Chapter 14

GASEOUS EXCHANGE

Respiration

- It is energy (ATP) yielding process.
- It made possible the continuous supply of energy (ATP) to living cells for their metabolic activities.
- occurs at two levels:
  (1) Organismic level
  (2) Cellular level

Organismic level of respiration

- It is also known as breathing, ventilation or external respiration
- It involves taking in of air (inhalation or inspiration) and giving out of air (exhalation or expiration).
- Respiratory gases (O_2 & CO_2) are exchanges b/w body fluids and outside medium i.e. air or water.
- Carried out only by diffusion process
- There is no active mechanism to move respiratory gases across biological membranes.
- In human lungs are involved in ventilation.
- Respiratory related area of lungs consists of respiratory bronchioles, alveolar ducts, alveolar sacs and thin membrane alveoli
- Lungs consists of branching airways that ends into microscopic sac like structures K/a alveoli.
- Alveoli are made up of ciliated epithelial cells
- Alveoli are lined with thin film of moisture with separate adjacent alveoli.
- Bronchioles of both lungs and large air passageways (trachea and bronchi) cross the gases (air) to the site of gas exchange (alveoli), where interchange of gases (air) b/w alveolar air and blood of capillaries takes place.

Respiratory media

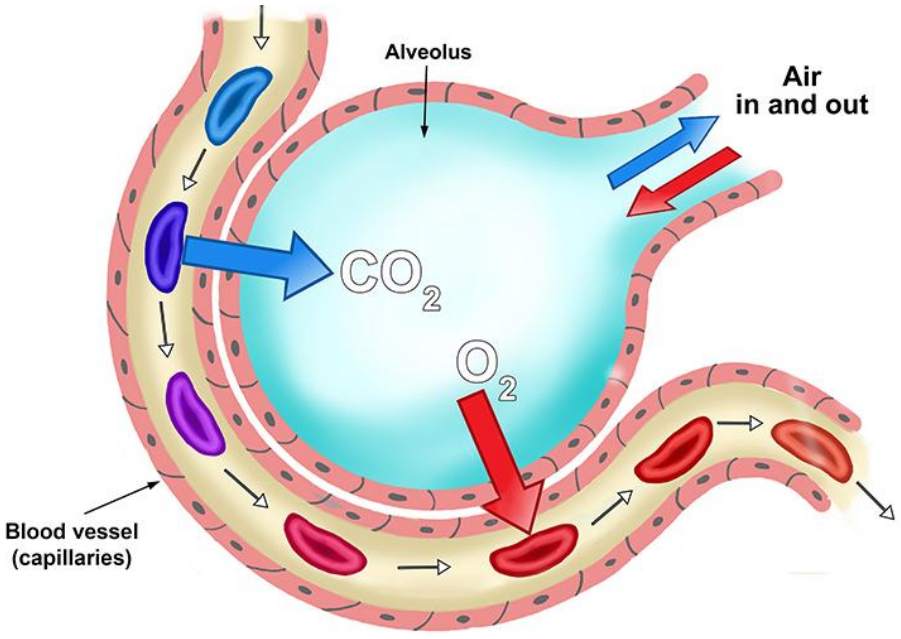
- The source of oxygen is called respiratory media.
- Respiratory media for aquatic organisms is water and for terrestrial organisms is air.
- Oxygen content of air is much greater (21%) than the oxygen content (5%) of equal volume of water.
- Ventilation (gaseous exchange) of water is far more difficult than ventilation in air because of:
  - ☞ Oxygen diffuses about 8000 times more quickly in air than in water.
  - ☞ Because water is 8000 times denser than air
  - ☞ Water is 50 times more viscous than air

Respiratory Surface

- Area or the surface where the exchange of gases takes place with its environment is called respiratory surface. e.g. skin in earthworm, alveoli in human, gills in fish etc.
- Respiratory surface in animals depends upon the structure, habitat and activity of animal.

Properties of respiratory surfaces

- The respiratory surface must have the following properties so that the diffusion of respiratory gases can occur effectively:
  - **(A) Moist**— allow to pass dissolved gases through them
  - **(B) Permeable**— respiratory gases (O_2 & CO_2) can pass through it.
  - **(C) Thin**— because reduced diffusion distance (i.e. 1 mm or less) is efficient for gases exchange. In most animals the epithelium which separates air and blood is only 2 cells thick so the distance for diffusion is very short.
  - **(D) Large surface area** — so that sufficient amount of gases can be exchanged according to organism's need. In our both lungs we have approximately 700 million alveoli whose surface area is about 100 m2 (equal to that of tennis court or 50 times the skin surface and 1000 km of capillaries)
  - **(E) Significant blood supply**— blood should flow all the time at an adequate speed b/s of this highly concentrated oxygenated blood (O2 rich) is taken away and deoxygenated blood (CO2 rich) is taken to lungs.
  - **(F) Large diffusion gradient**— there should be higher concentration of O_2 in alveoli than in capillaries (steep diffusion gradient) which helps in rapid diffusion of O_2 from alveoli to the blood and CO_2 diffuses opposite direction.



Respiration in Hydra

- Hydra is aquatic multicellular animal belongs to phylum Cnidaria (Coelentrata) and class Hydrozoa.
- It has tissue level of organization (diploblastic i.e. having ectoderm and endoderm) but no organ.
- It has no specialized organ for respiration.
- It has large surface area in relation to its volume.
- Being aquatic, its entire external surface (ectodermal cells) and internal lining of gastrovascular cavity (endodermal cells) remain in contact with water, so ectodermal cells exchange gases with external water while endodermal cells with water that comes within gastrovascular cavity.

Respiration in earthworm

- Earthworm (Pheretima) is multicellular animal belongs to phylum annelida (segmented worms) and class oligochaeta.
- It has tubular body pattern with developed organs and systems but does not have any specialized respiratory organs.
- It uses its wet skin as respiratory surface.
- In order to keep skin moist, it has to live in damp soil.
- The epidermal mucous glands (goblet glands) and coelomic fluid make the surface of skin moist with their secretions to assist gaseous exchange.
- It has been observed that if its skin dries the worm dies of suffocation i.e. asphyxia.
- Due to larger size and complexity of the body of the earthworm alone diffusion can not distribute the gases rapidly to distant cells. Therefore, it has blood vascular system (closed type) for rapid and efficient gaseous exchange within the body.
- The blood of earthworm is red colored due the presence of a respiratory pigment hemoglobin in it. The hemoglobin is not contained in the corpuscles like the vertebrate but it is found dissolved state in its plasma.
- The atmospheric oxygen diffuses in the capillaries of skin and combines with hemoglobin to form oxyhemoglobin.
- The oxyhemoglobin is circulated by the blood into the tissue and breaks up to release oxygen to tissues. At the same time CO2 from the tissues diffuses in the blood and blood carries it to the epidermal capillaries where CO2 diffuses out in the atmosphere.

Respiration in Cockroach

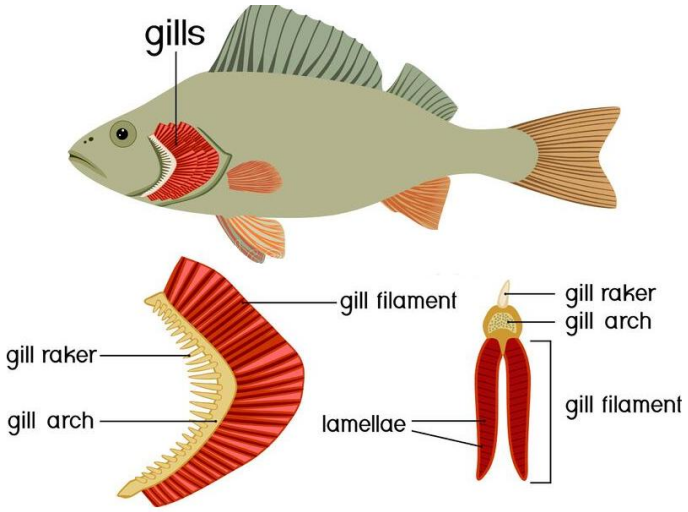
- Cockroach is the member of phylum arthropoda and class insecta or hexapoda.
- Cockroach and all other terrestrial insects contain a special type of invaginated respiratory system called tracheal system.
- Tracheal system is specially adapted for terrestrial mode of life, high metabolic rate and the compact body of an insect. It also compensates the absence of respiratory pigment in blood.
- Tracheal system consists of air tubes (trachea) and spiracles.

  - **Trachea**:
    - These are internal branching air tubes through which every tissue of the cockroach body remains in contact with the atmospheric air for gaseous exchange.
    - Lined by chitin and found in the hemocoel (body cavity of insects).
    - The main tracheae divide and subdivide forming very thin walled tubes called tracheoles.
    - Tracheoles finally end into blind, partly fluid filled, fine branches which are attached in the tissue cells.
    - In a resting cockroach when respiratory activity is not high, the tracheoles are filled, not with air but with tissue fluid of the cells in which oxygen dissolves.
  - **Spiracles (stigmata):**
    - These are minute, slit like pores through which atmospheric air enters into and escapes from the trachea.
    - The main **Mechanism of respiration:**
    - the movement tracheal trunk communicates with exterior by 10 pairs of spiracles, present on the lateral sides of the body. Two pairs in thorax while the rest eight pairs are in first eight abdominal segments.

- ☞ Each spiracle guarded by bristles of hairs to prevent the passage of dirt.
- ☞ Spiracles are open and closed by valves regulated by sphincter or sphincter muscles.
- ☞ of the air through tracheal trunks transfer gases through inspiration and expiration.
- ☞ Air is pumped in (inspiration) and out (expiration) of the trachea by the expansion and contraction of the abdominal muscles (dorsoventral muscles).
- ☞ When abdomen expands, the first 4 pairs of the spiracles open and air rush into tracheoles.
- ☞ When abdomen contracts, the first 4 pairs of spiracles close and last 6 pairs of spiracles open. This forces the air through the tubes and eventually out of the body.
- ☞ From spiracles air enters into trachea and then tracheoles, from where gases exchange between tissue cells and air in tracheoles takes place.
- ☞ blood vascular system of cockroach devoid of hemoglobin. So the removal of CO_2 from the cells of the body is largely dependent upon plasma of the blood, which takes up CO_2 for its ultimate removal through the body surface via the cuticle.

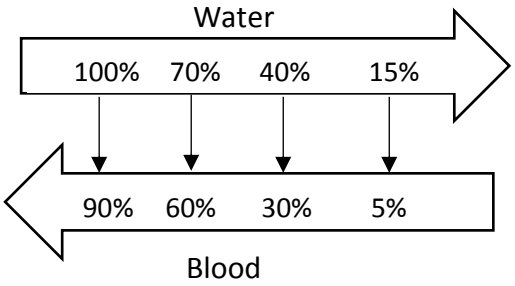
Respiration in fish

- Respiratory organs in fish are gills.
- Larva forms of a few fish and amphibians have external gills projecting from their bodies.
- Adult fishes have internal gills.
- Gills are formed as outgrowth of pharynx and lie internally within the body so they are protected from mechanical injuries.
- 5 to 4 pairs of gills which may open through gill slits and are visible on the surface of pharynx (cartilaginous fish).
- Gill slits of bony fishes are covered by operculum while is absent in cartilaginous fishes.
- In bony fish, the gills lie in branchial chamber covered by a bony gill cover (operculum).
- Each gill is highly vascularized structure and is composed of two rows of hundreds of filaments which are arranged in V-shape and is supported by a cartilage or long curved bone, the gill bar or gill arch.
- Each filament is folded to form numerous plate-like lamellae which greatly increase the surface area of the gill and each lamella is provided with a dense network of blood capillaries.
- Gill comprises (gill raker → gill arch → gill filaments → lamellae)
- the Heart of fish, through ventral aorta, pumps deoxygenated blood into the afferent branchial arteries (4-5 pairs) into the gills for oxygenation.

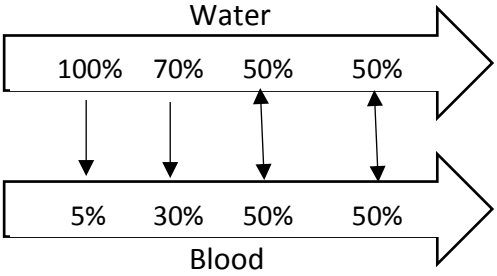


✸ Mechanism of ventilation

- In bony fishes, ventilation is brought about by the combined effect of mouth and operculum.
- Water → mouth → pharynx → gills → exits at the back of operculum.
- Deoxygenated blood → heart → ventral aorta → afferent branchial arties → capillary bed in the pharyngeal lamellae.
- Since O2 concentration is low in water and water is also denser than air. Fish must use considerable energy to ventilate its gills.
- Gaseous exchange in gills facilitated due to countercurrent exchange because water and blood flow in opposite directions on either side of the lamellae.
- In countercurrent exchange, water encounters blood that is almost completely oxygenated, but a diffusion gradient still favors the movement of more oxygen from the water to blood. As water continuous to move b/w lamellae, it loses oxygen to the blood because it is continually encountering blood with lower oxygen concentration. Thus, a diffusion gradient is maintained along the length of lamellae.
- Countercurrent exchange mechanism is very effective because it enables a fish to extract 80% to 90% oxygen from water that flows over the gills.



- If blood and water moved in parallel fashion, oxygen would diffuse from water to blood only until the oxygen concentration in blood equaled the oxygen concentration in water, and the exchange would be much less efficient.



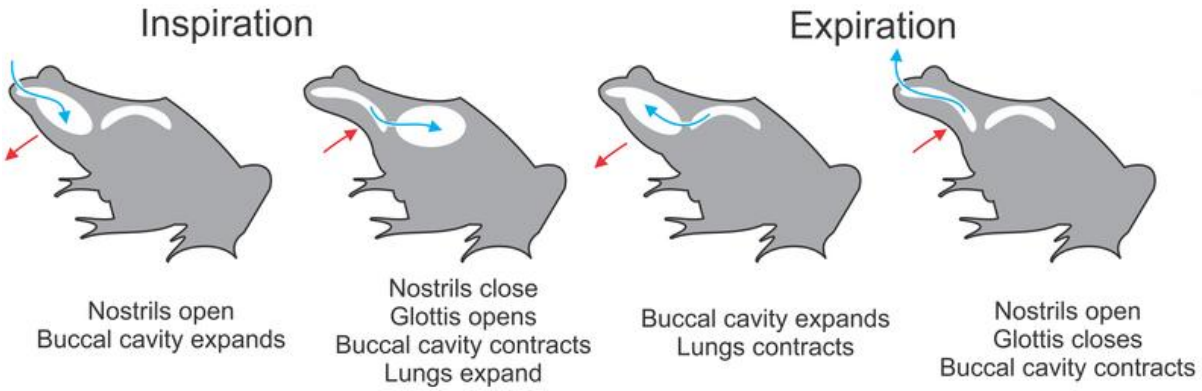
- Gill ventilation is often assisted by the fish's forward movement through the water with its mouth open (ram ventilation).
- Very active fishes, such as herring, mackerel, dolphin fish, tunas, can obtain sufficient water for their oxygen demand only by swimming forward (50-80 cm/s or greater speed) continuously to force water into their open mouth and across their gills. This process is called ram ventilation. Such fishes would be asphyxiated if placed in an aquarium that restricts free-swimming movements, even if the water is saturated with oxygen.

Respiration in frog

- Frogs belong to class Amphibia and oder Anura.
- Frog can respire by:
  (i) skin (cutaneous respiration)
  (ii) across the moist surface of the mouth and pharynx (Bucco-pharyngeal respiration)
  (iii) lung (pulmonary respiration)
  (iv) gills in its larval stage.

Pulmonary respiration

- Like other terrestrial vertebrates, frog has evolved, vascularized, paired outgrowths from the lower part of the pharynx known as lungs.
- Frog lungs ovoid, elastic simple sacs with their inner surfaces divided into network of septa that are subdivided into small terminal air chambers called faveoli.
- Faveoli of frog lungs are much larger than alveoli of amniote vertebrates (reptiles, birds and mammals), and consequently frog lungs have a smaller relative surface available to gas exchange.
- Inner surface of faveoli (alveoli) is single cell and attached with blood capillaries.
- Air passage of frog is:
  Nostrils → buuco-pharyngeal cavity → glottis → laryngo-tracheal chamber → Brochi → lungs
- Frog is a positive-pressure breather (i.e, fills its lungs with air by using a positive pressure pumping mechanism). The muscles of mouth and pharynx create a positive pressure to force air into the lungs.
- Ventilation in frog is single, two-way path.
- Breathing in frog involves two phases i.e. inspiration (1 and 2) and expiration (3):
  1. Nostrils open, glottis closes, bucco-pharyngeal floor lowered, therefore, new air drawn into bucco-pharyngeal cavity though nostrils, old air is retained under pressure in lung, hence incomplete ventilation.
  2. Nostrils close, glottis open, bucco-pharyngeal floor raised. Therefore, air forced from bucco-pharyngeal floor into lungs.
  3. Nostrils open briefly glottis opens. Therefore, air expelled from lungs by their elastic recoil and abdominal pressure.



Respiration in birds

- The respiratory system of birds is most efficient and is adapted for meeting the high metabolic demand of flight.
- Birds use negative pressure mechanism; that is they inhale (breath in) by suction.
- The respiratory system of birds consists of:
  (1) Lungs (2) Air sacs

(1) Lungs

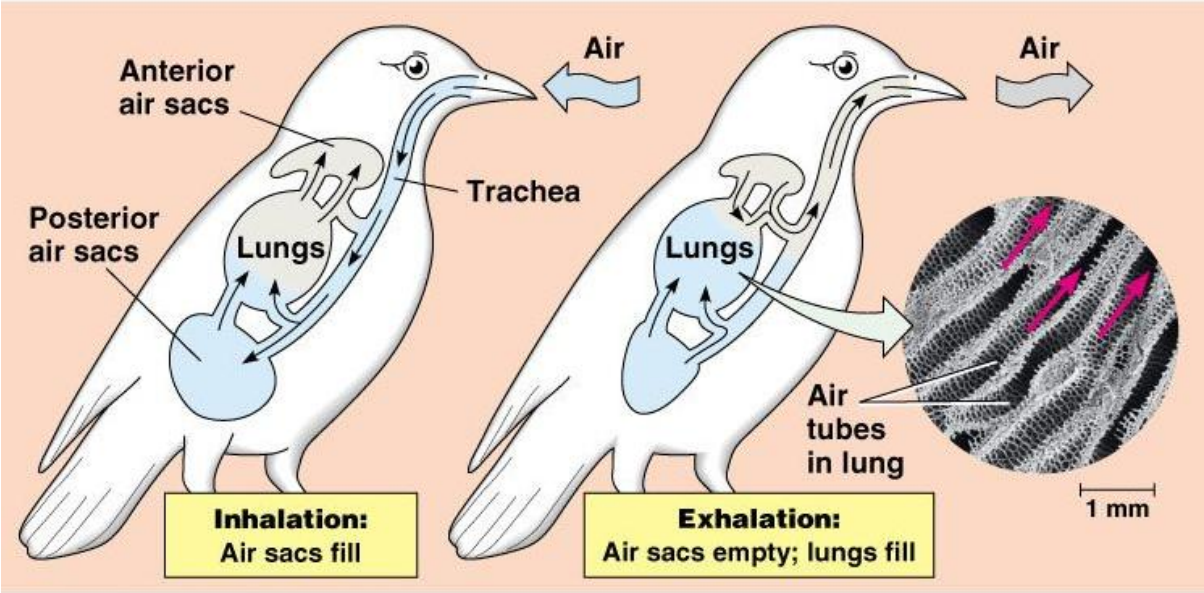
- ☞ Birds have a pair of lungs.
- ☞ The lungs of birds are internally subdivided into numerous, small, highly vascularized, thin membranous channels called parabrobhi instead of alveoli (i.e. in the birds the finest branches of bronchi, rather than ending in sac like alveoli as in mammals, are developed as tube like prarabronchi).
- ☞ These parabronchi are open at both ends and through which air flows continuously in one direction.
- ☞ The walls of the parabrobhi are chief site of gaseous exchange.

(2) Air sacs

- ☞ Around the lungs and connected with the ends of the main bronchial branches are thin walled, membranous, non-muscular and non-vascular air sacs.
- ☞ They are formed from the dilation of mucous membrane of bronchus.
- ☞ Airs sacs are located in abdomen, neck, wings and even extended by tinny tubes into the centers of long bones.
- ☞ These work as bellows that ensure the unidirectional flow of air or complete ventilation.
- ☞ These are connected to lungs in such a way that most of the inspired air bypasses the lungs and flows directly to posterior air sacs, which serve as reservoir for fresh air.

Mechanism of breathing in birds

- A bird must take two breaths to move air (one-way flow) completely through system of air sacs and lungs i.e.
  the **first breathe** draws fresh air into the posterior air sacs of lungs and the **second breath** pushes the first breath into the anterior air sacs and then outside of the body.
- This one-way flow of air enables a bird to fly at very high altitude without any shortage of oxygen, as the air coming in lungs is always oxygen-rich (complete ventilation)



Respiratory system of man

- Respiratory system of man can be divided into two regions:
  (1) Upper respiratory tract (Nostrils, nasal cavity and pharynx)
  (2) Lower respiratory tract (larynx, trachea, bronchi and lungs

Nose:

- ☞ It is only externally visible part of respiratory system.
- ☞ Human nose composed of bones, cartilage and fibro fatty tissues.
- ☞ The external feature of a nose depends upon the ethmoid bone and cartilages.
- ☞ The external opening of nose called nostrils or nares and inner hollow spaces are called nasal cavities. There are 2 nasal cavities which are separated by nasal septum (part of nasal bone). The anterior part of nasal cavities near the nostrils called vestibules and it contains hair. Both the nostrils and nasal cavities are lined by ciliated mucous membrane.
- ☞ Underneath the mucous membrane of nose, there are blood capillaries that help to warm the air to about 30 °C, depending upon the external temperature.

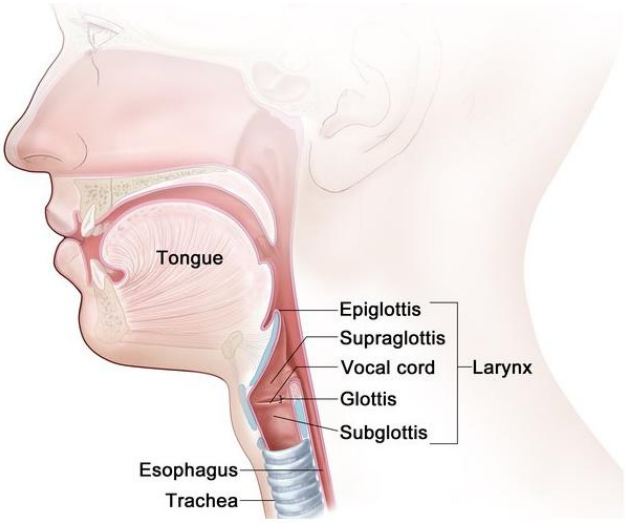
Pharynx (Throat):

- ☞ Pharynx is cone-shaped passageway leading from the oral and nasal cavities to the oesophagus and larynx.
- ☞ It is the part of both the digestive and respiratory system.
- ☞ In human, it divided into three sections i.e. Nasopharynx, oropharynx and laryngopharynx.

Larynx (Voice box):

- ☞ It is an enlargement in the airway at the top of trachea and below the pharynx.
- ☞ It serves dual function: as air canal to lungs and as organ of the voice.
- ☞ It is composed of muscles and cartilages.
- ☞ One of its cartilage is epiglottis which usually stands upright and allow air to enter the larynx. During swallowing, larynx is raised and epiglottis is pressed downward. As a result, epiglottis partially covers the opening into the larynx and prevents the food from entering in the air passage way.

- The opening of the larynx is called glottis.
- It is also lined with mucous membrane.
- Inside the larynx, there are two fibrous bands called vocal cards which are responsible for vocalization (any sound produced through the action of an animal's respiratory system and used in communication).



Trachea (Windpipe):

- It is the main airway to lungs that is lies below the larynx.
- It is fibro-cartilaginous tube of about 10-12 cm long and 2 cm wide.
- It has about 16 to 20 "C" shaped cartilaginous ring, provide rigidity and prevent trachea collapsing.
- It is lined with ciliated mucous membrane.

Bronchi:

- Trachea divides to form two major airways called primary bronchi (singular bronchus)
- Right bronchus is broader (larger in diameter), shorter and straighter than left one bronchus.
- Primary bronchi enter the two lungs. Each primary bronchus then divides into secondary bronchi.
- In the secondary bronchi, the "C" shaped cartilages are replaced with cartilage plates.
- There are two secondary bronchi in left lung and three in right lung.
- The secondary bronchi, in turn give rise to tertiary bronchi.

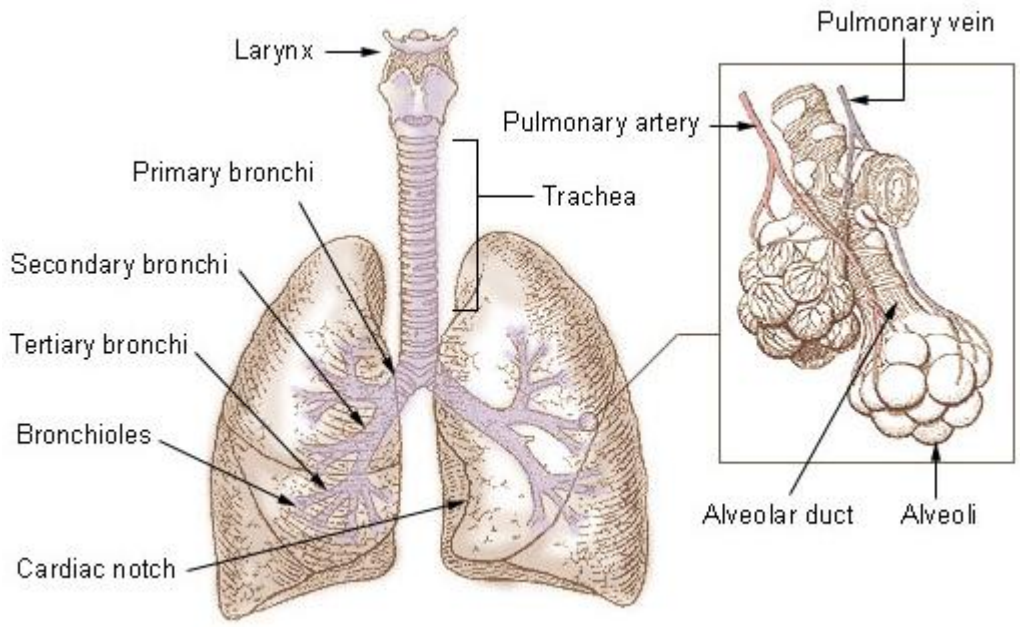
Bronchioles:

- The bronchi continue to branch, finally give rise bronchioles which are less than 1 mm in diameter and their walls consist of cuboidal epithelium and a layer of smooth muscles.
- Bronchioles are the first airway branches that do not contain cartilage.
- The bronchioles also subdivide several times to become even smaller terminal bronchioles which have no cartilage structure.

Alveolar ducts and alveoli:

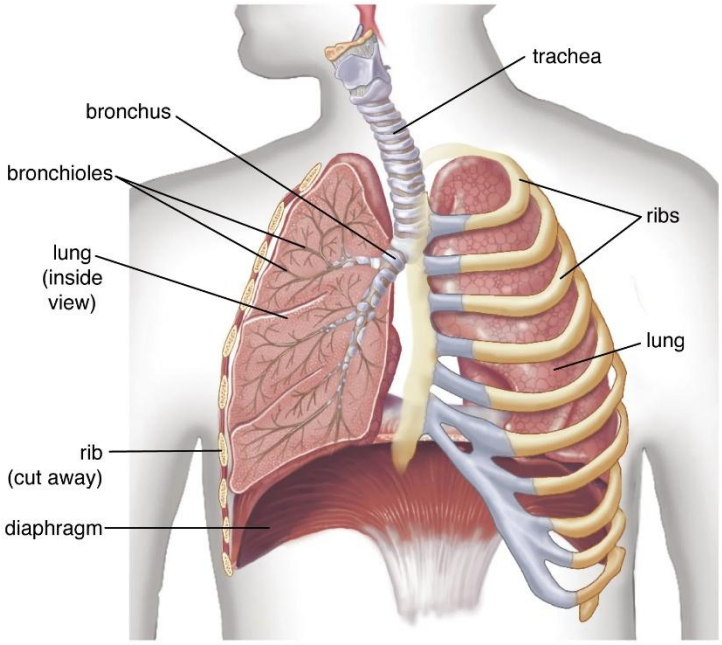
- The terminal bronchioles divide to form alveolar ducts and alveolar ducts end at tiny air-filled chambers called alveoli (singular alveolus) which are the site of gas exchange between the air and blood.
- Each alveolus is 0.1µm thick and on its outside is dense network of capillaries.
- Lining each alveolus is moist squamous epithelium. This consists of very thin flattened cells, reducing the distance over which diffusion must occur.

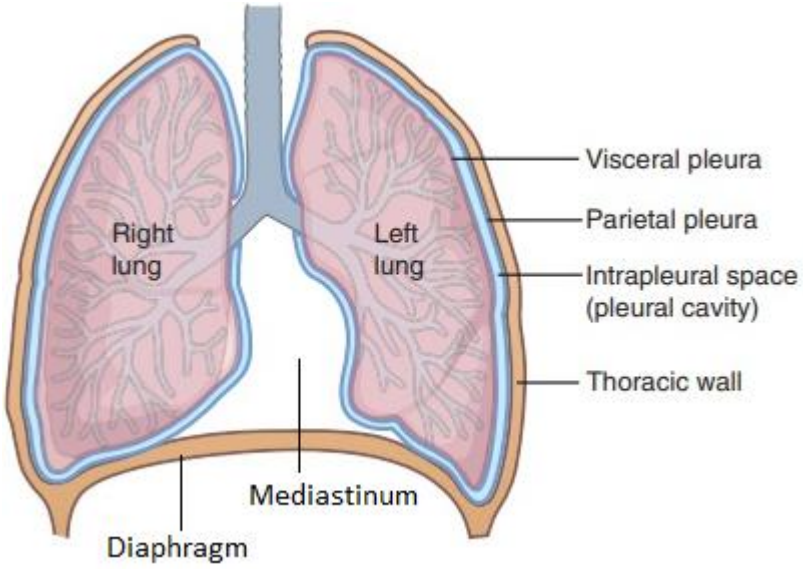
- Collagen and elastin proteins also present in the walls of alveoli which allow alveoli to expand and recoil easily during breathing.



Lungs:

- Lungs are paired, soft, spongy and highly vascularized structures, located in thoracic cavity.
- The walls of thoracic cavity are formed of intercoastal muscles, which are attached with a bony cage formed by 12 pairs of ribs, vertebral coloumn, and sternum bone.
- The thoracic cavity is separated from abdomen by dome-shaped muscular partition called diaphragm.
- Most of the thoracic cavity volume is occupied by lungs.
- The right and left lungs are slightly unequal in size.
- The right and left lung are separated medially by the mediastinum (space between the lungs that houses many vital structures i.e. heart, trachea and essential nerves etc.)
- The right lung represents 56% of total lung volume and has 3 main lobes:
  1. Superior lobe 2. Middle lobe 3. Inferior lobe
- The left lung, smaller in volume because of asymmetrical position of heart and has 2 lobes:
  1. Superior lobe 2. Inferior lobe
- The hilum is a triangular shaped depression of both the lungs where the blood vessels and airways pass into lungs.
- Lungs are covered by thin layer of tough epithelium known as visceral pleura. Continuous with this layer is similar layer, the parietal pleura, that lines the inner surface of the walls of the chest. The space between visceral and parietal pleura is known as pleural cavity (it maintains a partial vacuum or negative intrapleural pressure) that contains pleural fluid which act a lubricant.





The major functions of the respiratory system

- Respiratory system performs the following major functions:
  1. **Oxygen supplier:** it provides a continuous supply of oxygen to all tissues
  2. **Withdrawal:** removal of by-product carbon dioxide (CO_2).
  3. **Conversation (exchange) of gases:** involves in gases exchange b/w internal and external environment of the body.
  4. **Humidifier:** act as humidifier b/c it has the capability to humidify (moist) and keep the air warm.

Ventilation (Breathing)

- It is the process of taking in (inspiration/inhalation) and giving out of air (expiration/exhalation) from the atmosphere up to the respiratory surface and vice versa.
- It is mechanical process consisting of two phases, inspiration and expiration.
- In man including other mammals, it is termed as negative pressure breathing because air is drawn into lungs due to negative pressure (decrease in pressure in thoracic cavity in relation to atmospheric pressure).
- It is mechanical process consisting of two phases, inspiration and expiration.
  Inhalation is taking in of air from atmosphere up to alveoli.
  Exhalation is the giving out of the air from alveoli to the atmosphere.
- One breathing cycle comprises of one complete inhalation and exhalation.
- The person breaths how much in a minute it's called breathing rate. Breathing rate is varies upon a person's activity. It rises in running, walking or a heavy exercise. The adult normal breathing rate is about 12-20 times per minute and it may exceed or decrease due to due to different perspectives.

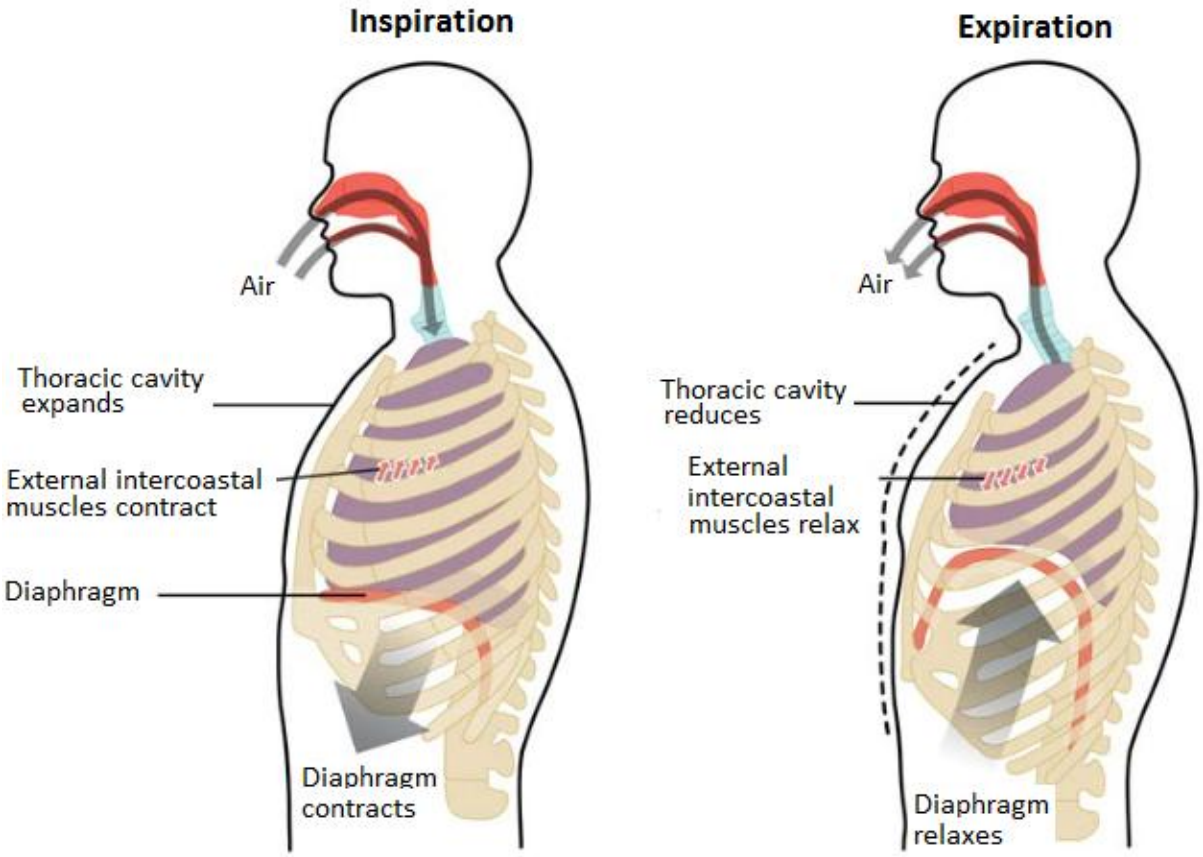
Mechanism of ventilation (Breathing)

1. Inspiration

- It is the process of taking in of air from atmosphere up to alveoli.
- It is active phase of breathing.
- During inspiration the inner space of thoracic cavity is increased due to:
  (i) Contraction of diaphragm causes its dome-shape to less dome-shaped or flattened.
  (ii) Contraction the external intercoastal muscles and relaxation of internal intercoastal muscles causes the rib cage to move upward and forward.
- Due to increase in inner space of thoracic cavity, the pressure in thoracic cavity and hence in lungs is reduced to less than atmospheric pressure. So, the air through respiratory passage rushes into the lungs up to the alveoli where exchange of gases occurs.

2. Inspiration

- It is the process of giving out of the air from alveoli to the atmosphere.
- It is passive phase of breathing.
- During expiration the inner space of thoracic cavity is decreased due to:
  (iii) relaxation of diaphragm causes it to become more dome-shaped.
  (iv) Relaxation of the external intercoastal muscles and contraction of internal intercoastal muscles causes the rib cage to move downward and inward.
- Due to decrease of inner space of thoracic cavity, the pressure in thoracic cavity and hence in lungs is increased to more than atmospheric pressure. As a consequence, lungs are compressed so the air along with water vapors is forced to expelled from the lungs through respiratory passage.



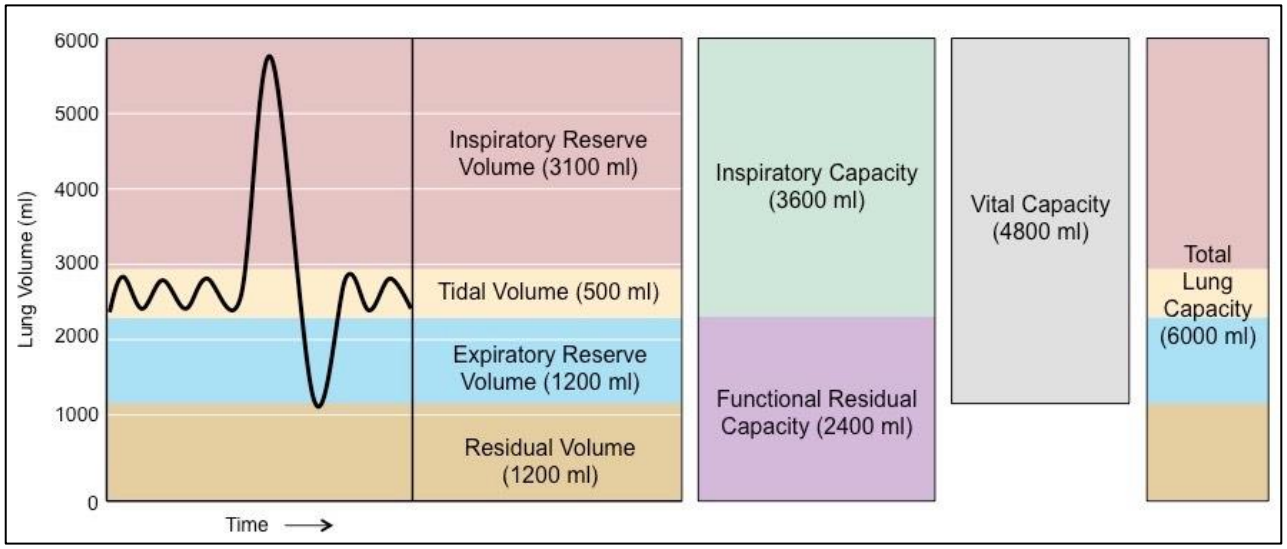
Lung volume and Lung capacity

- Lung volumes also known as lung respiratory volumes.
- Measurement of lung volume is an essential part to observe pulmonary (lung) function.
- Lung volumes (volume of inspired and expired air under various conditions) are measured by a special instrument called spirometer.
- Lung volumes vary due to certain factors: race, gender, age, body composition and respiratory diseases etc.
- Total lung volume of air is about 6000 ml (6 liter).
- The total lung capacity (TLC) of lung is about 6000 ml (6 liter) and is actually the sum of all the volumes given below:
  - **(1) Tidal volume (TV):** In normal breathing, human takes in (inspire) and gives out (expire) air approximately 450 to 500 ml or ½ liter. This volume is called Tidal volume.
  - **(2) Inspiratory reserve volume (IRV):** The maximal amount of air that can be inhaled over and above the resting tidal volume is termed as inspiratory reserve volume. It is about 2000 to 3100 ml. Tidal volume plus inspiratory reserve volume is called inspiratory capacity.
  - **(3) Expiratory reserve volume (ERV):** The maximal amount of air that can be forcibly exhaled over and above the resting tidal volume is called expiratory reserve volume. It is about 1200 to 1500 ml.

(4) Vital volume: The maximum amount of air inspired or expired during deep breath is called vital volume. It is approximately 4800 -5000 ml (5 liter). by summing of expiratory reserve volume (ERV) and the inspiratory capacity (IC), we obtain the vital capacity (VC).

(5) Residual volume (RV): we are not able to expel all the air out of lungs, even with maximal exhalation. It is called residual volume which about 1000 to 1200 ml of air. It occurs because the lungs are held stretched against the chest walls by pleural sac. Residual volume prevents the lungs from collapsing. It is not stagnant since Inspired air always mixes with residual volume of air. Aging, emphysema, etc. can increase the residual volume at the expense of vital capacity.

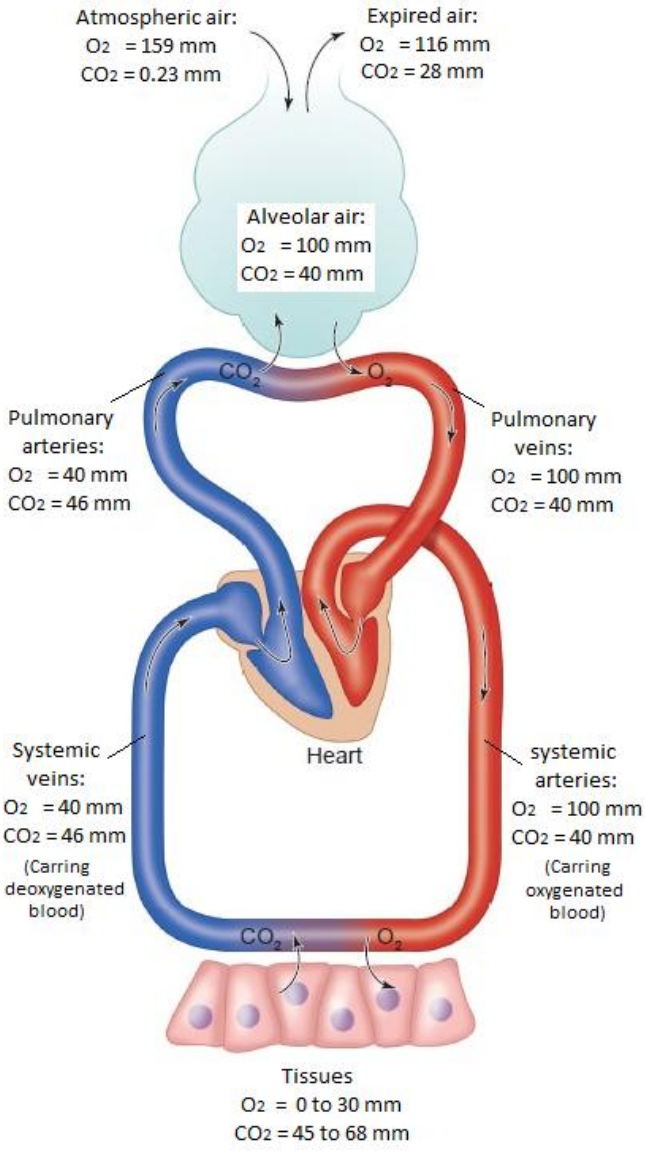
(6) Functional residual capacity: The expiratory reserve volume plus = residual volume called functional reserve capacity.



Gaseous exchange in lungs and body tissues: Diffusion and partial pressure

- Air (atmosphere) is a mixture of gases: about 71% nitrogen, 20.9% oxygen, in addition to fractional percentages of other gases, such as carbon dioxide (0.03%).
- Gravity attracts the atmospheric gases to the earth. At sea level the atmosphere exerts a pressure due to gravity equal to 760 mm Hg (atmospheric pressure; 1 atm).
- Because air is a mixture of gases, part of the 760 mm Hg pressure (partial pressure) is due to each component gas. For example, the partial pressure of oxygen is 0.209 × 760 = 159 mm, and that for carbon dioxide is 0.0003 × 760 = 0.23 mm in dry air. (in fact, atmospheric air is never completely dry, the varying amount of water vapors present exert a pressure in proportion to its concentration, like other gases.)
- As soon as air enters the respiratory tract, its composition changes. Inspired air becomes saturated with water vapors as it travels through the air-filled passageways toward alveoli.
- When inspired air reaches the alveoli, it mixes with residual air remaining from the previous respiratory cycle (residual volume of lungs.) so, partial pressure of oxygen drops and that of carbon dioxide rises.

- Upon expiration, air from the alveoli mixes with air in the dead space to produce still a different mixture. Although no significant gas exchange occurs in dead space, the air it contains is the first air to leave the body when expiration begins.
- Because the partial pressure of oxygen in lung alveoli is greater (100 mm Hg) than it is in the blood entering in lung capillaries (40 mm Hg), so oxygen diffuses into lung capillaries. In similar manner carbon dioxide in blood of lung capillaries has higher concentration (46 mm Hg) than is present in lung alveoli (40 mm Hg), so carbon dioxide diffuses from blood capillaries into the alveoli.
- In tissues respiratory gases also move along their concentration gradients.
- Body cells continuously use oxygen and produce carbon dioxide, so the partial pressure of oxygen in arterial blood (100 mm Hg) entering the tissue bed is greater than in the tissues (0 to 30 mm Hg), and partial pressure of carbon dioxide in tissues (45 to 68 mm Hg) is greater than that in blood (40 mm Hg). So, in each case gases diffuse from a location of higher concentration to one of lower concentration.



Respiratory gas	Atmospheric air	Lung alveoli	Pulmonary artery (deoxygenated blood)	Pulmonary vein (oxygenated blood)	Tissue
Partial pressure of Oxygen	159 mm Hg	100 mm Hg	40 mm Hg	100 mm Hg	0 - 30 mm Hg
Partial pressure of Carbon dioxide	0.23 mm Hg	40 mm Hg	46 mm Hg	40 mm Hg	45-68 mm Hg

Transportation of gases in human

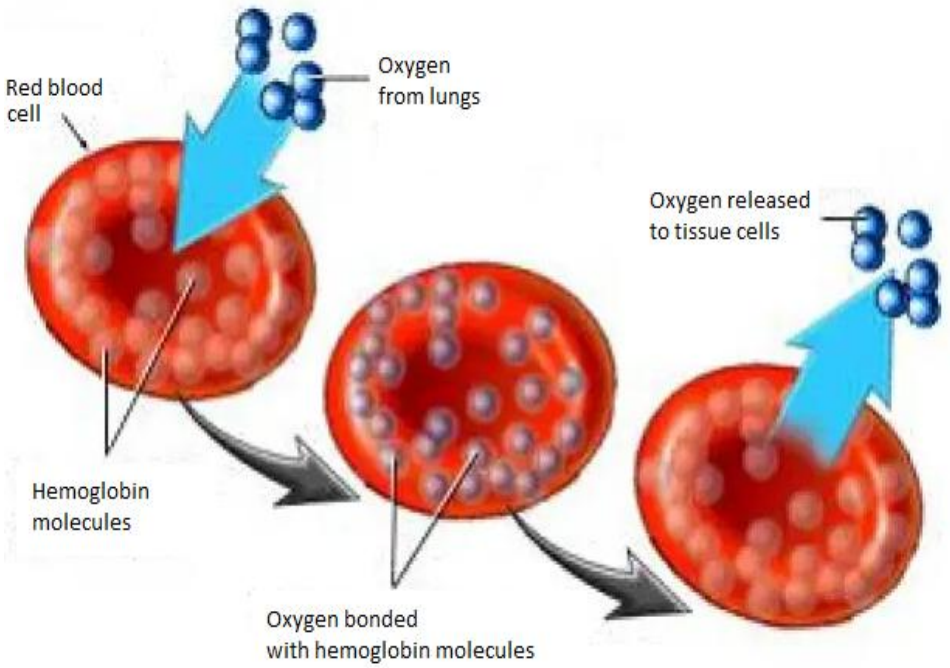
- Like other materials, respiratory gases are also transported in various region the body by means of blood. The blood transports oxygen from the lungs to different tissues and carbon dioxide from tissue to lungs.

(1) Transport of oxygen (O2)

- The inhaled air in lungs has high concentration of oxygen which produces concentration difference across respiratory surfaces. So, the oxygen rushes into blood capillaries around the alveoli. Now the blood is oxygenated and converted into bright red color. This oxygenated blood is then transported to the body cells.
- Approximately 97% of oxygen is transported by the red blood cell's hemoglobin as oxyhemoglobin, while 3% is transported as dissolved oxygen in blood plasma.
- At its high partial pressure (about 100 mm Hg in alveoli) oxygen binds with hemoglobin of deoxygenated blood (about 40 mm Hg partial pressure in capillaries of alveoli). This binding is reversibly that occurs in alveoli in the presence of carbonic anhydrase enzyme.
- Hemoglobin is red, iron containing protein present in all vertebrates and many invertebrates.
- In human, hemoglobin is contained in red blood cells.
- Each molecules of hemoglobin is 5% heme, (an iron containing compound giving the red color to blood) and 95% globin (color less protein).
- Each hemoglobin molecule binds with four molecules of oxygen to form oxyhemoglobin.

$$Hb + 4O_2 \longrightarrow Hb_4O_2$$

- Due to hemoglobin, blood could carry70 times more oxygen than plasma.
- The ability of hemoglobin to bind with oxygen is called oxygen carrying capacity.
- The heme portion of hemoglobin has great affinity for oxygen; one gram of hemoglobin can carry a maximum of approximately 1.3 ml of oxygen. 100 ml of blood contains approximately 15 grams of hemoglobin. Therefore fully oxygenated blood contain about 20ml of oxygen per 100 ml (1.3ml × 15g = 20ml/100ml).
- Hemoglobin can be almost completely oxygenated by an oxygen partial pressure of 100 mm Hg, which is present in lungs. When oxygen partial pressure falls below 60 mm Hg, as in many cells and tissues, the oxygen hemoglobin saturation of hemoglobin decreases very sharply and results in the liberation of large quantities of oxygen from hemoglobin. In this way in the tissue where oxygen tension is low oxyhemoglobin dissociates rapidly.
- There are three important factors which affect the capacity of hemoglobin to combine oxygen.
  - **(i) Carbon dioxide,** Increased CO2 tension favors the greater liberation of oxygen from blood to tissue.
  - **(ii) Temperature,** Rise in temperature causes a decrease in oxygen carrying capacity of blood and facilitates the release of oxygen from hemoglobin.
  - **(iii) pH,** Increased blood pH increases the ability of hemoglobin to bind with oxygen. Conversely decreased pH of blood (acidity of blood) facilitates the release of oxygen from hemoglobin.



(2) Transport of carbon dioxide (CO_2)

- Due to its higher concentration in tissues carbon dioxide is diffuses out from tissues into the blood as a by-product. Now blood is deoxygenated and collected from all part of the body cells and return to the lungs. The color of the deoxygenated blood is dark maroon.
- Carbon dioxide is transported in the blood in three ways:
  - (i) As bicarbonate ions
  - (ii) As carbaminohemoglobin
  - (iii) As dissolved gas

(i) As bicarbonate ions

- About 70 % of carbon dioxide is transported by the water of RBCs in the presence of carbonic anhydrase.
- carbon dioxide diffuses into the blood, enters the red blood cells and combine with water to form carbonic acid (H_2CO_3) in the presence of carbonic anhydrase.

$$CO_2 + H_2O \xrightleftharpoons{\text{Carbonic anhydrase}} H_2CO_3$$

- carbonic acid (H_2CO_3) is an unstable compound which later dissociates into Hydrogen ion (H^+) and bicarbonate ion (HCO_3^-).

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

- bicarbonate ion (HCO_3^-) combine with sodium (Na^+) and Potassium (K^+) ions to form sodium bicarbonate ($NaHCO_3$) and potassium bicarbonate ($KHCO_3$) respectively.

$$Na^+ + HCO_3^- \xrightleftharpoons{\text{Carbonic anhydrase}} NaHCO_3$$

$$K^+ + HCO_3^- \xrightleftharpoons{\text{Carbonic anhydrase}} KHCO_3$$

- accumulations of H^+ ions increase acidity in the blood i.e. It leads to decrease in pH. This does not occur since hemoglobin act as buffer for the excess H^+ ions formed. The hydrogen ion (H^+) readily associates with oxyhemoglobin (Hb_4O_2) to form hemoglobinic acid (HHb) and oxygen is released to the tissues.

$$Hb_4O_2 + H^+ \longrightarrow HHb + O_2$$

- In turn, many of the negatively charged bicarbonate ions (HCO_3^-) diffuse from red cells into the plasma and chloride ions (Cl^-) diffuse from plasma into the red cells to take their place (the chloride shift or Hamburger phenomenon). This occurs in the presence of special bicarbonate-chloride carrier protein in the cell membrane of red cells.
- The chloride ions that enter the red cells combine with potassium (K^+) to form potassium chloride, whereas bicarbonate ion (HCO_3^-) in the blood plasma combine with sodium (Na^+) to form sodium bicarbonates. Thus, the pH of blood maintained at about 7.4 by the buffering mechanism that exists in blood.

(ii) <u>As carbaminohemoglobin</u>

- About 23% of carbon dioxide is transported as carbaminohemoglobin.
- This reaction depends upon the partial pressure of CO_2.
- When the partial pressure of CO_2 is higher in tissues than blood, Carbon dioxide combine reversibly with amino group of several amino acids of hemoglobin to form a compound called carbaminohemoglobin.
- When the partial pressure of CO_2 is higher in blood than tissues as in case of lungs, carbaminohemoglobin releases its CO_2.

OR

- All of these reactions are reversible. When blood reaches to lungs, CO_2 is transported back into red blood cells (the chloride shift transporter reverses direction), it reacts with H^+ that are released from hemoglobin as oxygen is bound preferentially, and it is converted back into CO_2. CO_2 diffuses from red blood cells into plasma, along with carbon dioxide released from hemoglobin as it combines with oxygen. This carbon dioxide ultimately from plasma into alveolar air.

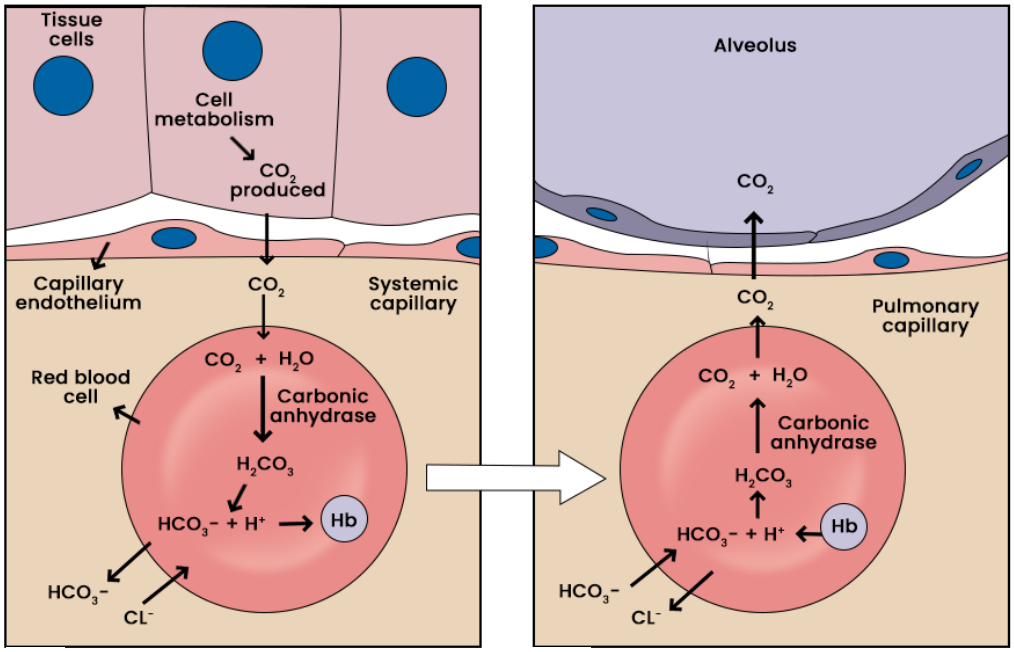


Figure: Transport of carbon dioxide in the blood

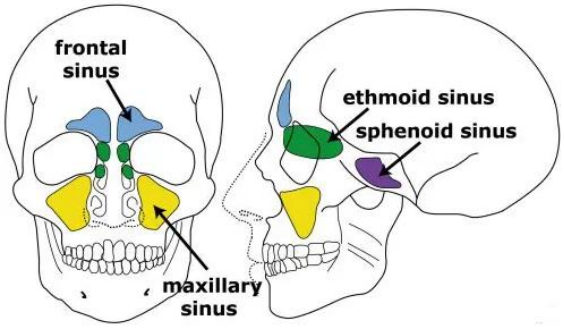
A, CO2 produced by cellular respiration diffuses from the tissues into plasma and red blood cells. Carbonic anhydrase in red blood cells catalyzes conversion of CO2 into carbonic acid, then bicarbonates and hydrogen ions. The bicarbonate ion diffuses out of the cells, and diffusion inward of chloride ions maintain electrical balance. Hydrogen ions associate with hemoglobin **B,** The lower partial pressure of CO2 in the alveoli of the lungs favors reversal of these reactions

(iii) As dissolved gas

- About 7% of carbon dioxide is carried in this way.
- This is rather inefficient way to carry carbon dioxide, but it does occur.

Sinuses

- Sinuses are hollow air-filled cavities.
- These are found in skull and linked to the nasal air passage.
- Human has four pairs of nasal cavities.
  - **(1) Frontal sinus,** in the forehead region.
  - **(2) Maxillary sinus,** in behind the cheeks.
  - **(3) Ethmoid sinus,** between the eyes.
  - **(4) Sphenoid sinus,** located in deep behind the ethmoid.



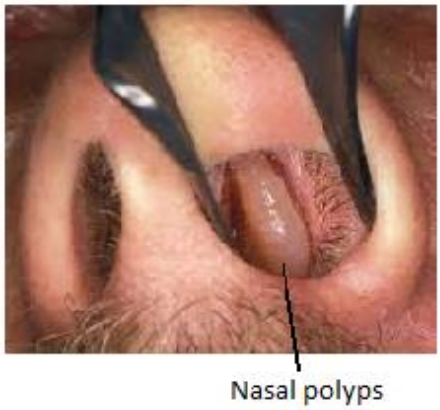
Respiratory disorders

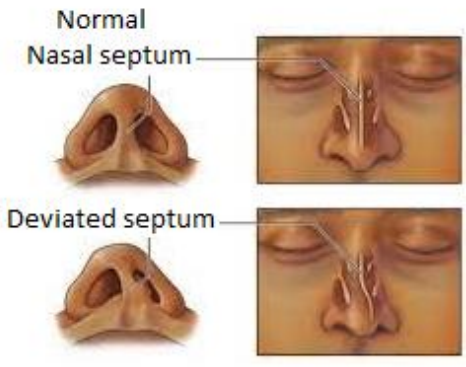
- The respiratory disorders are broadly categorized into two groups on the basis of location of respiratory tract i.e.
  (1) Upper respiratory tract infections (2) Lower respiratory tract infections

(1) Upper respiratory tract infections

(i) Sinusitis

- It is inflammation of sinuses.
- Normally sinuses are filled with air, but in sinusitis these are filled with fluid due to which it may harbor pathogens.
- sinusitis may be acute (symptoms lasts 2-8 weeks) or chronic (symptoms last much longer).
- Following reasons that can cause sinusitis are:
  - ☞ Common cold
  - ☞ Atmospheric pollution
  - ☞ Smoke
  - ☞ dust
  - ☞ Allergic rhinitis (swelling in the lining of the nose)
  - ☞ Nasal polyps (nose lining show small growths)
  - ☞ Physical deviation of nasal septum of nose (dislocation of the nasal septum)
  - ☞ Dental infections
  - ☞ Viral infections





- **Symptoms of sinusitis** include: headache, fever, congestion (nasal stuffiness), raspy voice, pus-like nasal discharge, loss of sense of smell, ear pain, eye pain, facial pain and fatigue.
- **Treatment of sinusitis** include antibiotics or sulpha drugs in case of bacterial infection. Steam and saline nasal spray to wash nasal passage and consult your physician.

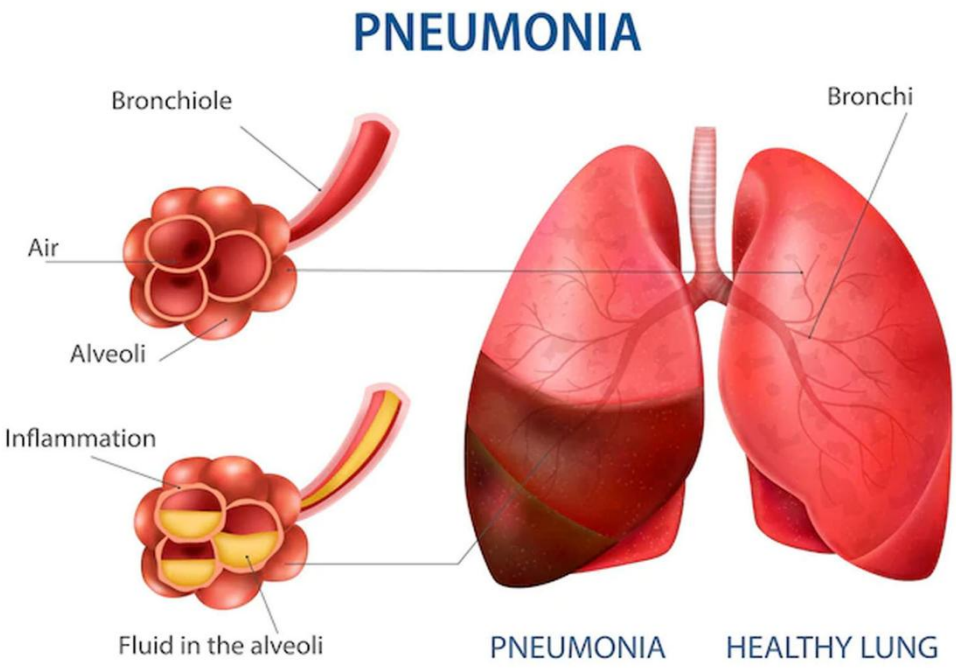
(ii) Otitis media

- It is inflammation or infection of middle ear.
- It is caused by cold, sore throat or upper respiratory infection.
- This infection usually a result of a malfunction of the eustachian tube.
- Eustachian tube is a canal that links the middle ear with the throat area.
- The eustachian tube helps to equalize the pressure between the outer ear and the middle ear.
- When eustachian tube is not working properly, it prevents normal drainage of fluid from the middle ear, causing a build up of fluid behind the eardrum. When this fluid cannot drain, it allows for the growth of bacteria and viruses in the ear that can lead to acute otitis media.
- Very common signs of media otitis are fever, unbalancing, hearing problems, unusual irritability and ear pain.
- Treatment of otitis media depend its type. Commonly antibiotic medicines by ear drops can be suggested by consultant (physician).

(2) Upper respiratory tract infections

(i) Pneumonia

- It is a lower respiratory tract infection caused by viruses, bacteria and fungi.
- In this infection air sacs filled with secretions and other fluids.
- **Lobar pneumonia** occurs in the lobes of lungs
- **Bronchial pneumonia (bronchopneumonia)** is a form of pneumonia that affects both the alveoli in the lungs and the bronchi.
- Symptoms of bacterial pneumonia (pneumonia caused by bacteria) are headache, lips and fingernails become bluish in color, fever with cough and yellowish green or bloody mucus may produce with cough, confused mental state, heavy sweating, loss of appetite, rapid breathing and shortness of breath.
- Viral and bacterial pneumonia have same symptoms in early stage i.e. shortness of breath, headache, muscle pain and weakness.
- Symptoms of **Mycoplasma pneumonia** (type of pneumonia caused by bacterium called mycoplasma pneumoniae) are acute cough with mucus.
- In most of bacterial pneumonia (pneumonia caused by bacteria), oral antibiotics are used but in viral pneumonia (pneumonia caused by viruses) antibiotic medications do not work.
- **Pneumonia** patients should hot drinks. Humidification and steamy bath also very helpful to open airways blockage.



(ii) <u>Pulmonary tuberculosis (TB)</u>

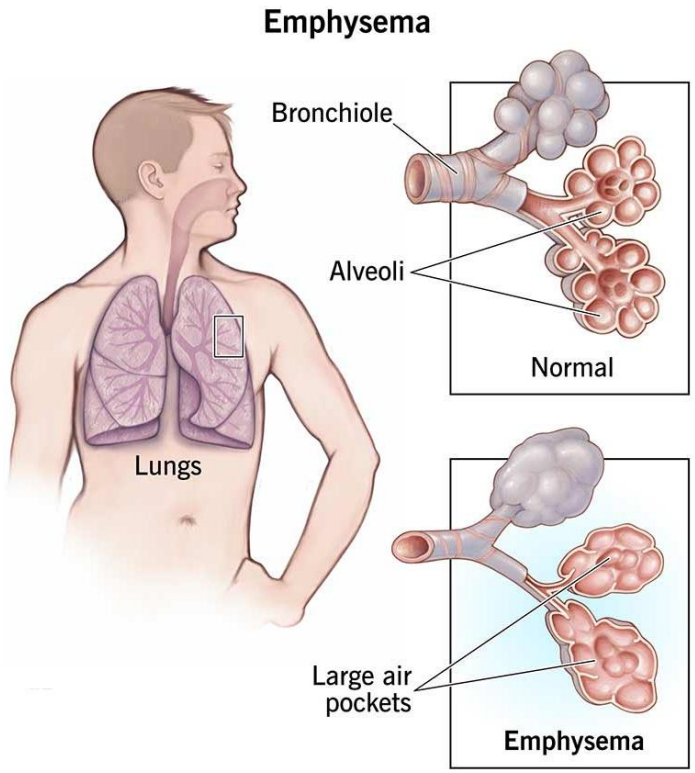
- It is a bacterial chronic infection of the lungs caused by bacterium called mycobacterium tuberculosis.
- Mycobacterium tuberculosis (causative agent of pulmonary tuberculosis), also known as Koch's bacillus because it was first discovered Robert Koch in 1882.
- In this infection, the alveoli burst and are replaced by inelastic connective tissue. The cells of lung tissue build a protective capsule around the bacilli (mycobacterium tuberculosis) and isolate them from rest of the body. This tiny capsule called **tubercle.** The tubercle can rapture, releasing bacteria that infect other parts of the lung.
- Its main symptoms are coughing up mucus (sometimes with blood in phlegm or sputum), pain in chest, shortness of breath, fever, sweating at night, weight loss and poor appetite.
- It can cause complication leading to death.
- This infection passed from person to person (contagious) in air-borne droplets produced by coughing or sneezing.
- Taking medicines for 9 months regularly can cure TB. This is called daily observed treatment short course (DOTS). This treatment is given to patients under supervision to ensure that the "medicine intake" completely cure the patient.

(iii) <u>Emphysema</u>

- It is a degenerative disease in which alveoli gradually deteriorate (broken down).
- It is more common in smokers.
- It happens when some toxic substance such as nitrogen oxides, Sulphur dioxides, etc. are constantly inhaled. Due to such toxic substances, the elasticity of lung decreases. As a consequence, alveoli are raptured and lungs become harder. So, the tissue of the body

including brain are supplied less and less oxygen. Thus, the victim's breathing become labored day by day. It also makes him depressed, irritable and sluggish.

- Emphysema also produces increased airway resistance because the bronchioles are obstructed as a result of inflammation and because damaged bronchioles collapse during expiration, trapping air within the alveolar sacs.



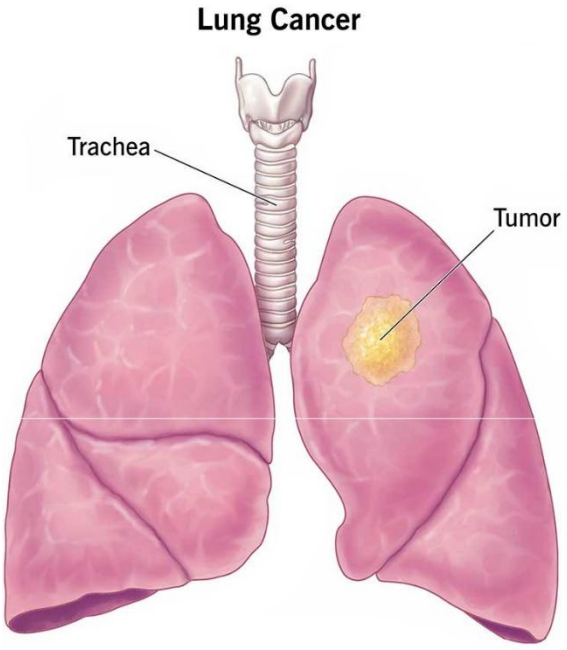
(iv) Asthma

- It is another respiratory tract disorder in which there are recurrent attacks of breathlessness. Characteristically accompanied by wheezing when breathing out.
- It may be caused by allergic reaction to external factors like pollens, dust, animal fur, common cold, cough, smoke, humidity, pollution etc which manifest itself by spasmodic contraction of small bronchiole tube.
- Asthma results in the release of inflammatory chemicals such histamines into circulatory system that cause severe contraction of the bronchiole.
- In many cases, there is no apparent cause of asthma. Heredity is a major factor in development of asthma.
- Severe attack of asthmatic attack can be fatal.

(v) Lung cancer

- Cancer or carcinoma is a malignant tumor which may develop due to uncontrolled cell division that expands locally by invasion and systemically by metastasis.
- It is usually a consequence of smoking either actively or passively.

- As the smoke passes through the respiratory passage, its toxic contents like nicotine, SO2, etc, cause gradual loss of cilia of epithelial cells of respiratory passage so the dust and germs are settled inside the lung. Later, cells with abnormal nuclei appear in the epithelial lining, which start divide rapidly without following normal cell cycle. Finally, these cells with abnormal nuclei break the thickened epithelial lining and penetrate into the other tissues (metastasis) causing cancer.
- Symptoms of lung cancer are coughing with blood, chest infections that keep coming back pain when breathing or coughing, persistent breathlessness and continuous tiredness.
- The chance of lung cancer is are ten times more in those persons who smoke or live in smoky and congested areas as compared to those who do not smoke.
- It is now estimated that 90% of lung cancer is caused by smoking.
- Recent research indicates that the more than ten compounds in tar of tobacco smoke are involved in causing in cancer.
- Treatment In lung cancer are chemotherapy, radiation therapy, targeted therapy and surgery (pneumonectomy) according to consultant.



Smoking is dangerous for respiratory system

- The effect of tobacco smoking on respiratory system is the larynx and tracheal passage irritation.
- Tobacco smoke may cause swelling in air passage that produce mucus which can block air ways. This cause lung infection and may damage the alveoli.

Controlling mechanism of breathing

- We can hold our breath for short time and can breath faster and deeper at our will. This is termed as voluntary control. But mostly, rate of breathing is controlled automatically. This is termed as involuntary control.
- Vertebrate respiratory and circulatory systems work together to regulate gas delivery and plasma pH by:
  (1) regulating ventilation,
  (2) altering oxygen carrying capacity and affinity, and
  (3) altering perfusion (The delivery of blood to capillary bed in tissue).

- A breathing or respiratory center (pre-botzinger complex) located in the medulla of brain carries out involuntary control of breathing.
- Pre-botzinger complex is composed of neurons. These are important for the generation of breathing rhythm (rhythmogenesis). These neurons are found in a bilaterally pair of neuron clusters with in the ventrolateral medulla of brain stem.
- Pre-botzinger complex or respiratory center is divided into three major collections of neurons:
  (a) Dorsal respiratory group (DRG): It is located in dorsal portion of medulla and chiefly concerned with inspiration. The DRG function in every respiratory cycle, whether quiet or forced. The DRG's inspiratory center contains neurons that control lower motor neurons innervating the external intercostal muscles and the diaphragm.
  (b) Ventral respiratory group (VRG): It is located in ventrolateral portion of medulla and chiefly associated with expiration. The VRG functions only during forced breathing. It has an expiratory center consisting of neurons that innervate lower motor neuron controlling accessory respiratory muscles involved in active exhalation, its inspiratory center contains neurons involved in maximal inhalation, such as gasping.
  (c) Pneumotaxic center: It is located dorsally in the superior portion of the pons and mainly controls rate and depth of breathing.
- The voluntary control of respiration reflects the activity in the cerebral cortex. This activity affects the output of either the respiratory centers in the medulla oblongata (DRG and VRG) and pons (pneumotaxic and apneustic centers) or the motor neurons in the spinal cord that control respiratory muscle.
- Limbic system also affects the respiratory center.
- it has been found that increased concentration of CO_2 and H^+ in blood are basic stimuli to increase the rate of breathing. Their concentrations are monitored by peripheral chemoreceptors known as aortic bodies (located in aorta) and carotid bodies (located in carotid arteries). Any change in the concentration of CO_2 and H^+ detected by medulla (a part of brain). Moreover, medulla oblongata is itself sensory to changes in the concentration of CO_2 and H^+ present in the cerebro-spinal fluid (because medulla oblongata contains chemoreceptors). In response to increased concentration of CO_2 and hydrogen ions, it sends impulses to intercostal muscles and diaphragm to increase breathing rate.