Oxygen and Carbon dioxide Transport

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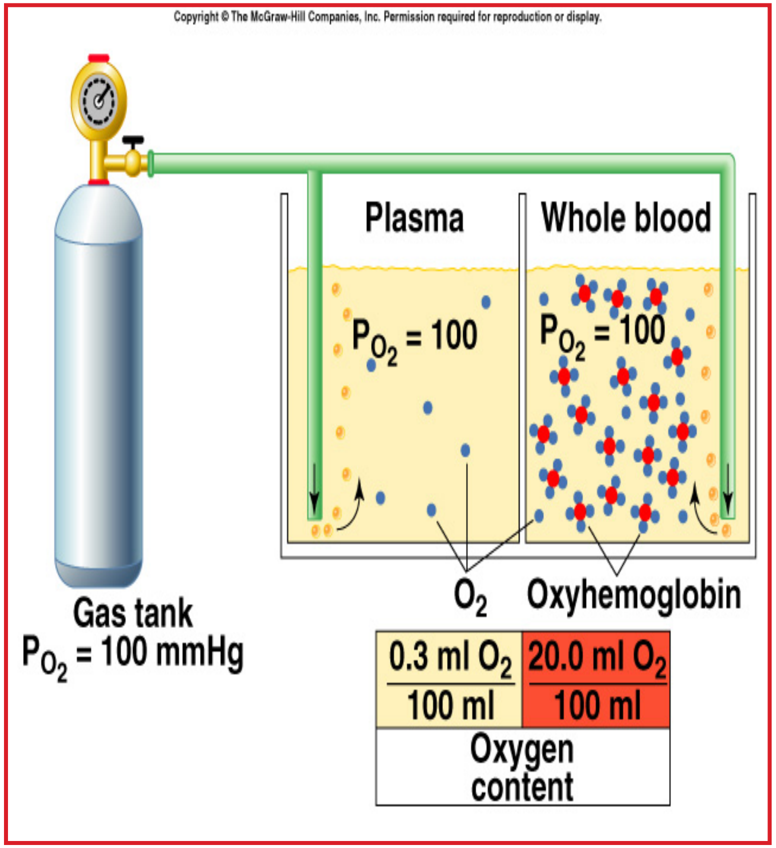
Objectives

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.

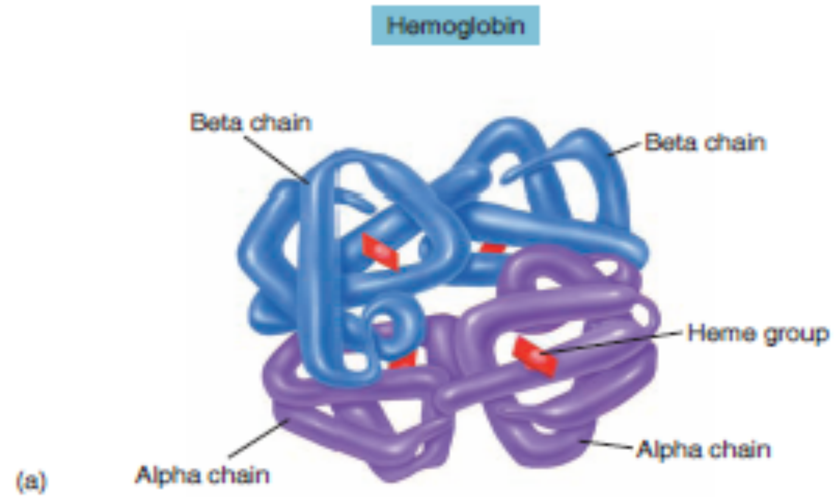
Forms of O2 transport

- The presence of hemoglobin in the red blood cells allows the blood to transport 30 to 100 times as much oxygen as could be transported in the form of dissolved oxygen in the water of the blood.



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



Terminology

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).

Cont…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).

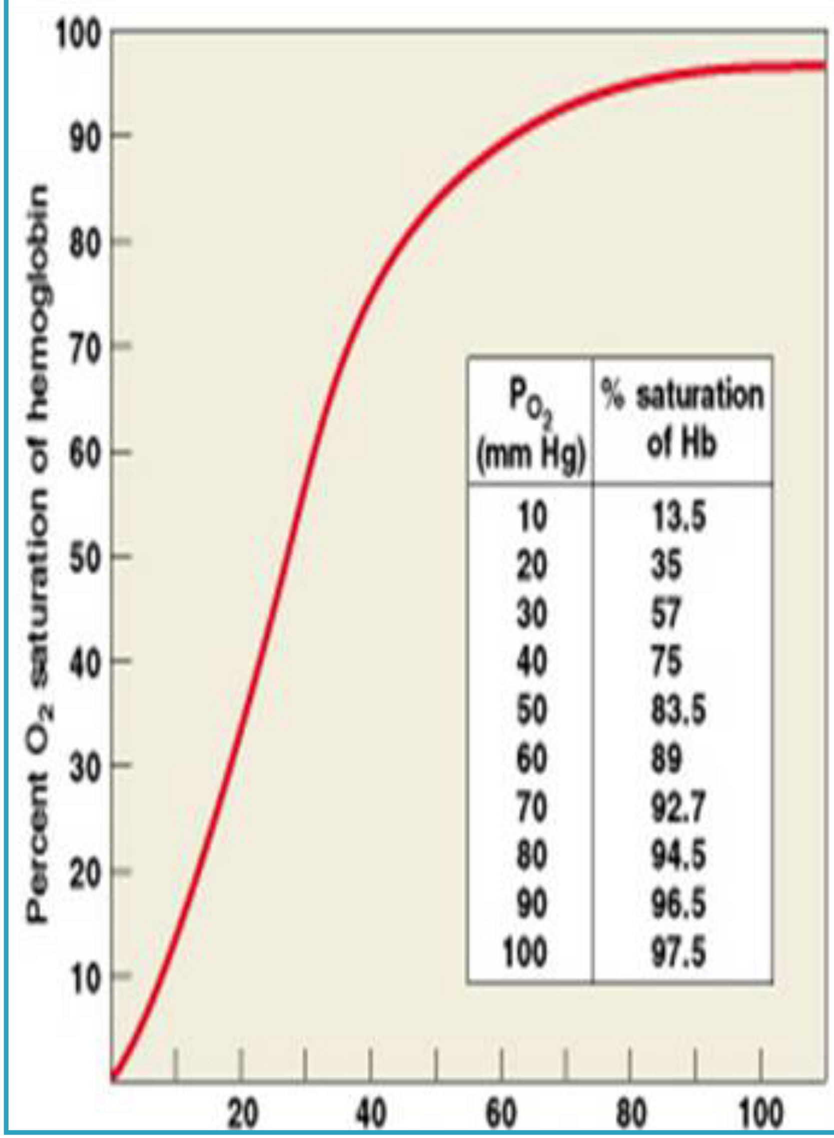
- Amount of oxygen released from the hemoglobin to the tissues is 5ml O_2 per each 100ml blood.
  So O_2 content in venous blood =19.4-5= 14.4 ml.

- 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

Oxygen transport in Blood

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

- Higher PO_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



P_{O_2} (mm Hg)	% saturation of Hb
10	13.5
20	35
30	57
40	75
50	83.5
60	89
70	92.7
80	94.5
90	96.5
100	97.5

Oxyhemoglobin Dissociation Curve

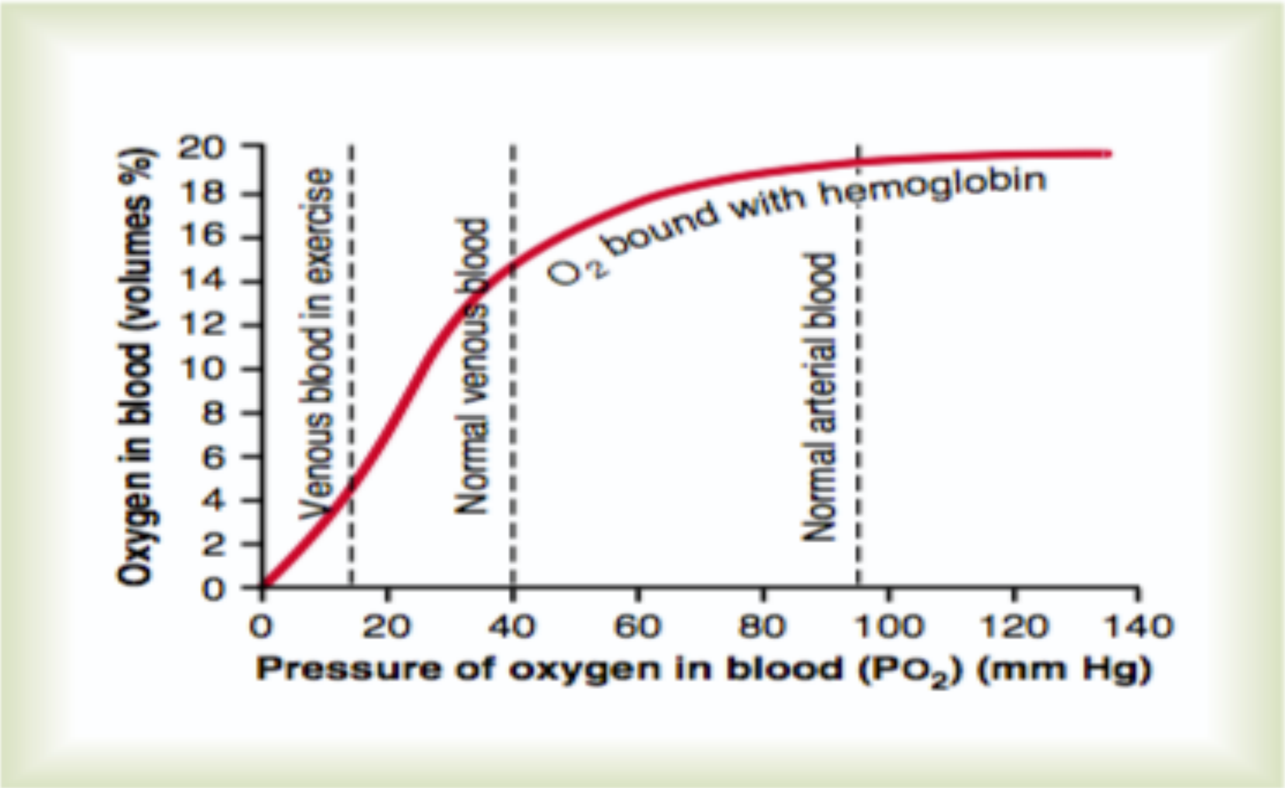
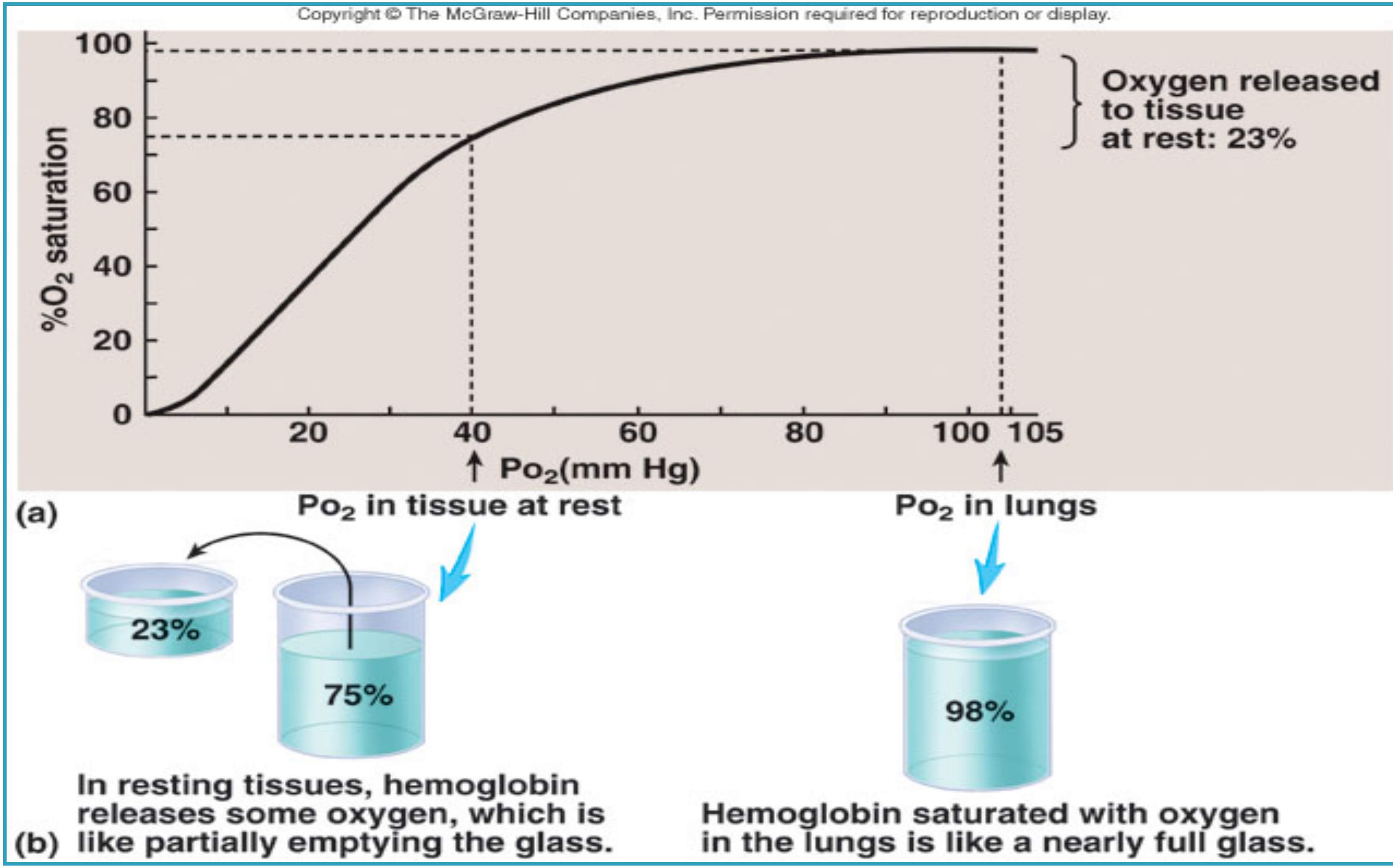


Figure 40–9

Effect of blood Po_2 on the quantity of oxygen bound with hemoglobin in each 100 milliliters of blood.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100
80
60
40
20
0
%O2 saturation
20
40
60
80
100
105
Po2(mm Hg)
Oxygen released
to tissue
at rest: 23%
(a)
Po2 in tissue at rest
Po2 in lungs
23%
75%
98%
In resting tissues, hemoglobin
releases some oxygen, which is
(b) like partially emptying the glass.
Hemoglobin saturated with oxygen
in the lungs is like a nearly full glass.

Factors that shift the O2- Hb dissociation curve

- The position of the dissociation curve can be determined by measuring the P50
- **P50:** The arterial PO2 at which 50% of the Hb is saturated with O2,

  normally P50= 26.5
- **Decreased P50** means increased affinity of Hb to O2 or shift of the curve to left
- **Increased P50** means decreased affinity or shift of the curve to right

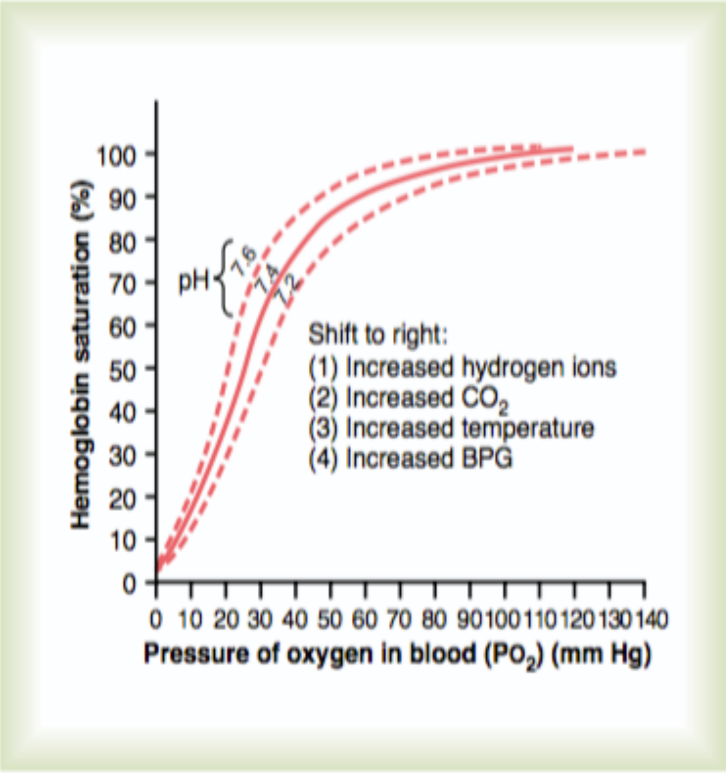
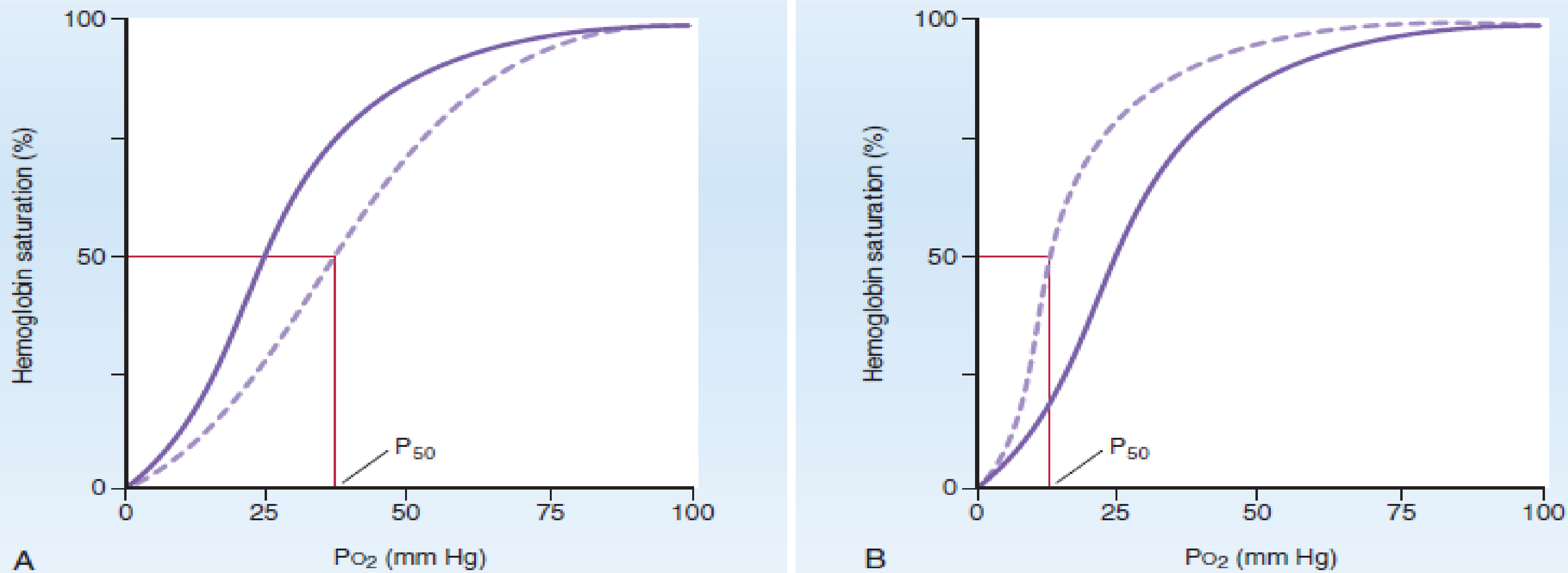


Figure 40–10

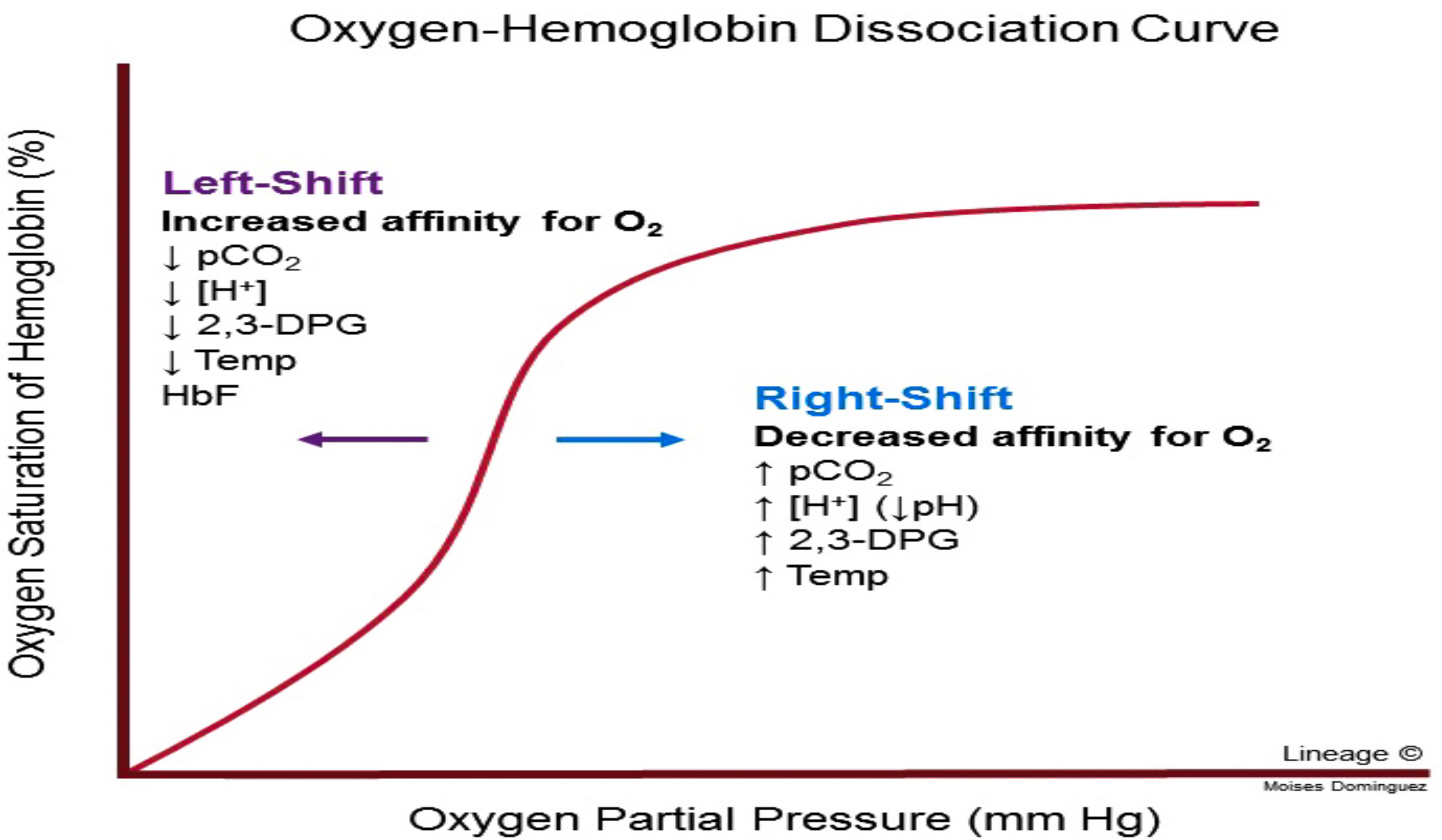
Shift of the oxygen-hemoglobin dissociation curve to the right caused by an increase in hydrogen ion concentration (decrease in pH). BPG, 2,3-biphosphoglycerate.

Shifts of O2-hemoglobin dissociation curve

Causes of shift to the right	Causes of shift to the left
↑ P_{CO_2} ↓ pH ↑ Temperature ↑ 2,3-DPG	↓ P_{CO_2} ↑ pH ↓ Temperature ↓ 2,3-DPG Hemoglobin F



The Oxygen-Hb Dissociation Curve



The Rt and Lt shifts:

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

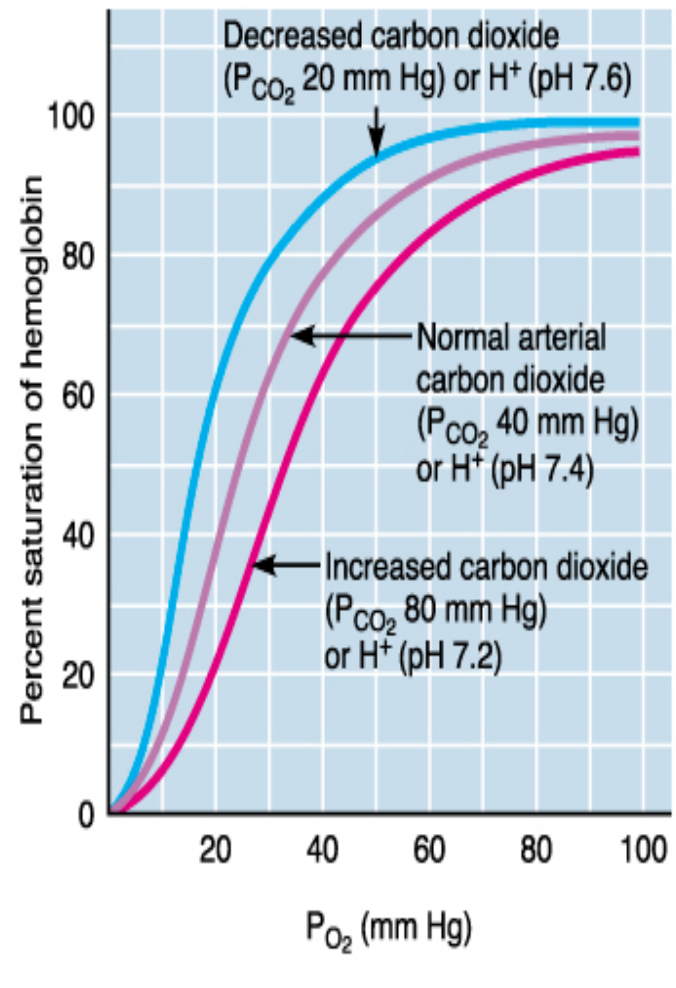
  Increased *2,3DPG, H+, Temperature , PCO2 shift the curve to right.*
- 2,3DPG is synthesized in RBCs from the glycolytic pathway , it binds tightly to reduced Hb. increased 2,3 DPG facilitate the oxygen release and shifts the dissociation curve to Rt.
- 2,3 DPG increases in the RBCs in anemia and hypoxemia, and thus serves as an important adaptive response in maintaining tissue oxygenation
- *Fetal Hb: has a P50 of 20 mmHg in comparison to 27 mmHg of adult Hb.*

Bohr Effect

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

At lung movement of CO2 from blood to alveoli will decrease blood CO2 &H+ →shift the curve to left and increase O2 affinity to Hb allowing more O2 transport to tissues

At tissues: the reverse occur



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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*.

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

- *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.

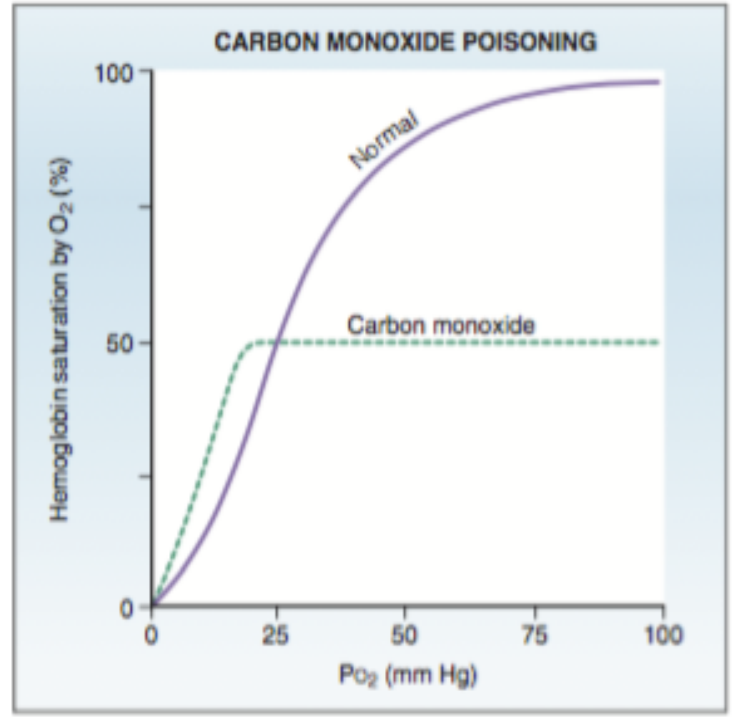


Fig. 5.23 Effect of carbon monoxide on the O_2-hemoglobin dissociation curve. CO reduces the number of sites available for O_2 binding to hemoglobin and causes a shift of the O_2-hemoglobin dissociation curve to the left.

Pulse Oximetry

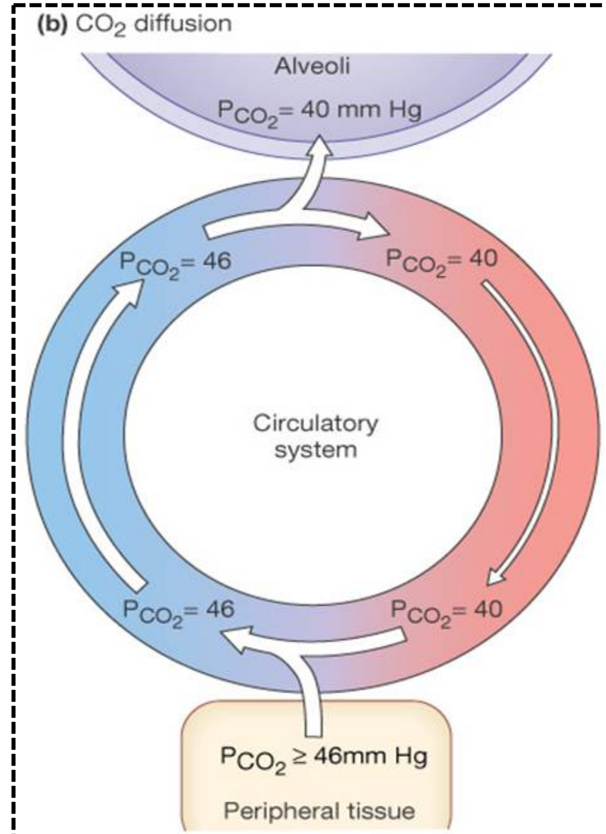
- Measures % saturation of arterial blood (e.g., of the finger) using dual-wavelength spectrophotometry. Because oxyhemoglobin and deoxyhemoglobin have different absorbance characteristics, the machine calculates % saturation from absorbance at two different wavelengths.
- Pulse oximetry does *not* directly measure PaO2. However, knowing % saturation, one can estimate PaO2 from the O2-hemoglobin dissociation curve.

Transport of carbon dioxide in the blood

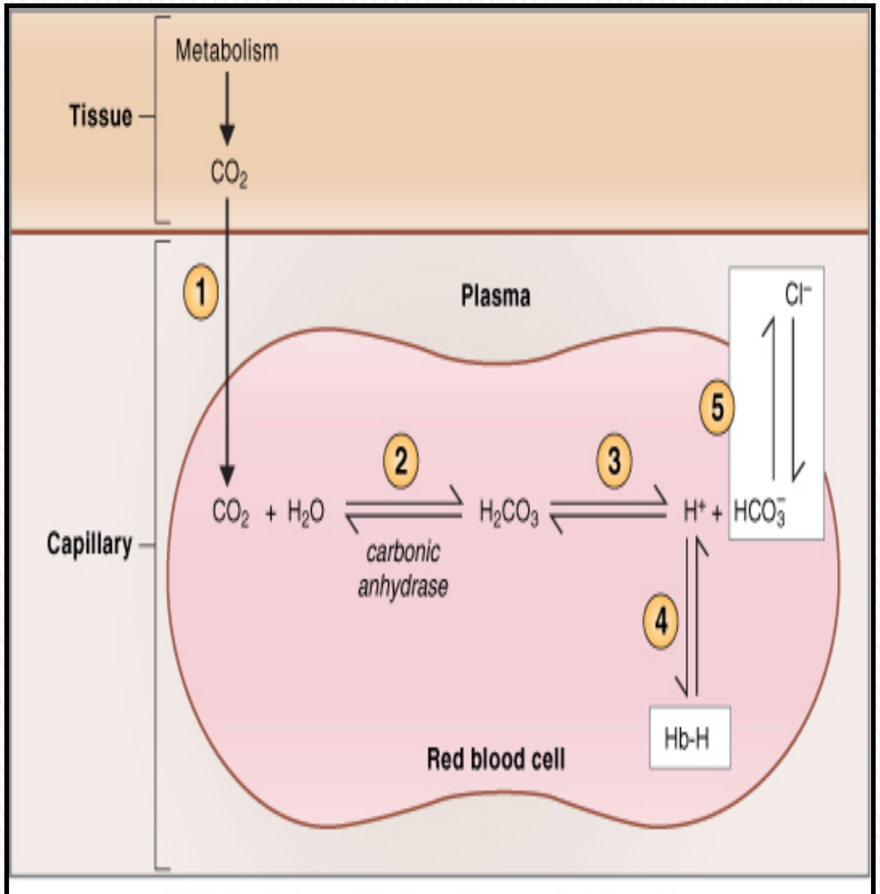
Carbon dioxide is transported in three forms.

- *Dissolved CO2 7%*
- *bicarbonate ions 70 %*
- *Carbaminohemoglobin (with Hb) 23%.*

Each 100 ml of blood carry 4 ml of CO2 from the tissues.



Formation of HCO3- & Chloride shift



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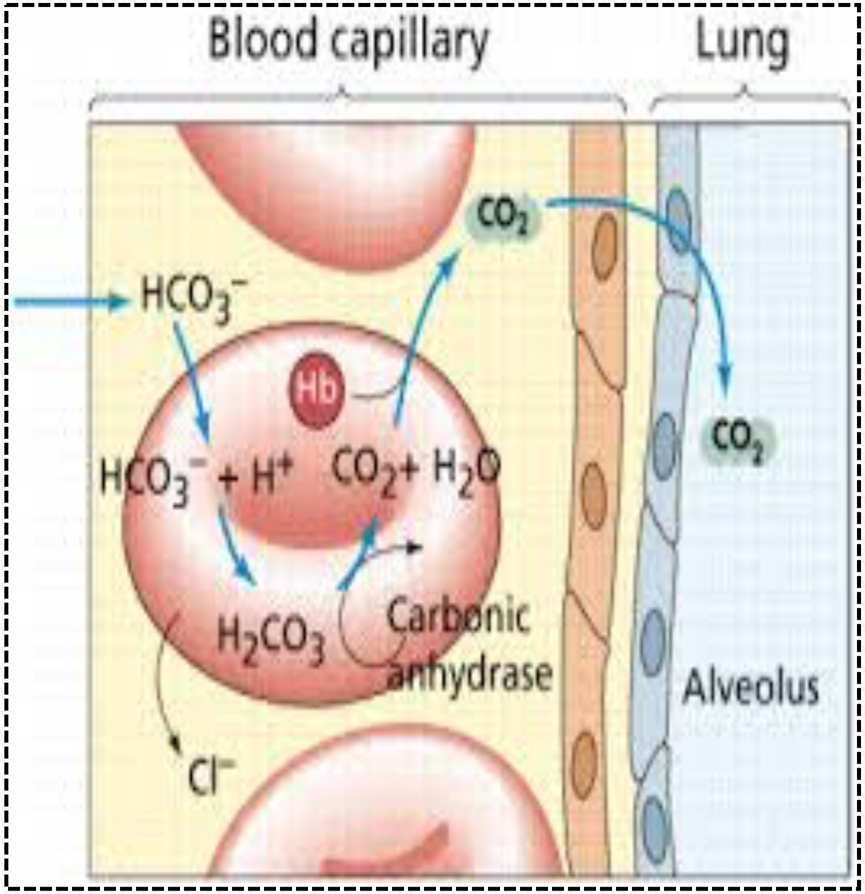
In Tissues

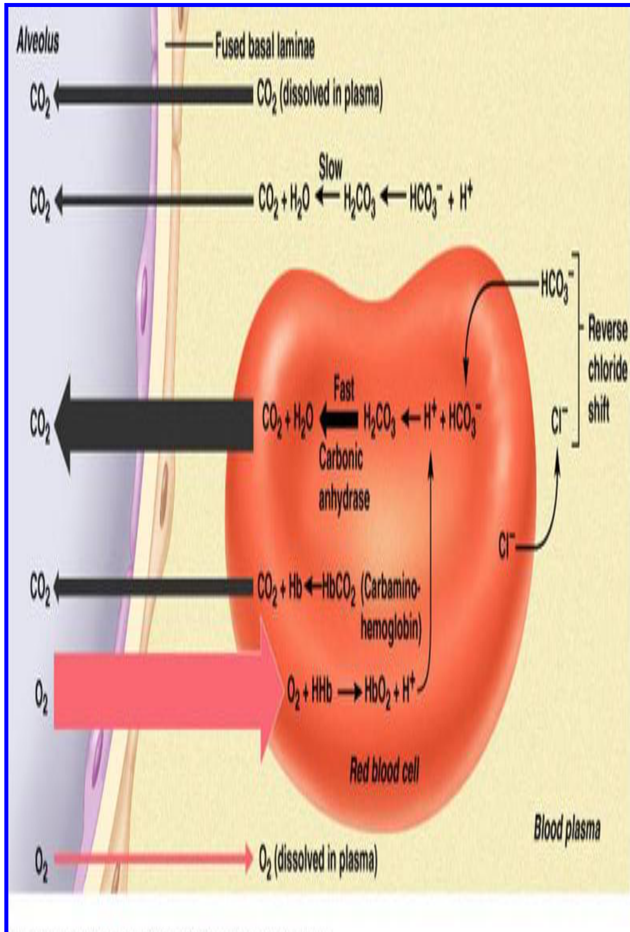


In Pulmonary capillaries

The Haldane effect

- When oxygen binds with hemoglobin , carbon dioxide is released- to increase CO2 transport
- Binding of Hb with O2 at the lung causes the Hb to become a stronger acid and , this in turn displaces CO2 from the blood and into the alveoli
- **Change in blood acidity during CO2 transport.**

 Arterial blood has a PH of 7.41 that of venous blood with higher PCO2 falls to 7.37 (i.e change of 0.04 unit takes place)



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

Respiratory Exchange ratio (Respiratory Quotient)

$$R = \frac{\text{Rate of carbon dioxide output}}{\text{Rate of oxygen uptake}}$$

- 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
- The reason for this difference is that when O2 is metabolized with carbohydrates, one molecule of CO2 is formed for each molecule of O2 consumed; when O2 reacts with fats, a large share of the O2 combines with hydrogen atoms from the fats to form water instead of CO2.