Gas Transfer
(Diffusion of O_2 and CO_2)

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objectives:

1-Define partial pressure of a gas.

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.

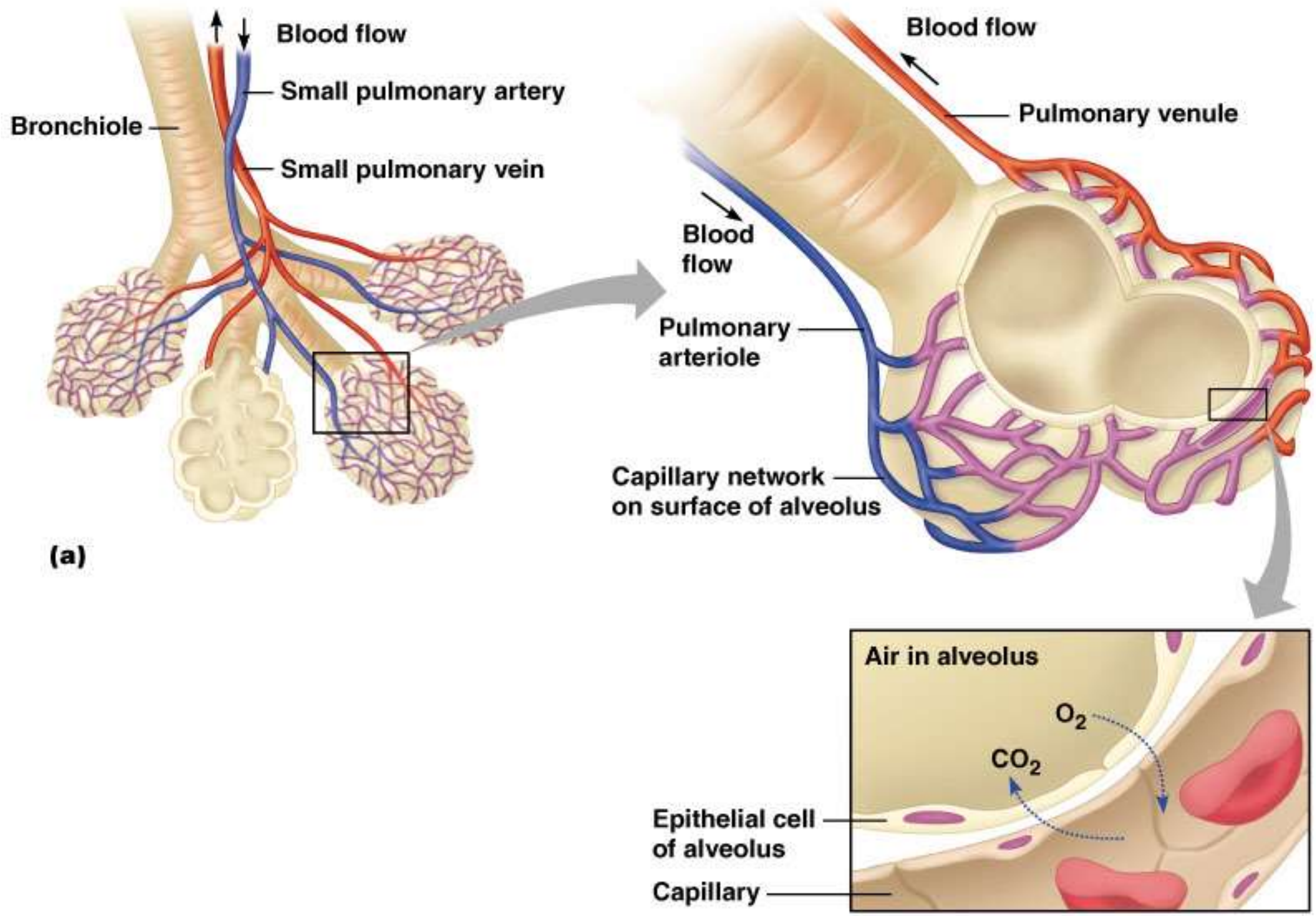
5- Describe the components of the alveolar-capillary membrane (i.e., what does a molecule of gas pass through).

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



Partial pressure of gases (in a mixture)

- The pressure of gas is caused by the constant kinetic movement of gas molecules against the surface.
- In respiratory physiology, there is a mixture of gases mainly of O_2, N_2, and CO_2.
- The rate of diffusion of each of these gases is directly proportional with the partial pressure of the gas.

Pressure of gases dissolved in water and tissue:

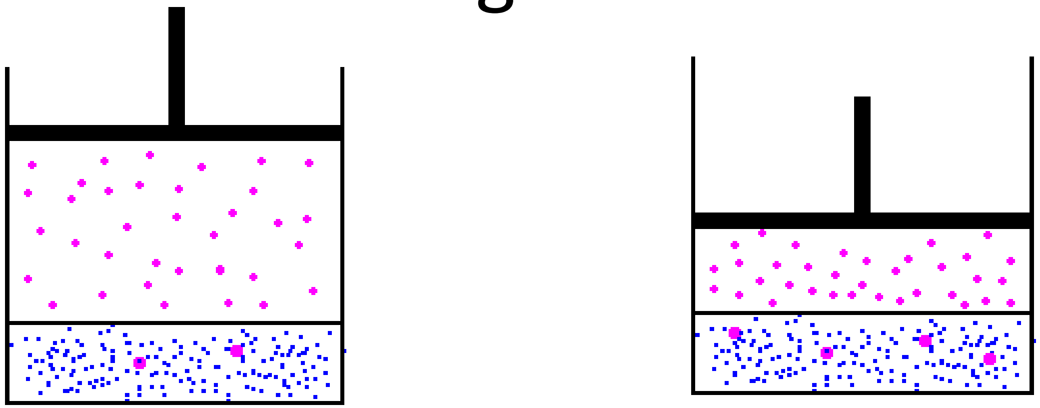
The pressure of gases dissolved in fluid is similar to their pressure in the gaseous phase and they exert their own individual partial pressure.

2-Dalton's Law of Partial Pressures

- It states that the total pressure exerted by a mixture of gases is the sum of partial pressure of each individual gas present.
  - $P_{total} = P_1 + P_2 + P_3 + . .$

3-Henry's Law

- Gas solubility is proportional to the gas partial pressure. If the temperature stays constant increasing the pressure will increase the amount of dissolved gas.



Low pressure equilibrium
Low concentration

Double the pressure equilibrium
Double the concentration

4-Factors that affect the rate of gas diffusion through the respiratory membrane

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

D: diffusion rate

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

4-Factors that affect the rate of gas diffusion through the respiratory membrane

- **The diffusion rate of the specific gas:**

Diffusion coefficient for the transfer of each gas through the respiratory membrane depends on:

  - **Directly on its solubility (S) through the membrane**
  - **Inversely on the square root of its molecular weight (MW).**

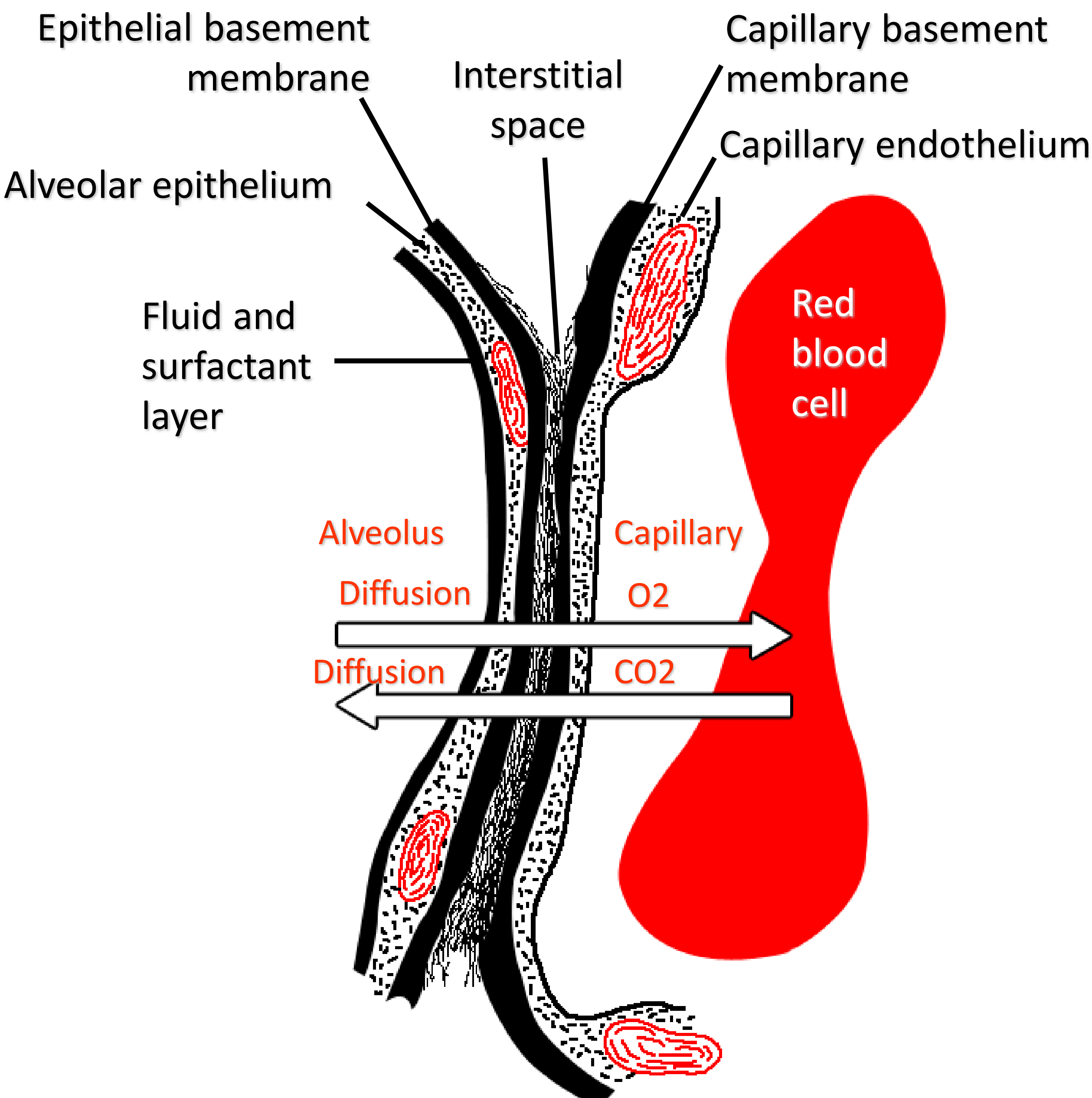
- **CO_2 diffuses 20 times as rapidly as O_2.**

4-Factors that affect the rate of gas diffusion through the respiratory membrane

- P: Partial pressure differences
- **The pressure difference between the two sides of the membrane (between the alveoli and the blood).**
  - **When the pressure of the gas in the alveoli is greater than the pressure of the gas in the blood as for O_2, net diffusion from the alveoli into the blood occurs.**
  - **When the pressure of the gas in the blood is greater than the pressure in the alveoli as for CO_2, net diffusion from the blood into the alveoli occurs.**

4-Factors that affect the rate of gas diffusion through the respiratory membrane

- **Surface area of the membrane (A).**
  - **Removal of an entire lung decreases the surface area to half normal.**
  - **In emphysema with dissolution of the alveolar wall → ↓ S.A. to 5-folds because of loss of the alveolar walls.**
- **The thickness of the respiratory membrane (d**:Diffusion distance)
  - **↑ thickness of the respiratory membrane e.g., edema → ↓ rate of diffusion.**
  - **The thickness of the respiratory membrane is inversely proportional to the rate of diffusion through the membrane.**



Epithelial basement membrane
Interstitial space
Capillary basement membrane
Capillary endothelium
Alveolar epithelium
Fluid and surfactant layer
Red blood cell
Alveolus
Capillary
Diffusion
O2
Diffusion
CO2

Composition of alveolar air and its relation to atmospheric air:

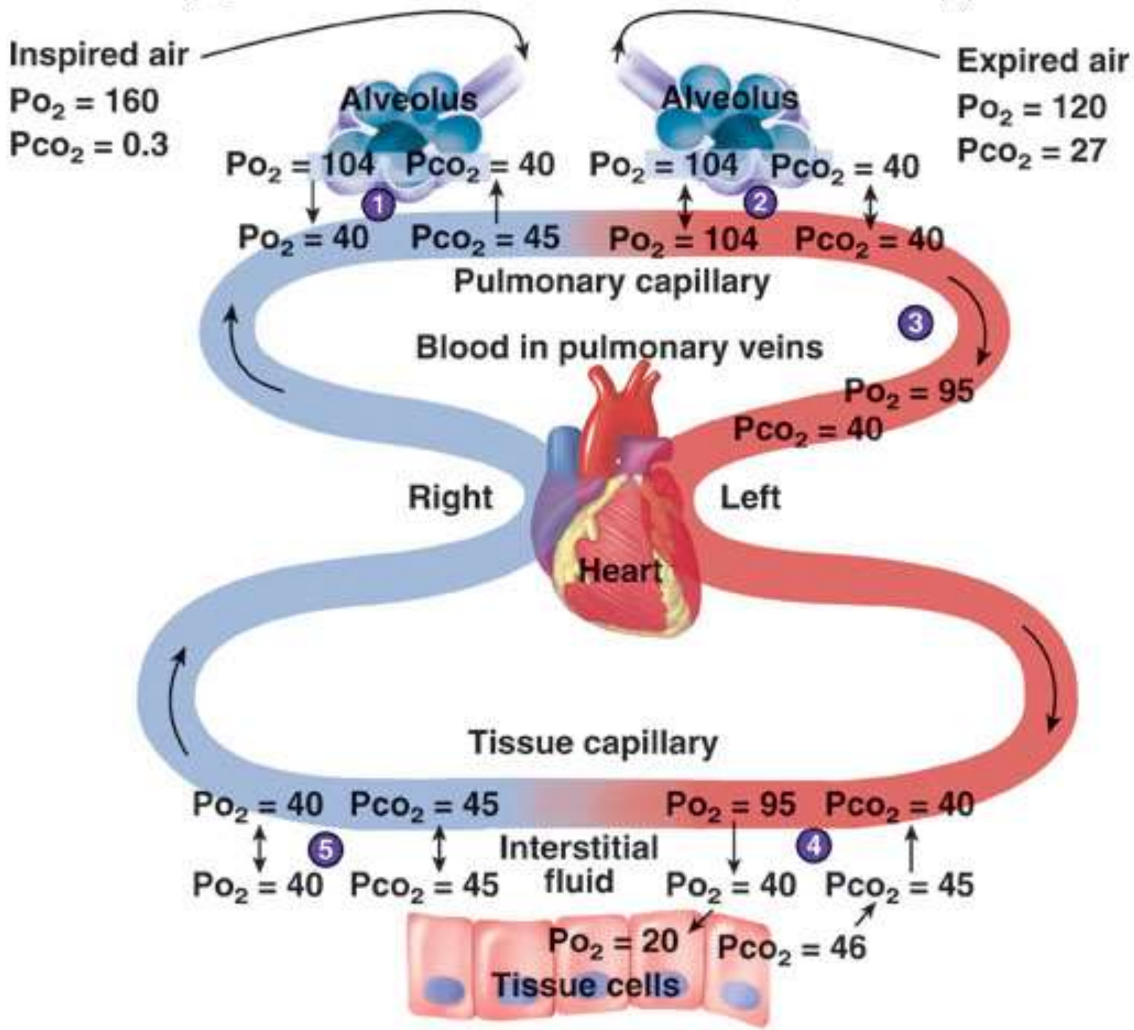
- Alveolar air is partially replaced by atmospheric air with each breath.
- O_2 is constantly absorbed from the alveolar air.
- CO_2 constantly diffuses from the pulmonary blood into the alveoli.
- The dry atmospheric air enters the respiratory passage is humidified before it reaches the alveoli.

Partial pressures of respiratory gases as they enter and leave the lungs (at sea level)

	N_2	O_2	CO_2	H_2O
Atmospheric Air* (mmHg)	597.0 (78.62%)	159.0 (20.84%)	0.3 (0.04%)	3.7 (0.50%)
Humidified Air (mmHg)	563.4 (74.09%)	149.3 (19.67%)	0.3 (0.04%)	47.0 (6.20%)
Alveolar Air (mmHg)	569.0 (74.9%)	104.0 (13.6%)	40.0 (5.3%)	47.0 (6.2%)
Expired Air (mmHg)	566.0 (74.5%)	120.0 (15.7%)	27.0 (3.6%)	47.0 (6.2%)

Partial Pressure of O_2 and CO_2

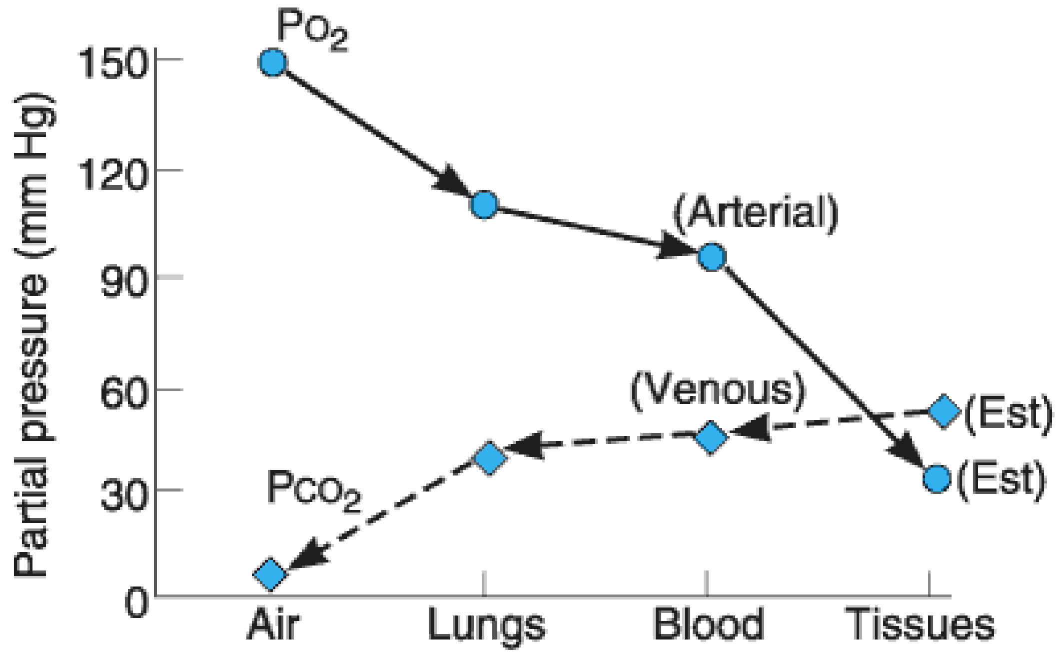
- **Oxygen concentration in the atmosphere is 21%**
- **So PO_2 in atmosphere =760mmHg x 21%=160 mmHg.**
- **This mixes with “old” air already present in alveolus to arrive at PO_2 of 104 mmHg in alveoli.**
- **Carbon dioxide concentration in the atmosphere is 0.04%**
- **So PCO_2 in atmosphere =760 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.**



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
3
Blood in pulmonary veins
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 PCO2 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

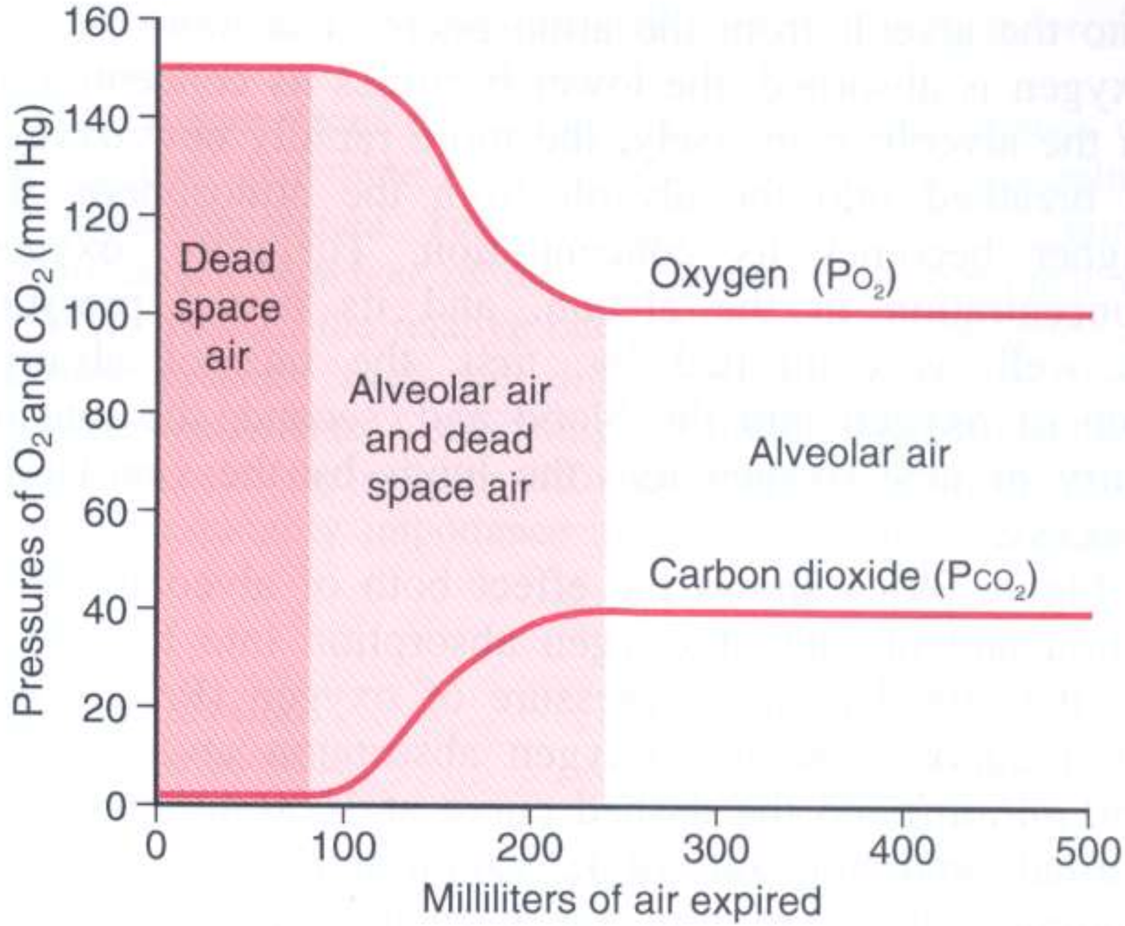
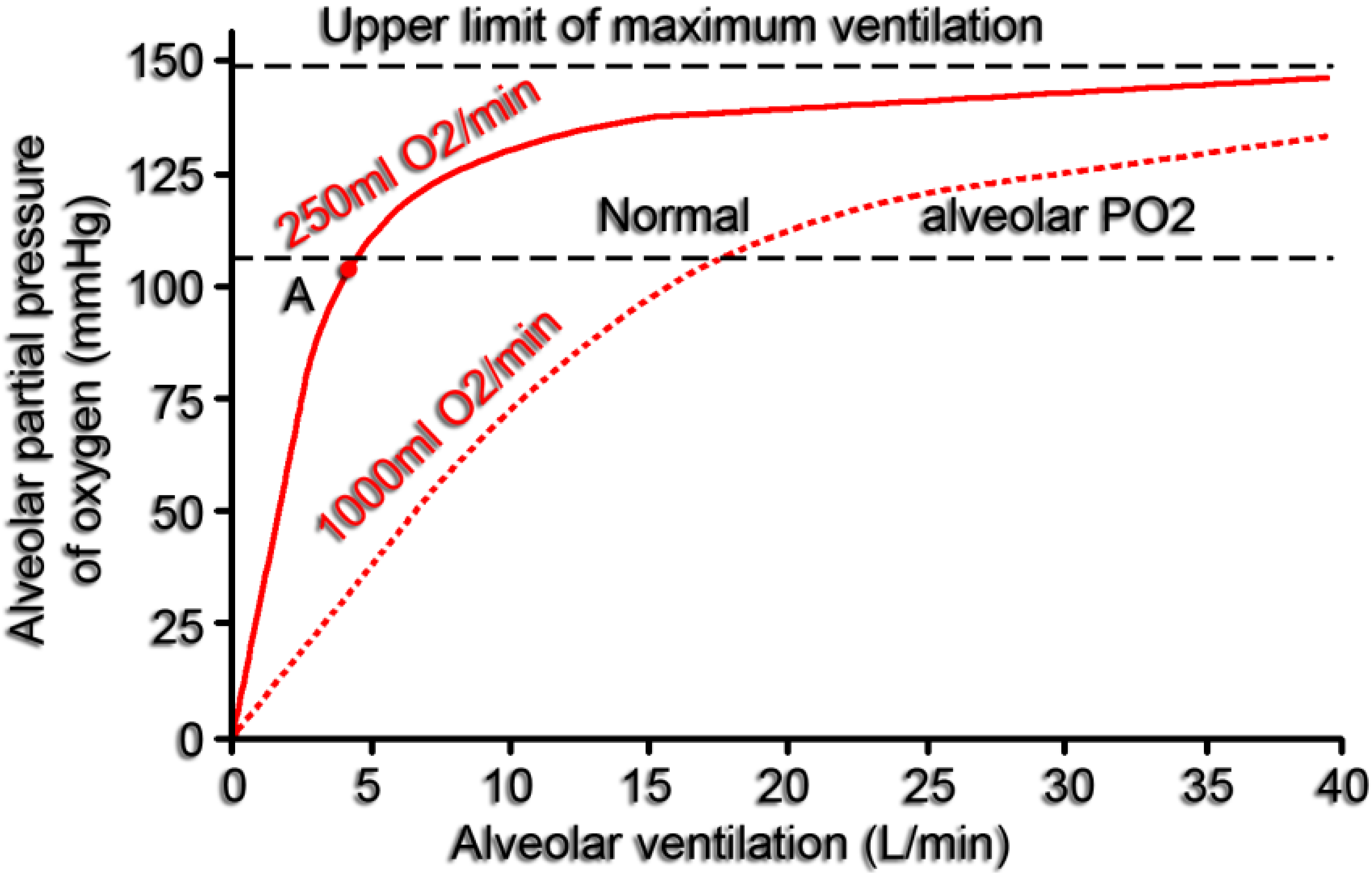


FIGURE 39 – 6

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

O_2 concentration in the alveoli

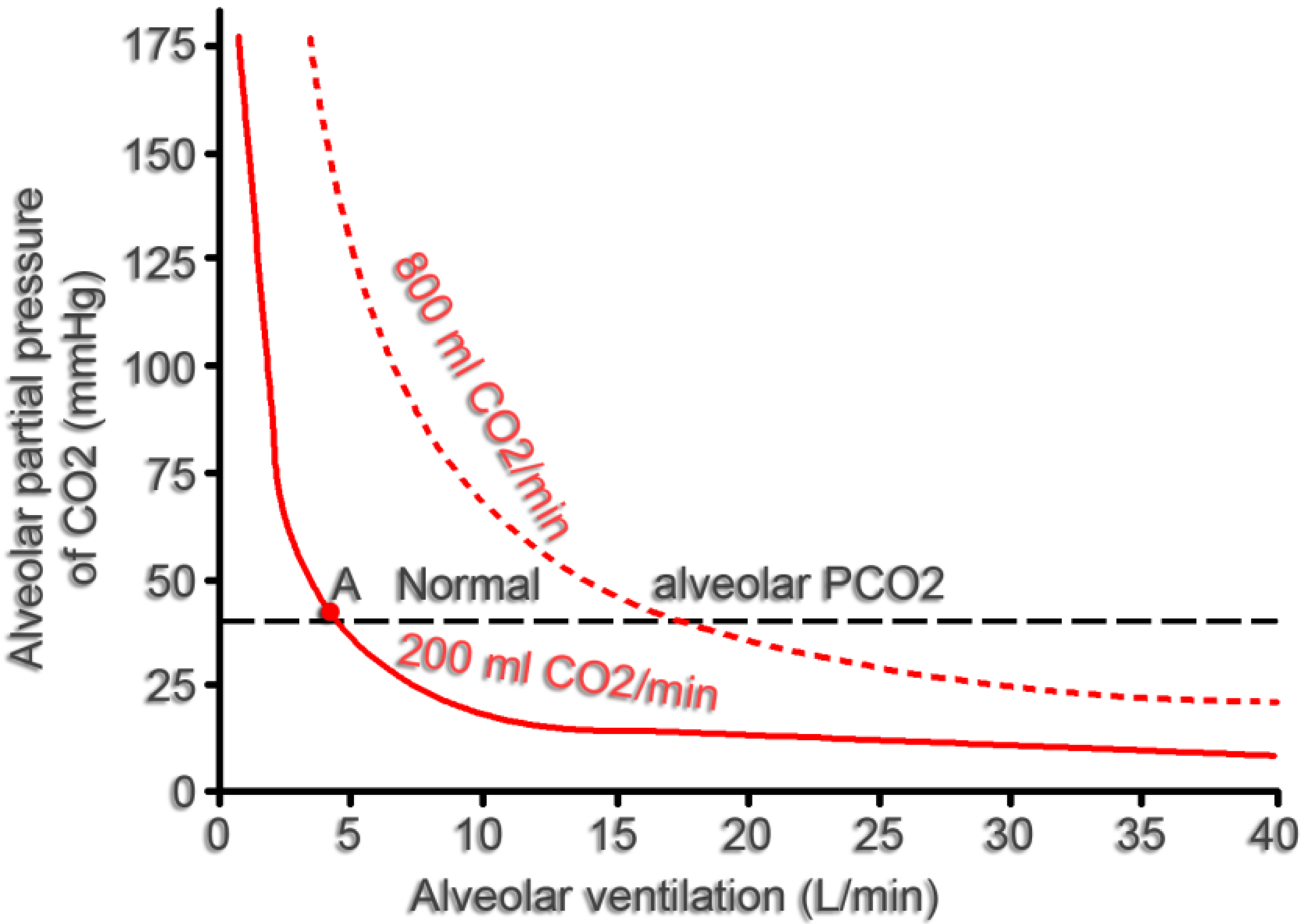
- **At resting condition 250 ml of oxygen enter the pulmonary capillaries/min at ventilatory rate of 4.2 L/min.**
- **During exercise 1000 ml of oxygen is absorbed by the pulmonary capillaries per minute, the rate of alveolar ventilation must increase 4 times to maintain the alveolar PO2 at the normal value of 104 mmHg.**



Upper limit of maximum ventilation
250ml O2/min
Normal
alveolar PO2
A
1000ml O2/min
Alveolar partial pressure of oxygen (mmHg)
150
125
100
75
50
25
0
0
5
10
15
20
25
30
35
40
Alveolar ventilation (L/min)

CO_2 concentration in the alveoli

- **The solid curve represents the normal rate of CO_2 excretion of 200ml/min at normal ventilation of 4.2 liters/min,**
- **The operating point for alveolar PCO_2 is at point A at 40mmHg.**
- **Alveolar PCO_2 increases directly in proportion to the rate of CO_2 excretion, as represented by the dotted curve for 800ml CO_2 excretion/min.**
- **Alveolar PCO_2 decreases in inverse proportion to alveolar ventilation**



Alveolar partial pressure of CO2 (mmHg)
175
150
125
100
75
50
25
0
800 ml CO2/min
A
Normal alveolar PCO2
200 ml CO2/min
0
5
10
15
20
25
30
35
40
Alveolar ventilation (L/min)