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 like 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) → nasopharynx (a part of pharynx) → glottis → larynx → trachea → primary bronchi → secondary bronchi → tertiary bronchi → bronchioles → terminal bronchioles → respiratory bronchiole → alveolar duct.
- Each terminal bronchiole gives rise to a number of 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

- 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 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 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***.
- These changes reduce pressure inside the thorax causing the expansion of lungs. 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 the **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 the alveolus **(40 mm Hg).** So CO_2 diffuses to alveolus.

- **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) **Thin 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 RBC. O_2 binds with **haemoglobin** (red coloured iron containing pigment present in the RBCs) 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.

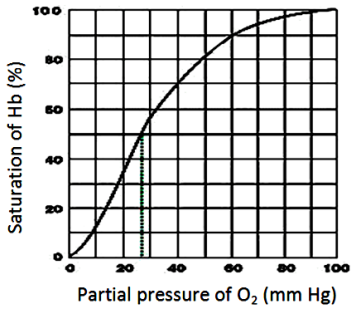
$$Hb_4 + 4O_2 \underset{\text{Low } pO_2\text{/ High } pCO_2 \text{ (Tissues)}}{\overset{\text{High } pO_2\text{/ Low } pCO_2 \text{ (lungs)}}{\rightleftharpoons}} Hb_4O_8$$

- 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 useful 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 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, about **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:** About **70%** of CO_2 is transported by this method. RBCs and plasma contain an enzyme, *carbonic anhydrase*. This enzyme facilitates the following reactions.

$$CO_2 + H_2O \underset{}{\overset{\textit{Carbonic anhydrase}}{\rightleftharpoons}} H_2CO_3$$

$$H_2CO_3 \underset{}{\overset{\textit{Carbonic anhydrase}}{\rightleftharpoons}} HCO_3^- + H^+$$

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

Respiratory centres present in the brain include

- **Respiratory rhythm centre (Inspiratory & Expiratory centres):** In **medulla oblongata**.
- **Pneumotaxic centre:** In **Pons**. It moderates the functions of the respiratory rhythm centre. Neural signal from this centre reduces the duration of inspiration and thereby alter the 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** and **carotid artery** also recognize changes in CO_2 and H^+ concentration and send signals to the 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.