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PRE-MEDICAL

ZOOLOGY

ENTHUSIAST | LEADER | ACHIEVER

STUDY MATERIAL

Breathing and exchange of gases

ENGLISH MEDIUM

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BREATHING AND EXCHANGE OF GASES

01. INTRODUCTION

- **Introduction**
- **Respiratory Organs**
- **Mechanism of Breathing**
- **Exchange of Gases**
- **Transport of Gases**
- **Regulation of Respiration**
- **Disorders of Respiratory System**

- Oxygen (O_2) is utilised by the organisms to indirectly break down of 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 is for energy liberation.

02. RESPIRATORY ORGANS

- Mechanisms of breathing vary among different groups of animals depending mainly on their habitats and levels of organisation.
- Lower invertebrates like sponges, coelenterates(Hydra), flatworms(Tapeworm), etc., 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.
- Among vertebrates, fishes use gills whereas reptiles, birds and mammals respire through lungs.
- Amphibians like frogs can respire through their moist skin also (Mainly during hibernation and aestivation).
- Mammals have a well-developed respiratory system.

Respiration through gills is called gill/branchial respiration	**Respiration through skin is called cutaneous respiration**
Respiration through lungs is called pulmonary respiration	**Respiration through trachea is called tracheal respiration**
Respiration through buccopharyngeal cavity is called buccopharyngeal respiration	

	NAME OF THE ORGANISM	RESPIRATORY ORGAN		NAME OF THE ORGANISM	RESPIRATORY ORGAN
1	PROTOZOA	Respiratory organs are absent but respiration takes place by general body surface	10	MOLLUSCA	Gills (Ctinidia)
2	PORIFERA		11	ECHINODERMATA	Body surface
3	COELENTERATA		12	FISHES	Gills
4	CTENOPHORA		13	TADPOLE	Gills
5	PLATYHELMINTHES		14	FROG	Lungs /skin/ buccopharyngeal cavity
6	ASCHELMINTHES		15	REPTILES	Lungs
7	ANNELIDA (EARTHWORM)	Moist cuticle	16	BIRDS	Lungs
8	Insect (eg. Cockroach, Silkworm) Aquatic arthropods	Trachea Gills	17	MAMMALS	Lungs
9.	Arachnida (eg. Spider)	Book lungs			

BEGINNER'S BOX — INTRODUCTION AND RESPIRATORY ORGANS

1. Site of gaseous exchange in tadpole larva is
(1) Skin (2) Gills
(3) Lungs (4) Buccapharyngeal cavity

2. Respiratory organ of insect is -
(1) Lungs (2) Gills (3) Trachea (4) Pulmonary sac

3. Respiratory organs in frog (adult) are :-
(a) Lungs (b) Gills (c) Moist skin (d) Buccal cavity
(1) a, b (2) b, c (3) a, c & d (4) only a & d

4. Given below that list of animals -
Cockroach, *Prawn*, Spiders, *Fishes*, Frog, Earthworm, *Tadpole larva*, snakes.
How many are respire through "Gills" ?
(1) Two (2) Three (3) Four (4) Five

5. Respiration through skin is known as -
(1) Branchial respiration
(2) Cutaneous respiration
(3) Pulmonary respiration
(4) Tracheal respiration

6. A process by which we intake O_2 rich air and expel out the CO_2 rich air is known as -
(1) Respiration (2) Inspiration (3) Breathing (4) Expiration

7. Match the column-I and II and select the correct answer ?

Column-I (Name of animal)		Column-II (Respiratory organ)	
(i)	Earthworm	(a)	Trachea
(ii)	Cockroach	(b)	General body surface
(iii)	Lizards	(c)	Moist cuticle
(iv)	Sponges	(d)	Gills
(v)	Dog fish	(e)	Lungs

(1) i–c, ii–a, iii–e, iv–b, v–d (2) i–d, ii–a, iii–b, iv–c, v–e
(3) i–c, ii–a, iii–b, iv–d, v–e (4) i–b, ii–c, iii–d, iv–e, v–a

8. Oxygen (O_2) is utilised by an organism to -
(1) directly breakdown the nutrient molecules
(2) indirectly breakdown the nutrient molecules
(3) obtain nourishment from the food
(4) burn the organic compounds indirectly

9. O_2 exchange with CO_2 by simple diffusion over the entire body surface takes place in -
I. sponges II. coelenterates III. flatworms
Select the correct option to complete the given statement.
(1) I and II (2) II and III (3) I and III (4) All of the above.

03. HUMAN RESPIRATORY SYSTEM

(1) NOSE AND NASAL CHAMBER

Human have a pair of external nostrils opening out above the upper lip.

External nares open in vestibule region present in anterior part of nasal passage.

Vestibule posteriorly connected with nasal chambers.

Nasal passage is functionally divided into 3 regions :

(A) Vestibular region : Skin, hair, sebaceous glands.

(B) Respiratory region : Lined by PSCCGE.

(C) Olfactory region : Lined by Neurosensory epithelium (Olfactory epithelium/Schneidarian membrane)

The nasal chamber opens into **nasopharynx,** through internal nostrils (Choanae).

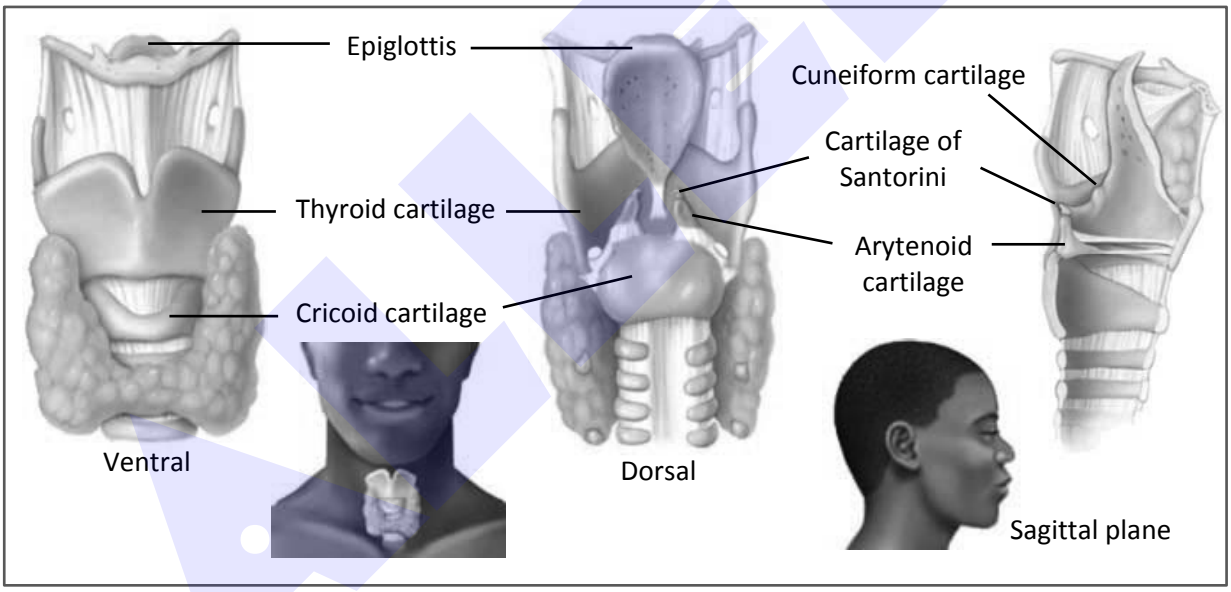
Nasopharynx is a portion of pharynx (the common passage for food and air). Nasopharynx opens into oropharynx which opens through glottis of the larynx region into the **trachea.**

(2) LARYNX

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.

On the basis of number	On the basis of shape	On the basis of origin
ONE	**THYROID** (Largest cartilage of larynx / Ventrally broad / laterally narrow/ dorsally absent/C shaped cartilage/In human males, ventral surface of thyroid cartilage make a process called as ADAM'S APPLE which is a secondary sexual character of males)	HYALINE CARTILAGE
ONE	**CRICOID** (Signet ring shape cartilage /dorsally broad /laterally narrow/ ventrally fibre like/)	HYALINE CARTILAGE
TWO	**ARYTENOID** (Conical shaped cartilage)	HYALINE CARTILAGE
TWO	**CARTILAGE OF SANTORINI** (Spherical cartilage on Arytenoids cartilage/smallest cartilage of larynx)	ELASTIC CARTILAGE

Larynx is the sound producing organ in which two types of vocal cords are present
(i) False (ii) True
False vocal cords provide moisture to the true vocal cords. Whereas true vocal cords are helpful in phonation (Sound production)



(3) TRACHEA

Trachea is a straight tube (diameter 2.5 cm) (length 12 cm) 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. On the dorsal side of rings, "trachealis muscles" are present. These are involuntary muscles and are helpful in forcible breathing and to dilate the trachea. 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.

Bronchial Tree (B.T.) and Respiratory Tree (R.T.)

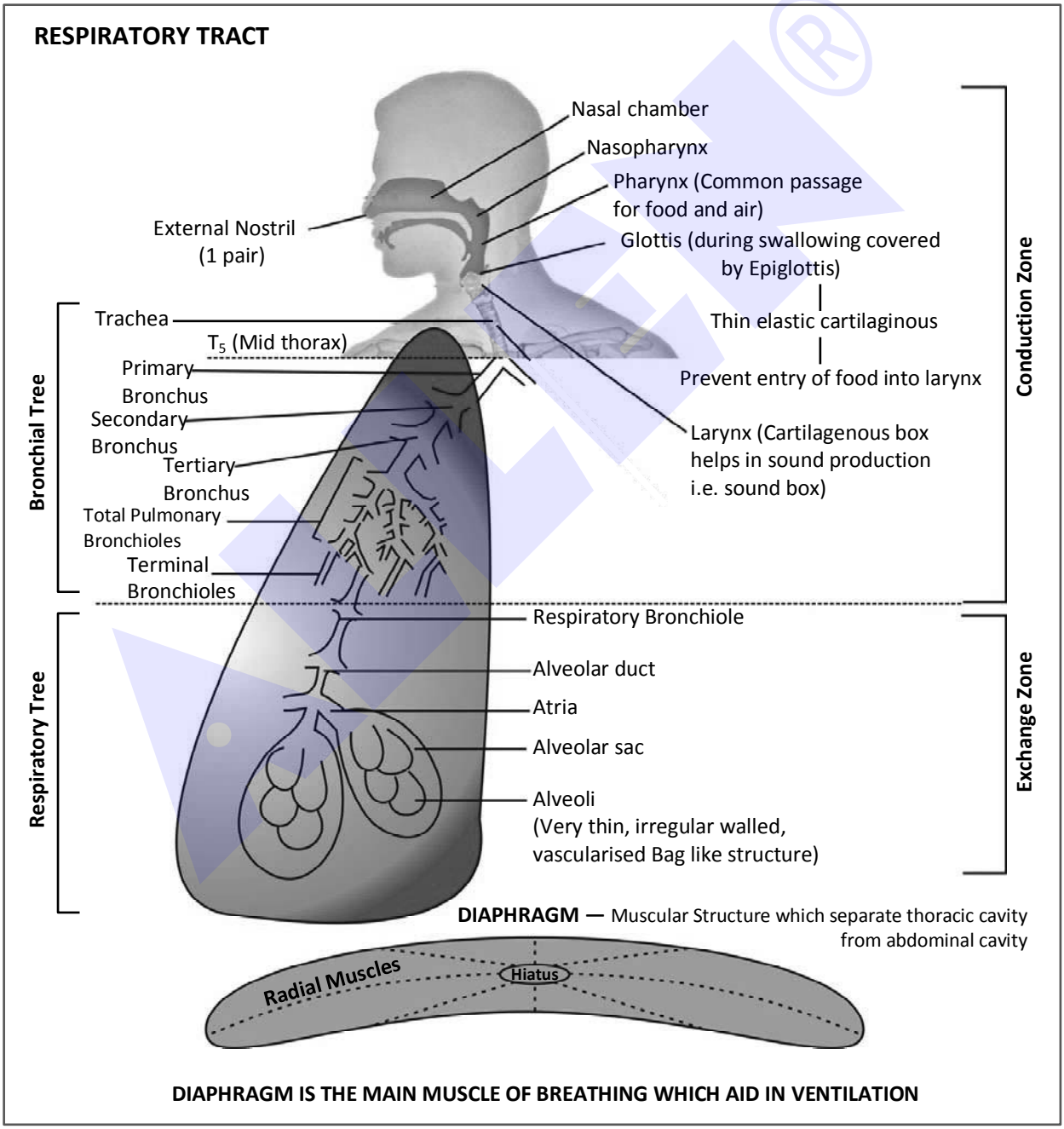
There are two zones.

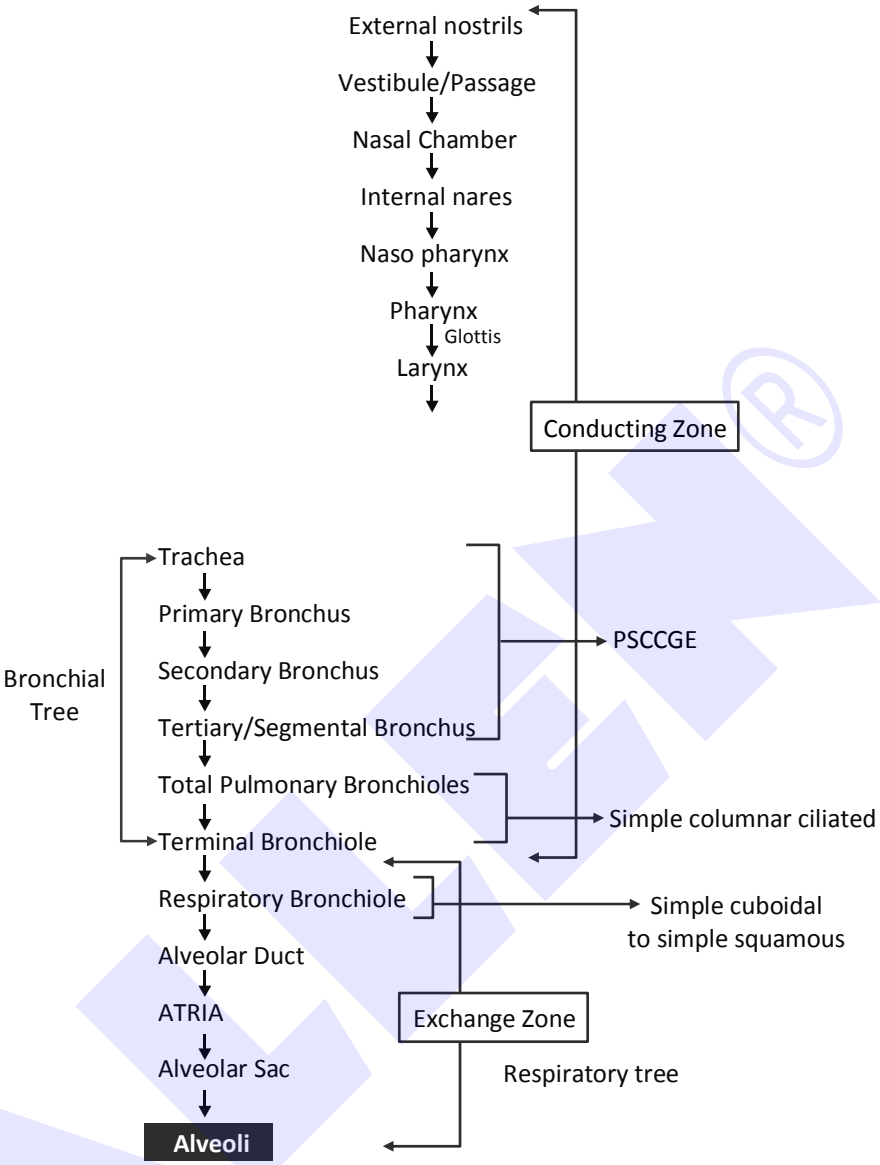
The part starting with the external nostrils up to the terminal bronchioles constitute the conducting part whereas the alveoli and their ducts form the respiratory or exchange part of the respiratory system.

The conducting part transports the atmospheric air to the alveoli, clears it from foreign particles, humidifies and also brings the air to body temperature.

Presence of 'C' shaped cartilagenous rings :- From Trachea to Initial Bronchiole.

Due to anatomical dead space (150 ml), pulmonary ventilation is always more than alveolar ventilation.





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

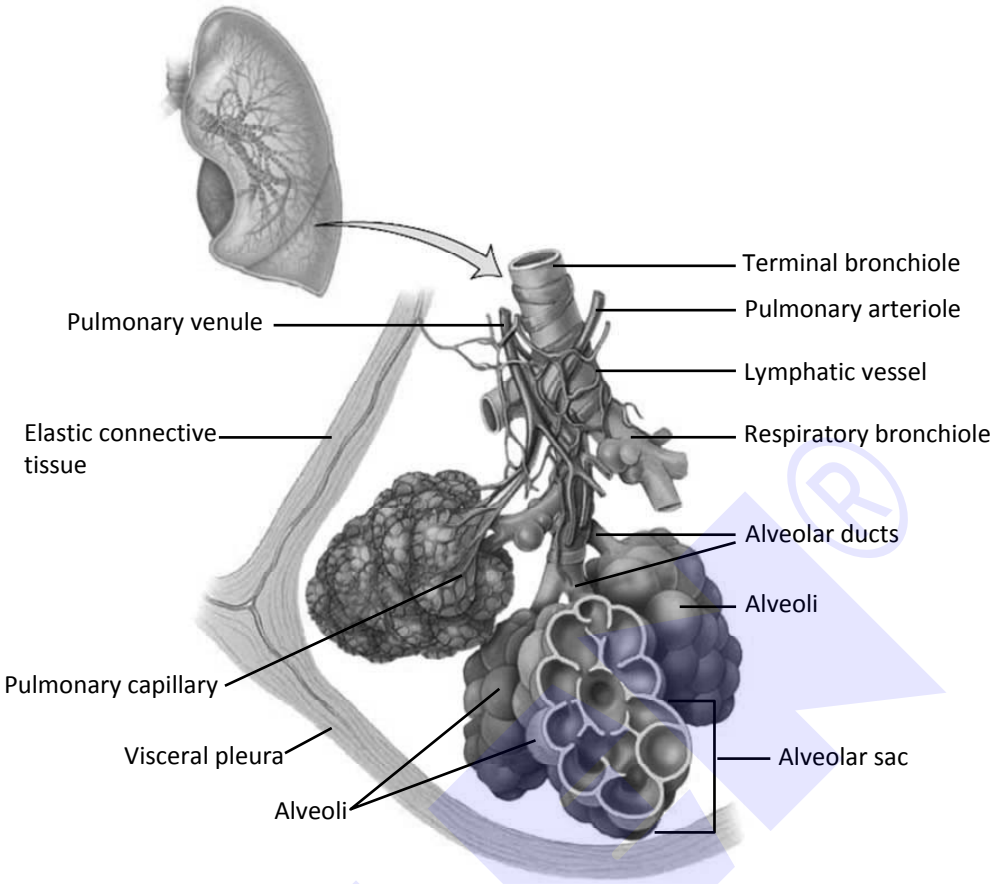
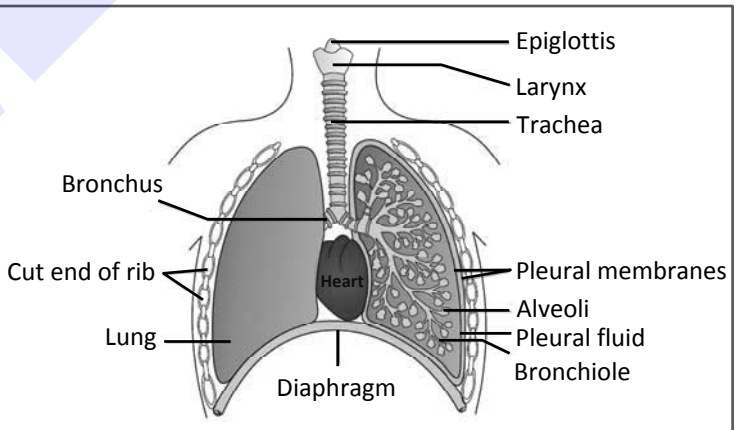


Diagram of a portion of a lobule of the lung

(4) LUNGS

We have two lungs (right lung is three lobed whereas left lung is two lobed) which are covered by a double layered pleura, with pleural fluid between them. It reduces friction on the lung surface and act as a shock absorber. The outer pleural membrane is in close contact with the thoracic lining whereas the inner pleural membrane is in contact with the lung surface. Intraplural pressure is lesser than intra pulmonary pressure.



Diagrammatic view of human respiratory system (sectional view of the left lung is also shown)

NCERT XI Page No. 269, Figure No. 17.1

Pulmonary vessels, bronchus and nerves enter or leave the lungs at the hilus.

Inflammation of pleural membrane is called pleurisy.

Problem in breathing due to pleurisy is called dyspnoea.

The lungs are situated in the thoracic chamber which is anatomically an air-tight chamber.

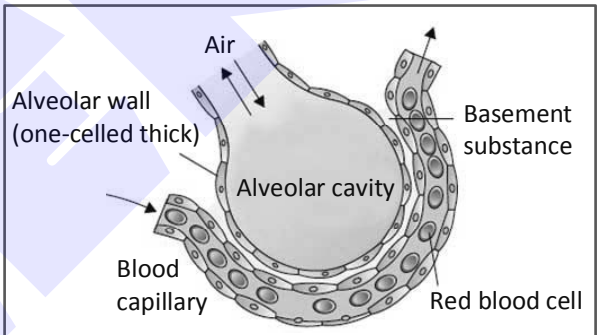
The thoracic chamber is formed dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs and on the lower side by the dome-shaped diaphragm.

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.

Mammalian lungs are solid and spongy without muscles so power of self contraction and self relaxation is not present in mammalian lungs.

(5) ALVEOLI

Alveoli are structural and functional units of lungs. Alveoli consist of two types of cells called pneumocytes. Pneumocytes I are smaller cells and helps in gaseous exchange whereas pneumocytes II are larger cells which secrete a phospholipid LECITHIN. Lecithin act as a surfactant reduces the surface tension of alveoli and keep alveoli always remain open for efficient gaseous exchange. On the outer side of alveoli yellow fibrous connective tissue is present. The total number of alveoli present in both the lungs of man is 300 million.



A Diagram of a section of an alveolus with a pulmonary capillary.
NCERT XI Page No. 273, Figure No. 17.3

Exchange part is the site of actual diffusion of O_2 and CO_2 between blood and atmospheric air.

Respiration involves the following steps:

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

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

(C) Transport of gases by the blood.

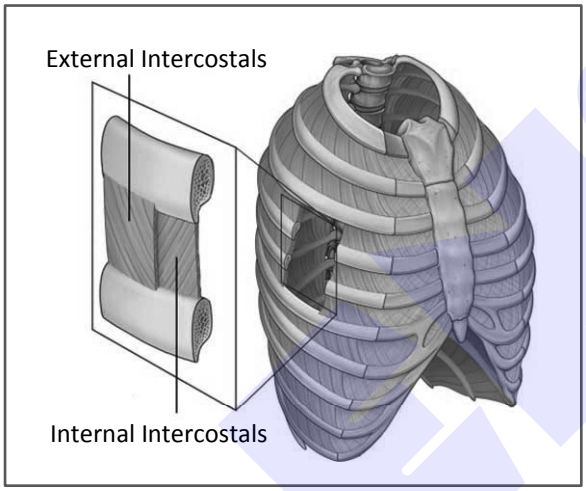
(D) Diffusion of O_2 and CO_2 between blood and tissues.

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

Thoracic Cavity :

Thoracic cage :- Coverings of thoracic cavity makes thoracic cage.

Anterior surface	:	Clavicle bones, Neck
Posterior surface	:	Diaphragm.
Dorsal surface	:	Vertebral column & ribs
Ventral surface	:	Sternum & ribs.
Lateral surface	:	Ribs



Diaphragm :-

It is the muscular structure which separate thoracic cavity from abdominal cavity. It is made up of muscles called radial muscles. Word related with diaphragm is phrenic. Diaphragm is the principal muscle of breathing and aid in ventilation. Other functions of diaphragm are parturition (child birth), micturition (passing out of urine) and defaecation (egestion). At the time of inspiration, diaphragm contracts and becomes flattened so that antroposterior axis, volume of thoracic cavity is increased. Phrenic nerve is for diaphragm contraction.

Intercoastal Muscles :

Spaces between two pair of ribs are called intercoastal spaces. Whereas muscles in these spaces are called intercoastal muscles. There are two types of intercoastal muscles

(a) External intercoastal muscles (EICM)

(b) Internal intercoastal muscles (IICM)

Muscles which connect dorsal face of upper rib with ventral face of lower rib are called external intercoastal muscles or inspiratory muscles.

Muscles which connect ventral face of upper rib with dorsal face of lower rib are called internal intercoastal muscles or expiratory muscles. At the time of inspiration, EICM contracts so that sternum moves outwardly and ribs move upwardly hence volume of thoracic cavity is increased in dorsoventral axis.

BEGINNER'S BOX — ANATOMY OF HUMAN RESPIRATORY SYSTEM

1. Larynx is a modified portion of

(1) Pharynx (2) Trachea (3) Bronchus (4) Lungs

2. Cartilaginous rings in trachea are incomplete at which surface.

(1) Dorsal (2) Ventral (3) Lateral (4) Ventrolateral

3. Wall of alveoli is composed of

(1) Simple squamous epithelium (2) Simple cuboidal epithelium

(3) Pseudostratified epithelium (4) Simple columnar epithelium

4. The structure which prevents the entry of food into respiratory tract is

(1) pharynx (2) Larynx (3) Glottis (4) Epiglottis

5. In which part of lungs gaseous exchange takes place in human :–

(1) Trachea & alveolar duct (2) Trachea & bronchi

(3) Alveolar duct & alveoli (4) Alveoli & Trachea

6. Respiratory organ of human are :-

(1) General Body surface (2) Book lungs

(3) Lungs (4) Tracheal tubes

7. In human lungs are divided into lobes

(1) 3 right & 2 left lobes (2) 2 right & 3 left lobes

(3) 2 right & 2 left lobes (4) 3 right & 3 left lobes

8. Arytenoid cartilage in larynx are

(1) Elastic (2) Hyaline (3) Calcified (4) All of these

9. The most important muscular structure in respiratory system of human is

(1) External intercostal muscles (2) Internal intercostal muscles

(3) Diaphragm (4) Vertebral column

10. Each lung is enclosed in a double membranes called as pleura. The membranes which closely covers the lung is

(1) Lung pleura (2) Visceral pleura (3) Peritoneal pleura (4) Parietal pleura

11. The most important function of diaphragm of mammals is

(1) To divide the body cavity into compartments (2) To protect lungs

(3) To aid in respiration (4) To aid in ventilation

12. Mammalian lungs are

(1) Hollow (2) Solid & spongy (3) Spongy (4) None

13. In thoracic cavity of man which one is present

(1) Lungs only (2) Lungs + Heart

(3) Lungs + heart + Stomach (4) Hearts only

14. During inspiration, the pressure of air is maximum in

(1) Trachea (2) Bronchus

(3) Alveoli (4) Environment

15. In human sound is produced by

(1) Syrinx (2) Larynx (3) Bronchus (4) Trachea

16. Match the columns

Column I	**Column II**
(a) Larynx	(p) Lid of larynx
(b) Trachea	(q) Air sacs
(c) Alveoli	(r) Voice box
(d) Epiglottis	(s) Wind pipe
	(t) Common passage

(1) a-r, b-s, c-q, d-p (2) a-t, b-s, c-p, d-q

(3) a-r, b-s, c-q, d-t (4) a-r, b-t, c-q, d-p

17. Air is breathed through

(1) Trachea → lungs → larynx → pharynx → alveoli

(2) Nose → larynx → pharynx → bronchus → alveoli → bronchioles

(3) Nostrils → pharynx → larynx → trachea → bronchi → bronchioles → alveoli

(4) Nose → mouth → lungs

04. MECHANISM OF BREATHING

- Breathing involves two stages : Inspiration during which atmospheric air is drawn in and expiration by which the alveolar air is released out.
- The movement of air into and out of the lungs is carried out by creating a pressure gradient between the lungs and the atmosphere.
- Inspiration can occur if the pressure within the lungs (intra-pulmonary pressure) is less than the atmospheric pressure, i.e., there is a negative pressure in the lungs with respect to atmospheric pressure.

- Similarly, expiration takes place when the intra-pulmonary pressure is higher than the atmospheric pressure. The diaphragm and a specialised set of muscles - external and internal intercostals between the ribs, help in generation of such gradients.
- Inspiration is initiated by the contraction of diaphragm which increases the volume of thoracic chamber in the antero-posterior axis.
- The contraction of external inter-costal muscles lifts up the ribs and the sternum causing an increase in the volume of the thoracic chamber in the dorso-ventral axis. The overall increase in the thoracic volume causes a similar increase in pulmonary volume. An increase in pulmonary volume decreases the intra-pulmonary pressure to less than the atmospheric pressure which forces the air from outside to move into the lungs, i.e., inspiration.
- Relaxation of the diaphragm and the inter-costal muscles returns the diaphragm and sternum to their normal positions and reduce the thoracic volume and thereby the pulmonary volume. This leads to an increase in intra-pulmonary pressure to slightly above the atmospheric pressure causing the expulsion of air from the lungs, i.e., expiration.
- We have the ability to increase the strength of inspiration and expiration with the help of additional muscles in the abdomen.
- On an average, a healthy human breathes 12-16 times/minute. The volume of air involved in breathing movements can be estimated by using a spirometer which helps in clinical assessment of pulmonary functions.
    - Two types of breathing are - thoracic and abdominal. Normal breathing is known as abdominal breathing.
    - Thoracic breathing is due to intercostal muscles mainly.
    - Abdominal breathing due to diaphragm mainly.
    - In fever breathing rate increases.
    - When CO_2 concentration increases in blood breathing rate becomes faster.
    - Breathing rate in infants is greater than adults.

MECHANISM OF BREATHING

MECHANISM OF BREATHING

Inspiration
2 sec. (atmospheric air is drawn in)
Active process
Intra-pulmonary pressure < atmospheric pressure

Contraction
Air entering lungs
Diaphragm
Ribs and sternum raised
Rib cage
Diaphragm contracted
Volume of thorax increased
EICM
(a)
Increase in Antero-posterior axis
Increase in Dorso-ventral axis
Pulmonary volume increases
Intrapulmonary pressure decreases
Forces air from outside to more into the lungs (inspiration)

Expiration
3 sec. (alveolar air is released out)
Passive process
Intra-pulmonary pressure > atmospheric pressure

Relaxation
Air expelled from lungs
Diaphragm
Ribs and sternum returned to original position
Diaphragm relaxed and arched upwards
Volume of thorax decreased
EICM
(b)
Decrease in Antero-posterior axis
Decrease in Dorso-ventral axis
Pulmonary volume decreases
Intrapulmonary pressure increases
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.

Mechanism of Breathing showing : (a) inspiration (b) expiration)

BEGINNER'S BOX — MECHANISM OF BREATHING

1. Thoracic cavity expands, due to contraction of :-
(1) Internal intercostal muscle (2) Diaphragm
(3) Lungs (4) All of these

2. Breathing rate in human is :-
(1) 12-16 /min (2) 36-38/min (3) 100/min (4) 300/min

3. At the time of an "inspiration", muscles of diaphragm are :-
(1) Contracted (2) Relaxed (3) unaffected (4) become coiled

4. During expiration :-
(1) Relaxation in diaphragm & ICM (2) Contraction in diaphragm & ICM
(3) Only contraction in diaphragm (4) Only contraction in ICM

5. When does expiratory muscles contract ?
(1) Deep inspiration (2) Normal inspiration & expiration
(3) Forceful expiration (4) Only normal expiration

6. At the time of fever, respiratory rate become :-
(1) Increases (2) Decreases (3) Stops (4) Unaffected

7. Expiratory muscles are :-
(1) Diaphragm + IICM (2) Diaphragm + EICM
(3) Abdominal muscles + IICM (4) Abdominal muscles + EICM

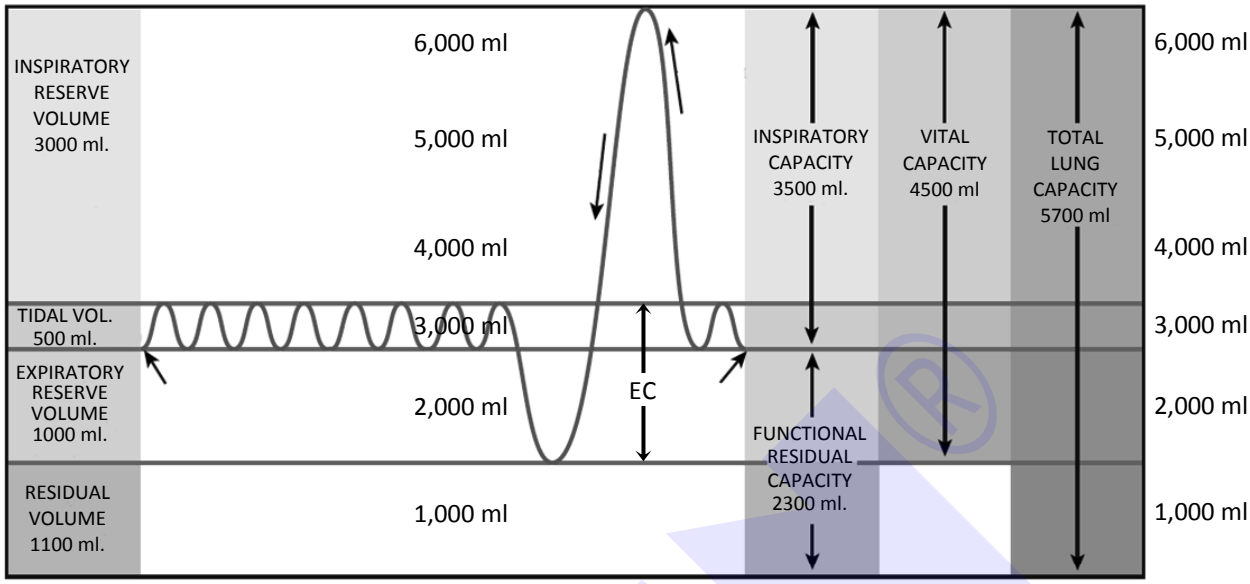
8. Abdominal breathing refers to
(1) Normal breathing (2) Slow breathing (3) Fast breathing (4) Forceful breathing

05. RESPIRATORY VOLUME 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.

- **Tidal volume [T.V.]** - It is amount of air inspired or expired during normal respiration. Its value for man is **500 ml**. Whole inspired air does not reach up to lungs.
  A healthy man can inspire or expire approximately 6000 to 8000 ml of air per minute.
- **Inspiratory Reserve Volume** [I.R.V.] - Volume of air a person can inspire by forcible inspiration over tidal volume. It's value is **2500 to 3000 ml**
- **Expiratory reserve volume** [E.R.V.] - It is the amount of air expired over tidal volume by most forceful expiration. Its value is **1000-1100 ml.**

- **Residual volume -** [R.V.] - It is the amount of air that remains inside lungs after forceful expiration. Residual volume can not be given out of lungs. Its value is **1100-1200 ml.**



Spirogram of pulmonary volumes and capacities

Pulmonary Capacities :

By adding up a few respiratory volumes, pulmonary, capacities can be derived, which can be helpful in clinical diagnosis.

- **Inspiratory capacity** - [I.C.] - Total volume of air a person can inspire after a normal expiration.

  I.C. = I.R.V. + T.V. = 3000 ml + 500 ml

  I.C. = 3500 ml

- **Expiratory capacity (EC) :** Total volume of air a person can expire after a normal inspiration.

  E.C. = TV + ERV

- **Functional Residual capacity** [FRC] - It is the amount of air that normally remains inside lungs after normal expiration. In it expiratory reserve volume and residual volume are included

  FRC = ERV + RV = 1000 ml + 1200 ml

  FRC = 2200 to 2500 ml

- **Vital capacity** - [V.C.] - It is the amount of air that can be expired by most forceful expiration after a deepest inspiration. Inspiratory reserve volume, expiratory reserve volume and tidal volume are included in it.

  V.C. = IRV + ERV + TV

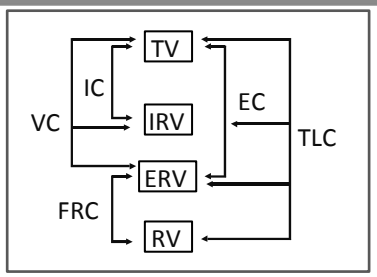
  = 3000 ml + 1000 ml + 500 ml

  = 4500 ml (4300 to 4800 ml)

- **Total lung capacity** - Total volume of air that can accommodated in the lungs at the end of forced inspiration.

  TLC = IRV + TV + ERV + RV = 3000 + 500 + 1000 + 1200

  TLC = 6000 ml (approx.) (5700 to 6000 ml)



BEGINNER'S BOX — RESPIRATORY VOLUME AND CAPACITIES

1. If expiratory reserve volume is 1100 ml residual volume is 1200 ml and tidal volume is 500 ml, what shall be the functional residual capacity

(1) 1600 ml (2) 2800 ml (3) 2300 ml (4) 1200 ml

2. Air filled in dead space is

(1) 150 cc (2) 350 cc (3) 500 cc (4) 1500 cc

3. Residual volume is :

(1) lesser than tidal volume (2) greater than inspiratory volume

(3) greater than vital capacity (4) greater than tidal volume

4. Vital capacity of lungs is

(1) TV + IRV + ERV (2) TV + IRV + RV (3) TV + ERV (4) IRV + ERV

5. Match the items in column I with column II and choose the correct option

Column I	**Column II**
(A) Tidal volume	(i) 2500 to 3000 mL of air
(B) Inspiratory reserve volume	(ii) 1000 mL of air
(C) Expiratory reserve volume	(iii) 500 mL of air
(D) Residual volume	(iv) 3400 to 4800 mL air
(E) Vital capacity	(v) 1200 mL of air

	A	**B**	**C**	**D**	**E**
(1)	(iii)	(iv)	(ii)	(i)	(v)
(2)	(iii)	(i)	(ii)	(v)	(iv)
(3)	(iii)	(i)	(iv)	(v)	(ii)
(4)	(iv)	(iii)	(ii)	(i)	(v)

6. Total lung capacity is

(1) One lit (2) 3 lit (3) 6 lit (4) 8 lit

7. Maximum expiration after full inspiration is called

(1) Vital capacity (2) Lung capacity

(3) Tidal volume (4) Residual volume

8. Air that remains in lung after most powerful expiration is

(1) Inspiratory air (2) Dead space air (3) Tidal air (4) Residual air

9. Residual air mostly occurs in

(1) Alveoli (2) Bronchus (3) Nostrils (4) Trachea

10. Volume of air inspired or expired with each normal breath is known as

(1) Inspiratory capacity (2) Total lung capacity

(3) Tidal volume (4) Residual volume

11. Arrange the following in an ascending order of volume :

a. expiratory capacity b. inspiratory capacity c. tidal volume d. residual volume

(1) c < d < a < b (2) d < a < c < b (3) d < b < a < c (4) c < d < b < a

12. About 1200 ml of air left in lungs is called

(1) Tidal volume (2) Inspiratory reserve volume

(3) Residual volume (4) Vital capacity

13. Pulmonary volumes are measured by -

(1) Spirometer (2) Hygrometer (3) Galvanometer (4) Sphygmomanometer

06. EXCHANGE OF GASES

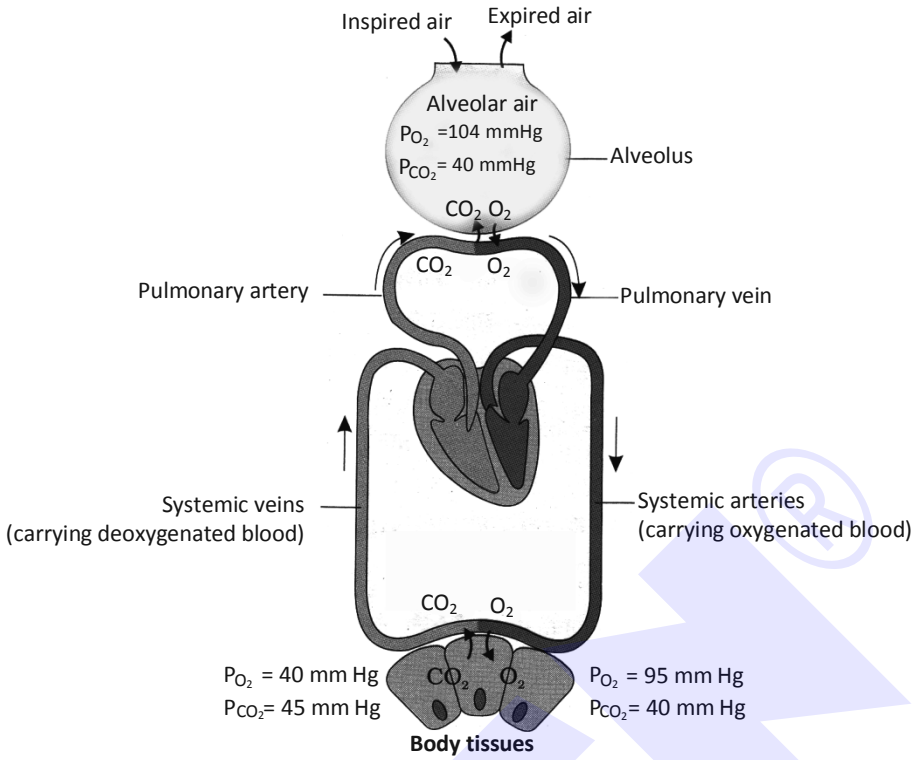
- Alveoli are the primary sites of exchange of gases. Exchange of gases also occur between blood and tissues. Exchange of gases in the lungs is done between alveolar air and deoxygenated blood.
- Gaseous exchange is a passive activity. It is done by **simple diffusion**.
- Diffusion pressure for every gas (in blood or in air) is called **partial pressure**. At the time of diffusion, gases move from high partial pressure to low partial pressure.

Table of partial pressure (in mm Hg) of oxygen and carbon dioxide :-

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

The partial pressure of O_2 in alveolar air [P_{O_2}] is 104 mm Hg, its value in arterial blood is 40 mm Hg, so oxygen goes from alveolar air to arterial air

- In alveolar air, partial pressure of CO_2 [P_{O_2}] is 40 mm Hg and its value in deoxygenated blood is 45 mm Hg. So CO_2 moves from arterial blood to alveoli. In this way, according to partial pressure exchange of gases takes place in the lungs.



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

NCERT XI Page No. 273, Figure No. 17.3

- Diffusing capacity depends on solubility of gases, thickness of the respiratory membrane and partial pressure difference.
- 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.
- **Diffusion membrane is made up of three major layers :-**

  (i) Thin squamous epithelium of Alveoli. (ii) Endothelium of Blood capillaries.

  (iii) Basement substances in between them.

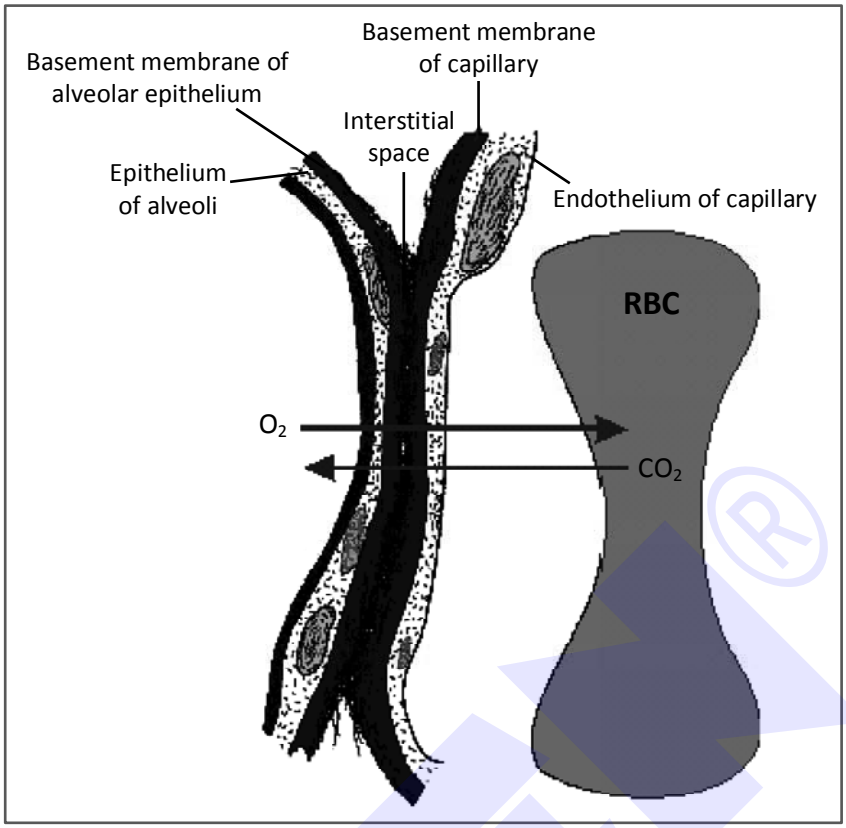
  Gaseous exchange takes place at alveoli on respiratory surface because

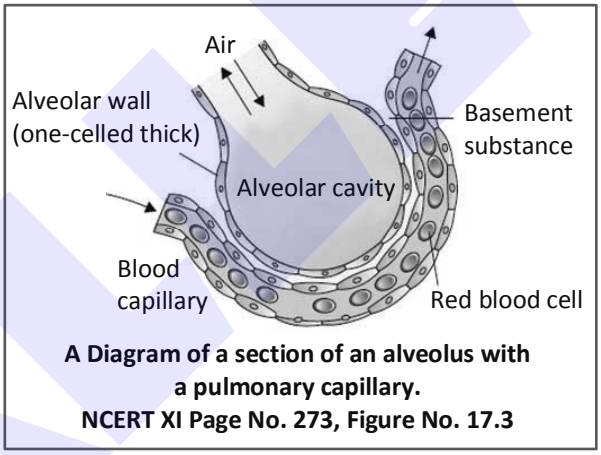
  (i) of rich supply of capillaries at alveoli

  (ii) of large surface area of alveoli

  (iii) of very thin respiratory membrane [Approximately less than 1 mm]

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





A Diagram of a section of an alveolus with a pulmonary capillary.
NCERT XI Page No. 273, Figure No. 17.3

BEGINNER'S BOX — EXCHANGE OF GASES

1. Very high number of alveoli present in a lung is meant for

(1) More space for increasing volume of inspired air

(2) More area for diffusion

(3) Making the organ spongy

(4) Increasing nerve supply

2. What is the value of Po_2 and Pco_2 in pulmonary vein?

(1) PCO_2 = 95 mmHg; PO_2 = 45 mmHg (2) PO_2 = 95 mmHg; PCO_2 = 40 mmHg

(3) PCO_2 = 40 mmHg; PO_2 = 45 mmHg (4) PCO_2 = 45 mmHg; PO_2 = 45 mmHg

3. Exchange of gases is not affected by -

(1) Solubility of gases

(2) Partial pressure gradient of gases

(3) Thickness of respiratory surface

(4) Amount of gases in alveoli

4. Which vein contains the oxygenated blood in humans -

(1) Hepatic vein (2) Hepato pancreatic vein

(3) Portal vein (4) Pulmonary vein

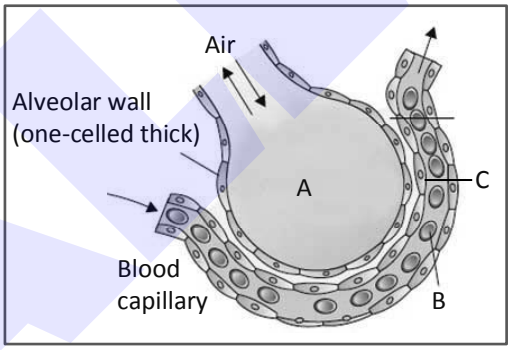
5.

Partial pressure of Gases	Blood (Deoxygenated)	Blood (Oxygenated)	Tissues
O_2	40	B	40
CO_2	A	40	C

Choose the correct option for A, B and C to complete the given data. -

(1) A-40,B-95,C-40 (2) A-45,B-95,C-45 (3) A-35,B-95,C-45 (4) A-35,B-95,C-95

6. Identify A, B and C in the given diagram and choose the correct option accordingly -



(1) A-Alveolar cavity, B-WBC, C-Capillary wall

(2) A-Alveolar cavity, B-RBC, C-Systemic wall

(3) A-Alveolar cavity, B-RBC, C-Capillary wall

(4) A-Alveolar cavity, B-WBC, C-Systemic wail

7. The total thickness of the diffusion membrane of alveolus capillary is -

(1) less than 1 cm (2) less than 2 cm

(3) less than 1 mm (4) more than 1 mm

07. TRANSPORT OF GASES

- Blood is the medium of transport for O_2 and CO_2. About 97 per cent of O_2 is transported by RBCs in the blood. The remaining 3 per cent of O_2 is carried in a dissolved state 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. About 7 per cent of CO_2 is carried in a dissolved state through plasma.

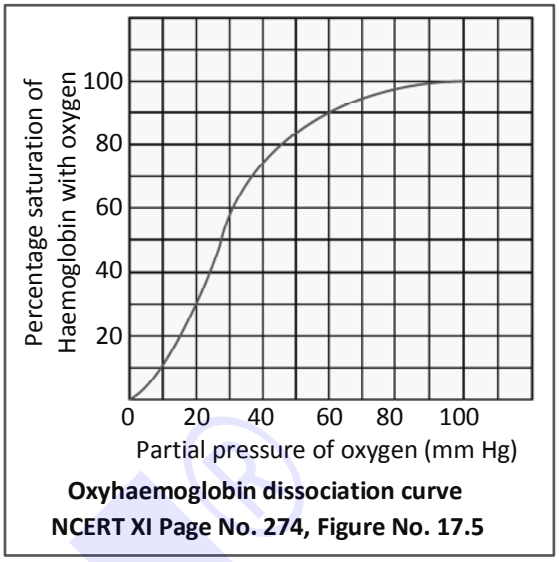
(1) TRANSPORT OF OXYGEN

$$Hb_4 + 4O_2 \underset{\text{in Tissues}}{\overset{\text{in Alveoli}}{\rightleftharpoons}} Hb_4O_8$$

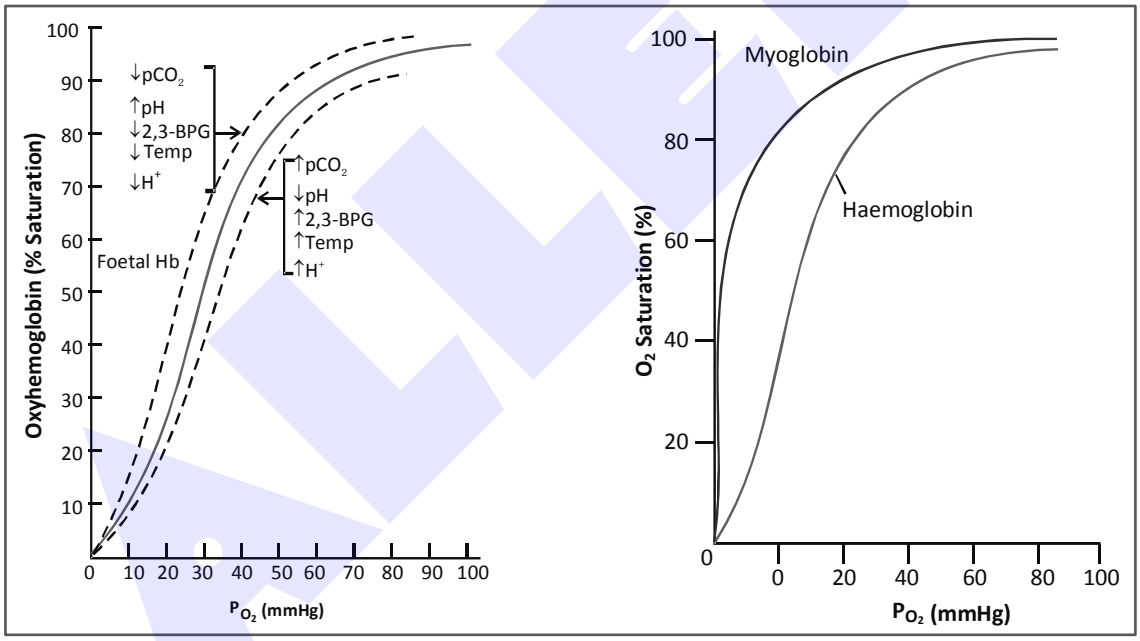
- O_2 can bind with Hb in a reversible manner to form **oxyhaemoglobin**.
- Haemoglobin is a red coloured iron containing pigment present in the RBC.
- Haemoglobin is made up of 4 units. Each unit has 1 Fe in +2 state. Each haemoglobin molecule can carry a maximum of four molecules of O_2.
- **1 gm of haemoglobin transports 1.34 ml of oxygen**. 100 ml (1 dL) of blood contains normally 15 gm of haemoglobin, so 100 ml blood transports approximately 20 ml of oxygen.
- In a conducting cycle blood gives its 25% O_2 to tissues. **So every 100 ml of oxygenated blood can deliver around 5 ml of O_2 to tissue under normal physiological condition.**
- Binding of oxygen with haemoglobin is primarily related to partial pressure of O_2. But PCO_2, hydrogen ion concentration and temperature are the other factors which can interfere with this binding.
- Oxygen does not oxidise haemoglobin. **Formation of oxyhaemoglobin is a process of oxygenation.** The valancy of iron is 2 in oxyhaemoglobin.
- At the time, oxyhaemoglobin reaches up to the tissues it dissociates. O_2 freed from it goes into the tissue fluid from blood. In place of it, CO_2 from tissue fluid comes into blood. Gaseous exchange between blood and tissue is called internal respiration or tissue respiration. It is also done by simple diffusion.

OXYGEN DISSOCIATION CURVE

- A graph is plotted between O_2 concentration and percentage saturation of haemoglobin with this curve is called oxygen dissociation curve.
- Dissociation curve is **sigmoid shape.**
- This curve is highly useful in studying the effect of factors like, H^+ concentration, temperature on binding of O_2 with Haemoglobin.
- **Shift to left** means that increase in affinity between O_2 and Hb.
- **Shift to Right** means that decrease in affinity between O_2 and Hb and dissociation of oxyhaemoglobin.



Oxyhaemoglobin dissociation curve
NCERT XI Page No. 274, Figure No. 17.5



- In **tissue** following conditions are favourable **for dissociation** of oxygen from oxyhaemoglobin :-

(a) Low PO_2

(b) High PCO_2

(c) High H^+ concentration

(d) Low pH

(e) Higher temperature.

- In the alveoli high PO_2, low PCO_2, Lesser H^+ concentration and lower temperature factors are favourable for the formation of oxyhaemoglobin.

Golden Key Points

- **P_{50} value –** at which the Hb is 50% saturated with O_2. Higher the P_{50} , lower is the affinity of Hb for O_2. A rise in P_{CO_2} , $H^{\oplus}$ conc. increases the value of P_{50}.
- 2, 3 bisphosphoglycreate (2, 3 BPG) – a substance formed during glycolysis.

  ↑ 2, 3 BPG will cause dissociation of oxyhaemoglobin .
- **Bohr's effect :** Dissociation of oxyhaemoglobin due to high CO_2 concentration in tissue is called Bohr's effect.
- During heavy exercise 100 ml blood delivered 15 ml O_2 to muscle.
- Hb cannot take up O_2 beyond a saturation level of 97%.

  The sigmoid shape of dissociation curve is because of the binding of O_2 to haemoglobin. As the first O_2 molecule binds to haemoglobin, it increases the affinity for the second molecule of oxygen to bind attract more oxygen.
- Lungs do not collapse between the breathing and some air always remains in the lungs which can never be expelled because there is a negative intra plural pressure pulling at the lung walls.

BEGINNER'S BOX

TRANSPORT OF O_2 AND HbO_2 DISSOCIATION CURVES

1. "Methemoglobin" refers to
(1) A colourless respiratory pigment
(2) Oxidized haemoglobin
(3) Oxygenated haemoglobin
(4) Deoxygenated haemoglobin

2. How much oxygen, blood supplies to tissues in one circulation
(1) 75% (2) 1.34% (3) 25% (4) 7%

3. How oxygen enters in blood from alveoli of lungs
(1) Pressure of CO_2 (2) Simple diffusion
(3) By Hb (4) None of these

4. Oxygen dissociation curve of haemoglobin is

(1) Sigmoid (2) Hyperbolic (3) Linear (4) Hypobolic

5. A molecule of haemoglobin can carry oxygen molecule :

(1) 2 (2) 4 (3) 6 (4) 8

6. Oxygen in lungs ultimately reaches

(1) Alveoli (2) Trachea (3) Bronchus (4) Bronchioles

7. In vertebrate blood the carrier of oxygen to the tissues or respiratory pigment is

(1) Plasma (2) Lymphocytes (3) Leucocytes (4) Haemoglobin

8. Haemoglobin is

(1) Vitamin (2) Skin pigment (3) Blood carrier (4) Respiratory pigment

9. Amount of oxygen present in one gram of haemoglobin is

(1) 20 ml (2) 1.34 ml (3) 13.4 ml (4) None of these

10. Which one is correct factor for right shifting of oxyhaemoglobin dissociation curve ?

(1) Low Pco_2 (2) High temp. (3) High pH (4) High Po_2

11. Oxygen haemoglobin dissociation curve will shift to right on decrease of

(1) Acidity (2) Carbon dioxide concentration

(3) Temperature (4) pH

12. Body tissues obtain O_2 from oxyhaemoglobin because of its dissociation in tissues caused by

(1) Low oxygen concentration and high CO_2 concentration

(2) High O_2 concentration

(3) Low CO_2 concentration

(4) High CO_2 concentration

13. Under normal conditions, what amount of O_2 is delivered by 100 mL of the oxygenated blood :-

(1) 5 mL (2) 4 mL (3) 3 mL (4) 2 mL

(2) TRANSPORT OF CARBON DIOXIDE

- The blood transports carbon dioxide comparatively easily because of its higher solubility.
- There are three ways of transport of carbon dioxide.

(a) **In dissolved state :** Approximately 7% of carbon dioxide is transported, being dissolved in the plasma of blood.

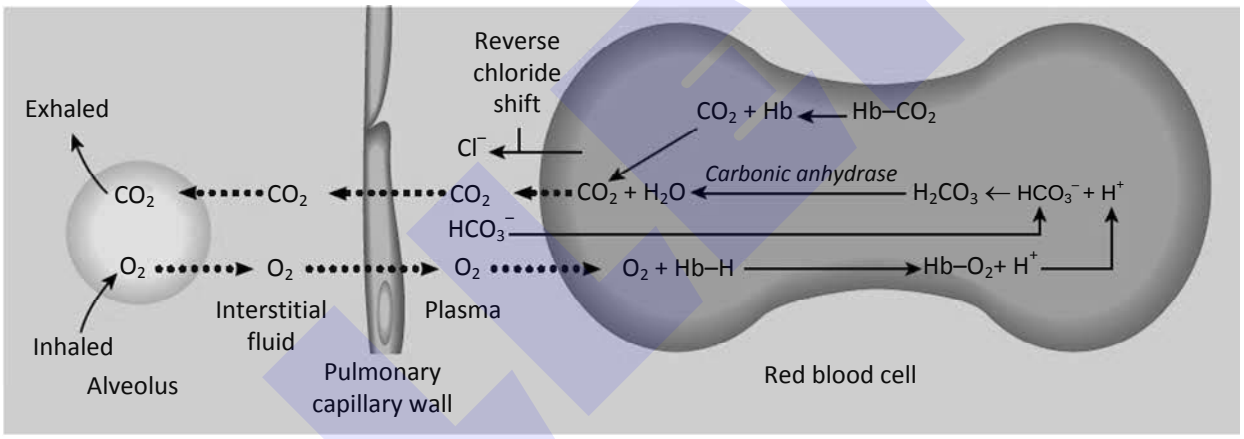
(b) As **Carbamino haemoglobin :** About 20-25% CO_2 react with the amine group of Haemoglobin and form carbamino-haemoglobin and transported by RBC.

(c) In the form of bicarbonate : 70% of CO_2 is transported by plasma as bicarbonate.

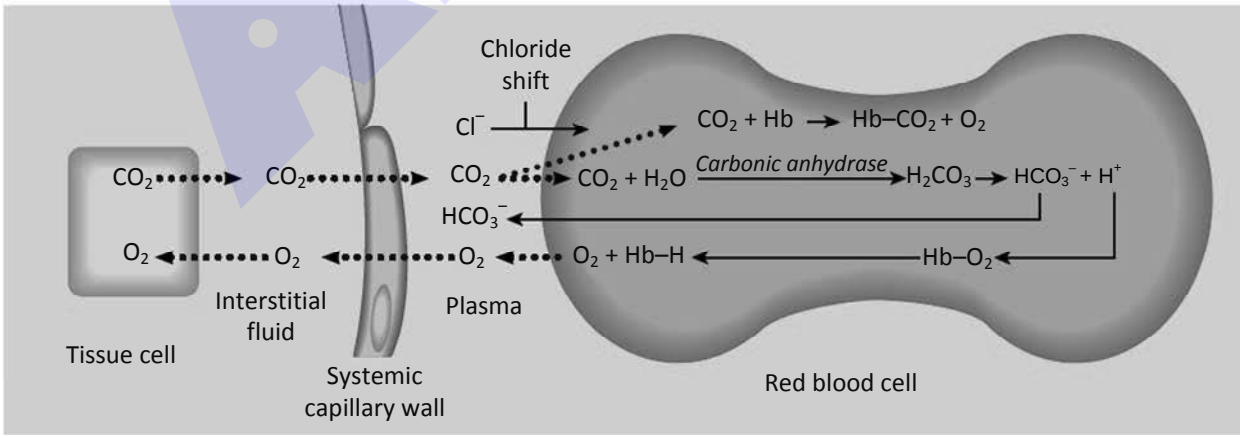
- Carbon dioxide produced by the tissues, diffuses into the RBCs, where it reacts with water to form carbonic acid (H_2CO_3). This reaction is catalysed by the enzyme, **Carbonic anhydrase**. RBCs contain a very high concentration of this enzyme & minute quantity is present in plasma too.

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

- The majority of bicarbonate ions (HCO_3^-) formed within the erythrocytes diffuse out into the plasma along a concentration gradient. In the plasma HCO_3^- combine with Na^+ and form **Sodium bicarbonate ($NaHCO_3$)**. Nearly 70% CO_2 transported by plasma as $NaHCO_3$ form.
- In response of HCO_3^-, chloride ions (Cl^-) diffuse from plasma into the erythrocytes to maintain the ionic balance. Thus, electrochemical neutrality is maintained. This is called **Chloride shift** or **Hamburger Phenomenon**.



Exchange of O_2 and CO_2 in pulmonary capillaries (external respiration)



Exchange of O_2 and CO_2 in systemic capillaries (internal respiration)

- When the deoxygenated blood reaches the alveoli of the lung, then carbaminohaemoglobin, and sodium bicarbonate dissociated because **PCO_2 is low and PO_2 is high** in the alveoli.
- This dissociation is stimulated by oxyhaemoglobin. This CO_2 freed from blood goes into atmosphere. The effect of oxyhaemoglobin on the dissociation of these compounds is known as **Haldane effect**. In this reaction oxyhaemoglobin acts like a strong acid i.e, it frees H^+ in the medium.
- Every 100 ml deoxygenated blood delivers around **4 ml CO_2** to alveoli.

BEGINNER'S BOX — CO_2 TRANSPORT

1. What percentage of CO_2 flows with blood in the form of bicarbonates

(1) 7% (2) 23% (3) 50% (4) 70%

2. Most of the carbon - di - oxide is carried in the blood as

(1) Bicarbonates (2) Carbon monoxide

(3) Carbonic acid (4) Carbonates

3. Carbon dioxide is transported from tissue to respiratory surface by only

(1) Plasma and erythrocytes (2) Plasma

(3) Erythrocytes (4) Erythrocytes and leucocytes

4. Carbon dioxide entering erythrocytes reacts with water to form carbonic acid. The enzyme is

(1) Carbonic anhydrase (2) Carboxypeptidase

(3) Hydrolase (4) Oxidoreductase

5. Partial pressure of carbon dioxide in Alveoli, atmospheric air and tissues will be :-

(1) (0.3, 40, 45) mmHg (2) (40, 0.3, 45) mmHg

(3) (0.3, 104, 28) mmHg (4) (104, 159, 40) mmHg

6. CO_2 is transported mainly as :-

(1) Carbaminohaemoglobin (2) Oxyhaemoglobin

(3) Bicarbonate (4) carboxyhaemoglobin

7. Every 100 ml deoxygenated blood delivers around _____ CO_2 to alveoli :-

(1) 20 ml (2) 4 ml (3) 5 ml (4) 25 ml

08. REGULATION OF RESPIRATION

- Human beings have a significant ability to maintain and moderate the respiratory rhythm to suit the demand of the body tissues. This is done by neural system.
- **The respiratory rhythm centre** in the Medulla is primarily responsible for this regulation.

  Following respiratory groups regulate respiration :-

  (a) The **dorsal respiratory group (DRG)** is present in the dorsal portion of medulla oblongata. The signals from these neurons generate the basic respiratory rhythm. The nervous signal released from this group is transmitted to the diaphragm & EICM.

  (b) The **ventral respiratory group (VRG)** of neurons are located anterolateral to the dorsal respiratory group. During normal respiration, this remains inactive.

  In the enhanced respiratory drive, the respiratory signal of this group contributes to fulfil the demand by regulating both inspiration and expiration. Few of the neurons of this group control inspiration, while few other control expiration, thus regulating both.

  (c) The **pneumotaxic centre** is located on **pons**. It is called **switch off point of inspiration. Neural signal from this centre can reduce the duration of inspiration and thereby alter the respiratory rate.** When this center send strong signal then lungs are filled partially.

- **Hering Breuer reflex arch :**

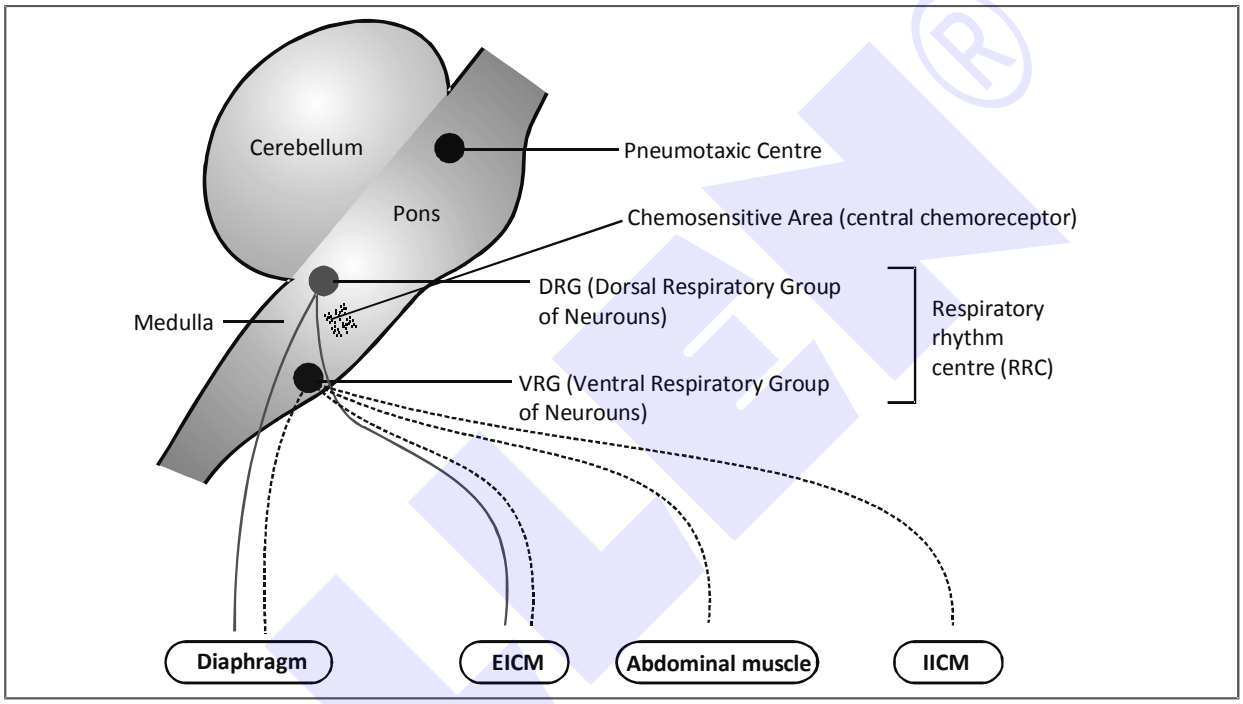
  In the walls of terminal bronchioles and atria stretch receptors are present, Which are normally inactive but they become active when alveoli are filled with maximum air. The Hering Breuer reflex arch now becomes activated and sends inhibitory signals to the inspiratory centre to switch off inspiration. This prevents the alveoli from over stretching and bursting. Thus Hering Breuer reflex arch is a protective reflex which works only **when normal mechanism of switch off of inspiration does not work timely due to any reason.**

- **A chemosensitive area** is situated adjacent to the rhythm centre which is **highly sensitive to CO_2 and hydrogen ions.** Increase in these substances can activate this centre which in turn can signal the rhythm centre and increase breathing rate. The role of oxygen in the regulation of respiratory rhythm is quite insignificant.

- **Aortic body** and **carotid body** are chemoreceptors associated with aortic arch and carotid artery. They also can recognise changes in CO_2 and H^+ concentration.
- The activity of respiratory centre is also affected by body temperature and blood pressure. Whenever body temperature is increased or blood pressure goes high, respiratory centre becomes more activated and this increases the respiration rate.

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 (Switch off point) — RRC
↓duration of inspiration
↑Rate of respiration

(4) Chemoreceptors

- Central
  - Central chemoreceptors (Medulla)
- Peripheral
  - Aortic body
  - Carotid labyrinth

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 eliminated

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

09. RESPIRATORY DISORDERS

- **Asthma** is a difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.
- **Bronchitis** is a disorder of bronchi in which there is regular swelling and itching of bronchi and is characterised by regular coughing.
- **Emphysema** is a chronic disorder in which alveolar walls are damaged due to which respiratory surface is decreased. One of the major causes of this is cigarette smoking.
- **Occupational Respiratory Disorders:** In certain industries, especially those involving grinding or stone-breaking, so much dust is produced that the defence mechanism of the body cannot fully cope with the situation. Long exposure can give rise to inflammation leading to fibrosis (proliferation of fibrous tissues) and thus causing serious lung damage. Workers in such industries should wear protective masks. e.g. Silicosis, Asbestosis.
- **Rhinitis :** Inflammation of nasal tract.

Golden Key Points

- **Hypoxia** - Low O_2 supply to tissues.
- **Asphyxia** - It is the state of suffocation due to high CO_2 concentration or low O_2 concentration.
- One molecule of haemoglobin combine with four molecules of **carbon monoxide gas** to form **carboxyhaemoglobin.** Affinity of CO to Hb is 200-300 x more than the O_2. Its colour is cherry red. Due to this oxygen affinity is reduced. It is referred as carbon monoxide poisoning.
- One molecule of myoglobin has $1Fe^{++}$ ions metal.
- Foetal haemoglobin differs from adult haemoglobin in structure. Foetal haemoglobin has higher affinity for O_2 than adult haemoglobin. When PO_2 is low. Foetal Hb can carry up to 30% more O_2 than maternal Hb. So dissociation curve for foetal Hb will appear on the left side.
- Bowman's glands are present in human nasal cavity.
- **Eupnoea** :- It is the state of normal breathing. In man rate of normal breathing is **12-16** per minute. In infants rate of breathing is 44 per minute. Rate of breathing is slowest while sleeping.
- **Bradypnoea or Hyponoea** :- It is the state of slow breathing.
- **Rapid breath or hypernoea** :- It is the state of fast breathing.
- **Apnoea** - It is the state of stoppage of breathing temporarily.
- **Dyspnoea** - It is the state of painful breathing due to pleurisy.
- **Asphyxia** - It is the state of suffocation due to high CO_2 concentration or low O_2 concentration.
- Some gases (e.g. Ozone) oxidise haemoglobin. This oxidised haemoglobin is called **Methamoglobin**. This type of gases are environmental pollutant.

BEGINNER'S BOX

REGULATION OF RESPIRATION AND DISORDERS OF RESPIRATORY SYSTEM

1. The impulse for voluntary muscles for forced breathing starts in

(1) Medulla oblongata (2) Vagus nerve (3) Cerebellum (4) Cerebrum

2. Respiratory centre of brain is stimulated by

(1) Carbon dioxide content in venous blood (2) Carbon dioxide content in arterial blood

(3) Oxygen content in venous blood (4) Oxygen content in arterial blood

3. Respiratory rhythm centre is present in :-

(1) cerebellum (2) Cerebrum (3) Medulla oblongata (4) Pons

4. Pneumotaxic centre is present in

(1) Pons (2) Medulla (3) Cerebrum (4) Cerebellum

5. Asthma is a respiratory disease caused due to

(1) Infection of trachea (2) Infection of lungs

(3) Bleeding into pleural cavity (4) Spasm in bronchial muscles

6. When CO_2 concentration in blood increases, breathing becomes –

(1) There is no effect on breathing (2) Slow and deep

(3) Faster (4) Shallower and slow

7. Haemoglobin shows maximum affinity with:-

(1) Carbon monoxide (2) Carbon dioxide

(3) Oxygen (4) Ammonia

8. Rate of respiration is directly affected by

(1) CO_2 concentration (2) O_2 in trachea

(3) Concentration of O_2 (4) Diaphragm expansion

9. "Chemoreceptors" which recognise the change in concentration of CO_2 and H^+ are found in -

(1) Aortic arch (2) Carotid artery (3) Medulla (4) All of these

10. "Emphysema" is a condition in which -

(1) Respiratory centre inhibited (2) Lot of fluid in the lungs

(3) The walls separating the alveoli break (4) Lungs have more O_2

11. An abnormal distension of bronchioles or alveolar sacs is encountered in :

(1) Bronchitis (2) Bronchial asthma

(3) Emphysema (4) Pneumonia

12. Match the disorders given in column I with symptoms under column II. Choose the answer which gives the correct combination of alphabets with numbers :

Column I	**Column II**
(a) Asthma	(i) Inflammation of nasal tract
(b) Bronchitis	(ii) Spasm of bronchial muscle
(c) Rhinitis	(iii) Damaged wall of alveoli
(d) Emphysema	(iv) Inflammation of bronchi
	(v) Cough with blood strained sputum

(1) a – iv, b – ii, c – v, d – i
(2) a – v, b – i, c – ii, d – iii
(3) a – iii, b – iv, c – i, d – iii
(4) a – ii, b – iv, c – i, d – iii

BEGINNER'S BOX — ANSWERS KEY

INTRODUCTION AND RESPIRATORY ORGANS

Que.	1	2	3	4	5	6	7	8	9
Ans.	**2**	**3**	**3**	**2**	**2**	**3**	**1**	**2**	**4**

ANATOMY OF HUMAN RESPIRATORY SYSTEM

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	**2**	**1**	**1**	**4**	**3**	**3**	**1**	**2**	**3**	**2**	**4**	**2**	**2**	**4**	**2**
Que.	16	17													
Ans.	**1**	**3**													

MECHANISM OF BREATHING

Que.	1	2	3	4	5	6	7	8
Ans.	**2**	**1**	**1**	**1**	**3**	**1**	**3**	**1**

RESPIRATORY VOLUME AND CAPACITIES

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13
Ans.	**3**	**1**	**4**	**1**	**2**	**3**	**1**	**4**	**1**	**3**	**1**	**3**	**1**

EXCHANGE OF GASES

Que.	1	2	3	4	5	6	7
Ans.	**2**	**2**	**4**	**4**	**2**	**3**	**3**

TRANSPORT OF O_2 AND HbO_2 DISSOCIATION CURVES

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13
Ans.	**2**	**3**	**2**	**1**	**2**	**1**	**4**	**4**	**2**	**2**	**4**	**1**	**1**

CO_2 TRANSPORT

Que.	1	2	3	4	5	6	7
Ans.	**4**	**1**	**1**	**1**	**2**	**3**	**2**

REGULATION OF RESPIRATION AND DISORDERS OF RESPIRATORY SYSTEM

Que.	1	2	3	4	5	6	7	8	9	10	11	12
Ans.	**4**	**2**	**3**	**1**	**4**	**3**	**1**	**1**	**4**	**3**	**3**	**4**

(1) Respiratory organs

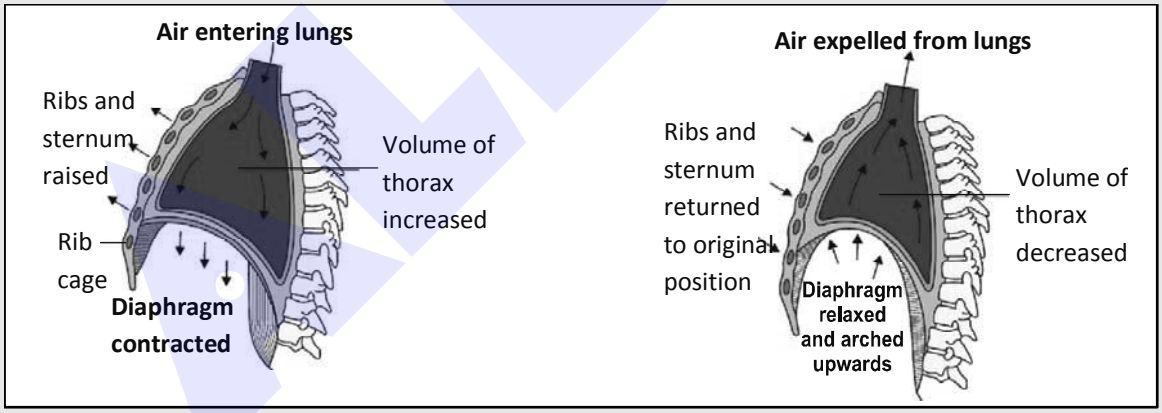
- Sponge, coelenterates, flat worms → Simple diffusion by body surface.
- Earthworm → Moist cuticle.
- Insects → Trachea
- Aquatic arthropods & molluscs → Gills
- Terrestrial forms - Lungs
- Fishes - Gills
- Reptiles, Bird, mammals-Lungs

(2) Path of air

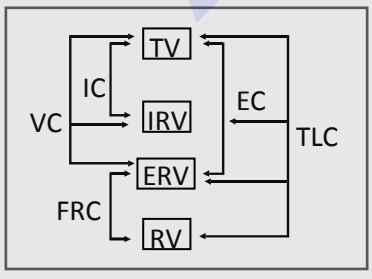
External nostrils → Vestibule/Passage → Nasal Chamber → Internal nares → Pharynx → Larynx → Trachea → Primary Bronchus → Secondary Bronchus → Tertiary Bronchus → Terminal Bronchiole → Respiratory Bronchiole → Alveoli

Exchange Zone

(3) Mechanism of breathing

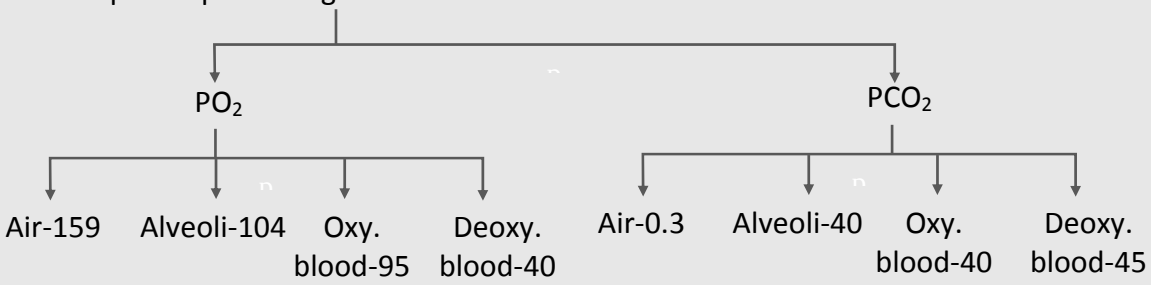


(4)

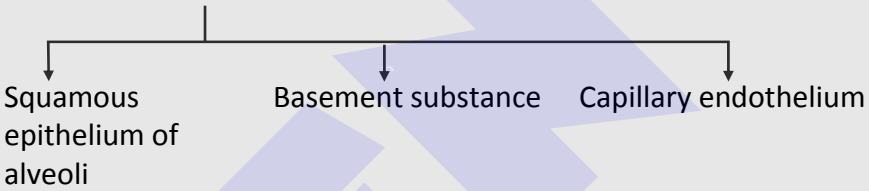


(5) Rate of gaseous exchange $\propto \frac{\Delta P.A.S.}{d}$

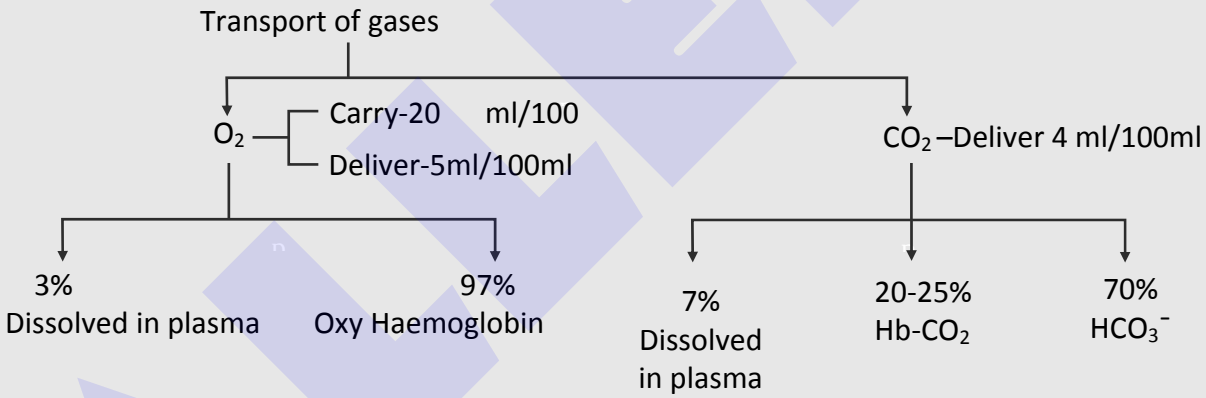
- $\Delta P \longrightarrow$ partial pressure gradient



- A = Area of respiratory membrane $\approx$ 70 m^2.
- S = Solubility of gases.
  solubility of CO_2 in water is 20 – 25 × more than O_2.
- d = Thickness of membrane, resp. membrane has three layers, thickness < 1 mm.



(6)



(7) Regulation :
Respiratory rhythm centre in medulla.
Pneumotaxic centre in pons.
Chemo sensitive area is highly sensitive to CO_2 & H+ ions.

(8) Disorders :