Transport of Oxygen And Carbon Dioxide in Blood

Respiratory Pigments

Dr. R. Prasad,
Assistant Professor,
Department of Zoology,
Eastern Karbi Anglong College

We know that two types of gas exchanges are constantly occurring in the animal body-one at the interphase of the respiratory membrane and external environment (which you have studied in the previous section) and the other in the rest of the animal tissues. The underlying principle is the same at both places - passive diffusion occurs along a pressure gradient.

In many invertebrates oxygen and carbon dioxide are carried dissolved in blood or haemolymph. Since the amount of oxygen carried in a simple solution is small, therefore, in highly organised animals (many invertebrates-and all vertebrates) oxygen is transported by being bound reversibly to proteins that are oxygen carriers. These proteins contain a metal, commonly iron or copper and are coloured. These proteins are thus, metalloproteins and are known as **respiratory pigments**. There are four major classes of respiratory pigments in animals. They are all metalloproteins that bind reversibly to oxygen at specific sites on the metal ion in their molecular structure. These are haemocynins (copper containing), haemerythrins, chlorocrurins and haemoglobins (all three have iron). Out of all these haemoglobins are the most widespread respiratory pigment in most vertebrates.

Haemoglobin

Among the respiratory pigments we shall consider haemoglobin in some detail as this is the most familiar, and widespread and is present in human. It is also the most efficient respiratory pigment. In vertebrates haemoglobins are packed into the red blood cells and combine with far greater amounts of oxygen than other respiratory pigments that are found dissolved in the plasma. If the amount of haemoglobin that is packed in the cells was to be free in plasma, the viscosity of blood would be vicous (thich) like syrup and blood would not be able to flow in the blood as it does.

Let us now consider the structure of haemoglobin in more detail so as to know why haemoglobin has better oxygen carrying capacity.In Fig 2.11 a and b you can see that hemoglobin(Hb) molecule is made up of four polypeptide subunits 2 alpha(α) and 2 (β) beta subunits and so is a letra. Each subunit has a haeme group (an iron-containing compound of the porphyrin class) embedded in it. Each haemoglobin is a forms a tetrahedral structure. Haeme, which accounts for only 4 percent of the weight of the molecule, is composed of a ring like organic compound known as a porphyrin to which an iron atom is attached (Fig. 2.11b). It is the iron atom that binds oxygen as the blood travels between the lungs and the tissues. Thus as there are four iron atoms in each molecule of haemoglobin, each haemoglobin can accordingly bind to four atoms of oxygen forming **oxyhaeomoglobin** in a reversible reaction. The unoxygenated haemoglobin compound is called **deoxyhaemoglobin.** Another molecule in the body that has the ability to bind oxygen is **myoglobin.** It is a single unit or monomeric form of haemoglobin and consists of a single polypeptide chain the globin in which the haeme group is embedded.

Myoglobin is found in striated muscles of vertebrates and combines with one molecule of oxygen.

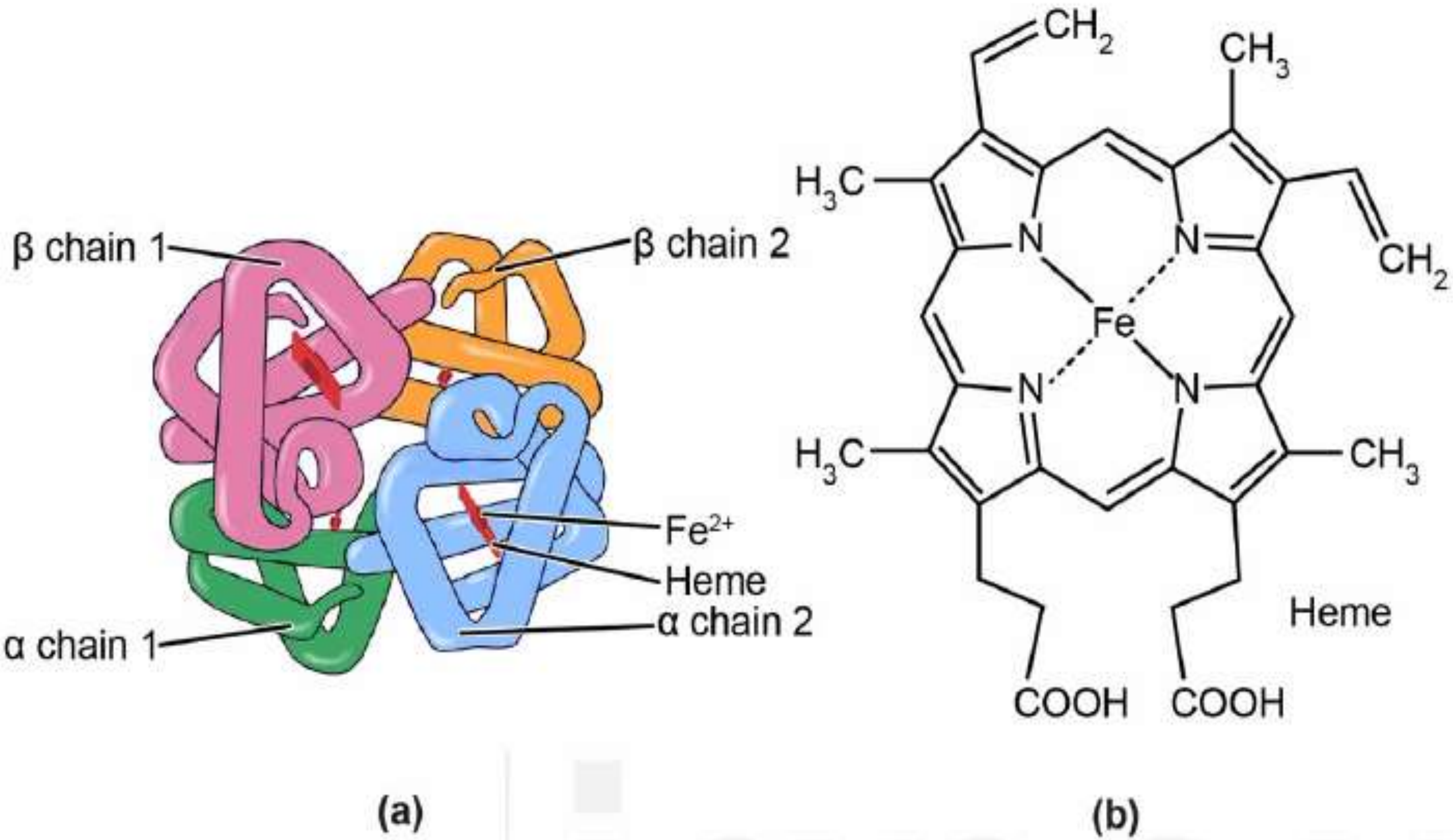


Fig. 2.12: a) Chemical structure of haeme group; b) Schematic representative of a single submit of haemoglobin.

Oxygen Transport in Blood

Haemoglobin has even a stronger affinity for carbon monoxide than oxygen. The bond is 210 times stronger. Carbon monoxide tends to displace oxygen in haemoglobin and remains attached as the blood passes through the tissues. The transport of oxygen is impaired leading to dangerous consequences and even death.

When no oxygen is bound to the haemoglobin molecule it is said to be in a tense state (**T-state).** Haemoglobin molecule has the ability to change its shape when it binds to the first molecule of oxygen. As a result of the first binding the affinity for oxygen increases and the molecule is said to be in a relaxed state (**R-state**). This change in the state of the haemoglobin molecule allows subsequent binding of oxygen molecules to the rest of the 3 haemes easier and rapid. This type of binding is known as **cooperative binding between active sites.**

The transport of oxygen in the blood takes place in two ways:1) the first and major one is through formation of oxyhaeomoglobin (HbO_2) and 2) the second is through oxygen dissolved in plasma. In the amount of oxygen bound as oxyhaeomoglobin is 20 ml/ 100 ml of blood and oxygen transported through plasma is only 0.2mL /100mL of blood.

The transport of oxygen in blood depends on : i) the Po_2 (partial pressure of oxygen) of the environment and ii) the bond strength or affinity between haemoglobin and oxygen. In the lungs where Po_2 in the inhaled air is high almost all deoxyhaemoglobin molecules bind to oxygen (Fig. 2.13). Low Po_2 in the systemic capillaries promotes unloading of oxygen. Haemoglobin has bond strength (affinity) which permits 97% of haemoglobin to combine with oxygen when leaving the lung. However, it has a stronger affinity for H^+ ions than oxygen. Therefore, in the presence of H^+ ions the oxyhaemoglobin molecule has the ability to unload or disassociate from its oxygen in the systemic capillaries. We will explain this as we study about oxygen disassociation curves.

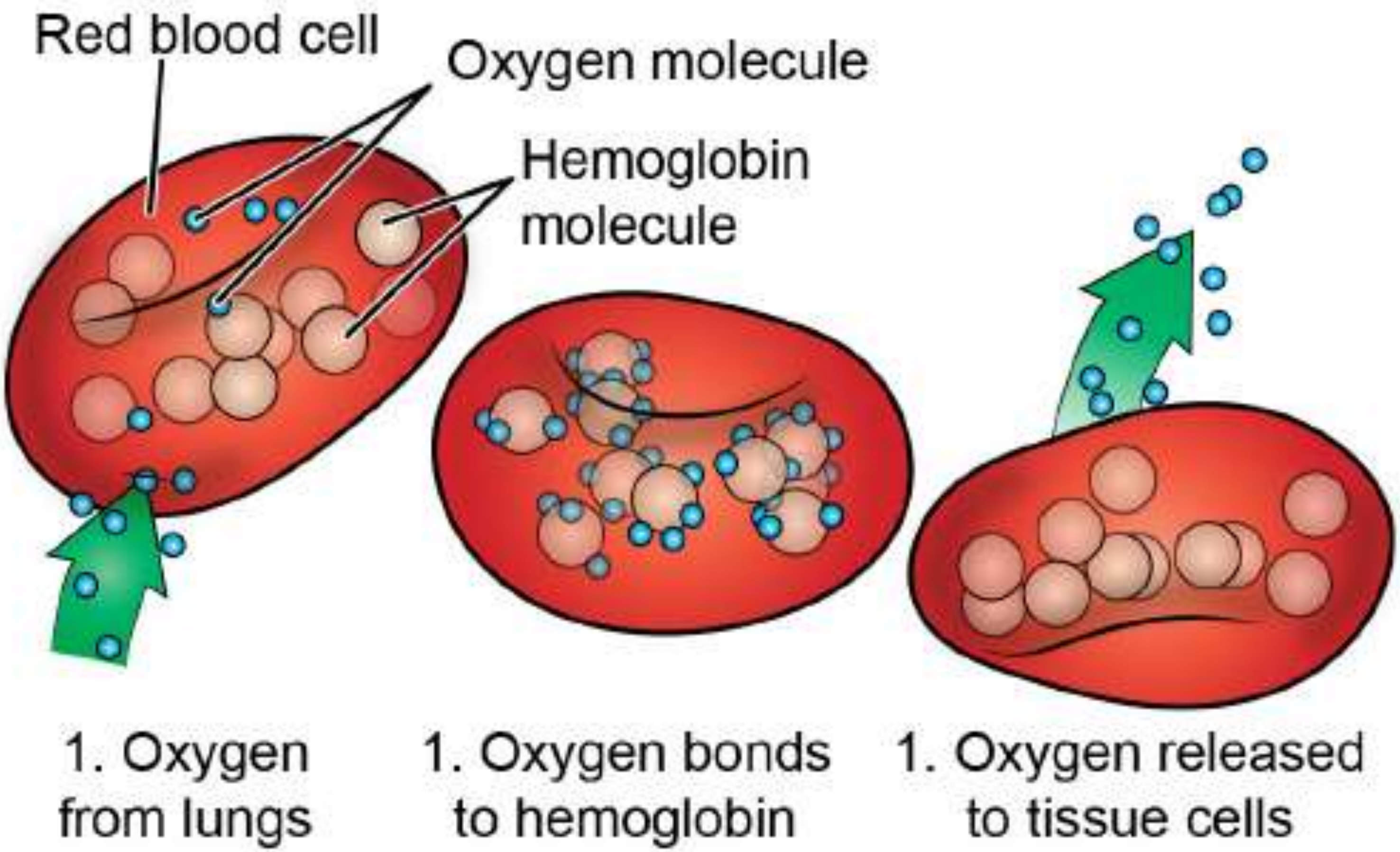


Fig. 2.13: Oxygen from the lungs binds to hemoglobin molecules and is carried through blood vessels to the rest of the body.

Carbon Dioxide Transport in Blood

The same transport system that brings oxygen to the tissues must take back carbon dioxide to the environment across the respiratory surface present in the alveoli. However, unlike oxygen that is transported exclusively by haemoglobin, carbon dioxide is transported in three ways:

1. as **dissolved carbon dioxide** in plasma (about 8%),

2. **in red cell as carbaminohaemoglobin**. About 25% of the total blood carbon dioxide is carried attached to the amino groups in haemoglobin.

$$\text{Haemoglobin} - N \genfrac{}{}{0pt}{}{<H}{<H} + CO_2 \rightarrow H^+ + \text{Haemoglobin} - NHCOO^-$$

Carbaminohaemoglobin is carried to the lungs where haemoglobin releases the carbon dioxide in exchange for oxygen,

3. as **carbonic acid** (H_2CO_3) and **bicarbonate/ bicarbonate** ion (HCO_3^-) which accounts for most of the carbon dioxide (67%) carried by blood.

Carbon dioxide is generated in the tissues and diffuses freely into the venous plasma and then into the RBCs. In the RBCs, CO_2 combines with H_2O to form carbonic acid (H_2CO_3).

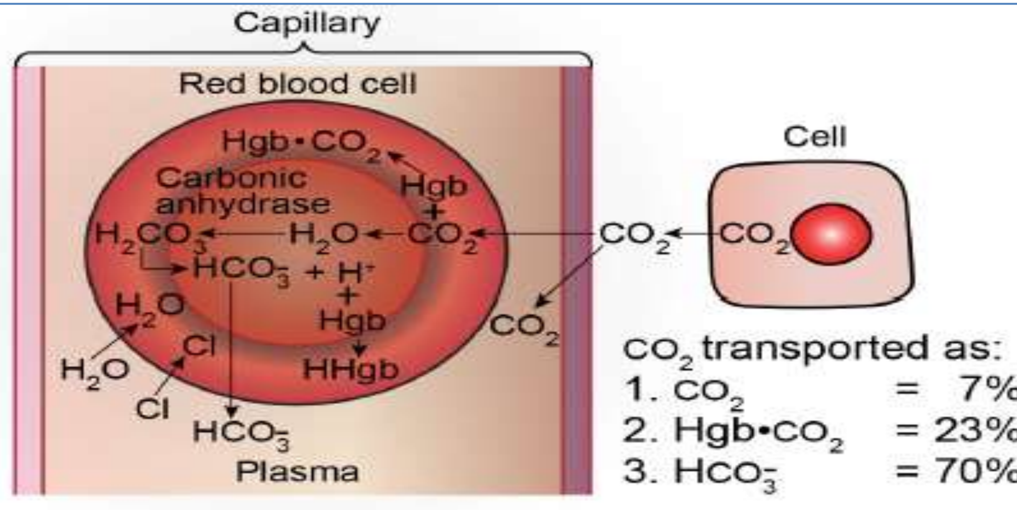
$$CO_2 + H_2O \longrightarrow H_2CO_3$$

This reaction occurs spontaneously in plasma at a very slow rate but much more rapidly within the blood cell due to the catalytic reaction of an enzyme, **carbonic anhydrase.**

The formation of carbonic acid is favoured by high PCo_2 in the capillaries of tissues. Carbonic acid dissociates rapidly in the red blood cells into hydrogen ion (H^+) and bicarbonate ion (HCO_3^-).

$$H_2CO_3 \longrightarrow H^+ + (HCO_3^-)$$

The H^+ (hydrogen ions) released are buffered by combining with haemoglobin and HCO_3^- moves out of the cells. The inside of the cell thus gains a net positive charge. This attracts the chloride ion (Cl^-) which moves inside the red blood cells. This exchange of anions as the blood moves through capillaries in tissue is known as **chloride shift** (Fig. 2.17 a). The red blood cells are very permeable to both Cl^- and HCO_3^-; because the membrane has a high concentration of a special anion carrier protein called band III protein that binds Cl^- and and transfers them in opposite direction through the RBC membrane.



(a)

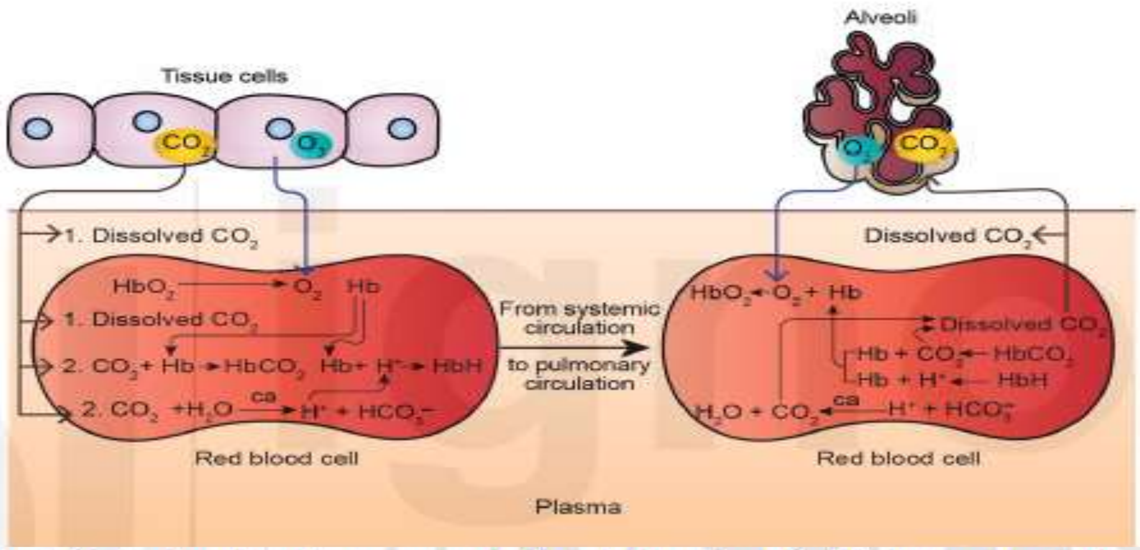


Fig. 2.17: Carbon dioxide transport in blood. a) carbon dioxide is transported in three forms: (i) as dissolved CO_2 gas in plasma, attached to haemoglobin as carbaminohaemoglobin, and as carbonic acid and bicarbonate in plasma due to chloride shift; b) carbon dioxide is released from the blood as it travels through pulomonary capillaries. A reverse chloride shift occurs and carbonic acid is transformed into CO_2 and H_2O releasing CO_2 in the alveolus.

The formation of carbonic acid enhances oxygen unloading (Bohr Effect) and oxygen unloading in turn improves the ability of blood to form carbonic acid and transport carbon dioxide.

When blood reaches the pulmonary capillaries deoxyhaemoglobin is converted to oxyhaeomoglobin which has a lower affinity for H^+. The H^+ is released in the red blood cells. This attracts HCO_3^- from plasma which combines with H^+ to form H_2CO_3

$$H^+ + HCO_3^- \longrightarrow H_2CO_3$$

Under low PCo_2 of pulmonary vessels carbonic anhydrase catalyses the formation of carbonic acid to carbon dioxide and water

$$H_2CO_3 \xrightarrow[\text{Low } PCo_2]{\text{Carbonic anhydrase}} H_2O + CO_2$$

Therefore, a **reverse chloride** shift occurs in the pulmonary capillaries to convert carbonic acid, and biocarbonate to CO_2 gas which is eliminated in the expired breath (Fig. 2.17b).