PASSION ACADEMIC TEAM YU - MEDICINE

Sheet# 7 physiology

Lec. Date :

Lec. Title : Gas exchange

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If you come by any mistake , please kindly report it to shaghafbatch@gmail.com

RESPIRATORY SYSTEM

Gas exchange in lungs

- Gas exchange occurs by two main mechanisms:
- 1) Bulk flow: the movement of air from high pressure to low pressure,

from eternal environment to internal environment, from the atmosphere

through the trachea (and airways) all the way down to the alveoli. This happens because of the difference in pressure between the alveoli and the atmosphere.

All molecules and gases move as unit.

<u>Driving pressure</u>: difference between alveolar and atmospheric pressure.

- 2) Diffusion: gas diffusion from alveoli to blood (specifically oxygen) AND diffusion of CO_2 from blood to alveoli.

Diffusion occurs due to several factors:

a) Pressure gradient.

Dalton's law:

<u>Partial pressure = specific gas fractional concentration x total gas pressure</u>

(total pressure is usually the atmospheric pressure)

Partial pressure = gas tension

Ex: At sea level, PO_2 is 160 mm Hg (760 mm Hg × 0.21).

Oxygen pressure varies among different sites; inspired PO_2 is 160, in the conducting zone it's 150, in the alveoli it's 102. WHY?

First, because of the remaining air from previous breath. second, the water vapor, PH2O is around 47, so the total gas pressure would be 760-47= 713, then the result would be multiplied by O2 fraction (0.21), so PO2= 0.21x713= 150. After that oxygen diffuses into blood in the alveoli, so finally it would be 102.

Diffusion gradient of O2 between alveoli and blood= alveolar PO2 (102) - (40) = 62

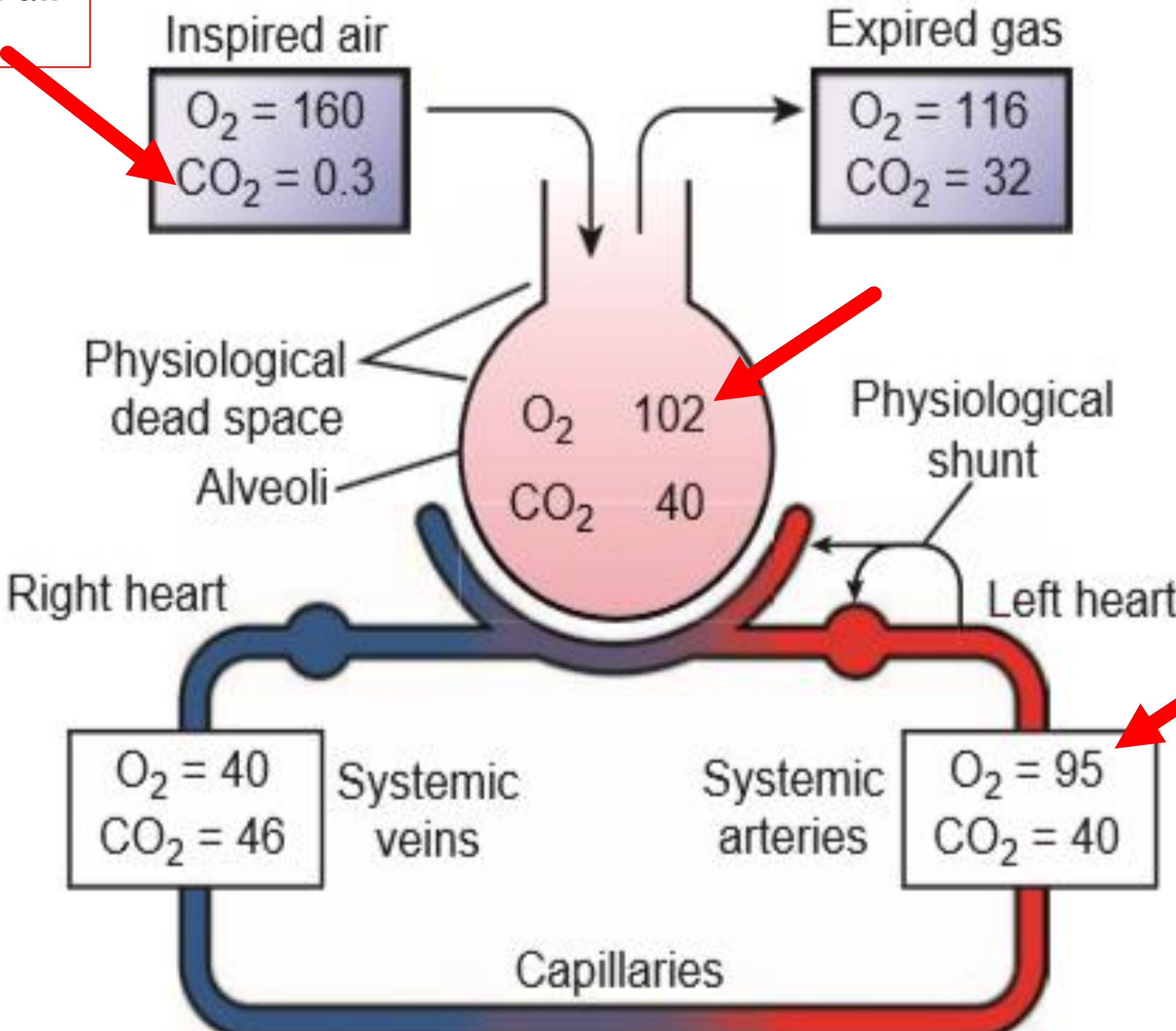
Diffusion gradient of CO2= venous blood PCO2 (46) – alveolar PCO2 (40)= 6

Diffusion gradient of O2 > Diffusion gradient of CO2

b) Diffusion properties of the alveolar-capillary membrane.

c) Pulmonary capillary blood flow.

Consider inspired air PCO2=0



-from previous pic:

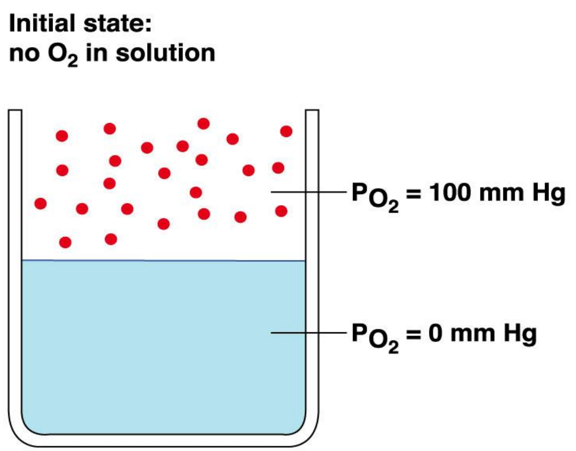
*PO2 is lowered in arterial blood (102 to 95) due to physiological shunt: deoxygenated blood from Bronchial circulation, and deoxygenated blood from coronary sinuses which supplies the myocardium (heart wall), and deoxygenated blood due to non functional alveoli. These 3 factors cause blood that passed oxygenation in the lungs to go to the left ventricle directly, lowering PO2 in the arteries.

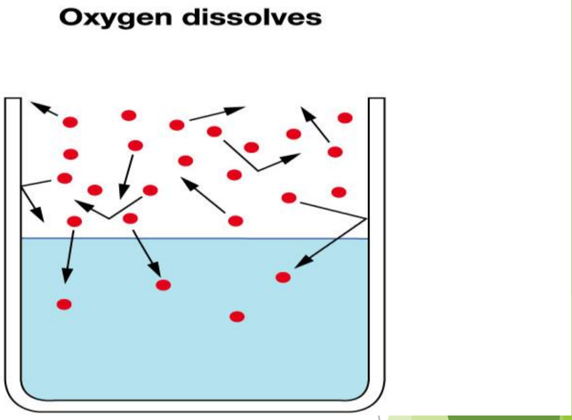
*Why is that PO2 in expired air = 116, when alveolar PO2 =102?

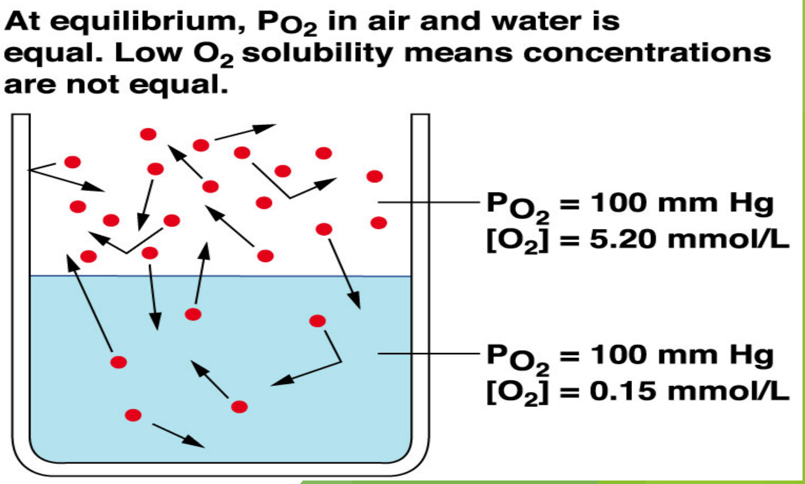
Because of fresh air in the conducting zone (anatomic dead space), around 150 ml, which increases PO2 in expired air.

Factors Affecting Diffusion of Gases

Partial Pressure Gradients

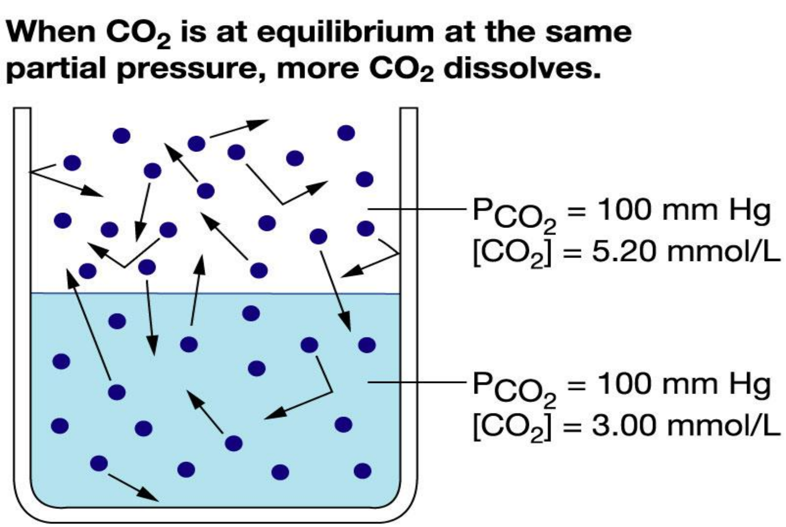


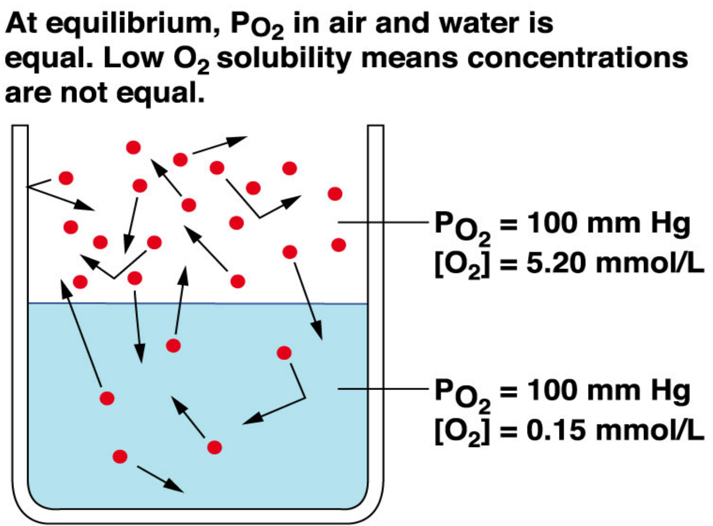




The Henry law states that at equilibrium, the amount of gas dissolved in a liquid at a given temperature is directly proportional to the **partial pressure** and the **solubility** of the gas.

- Warming up of inspired air decreases the solubility of gas in blood, preventing air bubble emboli, which can cause clotting in blood vessels.
- PO2 in blood is the amount dissolved gas, not the chemically combined gas (like hemoglobin bound O2).
- In the pic bellow: concentrations are not equal due to solubility in blood. Note: CO2 is more soluble in blood than O2, that's why CO2 concentration is larger than O2 concentration.





- Factors affecting solubility are: temperature (inversely proportional), and partial pressure.
- Concentration of dissolved gas= partial pressure x solubility

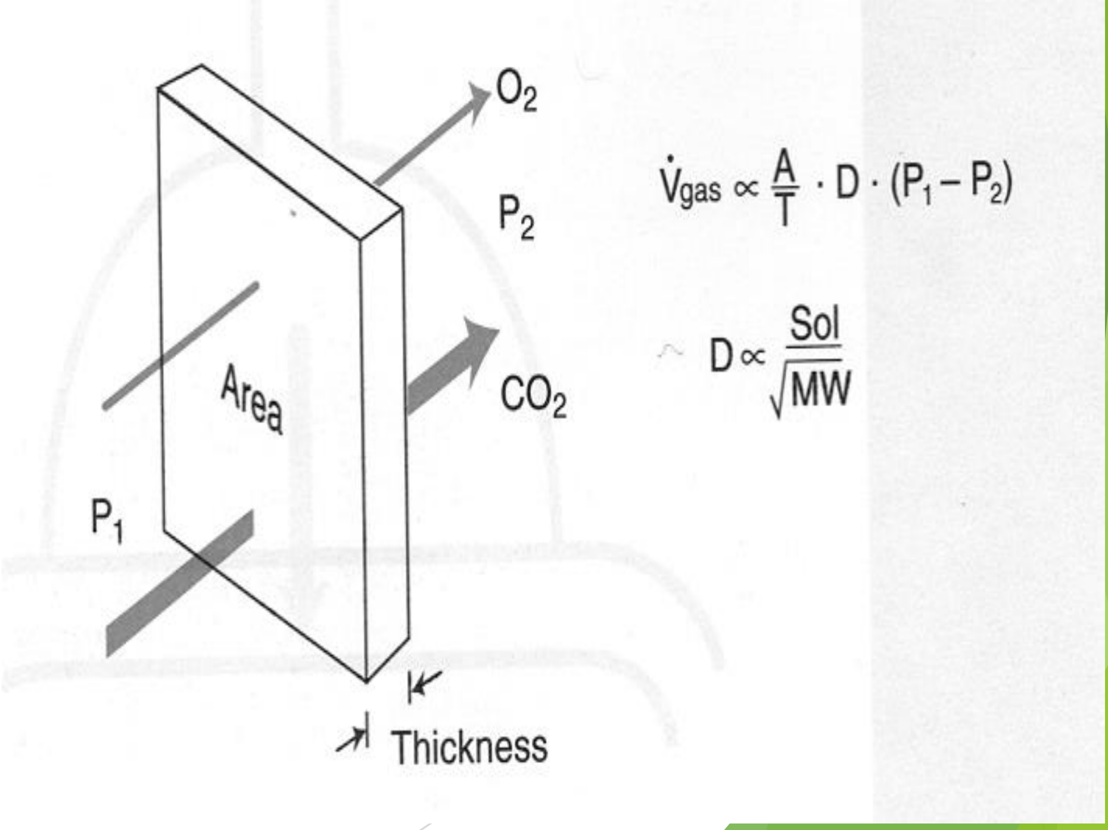
More solubility and more partial pressure difference mean more concentration.

- CO_2 is 24 time more soluble than O_2, and CO_2 has 1.5 times more molecular weight than O_2. But if we consider both of these factors CO_2 would diffuse 20 times faster than O_2, because it has large diffusion coefficient (D).
- Diffusion of any gas is directly proportional to: surface area, (D), pressure gradient. But diffusion is inversely proportional to thickness of the alveolar-capillary membrane (respiratory membrane) and molecular weight. (Fick's law).

- The diseases that are associated with hypoxia and hypercapnia, which one will appear faster? Or which one the body can get rid of faster?

we can answer that according to what we studied (that's what the doctor said).

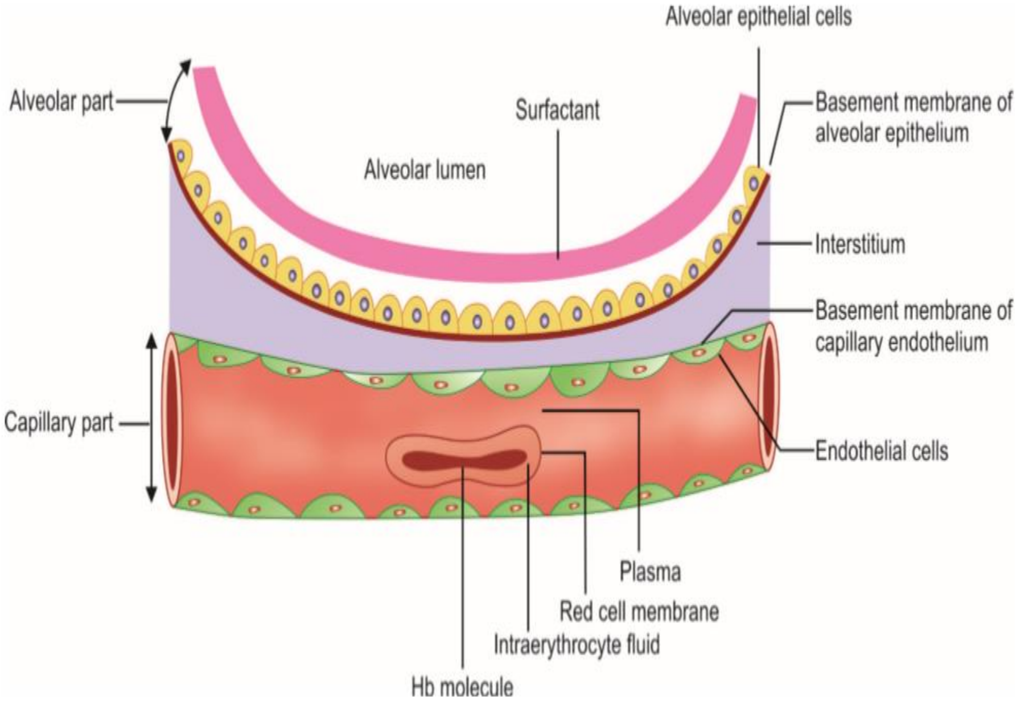
*CO2 outward diffusion is 20 times faster than inward O2 diffusion.



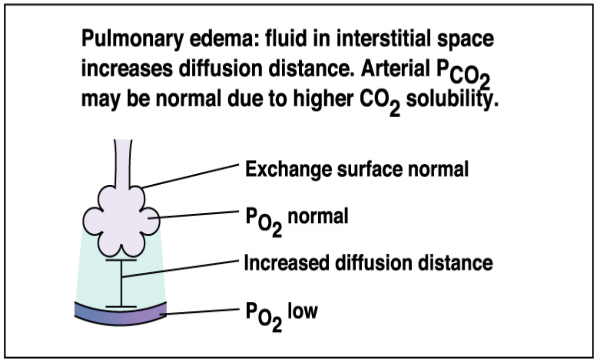
Factors Affecting Diffusion of Gases

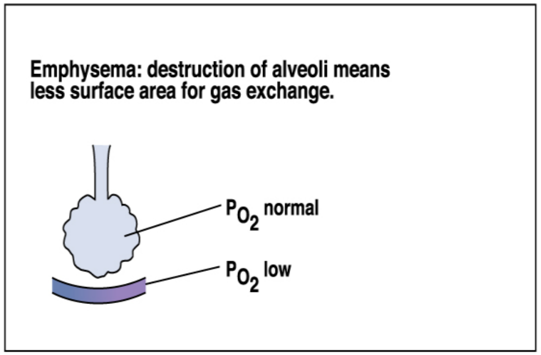
Alveolar-Capillary Membrane (respiratory membrane)

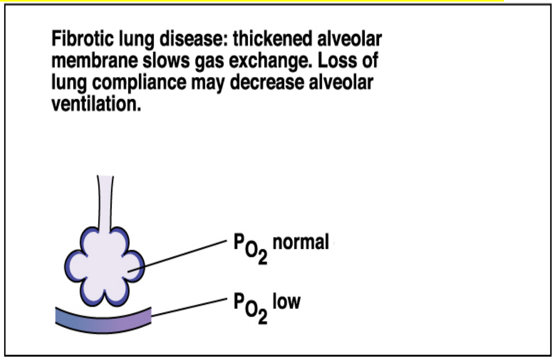
- Alveolar-capillary membrane (also called respiratory membrane) forms the blood-gas interface that separates blood in the pulmonary capillaries from the gas in the alveoli.
  - **The alveolar-capillary membrane is exceedingly thin, and is mainly composed of alveolar epithelium, interstitial fluid layer, and capillary endothelium.**



alveolar-capillary obstruction syndrome







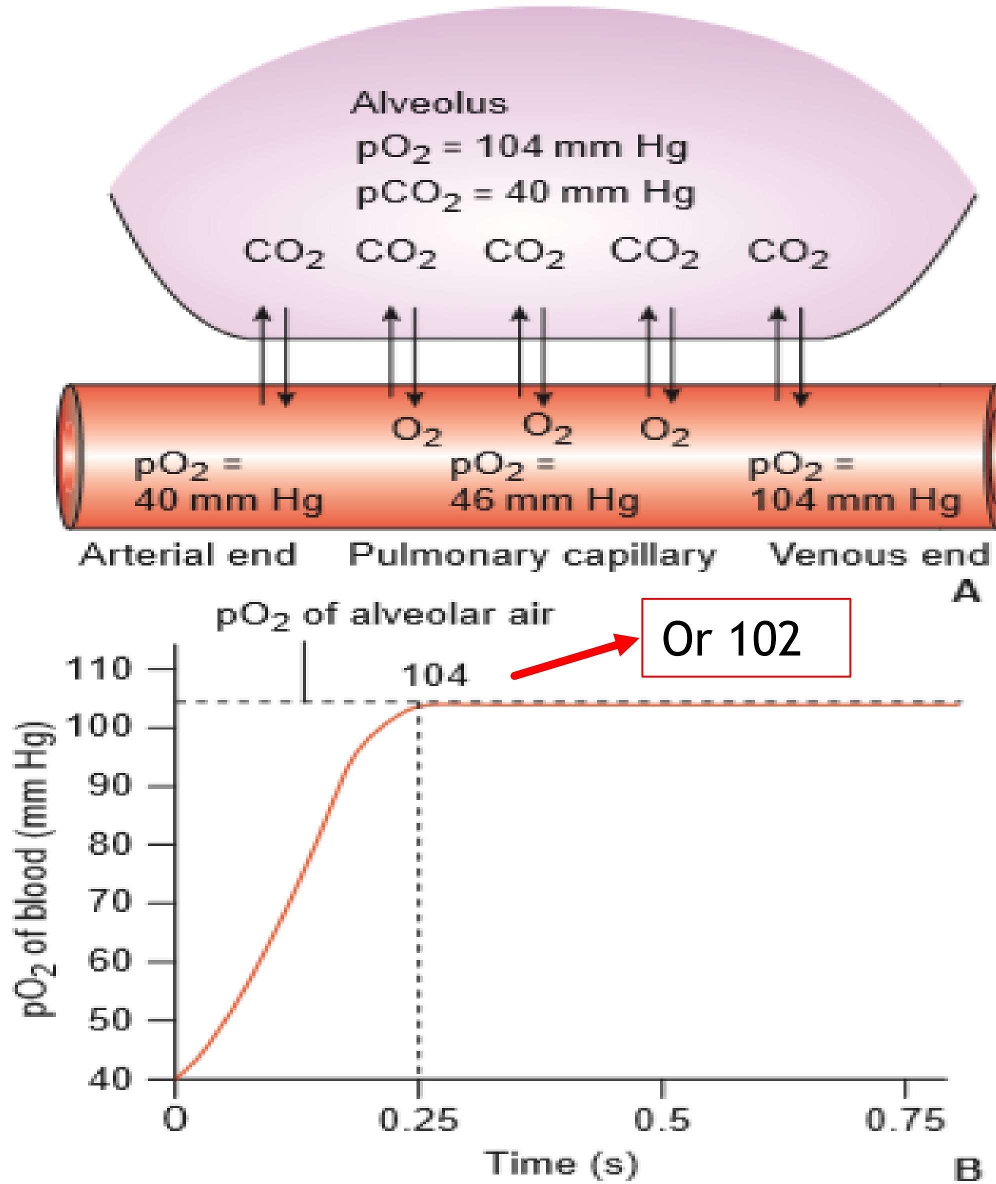
- What's the importance of the fluid layer in the alveoli?
- Making surface tension, and it plays a role in facilitating the transmission of O2 from the alveoli to the capillaries,, how ? Works as a trapping machinery of O2 , trapped O2 > diffuse it to the epithelial lining of alveoli .. in this way you transmit O2 from alveolar space (gas) into liquid layer then into intracellular fluids (type 1 cells) then interstitial fluids, finally into capillaries… so you minimize the sudden difference in physical states of transmission ,you may imagine it better by applying it on the oil droplets that we use in microscope resulting in a better view. (credits to our colleague Zainab Akram).

- In some diseases like fibrosis, there is thickening in the epithelial layer of the alveoli, meaning no good diffusion, leading to low PO_2 and high PCO_2, because of bad uptake of O_2 and bad removal of CO_2.
- In emphysema, there is a decrease in surface area, leading to decrease in gas diffusion, again bad diffusion will cause low PO_2 and high PCO_2.
- In edema, there is an accumulation of fluid in the interstitial fluid or even in the alveoli, which increases diffusion distance, leading to bad diffusion, low PO_2 and high PCO_2.

Factors Affecting Diffusion of Gases

Capillary Blood Flow

- Normally, the <u>transit time</u> (time taken by the red cells to pass through the capillary), is approximately 0.75 sec, during which the gas tension in the blood equilibrates with the gas tension in the alveoli.
- With increase in cardiac output, blood flow through the pulmonary capillaries increases that decreases the transit time (i.e., the time blood is in capillaries is less).

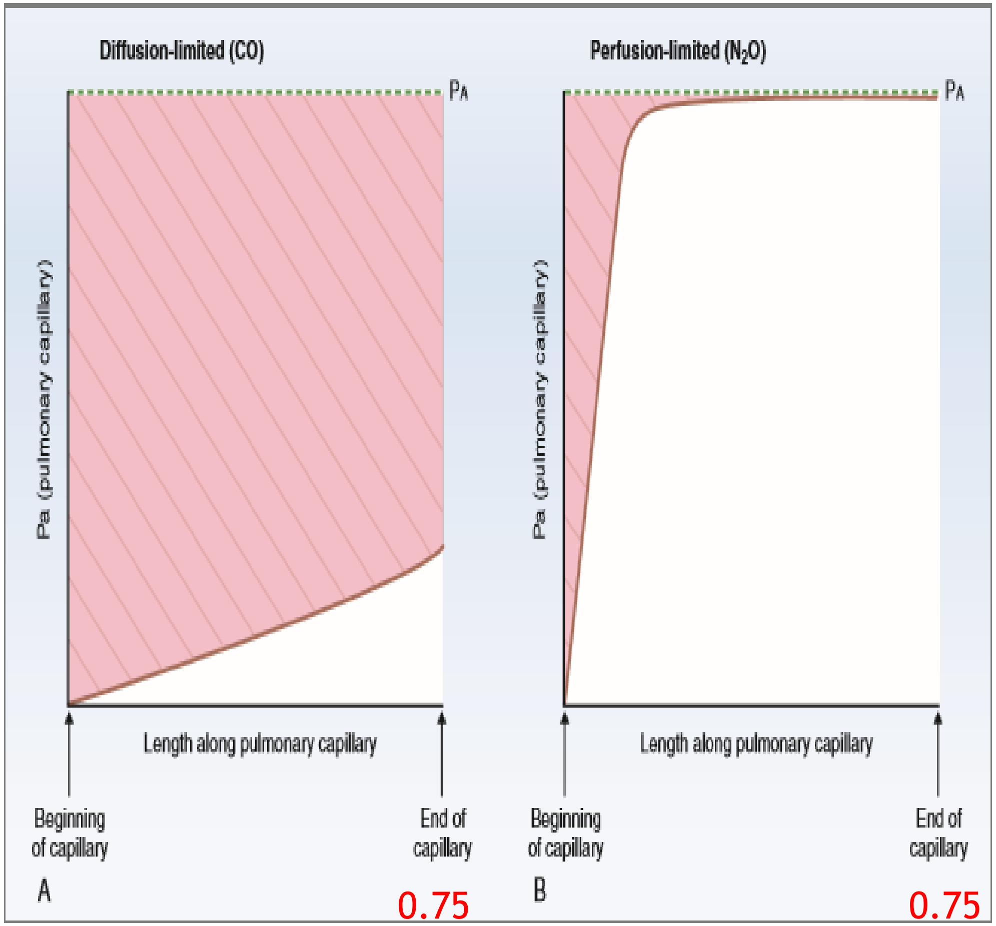


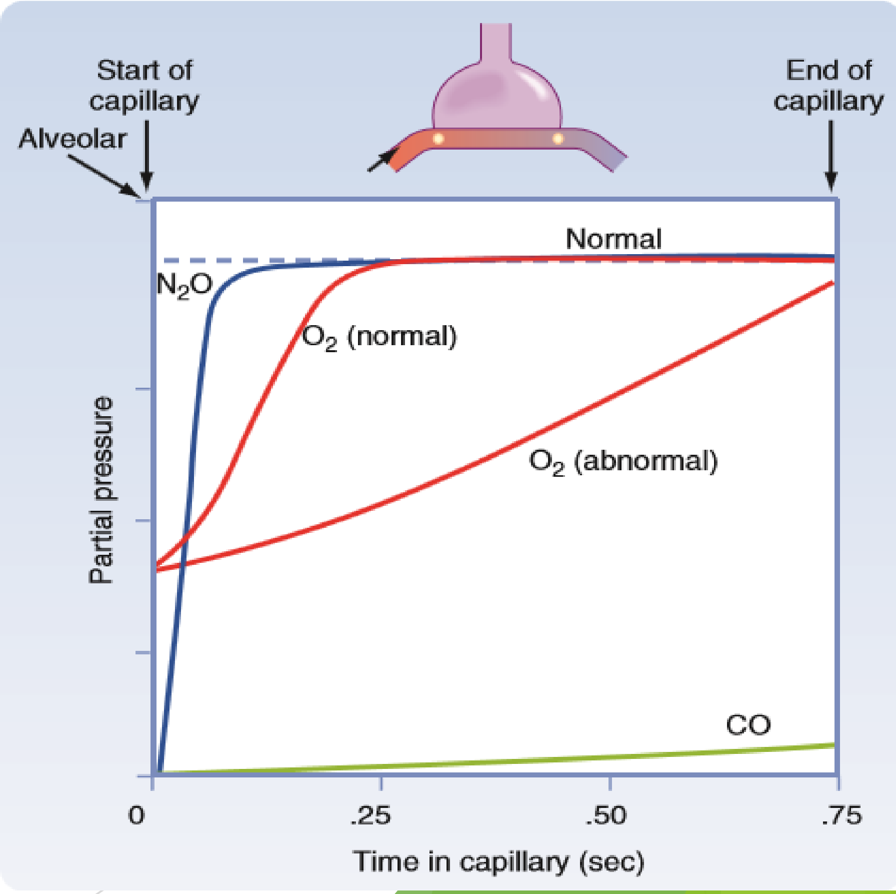
- The blood is fully saturated with O2 within the first third of the transit time, it takes only 0.25 sec for saturation, what is the importance of that?

To make a safety margin when blood flow is increased, like when we do exercise there will be more flow (increase in volume and speed), this relatively short amount of time insures fully saturation.

Types of Exchange

Gas exchange across the alveolar/pulmonary capillary barrier is described as either diffusion limited or perfusion limited.





- From previous slide:

*dashed green lines in the top of the first pic represent alveolar partial pressure.

In the beginning, blood PCO and PN2O is zero, so there will be a diffusion from alveoli to blood.

In the case CO diffusion, you can see that there is no equilibrium or saturation (the curve is going up), and the gradient is still present. This case is called diffusion limited (diffusion dependent).

In the case of N2O, you can see that there is an equilibrium or saturation. This case is called perfusion limited (perfusion dependent), because I can increase diffusion if I increase perfusion.

*O2 diffusion is perfusion limited (there is equilibrium in normal conditions)

Ventilation-Perfusion ratio

- Alveolar ventilation: is the amount of air that reaches the alveoli.

Alveolar ventilation= (tidal V-dead space V) x respiratory rate (12 breath\min) = 4.2 liter

Perfusion(Q): is the blood flow. (blood flow in 1 min is called cardiac output)

Cardiac output= stroke volume(70) x heart rate(70) = 5 liter

Ventilation-Perfusion ratio (V\Q)= 4.2\5 = 0.8 (normal)

*If the V\Q ratio is normal, this does not necessarily mean that ventilation is normal, V\Q just indicates the matching between ventilation and perfusion.

- cont.
- Ex: if there is problem with aeration in one part of the lung, ventilation will decrease, and V\Q will decrease too, but after some time there will be a physiological response called hypoxic vasoconstriction, that will lead to a decrease in perfusion. So a decrease in both ventilation and perfusion, the V\Q ratio will be normal again. However, neither ventilation nor perfusion is normal.

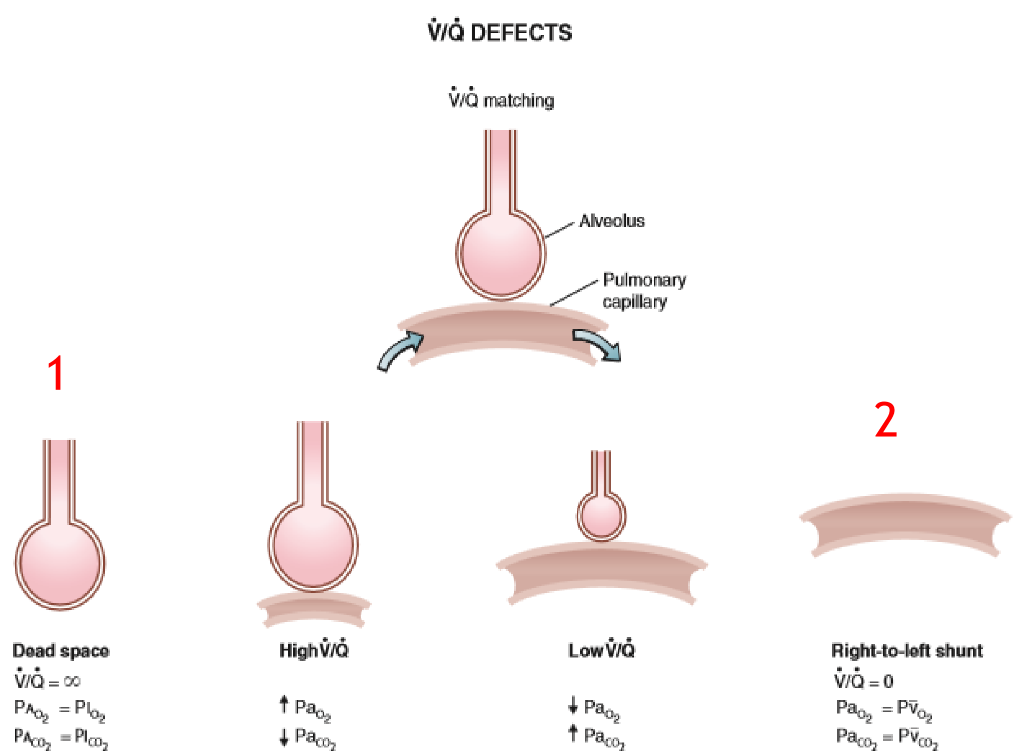
Ventilation-perfusion ratio

- Ventilation-perfusion ratio is the ratio of alveolar ventilation to blood flow (perfusion) in lung.

- Thus in a normal lung, the overall ventilation/perfusion ratio is approximately 0.8, but the range of V̇/Q̇ ratios varies widely in different lung units.

- A mismatch of ventilation and perfusion, called V̇/Q̇ mismatch, or defect, results in impaired O2 and CO2 transfer.

- A V̇/Q̇ defect can be caused by:
  1 • ventilation of lung regions that are not perfused (dead space) (V̇/Q̇ = ∞),
  2 • perfusion of lung regions that are not ventilated (shunt) (V̇/Q̇ = 0). and
  • Every possibility in between (<u>High V̇/Q̇, Low V̇/Q̇</u>)

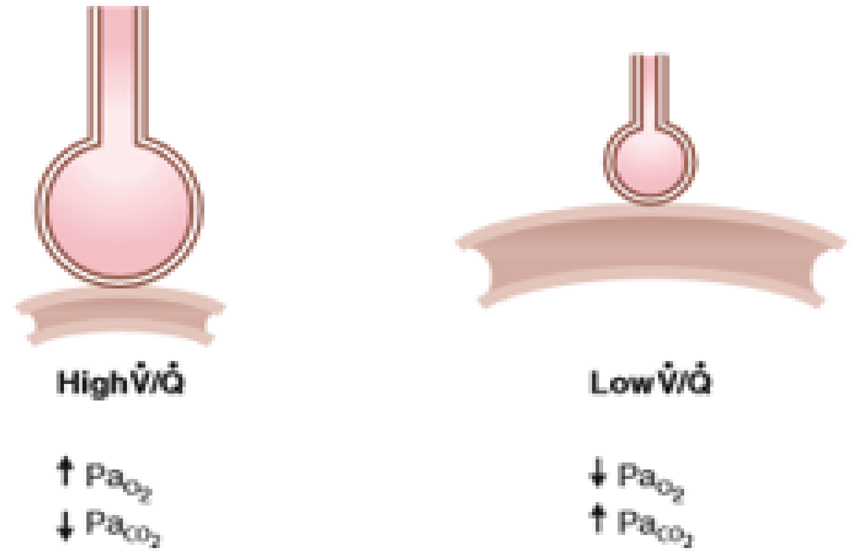


- 1) dead space case: the is no perfusion, so there is no gas exchange, and PCO2 in these alveoli = PCO2 in inspired air = 0. so the V\Q ratio = ∞
- 2) right-to-left shunt (simply shunt) case: the blood in the right side of the heart goes directly to the left side of the heart without being oxygenated in the lungs. In this case there is no aeration, and no ventilation. So the V\Q ratio = 0. and arterial PO2 = venous PO2= 40, because the venous blood didn't get oxygenated (no aeration, no ventilation).
- And there is in between,

High V\Q: relatively high ventilation

(in apex)

Low V\Q: high perfusion (in base)



Regional Differences in Ventilation/Perfusion Ratios