BREATHING AND EXCHANGE OF GASES

As you have read earlier, oxygen (O_2) is utilised by the organisms to indirectly break down nutrient molecules like glucose and to derive energy for performing various activities. Carbon dioxide (CO_2) which is harmful is also released during the above catabolic reactions. It is, therefore, evident that O_2 has to be continuously provided to the cells and CO_2 produced by the cells have to be released out. This process of exchange of O_2 from the atmosphere with CO_2 produced by the cells is called breathing, commonly known as respiration.

Respiration involves the following steps:

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

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

(iii) Transport of gases by the blood.

(iv) Diffusion of O_2 and CO_2 between blood and tissues.

(v) Utilisation of O_2 by the cells for catabolic reactions and resultant release of CO_2 (cellular respiration).

Respiratory organs

Depend on < Habitat / Level of organization

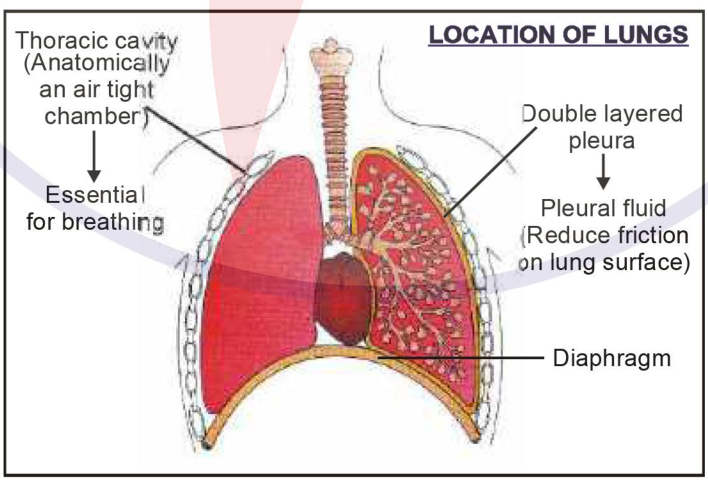
(1) Through general body surface = Sponges, coelenterates, flatworms
(Simple diffusion)

(2) Through Moist cuticle = Earthworm

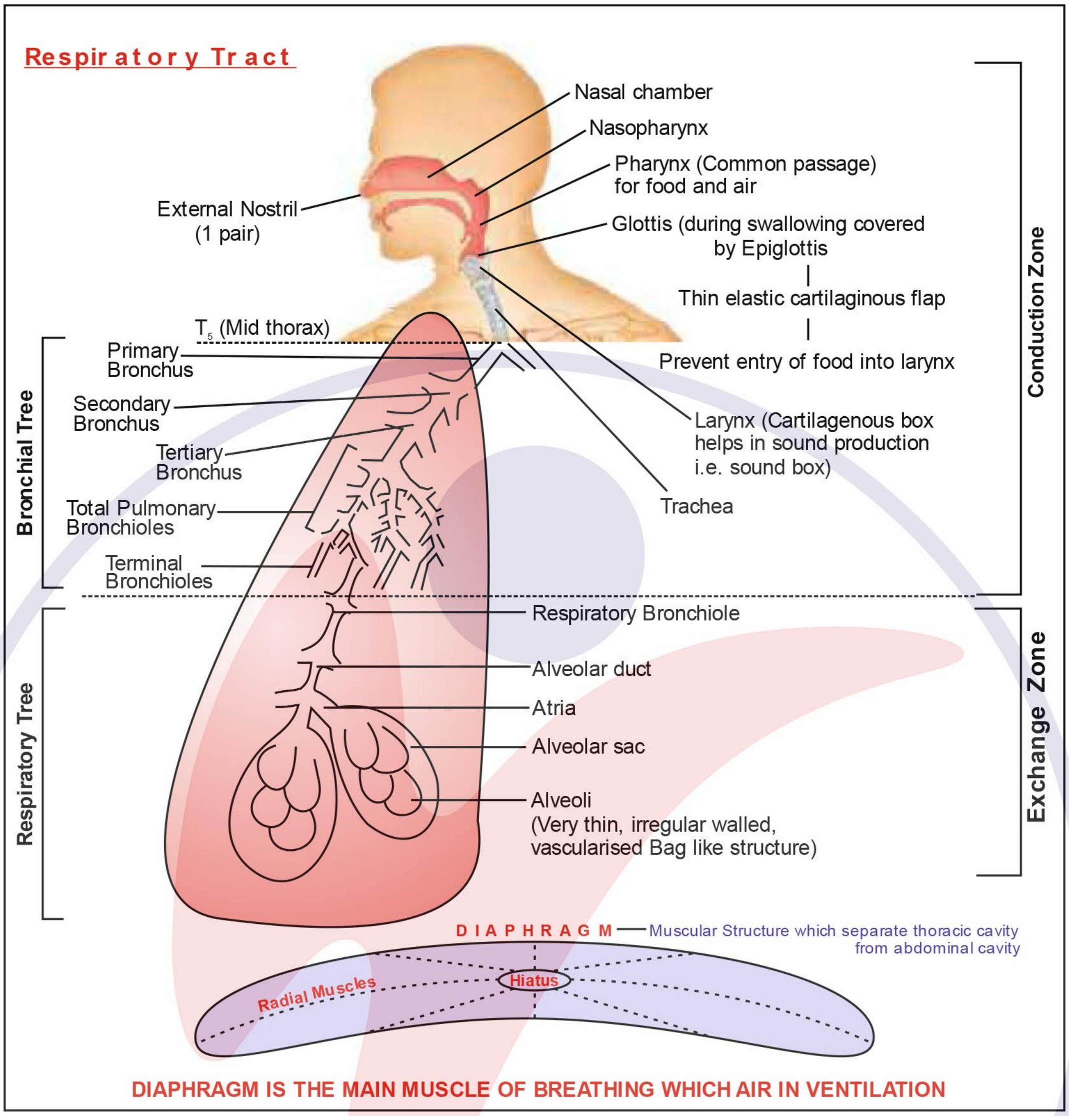
(3) Network of tracheal tubes = Insects

(4) Gills = Aquatic arthropods, molluscs, fishes

(5) Lungs (Vascularised bags) = Reptiles, Amphibians (also by Moist skin) birds, mammals



Outer pleural membrane is in close contact with the thoracic lining whereas the inner pleural membrane is in contact with the lung surface.



We have a pair of **external nostrils** opening out above the upper lips. It leads to a **nasal chamber** through the **nasal passage.** The nasal chamber opens into **nasopharynx,** which is a portion of **pharynx,** the **common passage for food and air.** Nasopharynx opens through glottis of the larynx region into the trachea. **Larynx** is a **cartilaginous** box which **helps in sound production** and hence **called the sound box.** During swallowing **glottis** can be covered by a thin elastic **cartilaginous flap** called **epiglottis** to **prevent the entry of food into the larynx. 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 **bronchi** 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 a number of very thin, irregular walled and vascularised bag-like structures called **alveoli.** The **branching network of bronchi, bronchioles and alveoli comprise the lungs.** We have two lungs which are covered by a **double layered pleura,** with **pleural fluid** between them. **It reduces friction on the lungsurface. 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 part starting with the external nostrils up to the terminal bronchioles constitute the conducting part whereas the alveoli and their ducts form the respiratory or exchange part of the respiratory system. The conducting part transports the atmospheric air to the alveoli, clears it from foreign particles, humidifies and also brings the air to body temperature. 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 which is anatomically an air-tight chamber. The thoracic chamber is formed dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs and on the lower side by the dome-shaped diaphragm. The anatomical setup of lungs in thorax is such that any change in the volume of the thoracic cavity will be reflected in the lung (pulmonary) cavity. Such an arrangement is essential for breathing, as we cannot directly alter the pulmonary volume.

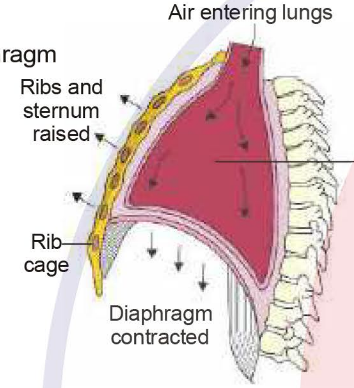
MECHANISM OF BREATHING

Inspiration
(atmospheric air is drawn in)

Intra-pulmonary pressure < atmospheric pressure

Contraction

- Diaphragm → Increase in Antero posterior axis
- EICM → Increase in Dorso-ventral axis



↓

Pulmonary volume ↑

↓

Intrapulmonary pressure ↓

↓

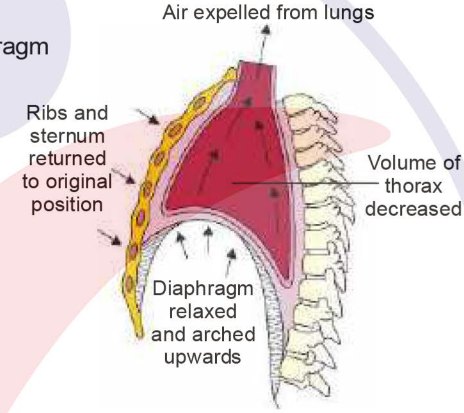
Forces air from outside to enter more into the lungs (inspiration)

Expiration
(alveolar air is released out)

Intra-pulmonary pressure > atmospheric pressure

Relaxation

- Diaphragm → Decrease in Antero-posterior axis
- EICM → Decrease in Dorso ventral axis



↓

Pulmonary volume ↓

↓

Intrapulmonary pressure ↑

↓

Causing expulsion of air from the lungs (expiration)

Note :- We have ability to increase the strength of inspiration and expiration with the help of additional muscles in abdomen.

In human beings breathing is negative pressure breathing where as in frog breathing is positive pressure breathing.

RESPIRTORY VOLUMES AND CAPACITIES

The volume of air involved in breathing movements can be estimated by using a spirometer which helps in clinical assessment of pulmonary functions.

1. **Tidal Volume (TV):** Volume of air inspired or expired during a normal respiration. It is approx. 500 mL., i.e., a healthy man can inspire or expire approximately 6000 to 8000 mL of air per minute.

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

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

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

   By adding up a few respiratory volumes described above, one can derive various pulmonary capacities, which can be used in clinical diagnosis.

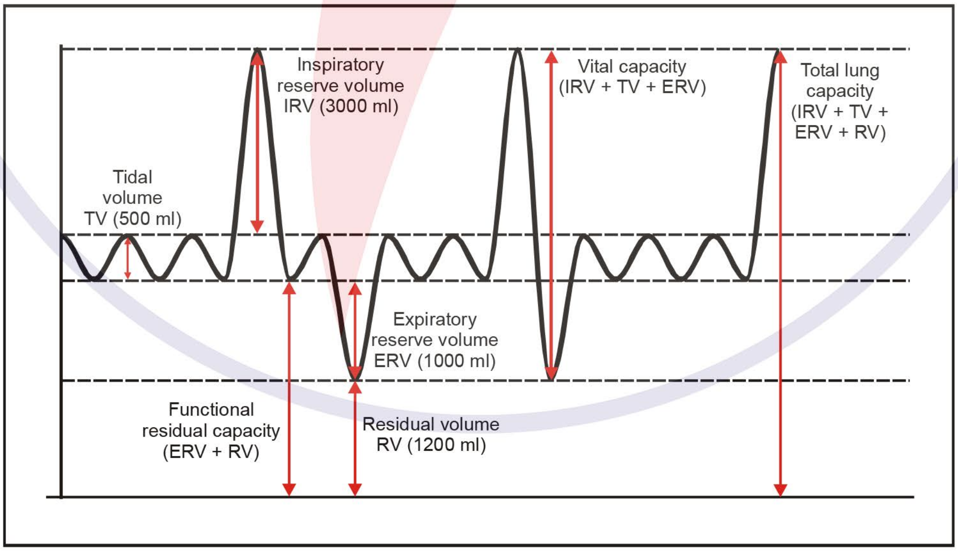
5. **Inspiratory Capacity (IC):** Total volume of air a person can inspire after a normal expiration. This includes tidal volume and inspiratory reserve volume (TV+IRV).

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

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

8. **Vital Capacity (VC):** The maximum volume of air a person can breathe in after a forced expiration. This includes ERV, TV and IRV or the maximum volume of air a person can breathe out after a forced inspiration.

9. **Total Lung Capacity:** Total volume of air accommodated in the lungs at the end of a forced inspiration. This includes RV, ERV, TV and IRV or vital capacity + residual volume.

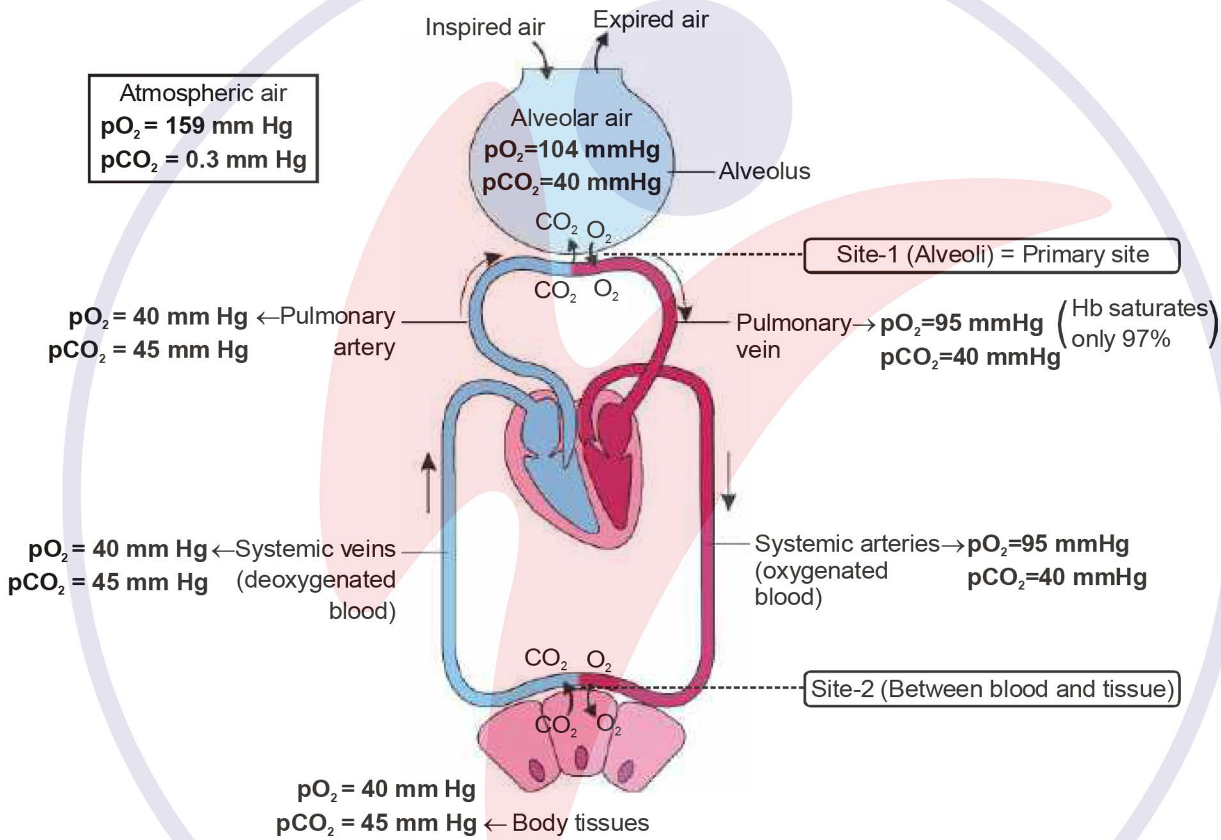


Vital capacity represents the maximum amount of air one can renew in the respiratory system in a single respiration. Thus, greater the vital capacity more is the energy available to the body.

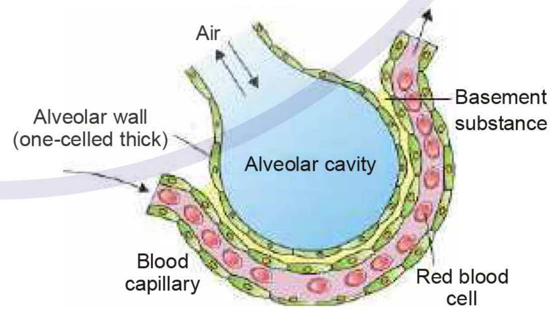
Que. What is Tidal volume? Find out the Tidal volume (approximate value) for a healthy human in an hour.
Que. State the volume of air remaining in the lungs after a normal breathing.

EXCHANGE OF GASES

Exchange of Gases → Simple diffusion → based on
- → **Pressure/concentration gradient** → Partial pressure gradient (Pressure contributed by an individual gas in a mixture of gases; represented by Po_2/Pco_2)
- → Solubility $CO_2 > O_2$ (20-25 times)
- → Thickness of diffusion membrane



Diffusion Membrane :- 3 layers
(Thickness < 1mm)
- (1) Thin squamous epithelium of Alveoli
- (2) Endothelium of alveolar capillaries
- (3) Basement substance (in between them)



Diffusion capacity = Volume of gas diffuse through the diffusion membrane per unit difference in partial pressure in 1 min.

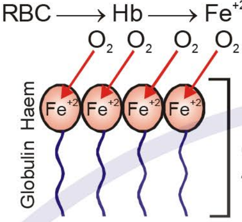
TRANSPORT OF GASES

TRANSPORT OF OXYGEN

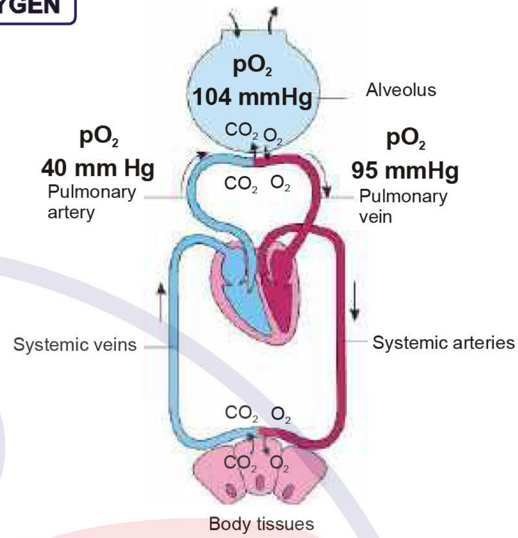
At Alveoli Level :-

O_2 → 3% ⟶ Plasma ⟶ Dissolved state

O_2 → 97% ⟶ RBC ⟶ Hb ⟶ Fe^{+2}



Each Hb molecule carry max. 4 molecules of O_2



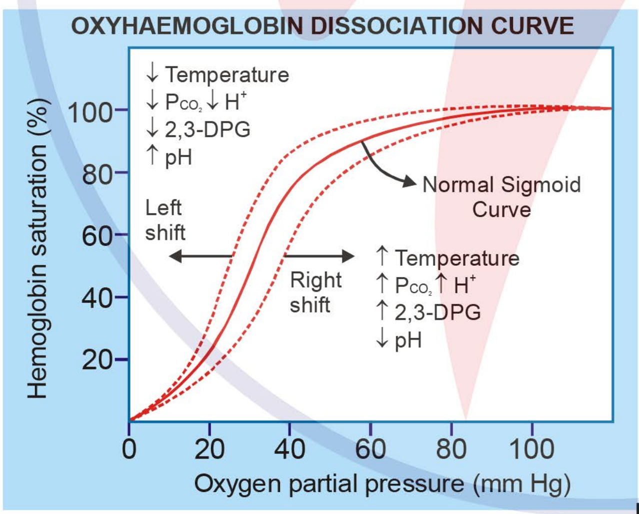
$$Hb + O_2 \rightleftharpoons HbO_2$$
Fe^{+2} Fe^{+2}

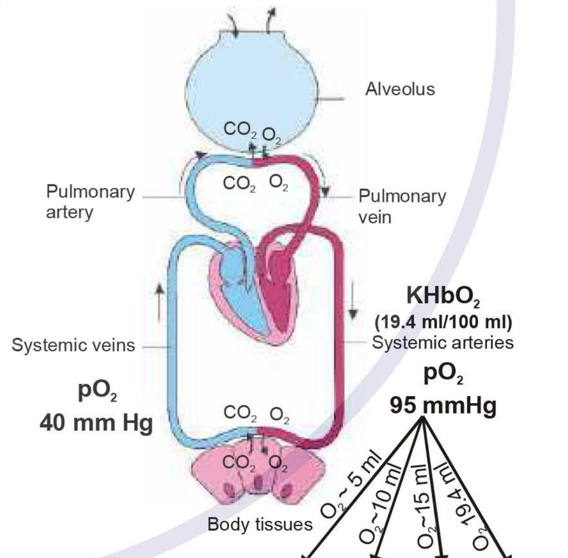
(Oxygenation not oxidation)

- **↑Po_2, ↓Pco_2, ↓$[H^+]$, ↓T, ↓2-3 DPG = Association, curve shift towards left, ↓P_{50} value.**
- **↓Po_2, ↑Pco_2, ↑$[H^+]$, ↑T, ↑2-3 DPG = Dissociation, curve shift towards righ, ↑P_{50} value.**

Note :-
100 ml Blood carry = 19.4 ml of O_2
(Calculation = 100 ml blood → 15 gm Hb → 15 × 1.34 ml → 20.1 ml O_{2l};
20.1 × 97/100 = 19.4 ml)

At Tissue Level :-





pO_2 (mm Hg)	40 (physiological condition)	30	20 (Heavy exercise)	0
% dissociation of HbO_2	25%	50%	75%	100%
% saturation of Hb with O_2	75%	50%	25%	0%

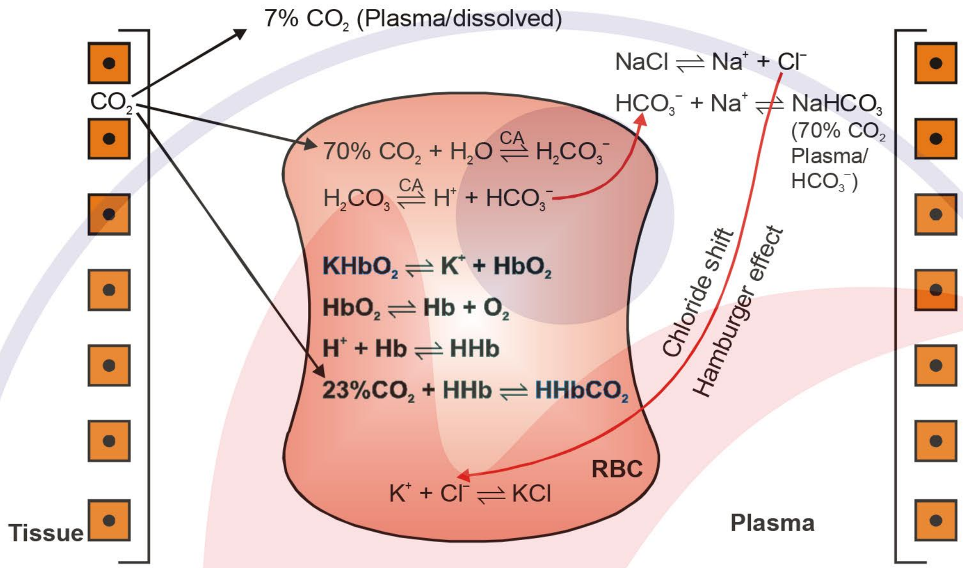
Note :- Every 100 ml of oxygenated blood can deliver around 5 ml of O_2 to the tissue under normal physiological condition.

This sigmoid shape of the dissociation curve is because of the binding of oxygen to haemoglobin. As the first oxygen molecule binds to haemoglobin, it increases the affinity for the second molecule of oxygen to bind. Subsequently, haemoglobin attracts more oxygen.

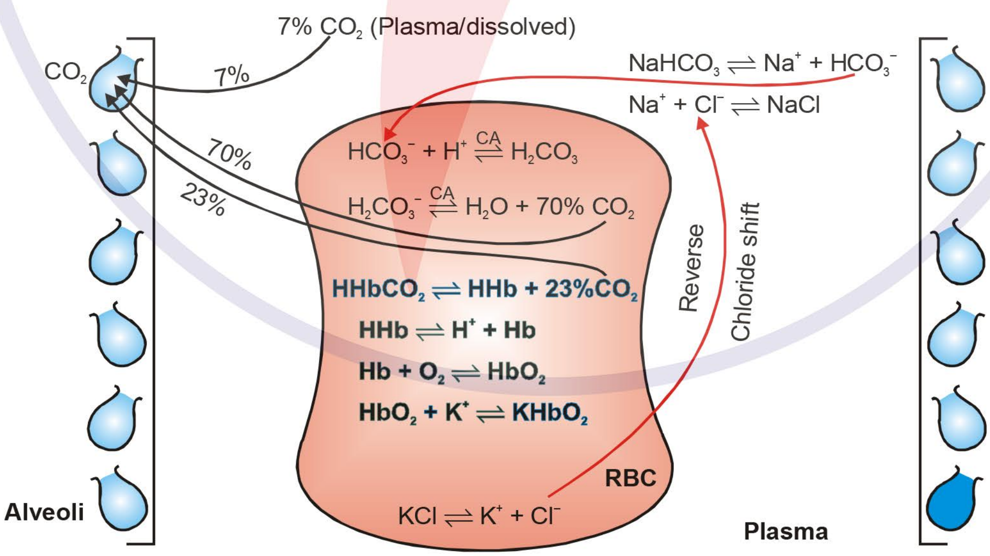
TRANSPORT OF CO_2

At Tissue Level :-

CO_2
- 7% → Plasma → Dissolved state
- 70% → Plasma → Bicarbonate
- 20-25% → Hb → Carbaminohaemoglobin



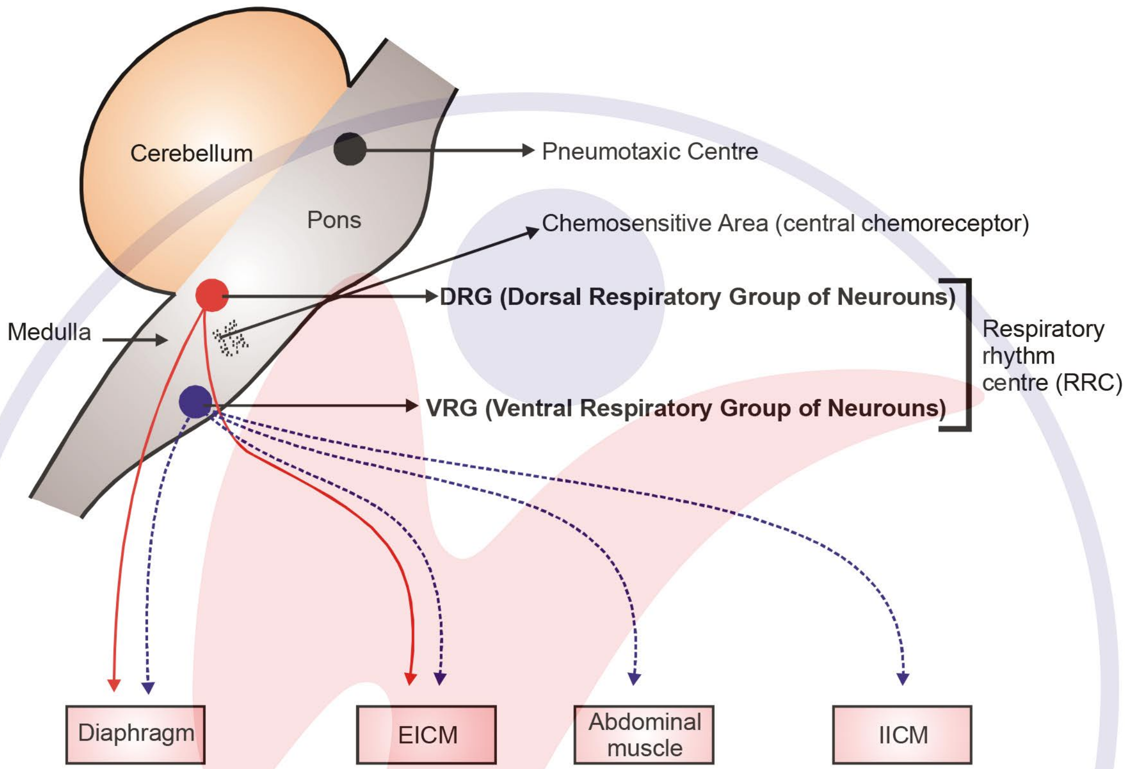
At Alveoli Level :-



Note :- Every 100 ml of deoxygenated blood can deliver approximately 4 ml of CO_2 to the alveoli.

REGULATION OF RESPIRATION

(Human have significant ability to maintain and moderate the respiratory rhythm with the help of neural system)



(1) DRG → Normal Inspiration
VRG → Forceful Inspiration
→ Forceful Expiration

(2) 4 cases :-
(i) Normal Inspiration = DRG
(ii) Normal Expiration = Passive process
(iii) Forceful Inspiration = VRG
(iv) Forceful Expiration = VRG

(3) Pneumotaxic centre → RRC
(Switch off point)
↓
↓duration of inspiration
↓
↑Rate of respiration

(4) Chemoreceptors

- Central → Central chemoreceptors (Medulla)
- Peripheral → Aortic body, Carotid body

↓
Highly sensitive to CO_2 and $[H^+]$
↓
Increase in these substance can activate this centre
↓
Make necessary adjustments in respiratory centre by which these substances can be eliminates

Note :- Role of oxygen in the regulation of respiratory rhythm is quite insignificant

DISORDERS OF RESPIRATORY SYSTEM

(1) Asthma

Allergen

↓

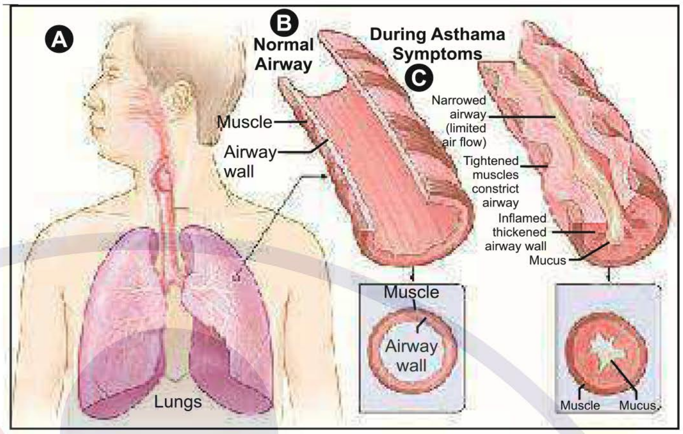
Inflammation of Bronchi and Bronchiole

↓

Bronchoconstriction

↓

Wheezing | Dificulty in Breathing



(2) Emphysema

Long exposure to certrain factors (Cigarette smoking)

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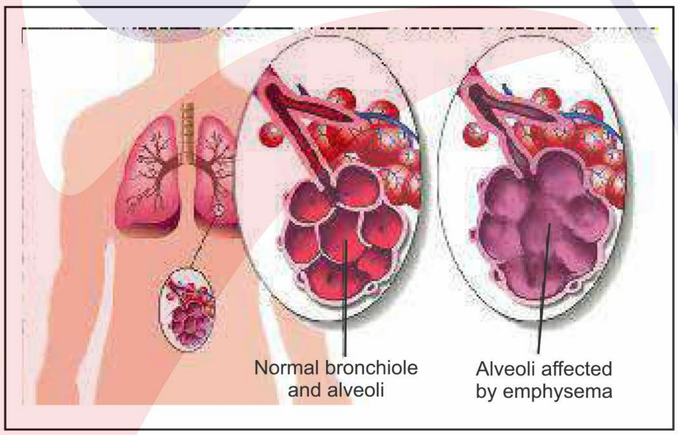
Inflammation of Alveolar walls

↓

Damage to alveolar walls

↓

Respiratory surface is decreased



(3) Occupational respiratory disorders

Long exposure to certain factors (Dust etc.) at working place (grinding/stone breaking industry)

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When defense mechanism of body cannot cope fully with the situation

↓

Inflammations of lungs

↓

Fibrosis of lung tissue