Gas Transfer
(Diffusion of O_2 and CO_2)

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Objectives

1-Define partial pressure of a gas, how is influenced by altitude.

2- Understand that the pressure exerted by each gas in a mixture of gases is independent of the pressure exerted by the other gases (Dalton's Law)

3- Understand that gases in a liquid diffuse from higher partial pressure to lower partial pressure (Henry's Law)

4- Describe the factors that determine the concentration of a gas in a liquid.

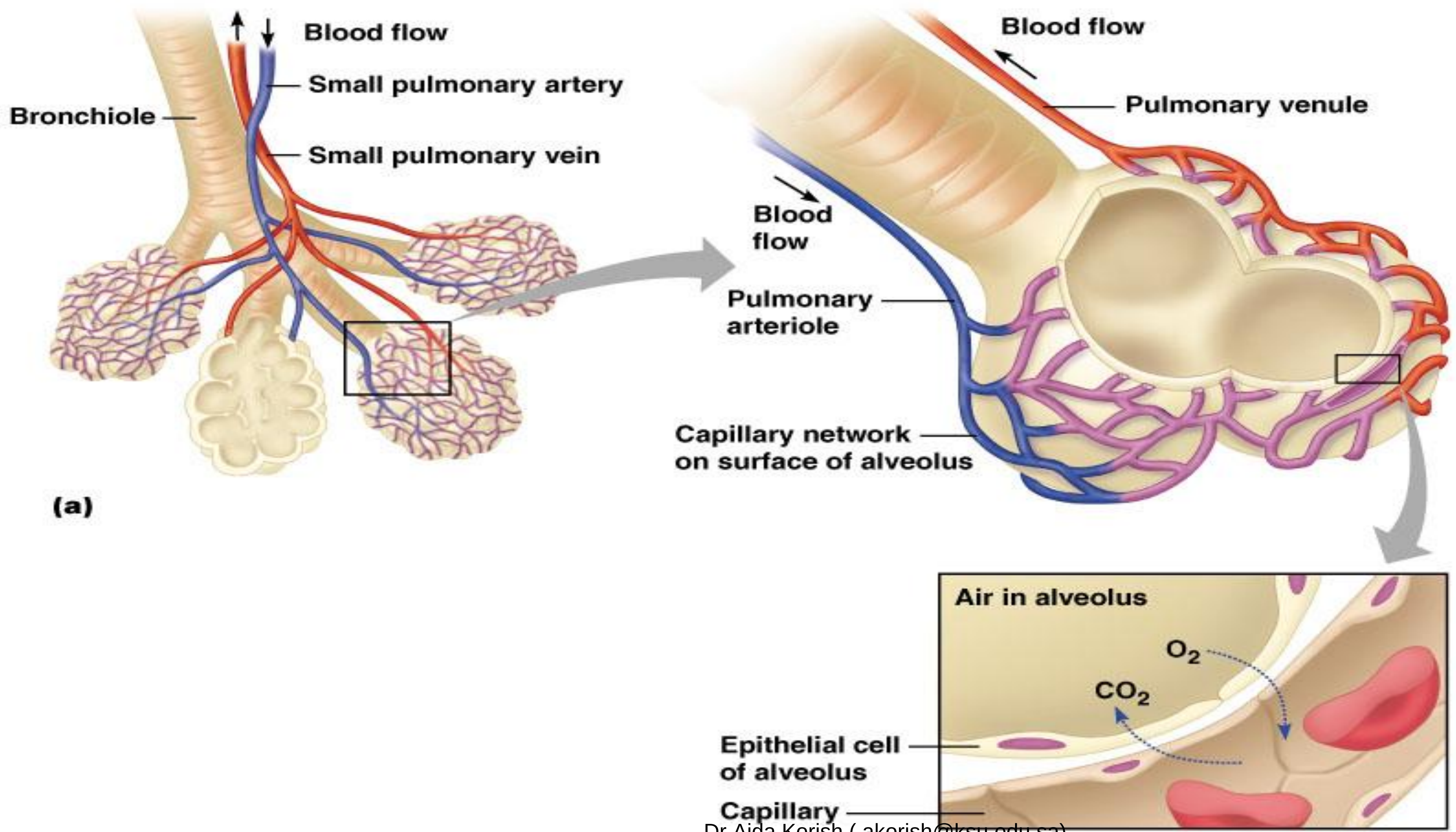
5- Describe the components of the alveolar-capillary membrane (i.e., what does a molecule of gas pass through).

6- Knew the various factors determining gas transfer: -

Surface area, thickness, partial pressure difference, and diffusion coefficient of gas

7- State the partial pressures of oxygen and carbon dioxide in the atmosphere, alveolar gas, at the end of the pulmonary capillary, in systemic capillaries, and at the beginning of a pulmonary capillary.

Gas exchange through the respiratory membrane



- After ventilation of the alveoli with fresh air the next step is the process called Diffusion of oxygen and carbon dioxide.

- The rate of diffusion of each of these gases is directly proportional to the pressure caused by this gas alone which is called the partial pressure of the gas

- Pressure is caused by the constant impact of kinetically moving molecules against a surface.

Factors affecting gas diffusion

$$D \quad \alpha \quad \frac{\Delta P \times A \times S}{d \times \sqrt{MW}}$$

1. P: Partial pressure differences
2. A: Surface area for gas exchange
3. d: Diffusion distance
4. MW: Molecular weight and (S)solubility of gas

O_2 has lower molecular weight than CO_2

But CO_2 is 24 times more soluble than O_2

Net result: CO_2 diffusion approx 20 times faster than O_2 diffusion

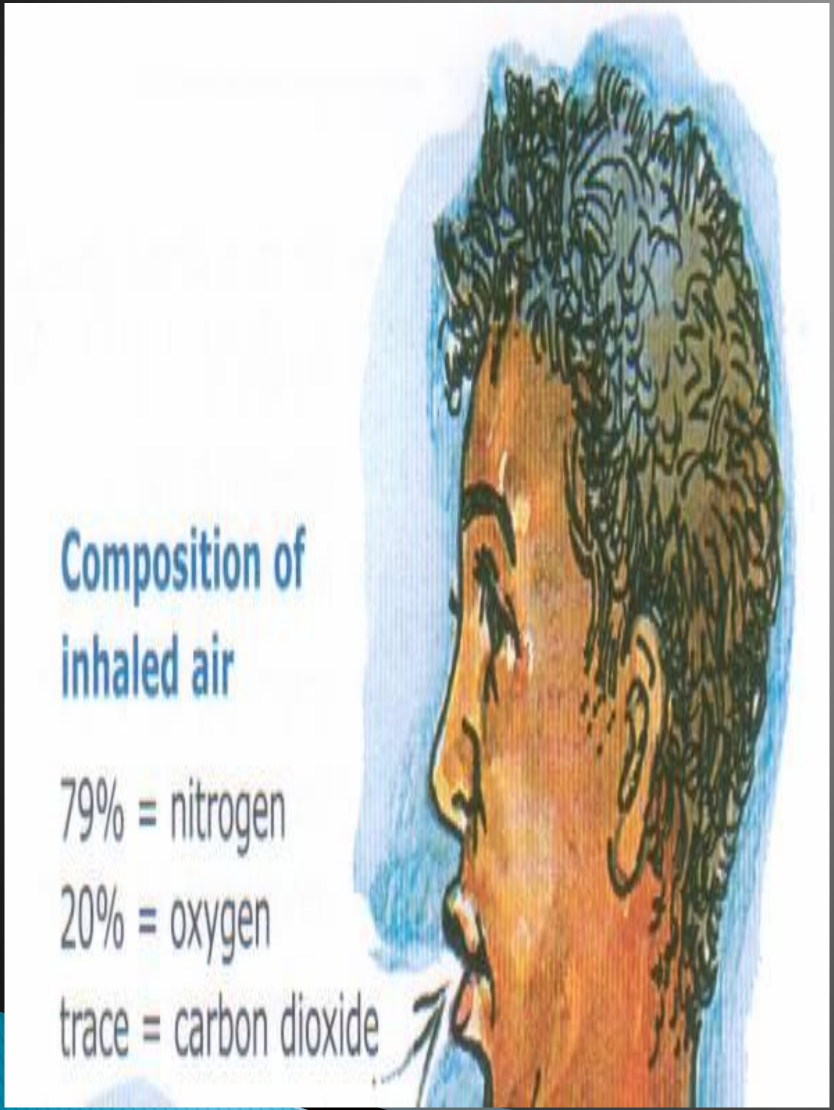
Cont….Factors affecting diffusion across the respiratory membrane

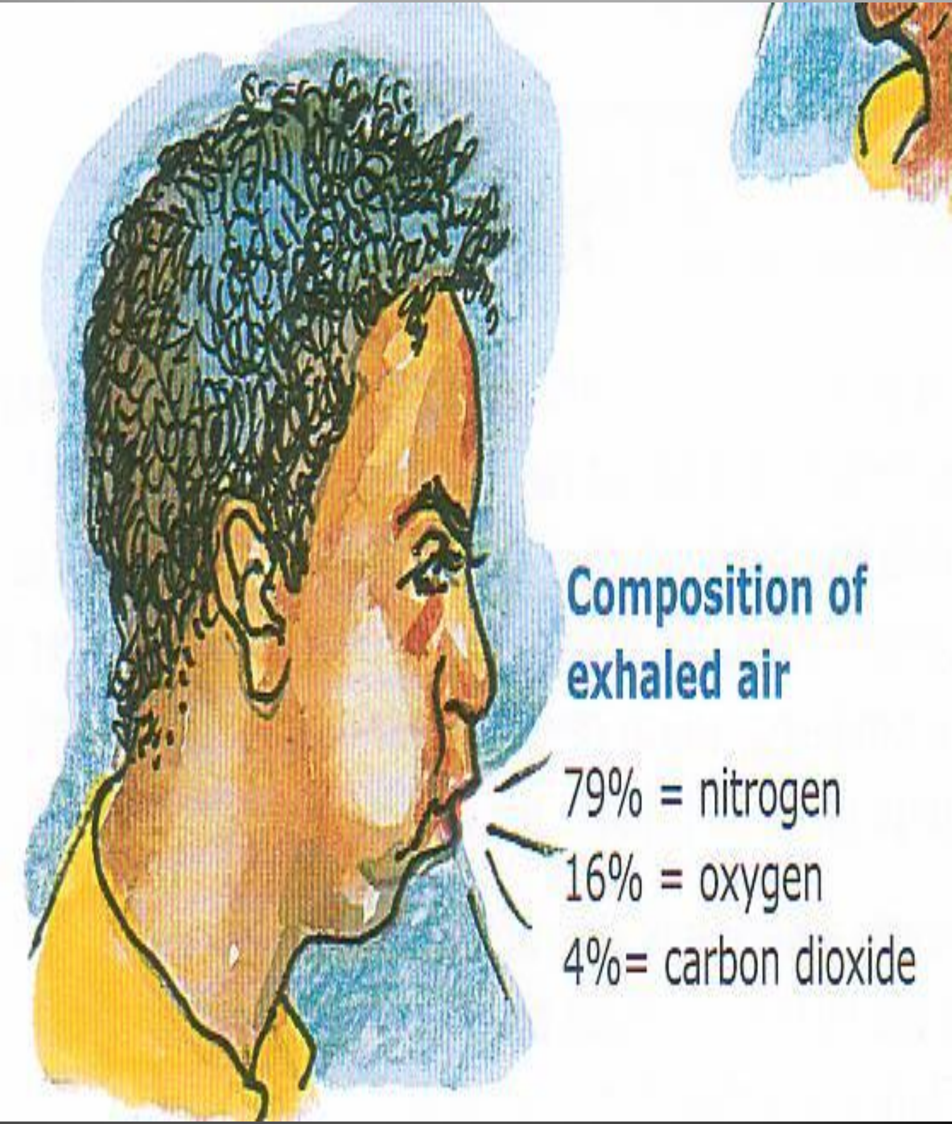
- $S/\sqrt{MW}$ is called *the diffusion coefficient* of the gas.

For Oxygen = 1.0 carbon dioxide =20.0 nitrogen =0.53.

The relative rates at which different gases at the same pressure level will diffuse are proportional to their diffusion coefficient.

Composition of respiratory air





Partial Pressure of O_2 and CO_2

- Oxygen concentration in the atmosphere is 21%

  So PO_2 in atmosphere = 760 mmHg x 21% = 160 mmHg.
- This mixes with "old" air already present in alveolus to arrive at PO_2 of 104 mmHg in alveoli.
- Carbon dioxide concentration in the atmosphere is 0.04%

  So PCO_2 in atmosphere =760 mmHg x 0.04% = 0.3 mm Hg
- This mixes with high CO_2 levels from residual volume in the alveoli to arrive at PCO_2 of 40 mmHg in the alveoli.

Partial Pressures of Gases in Inspired Air and Alveolar Air

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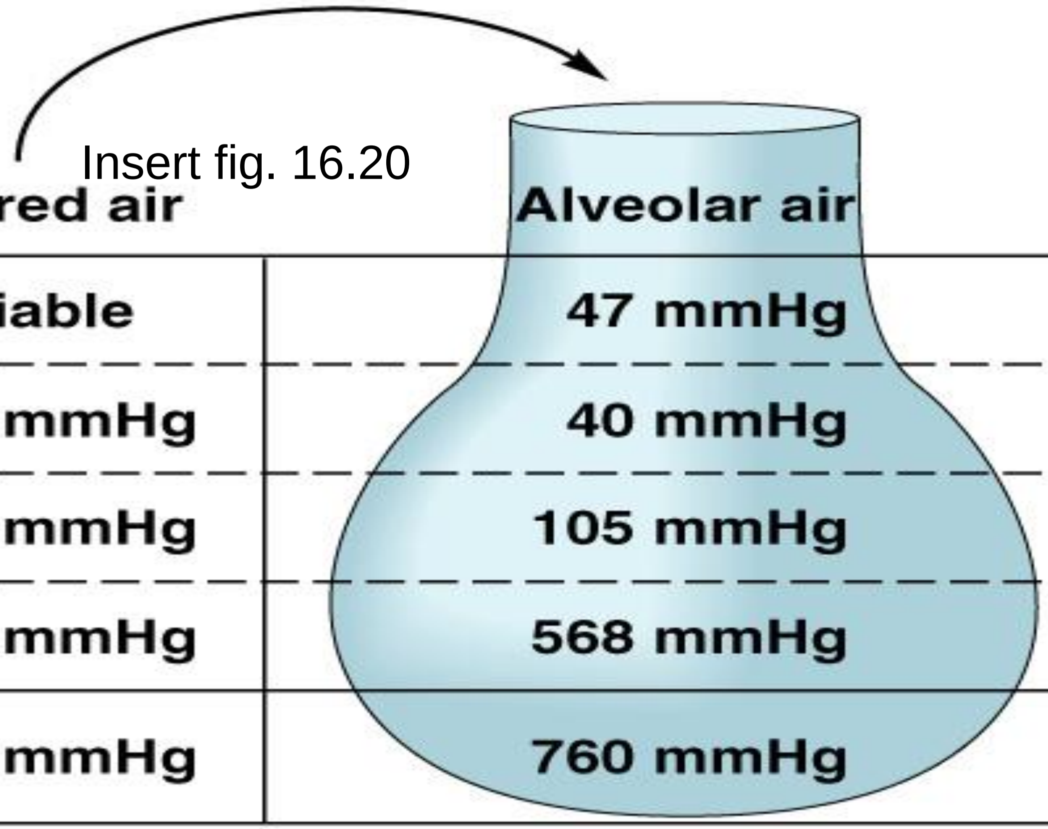
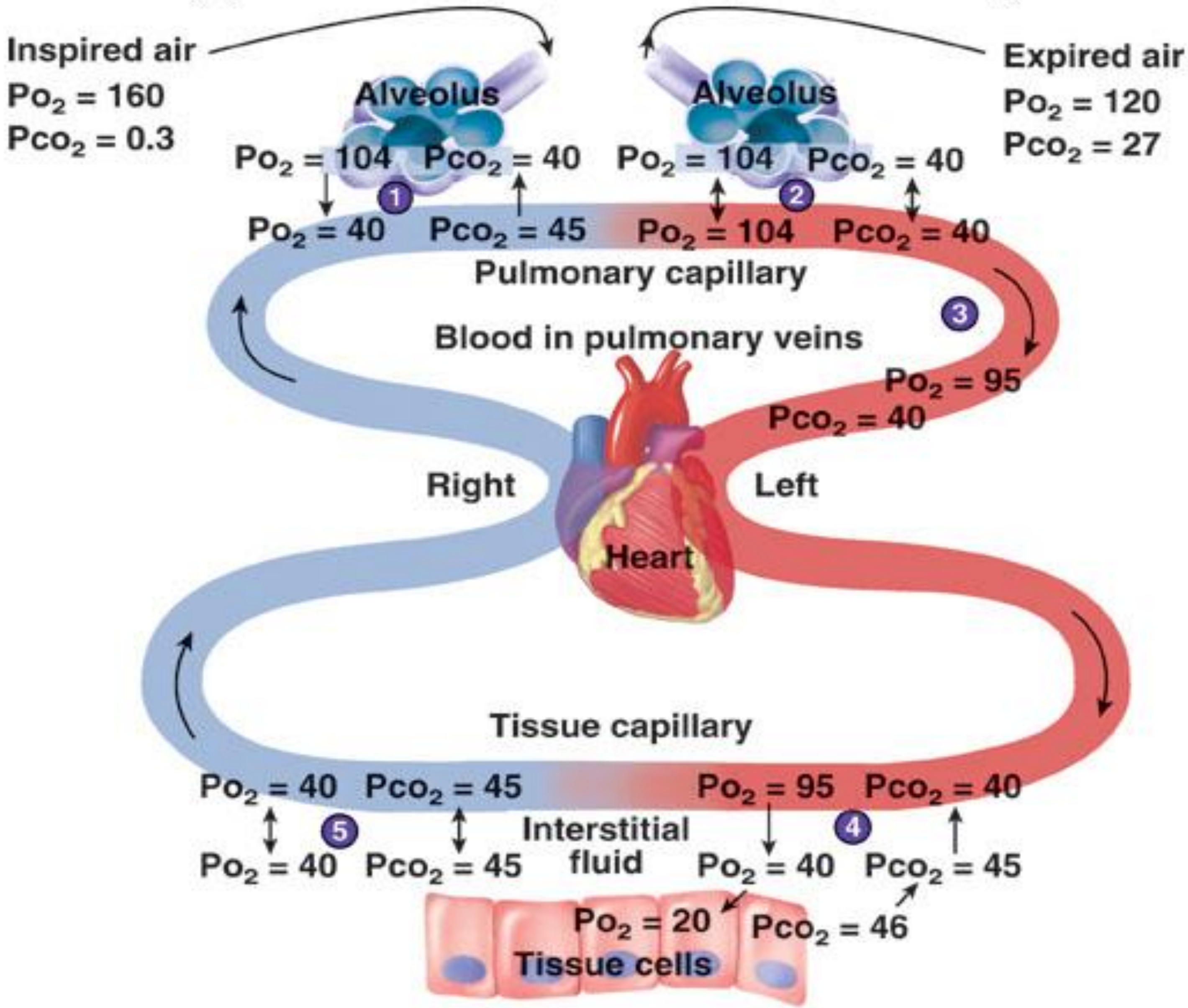


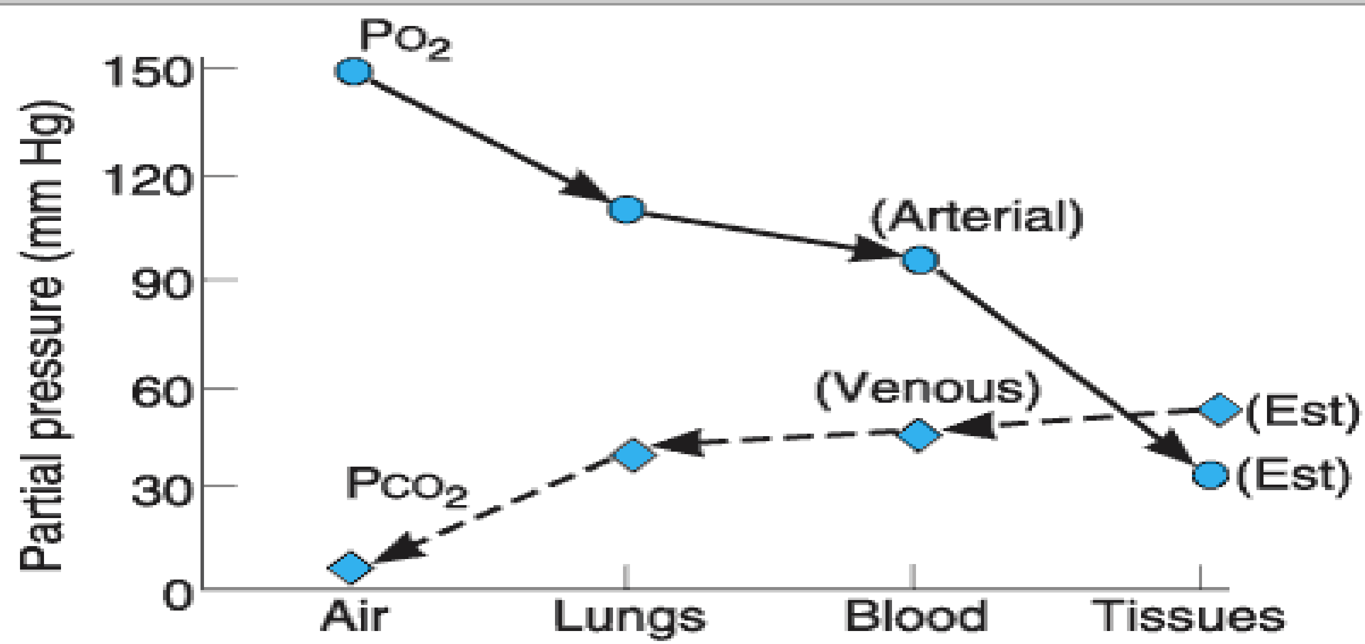
	Inspired air	Alveolar air
H_2O	Variable	47 mmHg
CO_2	000.3 mmHg	40 mmHg
O_2	159 mmHg	105 mmHg
N_2	601 mmHg	568 mmHg
Total pressure	760 mmHg	760 mmHg



Inspired air
Po2 = 160
Pco2 = 0.3
Alveolus
Po2 = 104
Pco2 = 40
1
Po2 = 40
Pco2 = 45
Alveolus
Po2 = 104
Pco2 = 40
2
Po2 = 104
Pco2 = 40
Expired air
Po2 = 120
Pco2 = 27
Pulmonary capillary
Blood in pulmonary veins
3
Po2 = 95
Pco2 = 40
Right
Left
Heart
Tissue capillary
Po2 = 40
Pco2 = 45
5
Po2 = 40
Pco2 = 45
Interstitial fluid
Po2 = 95
Pco2 = 40
4
Po2 = 40
Pco2 = 45
Po2 = 20
Pco2 = 46
Tissue cells

PO2 and PC2 in air, lung and tissues

Figure 35–1.



Summary of PO_2 and PCO_2 values in air, lungs, blood, and tissues, graphed to emphasize the fact that both O_2 and CO_2 diffuse "downhill" along gradients of decreasing partial pressure. (Redrawn and reproduced, with permission, from Kinney JM: Transport of carbon dioxide in blood. Anesthesiology 1960;21:615.)

PO2 and PCO2 in various potions of normal expired air

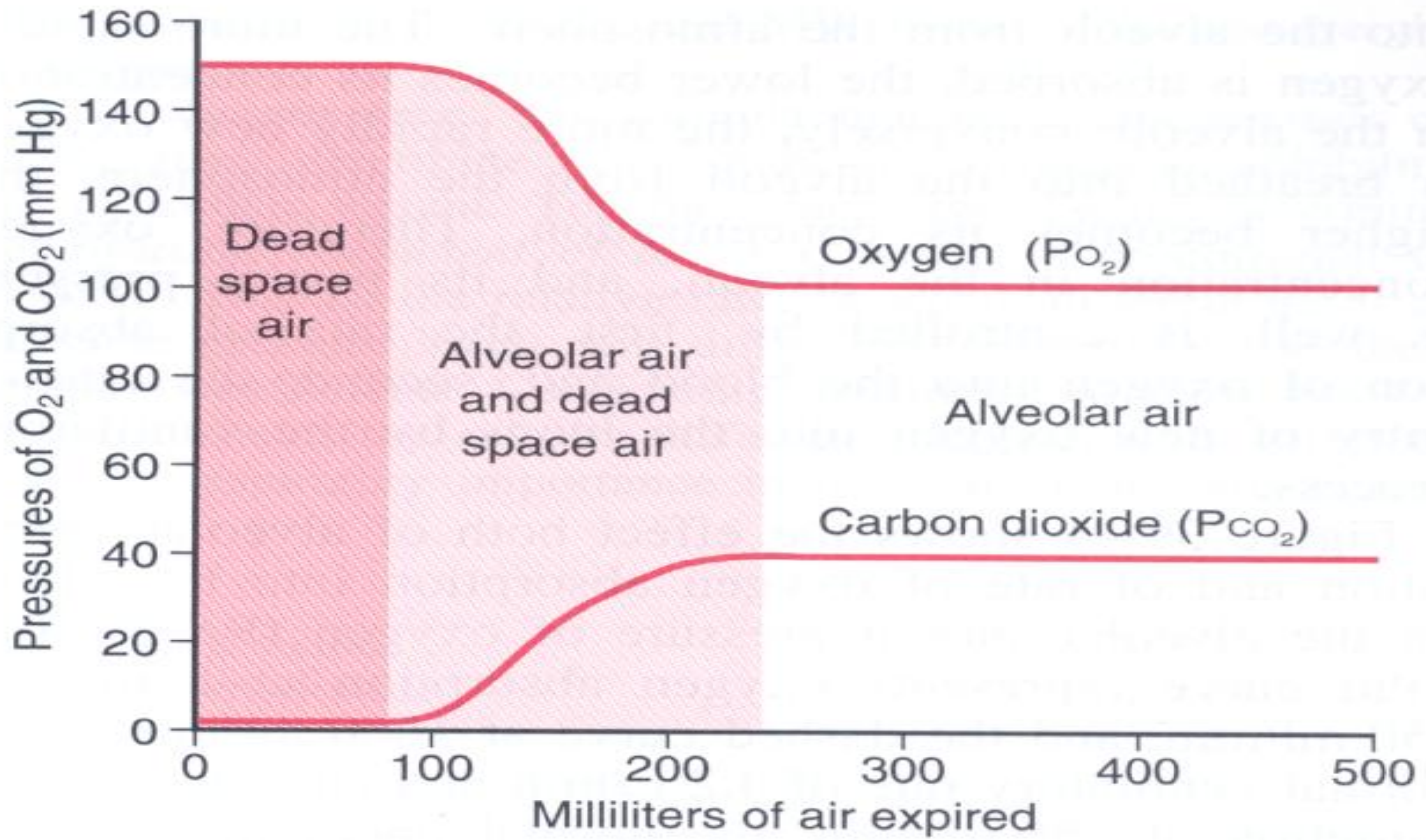


FIGURE 39 – 6

Oxygen and carbon dioxide partial pressures in the various portions of normal expired air.

O_2 and CO_2 concentration in the alveoli

- At resting condition 250ml of oxygen enter the pulmonary capillaries/min at ventilatory rate of 4.2 L/min.
- During exercise is absorbed by the pulmonary capillaries per 1000 ml of oxygen minute, the rate of alveolar ventilation must increase four times to maintain the alveolar PO_2 at the normal value of 104mmHg.
- Normal rate of carbon dioxide excretion is 200ml/min, at normal rate of alveolar ventilation of 4.2L/min.

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.

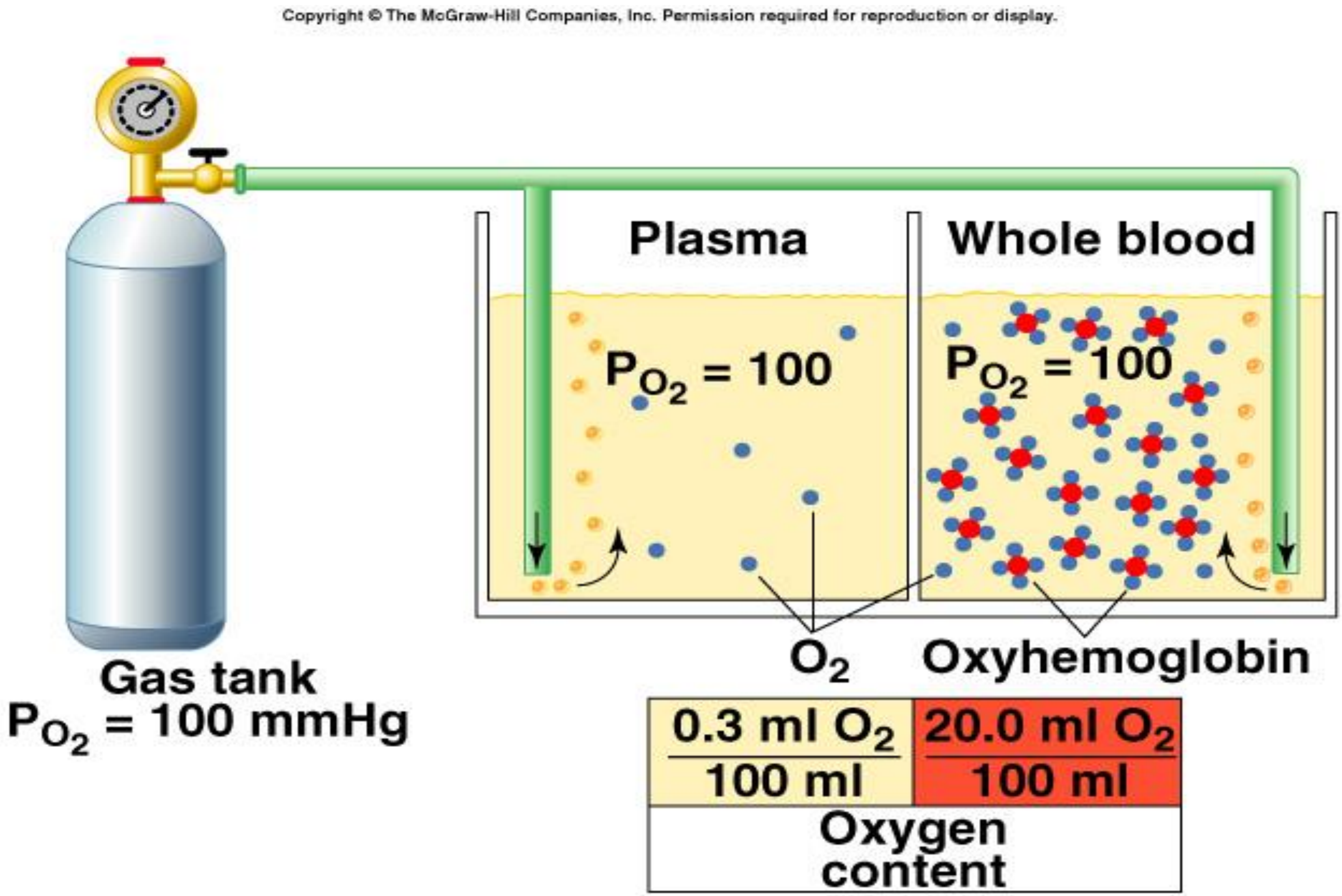
3- Describe (Oxygen- hemoglobin dissociation curve)

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.

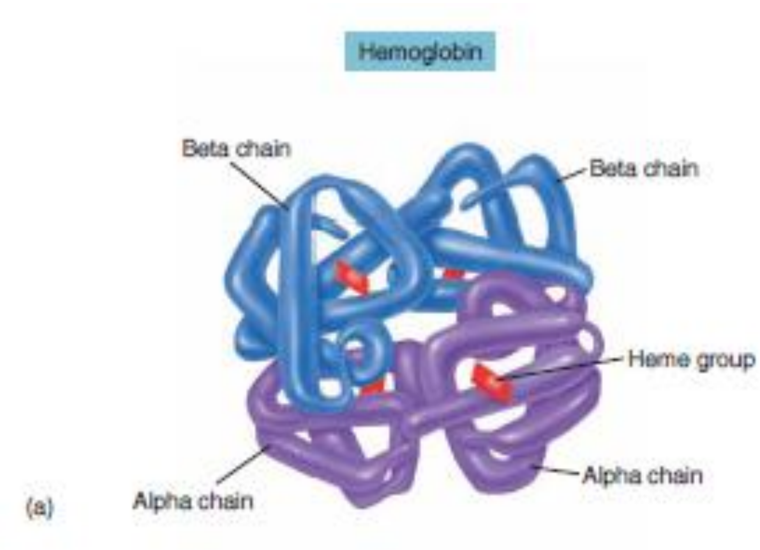
6-Describe the three forms of carbon dioxide that are transported in the blood, and the chloride shift.

Forms of O2 transport



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 ml 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

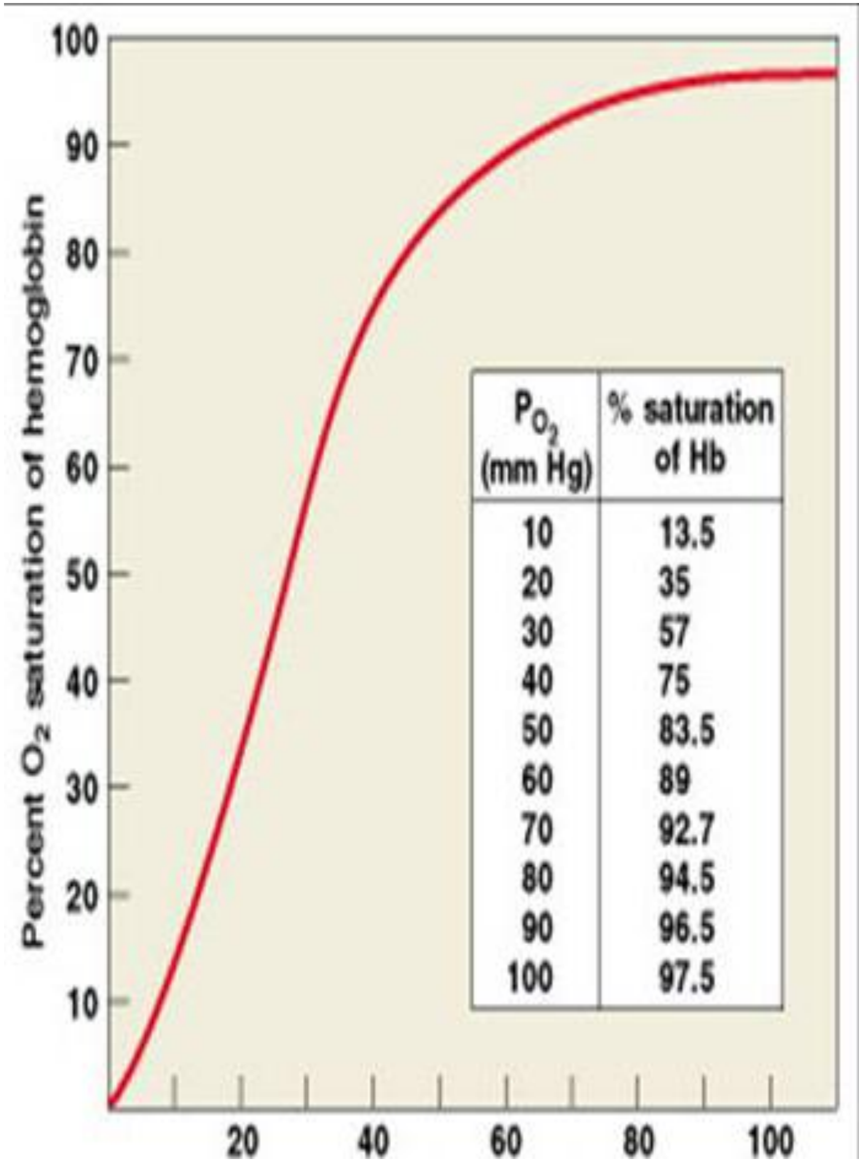
Oxygen transport in Blood

- 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



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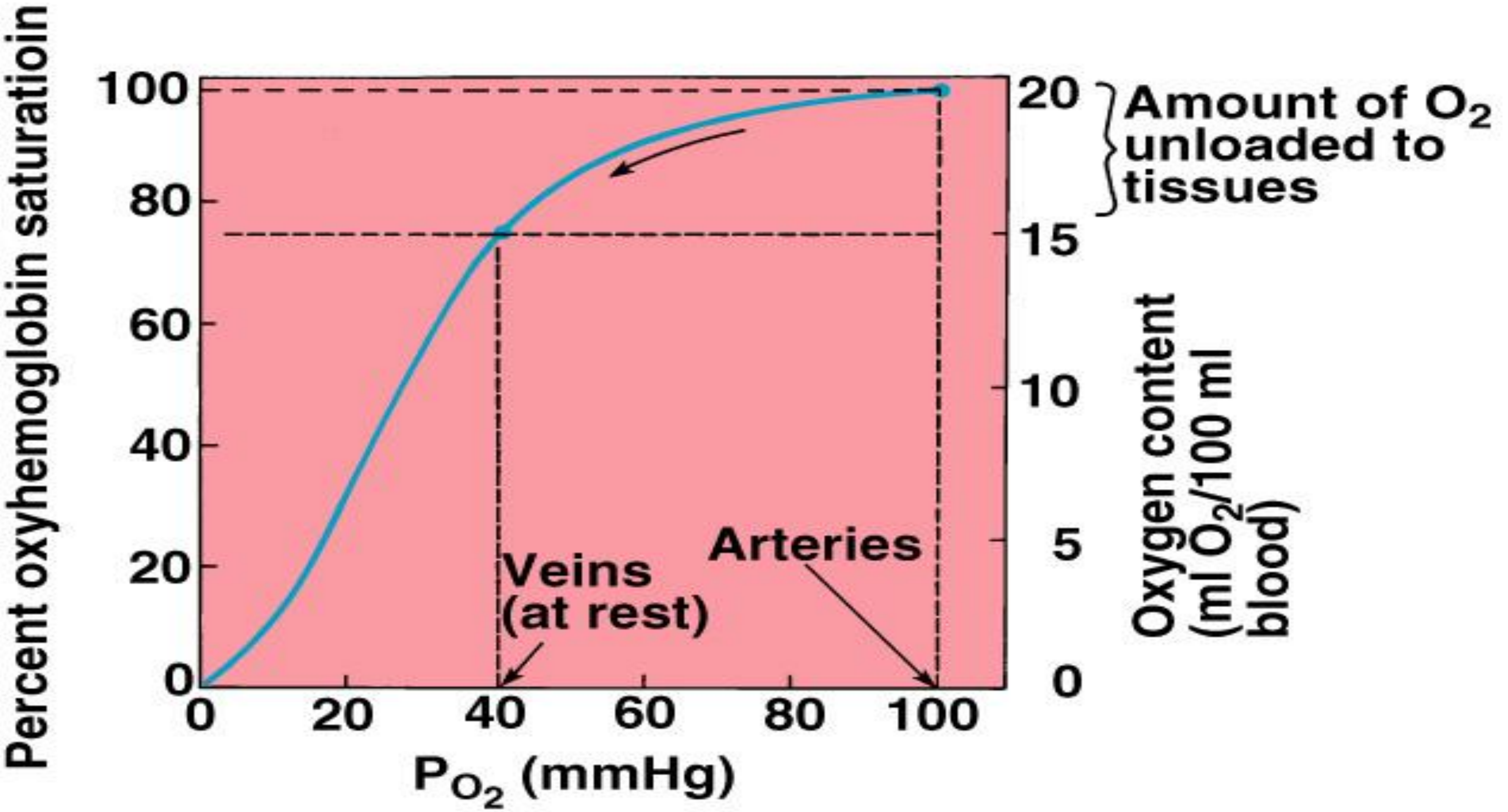
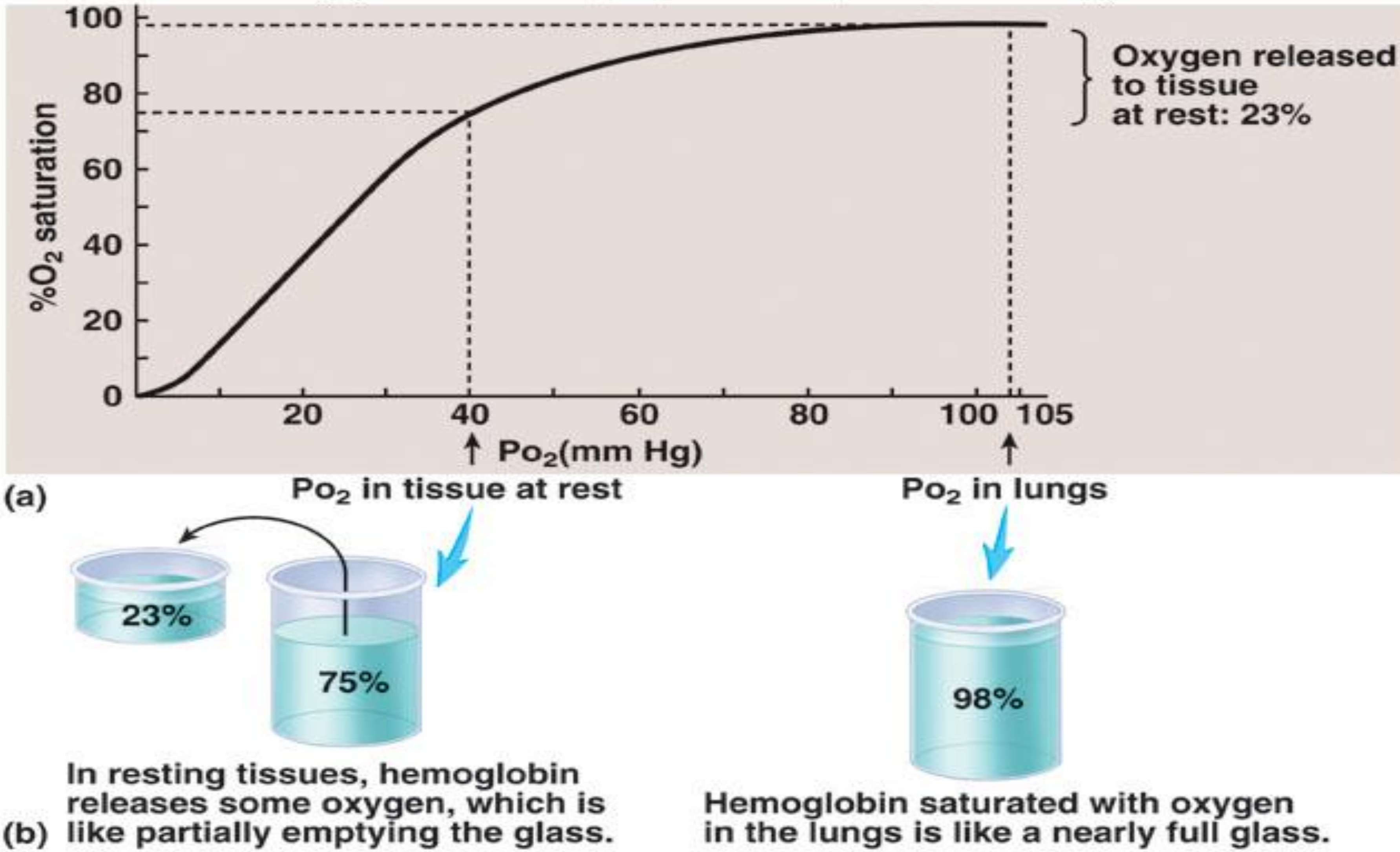
Oxyhemoglobin Dissociation Curve





100
80
60
40
20
0
%O_2 saturation
20
40
60
80
100
105
↑ Po_2(mm Hg)
↑
Oxygen released to tissue at rest: 23%
(a)
Po_2 in tissue at rest
Po_2 in lungs
23%
75%
98%
In resting tissues, hemoglobin releases some oxygen, which is like partially emptying the glass.
(b)
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

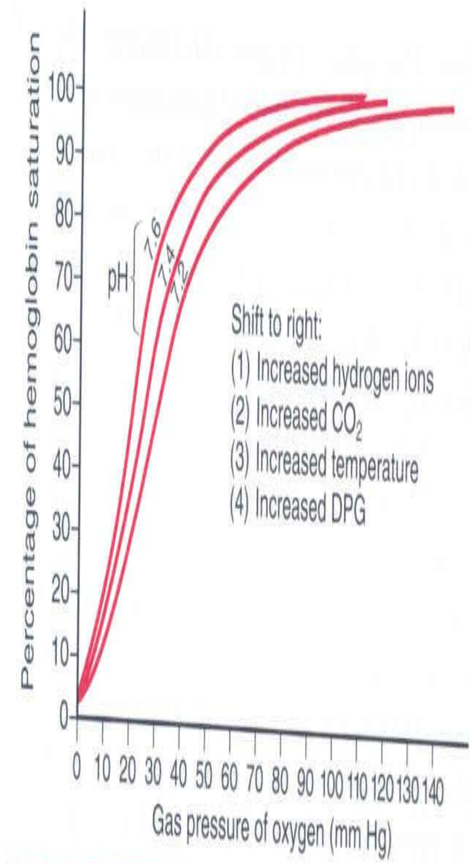
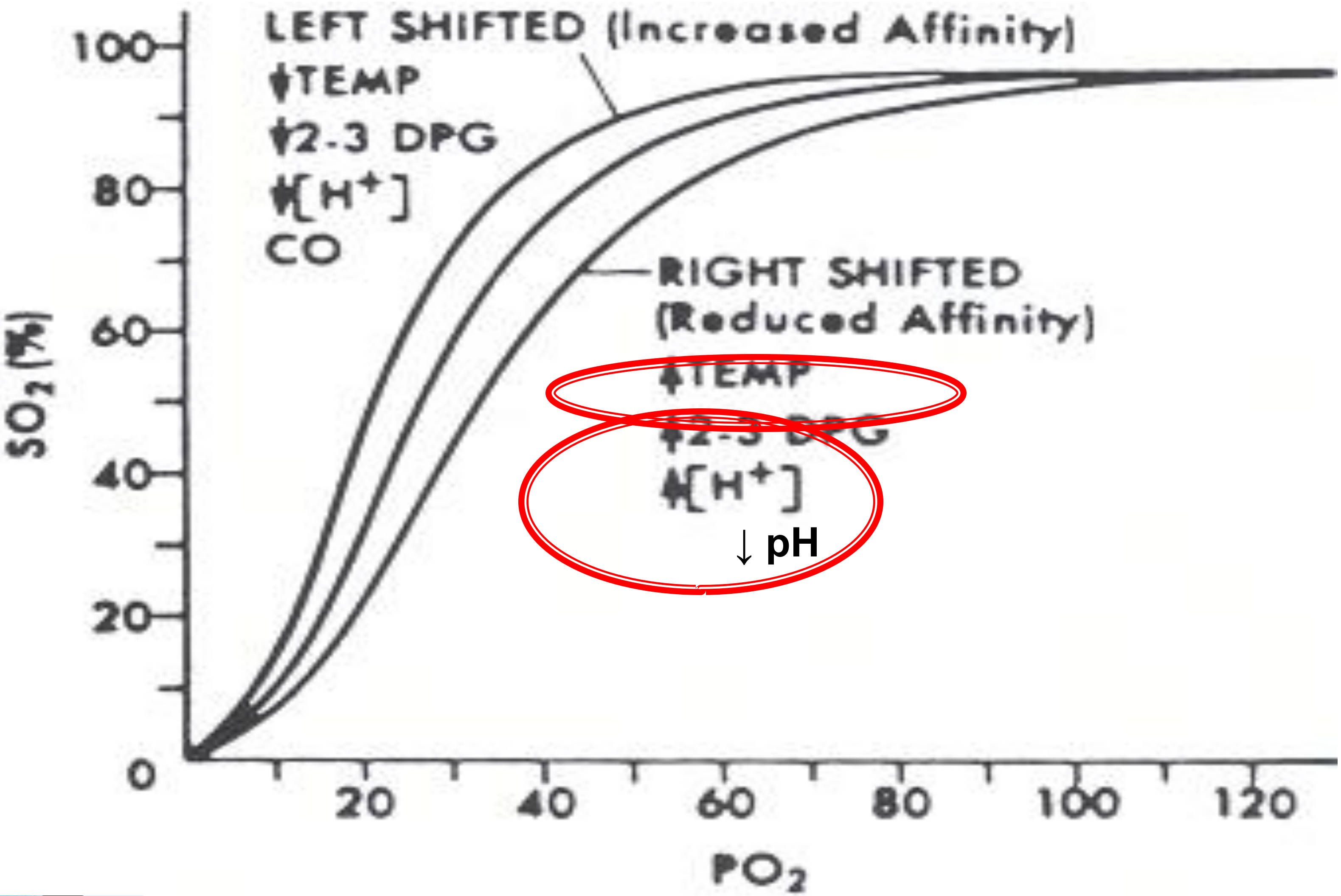


FIGURE 40-10

Shift of the oxygen-hemoglobin dissociation curve to the right by increases in (1) hydrogen ions, (2) CO_2, (3) temperature, or (4) 2,3-diphosphoglycerate (DPG).

Oxyhemoglobin Dissociation Curve



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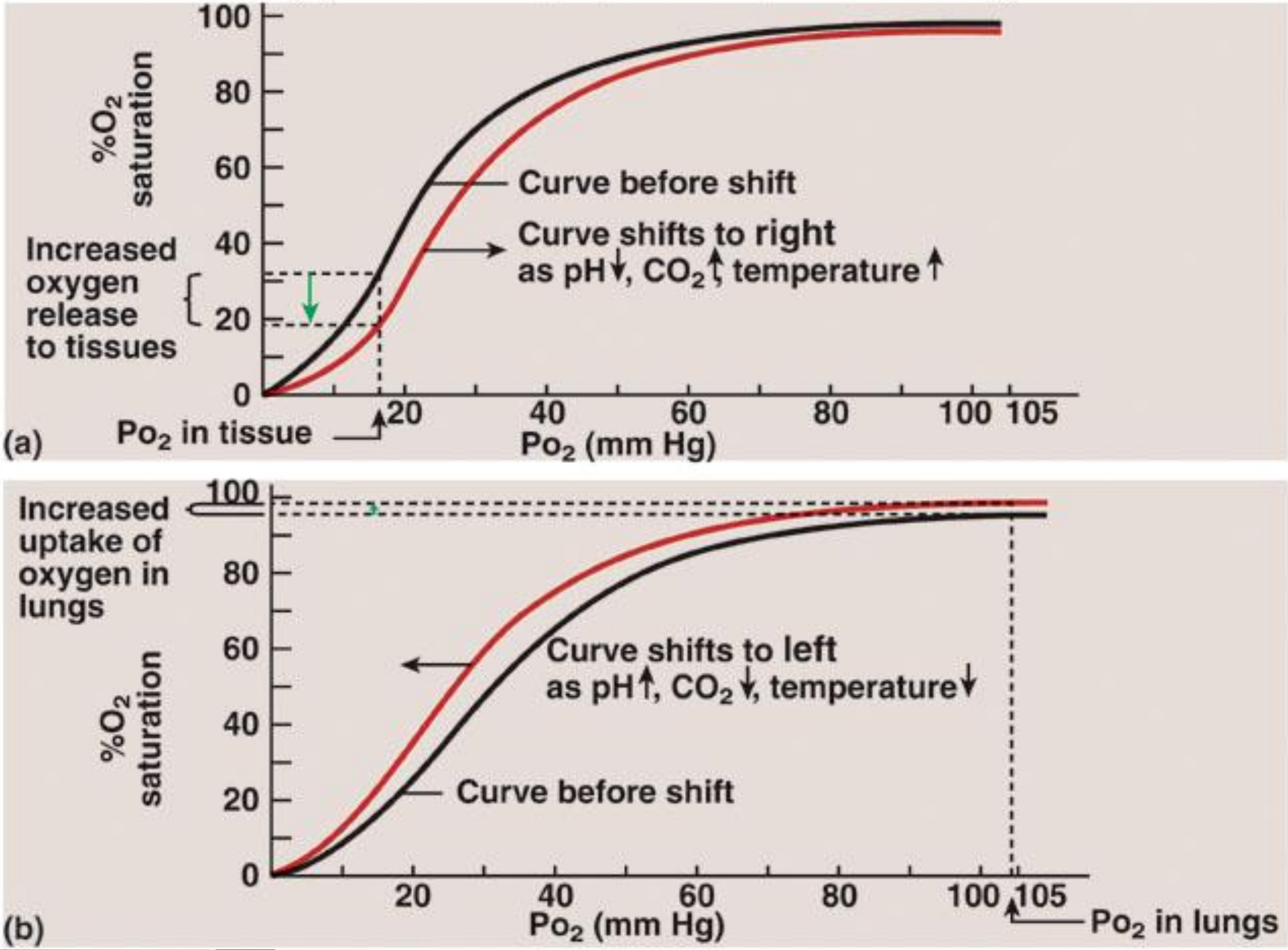


100
80
60
40
20
0
%O_2 saturation
Increased oxygen release to tissues
Curve before shift
Curve shifts to right as pH↓, CO_2↑, temperature↑
20
40
60
80
100 105
(a)
Po_2 in tissue
Po_2 (mm Hg)
Increased uptake of oxygen in lungs
Curve shifts to left as pH↑, CO_2↓, temperature↓
Curve before shift
Po_2 in lungs
(b)

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.*

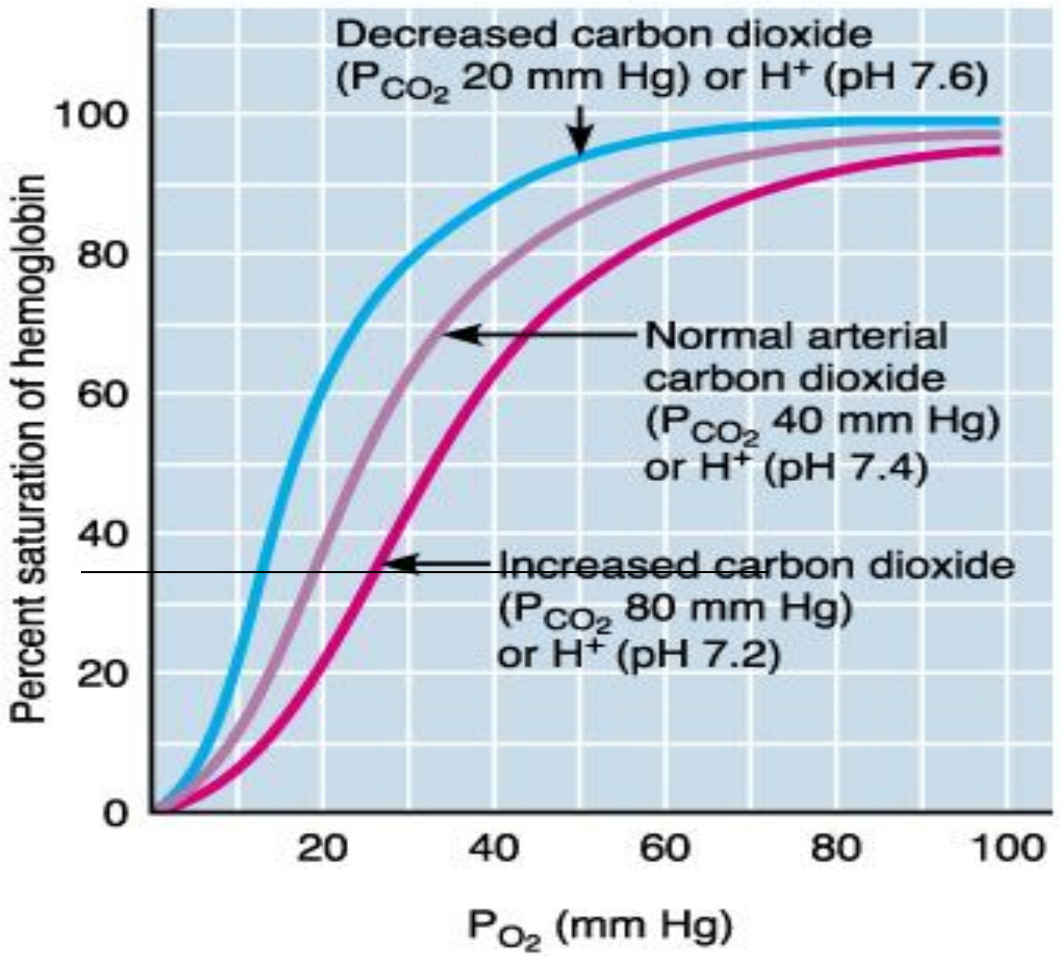
- 2,3DPG is synthesized in RBCs from the glycolytic pathway , it binds tightly to reduced Hb. increased 2,3 DPG facilitate the oxygen release and shifts the dissociation curve to Rt.
- 2,3 DPG increases in the RBCs in anemia and hypoxemia, and thus serves as an important adaptive response in maintaining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

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 to Hb allowing more O_2 transport to tissues

At tissues: the reverse occur

Bohr Effect



(b)

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 O_2 is transported in the dissolved state,*
- at normal arterial PO_2 of 95 mmHg , about 0.29 ml of oxygen is dissolved in each 100ml of blood.
- When the PO_2 of the blood falls to 40 mmHg in tissue capillaries, only 0.12 of oxygen remains dissolved.
- i.e 0.17 ml of oxygen is normally transported in the dissolved state to the tissues per each 100 ml of blood

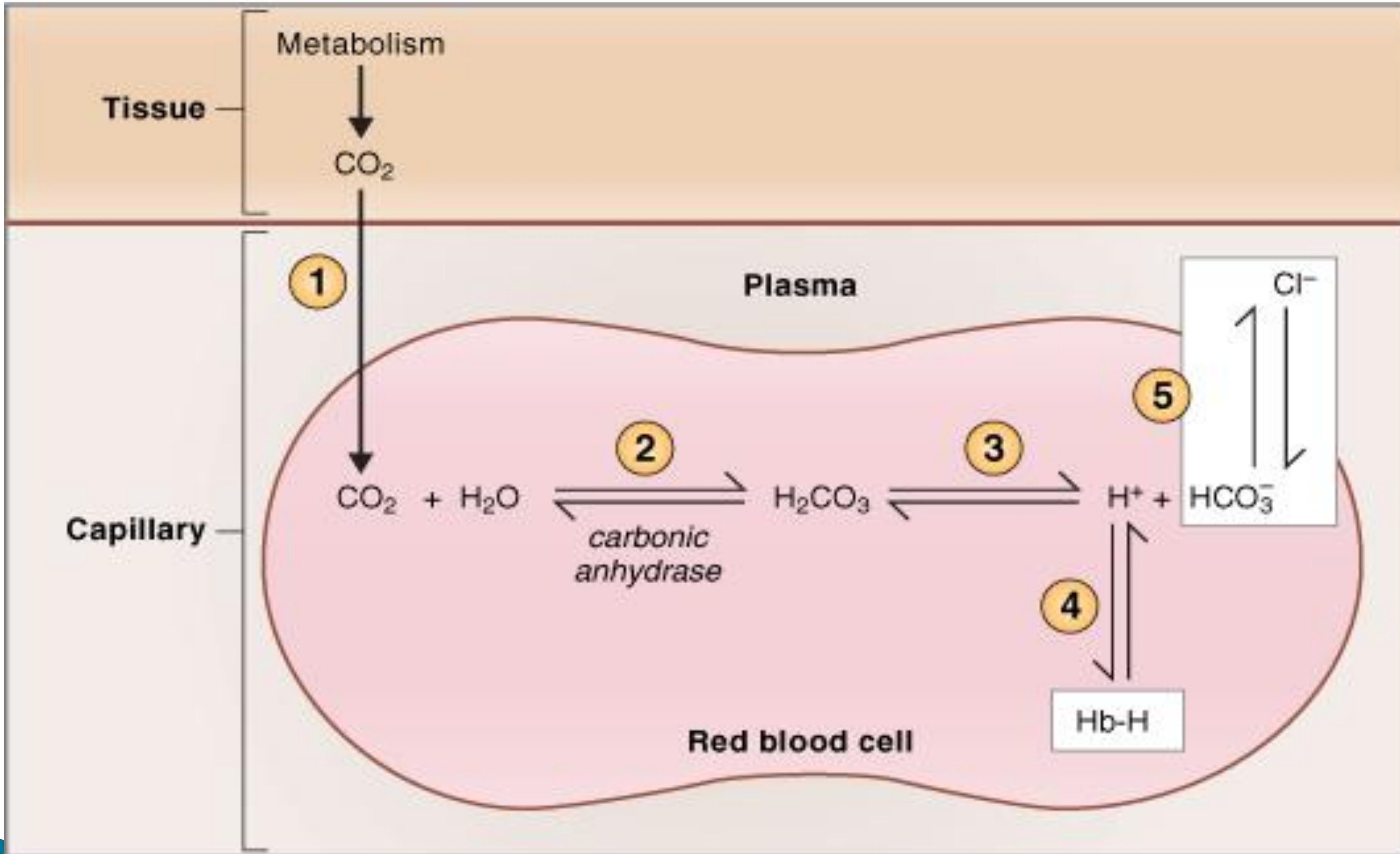
Combination of Hb with CO ----- displacement of oxygen

- 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 O_2 (affinity of Hb to CO is very high (250 times) that to O_2.It causes Lt shift of the O_2-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/min .

Formation of HCO3 &Chloride shift inside RBC



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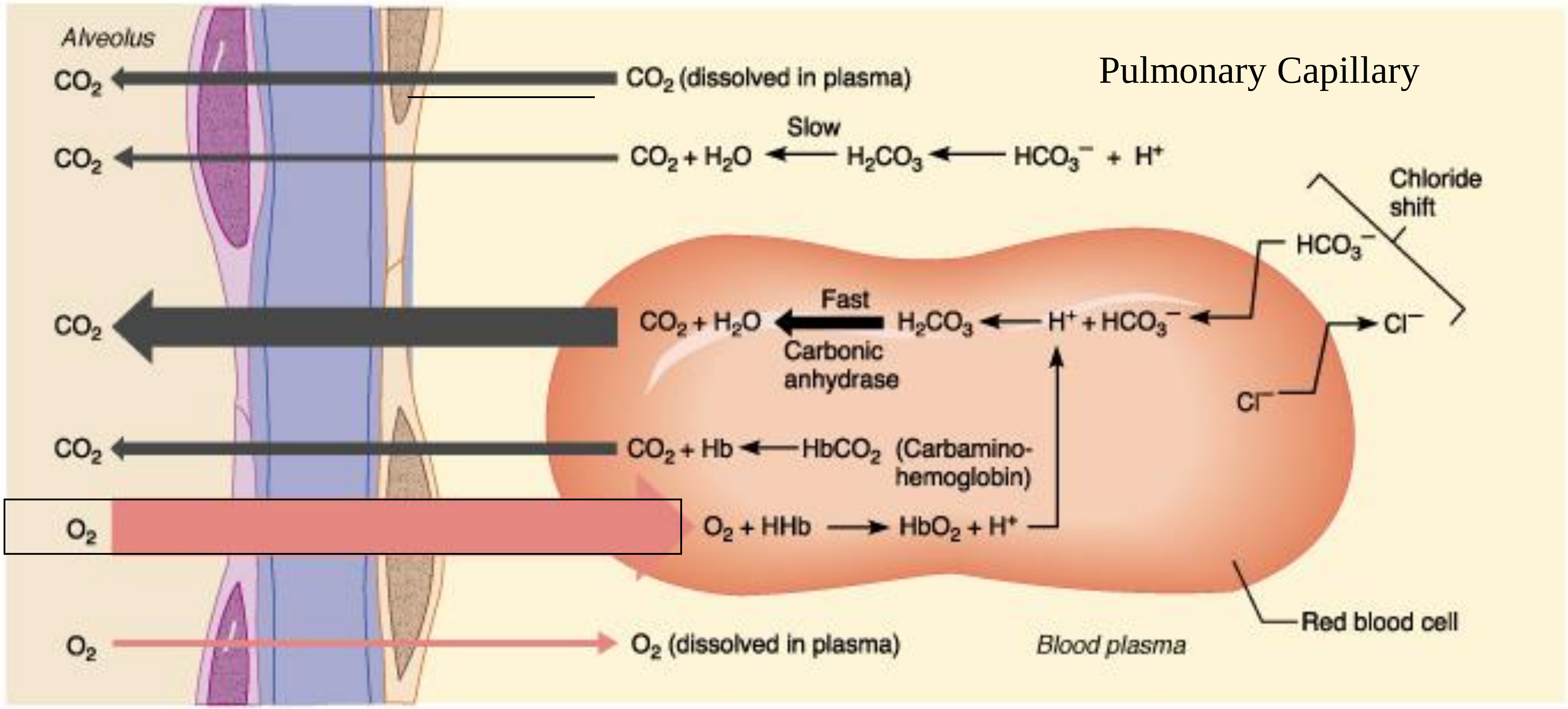
Chloride Shift in Pulmonary Capillaries



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

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

R= <u>Rate of carbon dioxide output</u>

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

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