   (v) **Cuneiform -** There are two small elongated club shaped nodules of elastic fibro-cartilage which lie above and anterior to corniculate cartilages. These connect epiglottis to arytenoid cartilage.

   (vi) **Epiglottis** is a single leaf shaped cartilage which projects into the pharynx.

   Thus, a total of 9 cartilages - 3 paired (iii, iv, v) and 3 unpaired (i, ii, vi).

   The thyrohyoid membrane is a broad, flat membrane attached to the **hyoid bone** above and to the thyroid cartilage below. Inside the larynx are present two pairs of vocal cord one pair, of false vocal cords which have little to do with sound production and the second inner pair or true vocal cords. When air is forced through the larynx, it causes vibration of the true vocal cords and sound is produced. The pitch of a sound is determined by the tension on the vocal cords– the greater the tension, the higher the pitch.

true vocal cord present inbetween Thyroid cartilage & Arytenoid cartilage (b one)

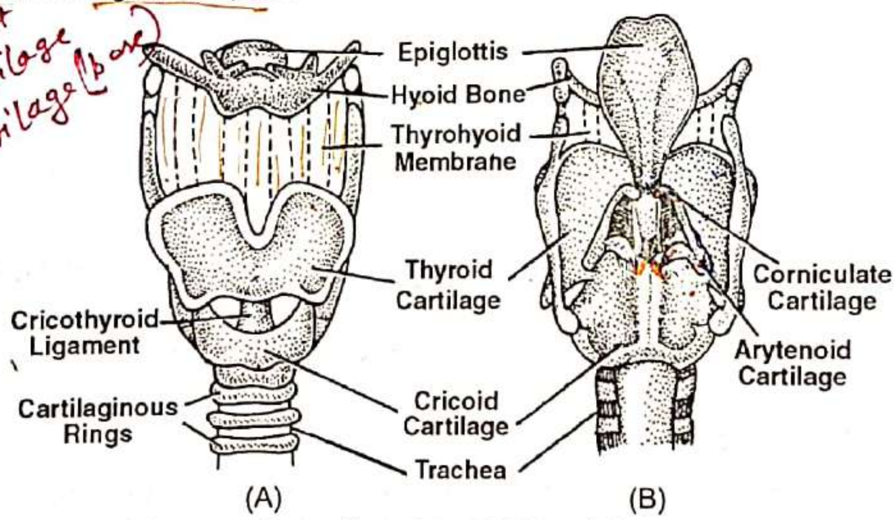


Fig. Larynx of man from lateral (A) and dorsal (B) views

6. **Trachea :** It is also known as wind pipe. It is a straight tube extending upto the mid-thoracic cavity, commonly called chest cavity. This tube finally divides into right and left primary bronchi at the level of 5th thoracic vertebra. It is lined by incomplete cartilaginous rings to prevent it from collapsing during inspiration.

7. **Bronchi (pleural), bronchus (sing.) :** Each bronchus undergoes repeated divisions to form its branches, these are secondary, tertiary bronchi and bronchioles. Bronchioles are the terminal branching of bronchi. Finally, bronchioles give rise to a number of very thin, well-supplied with blood vessels, irregular walled balloon-like structures called alveoli. The walls of the bronchi and initial bronchioles are supported by incomplete cartilaginous rings.

8. **Alveoli :** Bronchioles open into the alveolar ducts, *i.e.*, a tube-like structure which lead into an expanded passages, the atria which open into the alveolar sacs or air sacs. There are about 300 millions of alveoli in two lungs. The membrane of alveoli is very thin, irregular and richly supplied with blood vessels. Due to very close contact of blood vessels with alveoli, the exchange of gases takes place easily.

squamous cells of Alveoli are called pneumocytes cells.

Bronchioles $\xrightarrow{\text{Lead to}}$ Alveolar ducts $\xrightarrow{\text{Lead to}}$ Atria $\xrightarrow{\text{Lead to}}$ Alveolar sacs

Lungs

A pair of lungs is present in humans, lie in an air-tight chamber known as thoracic cavity or chest cavity. This cavity is formed dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs. It is closed below by the diaphragm which is a dome-shaped structure made up of muscles and separates thoracic cavity from abdominal cavity (containing most of the digestive organs).

- **Membranes enclose the lungs :** Each lung is enclosed in two membranes known as pleura or pleural membranes. The outer pleural membrane is in close contact with the thoracic cavity whereas inner pleural membrane is in close contact with lungs surface. In between these two membranes, a narrow space is present known as pleural cavity. This pleural cavity is filled with a fluid secreted by pleural membranes known as pleural fluid.
- **Function of pleural fluid :** It lubricates the pleural membranes so that they may slide over each other without friction during breathing. If fluid is not present, then there will be damage to the membranes which finally affects the breathing.
- **Internal structure of lungs :** Internally, lungs are made up of branching network of bronchi, bronchioles and alveoli. Network of bronchi include primary, secondary and tertiary bronchi. Alveoli are the main sites where actual diffusion of gases O_2 and CO_2 takes place between blood and atmospheric air.

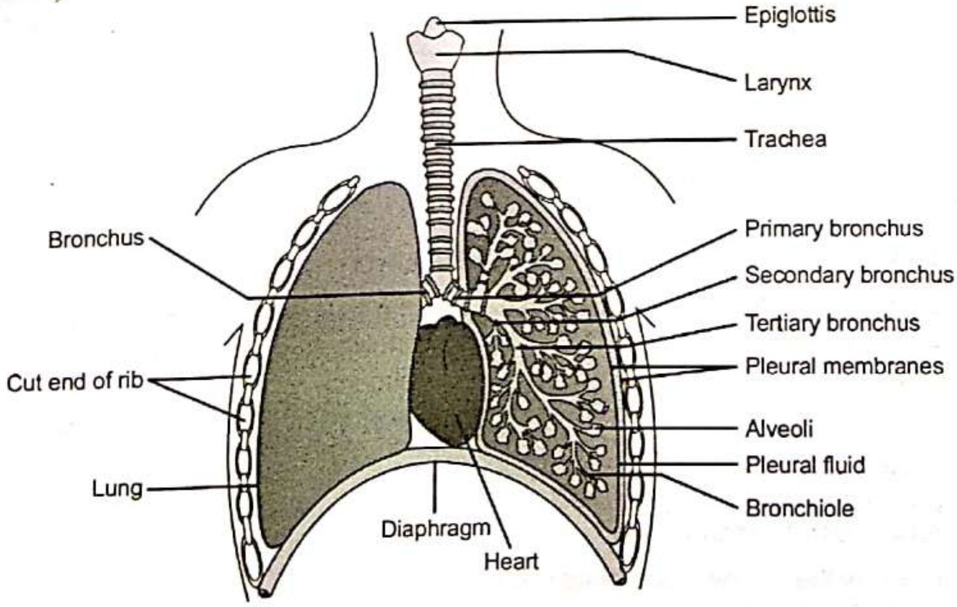


Fig. : Diagrammatic view of human respiratory system (Sectional view of the left lung is also shown)

Flow chart showing structures involved in respiratory passage

↓ Opens into

Conducting part:

External nostrils
↓
Nasal chamber
↓
Internal nares
↓
Nasopharynx
↓
Glottis (a part of larynx)
↓
Trachea
↓
Primary bronchi
↓
Secondary bronchi
↓
Tertiary bronchi
↓
Bronchioles
↓

Exchange/Respiratory part:

Alveolar ducts
↓
Atria
↓
Alveolar sac
↓
Alveoli

Two parts of human respiratory system are :

Conducting Part	Exchange or Respiratory Part
This part consists of external nostrils, nasal chamber, internal nares, nasopharynx, larynx, trachea, bronchi and bronchioles (upto terminal bronchioles)	It include alveoli and their ducts.
Functions ❖ Conducts air from external nostrils upto bronchioles. ❖ Clears the incoming air by trapping dust particles present in it. ❖ Makes the incoming air humid by providing moisture produced by epithelium of nasal cavities. ❖ It brings the temperature of air upto the body temperature.	**Function** It is the main site of human respiratory system where diffusion of gases O_2 and CO_2 occurs.

Steps involve in respiration : Respiration is a complex process which occurs in number of steps. These are :

1. **Breathing :** It is simply the inhalation of atmospheric air and exhalation of CO_2 rich alveolar air. It is also known as pulmonary ventilation.

2. **Diffusion of gases between alveoli and blood :** Diffusion of gases O_2 and CO_2 takes place across the alveolar membrane to the blood capillaries surrounding it. The membrane is very thin and richly supplied with blood capillaries.

3. **Transport of gases :** Blood is the medium for transport of gases O_2 and CO_2, which transports O_2 to the body cells from alveoli and CO_2 from the body cells to alveoli.

4. **Diffusion of gases between blood and tissues :** O_2 is diffused from blood to tissues and CO_2 is diffused from tissues to blood.

5. **Utilisation of O_2 :** O_2 is used by the body cells for the release of energy. Breakdown of glucose occurs in presence of O_2 which produces CO_2, water and energy. This is also known as cellular respiration as it occurs inside the cells. It is a biochemical reaction. The CO_2 produced is eliminated out of the body.

Reaction involved is

$$\underset{\text{Glucose (present inside the cells)}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} \longrightarrow \underset{\text{Eliminated out of the body}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \underset{\text{Utilised to perform bodily activities}}{\text{Energy}}$$

Example 3 : *Name the organ which helps in sound production.*

Solution : Larynx

Example 4 : *Why is trachea surrounded by cartilaginous rings?*

Solution : Trachea is surrounded by cartilaginous rings to prevent it from collapsing during inspiration.

Try Yourself

5. In which part nasal chamber opens?
6. What is the role of pleural membranes?
7. Which is the first step of respiration?
8. What is glottis?

MECHANISM OF BREATHING

It includes two stages :

Inspiration	Expiration
1. It is defined as a process by which fresh air enters the lungs.	1. It is defined as a process by which the foul air (containing CO_2) is expelled out of the lungs.
2. It is inflow or inhalation of fresh air.	2. It is outflow or exhalation of air.

The movement of air into and out of the lungs is carried out by creating a pressure gradient between lungs and the atmosphere. Pressure gradient is the pressure difference which creates the flow of gases from their higher pressure region to their lower pressure region. For example, pressure of O_2 in atmospheric air is higher than the alveoli, so O_2 diffuses from atmospheric air to alveoli.

1. **Inspiration** : Diaphragm and external intercostal muscles play an important role but some additional muscles in the abdomen also helps in inspiration. The pressure within the lungs is made less than the atmospheric pressure so that air can flow to lungs.

   - **Role of diaphragm in inspiration :** The contraction of muscle fibres of diaphragm causes it to become flat and lowered down thereby increasing the volume of thoracic cavity in antero-posterior axis, in rabbit or lengthwise in man.

     Increase in the volume of thoracic cavity —Leads to→ Similar increase in the volume of pulmonary cavity

     ↓ Causes

     Decrease in pressure within the pulmonary cavity (as we know that pressure and volume are inversely proportional)

     ↓ Causes

     Air enters from atmosphere to the lungs as it moves from higher pressure to lower pressure

   - **External intercostal muscles :** These muscles are present between the ribs. The contraction of these muscles lift ribs and sternum up and outward causing an increase in the volume of the thoracic cavity in the dorso-ventral axis, *i.e.*, backward-forward direction.

     Increase in the volume of thoracic cavity —Leads to→ Similar increase in the volume of pulmonary cavity

     ↓ Causes

     Decrease in pressure within the pulmonary cavity which is less than the atmospheric pressure

     ↓ Causes

     Atmospheric air enters into the lungs (inhalation)

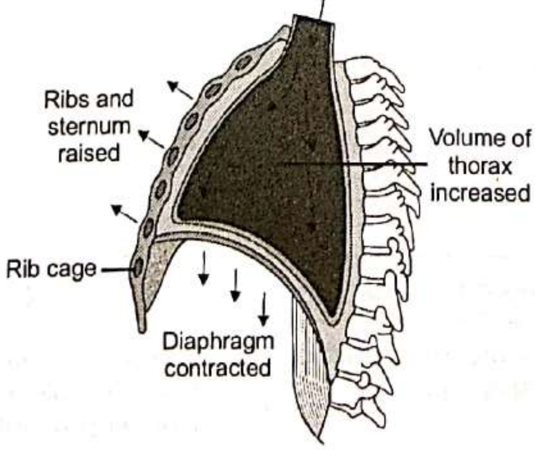


Fig. : Mechanism of breathing showing : Inspiration

Forceful Inspiration :

Abdominal muscles : These are additional muscles play a passive role in forceful inspiration. During forceful inspiration, these muscles relax and allow compression of abdominal organs by the diaphragm. Finally,

The volume of thoracic cavity increases —Leads to→ Similar increase in the volume of pulmonary cavity

↓ Causes

Decrease in pressure within the pulmonary cavity, less than the atmospheric pressure

↓ Causes

Air enters from atmosphere to the lungs (inhalation)

- **Route of air during inspiration :**

  External nostrils → Nasal cavities → Pharynx → Larynx → Trachea → Bronchi → Bronchioles → Alveoli

Knowledge Cloud

Hicupps : It is a sharp jerky incomplete inspiratory sound which occurs due to sudden spasmodic contraction of diaphragm followed by a sudden closure of the glottis.

Snoring : Noise produced during sleep. It is the rough rattling inspiratory noise produced by vibration of vocal cords during sleep which occurs due to partial blockage of upper respiratory tract by the tongue.

2. **Expiration :** It is the moving of air out of lungs if the pressure within the lungs is more than the atmospheric pressure.

   Relaxation of the diaphragm and the external intercostal muscles returns the diaphragm and sternum to their normal thoracic volume and thereby pulmonary volume.

- **Diaphragm :** The relaxation of muscle fibres of diaphragm causes it to come in normal position which reduces the volume of thoracic cavity.

Decrease in the volume of thoracic cavity —Leads to→ Similar decrease in the volume of pulmonary cavity

↓ Causes

Increase in the pressure of pulmonary cavity

↓ Causes

Expulsion of air from higher pressure (lungs) to lower pressure (atmosphere)

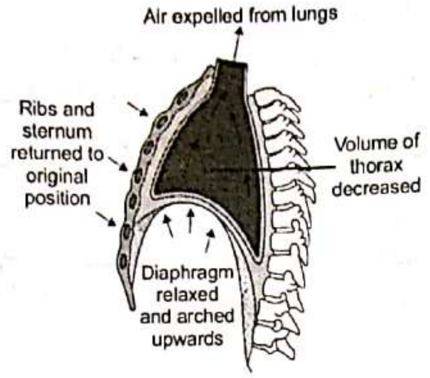


Fig. : Mechanism of breathing showing : Expiration

Forceful expiration : We have ability to increase the strength of expiration. It is due to contraction of internal intercostal and abdominal mucles.

(i) **Internal intercostal muscles :** Contraction of these muscles leads to the pulling of ribs downward and inward, decreasing the volume of thoracic cavity.

Decrease in the volume of thoracic cavity —Leads to→ Similar decrease in the volume of pulmonary cavity

↓ Causes

Increase in the pressure of pulmonary cavity

↓ Causes

Expulsion of air from higher pressure (lungs) to lower pressure (atmosphere)

(ii) **Abdominal muscles :** Abdominal muscles contract thereby compress the abdomen and pushes its contents towards the diaphragm. Therefore,

Volume of thoracic cavity decreases —Leads to→ Similar decrease in the volume of pulmonary cavity

↓ Causes

Increase in the pressure of pulmonary cavity

↓ Causes

Expulsion of air from higher pressure (lungs) to lower pressure (atmosphere)

❖ **Route of air during expiration :**

Alveoli → Bronchioles → Bronchi → Trachea → Larynx → Pharynx → Nasal cavities → External nostrils

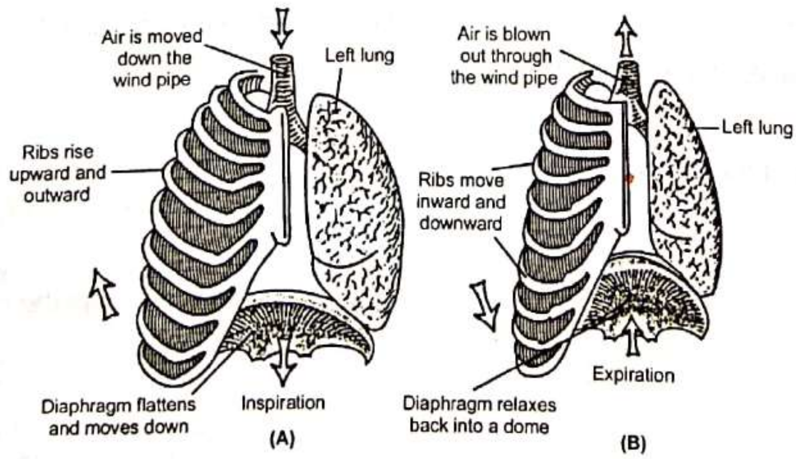


Fig. : Ribs, lungs and diaphragm – (A) During inspiration, (B) During expiration

Table : Role of muscles in inspiration and expiration

	Stage of Breathing	Muscles involved	Contraction/ Relaxation	Volume of thoracic cavity
1.	(i) Normal inspiration	(a) Diaphragm	Contracts	Increases
		(b) External intercostal muscles	Contract	Increases
	(ii) Forceful inspiration	(a) Abdominal muscles	Relaxes	Increases
2.	(i) Normal inspiration	(a) Diaphragm	Relaxes	Decreases
	(ii) Forceful expiration	(a) Internal intercostal muscles	Contract	Decreases
		(b) Abdominal muscles	Contract	Decreases

- The rate of breathing in a normal healthy man is 12–16 times/min.
- An instrument known as **spirometer** is used to estimate the volume of air involved in breathing movements which helps in clinical assessment of pulmonary functions.

Example 5 : *What happens to the volume of thoracic cavity when muscle fibres of diaphragm contract?*

Solution : The volume of thoracic cavity increases in antero-posterior axis.

Example 6 : *What is the rate of breathing in a normal healthy man?*

Solution : 12–16 times/min.

Try Yourself

9. What is the effect on the volume of pulmonary cavity when volume of thoracic cavity increases?
10. What happens to ribs and sternum during contraction of external intercostal muscles?
11. Name the additional muscles which help in increasing the strength of breathing.
12. What happens when the pressure within the pulmonary cavity is more than the atmospheric air?

Pulmonary/Respiratory Volumes and Capacities

Respiratory volume : It is defined as quantity of air which our lungs can hold or expel under different conditions.

1. **Tidal Volume (TV) :** During normal breathing, the volume of air inspired or expired is known as tidal volume. Its value is approximately 500 ml. If we take the case of healthy man, he can inspire or expire approx. 6000 ml to 8000 ml of air/min. But in a diseased person suffering from any kind of pulmonary problems, its value will be altered. Value of tidal volume is the lowest among all types of respiratory volumes.
2. **Inspiratory Reserve Volume (IRV) :** It is defined as the additional or extra volume of air, a person can inspire by forceful inspiration. This volume averages 2500 ml to 3000 ml.

Knowledge Cloud

Hering-Breuer reflex : In the walls of bronchi and bronchioles **stretch receptors** are located and are stimulated by overstretching of the lungs, nerve impulses are sent along the vagus nerve to inhibit the inspiratory area. The result is that expiration begins. Therefore it is mainly a protective mechanism for preventing excessive inflation of the lungs.

3. **Expiratory Reserve Volume (ERV) :** It is defined as the additional or extra volume of air, a person can expire by forceful expiration. This volume averages 1000 ml to 1100 ml.

4. **Residual Volume (RV) :** The volume of air which remains in the lungs even after the forceful expiration. It is about 1100 ml to 1200 ml.

Respiratory volumes	Value
1. Tidal Volume (TV)	500 ml
2. Inspiratory Reserve Volume (IRV)	2500 ml – 3000 ml
3. Expiratory Reserve Volume (ERV)	1000 ml – 1100 ml
4. Residual Volume (RV)	1100 ml – 1200 ml

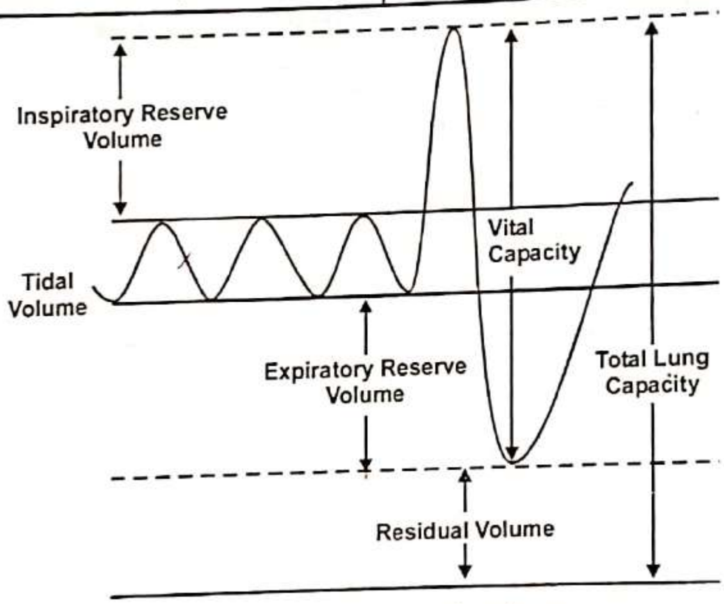


Fig. Various pulmonary air volumes

5. **Respiratory capacities :** Sum of two or more respiratory volumes is called respiratory capacities.

   (i) **Inspiratory Capacity (IC) :** It is the total volume of air a person can inspire after a normal expiration. This includes tidal volume and inspiratory reserve volume.

   (ii) **Expiratory Capacity (EC) :** After a normal inspiration, the total volume of air a person can expire is known as expiratory capacity. This includes tidal volume and expiratory reserve volume.

   (iii) **Functional Residual Capacity (FRC) :** It is defined as the volume of air that will remain in the lungs after a normal expiration. This includes expiratory reserve volume and residual volume.

   (iv) **Vital Capacity (VC) :** It is defined as the maximum volume of air a person can breathe in after a forceful expiration or the maximum volume of air a person can breathe out after a forceful inspiration. This includes expiratory reserve volume, tidal volume and inspiratory reserve volume. Depending upon the age, sex and height of individual, its value varies from 3400 ml to 4800 ml. For example, its value is high in athletes than asthenic (slight build), in men than women and in young ones than in the old persons.

(v) **Total Lung Capacity :** It is defined as the total volume of air present in the lungs and the respiratory passage after a maximum inspiration. It includes residual volume, expiratory reserve volume, tidal volume and inspiratory reserve volume. In other words, it is combination of vital capacity and residual volume.

Respiratory capacities	Formulae	Value
1. Inspiratory capacity (IC)	TV + IRV	2500–3000 ml
2. Expiratory capacity (EC)	TV + ERV	1500–2000 ml
3. Functional Residual Capacity (FRC)	ERV + RV	2500–3000 ml
4. Vital Capacity (VC)	ERV + TV + IRV or IC + ERV	3500–4000 ml
5. Total Lung Capacity (TLC)	RV + ERV + TV + IRV or IC + FRC	5000–6000 ml

Example 7 : *What is the value of expiratory reserve volume (ERV)?*

Solution : 1000 ml to 1100 ml

Example 8 : *Define tidal volume.*

Solution : It is the volume of air inspired or expired during a normal breathing.

Example 9 : *What is respiratory capacity?*

Solution : It is the sum of two or more respiratory volumes.

Try Yourself

13. What is the value of tidal volume in a normal healthy man per minute?
14. What is respiratory volume?
15. What are the factors on which vital capacity of lungs depend?
16. How can you estimate the value of functional residual capacity (FRC)?
17. In which of the following vital capacity is maximum?

    Athlete, Old man, Women and Asthmatic
18. Among all the respiratory volumes, which has lowest value?

EXCHANGE OF GASES

Gases are exchanged by simple diffusion mainly based on pressure or concentration gradient. To explain the exchange of O_2 and CO_2, partial pressure is studied. It is the pressure contributed or exerted by an individual gas in a mixture of gases. Partial pressure for oxygen is represented as pO_2 and for CO_2 it is pCO_2. The diffusion of gases takes place from a region of their higher partial pressure to a region of their lower partial pressure.

Factors that affect the rate of diffusion

1. **Solubility of gases :** A gas having high solubility, diffused at faster rate than the gas having low solubility. For example, solubility of CO_2 is 20–25 times higher than that of O_2, the amount of CO_2 that diffuses across diffusion membrane is much higher than that of O_2.
2. **Partial pressure :** As we know that gases are diffused according to their partial pressure. For example, O_2 is diffused from atmospheric air having partial pressure 159 mm Hg to the alveoli where pO_2 is less, *i.e.*, 104 mm Hg.
3. **Thickness of membrane :** More the thickness of membrane, less will be the rate of diffusion. More the membrane thin, more will be the rate of diffusion. For efficient diffusion to occur, membrane should be very thin.

There are two sites where exchange of gases takes place.

1. **Exchange of gases between alveoli and blood :**
   - **Diffusion membrane :** The wall of alveoli is very thin and has rich network of blood capillaries. Due to this network, alveolar wall looks like a sheet of flowing blood and is called diffusion or respiratory or alveolar-capillary membrane. This membrane is made up of three layers.
     (i) Thin squamous epithelium of alveoli that lines it.
     (ii) Endothelial lining of alveolar capillaries that surround it.
     (iii) **Basement substance :** In between thin squamous epithelium of alveoli and endothelium of alveolar capillaries, basement substance is present.

     All these three layers make the total thickness of diffusion membrane much less than a millimetre which is about 0.2 mm.

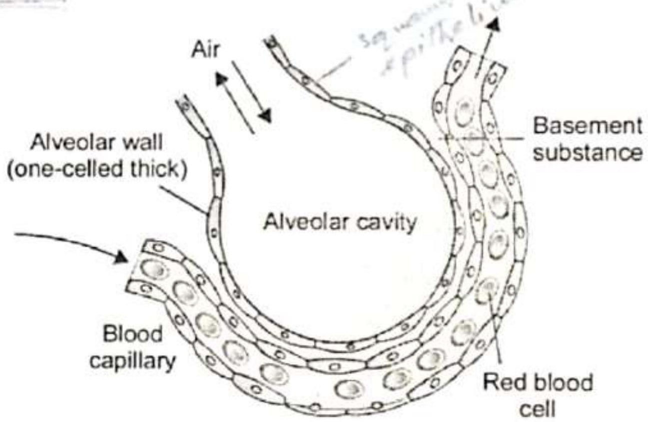


Fig. : A diagram of a section of an alveolus with a pulmonary capillary

Table : Partial Pressures (in mm Hg) of Oxygen and Carbon dioxide at Different Parts Involved in Diffusion in Comparison to those in Atmosphere

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

- The pO_2 in the atmospheric air is higher, *i.e.*, 159 mm Hg than that in the alveoli, *i.e.*, 104 mm Hg and pO_2 in alveoli is higher than that in the deoxygenated blood in the capillaries of the pulmonary arteries (40 mm Hg). As we know, gases diffuse from their higher partial pressure to their lower partial pressure. Therefore, O_2 moves from atmospheric air to alveoli and then finally to blood, whereas the CO_2 movement is in opposite direction. The pCO_2 is higher in deoxygenated blood (45 mm Hg) than that in alveoli (40 mm Hg) and it is further low in atmospheric air, *i.e.*, 0.3 mm Hg. Therefore, CO_2 moves from deoxygenated blood to alveoli and finally to atmospheric air.

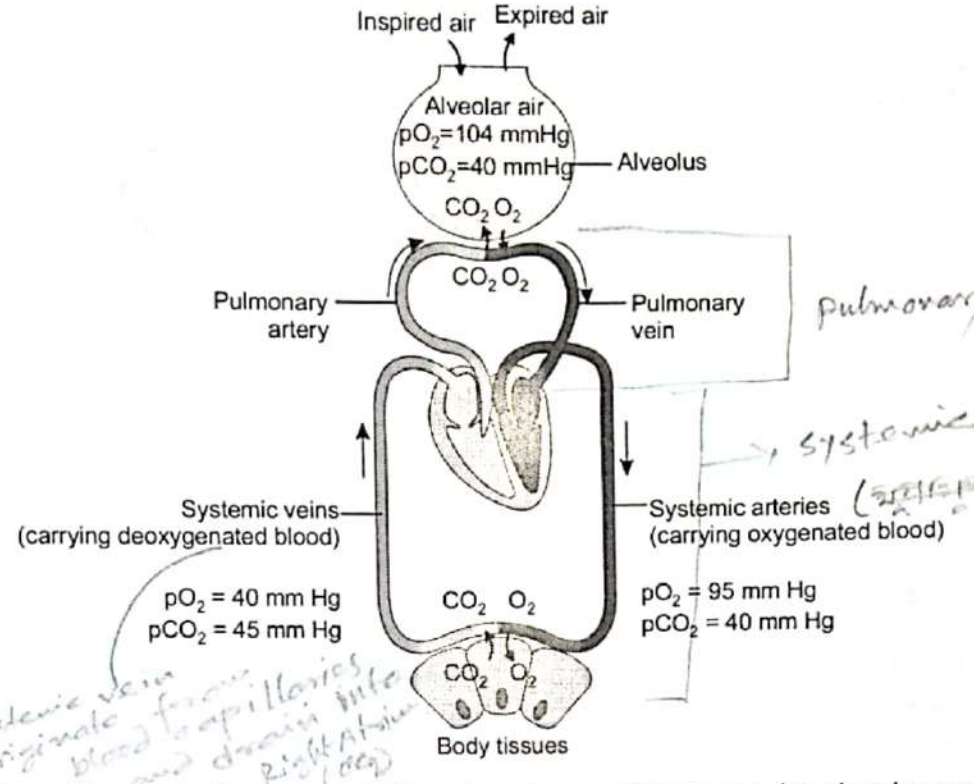


Fig. : Diagrammatic representation of exchange of gases at the alveolus and the body tissues with blood and transport of oxygen and carbon dioxide

2. **Exchange of gases between blood and tissues :**

Gases like O_2 and CO_2 are exchanged from blood capillaries to body cells and from body cells to blood capillaries, respectively. The pO_2 is higher in systemic arteries carrying oxygenated blood, *i.e.*, 95 mm Hg than that in tissues or body cells, *i.e.*, 40 mm Hg. Therefore, O_2 moves from systemic arteries to body cells where it is utilised for catabolic reaction during which CO_2, H_2O and energy are produced. As the CO_2 is produced in the body cells, the pCO_2 is increased within the body cells, *i.e.*, 45 mm Hg than that in blood capillaries, *i.e.*, 40 mm Hg. Therefore, CO_2 moves from body cells to the capillary blood through tissue fluid. Now, the blood becomes deoxygenated which is carried to the heart and hence to the lungs via pulmonary artery.

Knowledge Cloud

Pneumonia : It is the infection of lungs caused by bacteria that leads to the accumulation of mucus and lymph in alveoli which impairs the exchange of gases, uptake of O_2 is adversely affected and as a result oxygen level of the blood falls.

Example 10 : *Which is the primary site for exchange of gases?*

Solution : Alveoli

Example 11 : *How are gases like O_2 and CO_2 exchanged in our body?*

Solution : By simple diffusion based on pressure gradient.

Example 12 : *Why is O_2 gas passed from atmospheric air to alveoli?*

Solution : It is because the pO_2 in atmospheric air is higher, *i.e.*, 159 mm Hg than in alveoli, *i.e.*, 104 mm Hg.

Try Yourself

19. Which epithelium lines the alveoli? (squamus epithellium)
20. Which gas, out of O_2 and CO_2 is more soluble?
21. What is the thickness of diffusion membrane?
22. How many layers form the diffusion membrane?
23. Why is CO_2 gas transferred from alveoli to atmospheric air?
24. Which gas has higher partial pressure in tissues?

TRANSPORT OF GASES

Blood transports nutrients, vitamins, gases etc. within the body. Some amount of gases get dissolved in plasma and transported, whereas some amount is transported in bound state. O_2 and CO_2 bind with haemoglobin present in RBCs. Now, we discuss the transport of O_2 and CO_2 in detail.

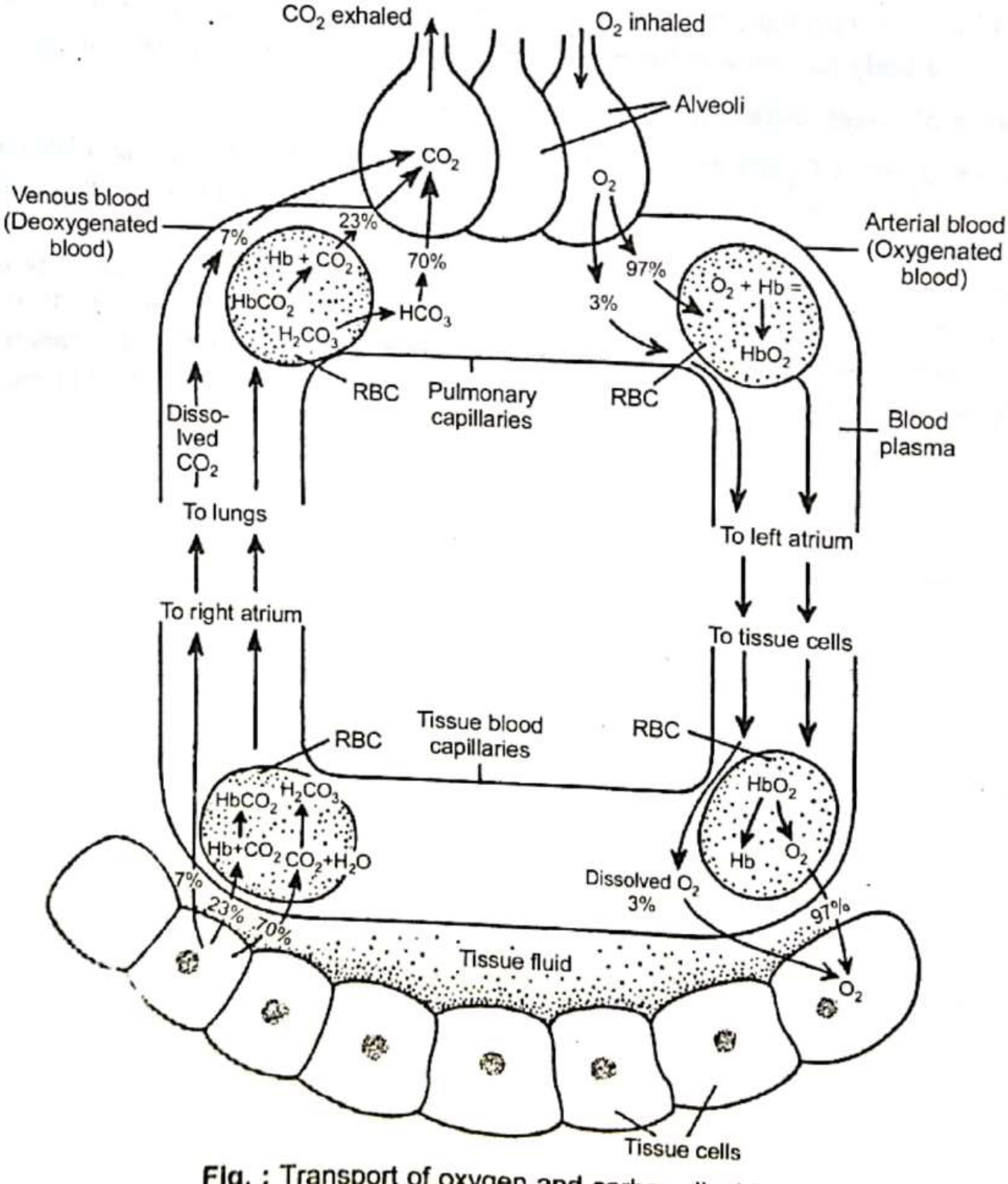


Fig. : Transport of oxygen and carbon dioxide

Transport of O_2

Blood carries oxygen from the lungs to the heart and from there it reaches to various body cells.

Oxygen is transported in the following manner :

1. **In dissolved form :** About 3% O_2 is carried in dissolved state through plasma.
2. **As oxyhaemoglobin :** About 97% O_2 is transported by RBCs in the blood. Haemoglobin (Hb) is made up of two parts – haem and globin. Haem is iron part and globin is protein part.

$$\underset{\text{Haemoglobin}}{Hb} \longrightarrow \underset{\text{(Iron part)}}{Haem} + \underset{\text{(Protein part)}}{Globin}$$

It is red coloured iron containing pigment present in RBCs. It binds with O_2 in a reversible manner to form oxyhaemoglobin (OxyHb) and transports it.

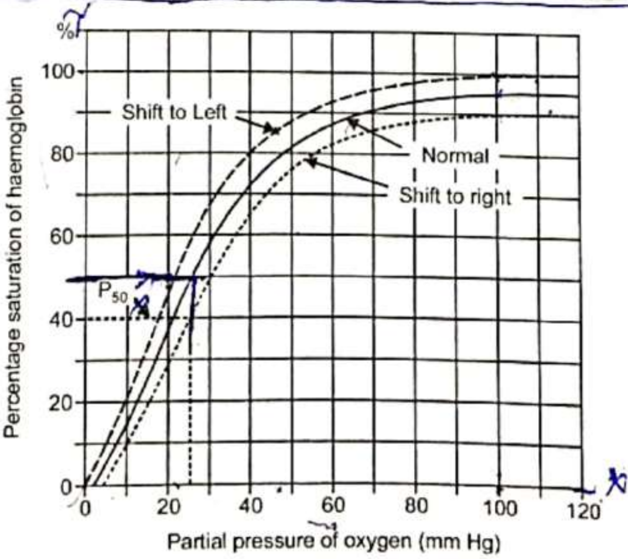
Single molecule of Hb can carry a maximum of four molecules of oxygen. This is because it has four polypeptide chains and four haem groups each containing an iron atom to which an oxygen can attach. Each polypeptide chain carries a haem group and each haem group carries an iron atom.

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{Oxygen}}{O_2} \underset{\text{Tissues}}{\overset{\text{In lungs}}{\rightleftharpoons}} \underset{\substack{\text{Oxyhaemoglobin}\\\text{(OxyHb)}}}{HbO_2}$$

O_2 binds with Hb at the lungs surface and gets dissociated at the tissues. Under the high partial pressure, oxygen easily binds with Hb in the pulmonary blood capillaries. When this oxygenated blood reaches to different tissues, the pO_2 decreases and the bonds holding oxygen to Hb become unstable. As a result, oxygen is released from blood capillaries to tissues where it is utilised for oxidation of glucose.

Oxyhaemoglobin dissociates near tissues due to increase in acidity and decrease in pH. It can also be caused due to high temperature. In a normal person, the hemoglobin level is about 15 g per 100 ml. **The capacity of 1 g of hemoglobin to combine with O_2 is 1.34 ml**. Therefore Arterial blood carries about 20 ml of O_2/100 ml of blood. Under normal condition, the O_2 level falls to about 14.4 ml/100 ml in the venules. It indicates that under normal condition, approximately 5 ml oxygen is transported by blood. **Under strenous conditions or during exercise, the O_2 level falls to about 4.4. ml/100 ml *i.e.*, approximately 15 ml of O_2 is transported by Hb during exercise.**

Oxygen-dissociation curve : A graphical representation of relationship between pO_2 and percentage saturation of Hb with O_2 is known as O_2-dissociation curve or oxygen haemoglobin dissociation curve. It is sigmoid or 'S' shaped. The amount of O_2 that can bind with Hb is determined by partial pressure of oxygen. The percentage of Hb that is bound with O_2 is called percentage saturation of Hb.



As shown in the graph, Hb gets saturated to about 50% when the pO_2 is 25 mm Hg. It means the blood contains about 50% oxygen. The partial pressure at which Hb saturation is 50% is called P_{50}.

Factors that affect the O_2-dissociation curve : This curve is very much useful in studying the effect of factors like pO_2, pCO_2 etc. on binding of O_2 with Hb. For example, if pO_2 decreases, then dissociation of O_2 from Hb takes place which occurs in tissues. It shifts the curve towards right which indicates dissociation of O_2 from Hb. Various factors are responsible for shifting the curve either to left or right.

1. **Shift to right :** Shifting of curve towards right indicates the dissociation of oxygen from Hb and this dissociation occurs in tissues. Following are the conditions responsible for shifting oxygen-haemoglobin curve towards right.

   (1) Low partial pressure of oxygen.

   (2) High partial pressure of CO_2.

   Bohr's Effect : The relationship between the pO_2 and percent saturation of haemoglobin when represented on a graph is termed as **oxygen-haemoglobin dissociation curve** and is **sigmoid** in shape. A rise in pCO_2 or fall in pH **decreases** oxygen affinity of haemoglobin, raising the P_{50} value. This is called Bohr's effect (P_{50} value is the value of pO_2 at which haemoglobin is 50% saturated with oxygen to form oxyhaemoglobin). Conversely a fall in pCO_2 and rise in pH increases oxygen affinity of haemoglobin.

   (3) High H^+ ion concentration and decrease in pH means increase in acidity.

   (4) High temperature.

   All these factors are favourable for the dissociation of O_2 from Hb which occurs in the body tissues.

2. **Shift to left :** This shift indicates the association of O_2 and Hb. Following are the conditions responsible for shifting the curve (O_2-dissociation curve) towards left.

   (1) High partial pressure of oxygen.

   (2) Low partial pressure of CO_2.

   (3) Less H^+ ion concentration and high pH.

   (4) Low temperature.

   All these factors are favourable for the association of O_2 and Hb which occurs in alveoli.

Knowledge Cloud

❖ A rise in pCO_2, H^+ ions [fall in pH], temperature and **Diphosphoglyceric acid** shifts the HbO_2 dissociation curve to right and vice versa (raising the P_{50} value).

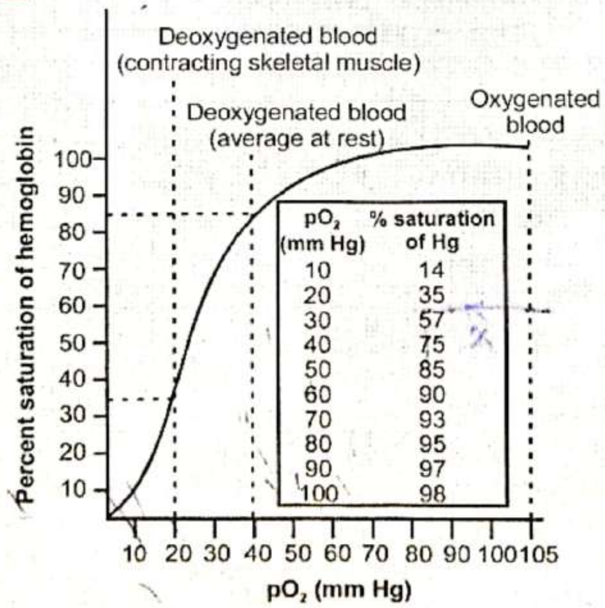


Fig. Oxygen-hemoglobin dissociation curve at normal body Temperature showing the relationship between hemoglobin saturation and pO_2

❖ **Fetal hemoglobin** (Hb-F) differs from adult hemoglobin (Hb-A) in structure and in its affinity for O_2. Hb-F has a higher affinity for O_2 because it binds BPG less strongly. Thus, when pO_2 is low, Hb-F can carry up to 30% more O_2 than maternal Hb-A. Therefore oxygen - hemoglobin dissociation curve for fetal hemoglobin will appear on the left side.

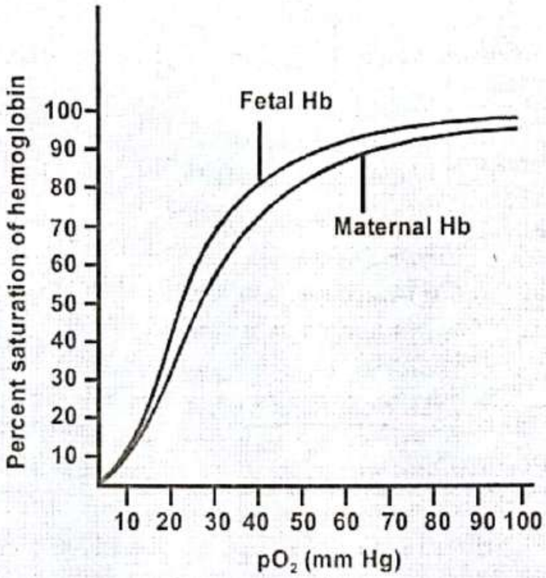


Fig. Oxygen-hemoglobin dissociation curves comparing fetal and maternal hemoglobin

Myoglobin present in the muscle also has more affinity for O_2. But as it has only one Fe^{2+} group, the curve obtained will be hyperbolic, than being sigmoid.

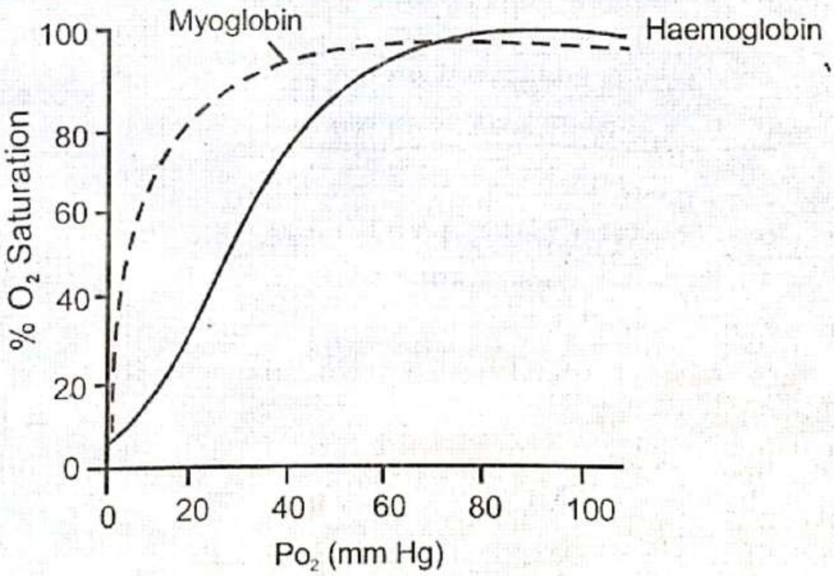


Fig. Dissociation curve for haemoglobin and myoglobin at 37°C, pCO_2 40 mmHg and pH 7.4

❖ **Carbon Monoxide Poisoning :** If a person sleeps in a closed room with a lamp burning, the absence of sufficient amount of oxygen causes an incomplete combustion of carbon and produces carbon monoxide in the room. As the person inhales carbon monoxide, it diffuses from the alveolar air to the blood and binds to haemoglobin forming carboxyhaemoglobin. The later is a relatively stable compound and cannot bind with oxygen. So, the amount of haemoglobin available for oxygen transport is reduced. The resulting deficiency of oxygen causes headache, dizziness, nausea and even death. Carbon monoxide combines with haemoglobin at the same point on haemoglobin molecule as does oxygen. It binds with haemoglobin 250 times faster than oxygen.

❖ **SARS (Severe Acute Respiratory Syndrome) :** The first patient of SARS was reported on February 26, 2003 in China. The causative agent is human **Corona virus**. It is a new member of influenza virus family which is considered as a mutant form of influenza virus.

Did You Know?

Respiratory pigment Hb which is present in vertebrates, also found in some invertebrates like earthworm, *Nereis*.

Cyanosis : It is a condition in which the colour of skin and mucous membrane becomes bluish due to deficiency of oxygen in blood.

Hypoxia : It is a condition of oxygen shortage in the tissues. It is of four types.

(1) **Anaemic hypoxia :** The amount of oxygen carrying haemoglobin is reduced due to anaemia.

(2) **Cytotoxic hypoxia :** It is a rare condition but is most often due to cyanide poisoning. Utilization of O_2 is impaired in the body cells.

(3) **Stagnant hypoxia :** Due to heart failure or reduced pumping activity of heart.

(4) **Hypoxic hypoxia :** Insufficient oxygen in air as at high altitude.

Transport of CO_2

When O_2 reaches the body cells, oxidation of food (glucose) takes place during which CO_2, H_2O and energy are produced. CO_2 in gaseous form diffuses out of the cells into the capillaries, where it is transported in three different means.

1. **In dissolved form through plasma :** About 7% CO_2 gets transported in dissolved form. It gets dissolved in the blood plasma and is carried in solution to the lungs. CO_2 has high solubility than O_2. Therefore, only about 3% O_2 is transported in dissolved form whereas about 7% CO_2 is transported in dissolved form.

2. **As bicarbonate ions:** About 70% of CO_2 is converted into HCO_3^- and transported in plasma. CO_2 diffuses in the RBCs where it binds with water, forming carbonic acid (H_2CO_3). Carbonic acid quickly dissociates into hydrogen and HCO_3^- ions as it is unstable. The reaction is facilitated by an enzyme known as carbonic anhydrase which is present in very high concentration in RBCs and in small quantity in plasma.

$$CO_2 + H_2O \xrightleftharpoons[Zn^{++}]{\text{Carbonic anhydrase}} \underset{\text{Carbonic acid}}{H_2CO_3} \xrightleftharpoons{\text{Carbonic anhydrase}} \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

As we know, the pCO_2 is high in tissues due to catabolism, *i.e.*, breakdown of glucose into H_2O, CO_2 and energy than in blood capillaries. So, diffusion of CO_2 occurs from tissues to blood (RBCs and plasma) where HCO_3^- and H^+ ions are formed. The HCO_3^- ions formed in RBCs quickly diffuse into the plasma, where they are carried to the lungs.

At the alveolar site (lungs), the process is reversed means CO_2 and H_2O are formed from HCO_3^- and H^+. The reaction proceeds as

$$HCO_3^- + H^+ \xrightleftharpoons[\text{anhydrase}]{\text{Carbonic}} H_2CO_3 \xrightleftharpoons[\text{anhydrase}]{\text{Carbonic}} H_2O + CO_2$$

Bicarbonate ions re-enter the RBCs and bind with H^+ to form carbonic acid which then quickly splits into H_2O and CO_2. Finally, CO_2 is diffused from blood to the lungs, where pCO_2 is low.

3. **By RBCs as carbaminohaemoglobin ($HbCO_2$)** : About 20-25% CO_2 is transported as carbaminohaemoglobin. CO_2 that enters in the RBCs forms a reversible compound, *i.e.*, $HbCO_2$. CO_2 binds with amino group of globin protein which is a part of Hb. The reaction is similar to the oxygen but CO_2 binds not with haem part but with protein part of Hb.

Hb	+	CO_2	$\rightleftharpoons$	$HbCO_2$
Haemoglobin (RBCs)		Carbon dioxide		Carbamino-haemoglobin

Factors that affect the binding of CO_2 with Hb :

In tissues : High pCO_2 and low pO_2 in tissues are responsible for binding more CO_2 with Hb.

$$Hb + CO_2 \longrightarrow HbCO_2$$

In alveoli : Low pCO_2 and high pO_2 in alveoli are responsible for dissociation of CO_2 from carbaminohaemoglobin.

$$HbCO_2 \longrightarrow Hb + CO_2$$

In this way, the CO_2 bound to Hb from tissues is delivered at the alveoli, where it is exhaled out.

Under normal conditions, approximately 4 ml of CO_2 is delivered to the alveoli by every 100 ml of deoxygenated blood.

Knowledge Cloud

Hamburger's Phenomenon : HCO_3^- ions diffuse out into plasma and Cl^- ions enter into the RBCs at the level of tissues (internal respiration). This is known as "chloride shift" or "Hamburger phenomenon." At the level of external respiration or alveoli, Cl^- move out as HCO_3^- move in this is called reverse of chloride shift.

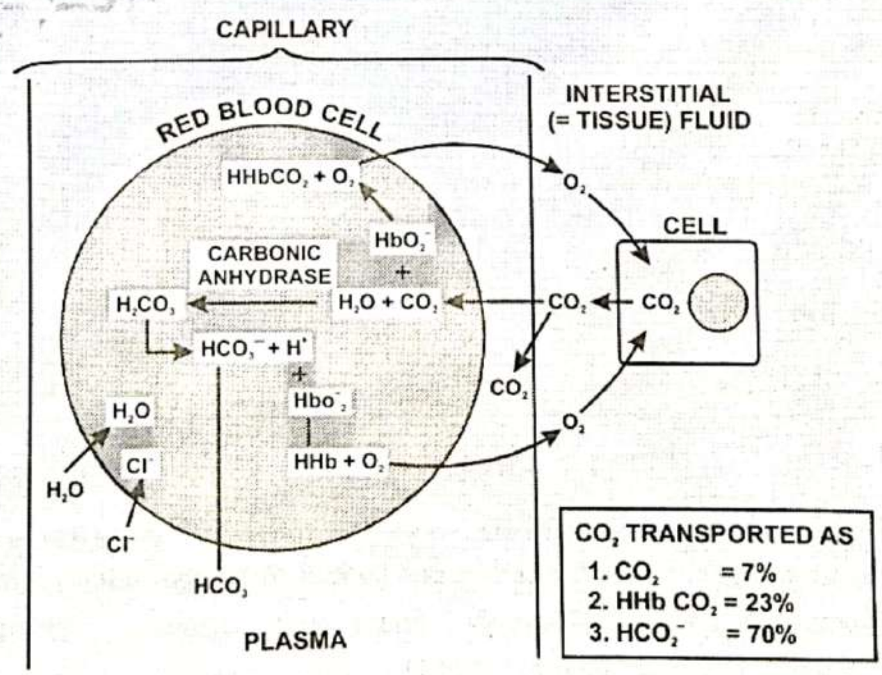


Fig. Transportation of CO_2 by blood

Haldane's Effect : It is related to the transport of CO_2 in the blood. It is based on the simple fact that **oxyhaemoglobin behaves as strong acid** and releases an excess of H^+ ions which bind with bicarbonate HCO_3^- ions to form H_2CO_3 which dissociates into H_2O and CO_2. Secondly, due to the increased acidity, CO_2 loses the power to combine with haemoglobin and form carbamino-haemoglobin. Effect of oxyhaemoglobin formation or dissociation on CO_2 transport is called **Haldane's effect.**

Example 13 : *What is the medium of transport for O_2 and CO_2?*

Solution : Blood

Example 14 : *What is the percentage of O_2 transported in bound form?*

Solution : About 97%

Example 15 : *What is O_2-dissociation curve?*

Solution : A graphic representation between the relationship between pO_2 and percentage saturation of Hb with O_2.

Example 16 : *Which compound is formed when O_2 binds with Hb?*

Solution : Oxyhaemoglobin

Try Yourself

25. What is the shape of O_2-dissociation curve for haemoglobin?
26. Write any two factors that are favourable for the formation of oxyhaemoglobin.
27. Which compound is formed when CO_2 binds with Hb?
28. What are the conditions responsible for more binding of CO_2 with Hb in tissues?
29. What is the percentage of CO_2 transported as bicarbonate ions?
30. Write down the reaction facilitated by an enzyme carbonic anhydrase present in RBCs.
31. In which form, CO_2 is trapped at the tissue level?
32. How much CO_2 is delivered to the alveoli by every 100 ml of deoxygenated blood?

REGULATION OF RESPIRATION

Breathing occurs involuntarily, *i.e.*, it is not under our control. A normal adult human breaths 12–16 times/min in which inspiration lasts for about 2 seconds and expiration lasts for about 3 seconds and an infant breaths about 44 times/min. Humans have an ability to regulate the breathing rate according to the need of the body. Regulation of respiration includes both nervous and chemical.

Nervous Regulation

The respiratory rhythm is regulated by the neural or nervous system which consists of various respiratory centres present in the brain. The respiratory centre is composed of group of neurons located in the medulla oblongata and pons. The respiratory system regulates the rate and depth of the breathing.

There are two centres present in the brain for regulation of respiration.

1. **Respiratory rhythm centre :** It is a specialised centre located in the medulla region of hind brain. It can either cause expiration or inspiration according to the neurons which are activated and thereby, regulate the respiratory rhythm according to the need of the body.

2. **Pneumotaxic centre :** This centre is present in the pons region of hind brain. It moderates the function of respiratory rhythm centre. The neural signal from this centre can reduce the duration of inspiration and thereby alter the respiratory rate.

Chemical Regulation

A chemosensitive area, *i.e.*, sensitive for chemicals is located adjacent to the rhythm centre which contains chemoreceptors which are sensitive for CO_2 and H^+ ions. The respiratory centre is stimulated by concentration or partial pressure of CO_2 (pCO_2) and H^+ ions (pH) in blood and body fluids. Chemosensitive area gets activated due to an increase in CO_2 and H^+ ions concentration which in turn activates the respiratory rhythm centre for altering the rate of respiration. For example, increase of CO_2 in blood increases the rate and depth of respiration and decrease in CO_2 depresses rate and depth of respiration.

CO_2 and H^+ ions sensitive receptors (chemoreceptors) are also present in

1. **Aortic arch :** It is the curved portion between the ascending and descending portions of the aorta, giving rise to the left carotid and the left subclavian arteries.

2. **Carotid artery :** It supplies blood to brain. Increased concentration of CO_2 in blood lowers its pH and low concentration of CO_2 raises the pH of blood. The low pH of blood increases the rate of respiration.

Knowledge Cloud

Narcosis : It is the depression of central nervous system which includes the respiratory centres and affects the regulation of respiration.

Example 17 : *Which is the main centre of brain that regulates the respiration rate?*

Solution : Respiratory rhythm centre

Example 18 : *Where is respiratory rhythm centre located in brain?*

Solution : Medulla oblongata of hind brain.

Try Yourself

33. What is the location of pneumotaxic centre in brain?
34. How pneumotaxic centre regulates the respiratory rate?
35. Where is the chemosensitive area located in the brain which regulates the respiration?
36. To which substances, chemosensitive area is highly sensitive?

ADDITIONAL INFORMATION

1. Pulmonary ventilation / Minute volume of respiration = Tidal volume x Breathing rate
2. **Carbon-Monoxide poisoning:** CO combines with haemoglobin far more readily than O_2, forming a relatively stable compound carboxyhaemoglobin. This causes low supply of O_2 to the body cells. It is characterised by headache, dizziness, nausea, paralysis and even death.
3. **Hering-Breuer inflation reflex** is a protective mechanism for preventing excess lung inflation.
4. **Hiccough** is spasmodic contraction of the diaphragm followed by a spasmodic closure of the glottis produces a sharp inspiratory sound. Stimulus is usually irritation of the sensory nerve endings of digestive tract.
5. **Anoxia:** Absence of oxygen in inspired gases, arterial blood or tissues.
6. **Hypercapnia:** It is increase in carbon dioxide content of blood.
7. **Asphyxia:** It is a combination of hypoxia and hypercapnia.
8. **Hypopnea**: Breathing rate is less than normal.
9. **Hyperpnea:** Breathing rate is higher than normal.
10. The air which is inhaled contains dust, bacteria etc. get filtered in the nose, so, the air which goes into lungs is cleaner and warmer. Thus the breathing through nose is healthier.

Some Important Definitions

- **Respiration :** It is an oxidation of food (glucose) to form CO_2, water and energy is released. Reaction involves :

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

- **Diffusion :** The flow of molecules (ions, gases) from a region of their higher concentration to a region of their lower concentration.
- **Diffusion membrane :** It is formed of thin squamous epithelium of alveoli, endothelium of alveolar capillaries and basement substance between them across which gases are diffused.
- **Epiglottis :** A thin elastic cartilaginous flap which covers the glottis to prevent the entry of food into the larynx.
- **Alveoli :** It is the site for exchange of gases O_2 and CO_2, very thin, irregularly walled and highly vascularised balloon like structures.
- **Trachea :** It is a straight tube extending upto the mid-thoracic cavity divides into right and left primary bronchi at the level of 5^{th} thoracic vertebra.
- **Inspiration :** The process by which fresh air is taken in the lungs.
- **Expiration :** The process by which foul air containing CO_2 is expelled out of the lungs.
- **Diaphragm :** It is a dome-shaped structure made up of muscles which separates thoracic cavity and abdominal cavity.
- **Tidal volume (TV) :** It is the volume of air inspired or expired during normal breathing. It is about 500 ml.
- **Residual volume (RV) :** Amount of air left inside the lungs after the most powerful expiration. It is about 1100 ml to 1200 ml.
- **Vital capacity (VC) :** It is the maximum volume of air a person can breathe in after a forceful expiration or maximum of air a person can breathe out after a forceful inspiration. It is about 3500 ml to 4000 ml.
- **Total lung capacity (TLC) :** It is the total volume of air present in the lungs and the respiratory passage after a maximum inspiration. It is about 5000 ml to 6000 ml.
- **Oxyhaemoglobin :** A reversible compound forms on binding of O_2 with Hb in the RBCs.

$$Hb + O_2 \rightleftharpoons \underset{\text{Oxyhaemoglobin}}{HbO_2}$$

- **O_2-dissociation curve :** A graph shows the relationship between pO_2 and percentage saturation of the haemoglobin with O_2. It is sigmoid or 'S' shaped.
- **Respiratory rhythm centre :** A specialised centre located in the medulla region of brain to regulate the respiration process.

Quick Recap

1. Different animals have different respiratory organs based on their habitat and level of organisation.
2. Human respiratory tract has conducting and respiratory part.
3. Alveoli is the site of exchange of gases (O_2 and CO_2) as it is thin, irregularly walled and highly vascular.
4. Breathing is the first step in respiration. It involves inhalation and exhalation of air.
5. Pressure gradient is responsible for the movement of air into and out of the lungs.
6. Rate of diffusion of gases depends upon their solubility, thickness and vascularity of membrane.
7. On contraction, diaphragm and external intercostal muscles cause inspiration.
8. Relaxation of diaphragm and contraction of internal intercostal muscles cause expulsion of air.
9. Blood is the medium for transport of gases.
10. Oxygen and CO_2 binds with Hb to form oxyhaemoglobin and carbaminohaemoglobin.

$$Hb + O_2 \rightleftharpoons \underset{\text{Oxyhaemoglobin}}{HbO_2}$$

$$Hb + CO_2 \rightleftharpoons \underset{\text{Carbaminohaemoglobin}}{HbCO_2}$$

11. O_2 is transported as dissolved form (about 3%) and in oxyhaemoglobin (about 97%) form.
12. CO_2 is transported as bicarbonate ions (about 70%), carbaminohaemoglobin (about 20–25%) and carbonic acid (about 7%).
13. The O_2-dissociation curve is sigmoid or 'S' shaped.
14. The curve helps in studying the effect of factors like pO_2, pCO_2, H^+ ions concentration and temperature.
15. Respiration is regulated by
    - Respiratory rhythm centre
    - Pneumotaxic centre
    - Chemosensitive area
    - Receptors associated with aortic arch and carotid artery.

❑ ❑ ❑

DEAD SPACE

DEFINITION

Dead space is defined as the part of the respiratory tract, where gaseous exchange does not take place. Air present in the dead space is called dead space air.

TYPES OF DEAD SPACE

Dead space is of two types:

1. Anatomical dead space.
2. Physiological dead space.

Anatomical Dead Space

Anatomical dead space extends from nose up to terminal bronchiole. It includes nose, pharynx, trachea, bronchi and branches of bronchi up to terminal bronchioles. These structures serve only as the passage for air movement. Gaseous exchange does not take place in these structures.

Physiological Dead Space

Physiological dead space includes anatomical dead space plus two additional volumes.

Additional volumes included in physiological dead space are:

1. Air in the alveoli, which are **non-functioning.** In some respiratory diseases, alveoli do not function because of dysfunction or destruction of alveolar membrane.
2. Air in the alveoli, which do not receive adequate blood flow. Gaseous exchange does not take place during inadequate blood supply.

These two additional volumes are generally considered as wasted ventilation.