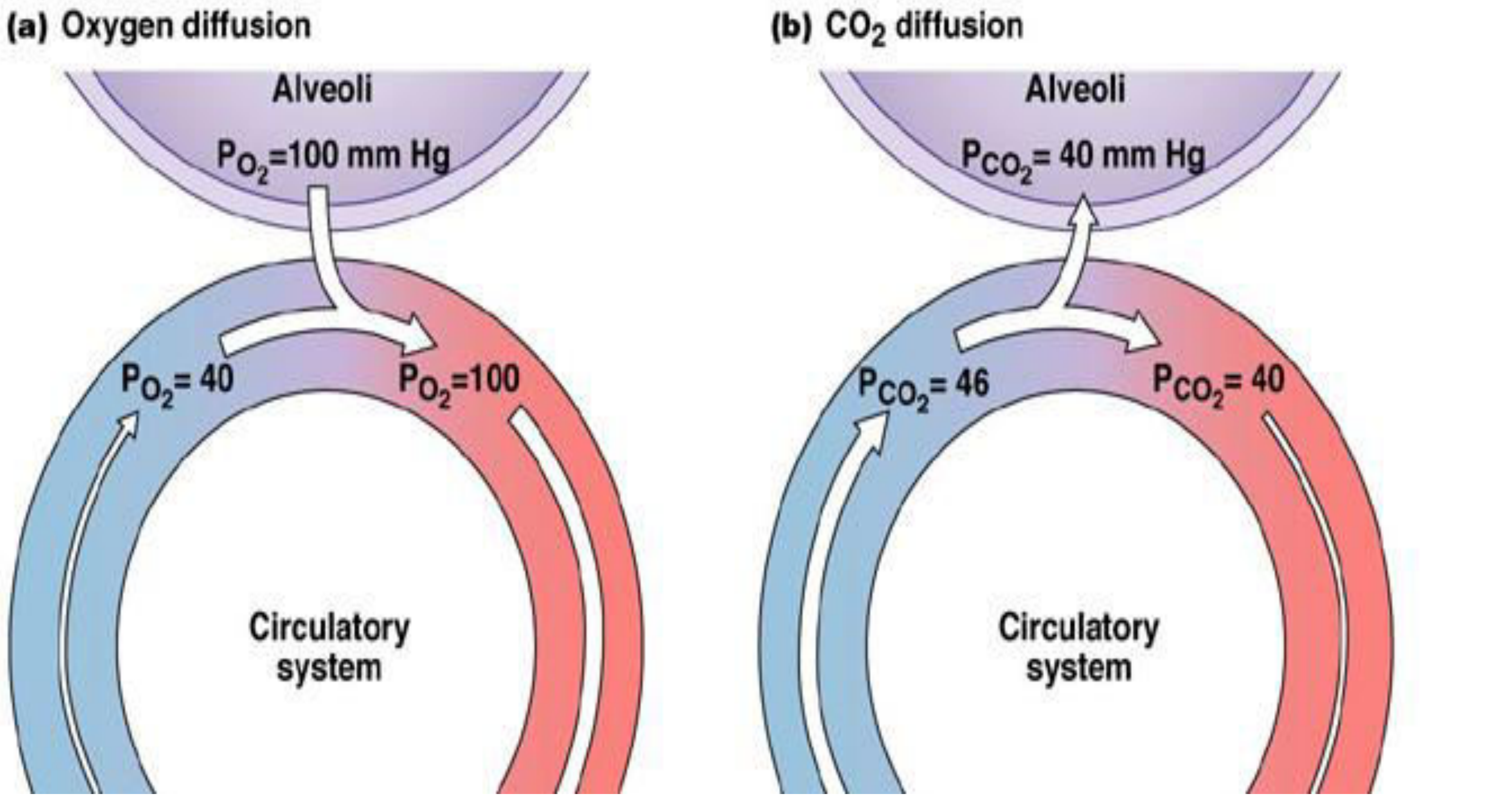
Gas exchange

Objectives

- Composition of air in different parts of respiratory system and difference in the composition of atmospheric air and alveolar air
- Factors affecting diffusion of gases through respiratory membrane
- Diffusion limited and perfusion limited gas exchange
- Definition of diffusion capacity, the difference between the diffusion capacity of O_2 and that of CO_2 in the lungs.
- Effect of V/Q on alveolar gas concentration

Gas exchange

- Is a continuous process
- Occurs through alveolo-capillary membrane by simple diffusion due to differences in partial pressure



Composition of air in different parts of respiratory system

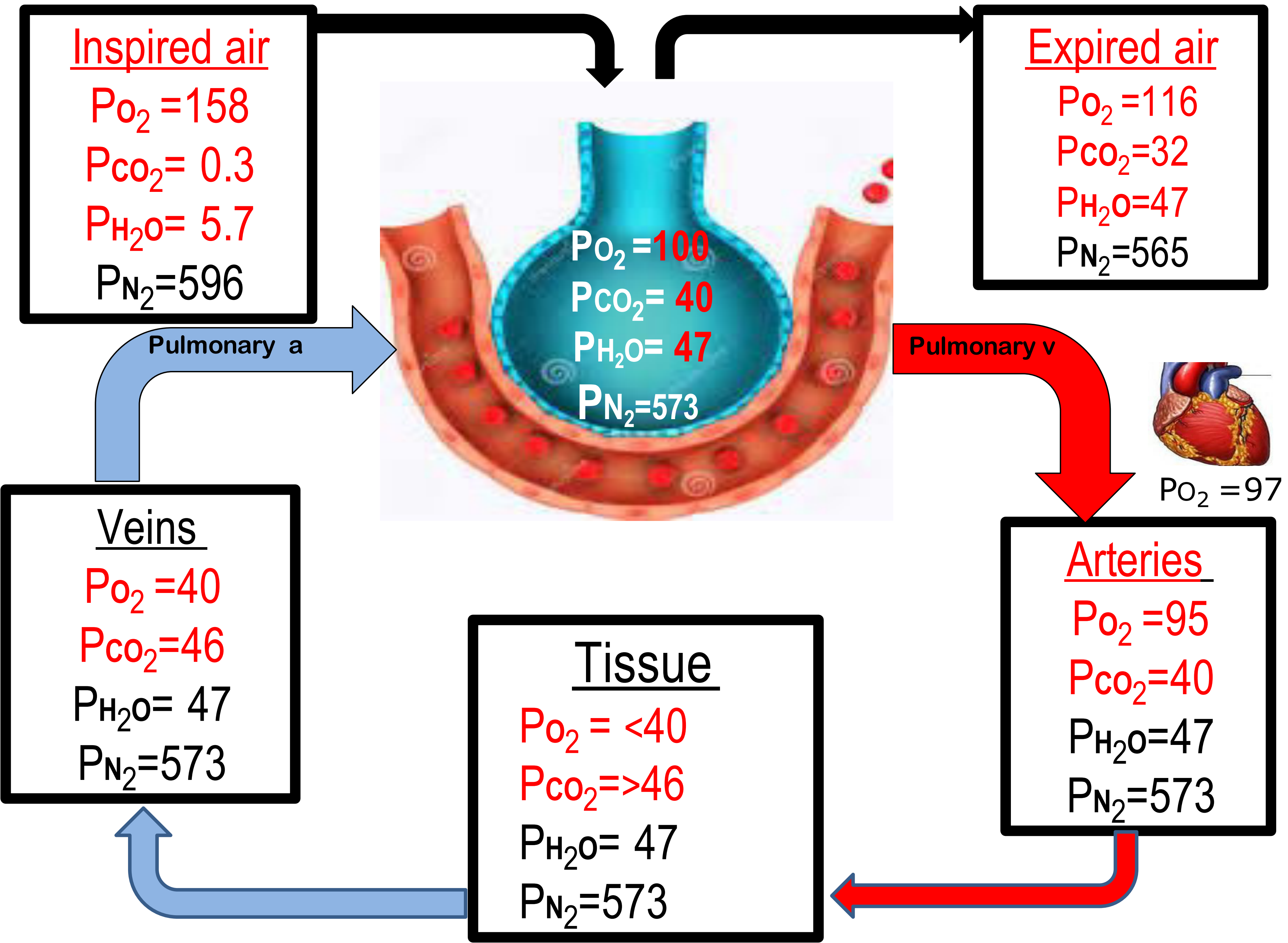
Pressure mm Hg	Dry atmosph. air	Inspired air	Dead space air	Alveolar air
PO_2	160	0.21 ×754 =158	0.21×713= 149.7	100
PCO_2	0.3	0.004 ×754= 0.3	0.004 × 713= 0.3	40
PH_2O		5.7	47	47
PN_2	600	0.79×754= 596	0.79 × 713= 563	573
Total	760	760	760	760

Reasons for the Difference in the Composition of Atmospheric Air and Alveolar Air

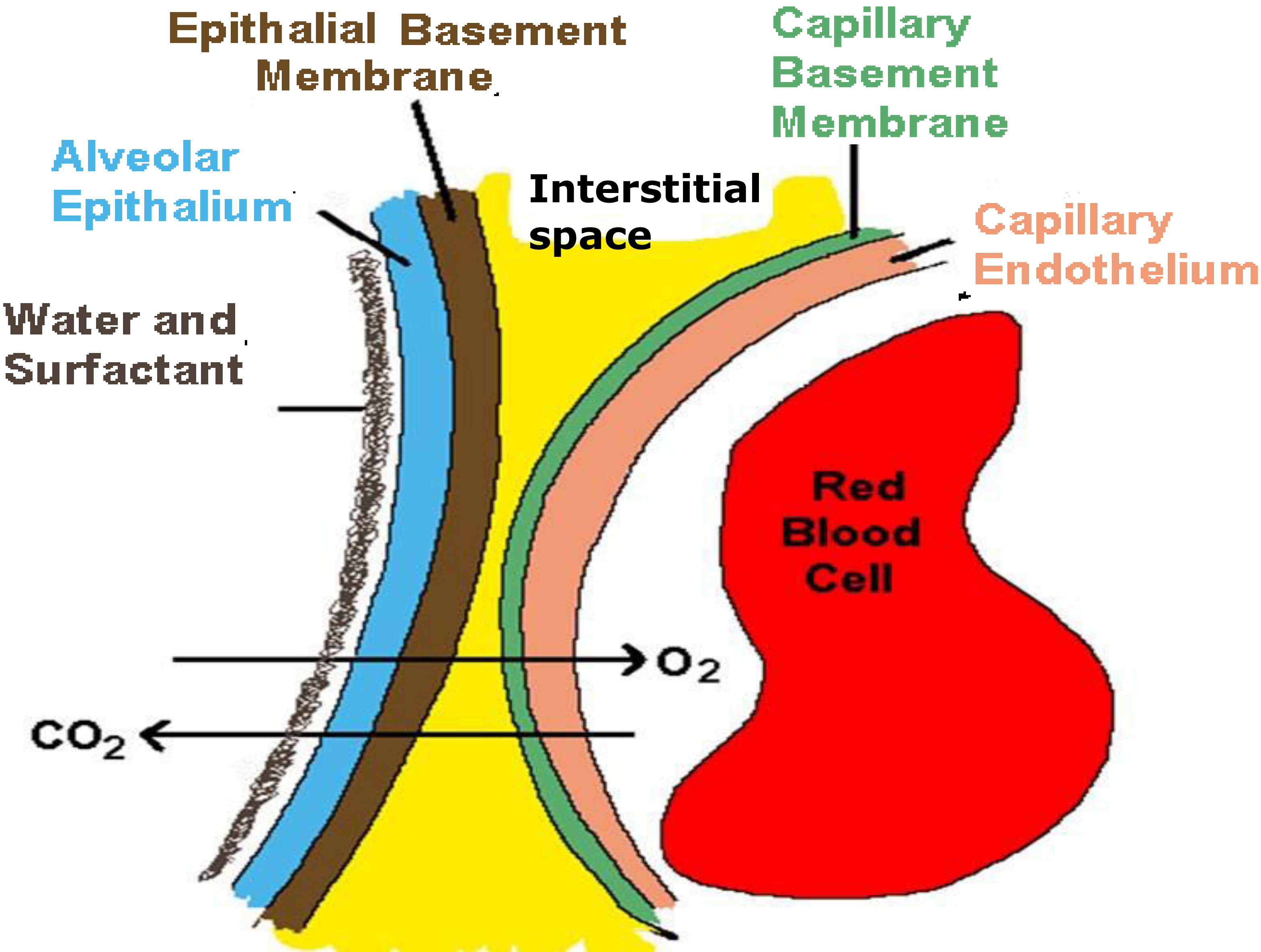
- Constant absorption of O_2 from alveoli to pulmonary capillaries & diffusion of CO_2 from pulmonary capillaries to alveoli.
- Humidification of atmospheric air as it passes through the respiratory passages leads to dilution of gases.
- Partial replacement of alveolar air by atmospheric air with each breath.

Mechanisms by which Composition of Alveolar Air is Kept Constant (Po_2 = 100mHg, Pco_2 =40mHg)

1) By proper ventilation and perfusion of lung:
   - O_2 continuously diffuses out of the alveoli into the blood stream and CO_2 continuously diffuses into the alveoli from blood
   - Inspired air mixes with alveolar air, replacing the O_2 and diluting the CO_2.
2) Because of FRC of about 2 L at the end of expiration, 350 mL of inspired air or expired air has little effect on PO_2 and PCO_2 of alveolar air and alveolar gas composition remains constant.
3) Central and peripheral control mechanisms also operate to maintain alveolar gas composition constant.


Inspired air
Po2 =158
Pco2= 0.3
PH2o= 5.7
PN2=596
Expired air
Po2 =116
Pco2=32
PH2o=47
PN2=565
Po2 =100
Pco2= 40
PH2O= 47
PN2=573
Pulmonary a
Pulmonary v
Po2 =97
Veins
Po2 =40
Pco2=46
PH2o= 47
PN2=573
Arteries
Po2 =95
Pco2=40
PH2o=47
PN2=573
Tissue
Po2 = <40
Pco2=>46
PH2o= 47
PN2=573

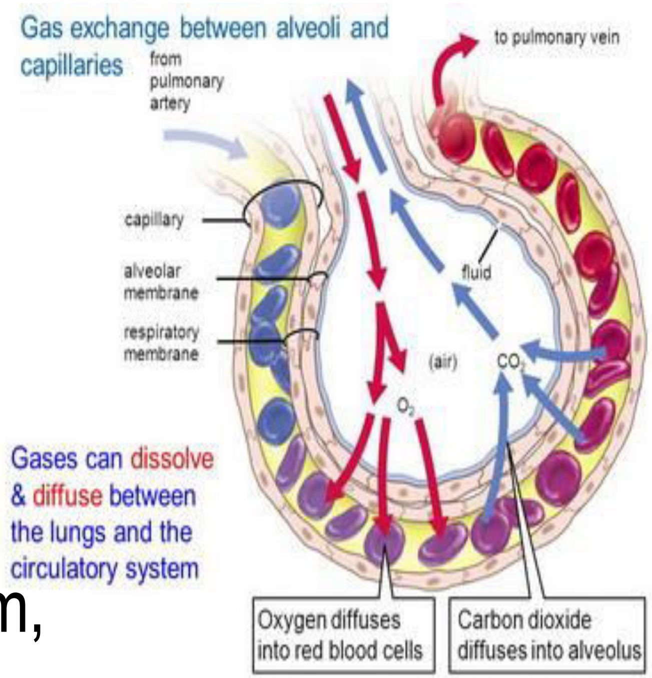
Diffusion of gases through Respiratory Membrane
Layers of the respiratory membrane



Factors that affect rate of gas diffusion through the respiratory membrane

1) Thickness of respiratory membrane

- 2 Factors increases the rate of diffusion through the respiratory membrane



1) Thin respiratory membrane (0.6 μm)
   - ↑ Thickness ⇨ ↓ rate of diffusion (e.g. pulmonary edema & fibrosis)

2) Diameter of pulmonary capillary = 8 μm, diameter of RBC =7.2 μm
   - RBC are squeezed through pulmonary capillary → in close contact with respiratory membrane

2) Surface area of respiratory membrane:

- Rate of diffusion is directly proportional to the surface area of respiratory membrane (70 m^2)
  - ↓ Emphysema, chronic smokers and pneumectomy

3) Partial pressure difference of gases

- ↑Partial pressure gradient →↑ rate of diffusion
  - Gases diffuse from a region of higher partial pr to a region of lower partial pr across the membrane until the pr of the gases on the two sides become equal

	Alveolar air	**Pulmonary capillary blood**	**Partial pressure gradient**
PO_2 mm Hg	100	40	60
PCO_2 mm Hg	40	46	6

4) Diffusion coefficient

- Definition: Volume of gas in ml which diffuses through $1 cm^2$ of a membrane in one minute when there is a pressure difference of 1mm Hg across the membrane

$$\text{Diffusion coefficient} \propto \frac{S}{\sqrt[2]{M.Wt}}$$

- ↑Diffusion coefficient⇨ ↑ rate of gas diffusion
- Diffusion coefficient of O_2=1, CO_2=20, N_2=0.5, CO=0.8, He=0.9 (The diffusion coefficient of CO_2 is 20 times more than that of O_2)

$$D \propto \frac{\Delta P \times A \times S}{d \times \sqrt[2]{M.Wt}}$$

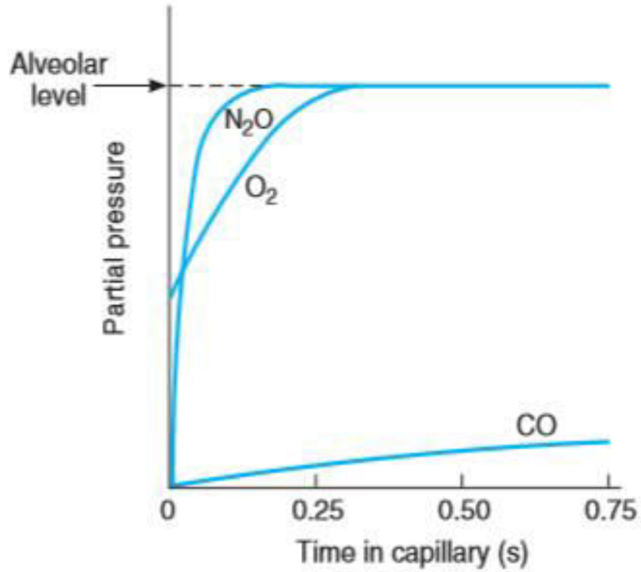
- D=Rate of diffusion of the gas, ΔP= Pressure gradient, A=Surface area, S=Solubility of the gas, d=Thickness of the respiratory membrane, MW= Molecular weight of the gas.

Perfusion- limited & diffusion limited gas exchange

- Depends on their reaction with substances in the blood
- Blood takes 0.75 sec to traverse the pul capillaries at rest

Perfusion limited exchange

- Aesthetic gas nitrous oxide (N_2O)
  - Doesn't form bond with Hb
  - ↑ N_2O content of blood ⇨ rapid ↑ P_{N_2O} (equilibrium within 0.1 sec)
  - Diffusion of N_2O can be increased only if perfusion increases



- Oxygen (O_2)
  - Reach equilibrium with within 0.3 sec (perfusion limited)
  - In fibrosis (thickening of resp membrane) & emphysema (↓surface area of resp membrane) ⇨ ↓ O_2 diffusion (diffusion limited)

Diffusion limited exchange

⦿Carbon monoxide (CO)

- Strong bond to Hb →↑CO in blood ⇨ minimum ↑ Pco
- Equilibrium is not reached in 0.75 sec
- Transfer of CO is limited by the rate of diffusion, not the amount of blood available

Perfusion limited gases	**Diffusion limited gases**
N_2O (anesthetic gas)	CO
CO_2	
O_2 (Normal condition)	O_2 (Emphysema, fibrosis, exercise)

The diffusion capacity of the lung to the gases:

- **Definition:** The volume of gas which is diffused/min/1mmHg difference in partial pressure of the gas.
- **Measurement:** The diffusion capacity for CO (D_{LCO}) is measured as an index of diffusion capacity because its uptake is diffusion limited.
  - D_{LCO} is proportional to the amount of CO entering the blood (V_{CO}) divided by P_{CO} in the alveoli (P_{ACO}) minus the partial pressure of CO in the blood entering pulmonary capillaries ≈ zero (except in habitual smokers)

$$D_{LCO} = \frac{V_{CO}}{P_{ACO} - P_{aCO}} \rightarrow D_{LCO} = \frac{V_{CO}}{P_{ACO}}$$

- **Factors:** same factors that affect rate of gas diffusion through the respiratory membrane affects diffusion capacity of the lung
  - It is directly proportional to the surface area of alveolo-capillary membrane and inversely proportional to its thickness.

Normal value

- D_{LCO} at rest is 25mL/min/mmHg
  - It increases to three fold during exercise because of capillary dilation and an increase in the number of active capillaries
- $D_{LO_2} = D_{LCO}$ = 25mL/min/mm Hg
  - ↑ D_{LO_2} in Exercise
  - ↓ D_{LO_2} Diseases (fibrosis of alveolar walls)
- D_{LCO_2} = 400ml/min/mm Hg (> D_{LO_2})
  - High solubility of CO_2 in cell membrane (CO_2 retention is rarely a problem in patients with alveolar fibrosis even when the reduction in diffusion capacity for O_2 is sever)

Effect of V/Q on alveolar gas concentration

- Ratio of alveolar ventilation(V) to pulmonary blood flow (Q)
  - Matching ventilation and perfusion is important to achieve the ideal exchange of O_2 and CO_2
  - Normal V/Q (whole lung) at rest is 0.8 (4L/min ÷ 5L/min)

Ventilation	Normal	Zero	Normal
Perfusion	Normal	Normal	Zero
V/Q	Normal	Zero	Infinity
Situation	Normal	Complete airway obstruction →shunted blood	Pulmonary artery obstruction → dead space
Gas exchange	Optimal	No gas exchange	No gas exchange
Alveolar:Po_2mmHg Pco_2 mmHg	Po_2 = 100 Pco_2 = 40	Po_2 = 40 Pco_2 = 46	Po_2 = 149.7 Pco_2 = 0.3