Oxygen and Carbon dioxide Transport

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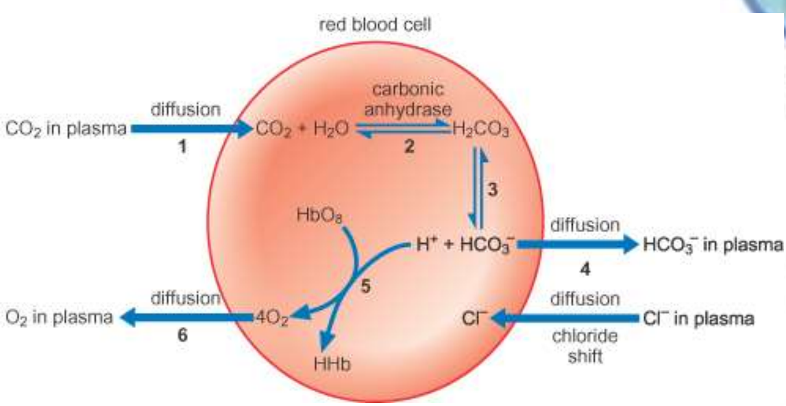
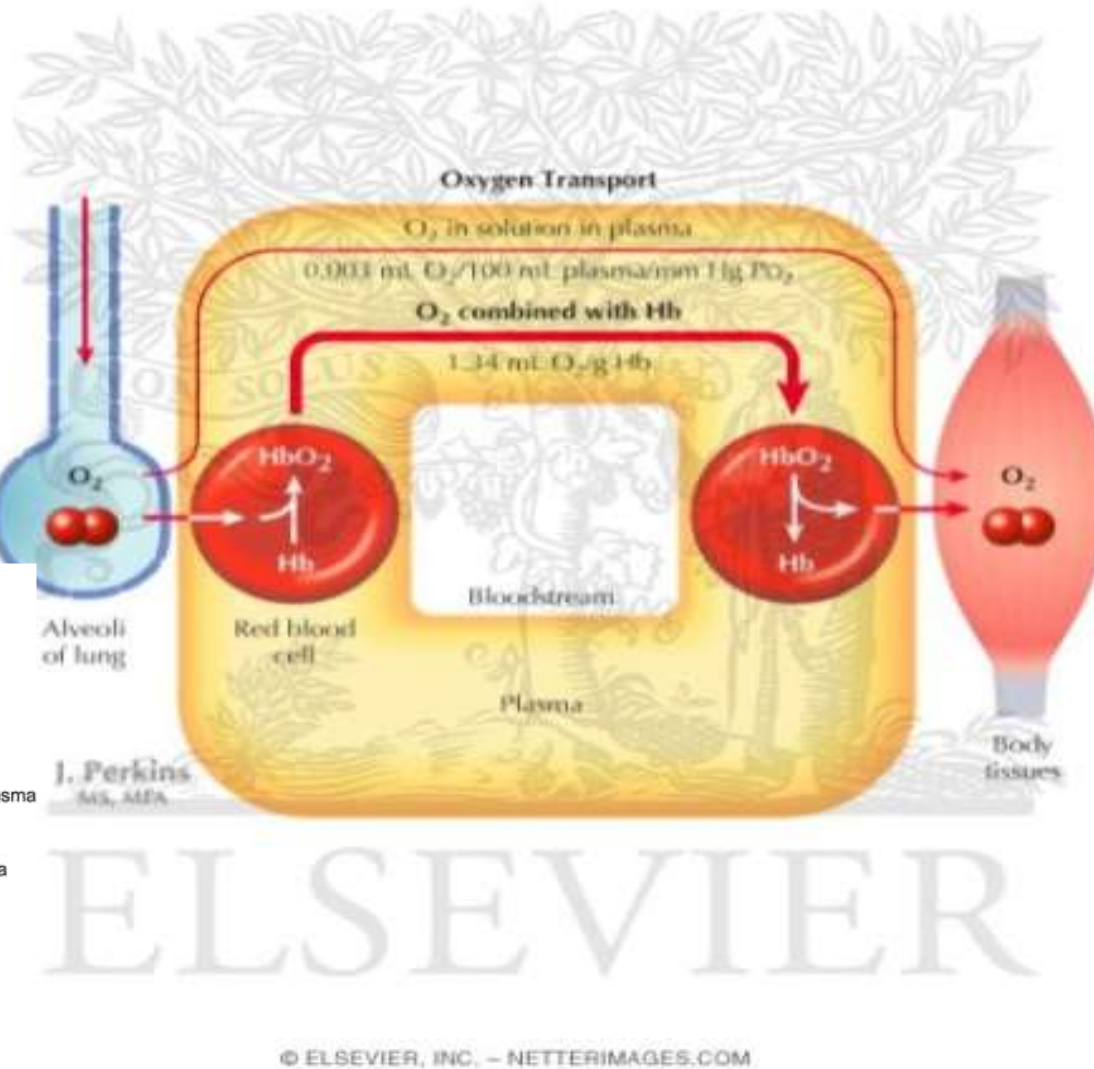
Objectives

1. Understand the forms of oxygen transport in the blood, the importance of each.
2. Differentiate between O2 capacity, O2 content and O2 saturation.
3. Describe (Oxygen- hemoglobin dissociation curve)
4. Define the P50 and its significance.
5. How DPG, temperature, H^+ ions and PCO_2 affect affinity of O_2 for Hemoglobin and the physiological importance of these effects.
6. Describe the three forms of carbon dioxide that are transported in the blood, and the chloride shift.


red blood cell
diffusion
CO2 in plasma
1
CO2 + H2O
carbonic anhydrase
2
H2CO3
3
HbO8
H+ + HCO3−
diffusion
HCO3− in plasma
4
5
diffusion
O2 in plasma
6
4O2
HHb
Cl−
diffusion
Cl− in plasma
chloride shift


Oxygen Transport
O2 in solution in plasma
0.003 mL O2/100 mL plasma/mm Hg PO2
O2 combined with Hb
1.34 mL O2/g Hb
O2
HbO2
Hb
HbO2
Hb
O2
Alveoli of lung
Red blood cell
Bloodstream
Plasma
Body tissues
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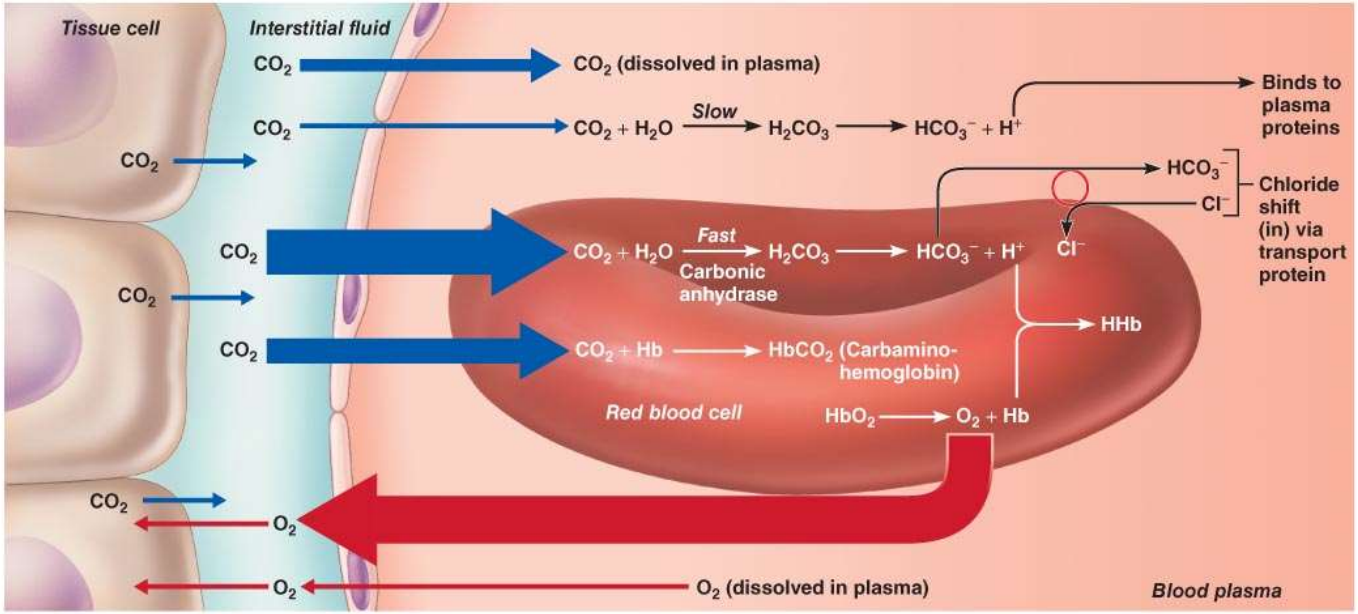
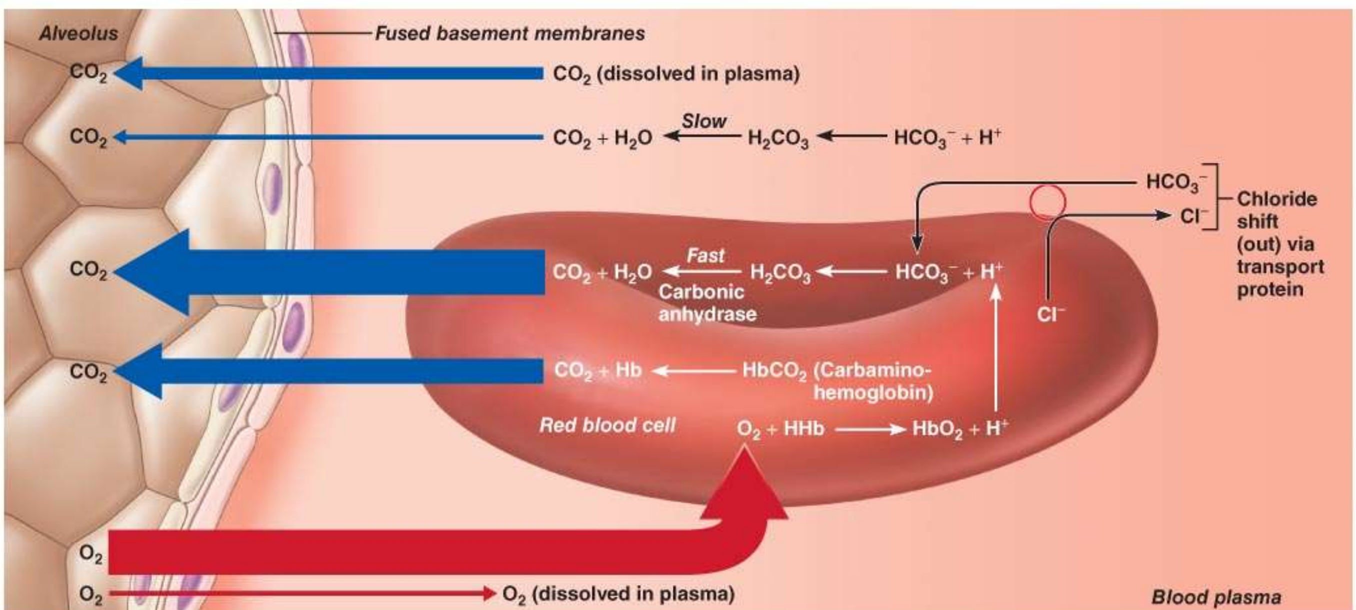


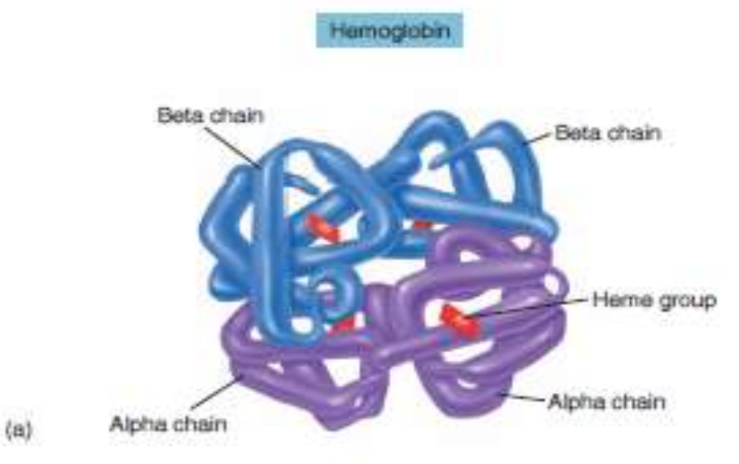
(a) Oxygen release and carbon dioxide pickup at the tissues



(b) Oxygen pickup and carbon dioxide release in the lungs

Transport of O2 and CO2 in the blood and body fluids

- O_2 is mostly transported in the blood bound to hemoglobin
- If the P_{O2} increases Hb binds O_2
- If P_{O2} decreases Hb releases O_2
- O2 binds to the heme group on hemoglobin, with 4 oxygens /Hb



- 3% dissolved in plasma
- 97% bound to hemoglobin (oxyhemoglobin)

- Higher $PO2_2$ results in greater Hb saturation.
- The relation between PO2 and Hb-O2 is not linear. The curve is called Oxyhemoglobin Saturation Curve
- Which is S- shaped or sigmoid

O2 capacity, content and saturation.

O_2 content: amount of O_2 in blood (ml O_2/100 ml blood)

O_2-binding capacity: maximum amount of O_2 bound to hemoglobin (ml O_2/100 ml blood) measured at 100% saturation.

Percent saturation: % of heme groups bound to O_2

$$\% \text{ saturation of Hb} = \frac{\text{oxygen content}}{\text{oxygen capacity}} \times 100$$

Dissolved $O_{2:}$ Unbound O_2 in blood (ml O_2/100 ml blood).

Transport of oxygen in arterial blood

- When blood is 100% saturated with O_2: each gram of Hb carry 1.34 ml O_2

  So O_2 content = 15g Hb x 1.34 O_2=20 ml.

  But when the blood is only 97% saturated with O_2:each 100 ml blood contain 19.4 ml O_2).

- Amount of oxygen released from the hemoglobin to the tissues is 5ml O_2 per each 100ml blood.

  So O_2 content in venous blood =19.4-5= 14.4 ml.

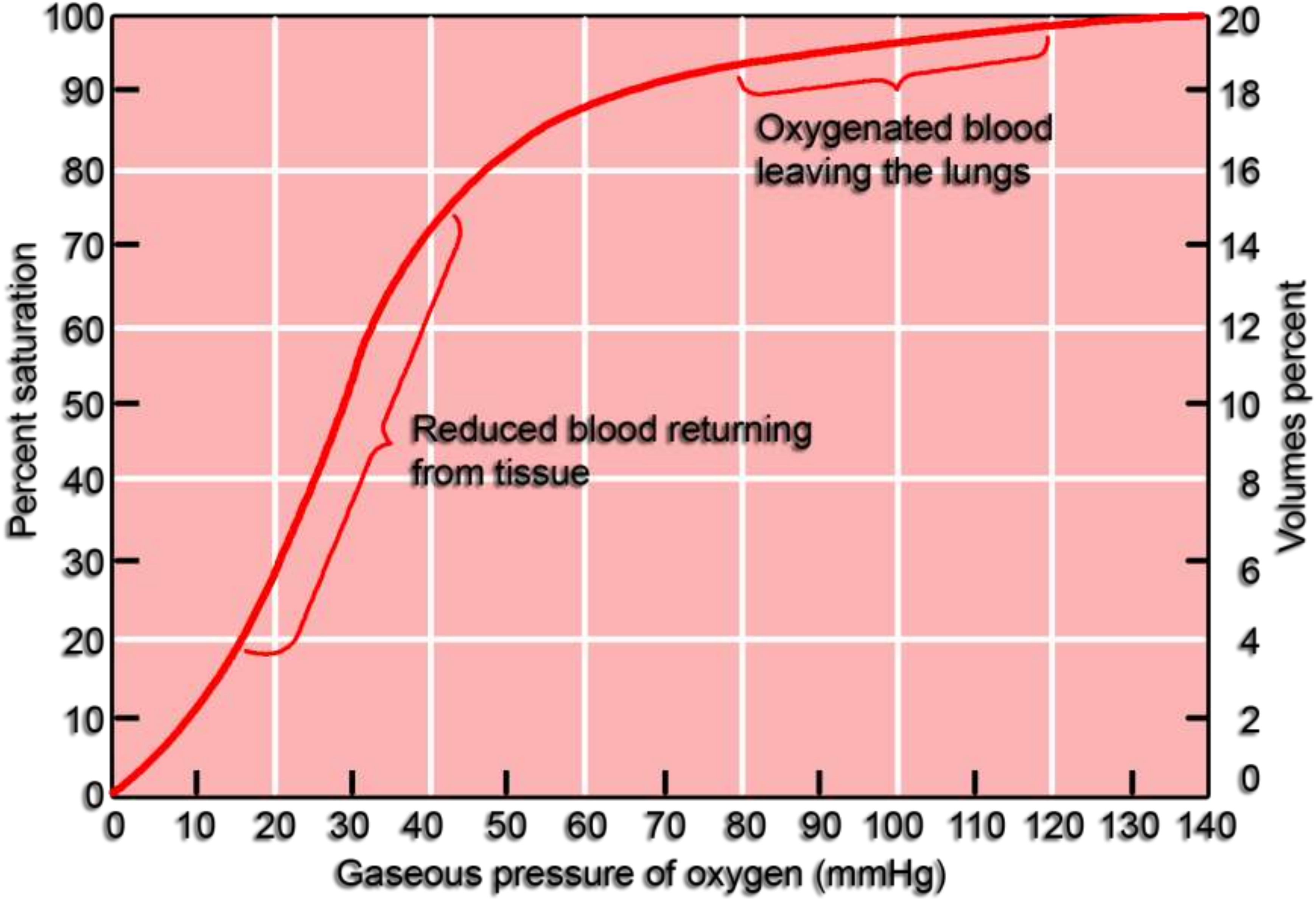
- During strenuous exercise the oxygen uptake by the tissue increases 3 folds so 15 ml O_2 is given /100 ml blood

  So O_2 content in venous blood =19.4-15=4.4 ml O_2 /100ml blood.

  At rest tissues consume 250 ml O_2 /min and produce 200ml CO_2

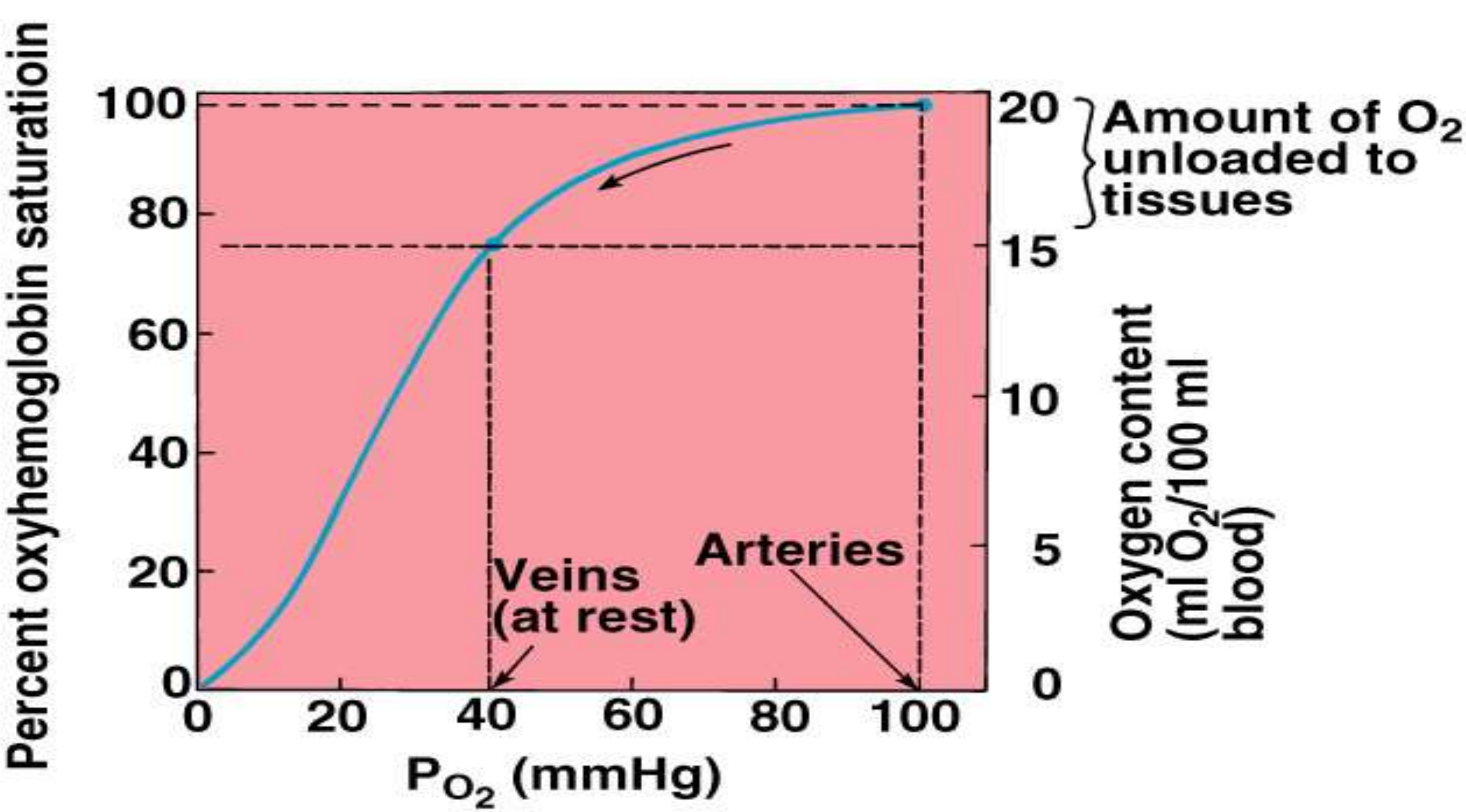
The oxygen-haemoglobin dissociation curve

- **It shows the progressive increase in the percentage saturation of the Hb with the increase in the PO_2 in the blood.**
- **The PO_2 in the arterial blood is about 95mmHg and saturation of Hb with O_2 is about 97%.**
- **In the venous blood returning from the tissues, the PO_2 is about 40mmHg and the saturation of Hb with O_2 is about 75%.**

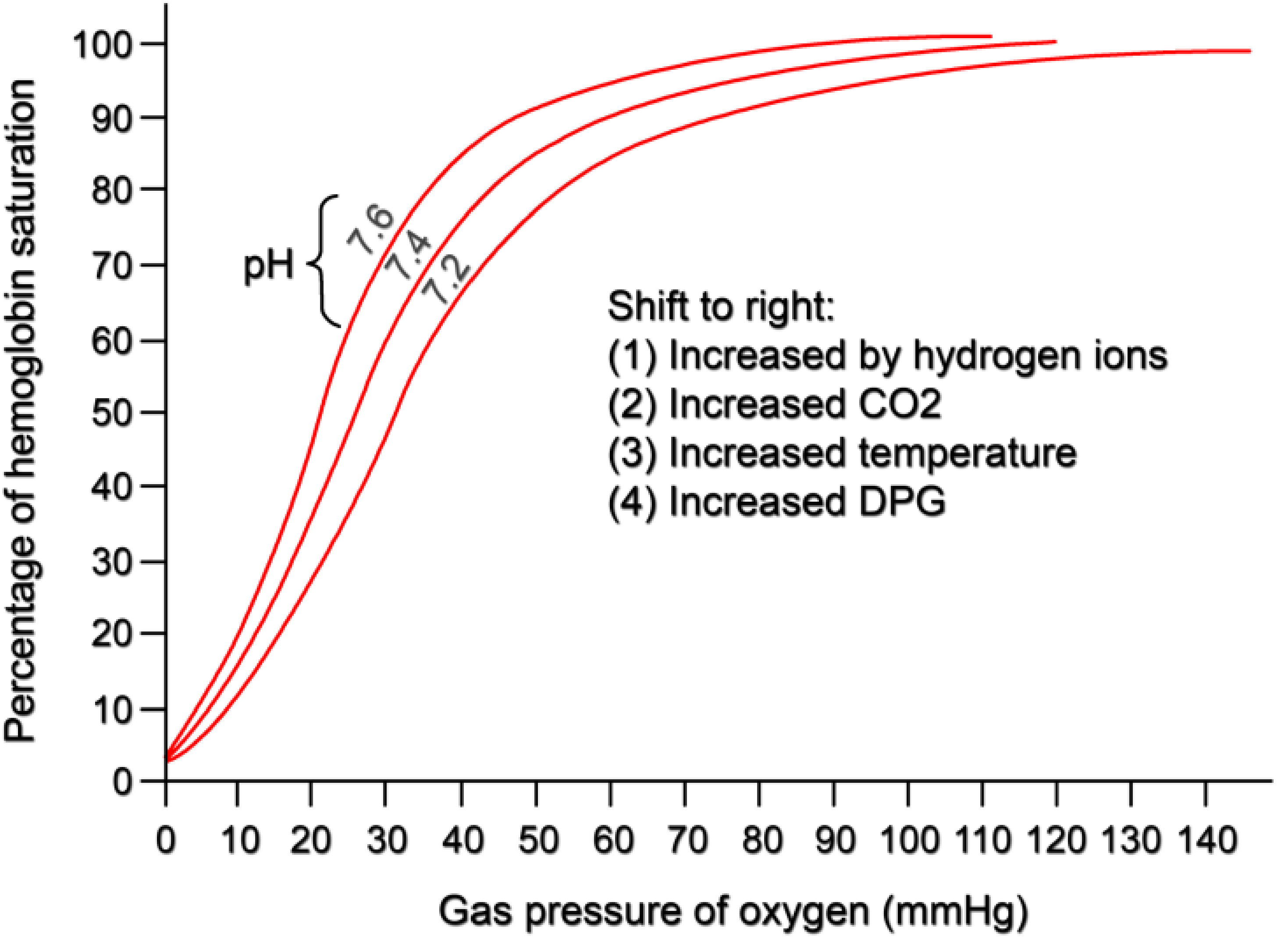


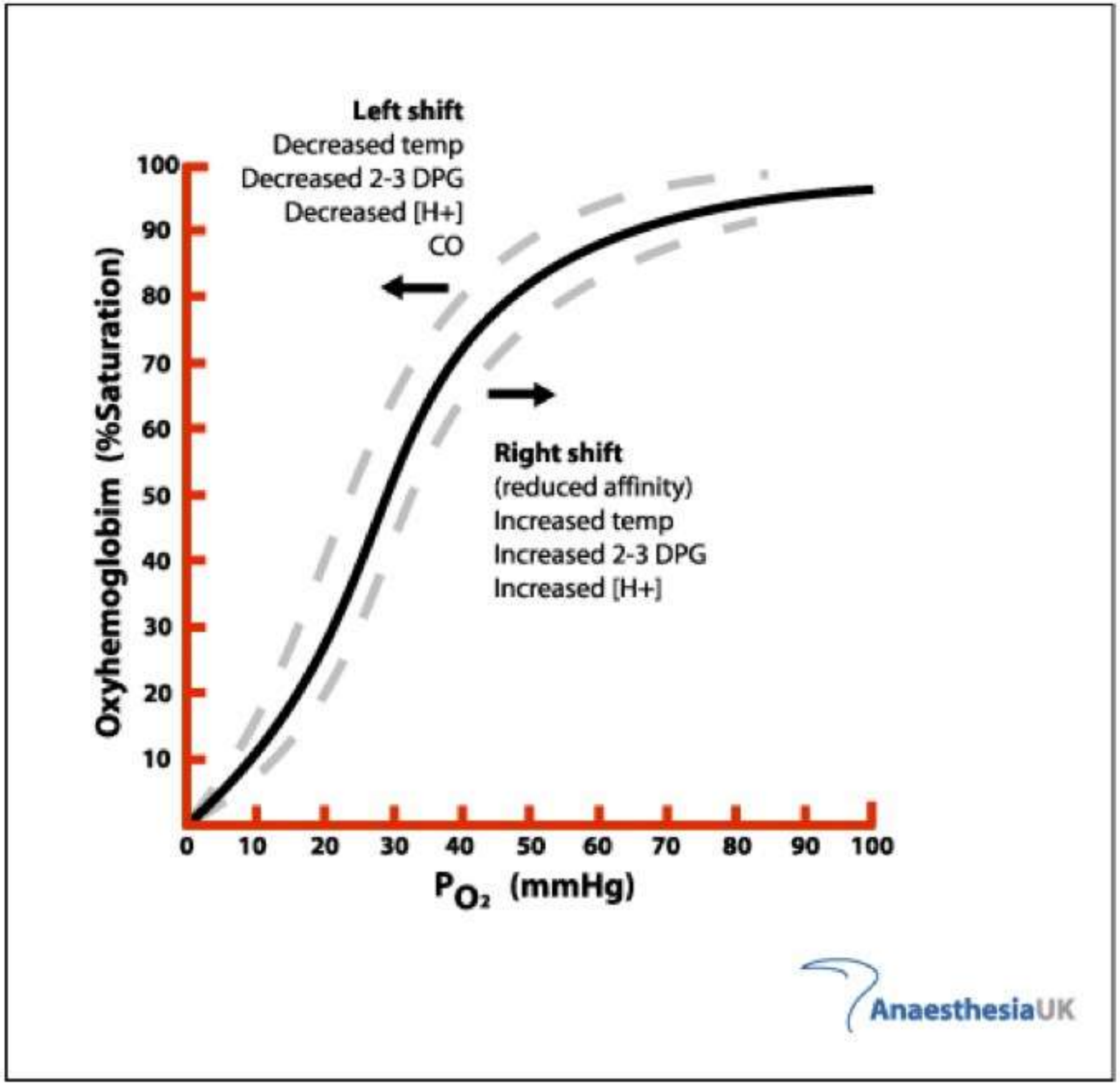
Percent saturation
Volumes percent
Gaseous pressure of oxygen (mmHg)
Oxygenated blood leaving the lungs
Reduced blood returning from tissue
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0
2
4
6
8
10
12
14
16
18
20

The oxygen-haemoglobin dissociation curve



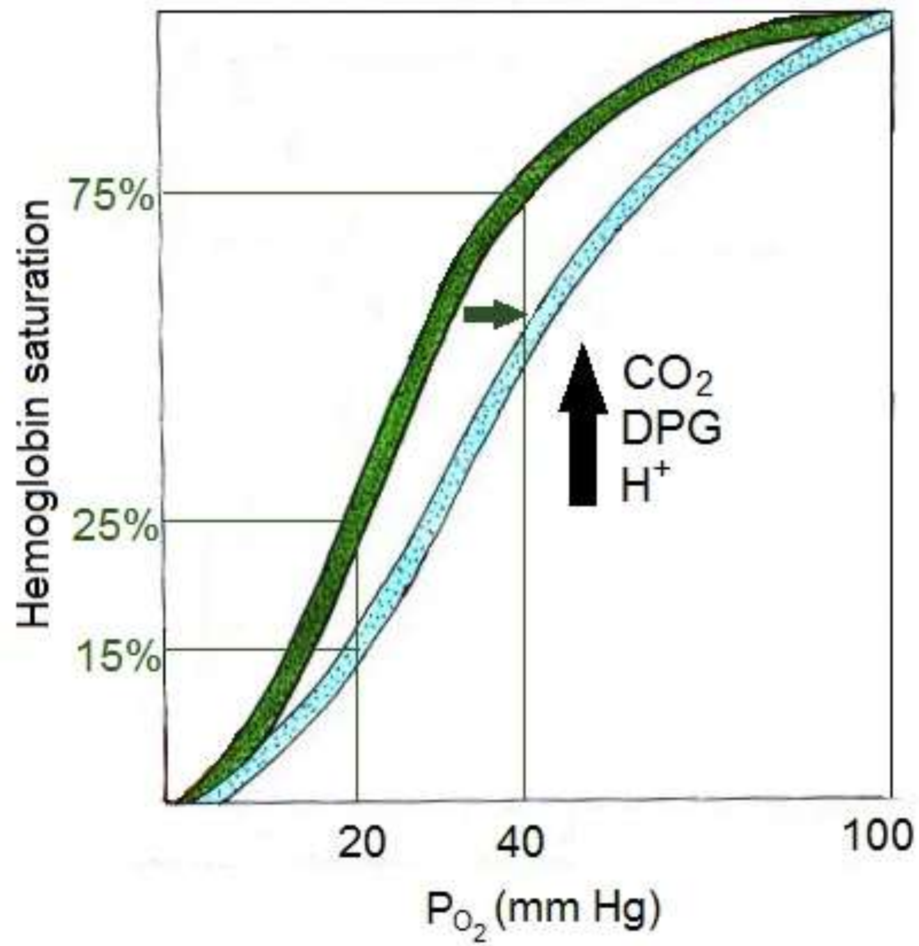
Factors shifting oxygen-haemoglobin dissociation curve to the right





Left shift
Decreased temp
Decreased 2-3 DPG
Decreased [H+]
CO
Right shift
(reduced affinity)
Increased temp
Increased 2-3 DPG
Increased [H+]
Oxyhemoglobim (%Saturation)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
P_{O_2} (mmHg)
AnaesthesiaUK

Factors affecting oxygen-haemoglobin dissociation curve



Factors affecting the affinity of Hb for O_2

4 important factors

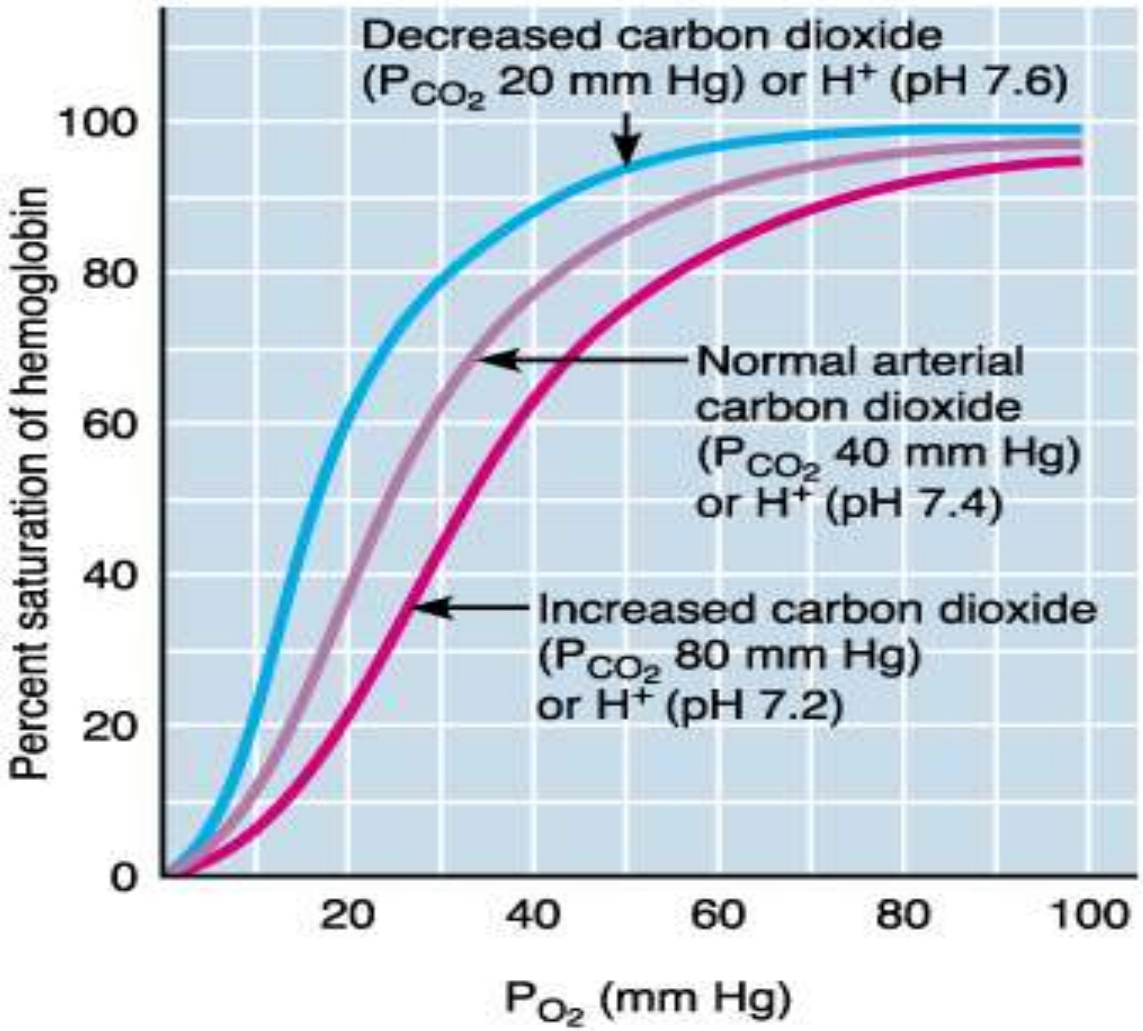
1) The ↓ pH or ↑(H+ conc),
2) the ↑ temperature,
3) and the ↑ concentration of 2,3 diphosphoglycerate (2,3-DPG).
4) ↑ PCO_2 concentration (Bohr effect) → all shift the curve to the right.

P50: it is the partial pressure of O_2 at which 50% of Hb is saturated with O_2.

↑ P50 means right shift → lower affinity for O_2.

↓ P50 means left shift → higher affinity for O_2.

Bohr Effect



(b)

The Rt and Lt shifts:

Definition:

- Rt shift means the oxygen is unloaded to the tissues from Hb
- Lt shift means loading or attachment of oxygen to Hb.

- Increased 2,3DPG, H+, Temperature , PCO_2 shift the curve to right.
  - 2,3DPG is synthesized in RBCs from the glycolytic pathway , it binds tightly to reduced Hb. increased 2,3 DPG facilitate the oxygen release and shifts the dissociation curve to Rt.
  - 2,3 DPG increases in the RBCs in anemia and hypoxemia, and thus serves as an important adaptive response in maintaining tissue oxygenation
  - Fetal Hb: has a P_{50} of 20 mmHg in comparison to 27 mmHg of adult Hb.

The Rt and Lt shifts:

- Effect of carbon dioxide and hydrogen ions on the curve (Bohr effect)

- At lung:
  - Movement of CO_2 from blood to alveoli will decrease blood CO_2 &H^+ →shift the curve to left and
  - Increase O_2 affinity of Hb allowing more O_2 transport to tissues
- At tissues:
  - Increase CO_2 &H^+ in blood leads to →shift the curve to right and
  - Decrease O_2 affinity of Hb allowing more O_2 transport to tissues

Shift of dissociation curve during exercise

- Exercise increases Temp, H+, 2,3 DPG and shift the curve to Rt.
  - Utilization Coefficient :The percentage of the blood that gives up its oxygen as it passes through the tissues capillaries is called utilization coefficient.

$$\text{Utilization Coefficient} = \frac{\text{O2 delivered to the tissues}}{\text{O2 content of arterial blood}}$$

  - Normally at rest = 5ml/20 ml= 25% ,
  - During exercise it = 15 ml/20 ml= 75 % - 85%

Transport of oxygen in the dissolved state.

- Only 3% of O2 is transported in the dissolved state,
- At normal arterial PO2 of 95 mmHg , about 0.29 ml of oxygen is dissolved in each 100ml of blood.
- When the PO2 of the blood falls to 40 mmHg in tissue capillaries, only 0.12 of oxygen remains dissolved.
- Therfore 0.17 ml of oxygen is normally transported in the dissolved state to the tissues per each 100 ml of blood

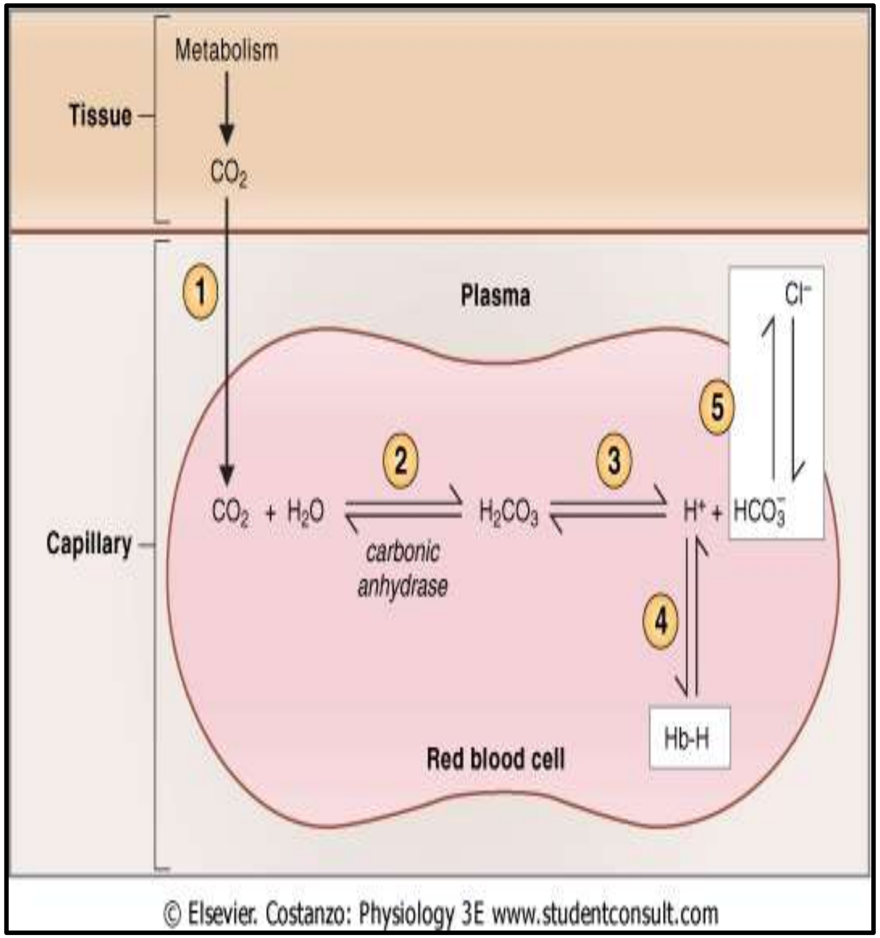
Combination of Hb with CO ----- displacement of oxygen

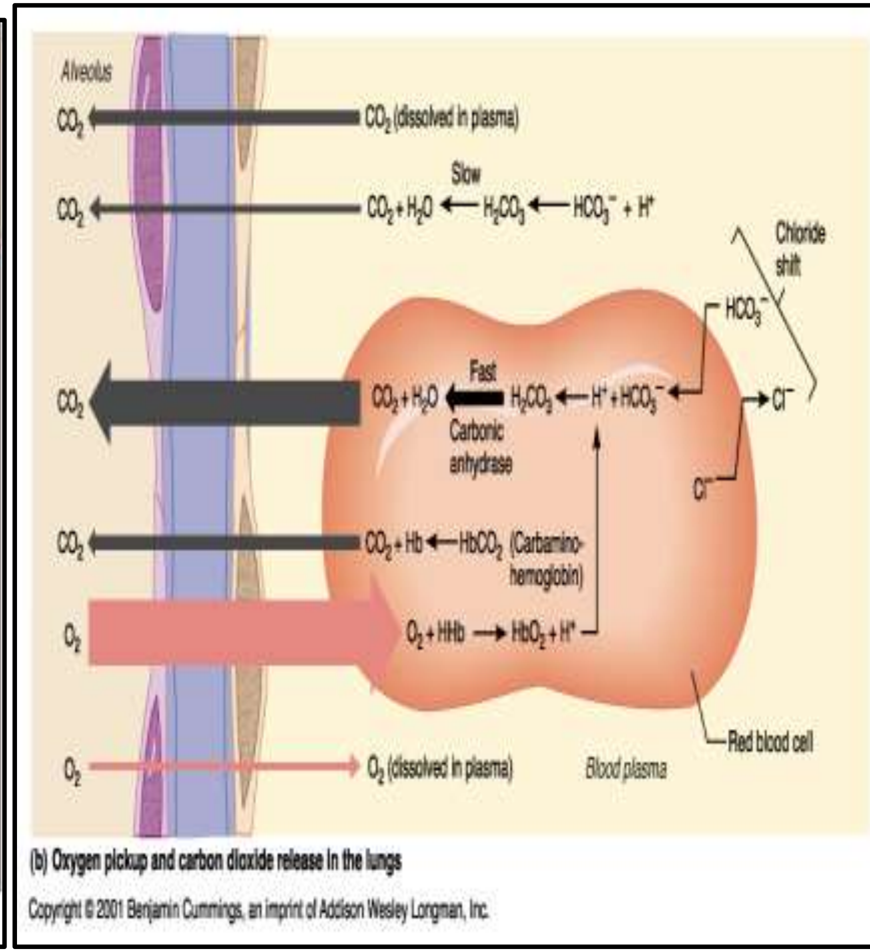
- CO combines with Hb at the same point on the Hb molecule as does oxygen,
- It binds with Hb about 250 times as much as O2 (affinity of Hb to CO is very high (250 times) that to O2.It causes Lt shift of the O2-Hb curve.

Transport of carbon dioxide in the blood

- **Carbon dioxide is transported in three forms**:
  - Dissolved CO_2 7%
  - Bicarbonate ions 70 %
  - Carbaminohemoglobin (with Hb) 23%.
- Each 100 ml of blood carry 4 ml of CO_2 from the tissues.

Formation of HCO3– & Chloride shift





- In Tissues
- In Pulmonary capillaries

The Haldane effect

- When oxygen binds with hemoglobin , carbon dioxide is released- to increase CO_2 transport
- Binding of Hb with O_2 at the lung causes the Hb to become a stronger acid and , this in turn displaces CO_2 from the blood and into the alveoli
- Change in blood acidity during CO_2 transport.
- Arterial blood has a PH of 7.41 that of venous blood with higher PCO_2 falls to 7.37 (i.e change of 0.04 unit takes place)

Respiratory Exchange ratio (Respiratory Quotient)

- Normally it is 4/5= 82%
- When Carbohydrate diet is used

  R = 1
- When fats only is used R=0.7
- A person on normal diet R=0.825