

TRANSPORT OF RESPIRATORY GASES



INTRODUCTION

Blood serves to transport the respiratory gases.

Oxygen, which is essential for the cells is transported from alveoli of lungs to the cells.

Carbon dioxide, which is the waste product in cells is transported from cells to lungs.

TRANSPORT OF OXYGEN

Oxygen is transported from **alveoli to the tissue by blood** in two forms:

1. As simple physical solution
2. In combination with **hemoglobin**. Partial pressure and content of oxygen in arterial blood and venous blood

TABLE 125.1: Gases in arterial and venous blood

| Gas | | Arterial blood | Venous blood |
|----------------|--------------------------|----------------|--------------|
| Oxygen | Partial pressure (mm Hg) | 95 | 40 |
| | Content (mL%) | 19 | 14 |
| Carbon dioxide | Partial pressure (mm Hg) | 40 | 46 |
| | Content (mL%) | 48 | 52 |



AS SIMPLE SOLUTION

Oxygen dissolves in water of plasma and is transported in this physical form.

Amount of oxygen transported in this way is **very negligible**.

It is only **0.3 mL/100 mL of plasma**.

It forms only about **3% of total oxygen in blood**.

It is because of **poor solubility of oxygen in water content of plasma**.

Still, transport of oxygen in this form becomes important during the conditions like **muscular exercise to meet the excess demand of oxygen by the tissues**.



IN COMBINATION WITH HEMOGLOBIN

Oxygen combines with hemoglobin in blood and is transported as **oxyhemoglobin**.

Transport of oxygen in this form is important because, **maximum amount (97%) of oxygen is transported** by this method..



OXYGENATION OF HEMOGLOBIN

Oxygen combines with hemoglobin only as a **physical combination**.

It is only oxygenation and not oxidation.

This type of combination of oxygen with hemoglobin has got some advantages.

Oxygen can be readily released from hemoglobin when it is needed.

Hemoglobin accepts oxygen readily whenever the **partial pressure of oxygen in the blood is more**.

Hemoglobin gives out oxygen whenever **the partial pressure of oxygen in the blood is less**.



OXYGEN CARRYING CAPACITY OF HEMOGLOBIN

Oxygen carrying capacity of hemoglobin is the amount of oxygen transported by **1 gram of hemoglobin**. It is 1.34 mL/g.



OXYGEN CARRYING CAPACITY OF BLOOD

Oxygen carrying capacity of blood refers to the amount of oxygen transported by blood.

Normal hemoglobin content in blood is 15 g%.

Since oxygen carrying capacity of hemoglobin is 1.34 mL/g, blood with 15 g% of hemoglobin should carry 20.1 mL% of oxygen, i.e. 20.1 mL of oxygen in 100 mL of blood.

But, blood with 15 g% of hemoglobin carries only 19 mL% of oxygen, i.e. 19 mL of oxygen is carried by 100 mL of blood.

Oxygen carrying capacity of blood is only 19 mL% because the hemoglobin is not fully saturated with oxygen. It is saturated only for about 95%.



SATURATION OF HEMOGLOBIN WITH OXYGEN

Saturation is the state or condition when hemoglobin is unable to hold or carry any more oxygen.

Saturation of hemoglobin with **oxygen** depends upon partial pressure of **oxygen**.

And it is explained by **oxygen hemoglobin dissociation curve**.



OXYGEN-HEMOGLOBIN DISSOCIATION CURVE

Oxygen-hemoglobin dissociation curve is the curve that demonstrates the relationship between partial pressure of oxygen and the percentage saturation of hemoglobin with oxygen.

It explains **hemoglobin's affinity for oxygen.**

Normally in the blood, hemoglobin is saturated with **oxygen only up to 95%**. Saturation of hemoglobin with oxygen depends upon the partial pressure of

oxygen.

When the partial pressure of oxygen is more, hemoglobin accepts oxygen and when the partial pressure of oxygen is less, hemoglobin releases oxygen.



METHOD TO PLOT OXYGEN-HEMOGLOBIN DISSOCIATION CURVE

Ten flasks or **tonometers** are taken.

Each one is filled with a known quantity of blood with known concentration of hemoglobin.

Blood in each tonometer is exposed to oxygen at different partial pressures.

Tonometer is rotated at a constant temperature till the blood takes as much of oxygen as it can. Then, blood is analyzed to measure the percentage saturation of hemoglobin with oxygen.

Partial pressure of oxygen and saturation of hemoglobin are plotted to obtain the oxygen-hemoglobin dissociation curve.



NORMAL OXYGEN-HEMOGLOBIN DISSOCIATION CURVE

Under normal conditions, oxygen-hemoglobin dissociation curve is ‘S’ shaped or sigmoid shaped.

Lower part of the curve indicates dissociation of oxygen from hemoglobin.

Upper part of the curve indicates the uptake of oxygen by hemoglobin depending upon partial pressure of oxygen.



P50

P50 is the **partial pressure of oxygen at which hemoglobin saturation with oxygen is 50%.**

When the partial pressure of oxygen is **25 to 27 mm Hg**, the hemoglobin is saturated to about **50%.**

That is, the **blood contains 50% of oxygen.**

At **40 mm Hg** of partial pressure of oxygen, the saturation is **75%.**

It becomes **95%** when the partial pressure of oxygen is **100 mm Hg.**

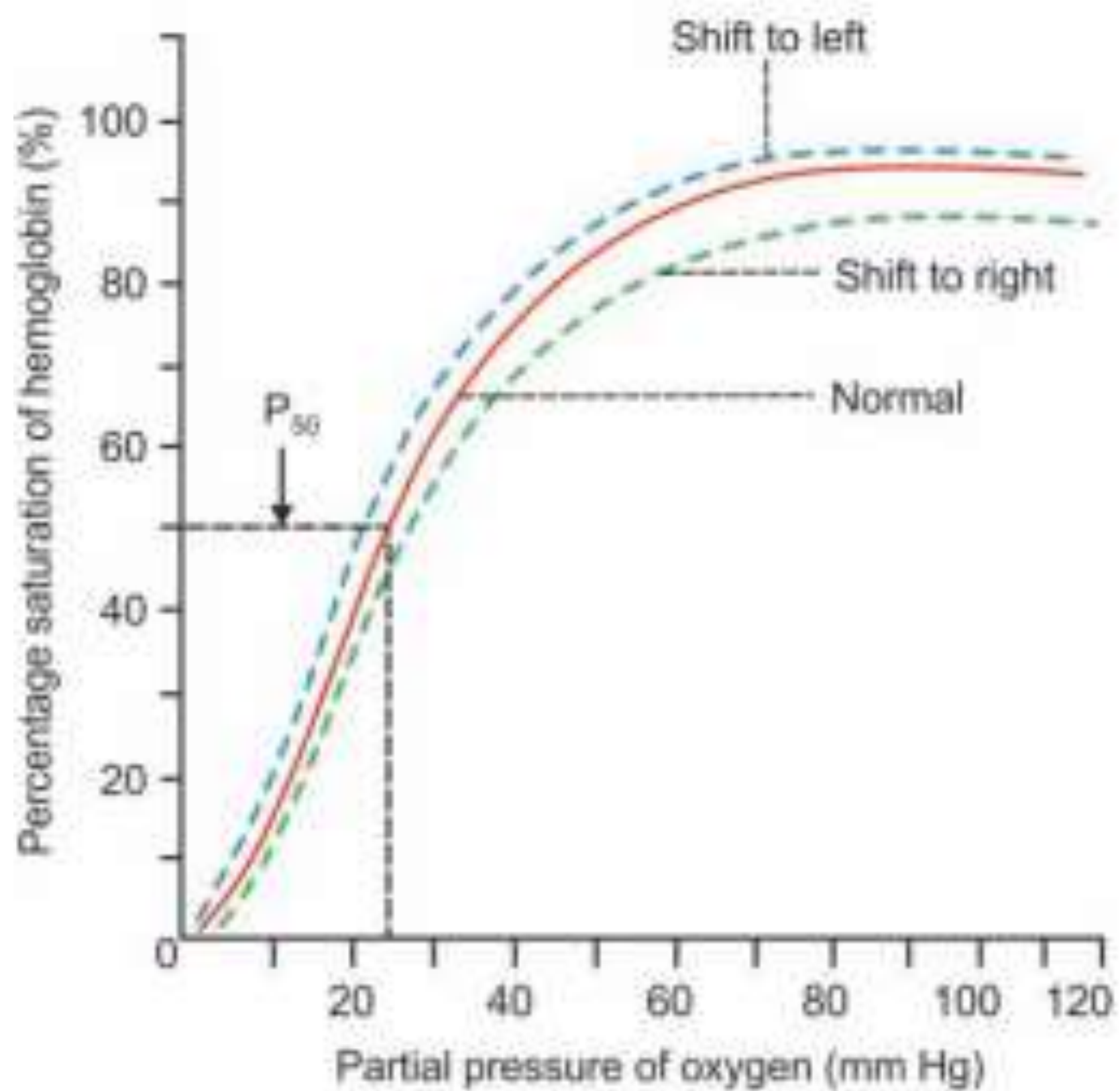


FIGURE 125.1: Oxygen-hemoglobin dissociation curve



Factors Affecting Oxygen-hemoglobin Dissociation Curve

Oxygen-hemoglobin dissociation curve is shifted to **left or right** by various factors:

1. Shift to left indicates **acceptance (association) of oxygen by hemoglobin**
2. Shift to right indicates **dissociation of oxygen from hemoglobin.**



1. Shift to right Oxygen-hemoglobin dissociation curve is **shifted to right** in the following conditions:

- i. Decrease in **partial pressure of oxygen**
- ii. Increase in **partial pressure of carbon dioxide** (Bohr effect)
- iii. Increase in **hydrogen ion concentration and decrease in pH** (acidity)
- iv. Increased **body temperature**
- v. Excess of **2,3-diphosphoglycerate (DPG)** in RBC.

It is also called **2,3-biphosphoglycerate (BPG)**.

DPG is a byproduct in **Embden-Meyerhof pathway** of carbohydrate metabolism. It combines with **β -chains of hemoglobin**. In conditions like **muscular exercise and in high attitude**, the **DPG increases in RBC**.

So, the oxygen hemoglobin dissociation curve shifts to right to a great extent.



2. Shift to left Oxygen-hemoglobin dissociation curve is shifted to **left** in the following conditions:

i. In fetal blood because, **fetal hemoglobin has got more affinity for oxygen than the adult hemoglobin.**

ii. Decrease in **hydrogen ion concentration and increase in pH** (alkalinity).



BOHR EFFECT

Bohr effect is the effect by which presence of carbon dioxide decreases the affinity of hemoglobin for oxygen.

Bohr effect was postulated by **Christian Bohr in 1904.**

In the tissues, due to **continuous metabolic activities**, the **partial pressure of carbon dioxide is very high** and the **partial pressure of oxygen is low.**



Due to this pressure gradient, carbon dioxide enters the blood and oxygen is released from the blood to the tissues.

Presence of carbon dioxide decreases the affinity of hemoglobin for oxygen. It enhances further release of oxygen to the tissues and oxygen dissociation curve is shifted to right.

FACTORS INFLUENCING BOHR EFFECT

All the factors, which shift the oxygen-dissociation curve to right (mentioned above) enhance the Bohr effect.



TRANSPORT OF CARBON DIOXIDE

Carbon dioxide is transported by the **blood from cells to the alveoli.**

Carbon dioxide is transported in the blood in four ways:

- 1. As dissolved form (7%)**
- 2. As carbonic acid (negligible)**
- 3. As bicarbonate (63%)**
- 4. As carbamino compounds (30%).**



AS DISSOLVED FORM

Carbon dioxide diffuses into blood and dissolves in the fluid of plasma forming a simple solution.

Only about 3 mL/100 mL of plasma of carbon dioxide is transported as dissolved state.

It is about **7% of total carbon dioxide in the blood.**



AS CARBONIC ACID

Part of dissolved carbon dioxide in plasma combines with the water to form carbonic acid.

Transport of carbon dioxide in this form is negligible.



AS BICARBONATE

About **63%** of carbon dioxide is transported as bicarbonate.

From plasma, **carbon dioxide enters the RBCs.**

In the RBCs, **carbon dioxide combines with water** to form carbonic acid.

The reaction inside RBCs is very rapid because of the presence of **carbonic anhydrase.**

This enzyme accelerates the reaction.

Carbonic anhydrase is present only inside the **RBCs and not in plasma.**

That is why carbonic acid formation is at least **200 to 300 times more in RBCs than in plasma.**



Carbonic acid is very **unstable**.

Almost all **carbonic acid (99.9%)** formed in **red blood corpuscles**, **dissociates into bicarbonate and hydrogen ions**.

Concentration of **bicarbonate ions in the cell increases more and more**.

Due to high concentration, bicarbonate ions diffuse through the cell membrane into plasma.



CHLORIDE SHIFT OR HAMBURGER PHENOMENON

Chloride shift or Hamburger phenomenon is the exchange of a chloride ion for a bicarbonate ion across RBC membrane.

It was discovered by Hartog Jakob Hamburger in 1892.

Chloride shift occurs when **carbon dioxide enters the blood from tissues.**

In plasma, plenty of sodium chloride is present. It dissociates into sodium and chloride ions.

When the negatively charged bicarbonate ions move out of RBC into the plasma, the **negatively charged chloride ions move into the RBC in order to maintain the electrolyte equilibrium (ionic balance).**



Anion exchanger 1 (band 3 protein), which acts like antiport pump in RBC membrane is responsible for the exchange of bicarbonate ions and chloride ions.

Bicarbonate ions combine with sodium ions in the plasma and form sodium bicarbonate.

In this form, it is transported in the blood.

Hydrogen ions dissociated from carbonic acid are buffered by hemoglobin inside the cell.



Reverse Chloride Shift

Reverse chloride shift is the process by which chloride ions are moved back into plasma from RBC shift.

It occurs in **lungs**.

It helps in **elimination of carbon dioxide from the blood**.

Bicarbonate is converted back into carbon dioxide, which has to be expelled out.

It takes place by the following mechanism:



When **blood reaches the alveoli**, sodium bicarbonate in plasma dissociates into sodium and bicarbonate ions.

Bicarbonate ion moves into the RBC.

It makes chloride ion to move out of the RBC into the plasma, where it combines with sodium and forms sodium chloride.

Bicarbonate ion inside the RBC combines with hydrogen ion forms carbonic acid, which **dissociates into water and carbon dioxide**.

Carbon dioxide is then **expelled out**.



AS CARBAMINO COMPOUNDS

About 30% of carbon dioxide is transported as carbamino compounds.

Carbon dioxide is transported in blood in combination with hemoglobin and plasma proteins.

Carbon dioxide combines with hemoglobin to form **carbamino hemoglobin or carbhemoglobin**.

And it combines with plasma proteins to form carbamino proteins.

Carbamino hemoglobin and carbamino proteins are together called carbamino compounds



Carbon dioxide combines with proteins or hemoglobin with a loose bond so that, carbon dioxide is easily released into alveoli, where the partial pressure of carbon dioxide is low.

Thus, the combination of carbon dioxide with proteins and hemoglobin is a reversible one.

Amount of carbon dioxide transported in combination with plasma proteins is very less compared to the amount transported in combination with hemoglobin.

It is because the quantity of proteins in plasma is only half of the quantity of hemoglobin

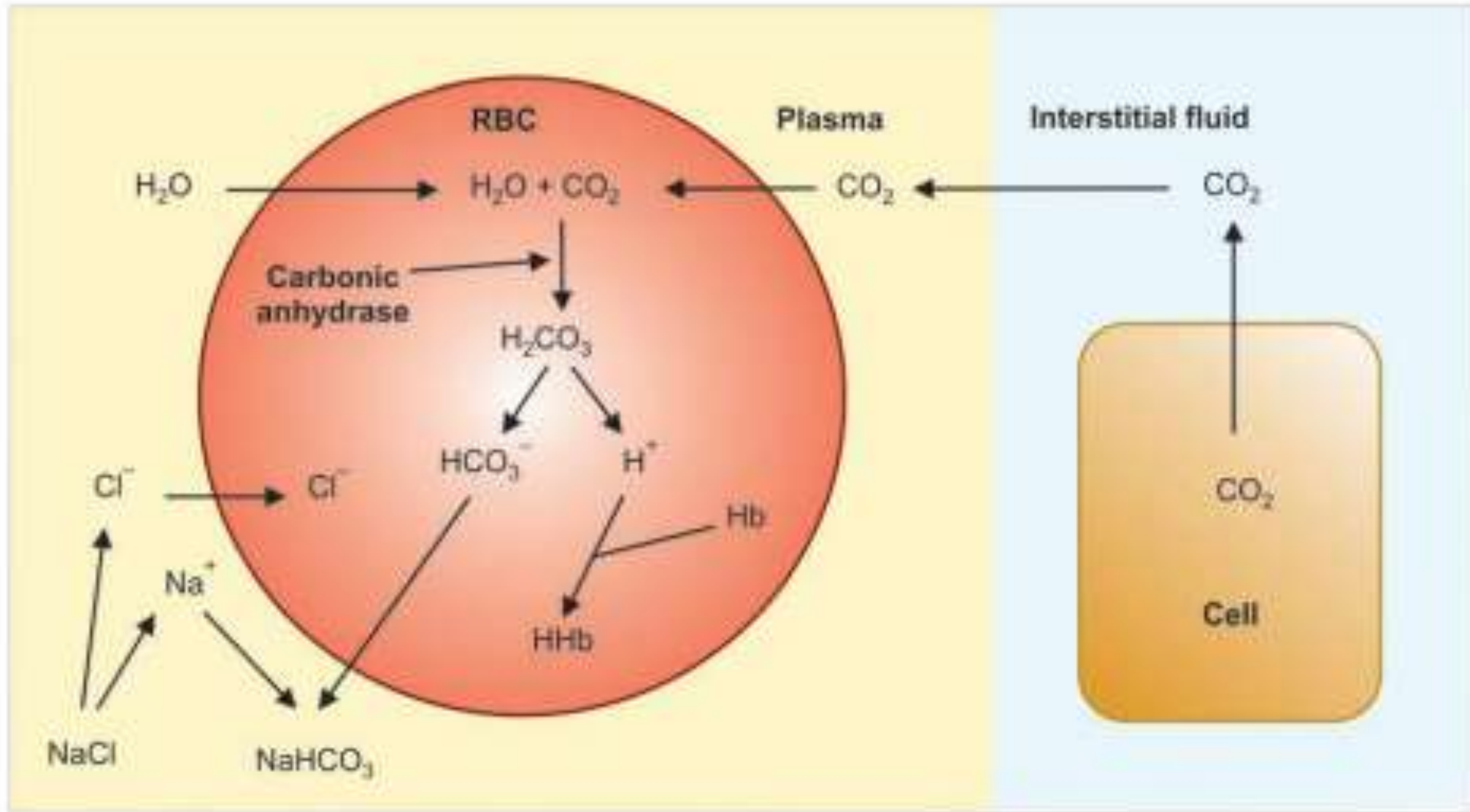


FIGURE 125.2: Transport of carbon dioxide in blood in the form of bicarbonate and chloride shift.



CARBON DIOXIDE DISSOCIATION CURVE

Carbon dioxide is transported in blood as physical solution and in combination with water, plasma proteins and hemoglobin.

The amount of carbon dioxide combining with blood depends upon the partial pressure of carbon dioxide.

Carbon dioxide dissociation curve is the curve that demonstrates the relationship between the partial pressure of carbon dioxide and the quantity of carbon dioxide that combines with blood.

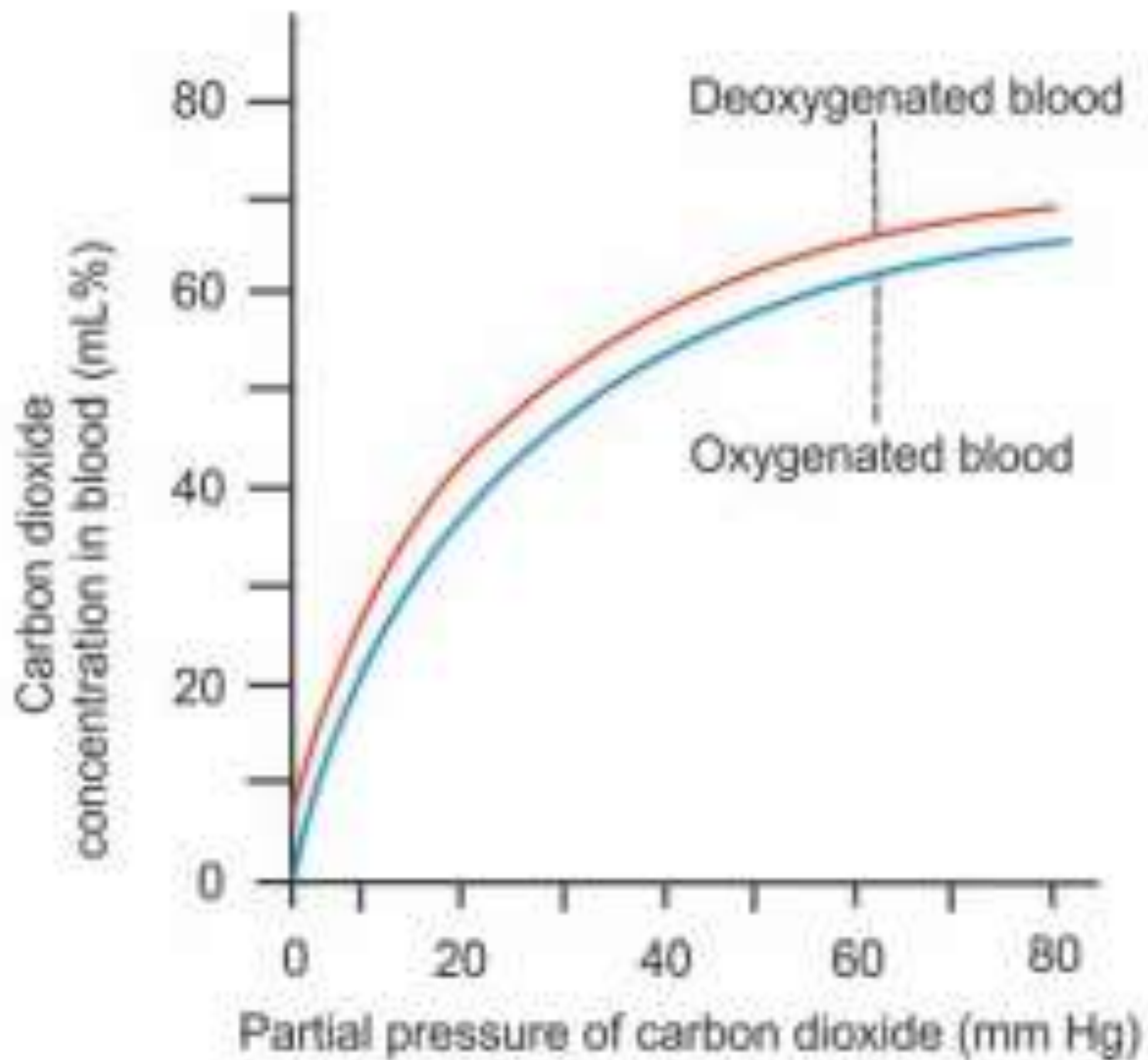


FIGURE 125.3: Carbon dioxide dissociation curve



NORMAL CARBON DIOXIDE DISSOCIATION CURVE

Normal carbon dioxide dissociation curve shows that the carbon dioxide content in the blood is 48 mL% when the partial pressure of carbon dioxide is 40 mm Hg

It is 52 mL% when the partial pressure of carbon dioxide is 48 mm Hg.

Carbon dioxide content becomes 70 mL% when the partial pressure is about 100 mm Hg.



HALDANE EFFECT

Haldane effect is the effect by **which combination of oxygen with hemoglobin displaces carbon dioxide from hemoglobin.**

It was first described by **John Scott Haldane in 1860.**

Excess of oxygen content in blood causes shift of the carbon dioxide dissociation curve to **right.**



CAUSES FOR HALDANE EFFECT

Due to the **combination with oxygen**, hemoglobin becomes **strongly acidic**.

It causes **displacement of carbon dioxide from hemoglobin** in two ways:

1. Highly acidic hemoglobin has **low tendency to combine with carbon dioxide**. So, carbon dioxide is displaced from blood.
2. Because of the acidity, **hydrogen ions are released in excess**. Hydrogen ions bind with bicarbonate ions to form **carbonic acid**.

Carbonic acid in turn dissociates into water and carbon dioxide.

Carbon dioxide is **released from blood into alveoli**.



SIGNIFICANCE OF HALDANE EFFECT

Haldane effect is essential for:

- 1. Release of carbon dioxide from blood into the alveoli of lungs**
- 2. Uptake of oxygen by the blood.**