BREATHING AND EXCHANGE OF GASES

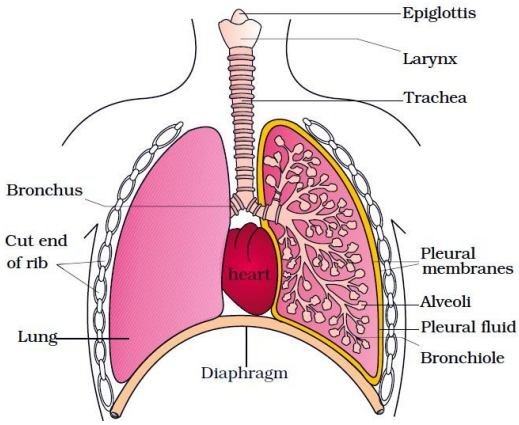
Respiration is the oxidation of nutrients in the living cells to release energy for biological work.
Breathing is the exchange of O_2 from the atmosphere with CO_2 produced by the cells.

RESPIRATORY ORGANS

- **General body surface:** E.g. lower invertebrates (sponges, coelenterates, flatworms etc).
- **Skin or moist cuticle (cutaneous respiration):** E.g. earthworms, leech, amphibians etc.
- **Tracheal tubes:** E.g. insects, centipede, millipede, spider.
- **Gills (Branchial respiration):** E.g. fishes, tadpoles, prawn.
- **Lungs (Pulmonary respiration):** E.g. most vertebrates.

HUMAN RESPIRATORY SYSTEM

It consists of a pair of ***air passages (air tract)*** and ***lungs***.



1. Air passages

- ***Conducting part*** which transports the atmospheric air into the alveoli, clears it from foreign particles, humidifies and brings the air to body temperature.

  External nostrils → nasal passage → nasal chamber (cavity) → pharynx → glottis → larynx → trachea → primary bronchi → secondary bronchi → tertiary bronchi → bronchioles → terminal bronchioles → respiratory bronchiole → alveolar duct.

- Each terminal bronchiole gives rise to many very thin and vascularised ***alveoli*** (in lungs).
- A cartilaginous ***Larynx*** (sound box or voice box) helps in sound production.
- During swallowing, ***epiglottis*** (a thin elastic cartilaginous flap) closes ***glottis*** to prevent entry of food into larynx.
- Trachea, all bronchi and initial bronchioles are supported by incomplete cartilaginous half rings.

2. Lungs

- Lungs situate in ***thoracic chamber*** and rest on ***diaphragm***.
- Right lung has 3 lobes and left lung has 2 lobes.
- Lungs are covered by double-layered ***pleura*** (outer **parietal pleura** and inner **visceral pleura).**
- The ***pleural fluid*** present in between these 2 layers lubricates the surface of the lungs and prevents friction between the membranes.
- ***Lungs= Bronchi + bronchioles + alveoli.***
- Alveoli and their ducts form the ***respiratory*** or ***exchange part*** of the respiratory system.
- ***Alveoli are the structural and functional units of lungs.***

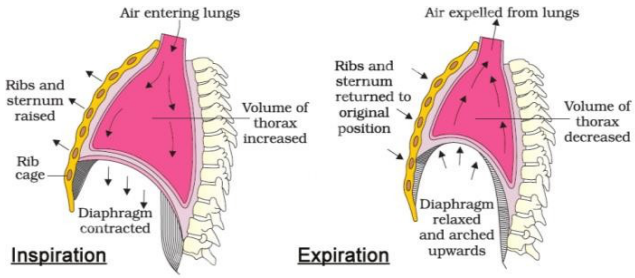
Steps of respiration

1. **Pulmonary ventilation (breathing).**
2. **Gas exchange between lung alveoli & blood.**
3. **Gas transport (O_2 transport & CO_2 transport).**
4. **Gas exchange between blood & tissues.**
5. **Cellular or tissue respiration.**

MECHANISM OF BREATHING (INSPIRATION & EXPIRATION)

a. Inspiration

- **Active** intake of air from atmosphere into lungs.
- During this, the **diaphragm contracts** (flattens) causing an increase in vertical thoracic volume *(antero-posterior axis).*
- Contraction of **external intercostal muscles** (muscles found between ribs) lifts up the ribs and sternum causing an increase in thoracic volume in the ***dorso-ventral axis***.
- Increase in thoracic volume reduces thoracic pressure. So, lungs expand. Thus, pulmonary volume increases resulting in decrease of ***intra-pulmonary pressure*** to less than the atmospheric pressure. So, air moves into lungs.



b. Expiration

- **Passive** expelling of air from the lungs.
- During this, ***intercostal muscles & diaphragm*** relax causing a decrease in thoracic volume and thereby pulmonary volume. So, air moves out.
- During **forceful expiration, abdominal muscles** and **internal inter-costal muscles contract.**

Respiratory volumes and capacities

- **Tidal volume (TV):** Volume of air inspired or expired during a normal respiration. It is about **500 ml.** i.e., **6000-8000 ml** per minute.
- **Inspiratory reserve volume (IRV) or complemental air:** Additional volume of air that can inspire by forceful inspiration. It is **2500-3000 ml.**
- **Expiratory reserve volume (ERV) or supplemental air:** Additional volume of air that can expire by a forceful expiration. It is **1000-1100 ml.**
- **Residual volume (RV):** Volume of air remaining in lungs after a forcible expiration. It is **1100-1200 ml.**

- **Inspiratory capacity (IC):** Total volume of air inspired after a normal expiration (TV + IRV). It is **3000-3500 ml.**
- **Expiratory capacity (EC):** Total volume of air expired after a normal inspiration (TV + ERV). It is **1500-1600 ml.**
- **Functional residual capacity (FRC):** Volume of air remaining in the lungs after a normal expiration (ERV + RV). It is **2100-2300 ml.**
- **Vital capacity (VC):** Volume of air that can breathe in after a forced expiration or Volume of air that can breathe out after a forced inspiration (ERV + TV + IRV). It is **3500-4500 ml.**
- **Total lung capacity (TLC):** Total volume of air in the lungs after a maximum inspiration. (RV + ERV + TV + IRV or VC + RV). It is **5000-6000 ml.**
- Part of respiratory tract (from nostrils to terminal bronchi) not involved in gaseous exchange is called ***dead space***. **Dead air volume** is about **150 ml.**

- ***Respiratory cycle=*** *an inspiration + an expiration*
- ***Normal respiratory (breathing) rate****: 12-16 times/min*
- ***Spirometer (respirometer):*** *To measure respiratory rate.*

GAS EXCHANGE

Gas exchange occurs between

1. Alveoli and blood **2. Blood and tissues**

Alveoli are the primary sites of gas exchange.

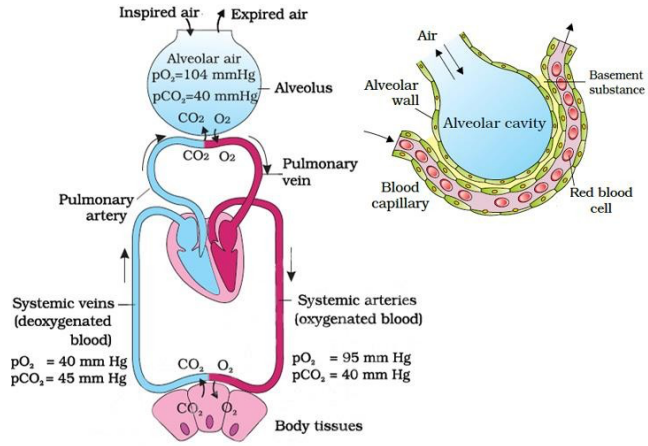
O_2 & CO_2 are exchanged by simple diffusion. It depends upon the following factors:

- **Pressure/ concentration gradient:** The ***Partial pressures*** (individual pressure of a gas in a gas mixture) of O_2 and CO_2 (pO_2 and pCO_2) are given below.

Respiratory gas	pO_2 (in mm Hg)	pCO_2 (in mm Hg)
Atmospheric air	159	0.3
Alveoli	104	40
Deoxygenated blood	40	45
Oxygenated blood	95	40
Tissues	40	45

pO_2 in **alveoli** is more **(104 mm Hg)** than that in **blood capillaries (40 mm Hg).** So O_2 diffuses into capillary blood. **pCO_2** in **deoxygenated blood** is more **(45 mm Hg)** than that in alveoli **(40 mm Hg).** So, CO_2 diffuses to alveoli.

- **Solubility of gases:** Solubility of CO_2 is 20-25 times higher than that of O_2. So, the amount of CO_2 that can diffuse through the diffusion membrane per unit difference in partial pressure is higher than that of O_2.
- **Thickness of membranes:** The diffusion membrane is made up of 3 layers:
  a) **Squamous epithelium** of alveoli.
  b) **Endothelium** of alveolar capillaries.
  c) **Basement substance** between them.
  Its total thickness is only 0.5 µm. It enables easy gas exchange.
- **Surface area:** Presence of alveoli increases the surface area of lungs. It increases the gas exchange.



GAS TRANSPORT (O_2 TRANSPORT & CO_2 TRANSPORT)

It is the transport of respiratory gases (O_2 & CO_2) from alveoli to the systemic tissues and vice versa.

1. O_2 TRANSPORT

It is the transport of O_2 from lungs to various tissues.

It occurs in 2 ways:

a. **In physical solution (blood plasma):** About **3%** of O_2 is carried in a dissolved state through plasma.

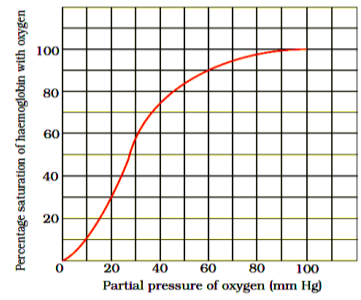
b. **As oxyhaemoglobin:** About **97%** of O_2 is transported by **haemoglobin** (red coloured iron containing pigment) on RBC. O_2 binds with haemoglobin (Hb) to form **oxyhaemoglobin.** This is called **oxygenation.** Hb has **4 haem units.** So, each Hb molecule can carry 4 oxygen molecules. Binding of O_2 depends upon pO_2, pCO_2, H^+ ion concentration (pH) and temperature.

$$Hb_4 + 4O_2 \underset{\text{Low } pO_2\text{/ High } pCO_2 \text{ (Tissues)}}{\overset{\text{High } pO_2\text{/ Low } pCO_2 \text{ (lungs)}}{\rightleftharpoons}} Hb_4O_8$$

- In the alveoli, high pO_2, low pCO_2, lesser H^+ ion concentration and lower temperature exist. These factors are favourable for the formation of oxyhaemoglobin.
- In tissues, low pO_2, high pCO_2, high H^+ ions and high temperature exist. So Hb_4O_8 dissociates to release O_2.
- Every 100 ml of oxygenated blood can deliver around 5 ml of O_2 to the tissues under normal physiological conditions.

Oxygen-haemoglobin dissociation curve

It is a sigmoid curve obtained when percentage saturation of Hb with O_2 is plotted against the pO_2. It is used to study the effect of factors like pCO_2, H^+ concentration etc., on binding of O_2 with Hb.



2. CO_2 TRANSPORT

It is the transport of CO_2 from tissues to lungs.

In tissues, pCO_2 is high due to catabolism and pO_2 is low. In lungs, pCO_2 is low and pO_2 is high. This favours CO_2 transport from tissues to lungs. It occurs in 3 ways:

a. **As carbonic acid:** In tissues, **7%** of CO_2 is dissolved in **plasma water** to form **carbonic acid** and carried to lungs.
b. **As carbamino-haemoglobin:** In tissues, **20-25%** of CO_2 binds to Hb to form **carbamino-haemoglobin**. In alveoli, CO_2 dissociates from carbamino-haemoglobin.
c. **As bicarbonates: 70%** of CO_2 transported by this method. RBCs contain an enzyme, *carbonic anhydrase*. (It is slightly present in plasma too).

At tissue site, it facilitates the following reactions:

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

In alveoli, the above reaction proceeds in opposite direction leading to the formation of CO_2 and H_2O.

Every **100 ml of deoxygenated blood** delivers about **4 ml of CO_2** to the alveoli.

REGULATION OF RESPIRATION

In brain, there are the following **Respiratory centres:**

- **Respiratory rhythm centre (Inspiratory & Expiratory centres):** In **medulla oblongata**. It regulates respiratory rhythms.
- **Pneumotaxic centre:** In **Pons**. It moderates functions of respiratory rhythm centre. Impulse from this centre reduces the duration of inspiration and thereby alter respiratory rate.
- **Chemosensitive area:** Seen adjacent to the rhythm centre. Increase in the concentration of CO_2 and H^+ activates this centre, which in turn signals rhythm centre. **Receptors** in **aortic arch** & **carotid artery** also recognize changes in CO_2 & H^+ concentration and send signals to rhythm centre. Role of oxygen in the regulation of respiratory rhythm is quite insignificant.

DISORDERS OF RESPIRATORY SYSTEM

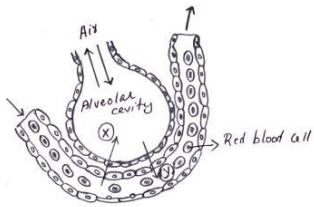
1. **Asthma:** Difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.
2. **Emphysema:** Damage of alveolar walls. It decreases respiratory surface. Major cause is cigarette smoking.
3. **Occupational respiratory disorders:** Certain industries produce so much dust. So, the defense mechanism of the body cannot cope with the situation. Long exposure causes inflammation leading to **fibrosis** (proliferation of fibrous tissues). It results in lung damage. Workers in such industries should wear protective masks.

MODEL QUESTIONS

1. Draw a flowchart showing the different parts of the air tract.
2. Match the following

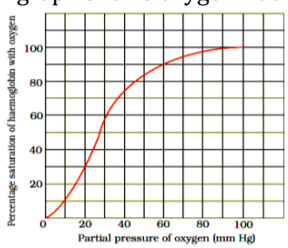
A	B	C
IC	TV + ERV	3500-4500 ml
EC	ERV + TV + IRV	2100-2300 ml
FRC	TV + IRV	3000-3500 ml
VC	ERV + RV	1500-1600 ml

3. Note the relationship between first two words and fill up the fourth place.
   a. TV: 500 ml IRV:..... b. Atmospheric air: 159 mm Hg Alveoli: .....
4. The given diagram shows the exchange of gases between alveolus and alveolar capillary.



   a. Identify X and Y.
   b. Name the Physical Process involved in gas exchange.
   c. Mention the factors that favour this process.

5. The given graph shows oxygen-haemoglobin dissociation curve.



   a. What is the nature of curve?
   b. Find out the pressure at which Haemoglobin is 50% saturated with O_2?
   c. What are the factors which influence it?

6. Identify the two true statements from the statements given below and rewrite the two false statements correctly.
   a. Pneumonia is a chronic disorder due to cigarette smoking.
   b. Carbon dioxide combines with haemoglobin to form carbamino haemoglobin.
   c. Respiratory rhythm is maintained by the respiratory centre in the heart.
   d. Alveoli are the primary sites of exchange of gases.