Aakash + BYJU'S NOTES

# Breathing and Exchange of Gases

# Key Takeaway

1. **Breathing and cellular respiration**
   - Types of cellular respiration
2. **Mechanism of gaseous exchange in invertebrates**
3. **Human respiratory system**
   - Conducting and respiratory parts
   - Process of exchange of gases in body
   - Location of the lungs

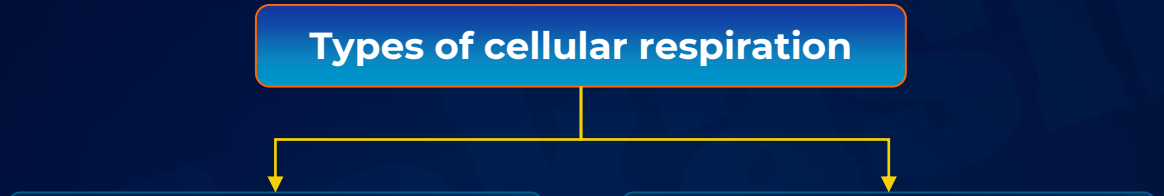
- **4 Mechanism of breathing**
  - Inspiration and expiration
  - Lung volumes and capacities
  - External respiration
  - Internal respiration
  - Transportation of gases in blood
- **5 Artificial respiration**
- **6 Respiratory disorders**

**Summary**

# Breathing and Cellular Respiration

| Breathing | Cellular respiration |
| --- | --- |
| Oxygen is inhaled and carbon dioxide is exhaled out of the lungs | Breakdown of food using oxygen to produce energy which is used by cells to carry out cellular function |
| No energy is produced during the process | Energy is released in the form of ATP |
| Takes place in respiratory organs | Takes place in cells |
| Physical process | Biochemical process |

# Types of Cellular Respiration




In the case of **aerobic respiration**, the oxygen inhaled during breathing is utilised for the breakdown of food, while the carbon dioxide that is generated is exhaled during breathing.

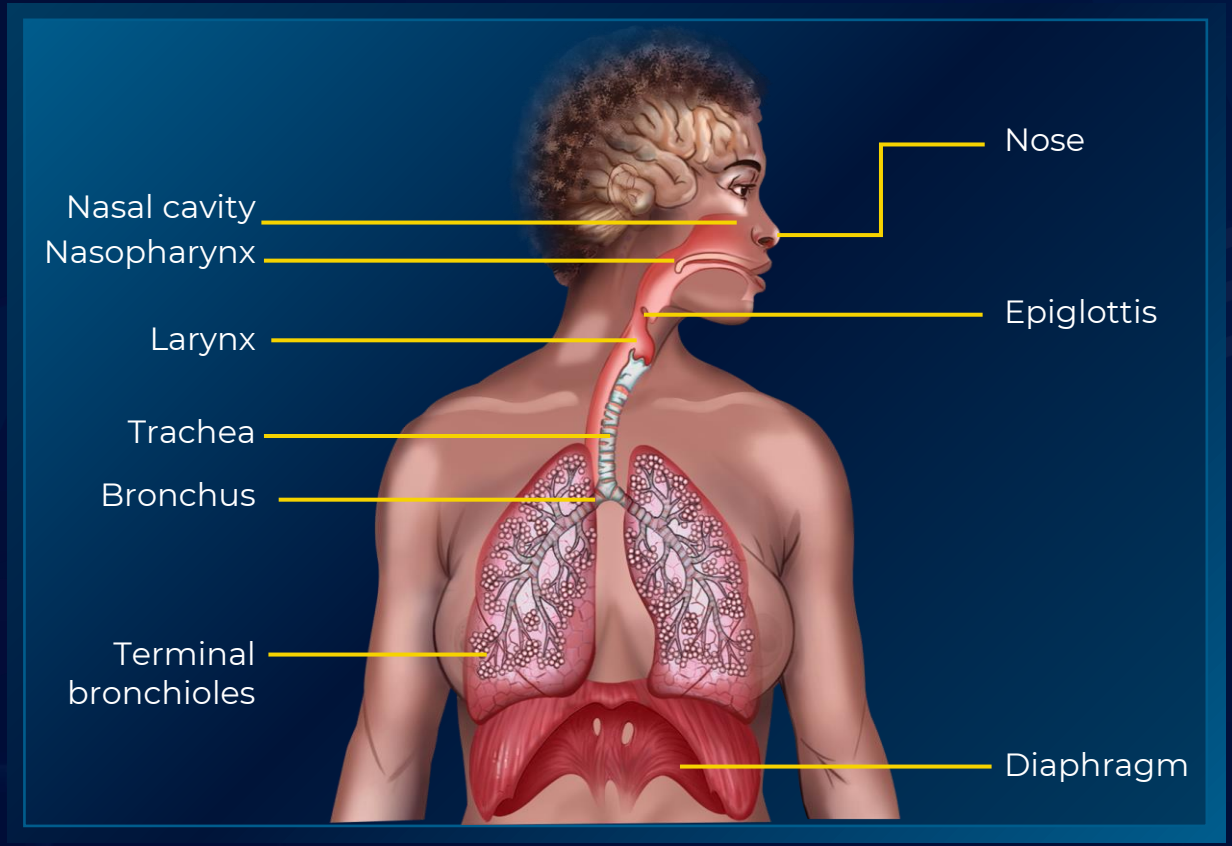
In the case of **anaerobic respiration**, the breakdown of food occurs in the absence of oxygen, and lactic acid or ethanol is produced.

# Mechanism of Gaseous Exchange in Various Organisms

- **Sponges**, **coelenterates**, **flatworms** etc. rely on the **movement of water through them** for gaseous exchange.
- **Earthworms** breathe through their **moist cuticle**.
- **Insects** use a network of **tracheal tubes** to transport air throughout the body.
- **Gills** are special vascularised structures used by **most aquatic arthropods, molluscs and fishes** for breathing.
- Most terrestrial organisms such as **reptiles, birds and mammals have lungs** for gaseous exchange.
- **Amphibians** can respire through their **moist skin** as well besides using **lungs.** E.g. – frog.

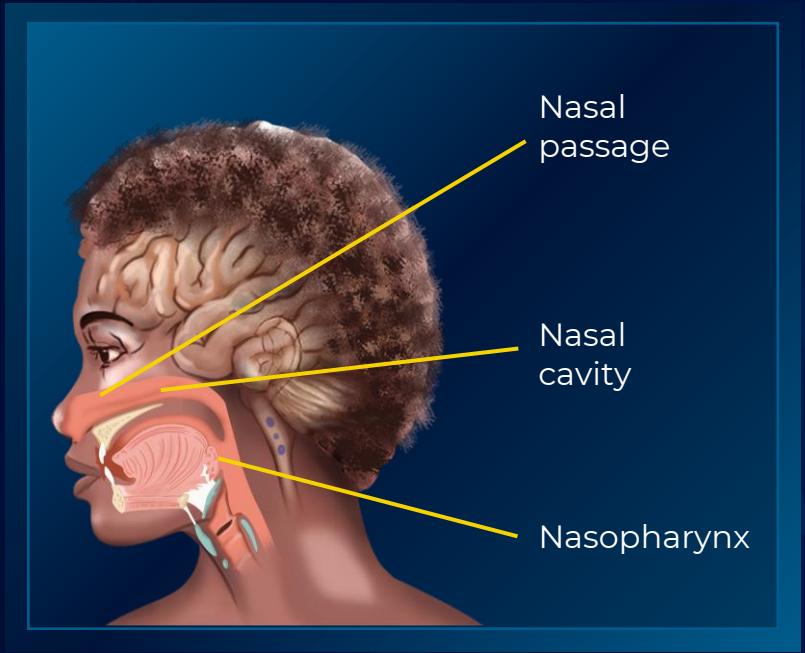
# Human Respiratory System

Pathway of oxygen



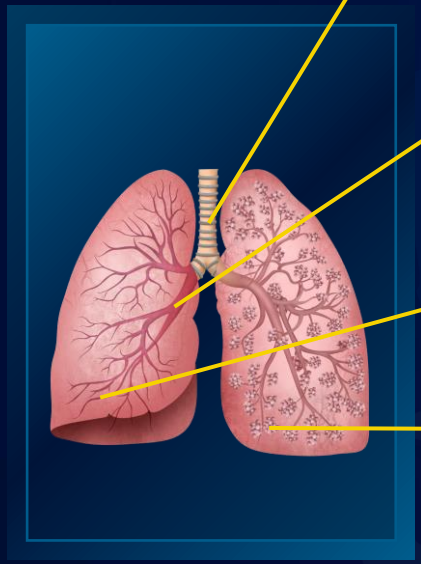

Pathway of carbon dioxide

# Human Respiratory System




- Air enters the respiratory system through the **nostrils**.
- It then travels through the **nasal passage**.
  - The nasal passage is separated into two chambers by the nasal septum.
  - It is lined with hair, which filters the dust particles present in the air.
- Presence of **rich vascular supply** allows the nose to change the temperature and the humidity of the inspired air.
- It helps to keep the **air** entering the **nose** from drying out the lungs and other parts of our respiratory system.
- The nasal cavity is at the farther end of the nasal passage.
- It leads to the **nasopharynx**.

# Human Respiratory System




- It is a straight tube extending up to the mid-thoracic cavity.
- It is surrounded by incomplete **cartilaginous rings** that provide support to the trachea and prevent it from collapsing.
- At its farther end, it divides into left and right bronchi, which are referred to as the **primary bronchi**.

- **Bronchi** divide into numerous branches, which again sub-divide further into **bronchioles**.
- These are the passages that carry the inhaled air from the trachea to the **bronchioles**.

- **Bronchioles** carry air to the millions of alveoli present in the lungs.

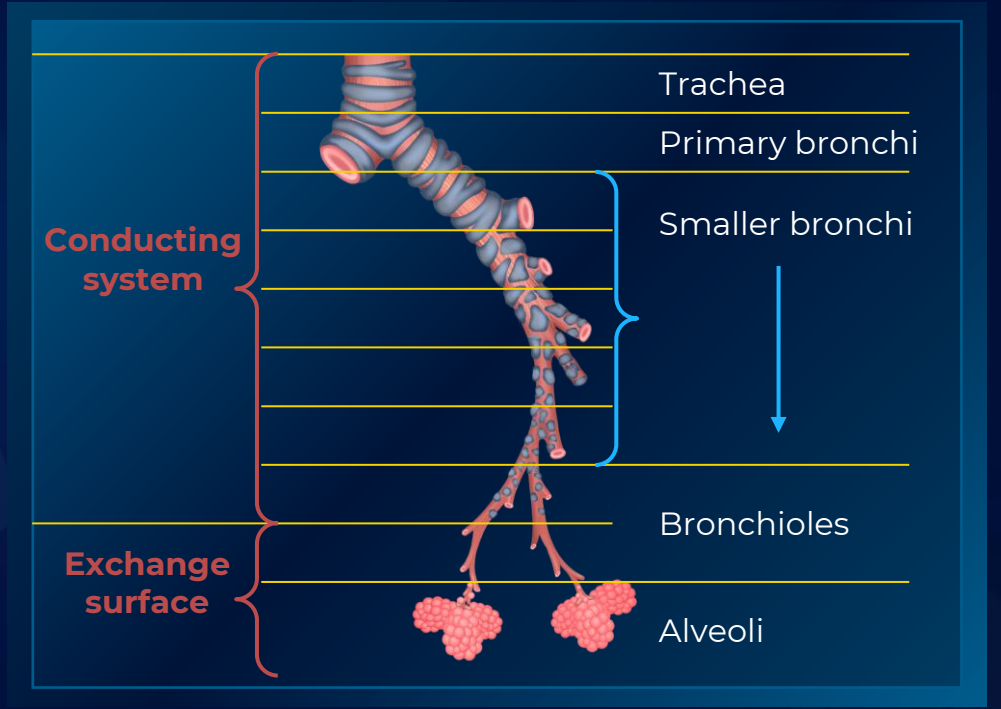
- Bronchioles eventually terminate into alveoli.
- **Alveoli** are small sac-like structures that swell when air enters them.
- Alveoli are in close contact with the **blood capillaries**.
- Hence, alveoli are sites where the gaseous exchange between blood and lungs occurs.

# Conducting and Respiratory Parts

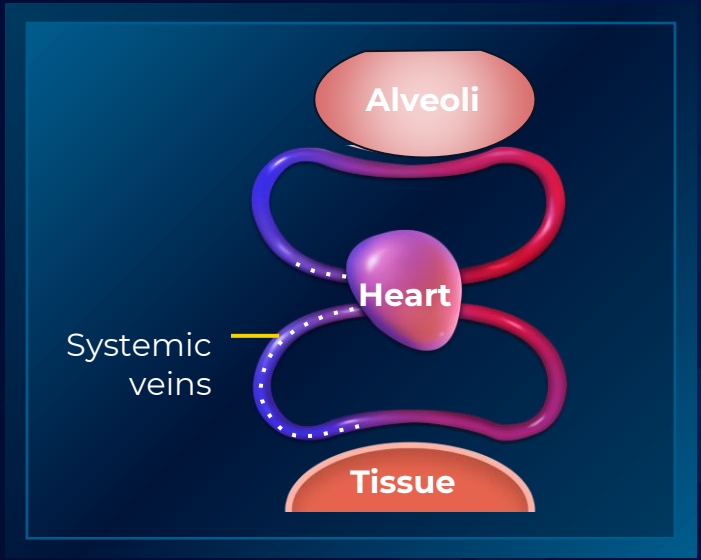
The human respiratory system can be divided into a conducting part and a respiratory part.

- **Conducting part**
  - It extends from the external nostrils up to the bronchioles.
  - It **conducts air** in and out of the lungs.
  - It **clears the air** of foreign particles.
  - It **humidifies** the air and brings it to the body temperature before it reaches the lungs.

- **Respiratory part/ Exchange part**
  - It includes alveoli and its ducts.
  - It is involved in the **exchange of gases** between the lungs and blood.



# Process of Exchange of Gases in Body

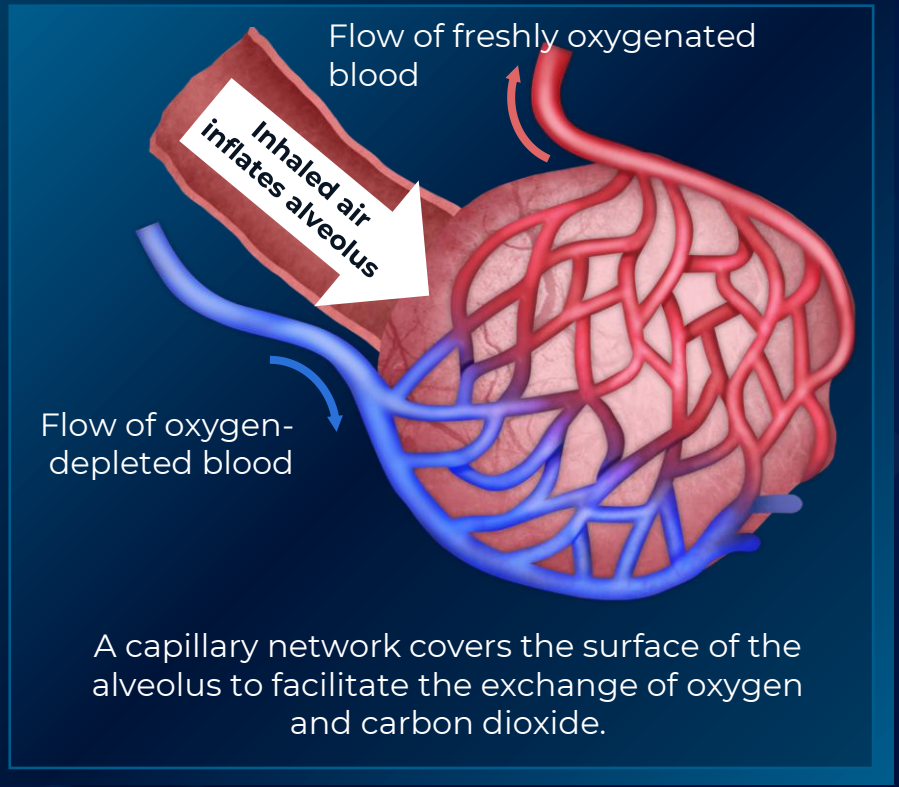



- Veins bring carbon dioxide-rich blood from all over the body to the heart.
  - This carbon dioxide is released during the process of cellular respiration.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} \longrightarrow \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \underset{\text{stored in ATP}}{\text{Energy}}$$

- The heart then pumps this $CO_2$-rich blood to the capillaries, surrounding the alveoli.
- The gaseous exchange occurs between the capillaries and the alveoli, where $CO_2$ diffuses into the alveoli, and $O_2$ from the alveoli diffuses into the capillaries.

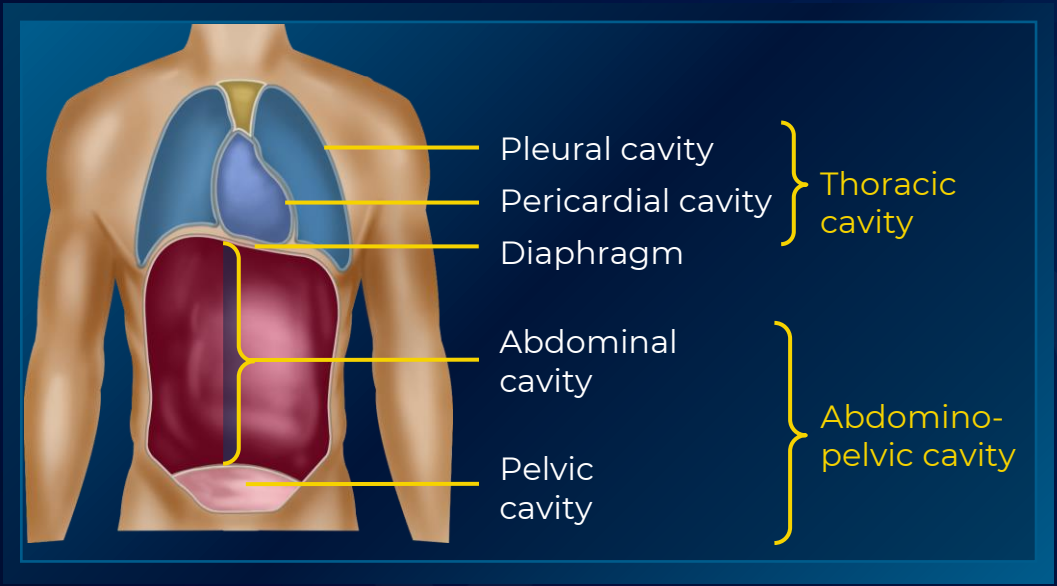
# Process of Exchange of Gases in Body




A capillary network covers the surface of the alveolus to facilitate the exchange of oxygen and carbon dioxide.

- Now, the oxygen-rich blood from the capillaries is carried to the heart, which pumps it throughout the body via arteries.
- Meanwhile, the **$CO_2$-rich air** is exhaled by the lungs.
- Now, the cells of the body utilise the supplied oxygen to generate energy and release $CO_2$ in the process.
- Meanwhile, the lungs inhale the **$O_2$-rich air** and the cycle repeats itself.

# Location of the Lungs




- Lungs are located in the **pleural cavity inside the thoracic cavity**.
- Lungs are surrounded by double layered **pleural membranes**.
- The thoracic cavity is covered in the following ways:
  - Dorsally by the vertebral column
  - Ventrally by the sternum
  - Laterally by the ribs
  - On the lower side by the dome-shaped diaphragm
- Any change in the volume of the thoracic cavity reflects in the volume of the lungs.

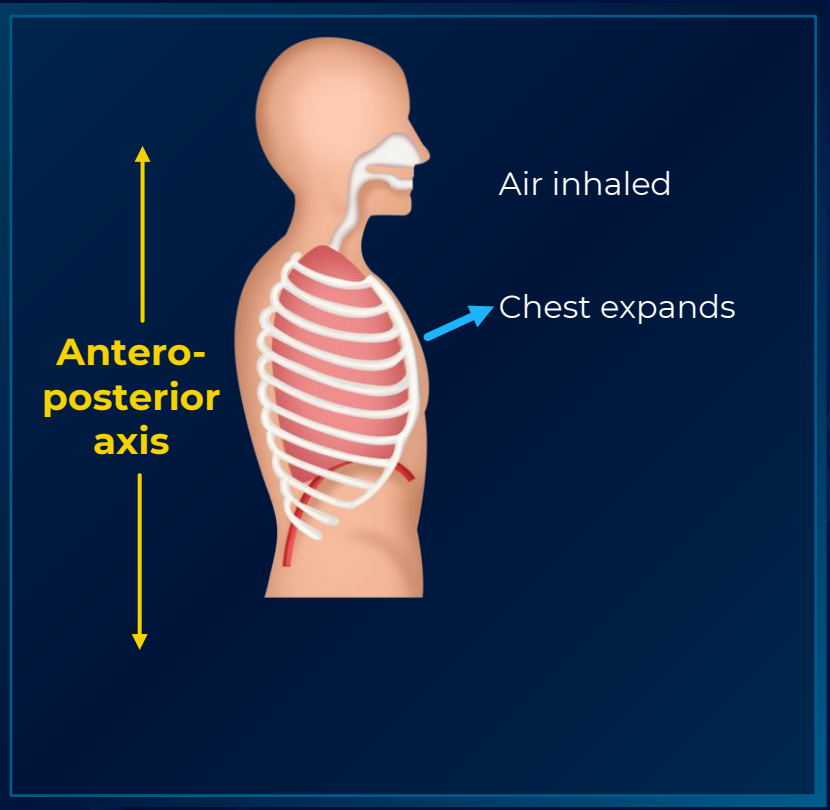
# Mechanism of Breathing

- Breathing is a **physical process** that takes place in the lungs.
- It involves the inspiration of oxygen and the expiration of carbon dioxide.
- It **does not release energy**.

## Inspiration

| Muscle that contracts | Consequence | Direction of expansion of thoracic cavity |
|---|---|---|
| Diaphragm | Diaphragm pulled down | Antero-posterior (up-down) direction |
| External intercostals | Rib cage expands upwards and outwards | Dorsoventral (front-back) direction |

# Mechanism of Breathing




## Inspiration

Diaphragm **contracts** and moves **downwards** and external intercostal muscles **contract** and move the ribs **upward** and **outward**

↓

The intrapulmonary volume **increases** and pressure **decreases**

↓

This creates **low pressure** inside lungs

↓

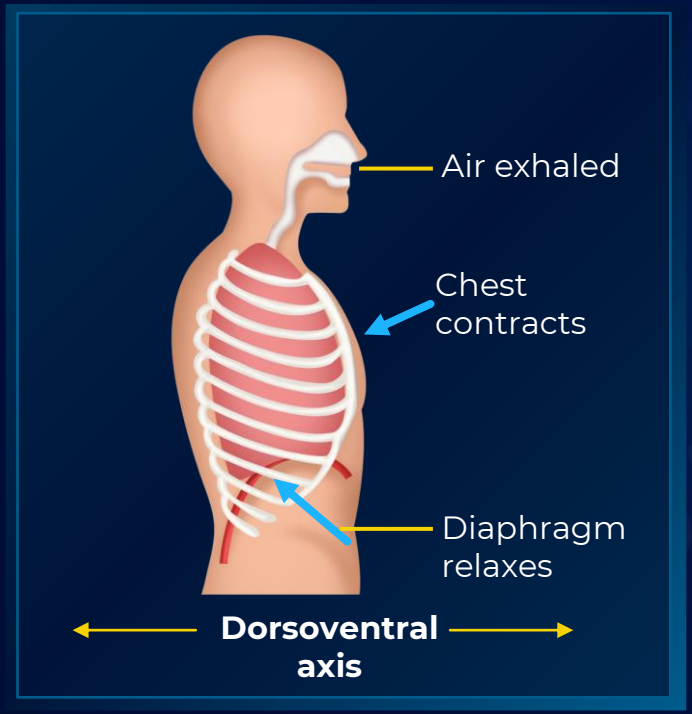
Air moves from **outside to inside** bringing about inhalation

# Mechanism of Breathing

## Expiration

| Muscle involved (quiet expiration) | Consequence | Direction of contraction of thoracic cavity |
|---|---|---|
| Diaphragm Relaxation | Diaphragm pulled up | Antero-posterior (up-down) direction |
| External intercostals relaxation | Rib cage comes back downwards and inwards | Dorsoventral (front-back) direction |

# Mechanism of Breathing




## Expiration

While **breathing out,** the **diaphragm relaxes** and the volume of the **thoracic cavity decreases** in the **longitudinal direction**.

- Decreased thoracic volume **reduces** the pulmonary volume
- Intrapulmonary pressure **increases**

# Lung Volumes and Capacities

Lung volumes and capacities measure the following:

- Amount of air that lungs can hold.
- Measure of the amount of air breathed in and out.

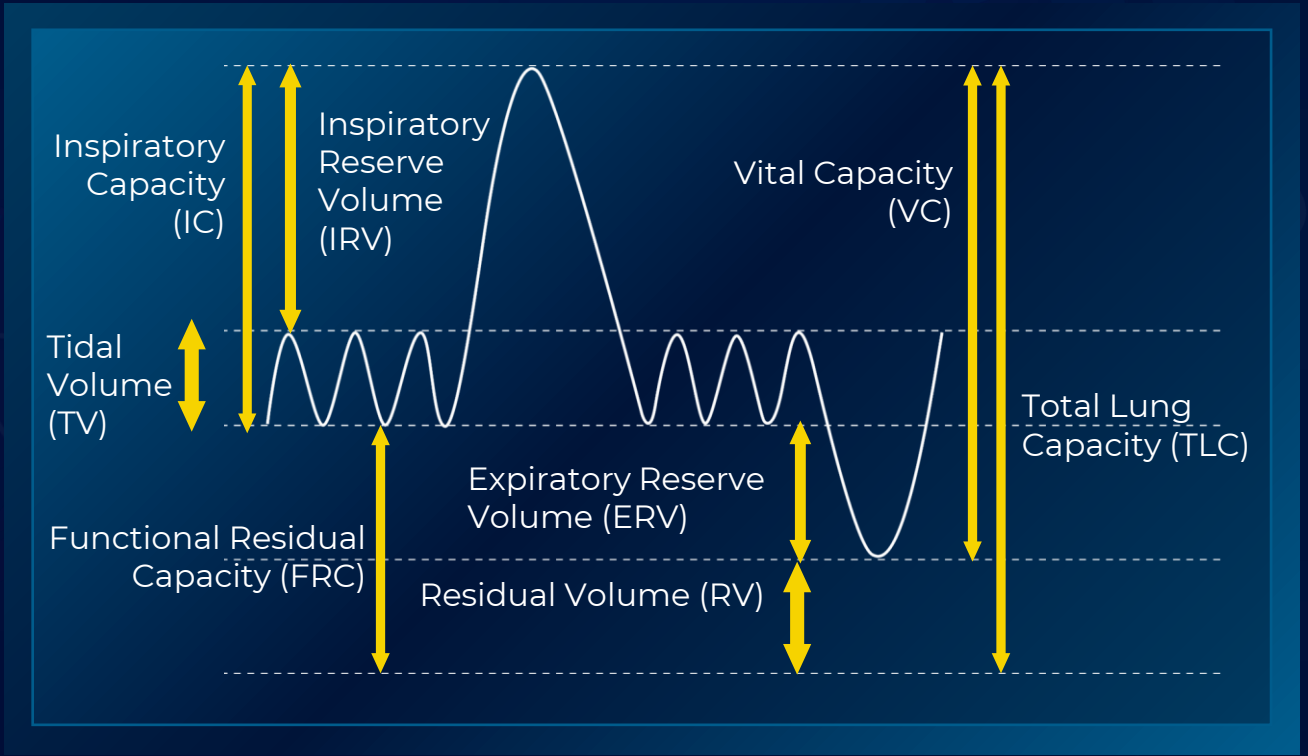
| Lung volume | Definition | Value (ml) |
|---|---|---|
| **Tidal Volume (TV)** | It is the volume of air inspired or expired during **normal respiration.** | 500 |
| **Inspiratory Reserve Volume (IRV)** | It is the **additional** volume of air that can be **breathed in** by **forcible inspiration.** | 2,500-3,000 |
| **Expiratory Reserve Volume (ERV)** | It is the **additional** volume of air that can be **breathed out** by **forcible expiration.** | 1,000-1,100 |
| **Residual Volume (RV)** | It is the volume of air left in lungs after **forcible expiration.** | 1,100-1,200 |

# Lung Capacities

| Lung capacity | Definition | Formula | Value/breath (ml) |
|---|---|---|---|
| **Inspiratory Capacity (IC)** | It is the **maximum** volume of air that can be **inspired** after **normal expiration**. | IC = TV + IRV | 500 + 2,750 = 3,250 |
| **Functional Residual Capacity (FRC)** | It is the volume of air that **remains** in **lungs** after **normal expiration**. | FRC = ERV + RV | 1,050 + 1,150 = 2,200 |
| **Vital Capacity (VC)** | It is the **maximum** volume of air that can be **inspired** after **forced expiration**. | VC = ERV + TV + IRV | 1,050 + 500 + 2,750 = 4,300 |
| **Total Lung Capacity (TLC)** | It is the **maximum** volume of air in lungs **after forced inspiration**. | TLC = RV + ERV + TV + IRV<br>TLC = RV + VC | 1,150 + 1,050 + 500 + 2,750<br>= 1,150 + 4,300<br>= 5,450 |

# Lung Volumes and Capacities

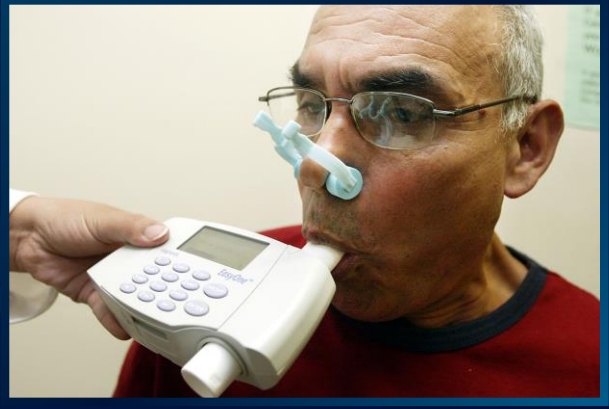
## Graphical representation



# Lung Volumes and Capacities

**Spirometer**

- Some of these volumes and capacities can be measured by an instrument known as a **spirometer**.
- It is useful in diagnosis of the following diseases:
  - Asthma
  - Shortness of breath
  - Assessing the effect of contaminants on lung infection
  - Effect of medication
  - Evaluating progress for disease treatment



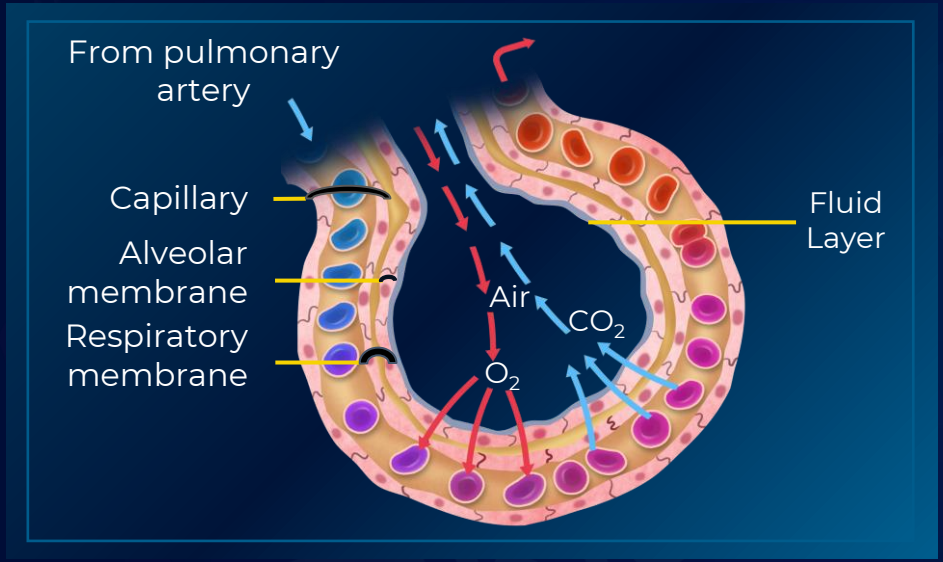
Spirometer

# Alveoli

- **Alveoli** are the **primary sites** of exchange of gases.
- They are tiny air sacs located at the distal end of the bronchial tree.
- They are thin-walled, moist, and richly supplied with blood capillaries.
- The moistness helps in the **dissolution of the gases and facilitates easy exchange of the gases**.

Gases move across the alveolar membrane through **diffusion.**

# Alveoli

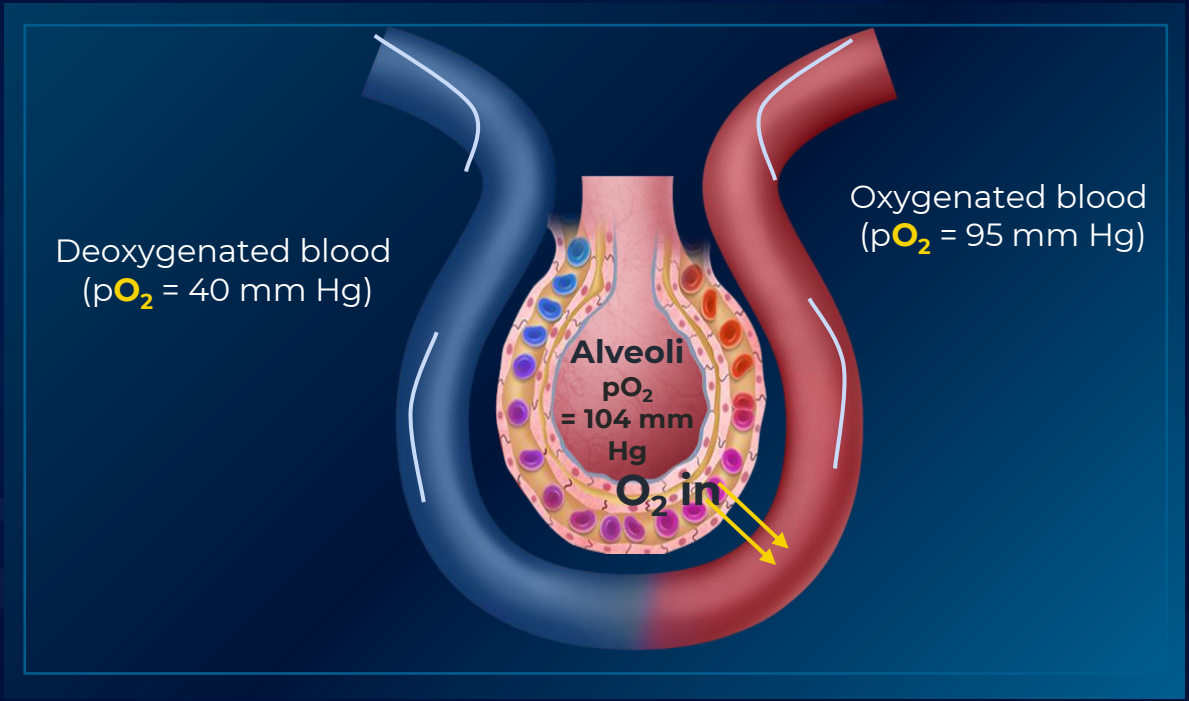



**Respiratory membrane (Diffusion membrane)**

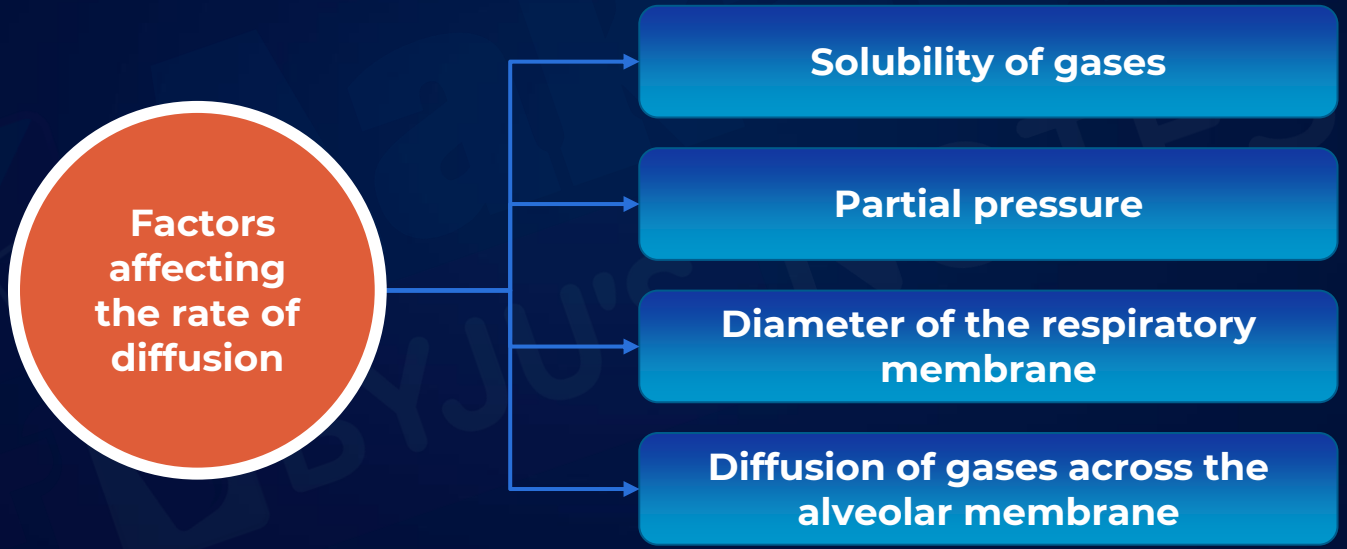
- The surface of the exchange of gases is known as **respiratory membrane** (diffusion membrane).
- The alveolar wall and the capillary wall, along with their basement membranes, form the respiratory membrane.
- The gases have to cross this membrane in order to enter into the bloodstream in the blood capillaries.

# External Respiration

- **Exchange of air** that takes place between the **blood capillaries and alveoli**.
- Diffusion of $O_2$ occurs from **alveoli to the blood** due to **partial pressure difference**.



# Factors Affecting the Rate of Diffusion



# Factors Affecting the Rate of Diffusion

**Solubility of gases**

- A gas having a high solubility diffuses at a faster rate than a gas having a lower solubility.
- The solubility of $CO_2$ is 20–25 times higher than that of $O_2$.

**Partial pressure**

- Partial pressure is the pressure contributed by an individual gas in a mixture of gases if it occupies the same volume on its own.
- **$pO_2$**- partial pressure of oxygen
- **$pCO_2$**- partial pressure of carbon dioxide
- A gas always moves from a region of **high partial pressure to a region of lower partial pressure**.

# Factors Affecting the Rate of Diffusion

**Diameter of the respiratory membrane**

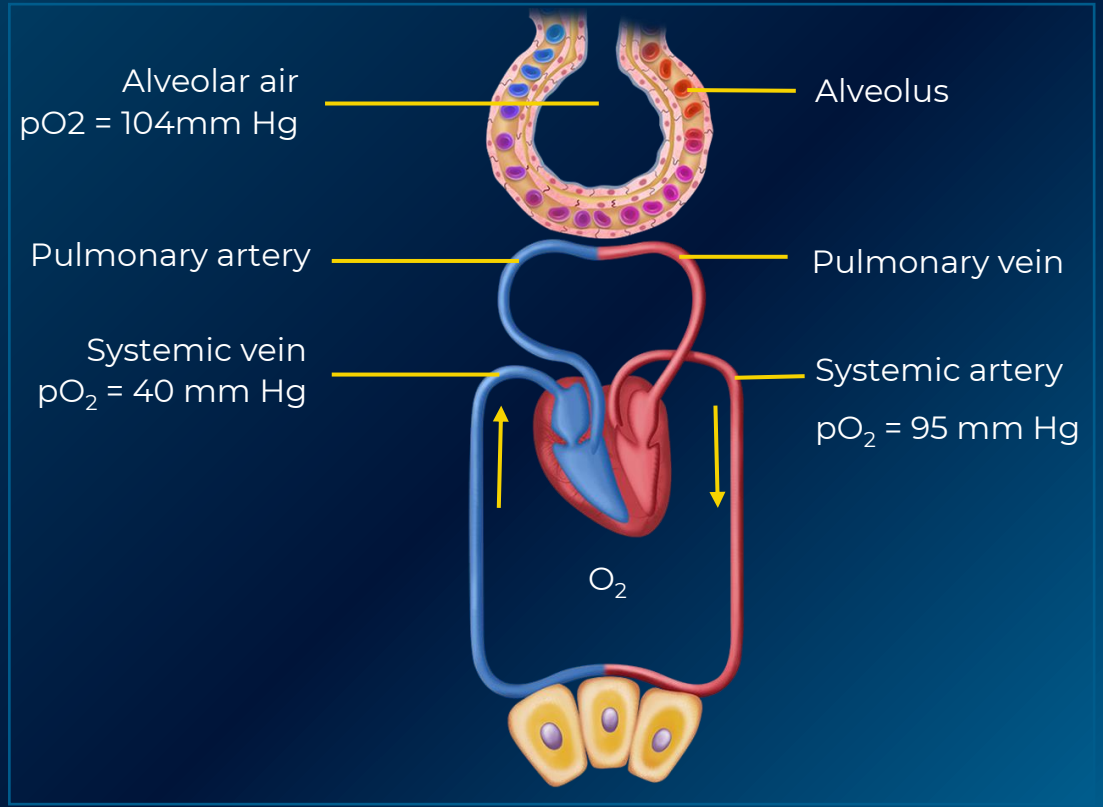
- The **thinner the membrane** involved in diffusion, the **faster is the diffusion** of gases.
- The total thickness of the respiratory membrane is less than a millimetre.

**Diffusion of gases across the alveolar membrane**

- **The $pO_2$ is higher in the alveoli than the deoxygenated blood.**
- **So, there is diffusion of $O_2$ from alveoli to the blood.**
- **This turns the deoxygenated blood to oxygenated blood.**
- **The blood that has higher concentration of oxygen is known as oxygenated blood.**

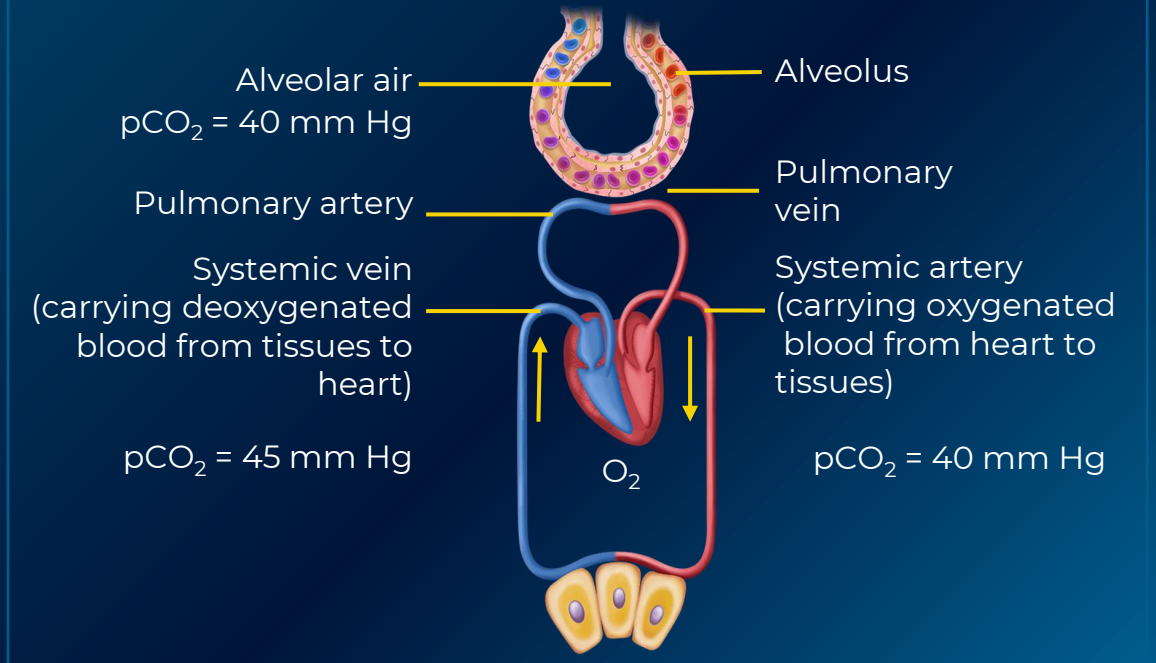
- The **capillaries bring the deoxygenated blood to lungs**, which has low oxygen concentration.
- Due to this low concentration of oxygen, the partial pressure of oxygen within the capillaries will also be low.

# Internal Respiration




- **Exchange of gases occurs** between the **blood and the tissues**.
- The $pO_2$ of **oxygenated blood is 95 mm Hg** same as what it was when it left the lungs.
- Now the $pO_2$ of the tissues is much lower at **40 mmHg**. So, the **oxygen diffuses from the blood to the tissues**.
- The $O_2$ is consumed and $CO_2$ is released out from the tissues.
- The $pCO_2$ is higher in the tissues compared to the oxygenated blood so, the $CO_2$ moves from tissues to the blood.

# Internal Respiration



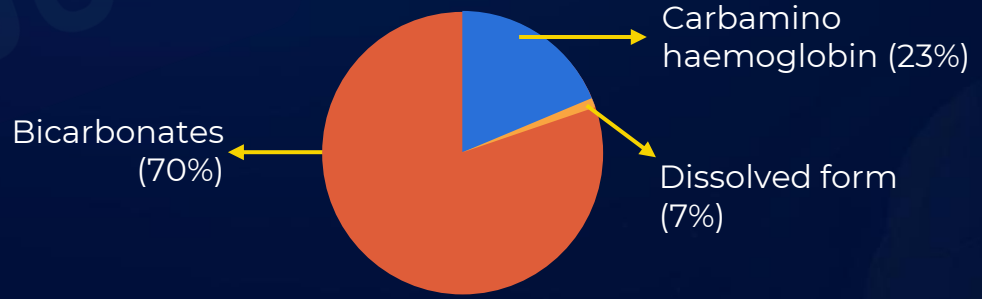

- The addition of carbon dioxide along with the removal of oxygen makes the blood deoxygenated. So, the $pCO_2$ changes from 40 to 45 mm Hg in the blood.
- The carbon dioxide diffuses from the blood to the alveoli via external respiration.

- The $pCO_2$ of deoxygenated blood is 45 same as what it was when it left the tissues.

# Transportation of Gases in Blood

**Transport of gases**

- **Oxygen**
  - Oxyhaemoglobin
  - Dissolved form
- **Carbon dioxide**
  - Carbaminohaemoglobin
  - Dissolved form
  - Bicarbonates

# Transport of Oxygen

## Dissolved form

- Oxygen is **dissolved** in the blood **plasma**.
- **The blood plasma,** a component of blood**, can also dissolve oxygen in it.**
- **However, oxygen is not very soluble in blood, so only 3% of oxygen is transported in the dissolved form.**

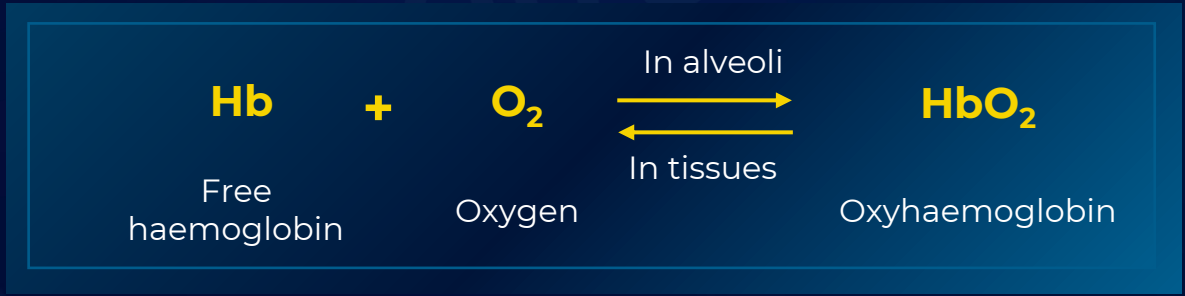
## Oxyhaemoglobin

- Since the majority of oxygen cannot be transported in the dissolved form, our bodies have evolved another system to transport oxygen. i.e. as **oxyhaemoglobin**.
- The red blood cells have a respiratory pigment, that is, **haemoglobin.**
- Haemoglobin comprises globin and haem.
- Globin is the protein molecule and haem is the red pigment that gives blood its red colour.
- There are **four protein chains** and **four haems**.
- Each haem has an **iron atom at its centre**.

# Transport of Oxygen

## Oxyhaemoglobin

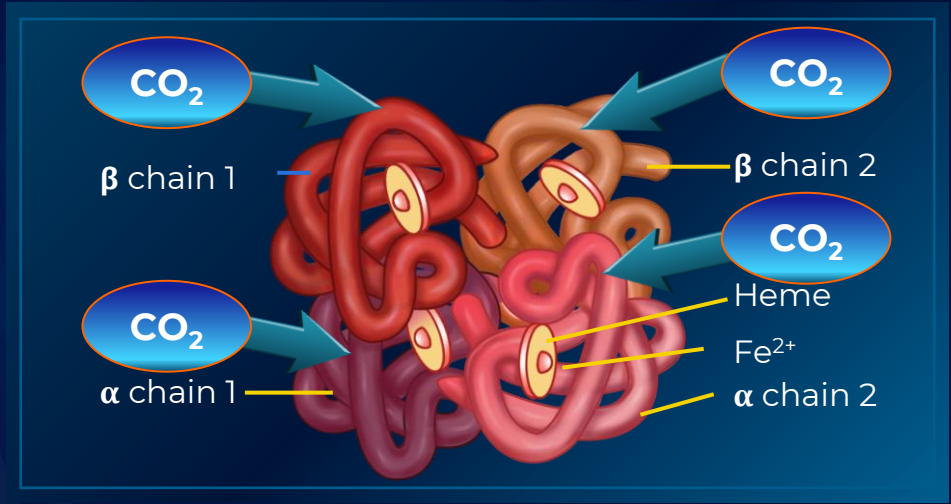
- **Haemoglobin** has an affinity for oxygen.
- It carries four molecules of oxygen.
- The **haem part** of haemoglobin **combines reversibly with oxygen** to form **oxyhaemoglobin**.
- Oxyhaemoglobin formation takes place in the alveoli.
- In tissues, this reverses and the oxyhaemoglobin releases oxygen.



# Transport of Carbon Dioxide

## Carbaminohaemoglobin

- Just like oxygen, four $CO_2$ molecules can bind to the Hb molecule.
- However, they do not bind to the iron atom.
- Instead, they **bind to the amine groups** on the protein chains.
- The haemoglobin picks up $CO_2$ from the cells and transports it as carbaminohaemglobin all the way from the tissues to the alveoli, which is an unstable molecule.
- $CO_2$ is dropped at the alveoli, and $O_2$ is picked up from the alveoli.




$$Hb + CO_2 \underset{\text{In alveoli}}{\overset{\text{In tissues}}{\rightleftharpoons}} HbCO_2$$

Free haemoglobin + Carbon dioxide ⇌ Carbaminohaemoglobin

# Transport of Carbon Dioxide

## Dissolved form

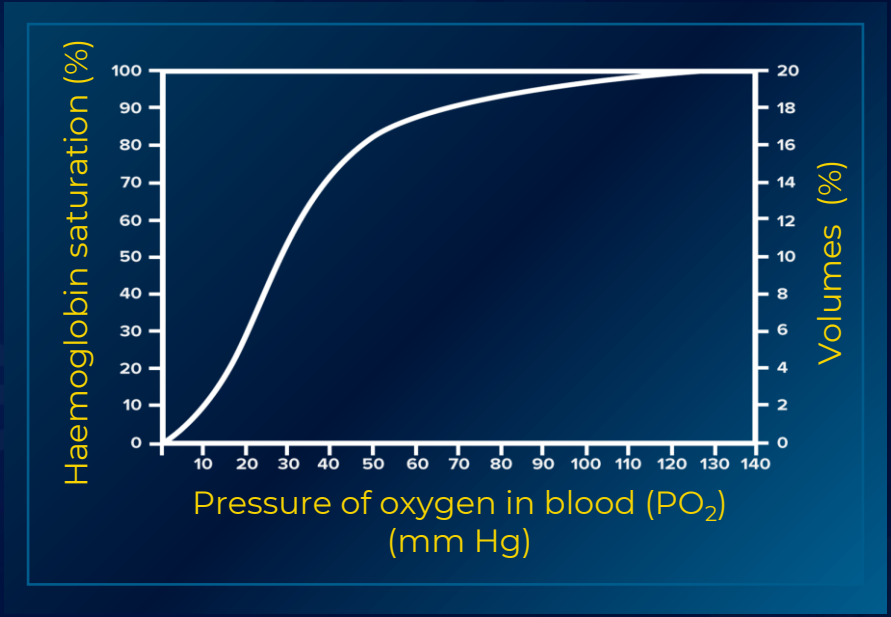
- The solubility of $CO_2$ is **20–25 times higher** than that of $O_2$.
- Therefore, **7%** of carbon dioxide **dissolves** in the blood plasma and is transported to the lungs.

## Bicarbonates

- The largest fraction of carbon dioxide is converted into **bicarbonate ions**.
- When carbon dioxide diffuses into RBCs at the tissues, it combines with water, forming carbonic acid.
- Since carbonic acid is unstable, it quickly dissociates into bicarbonate ions and hydrogen ions.
- Although, this reaction also occurs in plasma, it is a thousand times faster in RBCs because they contain the enzyme, **carbonic anhydrase**.
- This enzyme reversibly catalyses the conversion of carbon dioxide and water to carbonic acid.

# Saturation of Haemoglobin

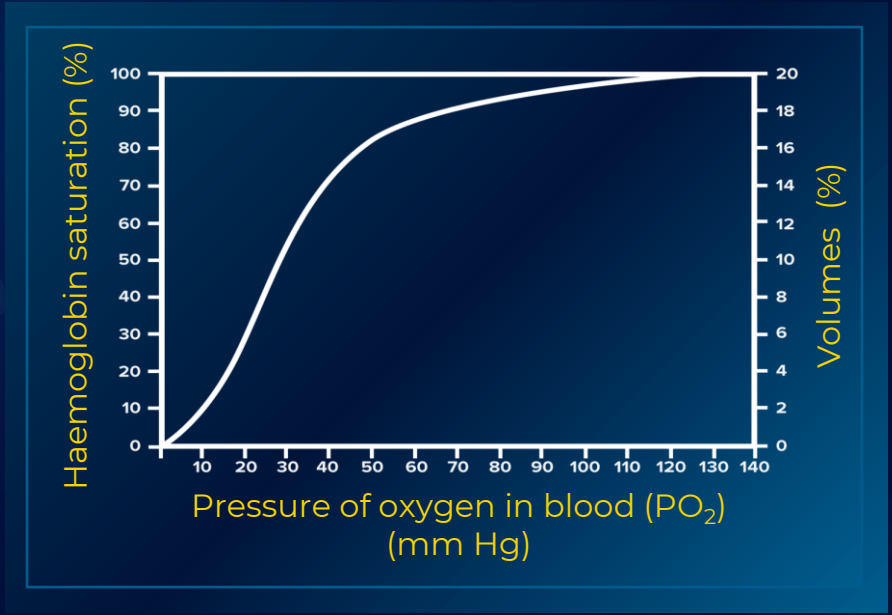
- The **ratio** of amount of **oxygen combined with haemoglobin** to the **amount of oxygen that haemoglobin is capable of carrying** gives the percentage saturation of haemoglobin.
- The saturation percentage and the partial pressure of oxygen are represented in the form of a curve known as the **oxygen-haemoglobin dissociation curve**.
- It is also known as the oxygen dissociation curve, and is **sigmoid** or **S-shaped**.



# Factors Affecting Oxygen-Haemoglobin Dissociation Curve

**$pO_2$, $pCO_2$, $H^+$ concentration and temperature**

- In alveoli:
  - There is high $pO_2$, low $pCO_2$, less $H^+$, and less temperature.
  - This favours oxyhaemoglobin association.
- In tissues:
  - There is low $pO_2$, high $pCO_2$, high $H^+$, and high temperature which favours the dissociation of $O_2$ from oxyhaemoglobin.
  - As the partial pressure of oxygen increases, the affinity of Hb for $O_2$ also increases.



# Factors Affecting Oxygen-Haemoglobin Dissociation Curve

## $CO_2$ concentration

When there is increase in $CO_2$ concentration **in blood**

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Increased carbon dioxide in blood reacts with water to form carbonic acid, giving more hydrogen and bicarbonate ions.

Higher $H^+$ lowers the blood pH

High **$H^+$** ions lower the blood pH and induces oxyhaemoglobin to give up more oxygen to the cells easily.

$O_2$ - Hb dissociation curve shifts right

# Artificial Respiration

It is a technique of **artificially stimulating the natural functioning of the respiratory system** when a person stops breathing because of drowning, electric shocks, accident, gas poisoning, anaesthesia etc.

**Artificial respiration**

## Manual method

Clearing the airways via mouth to mouth and compression

**CPR - Cardiopulmonary resuscitation**

## Mechanical method

**Ventilator**

Use of instruments to help breathe like **tracheostomy tube, iron lung, ventilator**

# Mechanical Method

Mechanical method can be defined as the technique through which **breathing and respiration is performed with the help of an external device** connected directly to the patient.

## Ventilator

- It is the **most common** method.
- Various machines are used to help the patient breathe.
- Patients breathing through a ventilator are said to be on **life support.**

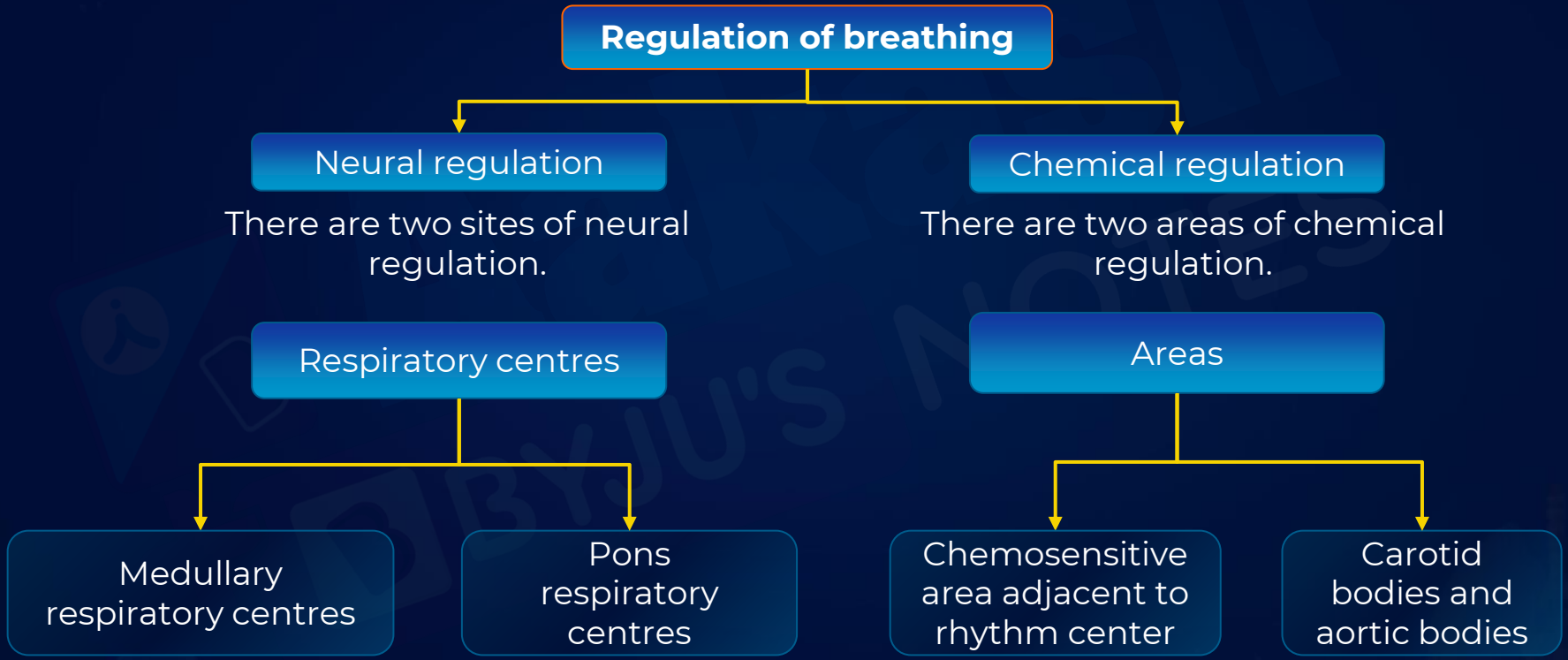
## Iron lung

- It is an enclosure used to **change the pressure in the space to make the person breathe**.

## Tracheostomy tube

- Involves insertion of a special tube by making a cut in the neck to **facilitate the entry of air into the lungs**.

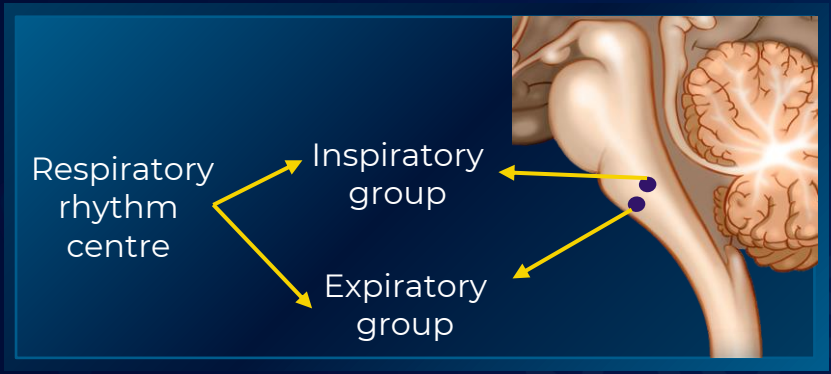
# Regulation of Breathing



# Respiratory Centres for Neural Regulation

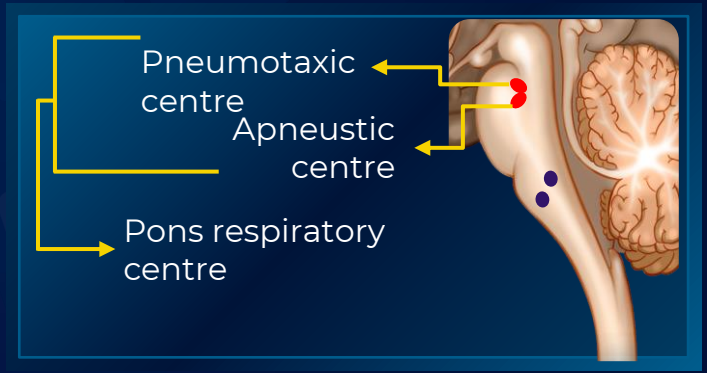
**Respiratory centres**

## Medullary respiratory centres




- **Inspiratory group** - Stimulates the respiratory muscles to contract during inspiration
- **Expiratory groups** - Stimulates muscles for expiration

## Pons respiratory centres




- The **pneumotaxic center**, located in the upper pons, sends signals to stop inspiration by inhibiting the **apneustic center**.
- It limits tidal volume.
- The apneustic and pneumotaxic center work against each other together to **control the respiratory rate**.

# Respiratory Centres for Chemical Regulation

Rhythm centres

Normal concentration of $CO_2$ and $H^+$ ions

Concentration of $CO_2$ and $H^+$ ions alters

**Rhythm centre** sends necessary signals to alter respiratory rate

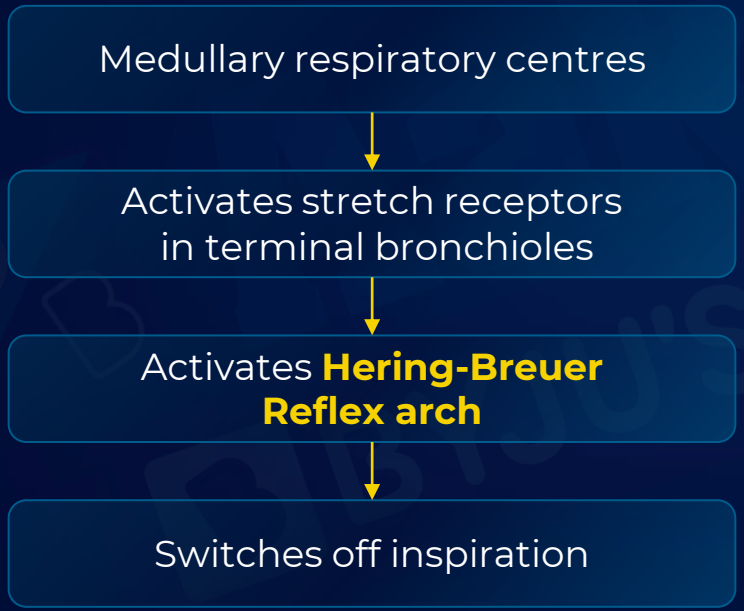
Medulla senses pH changes

Activates rhythm centre

**Carotid body and aortic body** sense changes

# Hering-Breuer Reflex Arch

- This reflex prevents the alveoli from bursting.

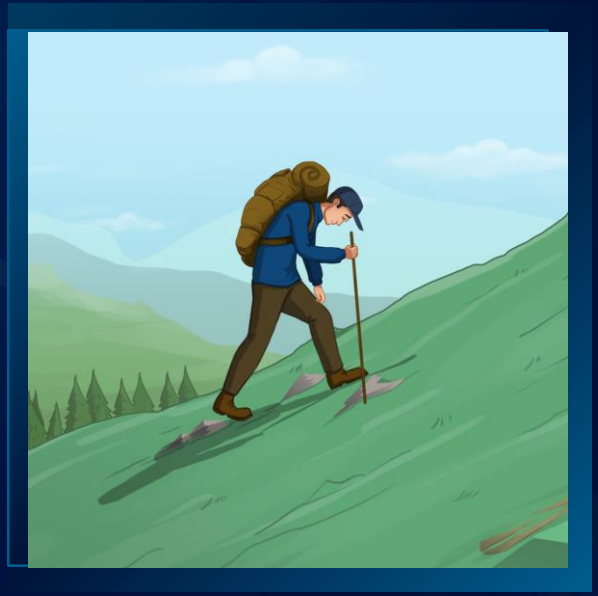



- This prevents alveoli from overstretching or bursting.
- Hence, this is called a **protective reflex**.

# Respiratory Disorders

## Mountain sickness

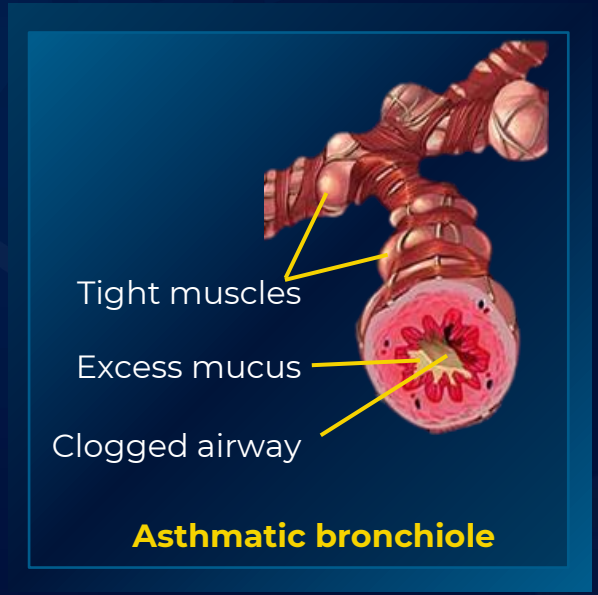
- Occurs due to **hypoxia** at high altitudes
  - Hypoxia = **Shortage of oxygen**
  - Occurs due to the presence of thin air at high altitudes
- **Symptoms:**
  - Vomiting
  - Breathlessness
  - Headache
  - Disorientation
  - Fatigue
  - Irritability



# Respiratory Disorders

## Bronchial asthma

- It is a chronic medical condition which results in the **swelling of the airway path of the lungs** which, as a result, **becomes narrow**.
- Due to this swelling, the air path produces excess mucus making it hard to breathe.
- It is caused by mould, dust mites, fragrance, cigarette smoke, cleaning chemicals, pets etc.
- **Symptoms:**
  - Coughing
  - Wheezing
  - Difficulty in breathing



**Asthmatic bronchiole**

# Respiratory Disorders

## Pulmonary Tuberculosis

- It is caused by ***Mycobacterium tuberculosis***.
- It is an airborne disease and spreads by inhalation.
- It results in destruction of lung tissue which then gets replaced by fibrous connective tissue.
- **Symptoms**:
  - Coughing and chest pain
  - Loss of appetite
  - Chills and fever
  - Night sweats
  - Fatigue

## Emphysema

- Emphysema means shortness of breath.
- It is caused by smoking and inhalation of toxic gases and smoke.
- This condition results in
  - **Loss of elasticity in lungs** as elastic tissue is replaced by connective tissue.
  - Alveoli becoming weak and their walls break down.
  - As a result, lungs remain inflated, and **expiration becomes difficult**.
- **Symptoms:**
  - Inflammation of bronchioles and alveoli
  - Expiration becomes difficult
- **Preventive measures:**
  - No smoking
  - Use pollution masks

# Respiratory Disorders

## Occupational respiratory disorders

- It is any lung condition that arises due to the role of the person at the workplace.
- It occurs because of repeated exposure to certain toxins over a period of time such as **gas fumes, dust, silica and asbestos**.
- Often seen in individuals working in **mining, stone grinding and stone breaking industries**.
- It results in
  - **Fibrosis of upper lung and inflammation** due to the damage to lung tissue. The lung tissue becomes scarred, thickened and stiff, making it difficult for the lungs to work properly.
- **Symptoms:**
  - Difficulty in breathing
- **Protection masks** can help in keeping the workers safe.

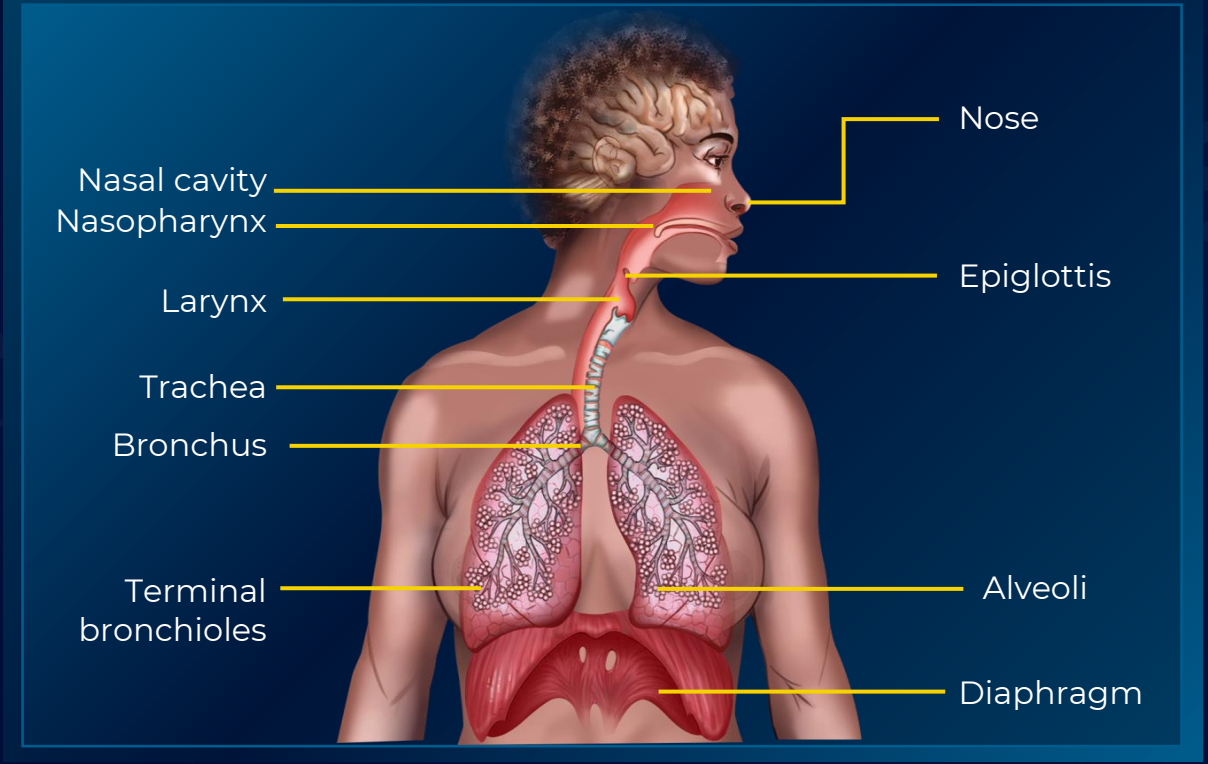
# Summary

## Mechanism of gaseous exchange In invertebrates

| | |
|---|---|
| Porifera | Water current entering through ostia |
| Annelida | Diffusion through cuticles |
| Platyhelminthes | |
| Arthropods | Spiracles and tracheoles |
| Aquatic arthropods | Book gills |
| Fishes | Gill slits |
| Amphibians | Skin, lungs and bucco-pharynx |
| Birds | Air sacs |

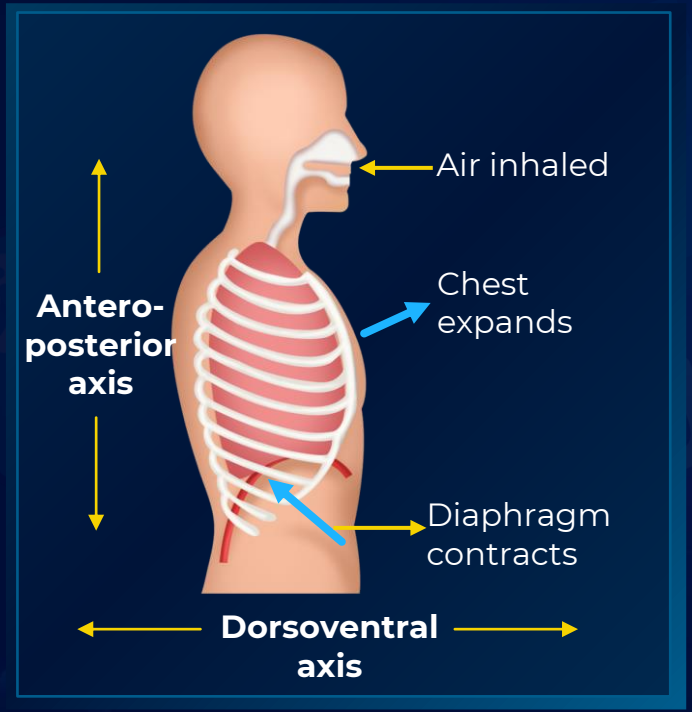
# Summary

## Human respiratory system

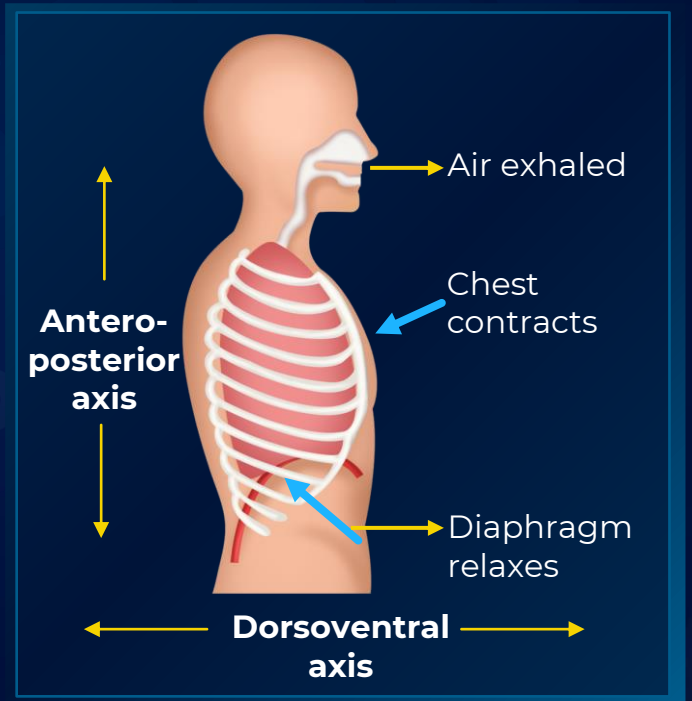


# Summary

## Inspiration

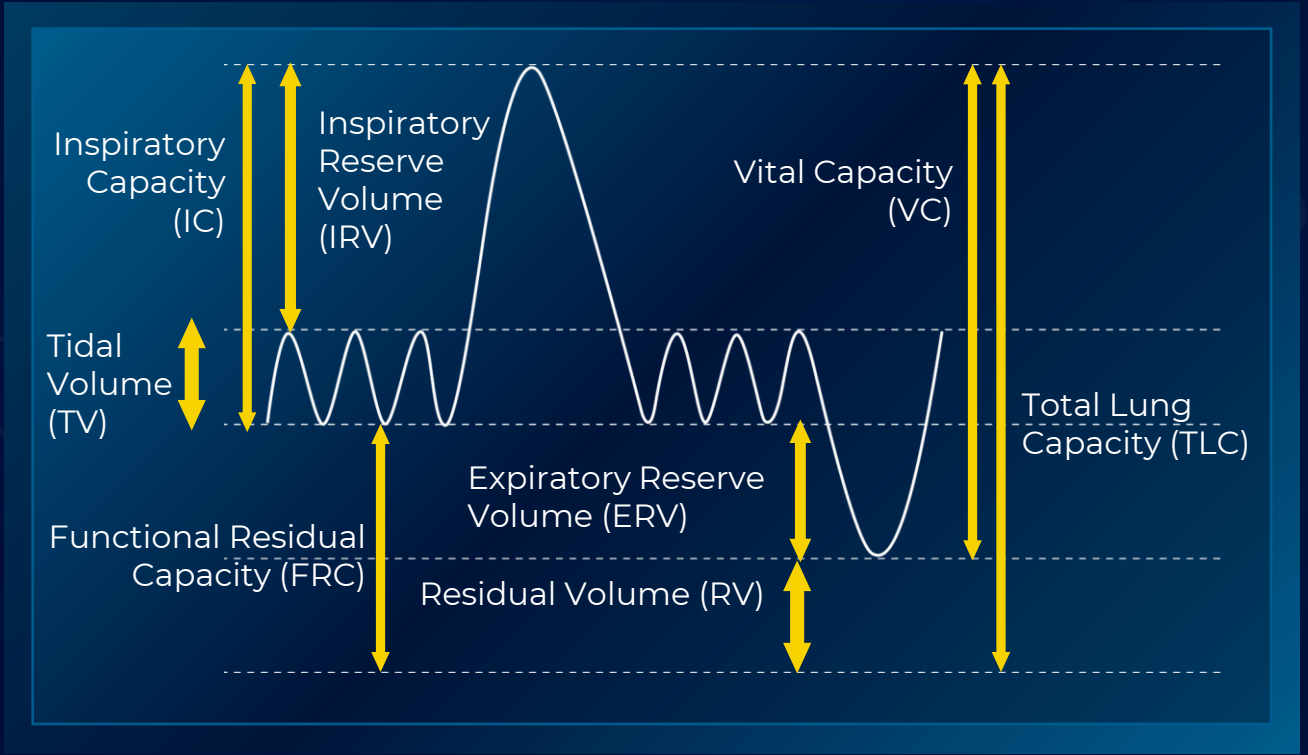



## Expiration



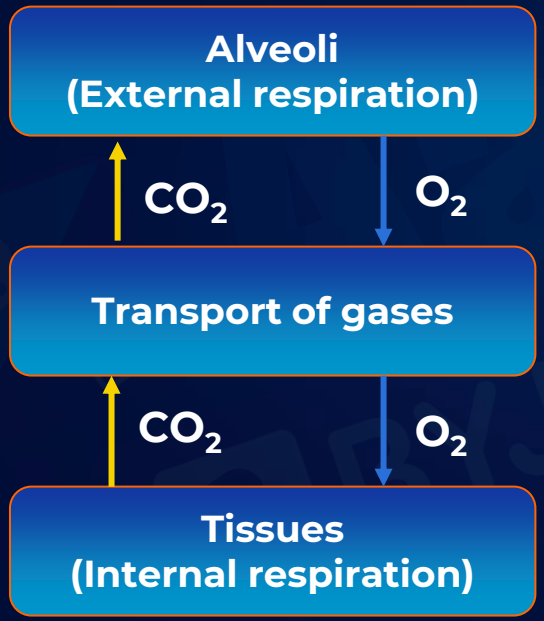
# Summary

## Graphical representations of lung capacities



# Summary

## Exchange of gases




**External respiration**: It is the exchange of air that takes place between the blood capillaries and the alveoli.

**Internal respiration:** It is the exchange of air that takes place between the blood and the tissues.

# Summary

## Artificial respiration

Artificial respiration involves induction of breathing by some manipulative technique when natural respiration has ceased or is faltering.

### Manual method

The manual methods include clearing the airways via mouth to mouth and CPR.

### Mechanical method

Mechanical method can be defined as the technique through which breathing, and respiration are performed with the help of an external device connected directly to the patient.

- Ventilator
- Iron lung
- Tracheostomy tube

# Summary