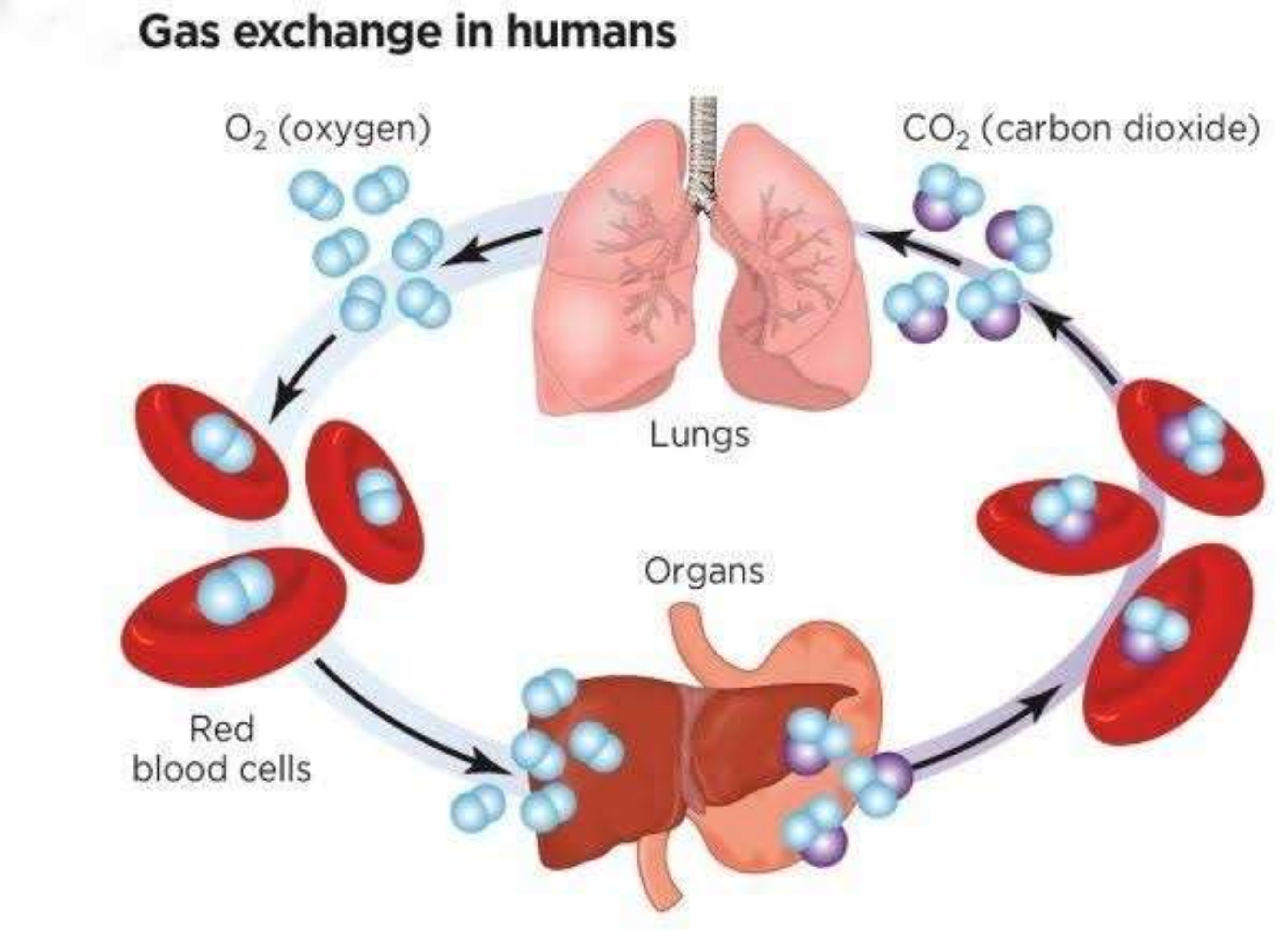
EXCHANGE OF RESPIRATORY GASES

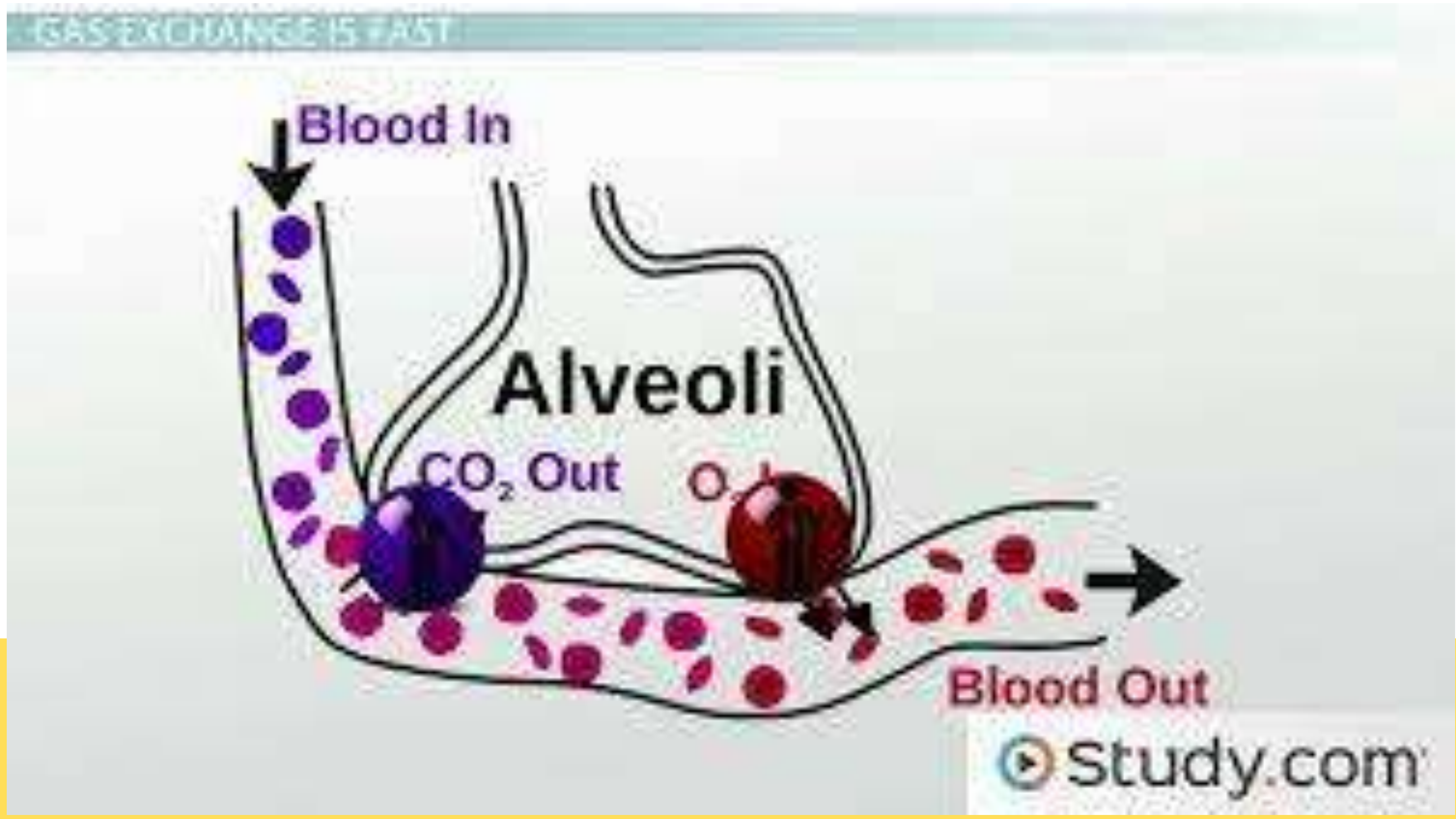


INTRODUCTION

Oxygen is essential for the cells.

Carbon dioxide, which is produced as waste product in the cells must be expelled from the cells and body.

Lungs serve to exchange these two gases with blood.



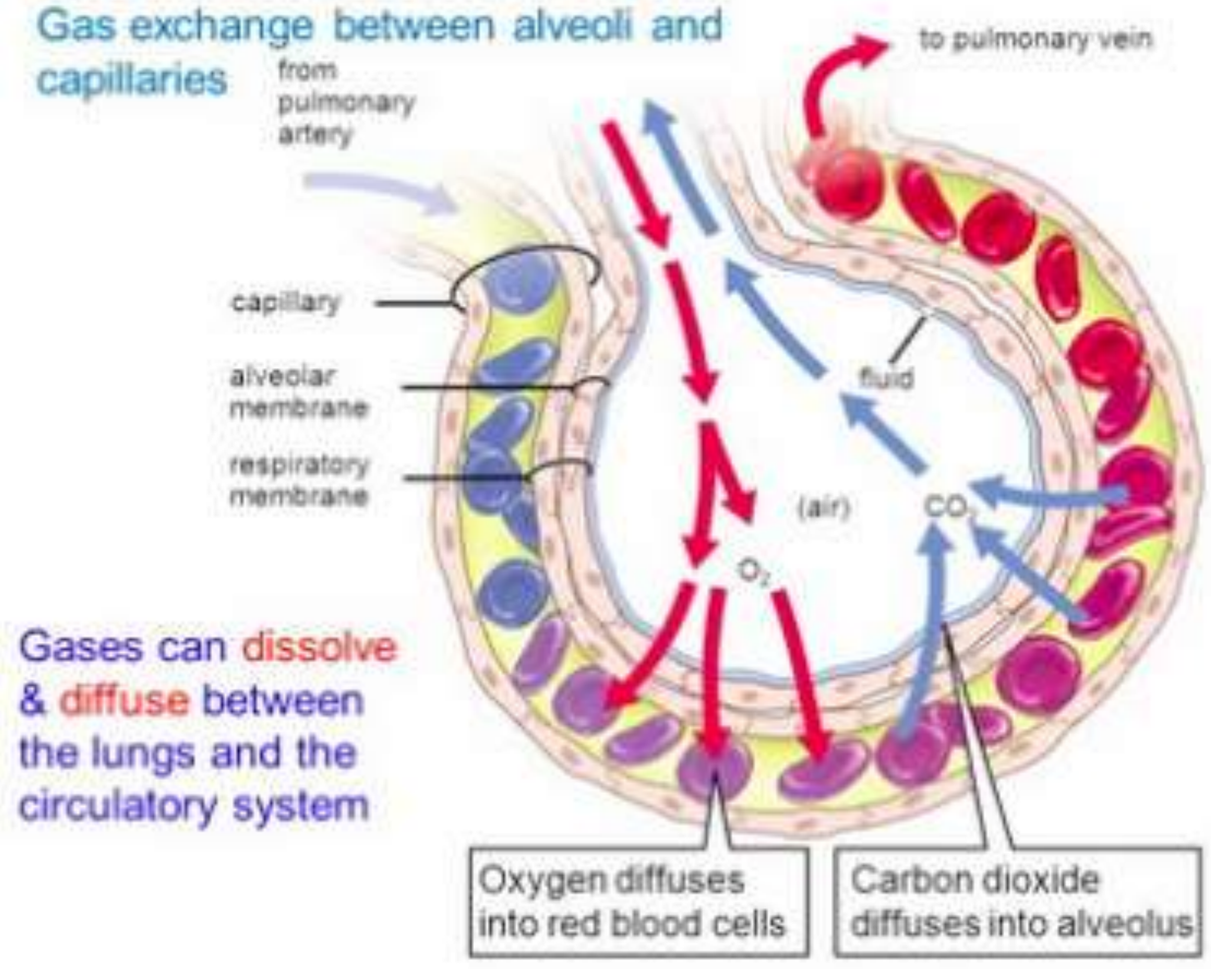
EXCHANGE OF RESPIRATORY GASES IN LUNGS

In the lungs, exchange of respiratory gases takes place between the alveoli of lungs and the blood.

Oxygen enters the blood from alveoli and carbon dioxide is expelled out of blood into alveoli.

Exchange occurs through bulk flow diffusion.

Exchange of gases between blood and alveoli takes place through respiratory membrane.



RESPIRATORY MEMBRANE

Respiratory membrane is a membranous structure through which exchange of respiratory gases takes place.

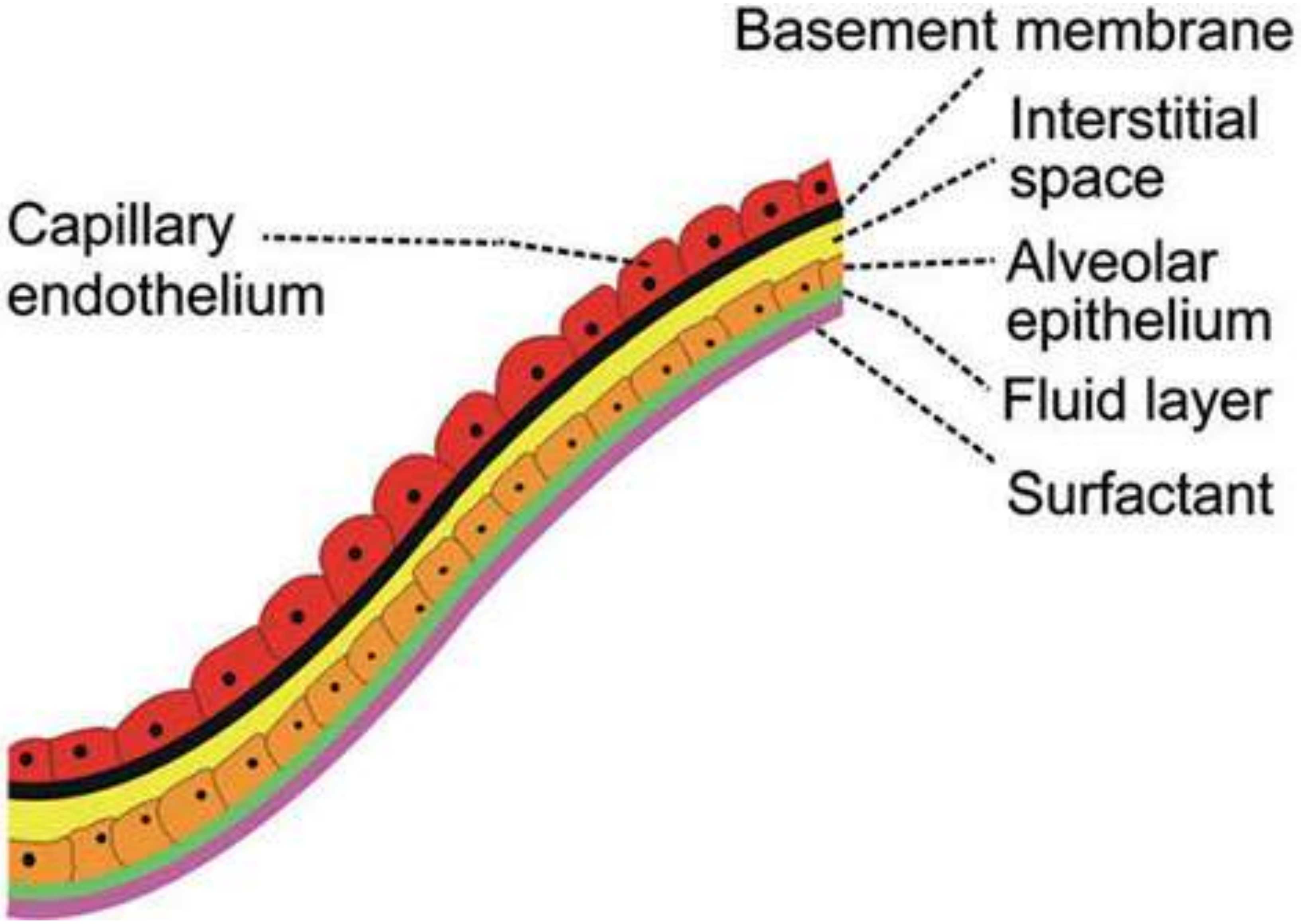
It is formed by epithelium of respiratory unit and endothelium of pulmonary capillary.

Epithelium of respiratory unit is a very thin layer .

Since, the capillaries are in close contact with this membrane, alveolar air is in close proximity to capillary blood.

This facilitates gaseous exchange between air and blood .

Respiratory membrane is formed by different layers of structures belonging to the alveoli and capillaries.


Basement membrane
Interstitial space
Capillary endothelium
Alveolar epithelium
Fluid layer
Surfactant

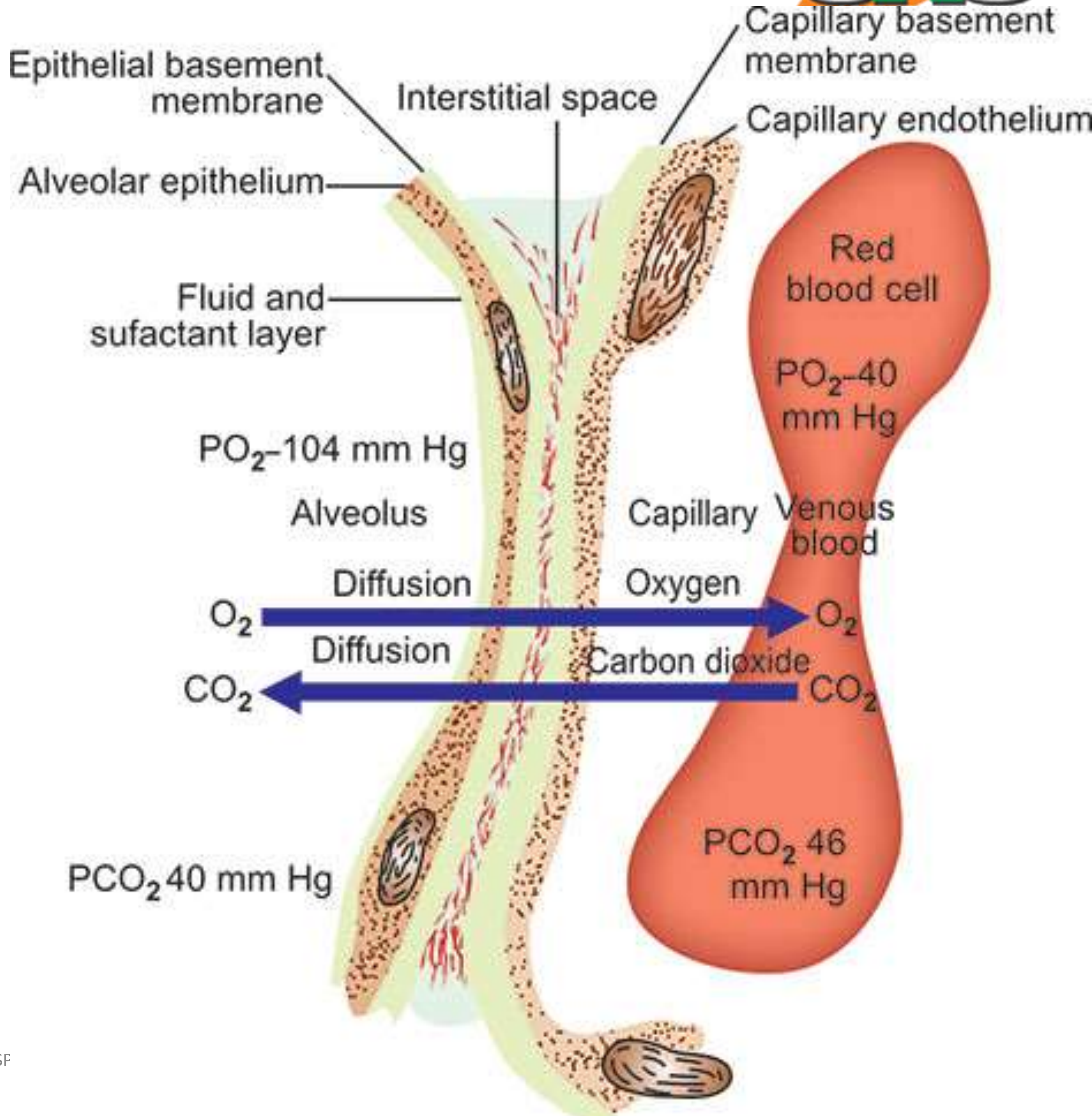
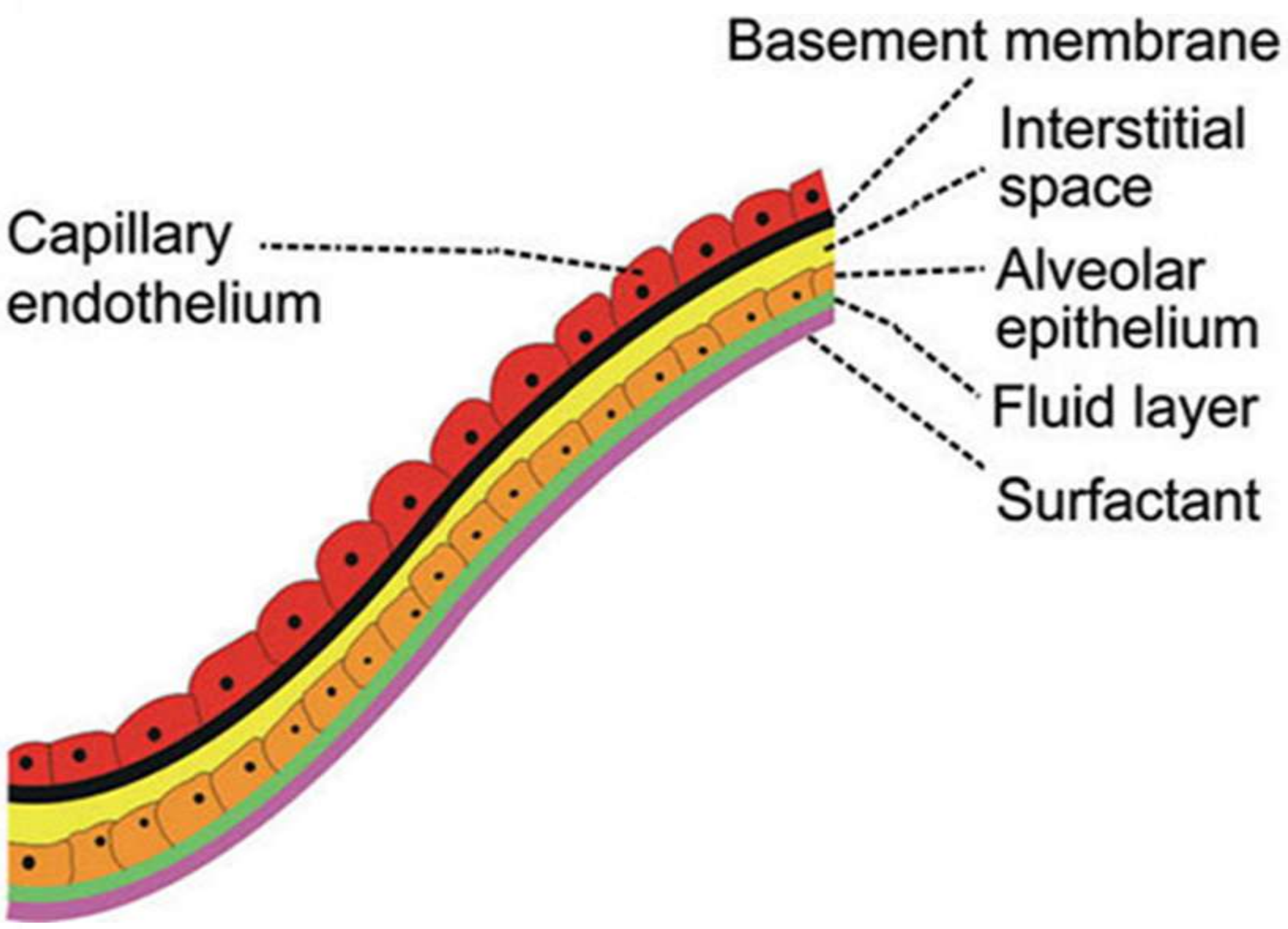

Capillary basement membrane
Epithelial basement membrane
Interstitial space
Capillary endothelium
Alveolar epithelium
Red blood cell
Fluid and sufactant layer
PO_2–40 mm Hg
PO_2–104 mm Hg
Alveolus
Capillary
Venous blood
Diffusion
Oxygen
O_2
O_2
Diffusion
Carbon dioxide
CO_2
CO_2
PCO_2 46 mm Hg
PCO_2 40 mm Hg

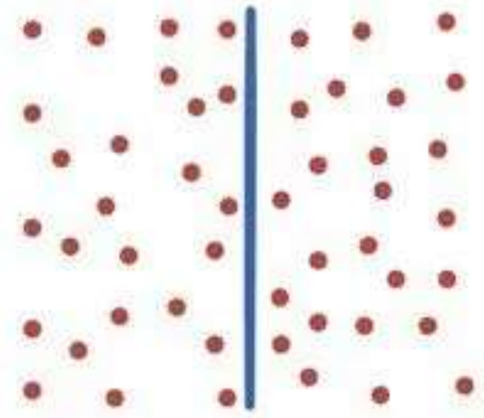
TABLE 124.1: Layers of respiratory membrane

Portion	Layers
Alveolar portion	1. Monomolecular layer of surfactant, which spreads over the surface of alveoli 2. Thin fluid layer that lines the alveoli 3. Alveolar epithelial layer, which is composed of thin epithelial cells resting on a basement membrane
Between alveolar and capillary portions	4. An interstitial space
Capillary portion	5. Basement membrane of capillary 6. Capillary endothelial cells



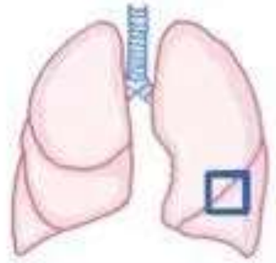
GAS EXCHANGE

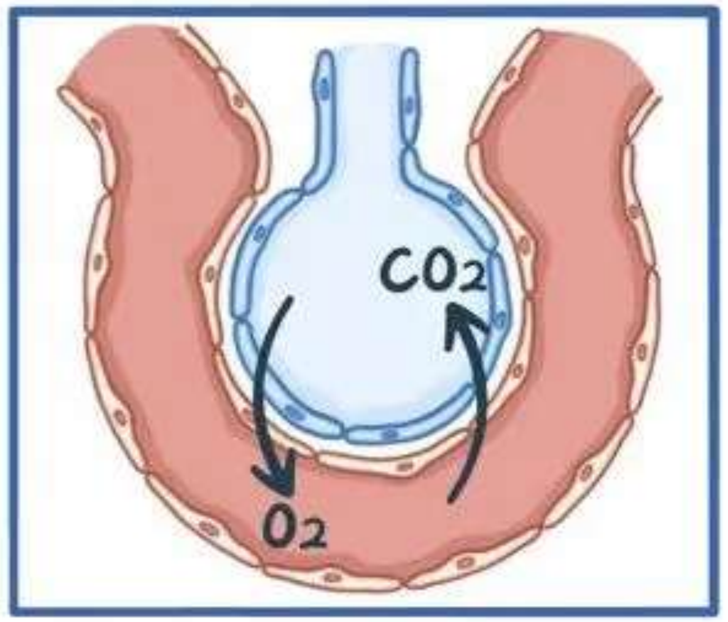
- GASES MOVE PASSIVELY



EXTERNAL RESPIRATION

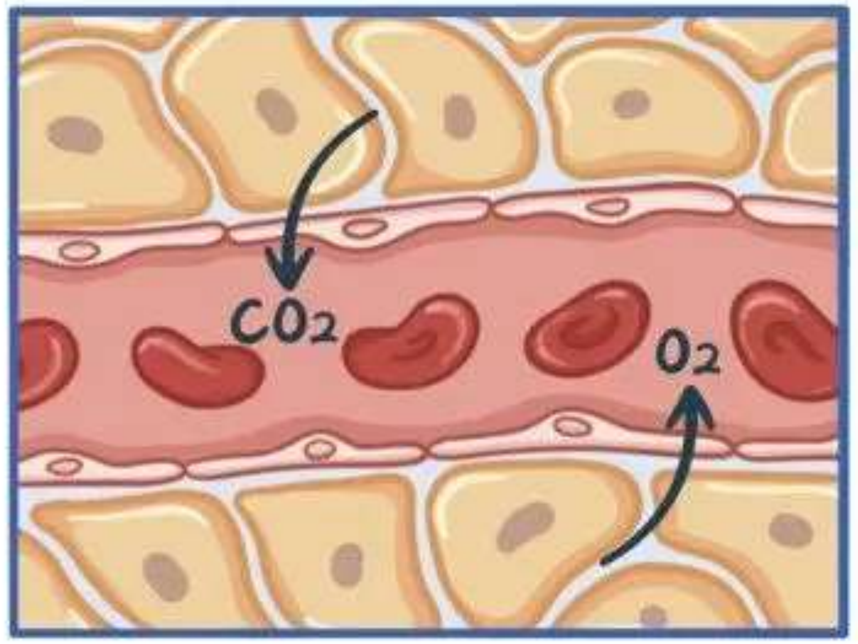
- BULK FLOW of AIR INTO & OUT of the LUNGS





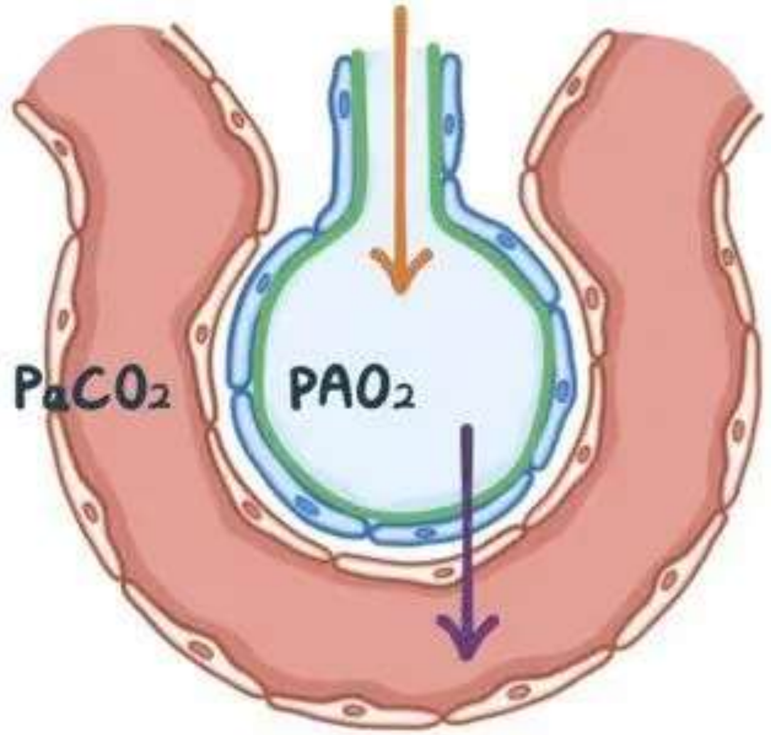
INTERNAL RESPIRATION

- CAPILLARY GAS EXCHANGE in BODY TISSUES



* FLOW of AIR from the EXTERNAL ENVIRONMENT HAPPENS DUE to PRESSURE CHANGES in the LUNGS

* ALVEOLAR GAS EXCHANGE
  1. SURFACE AREA
  2. PARTIAL PRESSURE GRADIENTS of GASES
  3. MATCHING of VENTILATION & PERFUSION



LAYERS OF RESPIRATORY MEMBRANE

Different layers of respiratory membrane from within outside.

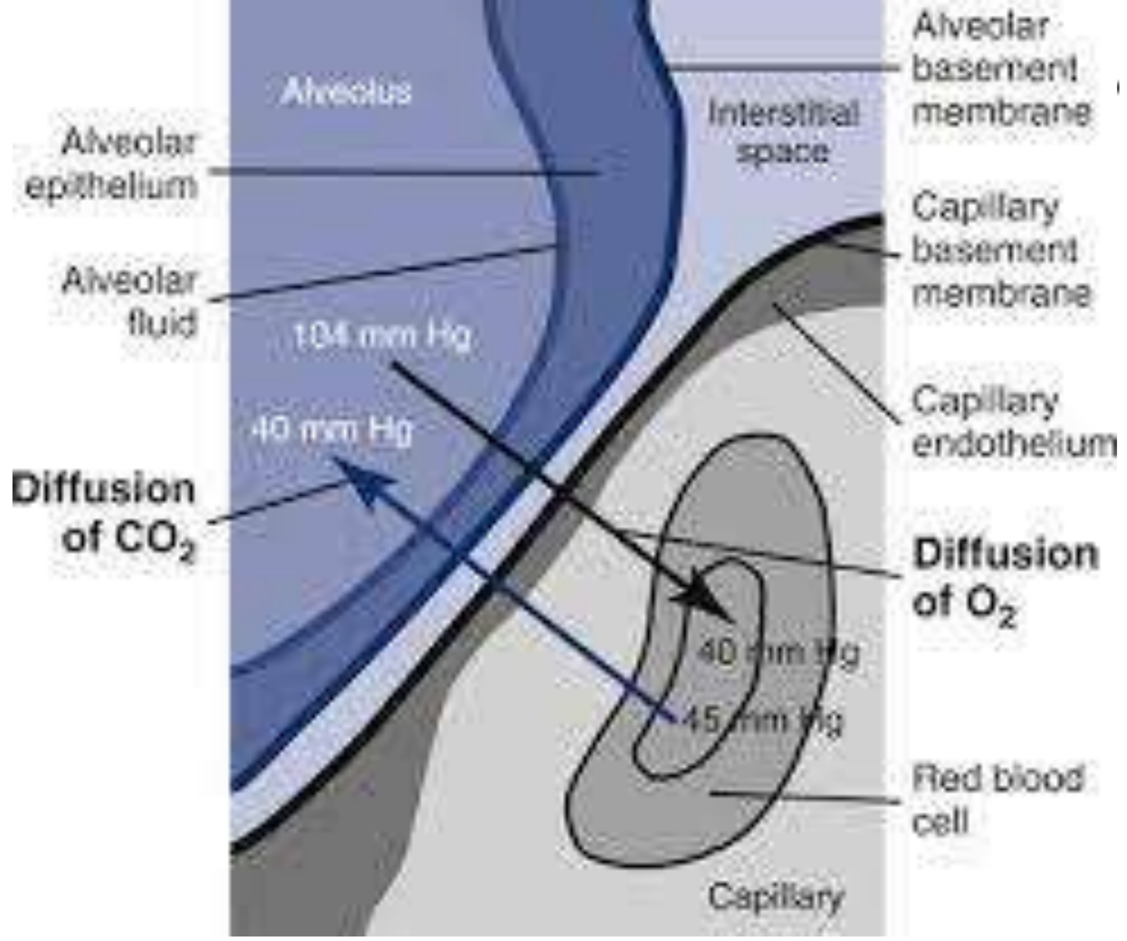
In spite of having many layers, respiratory membrane is very thin with an average thickness of 0.5 μ.

Total surface area of the respiratory membrane in both the lungs is about 70 square meter.

Average diameter of pulmonary capillary is only 8 μ, which means that the RBCs with a diameter of 7.4 μ actually squeeze through the capillaries.

Therefore, the membrane of RBCs is in close contact with capillary wall.

This facilitates quick exchange of oxygen and carbon dioxide between the blood and alveoli.



DIFFUSING CAPACITY

Diffusing capacity is defined as the volume of gas that diffuses through the respiratory membrane each minute for a pressure gradient of 1 mm Hg.

Diffusing Capacity for Oxygen and Carbon Dioxide

Diffusing capacity for oxygen is 21 mL/minute/1 mm Hg.
Diffusing capacity for carbon dioxide is 400 mL/minute/1 mm Hg.
Thus, the diffusing capacity for carbon dioxide is about 20 times more than that of oxygen.

Factors Affecting Diffusing Capacity

1. Pressure gradient

Diffusing capacity is directly proportional to pressure gradient.

Pressure gradient is the difference between the partial pressure of a gas in alveoli and pulmonary capillary blood

It is the major factor, which affects the diffusing capacity.

2. Solubility of gas in fluid medium

Diffusing capacity is directly proportional to solubility of the gas.

If the solubility of a gas is more in the fluid medium, a large number of molecules dissolve in it and diffuse easily

3. Total surface area of respiratory membrane

Diffusing capacity is directly proportional to surface area of respiratory membrane.

Surface area of respiratory membrane in each lung is about 70 sq m.

If the total surface area of respiratory membrane decreases, the diffusing capacity for the gases is decreased.

Diffusing capacity is decreased in emphysema in which many of the **alveoli are collapsed because of heavy smoking or oxidant gases**

4. Molecular weight of the gas

Diffusing capacity is inversely proportional to molecular weight of the gas.

If the molecular weight is more, the density is more and the rate of diffusion is less.

5. Thickness of respiratory membrane

Diffusion is inversely proportional to the thickness of respiratory membrane.

More the thickness of respiratory membrane less is the diffusion.

It is because the distance through which the diffusion takes place is long.

In conditions like **fibrosis and edema, the diffusion rate is reduced, because the thickness of respiratory membrane is increased**.

Relation between Diffusing Capacity and Factors Affecting it

Relation between diffusing capacity and the factors affecting it is expressed by the following formula:

$$DC \propto \frac{Pg \times S \times A}{Mw \times D}$$

DC = Diffusing capacity
Pg = Pressure gradient
S = Solubility of gas
A = Surface area of respiratory membrane
Mw = Molecular weight
D = Thickness of respiratory membrane.

DIFFUSION COEFFICIENT AND FICK LAW OF DIFFUSION

Diffusion Coefficient

Diffusion coefficient is defined as a constant (a factor of proportionality), which is the measure of a substance diffusing through the concentration gradient.

It is also known as diffusion constant.

It is related to size and shape of the molecules of the substance.

Fick Law of Diffusion

Diffusion is well described by Fick law of diffusion.

According to this law, amount of a substance crossing a given area is directly proportional to the area available for diffusion, concentration gradient and a constant known as diffusion coefficient.

Fick's First Law

Movement of particles (diffusion flux) from high to low concentration is directly proportional to the particle's concentration gradient

$$J \propto \frac{d\varphi}{dx} \quad \text{or} \quad J = -D\frac{d\varphi}{dx}$$

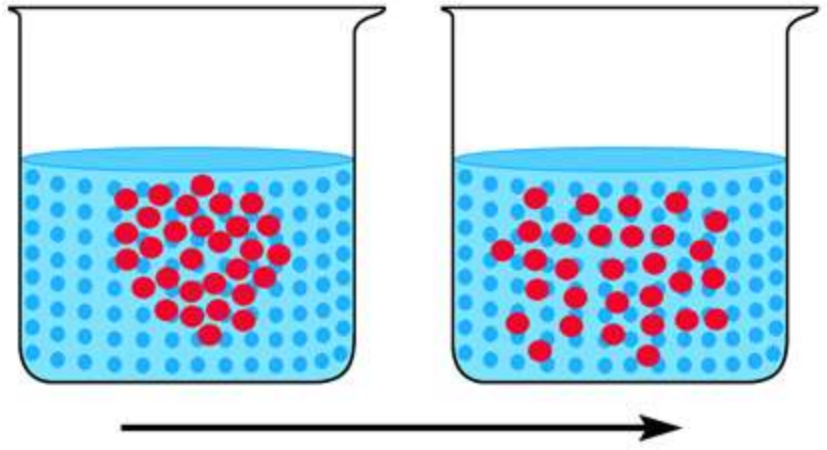
J = diffusion flux

D = diffusion coefficient or diffusivity

$d\varphi$ = change in concentration of the particle

dx = change in position

$\frac{d\varphi}{dx}$ = concentration gradient of the particle



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Thus,

Amount diffused = Area × Concentration gradient × Diffusion coefficient

Formula of Fick law:

$$J = -D \times A \times \frac{dc}{dx}$$

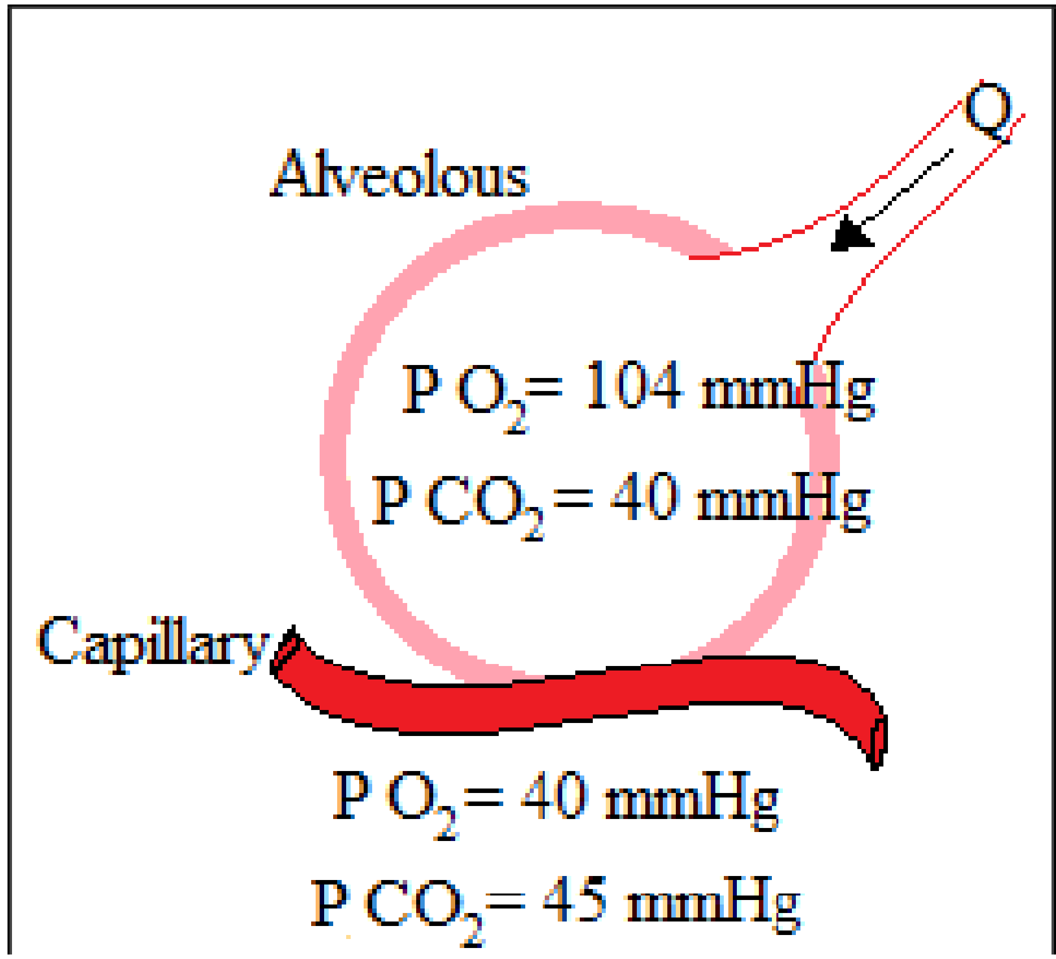
Where,

J = Amount of substance diffused

D = Diffusion coefficient

A = Area through which diffusion occurs

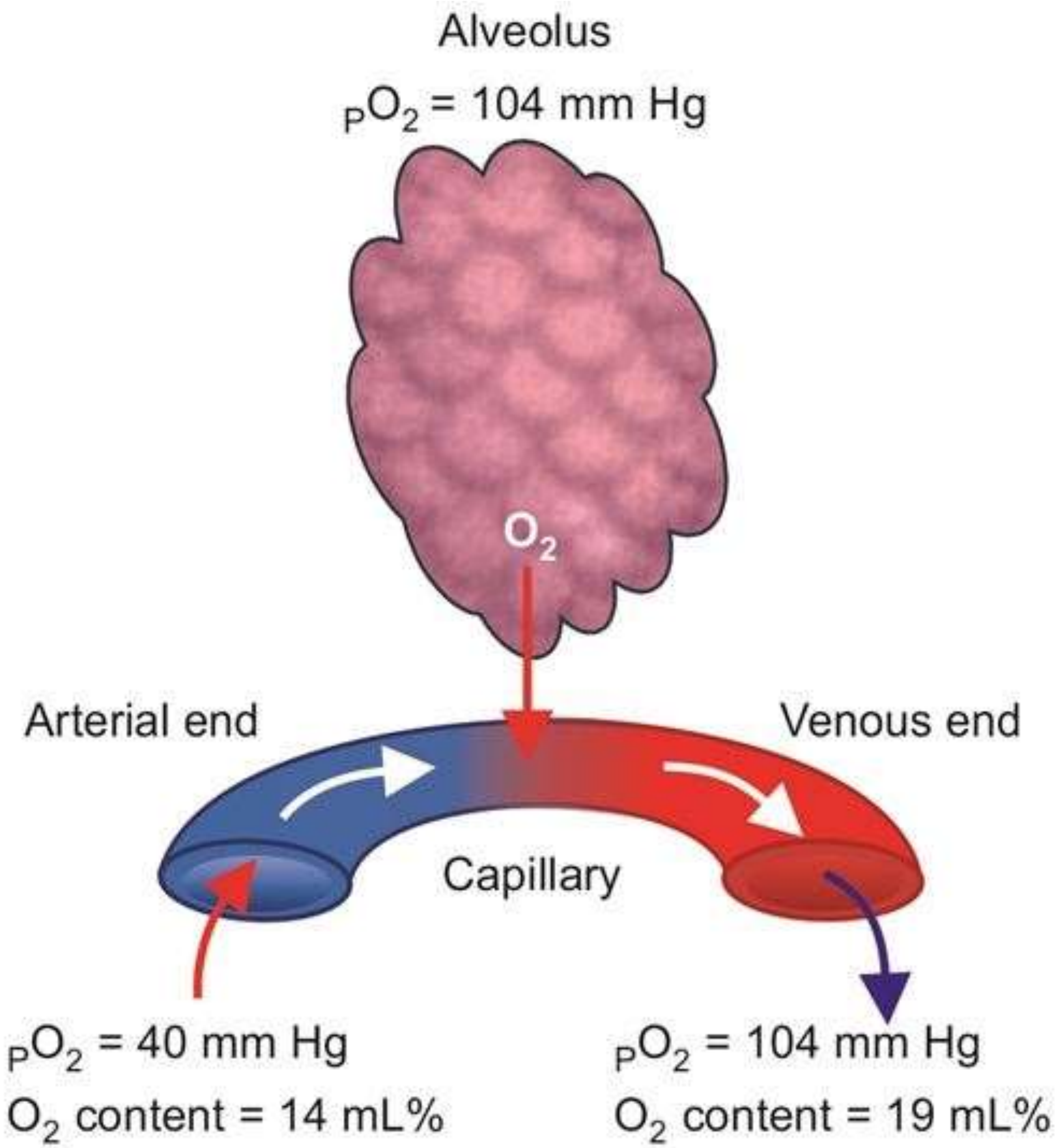
dc/dx = Concentration gradient.



DIFFUSION OF OXYGEN

Diffusion of Oxygen from Atmospheric Air into Alveoli Partial pressure of oxygen in the atmospheric air is 159 mm Hg and in the alveoli, it is 104 mm Hg.

Because of the pressure gradient of 55 mm Hg, oxygen easily enters from atmospheric air into the alveoli.


Alveolus
$_PO_2$ = 104 mm Hg
O_2
Arterial end
Venous end
Capillary
$_PO_2$ = 40 mm Hg
O_2 content = 14 mL%
$_PO_2$ = 104 mm Hg
O_2 content = 19 mL%

Diffusion of Oxygen from Alveoli into Blood

When blood passes through pulmonary capillary, RBC is exposed to oxygen only for 0.75 second at rest and only for 0.25 second during severe exercise.

So, diffusion of oxygen must be quicker and effective.

Fortunately, this is possible because of pressure gradient.

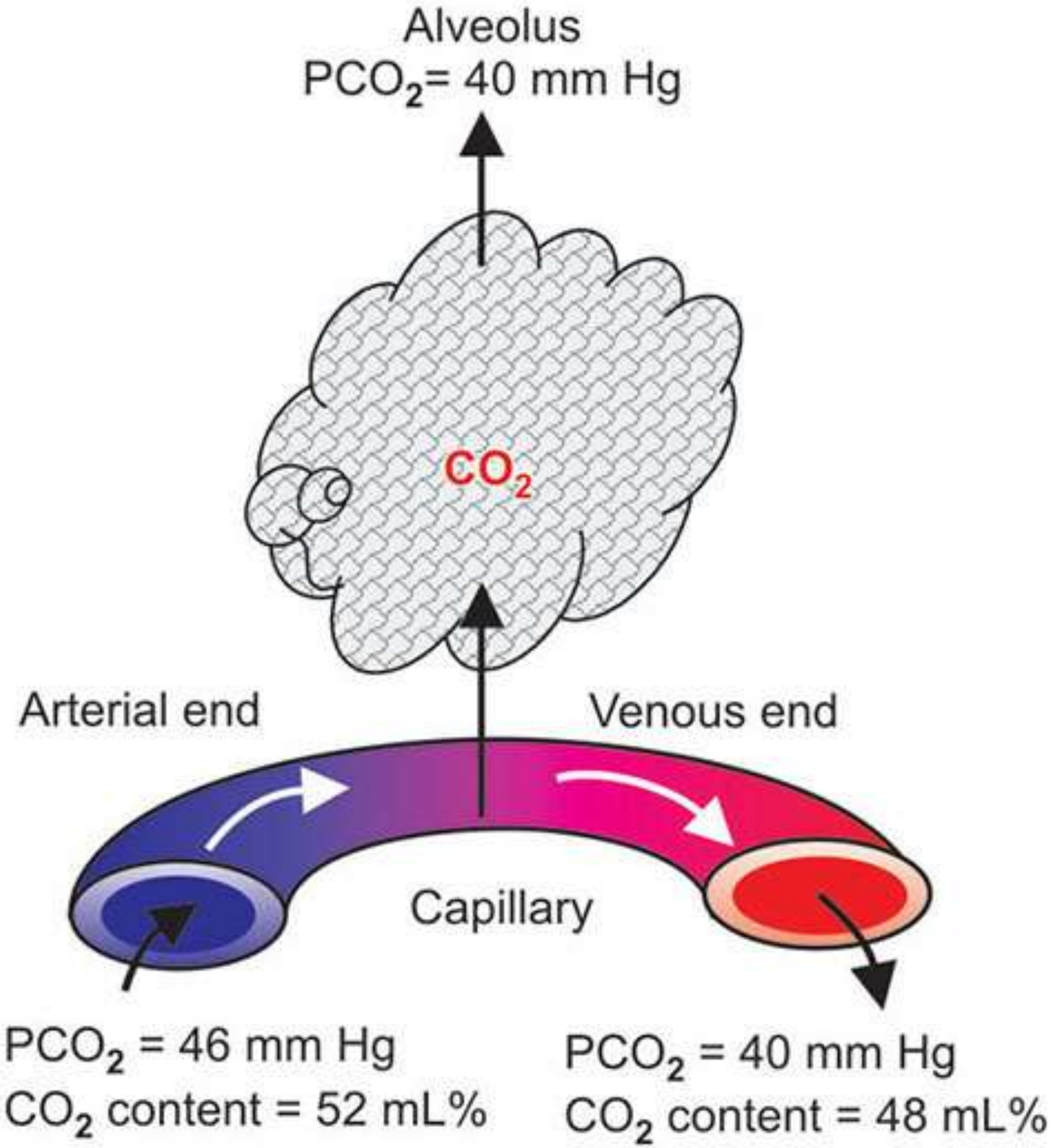
Partial pressure of oxygen in the pulmonary capillary is 40 mm Hg and in the alveoli, it is 104 mm Hg.

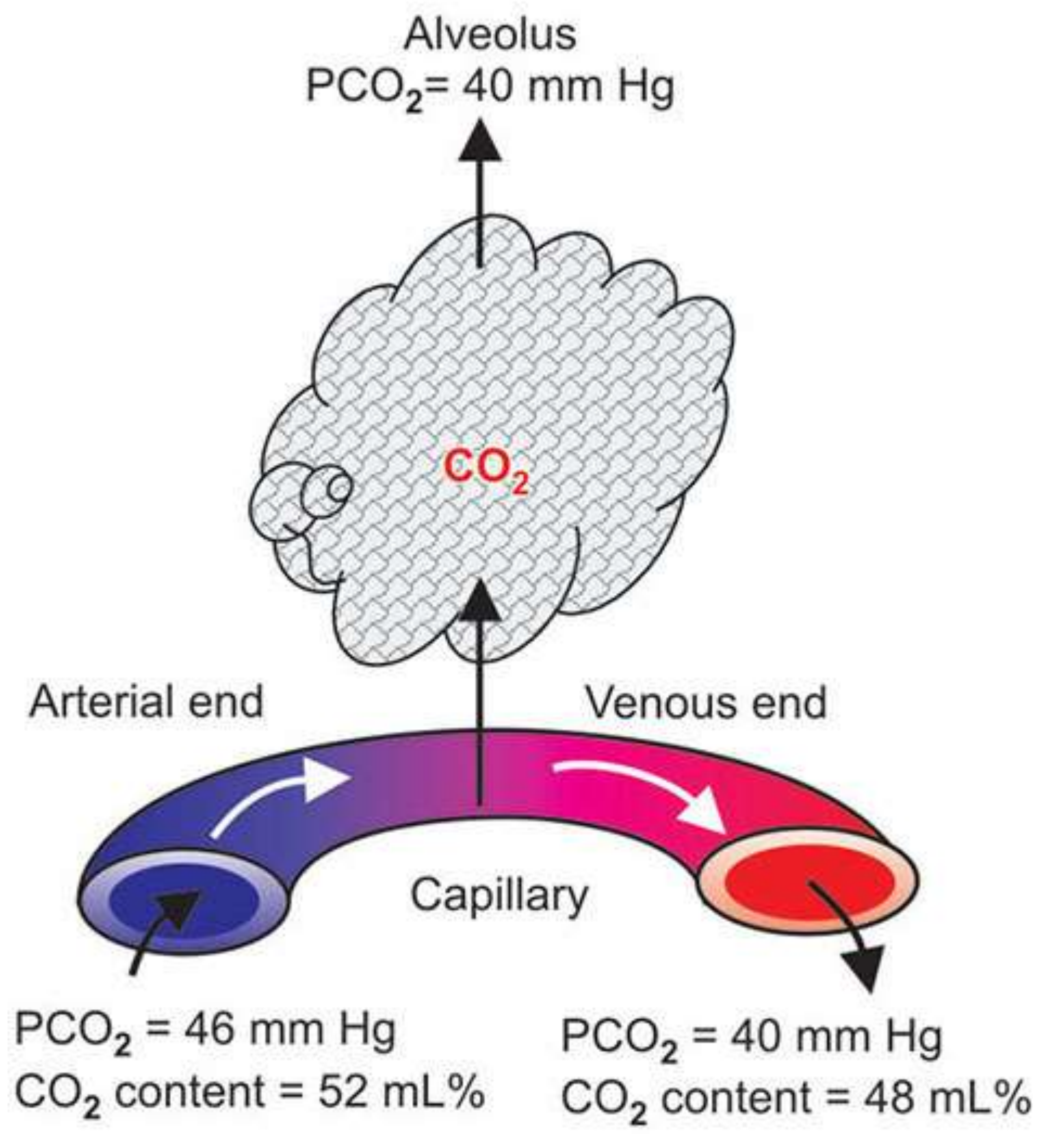
Pressure gradient is 64 mm Hg.

It facilitates the diffusion of oxygen from alveoli into the blood

DIFFUSION OF CARBON DIOXIDE

Diffusion of Carbon Dioxide from Blood into Alveoli Partial pressure of carbon dioxide in alveoli is 40 mm Hg whereas in the blood it is 46 mm Hg. Pressure gradient of 6 mm Hg is responsible for the diffusion of carbon dioxide from blood into the alveoli

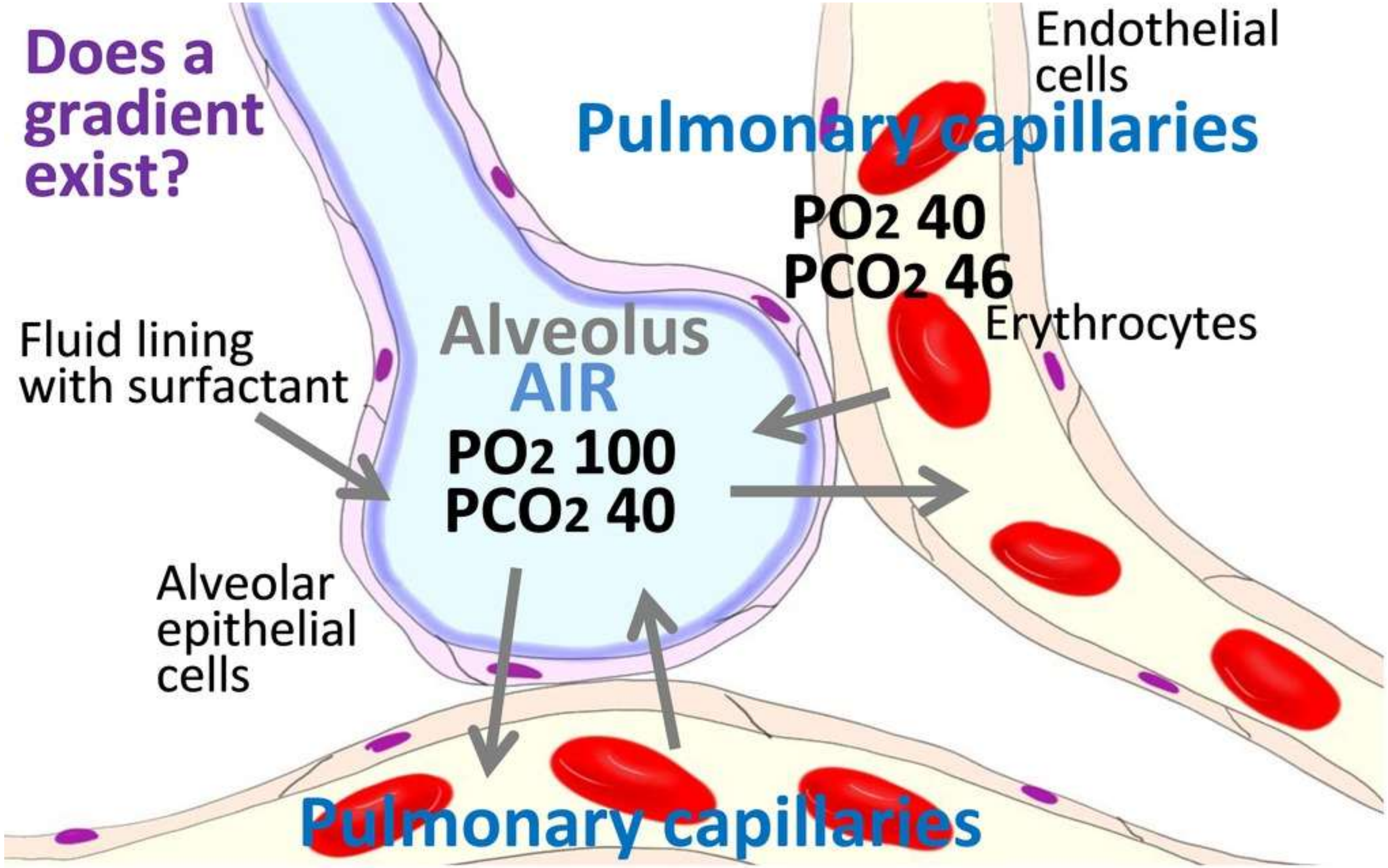

Alveolus
PCO2= 40 mm Hg
CO2
Arterial end
Venous end
Capillary
PCO2 = 46 mm Hg
CO2 content = 52 mL%
PCO2 = 40 mm Hg
CO2 content = 48 mL%



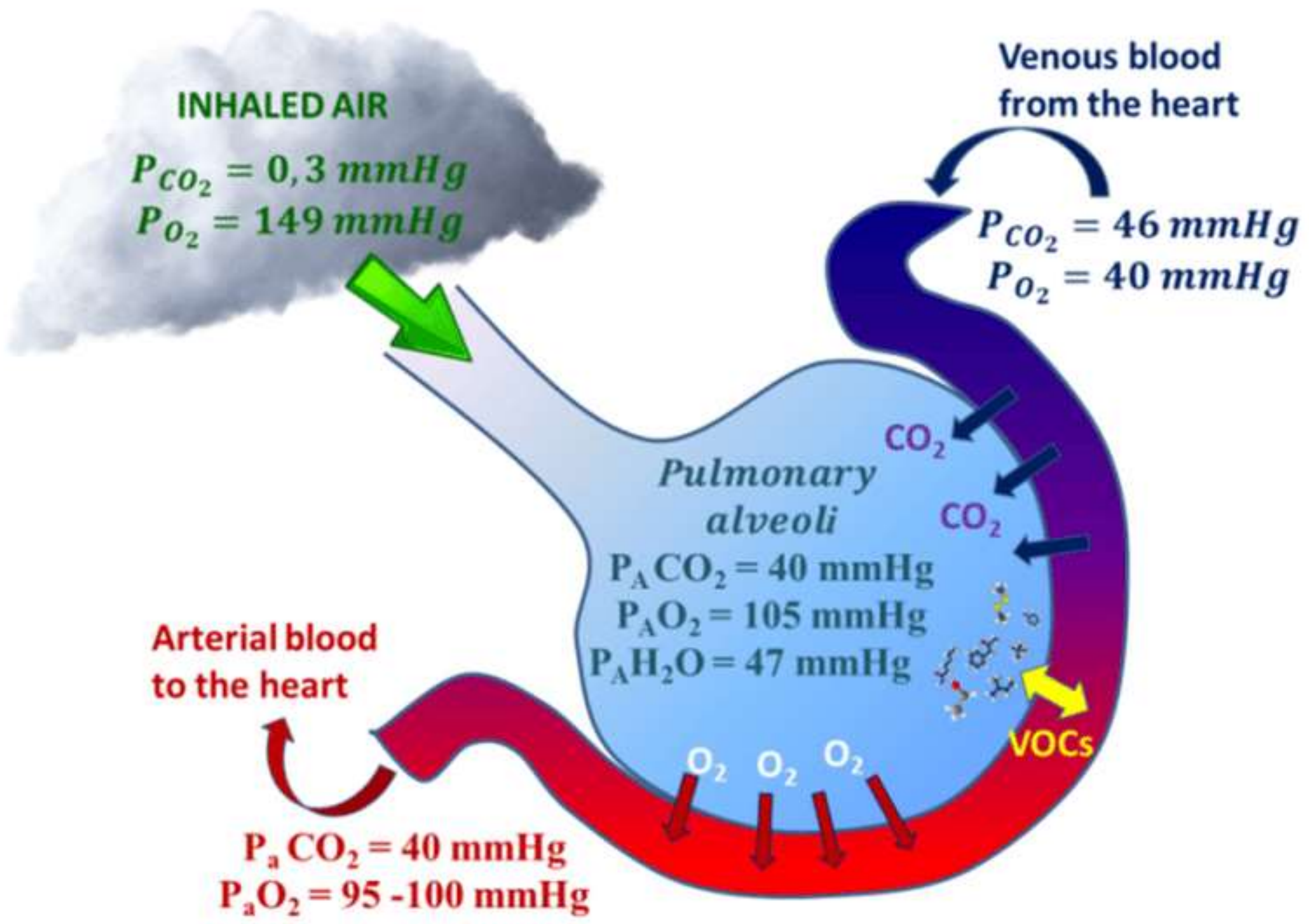
Diffusion of Carbon Dioxide from Alveoli into Atmospheric Air

In atmospheric air, partial pressure of carbon dioxide is very insignificant and is only about 0.3 mm Hg whereas, in the alveoli, it is 40 mm Hg.

So, carbon dioxide enters passes to atmosphere from alveoli easily



Does a gradient exist?
Endothelial cells
Pulmonary capillaries
PO2 40
PCO2 46
Erythrocytes
Fluid lining with surfactant
Alveolus
AIR
PO2 100
PCO2 40
Alveolar epithelial cells
Pulmonary capillaries


INHALED AIR
$P_{CO_2} = 0,3\ mmHg$
$P_{O_2} = 149\ mmHg$
Venous blood
from the heart
$P_{CO_2} = 46\ mmHg$
$P_{O_2} = 40\ mmHg$
CO_2
CO_2
Pulmonary
alveoli
$P_ACO_2 = 40$ mmHg
$P_AO_2 = 105$ mmHg
$P_AH_2O = 47$ mmHg
VOCs
O_2 O_2 O_2
Arterial blood
to the heart
$P_aCO_2 = 40$ mmHg
$P_aO_2 = 95$ -100 mmHg

EXCHANGE OF RESPIRATORY GASES AT TISSUE LEVEL

Oxygen enters the cells of tissues from blood and carbon dioxide is expelled from cells into the blood

DIFFUSION OF OXYGEN FROM BLOOD INTO THE TISSUES

Partial pressure of oxygen in venous end of pulmonary capillary is 104 mm Hg.

However, partial pressure of oxygen in the arterial end of systemic capillary is only 95 mm Hg.

It may be because of physiological shunt in lungs.

Due to venous admixture in the shunt , 2% of blood reaches the heart without being oxygenated.

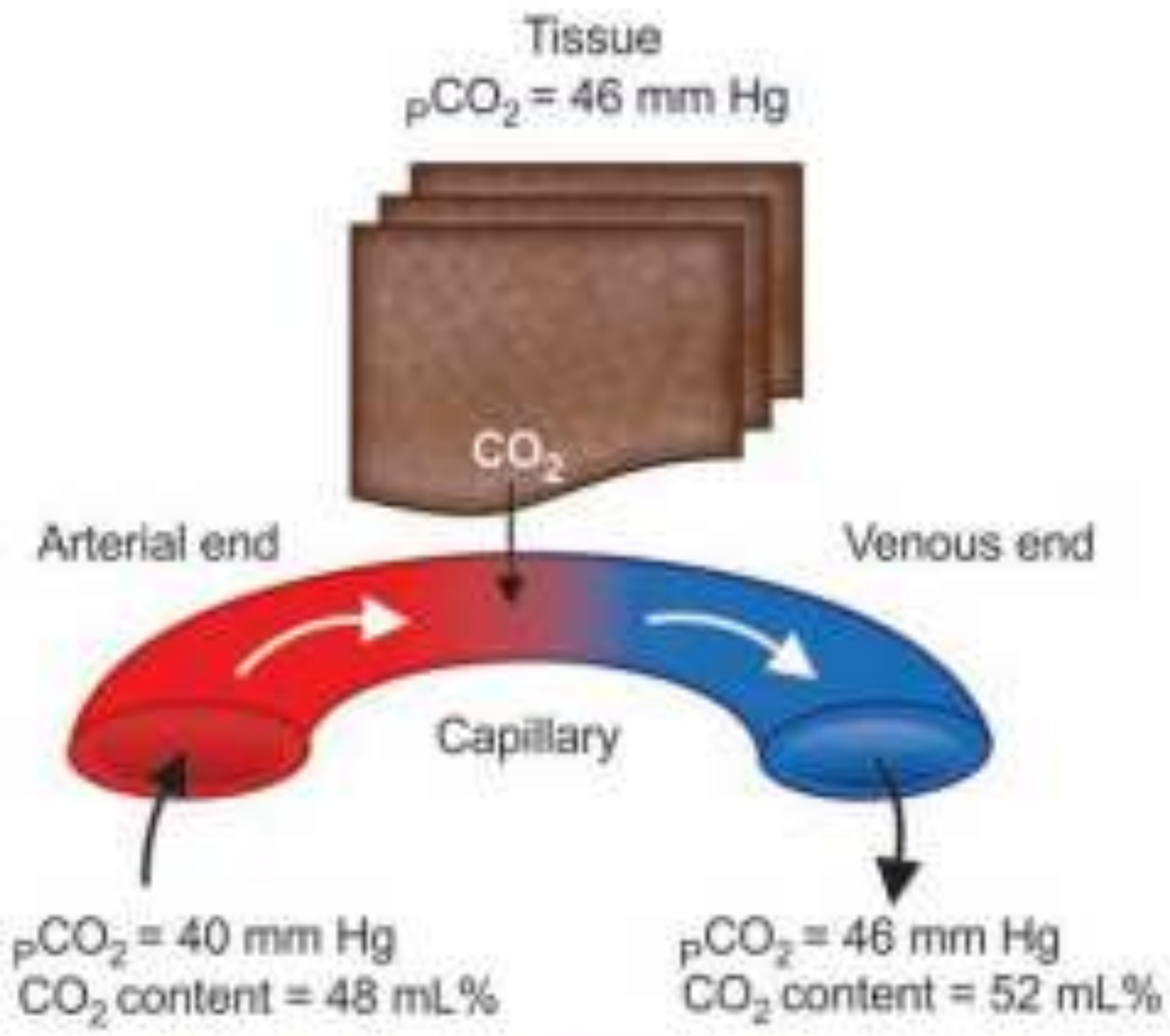


FIGURE 124.5: Diffusion of carbon dioxide from tissue to capillary

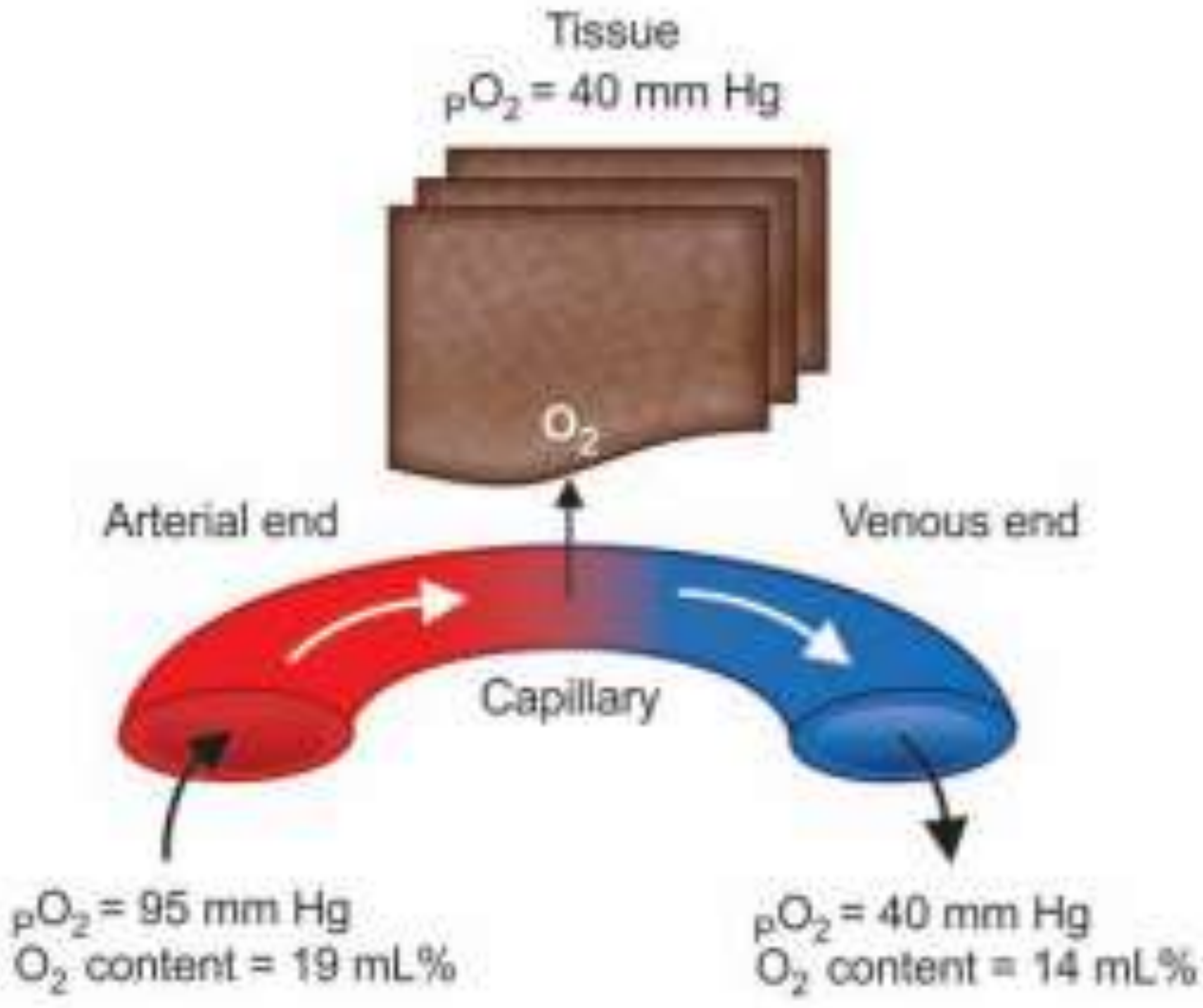


FIGURE 124.4: Diffusion of oxygen from capillary to tissue

Average **oxygen tension in the tissues** is 40 mm Hg.

It is because of continuous metabolic activity and constant utilization of oxygen.

Thus, a pressure gradient of about **55 mm Hg** exists between **capillary blood and the tissues so that oxygen can easily diffuse into the tissues**.

Oxygen content in arterial blood is 19 mL% and in the venous blood, it is **14 mL%.**

Thus, the diffusion of oxygen from blood to tissues is 5 mL/100 mL of blood

DIFFUSION OF CARBON DIOXIDE FROM TISSUES INTO THE BLOOD

Due to continuous metabolic activity, carbon dioxide is produced constantly in the cells of tissues.

So, the partial pressure of **carbon dioxide is high in the cells and is about 46 mm Hg.**

Partial pressure of **carbon dioxide in arterial blood is 40 mm Hg**.

Pressure gradient of 6 mm Hg is responsible for the diffusion of carbon dioxide from tissues to the blood.

Carbon dioxide content in arterial blood is 48 mL%.

And in the venous blood, it is 52 mL%.

So, the diffusion of carbon dioxide from tissues to blood is 4 mL/100 mL of blood

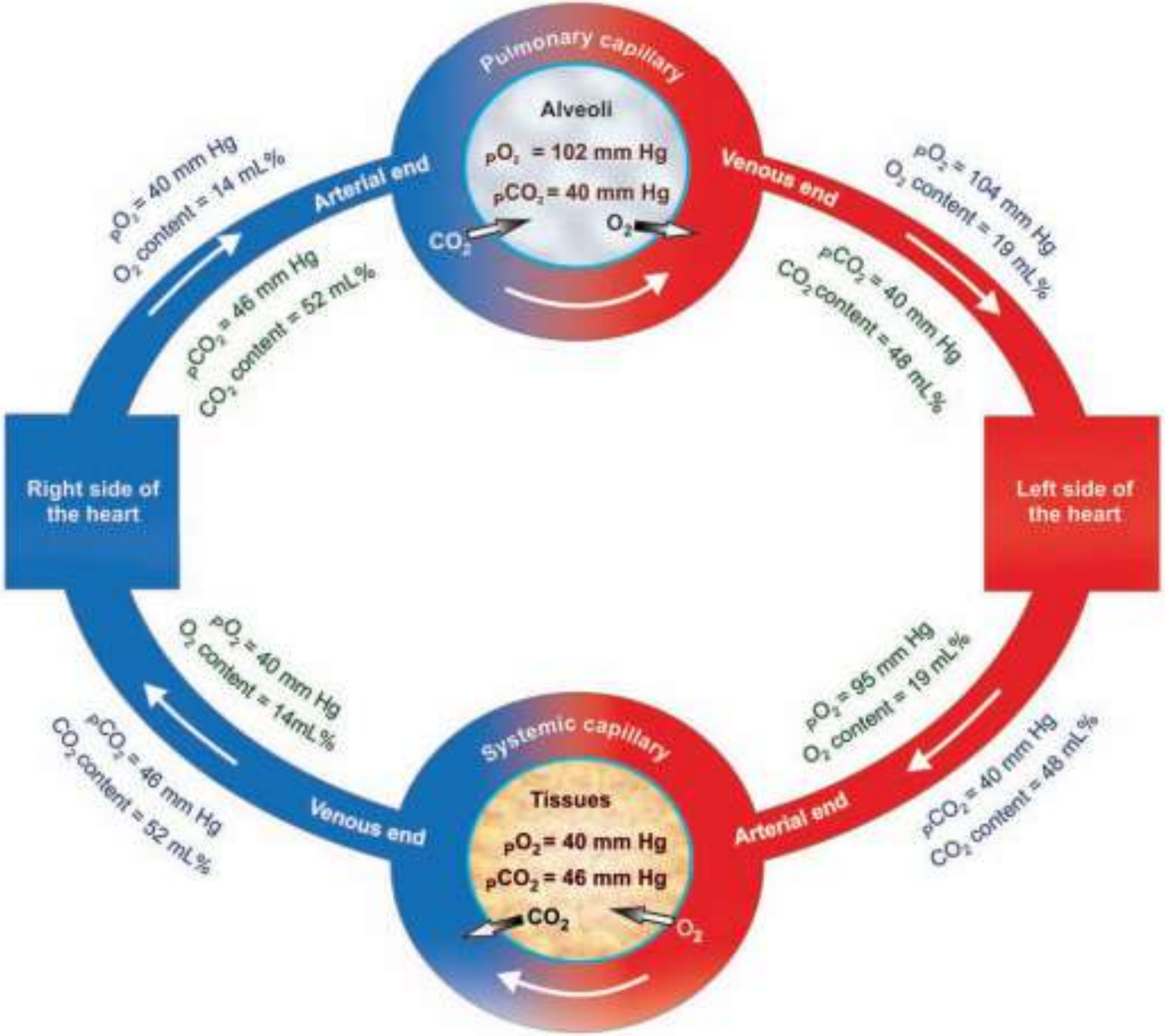


FIGURE 124.6: Partial pressure and content of oxygen and carbon dioxide in blood, alveoli and tissues

RESPIRATORY EXCHANGE RATIO

DEFINITION

Respiratory exchange ratio (R) is the ratio between the **net output of carbon dioxide from tissues to simultaneous net uptake of oxygen by the tissues.**

$$R = \frac{CO_2 \text{ output}}{O_2 \text{ uptake}}$$

NORMAL VALUES

Value of R depends upon the type of food substance that is metabolized.

When a person utilizes only carbohydrates for metabolism, **R is 1.0**.

That means during carbohydrate metabolism, the amount of carbon dioxide produced in the tissue is equal to the amount of oxygen consumed.

If only fat is used for metabolism, the **R is 0.7**.

When fat is utilized, oxygen reacts with fats and a large portion of oxygen combines with hydrogen ions to form water instead of carbon dioxide.

So, the carbon dioxide output is less than the oxygen consumed. And the **R is less.**

If only protein is utilized, **R is 0.803**.
However, when a balanced diet containing average quantity of proteins, carbohydrates and lipids is utilized, the **R is about 0.825**.
In steady conditions, **respiratory exchange ratio is equal to respiratory quotient.**

RESPIRATORY QUOTIENT DEFINITION

Respiratory quotient is the molar ratio of carbondioxide production to oxygen consumption.

It is used to determine the utilization of different foodstuffs.

NORMAL VALUE

For about 1 hour after meals the **respiratory quotient is 1.0**.

It is because usually, immediately after taking meals, only the carbohydrates are utilized by the tissues.

During the metabolism of carbohydrates, one molecule of carbon dioxide is produced for every molecule of oxygen consumed by the tissues.

Respiratory quotient is 1.0, which is equal to respiratory exchange ratio.

After utilization of all the carbohydrates available, body starts utilizing fats. Now the **respiratory quotient becomes 0.7.**

When the proteins are metabolized, it **becomes 0.8**.

During exercise, the respiratory quotient increases .