# Respiration in Mammals

## Mechanism of Respiration

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All animals depend on oxidation of food materials for their energy requirements. They utilize oxygen and produce carbon dioxide during the course of their metabolism. The process of oxygen uptake and release of carbon dioxide is called respiration. Respiration, includes two processes:

1) **External respiration,** which involves the absorption of $O_2$ and removal of $CO_2$ from the body as a whole; and
2) **Internal respiration,** that involves utilization of $O_2$ and production of $CO_2$ by cells and the gaseous exchanges between the cells and their fluid medium.

Firstly, we need to understand some of the physical properties of gases as, it is important for you to understand the underlying principles of gases and their behavior. This will help you in understanding respiratory physiology. The exchange of oxygen and carbon dioxide within an organism can occur only when they cross a barrier of living tissue. In the simplest animals gas exchange, takes place through the skin or or through the plasma membrane (unicellular). In most multicellular animals respiration is more complex as all the cells of the multicellular organism are not in direct contact with the respiratory medium (air or water). Therefore, respiratory strategy of animals depends on the medium in which the animal lives (aquatic or terrestrial).

# RESPIRATORY GASES

You must have studied in Class XI that physiologically the most important gases are oxygen, carbon dioxide and nitrogen. Molecular oxygen comprises 21% of the atmospheric air; carbon dioxide makes up only 0.3% while nitrogen forms 78.0%. All the gases present in the air exert a combined pressure which is referred to as **one atmosphere** (760 mm Hg = millimeters of mercury) or 101.3 k Pa (kilogram Pascal). You must remember that all the gases of concern in respiratory physiology are simple molecules that are free to move among one another, by the process called "diffusion."

Most of the oxygen is in the air but some of it is also dissolved in the water bodies. An animal's immediate source of oxygen or respiratory medium depending on its habitat therefore, is either air or water. Comparison of the gaseous composition and physical characteristics of air and water highlight the adaptations made by terrestrial and aquatic animals to overcome the problems of respiration. For example, the oxygen content of air is about 20 times that of water saturated with air. The diffusion rate for oxygen in air is much more than the diffusion rate in water. Moreover, carbon dioxide diffuses more rapidly from air into water. Thus, extraction of oxygen and elimination of carbon dioxide from different media (water and air) require special strategies depending on the physical properties of gases.

To understand the physiology of respiration, you must have a basic knowledge of some of the physical properties of gases. The exchange of oxygen and carbon dioxide either in the respiratory organ or at the tissue level is dependent on the partial pressure, concentration and diffusion of gases. Let us consider them one by one.

# Partial Pressure

Have you ever got the pressure of air in the tire/ tube of your car/bike/scooty/cycle checked? When you do this, you are measuring the pressure exerted by the gas molecules colliding with the walls of the tire/ tube. You all know that air is a mixture of different gases. Therefore, the total pressure P in that tire/tube will be a sum of the **partial pressures** exerted by all the gases in the mixture. This is **Dalton's law of partial pressures.** Dalton's law of partial pressures states that the total pressure of a mixture of gases is equal to the sum of the partial pressures of the component gases:

$$P_{Total} = P_{gas\,1} + P_{gas\,2} + P_{gas\,3} \ldots$$

So, we can calculate partial pressure of a gas x as:

$$\mathbf{Px=(x/100)P} \qquad \text{...(1)}$$

where Px is the partial pressure of the gas

x is the percentage of the specific gas in the total volume

P is the total pressure of the mixture (101.3 k Pa or 760 mm Hg, for dry air).

Thus partial pressure for oxygen at sea level would be

$$Po_2 = \frac{21}{100} x760 = 159.6 = 160 \text{ mmHg}$$

and for carbon dioxide the value would be

$$Po_2 = \frac{0.03}{100} \times 760 = 0.228 = 0.3 \text{ mm Hg}$$

When you calculate the partial pressure of a gas in air, you must remember that atmospheric air is not always dry. It usually contains water vapour which contributes to the total pressure of atmospheric gases. The amount of water vapour varies with temperature. For instance at 37$^{O}$C the partial pressure of water vapour – $P_{wv}$ is about 47.26 mm Hg. Under these conditions we subtract the water vapour from total atmospheric pressure as gases contribute only 712.74 mm Hg of the total pressure. Therefore, the equation (1) given above must be modified to accommodate water vapour.

$$\mathbf{p_x = \frac{x}{100} \ (P - P_{wv})} \qquad \mathbf{....(2)}$$

Therefore, when we calculate the partial pressures at sea level of the other gases in the air reaching the lungs we will get $Po_2$ (partial pressure of oxygen) =160 mm Hg; $Pco_2$ (partial pressure of carbon dioxide) = 0.3 mm Hg; and $P_{N2}$ (partial pressure of nitrogen + including the other inert gases) = 564 mm Hg.

Table 2.1: Major advantages of breathing air.

| Properties | Air | Water |
|---|---|---|
| Solubility of oxygen at 15°C | Air contains 209 ml of oxygen per litre | 7 ml of oxygen per litre |
| Energy needed to move medium (air or water) over the respiratory surface | Less energy needed to move air over the respiratory surface | More energy needed to move water over the respiratory surface as water is much more viscous than air, |
| Diffusion of Oxygen | Oxygen diffuses some 10,000 times more rapidly in air than in water and so can diffuse in lungs over several millimeters | Oxygen diffusion is slow from water to the respiratory surface in fish gill that thus take place only in a tiny fraction of a mulimeter. |

Lungs are of two types i) **diffusion lungs** which are characterised by air exchange with surrounding environment by means of diffusion only and are present in small animals such as pulmonate snails, small scorpions, some spiders and some isopods; ii) **ventilation lungs** which are typical of vertebrates. The air passes through a tube into inflatable lungs where gas exchange takes place and oxygen poor air and carbon dioxide rich air is then forced out usually through the same tube. This is known as **tidal flow of air.**

# HUMANS RESPIRATORY SYSTEM

The respiratory system begins at the nose and ends in the most distal **alveolus** (plu: alveoli) contained within the lung (Fig 2.2)**. Alveolus** refers to any of the many tiny air sacs of the lungs which allow for rapid gaseous exchange. The Respiratory system is divided into: upper airway and lower airway. The **upper airway** consists of all structures from the nose to the vocal cords, including sinuses and the larynx, whereas the **lower airway** consists of the trachea and airways (namely, paired bronchi and bronchioles and alveoli in the lungs).

**The respiratory system is made up of the following:**

1. The **nasal cavity,**
2. the **posterior pharynx,**
3. the **glottis** and **vocal cords,**
4. the **trachea,** and
5. Main stem bronchus
6. Lung with the **tracheobronchial tree structure, consisting of** the single tracheary paired lobar bronchi (plu: bronchus), branched segmental bronchi, branched **bronchioles,** and (sing : alveolus).

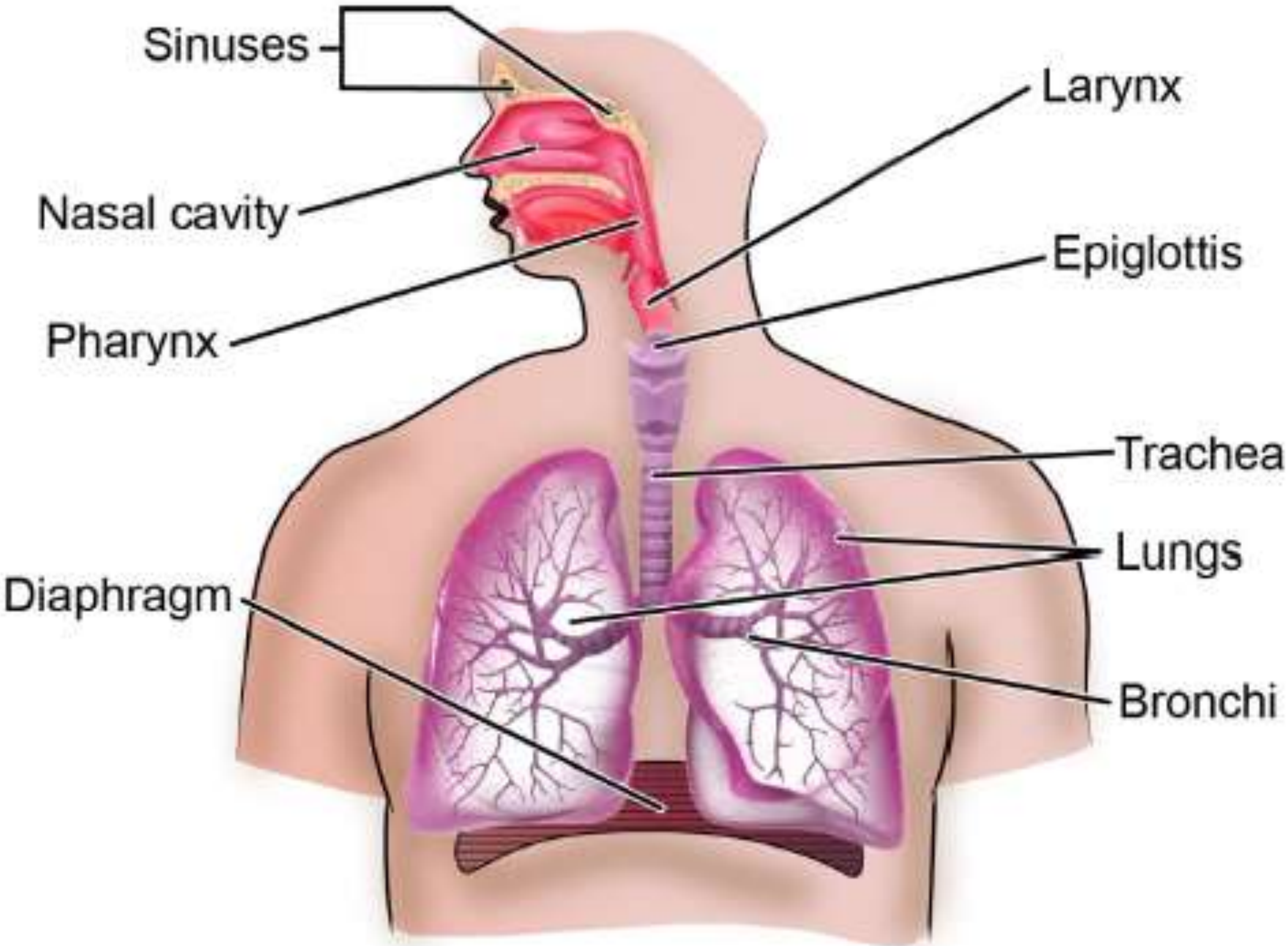


Fig. 2.2: The human respiratory system.

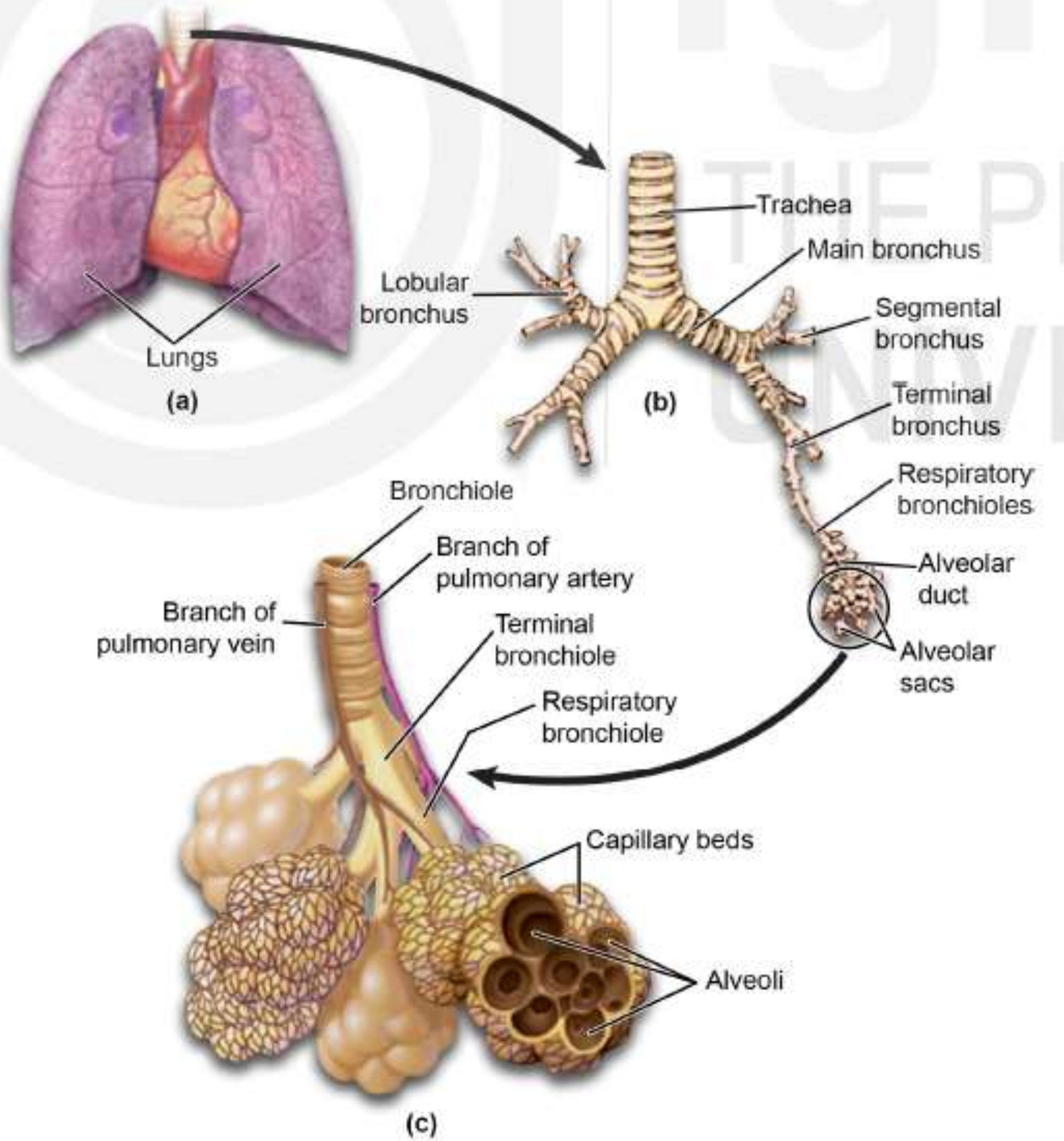


**Fig. 2.4 : a) Human lung; b) The bronchial tree of the respiratory tract; c) The terminal bronchiole enlarged to show the respiratory bronchioles ending in clusters of alveoli.**

# Gas Exchange in Alveoli

The major function of the lungs is to enable gas exchange between the inspired oxygen rich and the deoxygenated blood that comes from the body tissues to the heart and from there by the pulmonary artery to the lungs. Erythrocytes also known as red blood cells the respiratory tract is richly supplied with blood vessels both arteries venis respiratory. In this pigment lungs or RBC of blood, pick up oxygen from the oxygen rich inspired air and transport it to tissues throughout the body on its return journey. Thus the circulatory system of the body plays an important role in gas exchange. The pulmonary artery branches multiple times as it follows the bronchi, and each branch becomes progressively smaller in diameter. One arteriole and an accompanying venule supply and drain respectively one alveolar lobule. As they reach near the alveoli, the pulmonary arterioles become the pulmonary capillary network. The pulmonary capillary network consists of tiny vessels with very thin walls that lack smooth muscle fibers. The capillaries branch and follow the respiratory bronchioles and structure of the alveoli. It is at this point that the capillary wall meets the alveolar wall, creating the respiratory membrane. Once the blood is oxygenated, it drains from the alveoli by way of multiple bronchial veins.

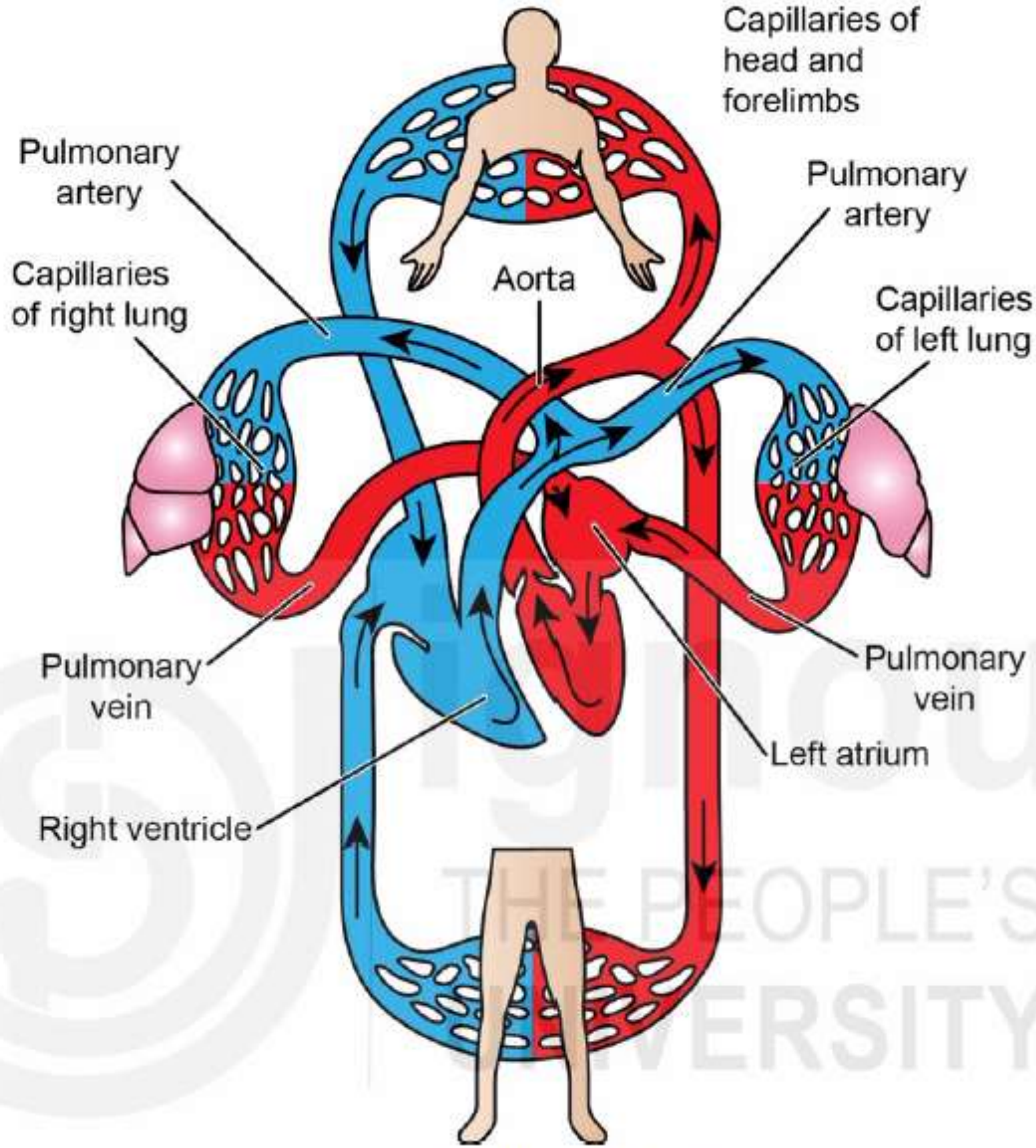


**Fig. 2.9: Blood supply to lungs.**

Trachea, bronchi and their branches are only connecting tubes and no exchange of gases take place in them. **Gas exchange takes place only in the respiratory bronchioles, alveolar ducts and alveolar sacs.** The oxygenated blood that enters the lungs from the heart is routed through body tissue where mitochondrial respiration, depletes the oxygen content. Thus lowery the partial pressure of oxygen ($PO_2$ = about 40 mm Hg). At the same time metabolic activity increases partial pressure of carbon dioxide in the cells of body tissue which increase partial pressure of carbon dioxide of blood entering the alveoli is 45 mm Hg. Thus, compared to partial pressures in the atmosphere, ($PO_2$=158 and $Pco_2$ =0.3) the blood entering lungs from the body tissue has low $Po_2$ and high $Pco_2$. This difference in partial pressure of oxygen in alveoli which contains the oxygen rich atmospheric air causes the oxygen and carbon dioxides gases to diffuse along their partial pressure gradient. The whole process of exchange is depicted in Fig. 2.9.

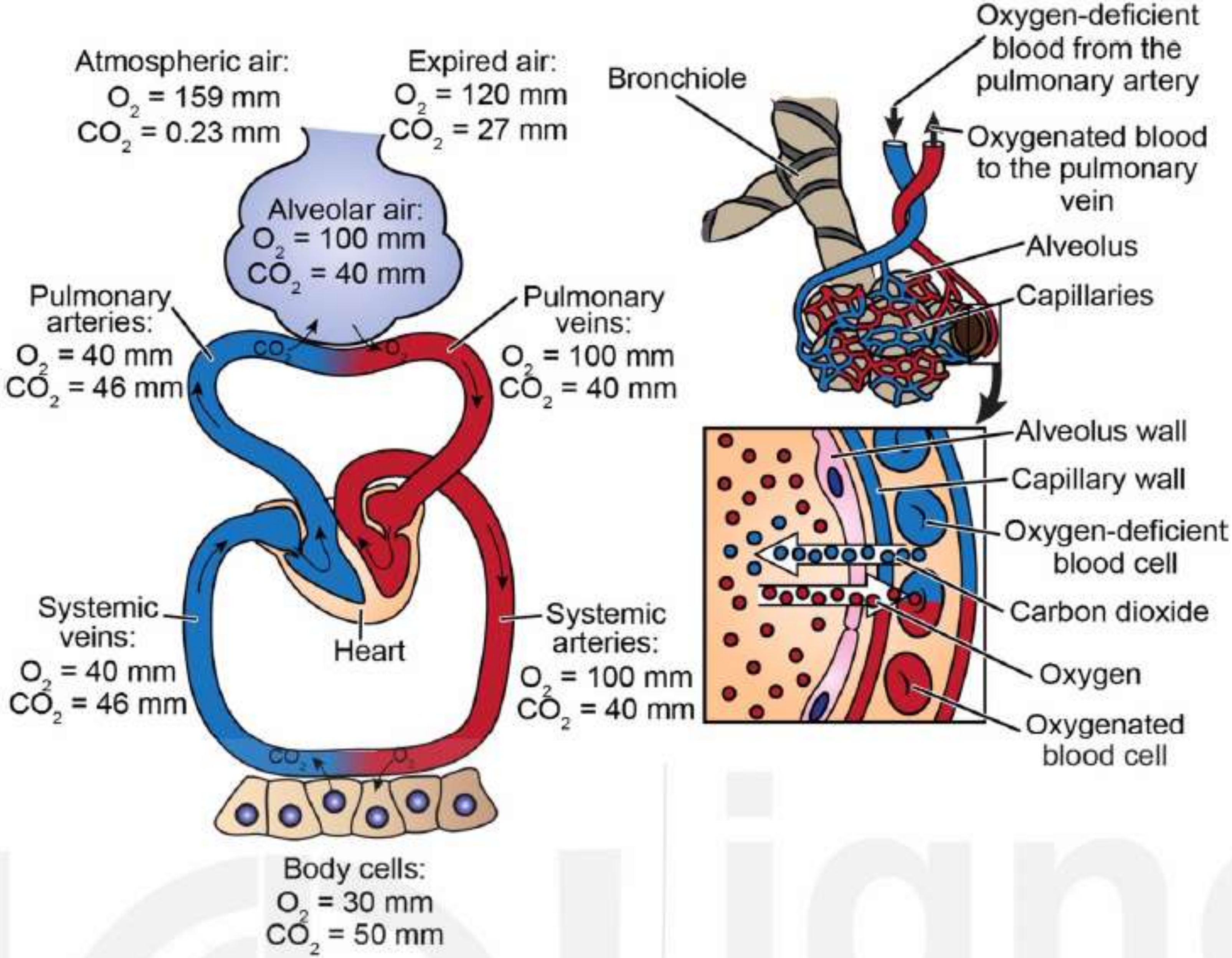


**Fig. 2.10: Exchange of respiratory gases in alveoli in lungs and tissue cells.**