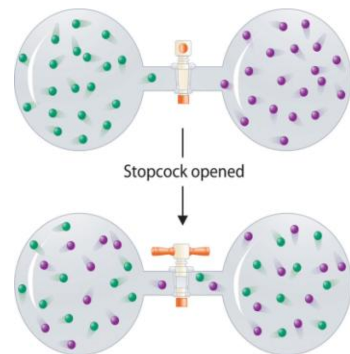
Gas Exchange :

Principles:

- Gases move across respiratory membrane between alveolar air and pulmonary capillaries by diffusion.
- **Diffusion:** is the net movement of the of solute or gas molecules from a region of high concentration to a region of low concentration.
- **Gas pressure** : Is the forced exerted by random motion of gas molecules against a surface .



- Gas pressure is directly proportional to the temperature and the number of gas molecules occupying certain volume
- Partial pressure: Is the pressure exerted by the molecules of each gas in the mixture of gases ex : PO_2 , PCO_2 , PN_2.
- Partial pressure of gases in a mixture = total gas pressure X fractional composition of these gases in the mixture (Dalton law)
- Partial pressure of **dissolved** gases in a solution is determined by
    1. Concentration of dissolved gas molecules
    2. Solubility coefficient of that gas

(Partial pressure = conc. Of dissolved gas molecules /solubility coefficient)

- ➢ solubility of CO_2 is 20 times that of O_2
- ➢ partial pressure of the dissolved gas is inversely related with its solubility : a dissolved gas that is highly soluble needs low pressure to get certain concentration.

Atmospheric air composition and partial pressure of its gases :

- Atmospheric air pressure equals 760 mmHg at sea level .
- Partial pressure of gases in the atmospheric air (inspired air) =

P_{O2} (21 % × 760) =159 mmHg

P_{CO2} (0. 04% × 760) = 0.3mmHg

P H2O (0. 5 %x 760 = 3.7 mmHg

Water Vapor pressure and its effect :

Inspired air in the **respiratory passages** is saturated with water vapor by the time it reaches the alveoli. The P_{H2O} at body temp is 47mmHg. → ↓ partial pressure of other gases (dilute other gases).

P_{O2} = 149 mmHg ↓

P_{CO2} = 0.3 mmHg **(dead space air)**

P_{H20} = **47** mmHg ↑

Composition of alveolar air

P_{O_2} = 104 mmHg ↓
P_{CO_2} = 40 mmHg ↑
P_{H_20} = 47 mmHg
Total =760 mmHg

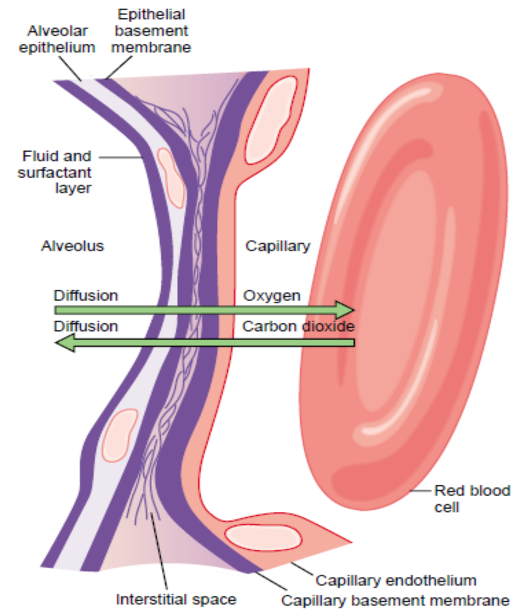
Causes of ↑ PCO_2 and ↓PO_2 in the alveolar air:

1. O_2 is constantly absorbed into the pulmonary blood from alveoli
2. CO_2 is constantly diffusing from pulmonary artery to the alveoli
3. Humidification of inspired before reaching the alveoli
4. The alveolar air is only partially and slowly replaced by atmospheric air .
   - the importance of this slow replacement is to :
     1. Prevent sudden changes in gas concentration in blood
     2. Prevent excessive ↑ or↓ of O2 ,Co2 ,pH when breathing is interrupted

Note : alveolar PO_2 depends On alveolar ventilation rate and rate of oxygen absorption and alveolar PCO_2 depends on alveolar ventilation rate and rate of CO2 excretion

Respiratory membrane

1. Respiratory membrane Fluid layer lining the alveoli
2. Alveolar epithelium (95 % is type I pneumocyte)
3. Epithelium basement membrane
4. Thin interstitial space



5. Capillary basement membrane
6. Capillary endothelium

❑ <u>Features :</u>

- It is a thin membrane. Sometimes the two basement membranes fused →↓the respiratory membrane thickness to 0.2 μm.
- Total gas exchange surface area 70 m2 →**large surface area** for gas exchange .
- Capillary diameter is narrow → RBC pass in close contact with membrane → fast diffusion

Factors affecting Gas Diffusion Through the Respiratory Membrane

CO_2 and O_2 are **highly lipid soluble** →highly soluble in cell membrane → limiting factor is the **tissue water solubility** .

Diffusion of gases through respiratory membrane Depends on :

1. Pressure difference factor
2. Membrane factor
3. Gas factor

D =(A / T) X DC X ΔP (P1- P2)

(A / T) → Membrane factor
DC → Gas factor
ΔP (P1- P2) → Pressure differences factor

D=Rate of gas diffusion

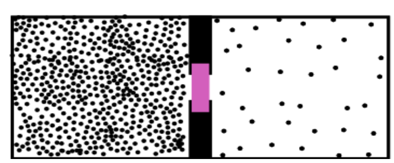
A=Surface area

T=Thickness of the respiratory membrane

DC =diffusion coefficient

ΔP=Pressure gradient,

1) **Partial Pressure Difference across the membrane :**



↑Partial pressure gradient →↑ rate of diffusion.

Gases diffuse from a region of higher partial pr to a region

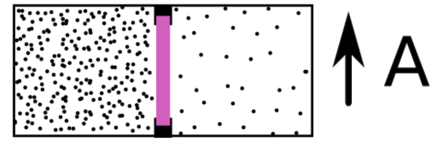
of lower partial pr. Ex :

PAO_2 (Alveolar) =104 ; PO_2 in pul.artery = 40 .difference is 64 mmHg

$PACO_2$ (Alveolar)= 40 ; PCO_2 in pul.artery =45 mmHg difference is 5 mmHg

Note
PA : Alveolar partial pressure
Pa : arterial partial pressure

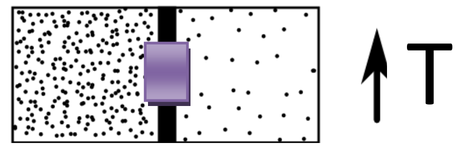
2) **Surface area of the respiratory membrane:**



↑ S.A →↑ diffusion

ex: ↓ diffusion in emphysema and surgical resection of lung

3) **the thickness of the membrane :**

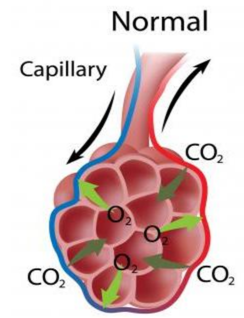


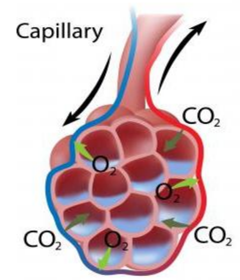
↑thickness →↓ diffusion ex: pulmonary edema

4)) **Diffusion Coefficient (DC) of the gas**

↑ DC⇨ ↑ rate of gas diffusion

- DC α s/$\sqrt{MW}$.
- s : solubility , MW : molecular weight
- It is a measure of the relative rate of gas diffusion for different gases.
- O_2=1 CO_2=20 (solubility of CO_2 is **20** >O_2)





Pulmonary edema

<u>Diffusion capacity of respiratory membrane (DL):</u>

is the volume of the gas that diffuses through the membrane each minute for a partial pressure difference of 1 mmHg.

All Factors (A, T ,ΔP and DC) affect DL

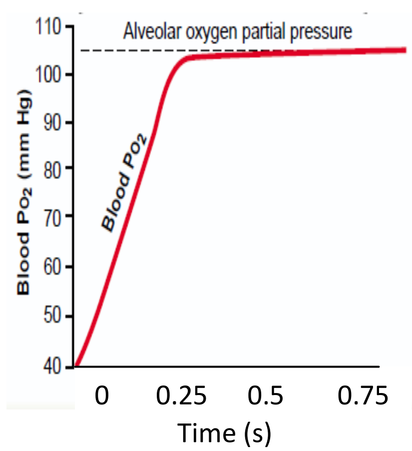
- ❑ DL for O_2 in quite breathing is 21ml /min/mmHg.
- ❑ During exercise : Surface area ↑by opening dormant capillary and distension of already open capillary with better V/Q ratio → D_LO_2 →65 ml/min/mmHg
- ❑ D_LCO_2 = 400 -450 ml/min/mmHg.

- ❑ Because of the Large difference in diffusion capacity between O_2 and CO_2 → O_2 diffusion is more affected than CO2 diffusion by a disease that ↓diffusion capacity of the lung. ex: fibrosis.
- ❑ CO (carbon monoxide) uses as a marker for Lung Diffusion capacity , Normal D_LCO at rest = 25ml/min/Hg

<u>CO_2 and O_2 diffusion</u>

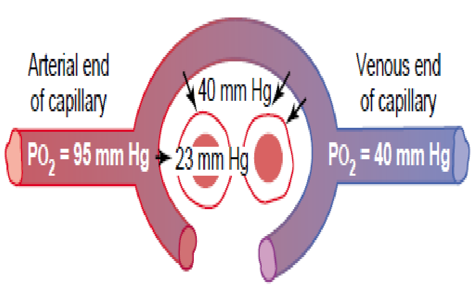
1. At alveoli level :

- Pulmonary veins exit the alveoli carrying oxygenated blood with **PO_2= 104 mmHg , PCO_2 = 40 mmHg** .
- Diffusion occurs in 1/3 the time needed by blood to pass the pulmonary Capillary length (Safety factor for exercise)
- Mixing with shunted blood→ ↓PaO2 to 95 mmHg in systemic circulation

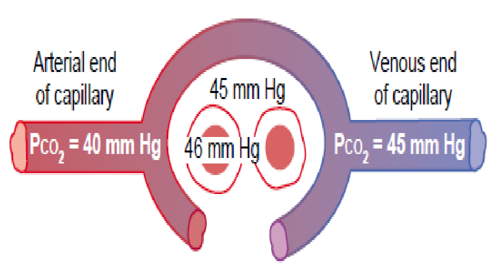


2. At tissue level:

- Systemic arteries deliver O2 to the tissues. Po_2 decrease from 95mmHg to **40 mmHg** in systemic veins.
- CO_2 is removed from the tissues. PCO_2 increases from 40mmHg to **45 mmHg** in systemic veins.



O2 diffusion

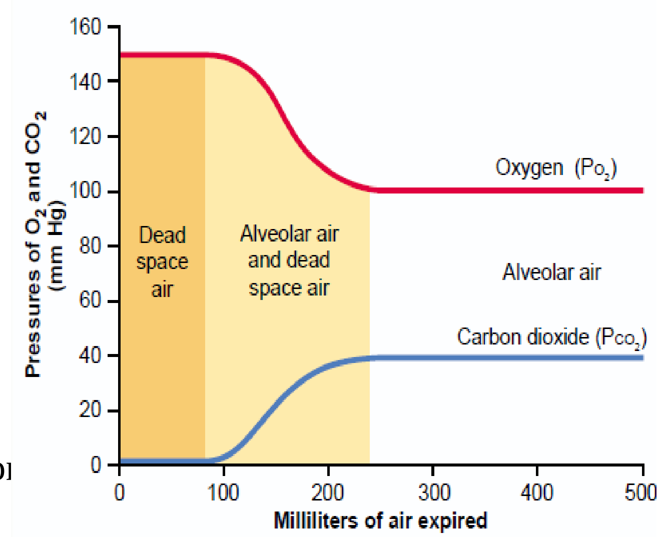


CO2 diffusion

Expired Air

Is a combination of dead Space and alveolar air :

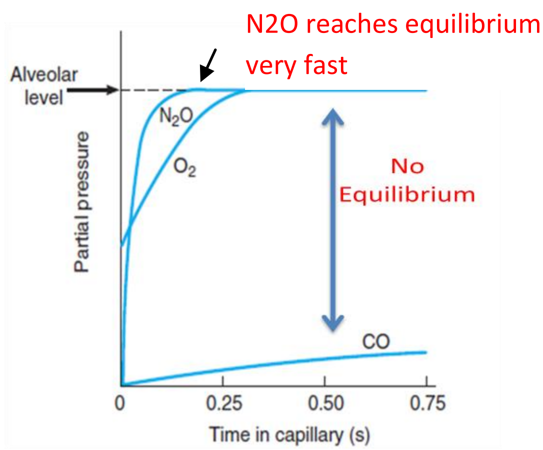
1. First portion of air is the dead space air which is humidified.
2. Second portion is a mixture of dead space and alveolar air
3. Last portion Only alveolar air at end of expiration

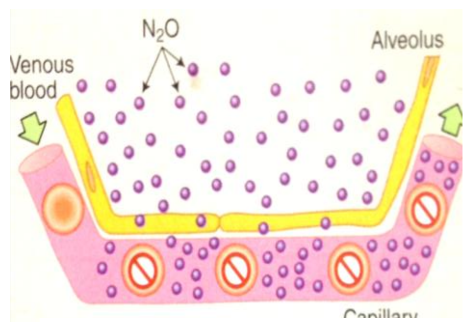


diffusion limited and perfusion limited gas exchange :

Perfusion-limited gas exchange : is the type of gas exchange in which the rate of gas transport to the tissue can only be increased by increasing pulmonary blood flow and gas partial pressure in the pulmonary capillaries reaches equilibrium with alveolar partial pressure ex : nitrous oxide N2O (anesthetic gas)

- O_2 also binds with Hb but it reaches equilibrium with alveolar PO2 before the blood leaves the pulmonary capillaries → perfusion limited





Perfusion limited /equilibrium

Diffusion limited gas exchange : is the type of gas exchange in which the rate of gas transport to the tissues is limited by the diffusion rate of the gas across the respiratory membrane and gas partial pressure in the blood does not reach equilibrium with alveolar partial pressure. ex : carbon monoxide CO.

diffusion limited /no equilibrium