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Introduction

Concepts

- Reductionist approach studies life via physio-chemical methods; neither molecular nor organismic alone reveals full truth.
- Organisms use oxygen to break down glucose, fatty acids, amino acids for energy; carbon dioxide is released as waste.
- Breathing: intake of oxygen-rich air and removal of carbon dioxide-rich air from the body.
- Respiration: exchange of oxygen from environment with carbon dioxide from cells during food oxidation.
- Respiration includes breathing, gas diffusion, gas transport by blood, cellular oxygen use, and carbon dioxide release.

Memory Aids

- Breathing = air in/out; Respiration = gas exchange + cellular use.
- Oxygen in, CO₂ out = respiration cycle.

Quick Checkpoints

- What is the reductionist approach?
- Define breathing and respiration.
- What gases are exchanged during respiration?

Respiratory Organs

Concepts

- Breathing mechanisms vary by animal habitat and complexity.
- Respiratory organs include:
 - Whole body surface: sponges, flatworms.
 - Moist skin: earthworms, frogs.

- Tracheae: insects.
- Gills: fishes, molluscs.
- Lungs: amphibians, reptiles, birds, mammals.

Table : Organs for exchange of gases in different animals

Respiratory organs	General body surface (Simple diffusion)	Moist skin (Cutaneous respiration)	Tracheal tubes (Tracheal respiration)	Gills (Branchial respiration)	Lungs (Pulmonary respiration)
Examples	<ul style="list-style-type: none"> – Sponges – Coelenterates – Flatworms 	<ul style="list-style-type: none"> – Earthworms – Frogs 	<ul style="list-style-type: none"> – Insects 	<ul style="list-style-type: none"> – Aquatic arthropods – Molluscs – Fishes 	<ul style="list-style-type: none"> – Amphibians – Reptiles – Birds – Mammals

Memory Aids

- Surface, Skin, Tracheae, Gills, Lungs = respiratory organ progression.
- Habitat dictates respiratory organ type.

Quick Checkpoints

- Which animals use skin for respiration?
- Name respiratory organs of aquatic animals.
- How do insects breathe?

Human Respiratory System

Concepts

- Air enters via external nostrils → nasal chamber → pharynx (common food/air passage) → larynx via glottis.
- Epiglottis covers glottis during swallowing to block food entry into larynx.
- Larynx (sound box) produces sound.
- Trachea divides into right and left primary bronchi at 5th thoracic vertebra.

- Bronchi branch into secondary, tertiary bronchi, then bronchioles ending in alveoli.
- Trachea and bronchi supported by incomplete cartilaginous rings.
- Alveoli: thin-walled, vascularized sacs for gas exchange; ~300 million in human lungs.
- Lungs enclosed by double-layered pleura with pleural cavity containing lubricating pleural fluid.
- Conducting part: nostrils to terminal bronchioles; transports, cleans, humidifies, and warms air.
- Respiratory part: alveoli and ducts; site of gas diffusion.
- Lungs lie in airtight thoracic chamber formed by vertebral column, sternum, ribs, diaphragm.
- Volume changes in thoracic cavity affect lung volume.
- Squamous alveolar cells (pneumocytes): type I for gas exchange, type II secrete surfactant (lecithin) to prevent alveolar collapse.
- Surfactant secretion develops late in pregnancy; absence causes lung collapse in newborns.
- Respiration steps:
 - Breathing (pulmonary ventilation): air inflow/outflow.
 - Gas diffusion across alveolar membrane.
 - Gas transport by blood.
 - Gas exchange between blood and tissues.
 - Cellular respiration: oxygen use and carbon dioxide release.

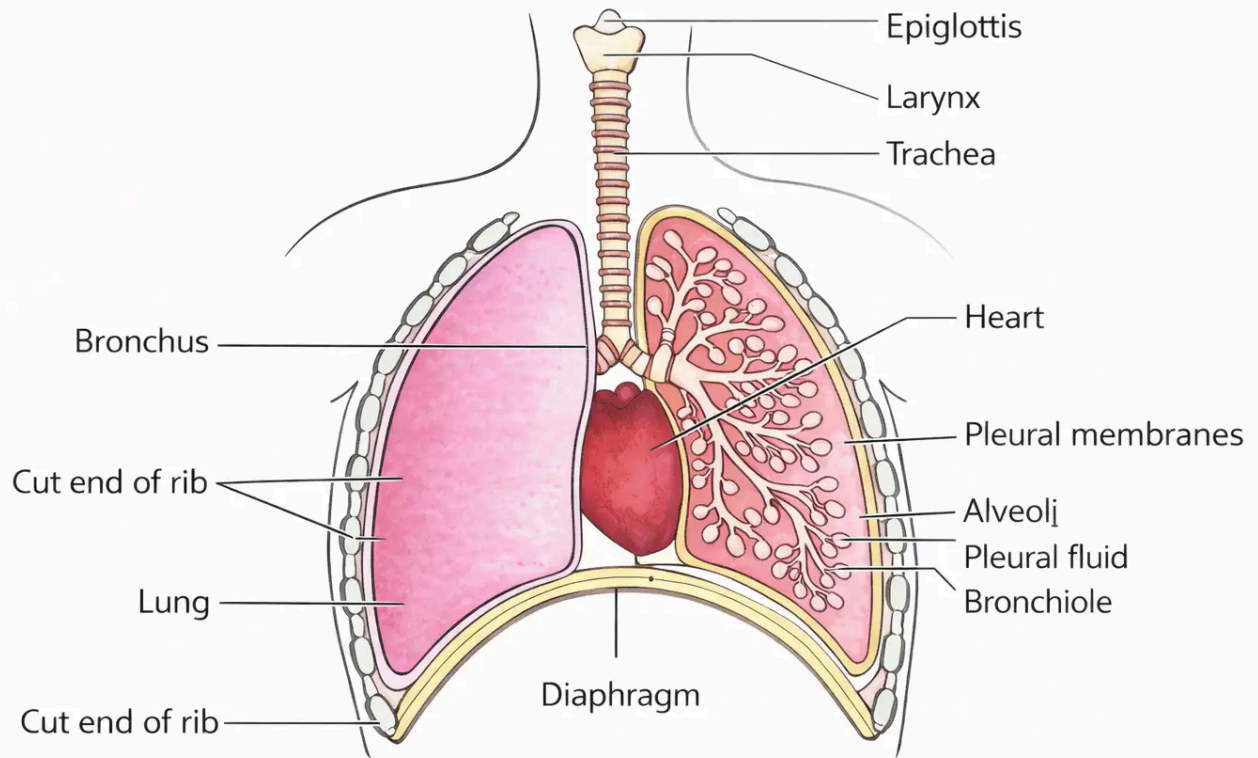


Fig.: Diagrammatic view of human respiratory system (sectional view of the left lung also)

Memory Aids

- Epiglottis = food blocker during swallowing.
- Larynx = sound box.
- Trachea → Bronchi → Bronchioles → Alveoli = air pathway.
- Pneumocytes: Type I = exchange, Type II = surfactant.
- Surfactant prevents alveolar collapse.
- Thoracic cavity volume controls lung volume.

Quick Checkpoints

- What is the role of epiglottis?
- Describe the structure of the trachea and bronchi.
- What are alveoli and their function?
- Explain the role of pleura and pleural fluid.
- List the steps of respiration.

Mechanism of Breathing

Process and Muscles Involved

- Breathing has two stages: **inspiration** (air intake) and **expiration** (air release).
- Air movement is driven by pressure gradients between lungs and atmosphere.
- Diaphragm and intercostal muscles (external and internal) between ribs create this pressure gradient.

Memory Aids

- Inspiration = air in; Expiration = air out.
- Diaphragm + intercostals = breathing muscles.

Quick Checkpoints

- What muscles create pressure changes for breathing?
- How does pressure gradient drive air movement?

Inspiration

Mechanism and Pathway

- Occurs when lung pressure (intra-pulmonary) is less than atmospheric pressure (negative pressure).
- Diaphragm contracts, flattens, and lowers, increasing thoracic volume front-to-back.
- External intercostals contract, lifting ribs and sternum, increasing thoracic volume top-to-bottom.
- Increased thoracic volume raises lung volume, lowering lung pressure below atmospheric.
- Air flows into lungs following pressure gradient.
- Abdominal muscles relax, allowing diaphragm to compress abdominal organs (passive role).
- Air pathway: External nares → Nasal cavities → Internal nares → Pharynx → Glottis → Larynx → Trachea → Bronchi → Bronchioles → Alveolar ducts → Alveoli.

Memory Aids

- Diaphragm down + ribs up = lung volume up = air in.
- Abdominal muscles relax during inspiration.

Quick Checkpoints

- What causes lung pressure to drop during inspiration?
- Which muscles contract in inspiration?
- Trace the air pathway into lungs.

Expiration

Mechanism and Pathway

- Occurs when lung pressure is higher than atmospheric pressure.
- Diaphragm and intercostal muscles relax, returning to resting position.
- Thoracic and lung volumes decrease, raising lung pressure above atmosphere.
- Air is pushed out of lungs following pressure gradient.
- Air pathway out: Alveoli → Alveolar ducts → Bronchioles → Bronchi → Trachea → Larynx → Glottis → Pharynx → Internal nares → Nasal cavities → External nares → Outside.
- Abdominal muscles can assist to increase expiration strength.
- Normal breathing rate: 12-16 breaths/min; inspiration ~2 sec, expiration ~3 sec.

Memory Aids

- Diaphragm up + ribs down = lung volume down = air out.
- Expiration is passive; muscles relax.

Quick Checkpoints

- What triggers expiration?

- Which muscles relax during expiration?
- Describe the air pathway out of lungs.

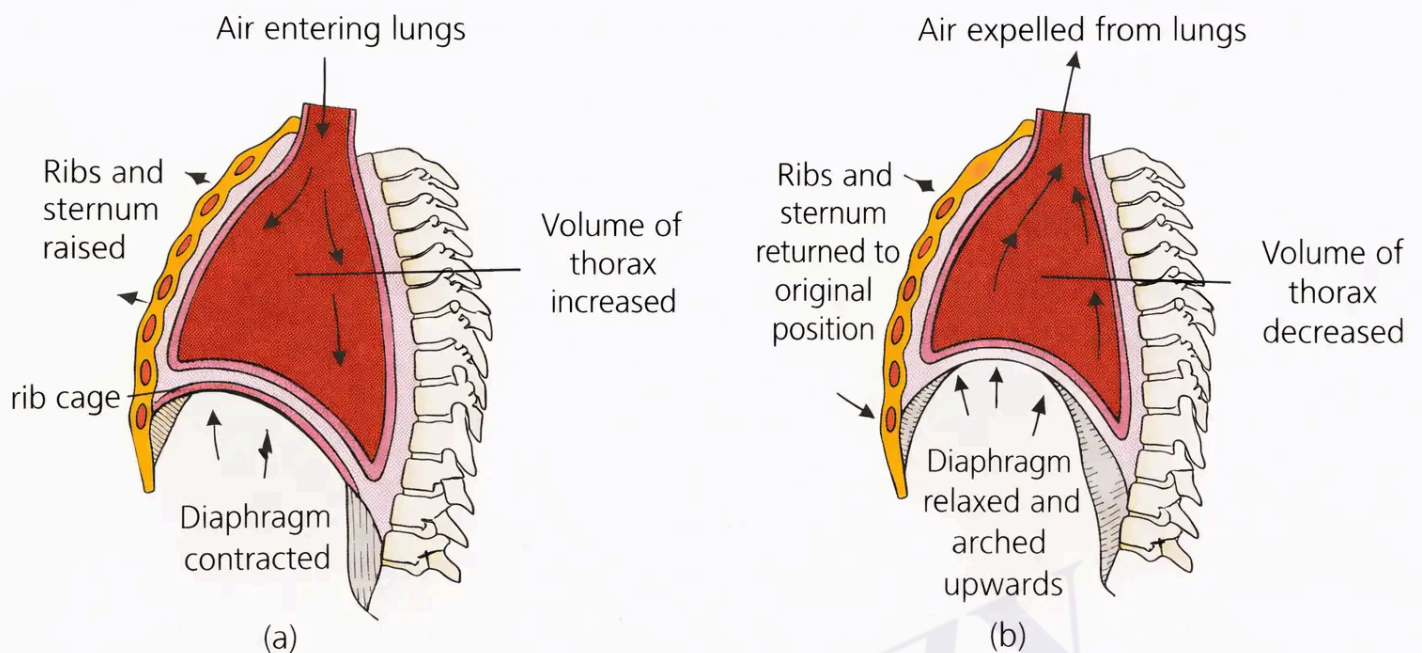


Fig.: Mechanism of breathing showing : (a) inspiration (b) expiration

Respiratory Volumes and Capacities

Definitions and Clinical Use

- Respiratory volumes: air amounts inhaled, held, or exhaled under conditions.
- Pulmonary capacities: sums of respiratory volumes, used in clinical diagnosis.
- Volumes and capacities are 20-25% less in women than men; higher in athletes than non-exercisers.
- Most volumes and capacities measured by spirometer, except Functional Residual Capacity (FRC) and Residual Volume (RV).

Memory Aids

- Volumes = individual air amounts; Capacities = sums of volumes.

- Women < men; athletes > non-athletes.

Quick Checkpoints

- What is the difference between respiratory volume and capacity?
- Which volumes cannot be measured by spirometer?

Table : Pulmonary volumes and capacities

	Type of pulmonary volume/capacity	Quantity of air (Approximately)	Characteristic
1.	Tidal Volume (TV)	500 mL	It is the volume of air inspired and expired during normal breathing without any effort.
2.	Inspiratory Reserve Volume (IRV)	2,500 mL-3,000 mL	It is an extra amount of air that can be inspired forcibly after a normal inspiration.
3.	Expiratory Reserve Volume (ERV)	1,000 mL-1,100 mL	It is an extra amount of air that can be expelled after forcible expiration.
4.	Residual Volume (RV)	1,100 mL-1,200 mL	It is the volume of air that remains in the lungs even after a forcible expiration.
5.	Vital Capacity (VC)	4,000 mL-4600 mL	It is the total volume of air inspired and expired to a maximum level. VC = TV + IRV + ERV.
6.	Inspiratory Capacity (IC)	3,000 mL-3,500 mL	It is the total volume of air that can be inhaled after a normal expiration. IC = TV + IRV.
7.	Expiratory Capacity (EC)	1,500 mL-1,600 mL	It is the total volume of air that can be expired after a normal inspiration. EC = TV + ERV.
8.	Functional Residual Capacity (FRC)	2,100 mL-2,300 mL	It is the volume of air that will remain in the lungs after a normal expiration. FRC = ERV + RV.
9.	Total Lung Capacity (TLC)	5,100 mL-5,800 mL	It is the total amount of air present in the lungs and respiratory passage after a maximum inspiration. TLC = VC + RV.

Pulmonary Volumes and Capacities Table

Types and Characteristics

- **Tidal Volume (TV):** Normal air breathed in/out without effort.
- **Inspiratory Reserve Volume (IRV):** Extra air inhaled after normal inspiration.
- **Expiratory Reserve Volume (ERV):** Extra air exhaled after normal expiration.
- **Residual Volume (RV):** Air remaining after forced expiration.
- **Vital Capacity (VC):** Max air exhaled after max inhalation (TV + IRV + ERV).
- **Inspiratory Capacity (IC):** Max air inhaled after normal exhale (TV + IRV).

- **Expiratory Capacity (EC):** Max air exhaled after normal inhale (TV + ERV).
- **Functional Residual Capacity (FRC):** Air left after normal exhale (ERV + RV).
- **Total Lung Capacity (TLC):** Total air lungs hold after max inhale (VC + RV).

Memory Aids

- $VC = TV + IRV + ERV$; $TLC = VC + RV$.
- RV always remains in lungs.

Quick Checkpoints

- Define each pulmonary volume and capacity.
- How are capacities derived from volumes?

Exchange of Gases

Gas Exchange Sites and Mechanism

- Alveoli are the primary sites for gas exchange.
- Gas exchange also occurs between blood and tissues by simple diffusion.
- Diffusion depends on pressure/concentration gradients.
- Solubility of gases and membrane thickness affect diffusion rate.
- Partial pressure (pO_2 for oxygen, pCO_2 for carbon dioxide) drives diffusion.
- CO_2 diffuses 20-25 times faster than O_2 due to higher solubility.
- Diffusion membrane consists of thin squamous epithelium of alveoli, endothelium of capillaries, and basement substance.
- Membrane thickness is less than a millimeter, favoring efficient gas exchange.
- Arterial blood leaving alveoli has pO_2 and pCO_2 nearly equal to alveolar air.

Table : Partial pressures (in mm Hg) of oxygen and carbon dioxide at different parts involved in diffusion in comparison to those in atmosphere

Respiratory gas	Atmospheric gas	Alveoli	Deoxygenated Blood	Oxygenated Blood	Tissues
O_2	159	104	40	95	40
CO_2	0.3	40	45	40	45

Gas Exchange Process

- Oxygen moves from alveoli (high pO_2) to blood (low pO_2).
- Carbon dioxide moves from blood (high pCO_2) to alveoli (low pCO_2).
- In tissues, oxygen moves from blood to tissues; carbon dioxide moves from tissues to blood.
- Blood circulation maintains concentration gradients for continuous diffusion.

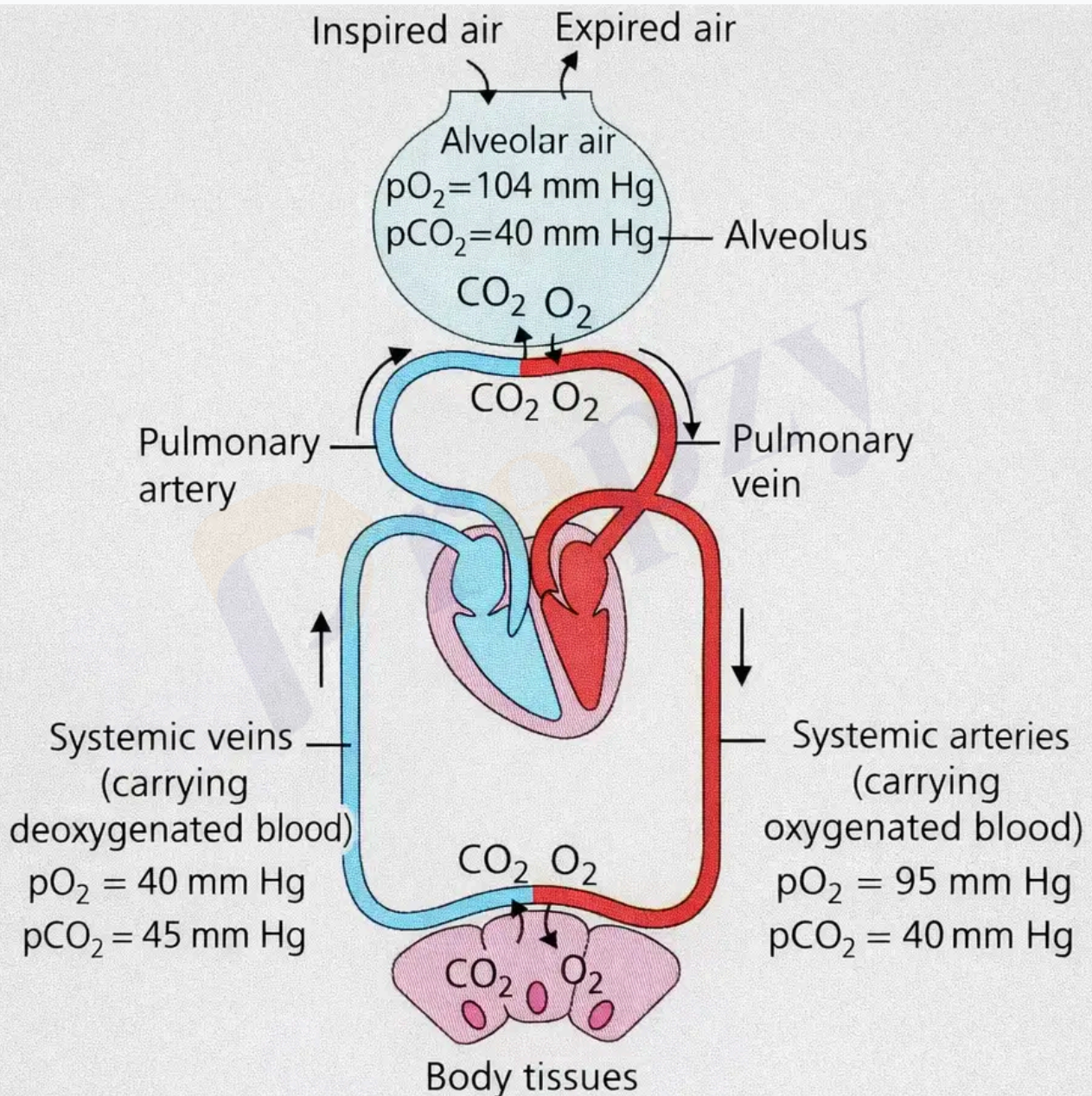


Fig: Diagrammatic representation of exchange of gases at the alveolus and the body tissues with blood and transport of oxygen and carbon dioxide.

Alveolar Structure and Function

- Alveoli have thin walls (one cell thick) for easy gas passage.
- Oxygen passes through alveolar wall, basement membrane, and capillary endothelium into red blood cells.
- Carbon dioxide passes from blood into alveoli to be exhaled.
- Blood enters capillaries via pulmonary artery (CO₂-rich) and leaves oxygenated via pulmonary vein.

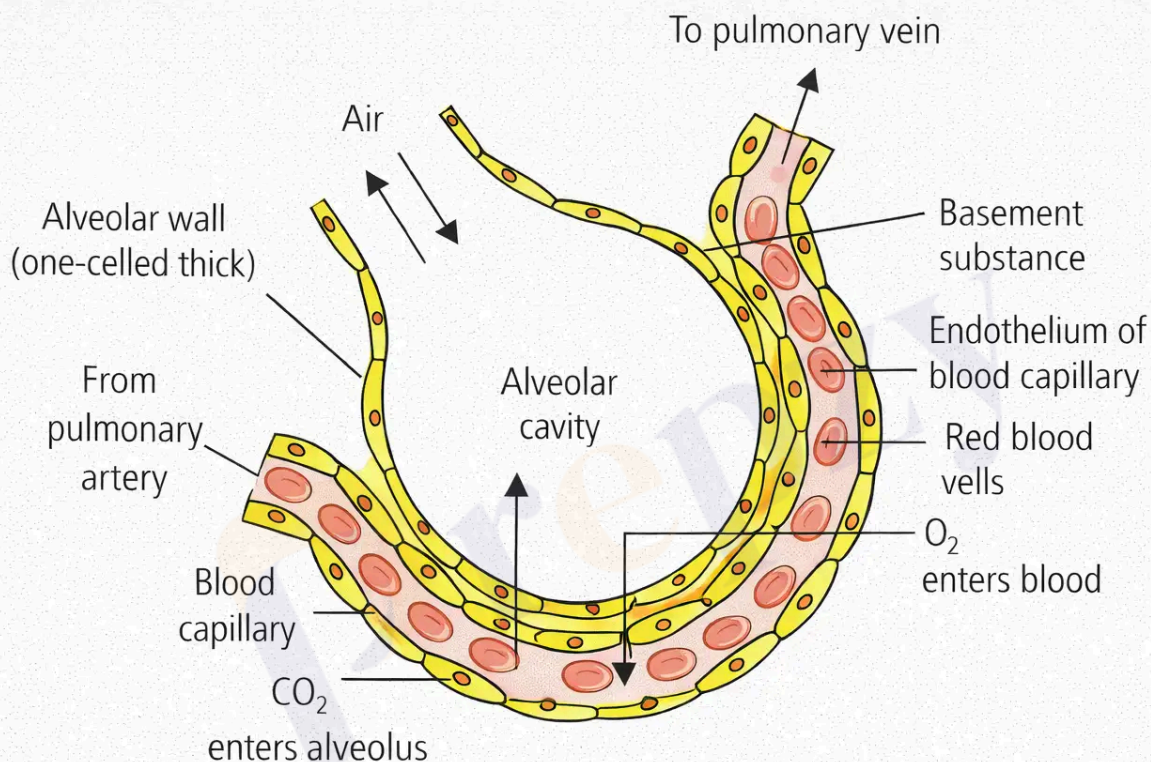


Fig.: A diagram of a section of an alveolus with a pulmonary blood capillary

Requirements for Efficient Gas Exchange

- Large surface area for gas exchange.
- Very short diffusion path between alveolar air and blood.
- Concentration gradients for oxygen and carbon dioxide.
- Presence of haemoglobin to increase O₂ and CO₂ carrying capacity.
- Thin, moist, and large respiratory membrane.

Memory Aids

- Partial pressure drives diffusion: pO_2 high to low, pCO_2 low to high.
- CO_2 diffuses faster due to higher solubility.
- Diffusion membrane is ultra-thin for quick gas exchange.
- Haemoglobin boosts oxygen and carbon dioxide transport.
- Large surface area and short path ensure efficient exchange.

Quick Checkpoints

- What is the role of partial pressure in gas exchange?
- Why does CO_2 diffuse faster than O_2 ?
- What layers form the diffusion membrane?
- How does haemoglobin aid gas transport?
- What structural features optimize alveoli for gas exchange?

Transport of Gases

Overview

- Blood transports oxygen (O_2) and carbon dioxide (CO_2).

Memory Aids

- Blood = main gas transport medium.

Quick Checkpoints

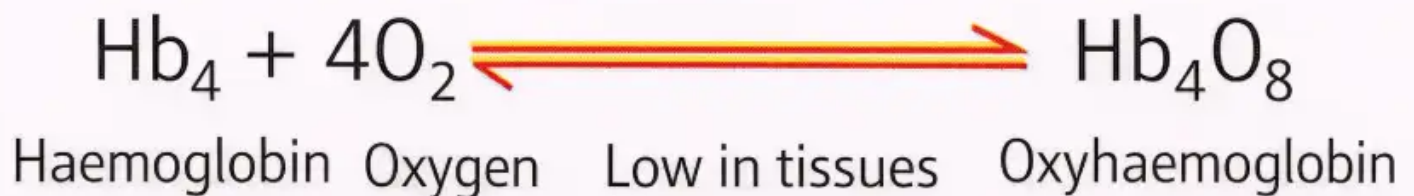
- What gases does blood transport?

Transport of Oxygen

Forms of Oxygen Transport

- Oxygen carried as dissolved gas in plasma (3%) and as oxyhaemoglobin in RBCs (97%).
- **Dissolved gas:** Oxygen is slightly soluble in plasma under normal conditions.
- **Oxyhaemoglobin:** Haemoglobin (Hb_4) in RBCs binds reversibly with 4 oxygen molecules to form Hb_4O_8 .
- Haemoglobin has high oxygen affinity, increased by low blood pCO_2 .
- Oxygen diffuses from alveoli (high pO_2) to RBCs forming oxyhaemoglobin.
- CO_2 diffusion from blood to alveoli lowers blood pCO_2 , enhancing oxygen uptake.
- Oxygen-haemoglobin dissociation curve is sigmoid, showing % saturation vs pO_2 .
- Alveolar $\text{pO}_2 \sim 105 \text{ mmHg}$; blood leaving alveoli $\sim 100 \text{ mmHg}$ due to incomplete plasma saturation.
- % saturation = % haemoglobin bound with oxygen; at 40 mmHg pO_2 , saturation $\sim 75\%$.
- Curve shifts right or left due to pO_2 , pCO_2 , H^+ concentration, temperature, and 2,3-DPG.
- **Right shift:** oxygen release favored; caused by low pO_2 , high pCO_2 , acidity, high temperature, excess 2,3-DPG.
- **Left shift:** oxygen binding favored; seen in fetal blood, alkalinity, low pCO_2 , high pO_2 , low temperature.
- Bohr effect: right shift due to increased pCO_2 at tissues, promoting oxygen release.
- Each 100 ml oxygenated blood delivers $\sim 5 \text{ ml O}_2$ to tissues.

High pO_2 in lungs



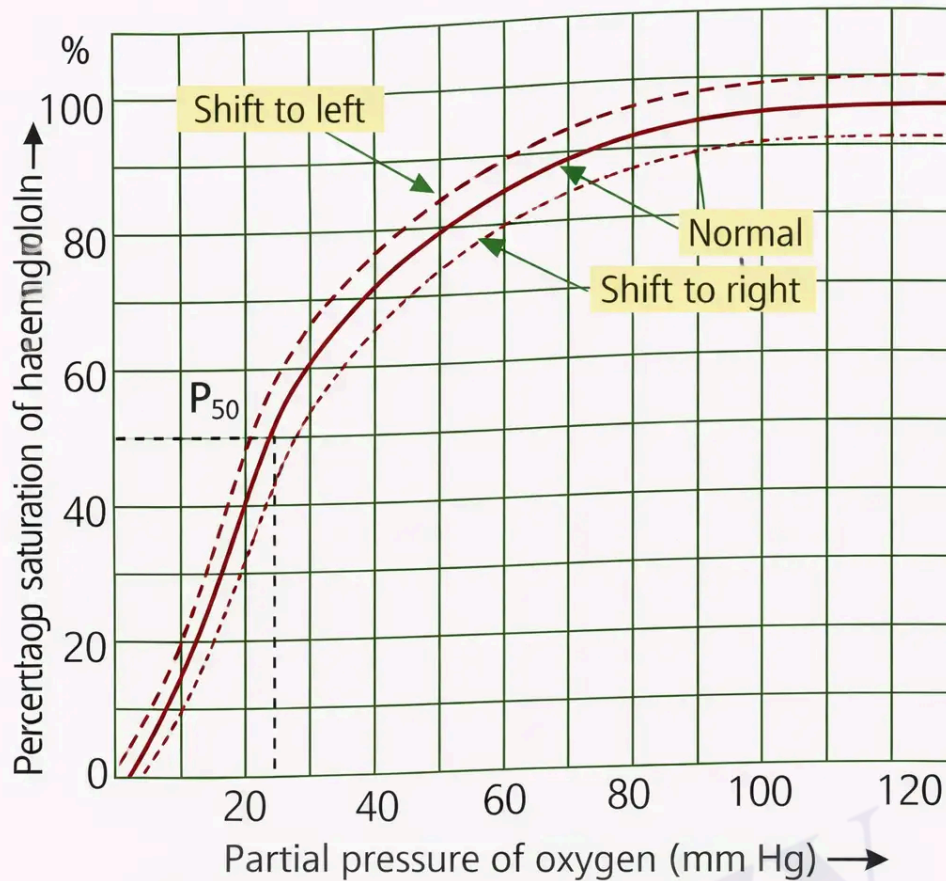


Fig: Oxygen-haemoglobin dissociation curve

Memory Aids

- Hb α_4 binds 4 O $_2$ molecules reversibly.
- Right shift = Release (R for Right, Release).
- Left shift = Load (L for Left, Load oxygen).
- Bohr effect = CO $_2$ increases oxygen release.

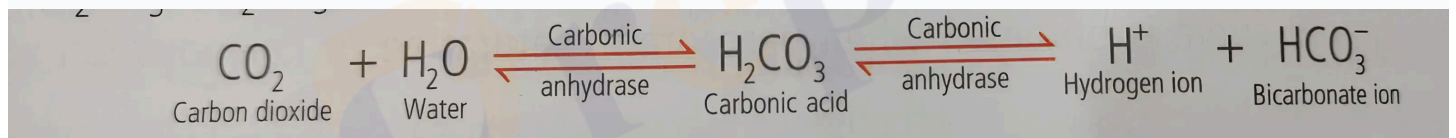
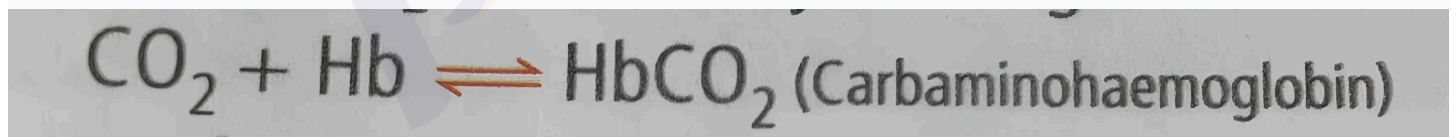
Quick Checkpoints

- What are the two forms of oxygen transport in blood?
- What causes the oxygen-haemoglobin dissociation curve to shift right?
- What is the Bohr effect?

Transport of Carbon dioxide

Forms of Carbon Dioxide Transport

- CO₂ diffuses from cells into capillaries and transported as:
- **Dissolved form:** ~7% dissolved in plasma due to high solubility.
- **Bicarbonate ions (HCO₃⁻):** ~70% converted inside RBCs; CO₂ + H₂O $\rightleftharpoons$ H₂CO₃; carbonic acid (H₂CO₃) dissociates into H⁺ and HCO₃⁻.
- Carbonic anhydrase enzyme in RBCs speeds this reaction.
- **Carbaminohaemoglobin:** ~20-25% CO₂ binds haemoglobin amine groups forming HbCO₂.
- At tissues (high pCO₂), CO₂ forms HCO₃⁻ and H⁺; at alveoli (low pCO₂), reaction reverses releasing CO₂.
- Each 100 ml deoxygenated blood delivers ~4 ml CO₂ to alveoli.
- **Chloride shift:** HCO₃⁻ exits RBCs, Cl⁻ enters to maintain ionic balance (Hamburger's phenomenon).
- **Haldane effect:** Oxygen binding to haemoglobin promotes CO₂ release; important for CO₂ transport.



Memory Aids

- CO₂ transport: Dissolved, Bicarbonate, Carbaminohaemoglobin.
- Chloride shift = Cl⁻ in, HCO₃⁻ out.
- Haldane effect = O₂ binding displaces CO₂.

Quick Checkpoints

- What are the three forms of CO₂ transport in blood?
- What enzyme speeds CO₂ conversion to bicarbonate?

- What is the chloride shift?
- Explain the Haldane effect.

Regulation of Respiration

Neural Control

- Breathing rate and depth controlled by neurons in medulla oblongata and pons varolii.
- Medulla oblongata has dorsal respiratory group (inspiration) and ventral respiratory group (inspiration or expiration).
- These groups form the respiratory rhythm centre.
- Pons varolii contains pneumotaxic centre that limits inspiration to control respiratory rate.

Chemical Control

- Chemoreceptors in carotid and aortic bodies monitor CO_2 and H^+ levels.
- Changes in CO_2 and H^+ send signals to respiratory rhythm centre for adjustment.
- Oxygen has minimal role in respiratory rhythm regulation.

Memory Aids

- "Dorsal = Drive In" (dorsal group causes inspiration).
- "Ventral = Versatile" (ventral group controls both inspiration and expiration).
- "Pneumotaxic = Pause" (limits inspiration duration).
- CO_2 and H^+ are key chemical signals, not oxygen.

Quick Checkpoints

- Which brain regions control breathing rhythm?
- What roles do dorsal and ventral respiratory groups play?
- How does the pneumotaxic centre affect breathing?
- Where are chemoreceptors located for chemical regulation?
- Which chemicals primarily regulate respiration?
- Does oxygen significantly regulate respiratory rhythm?

Disorders of Respiratory System

Common Respiratory Disorders

- **Asthma:** Difficulty in breathing with wheezing and coughing due to excess mucus blocking bronchi and bronchioles.
- **Emphysema:** Chronic damage to alveolar walls reducing respiratory surface; major cause is cigarette smoking.
- **Occupational Respiratory Disorders:** Caused by long-term inhalation of dust (e.g., silica, asbestos) leading to lung inflammation and fibrosis; examples include silicosis and asbestosis. Protective masks recommended.
- **Hypoxia:** Condition of oxygen deficiency in tissues.
- **Asphyxia:** Decreased oxygen and increased carbon dioxide in blood paralyzes respiratory center, stopping breathing and causing death.
- **Bronchitis:** Inflammation of bronchi with excessive mucus causing cough and greenish-yellow sputum; caused by infection, smoking, and pollutants.
- **COPD (Chronic Obstructive Pulmonary Disease):** Group of lung diseases including chronic bronchitis, emphysema, and chronic asthma.

Memory Aids

- Asthma: *Airway mucus blocks breathing.*
- Emphysema: *Alveolar walls destroyed by smoking.*
- Occupational disorders: *Dust exposure causes fibrosis.*
- Hypoxia: *Low oxygen in tissues.*
- Asphyxia: *Oxygen down, CO₂ up, breathing stops.*
- Bronchitis: *Bronchi inflamed, mucus cough.*
- COPD: *Chronic lung diseases combined.*

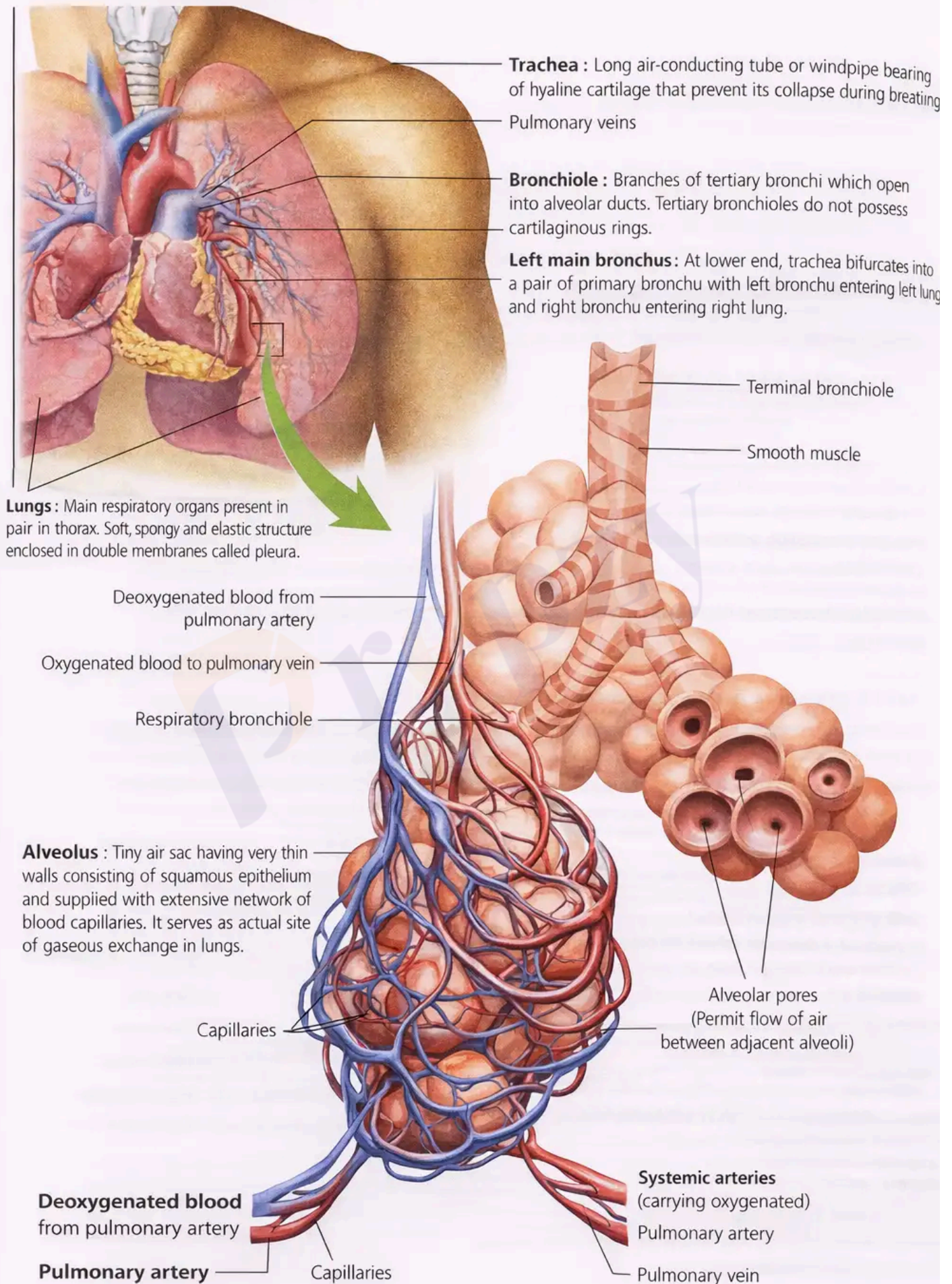
Quick Checkpoints

- What causes airway obstruction in asthma?
- How does emphysema affect alveoli?
- Which dusts cause occupational lung diseases?
- Define hypoxia in simple terms.

- What happens to respiratory center in asphyxia?
- Identify causes of bronchitis.
- What diseases are included in COPD?

Prepzy

Human Respiratory System



Respiratory System Overview

- Air enters through trachea, kept open by cartilage.
- Trachea divides into left and right main bronchi leading to lungs.
- Bronchi branch into smaller bronchioles ending in alveoli.
- Alveoli surrounded by capillaries for gas exchange.
- Deoxygenated blood arrives via pulmonary artery.
- Oxygen enters blood; oxygenated blood leaves via pulmonary veins.
- Alveolar pores allow air movement between alveoli for efficient gas exchange.

Memory Aids

- Trachea: *Cartilage keeps airway open.*
- Bronchi: *Main airways to lungs.*
- Alveoli: *Site of oxygen and CO₂ exchange.*
- Blood flow: *Pulmonary artery in, vein out.*
- Alveolar pores: *Equalize air pressure.*

Quick Checkpoints

- Trace the path of air from trachea to alveoli.
- Where does gas exchange occur?
- Which vessels carry deoxygenated and oxygenated blood?
- What is the role of alveolar pores?