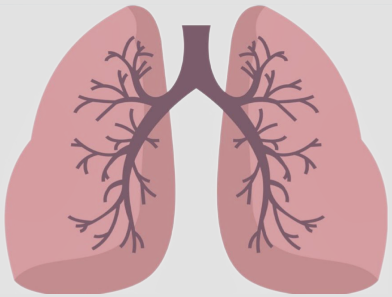
Gas diffusion



Respiratory Block

Physiology 439 team work

- Black: in male / female slides
- Red : important
- Pink: in female slides only
- Blue: in male slides only
- Green: notes
- Gray: extra information
- Textbook: Guyton + Linda

Editing file

@Physiology_439

Objectives :

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

02 . 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).

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

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

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

06 . Identify the various factors determining gas transfer: - Surface area, thickness, partial pressure difference, and diffusion coefficient of gas.

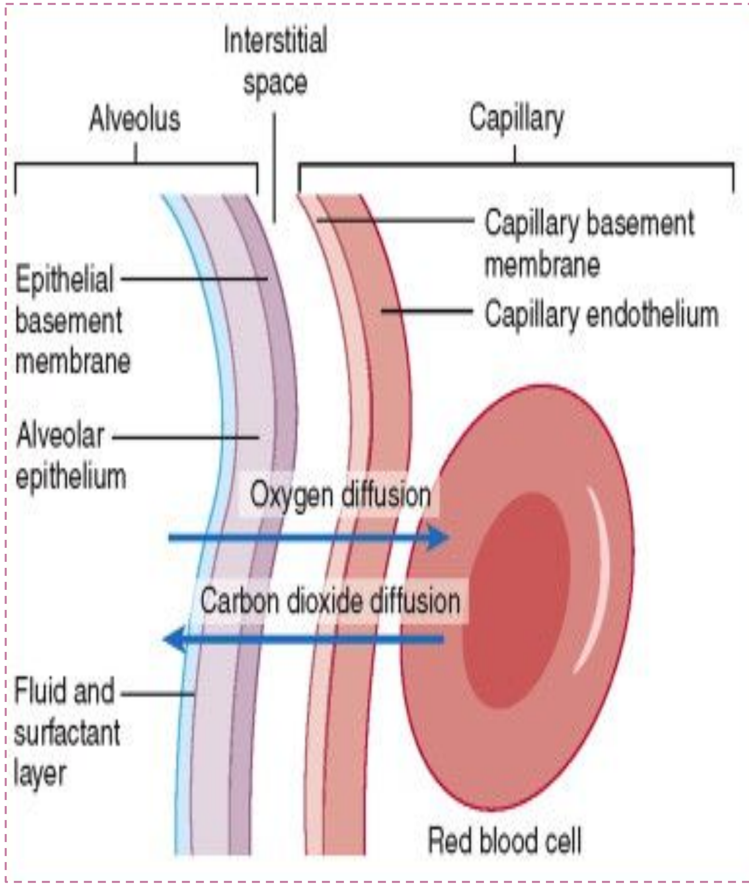
07 . State the partial pressures of oxygen and carbon dioxide in the atmosphere, alveolar gas, at the end of the pulmonary capillary, in systemic capillaries, and at the beginning of a pulmonary capillary.

Gas exchange at respiratory membrane

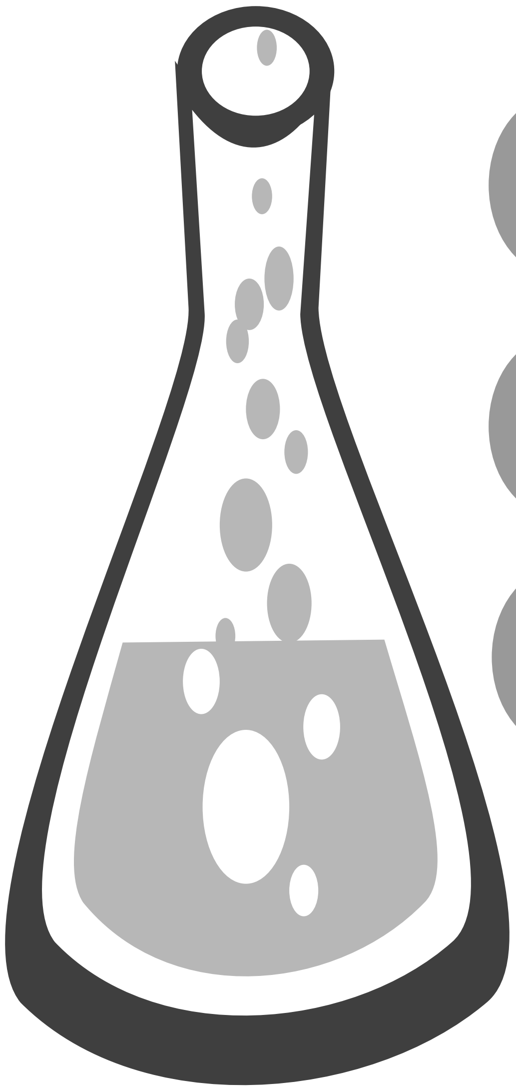
- After ventilation of the alveoli with fresh air the next step is the process called Diffusion of oxygen and carbon dioxide across the respiratory membrane.
- The total quantity of blood in the capillaries of the lungs at any given instant is 60 to 140 ml.

Respiratory Membrane Layers

- Fluid-surfactant layer that lines the alveolus and reduces the surface tension of the alveolar fluid.
- Alveolar epithelium which is composed of thin epithelial cells
- Epithelial basement membrane between the alveolar epithelium and the capillary membrane.
- A thin Interstitial space
- Capillary basement membrane that in many places fuses with the alveolar epithelial basement membrane.
- The Capillary endothelium membrane



partial pressure of gases



01 The gases of physiological importance are O_2, CO_2.

02 The rate of diffusion of each of these gases is directly proportional to the pressure caused by this gas alone which is called the <u>partial pressure of the gas.</u>

03 Pressure is caused by the constant impact of kinetically moving molecules against surface. باختصار الضغط قوة على مساحة بس يحبون يطولونها
$P=F/A$

molecules are transferred from regions of high concentration
to regions of low concentration until they reach equilibrium

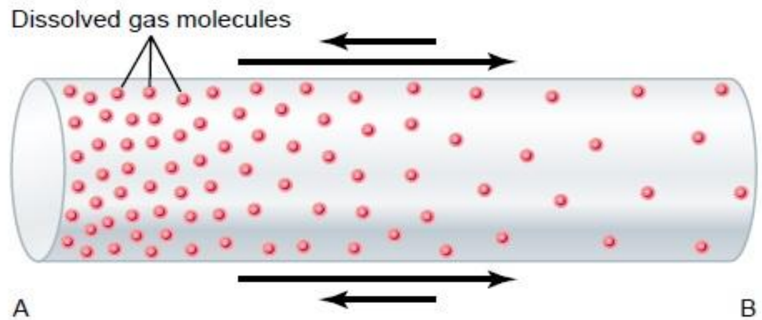


Figure 39–1

Diffusion of oxygen from one end of a chamber (A) to the other (B). The difference between the lengths of the arrows represents *net diffusion*.

Explanation of Partial pressure of gases (in a mixture)

From Guyton

The concept of partial pressure can be explained as follows:
Consider air, which has an approximate composition of 79% nitrogen and 21% oxygen. The total pressure of this mixture at sea level averages 760 mmHg. It is clear from the preceding description of the molecular basis of pressure that each gas contributes to the total pressure in direct proportion to its concentration.

- ➔ Therefore, 79% of the 760 mmHg is caused by nitrogen (600 mmHg) and 21% by O_2 (160 mm Hg).
- ➔ Thus, the "partial pressure" of nitrogen in the mixture is 600 mmHg, and the "partial pressure" of O_2 is 160 mmHg; the total pressure is **760 mm Hg**, the sum of the individual partial pressures.
- ➔ The partial pressures of individual gases in a mixture are designated by the PO_2, PCO_2, PN_2, and so forth.

Diffusion of Gases Between the Gas Phase in Alveoli and Blood

The partial pressure of each gas in the alveolar respiratory gas mixture tends to force molecules of that gas into solution in the blood of the alveolar capillaries. Conversely, the molecules of the same gas that are already dissolved in the blood are bouncing randomly in the fluid of the blood, and some of these bouncing molecules escape back into the alveoli. The rate at which they escape is directly proportional to their partial pressure in the blood.

But in which direction will net diffusion of the gas occur?
The answer is that net diffusion is determined by the difference between the two partial pressures. If the partial pressure is greater in the gas phase in the alveoli, as is normally true for oxygen, then more molecules will diffuse into the blood than in the other direction. Alternatively, if the partial pressure of the gas is greater in the dissolved state in the blood, which is normally true for CO_2, then net diffusion will occur toward the gas phase in the alveoli.

Dalton's law of partial pressures

It states that the partial pressure of a gas in a mixture of gases is the pressure that gas would exert if it occupied the total volume of the mixture.

Thus partial pressure is the total pressure multiplied by the fractional concentration of dry gas, or $PX = PB \times F$

for humidified gas : $PX = (PB - PH_2O) \times F$

PX = Partial pressure of gas (mm Hg)
PB = Barometric pressure" is the sum of the partial pressures of O_2, CO_2, N_2, and H_2O". (760mm Hg)
F = fractional concentration of gas (no units)
For example O_2 =0,21
PH_2O = Water vapor pressure at 37°C (47 mm Hg)

The percentages of gases in dry air at a barometric pressure of 760 mm Hg are as follows:

CO_2	0% (0)
O_2	21% (0.21)
N_2	79% (0.79)

Because air is humidified in the airways, water vapor pressure is obligatory and equal to **47 mm Hg** at 37°C.

partial pressure of O_2 and CO_2

Oxygen concentration in the atmosphere is **21%**

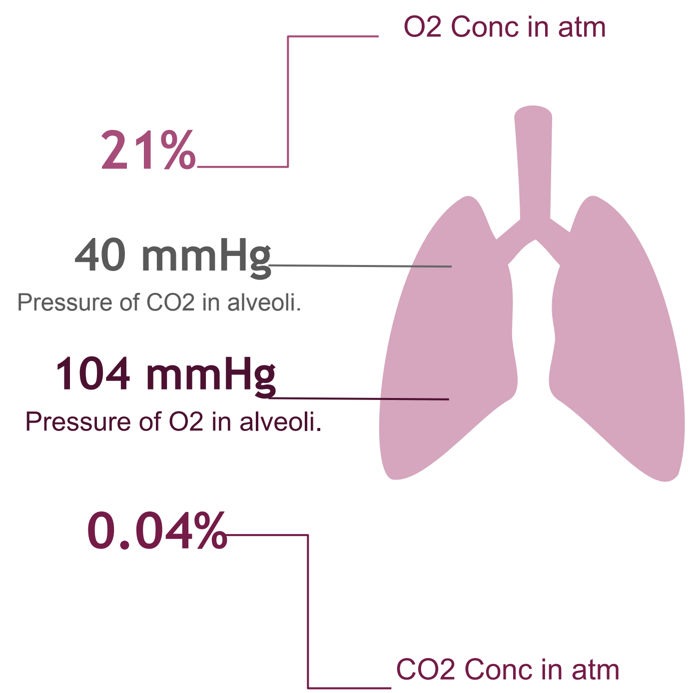
*So PO_2 in atmosphere = 760 mmHg x 21% = **160 mmHg**.

This mixes with "old" air already present in alveolus to arrive at PO_2 of **104 mmHg** in the alveoli.

Carbon dioxide concentration in the atmosphere is **0.04%**

*So PCO_2 in atmosphere= 760 mmHg x 0.04% = **0.3 mmHg**

This mixes with high CO_2 levels from residual volume in the alveoli to arrive at PCO_2 of **40 mmHg** in the alveoli.



*نضرب النسبة الي يشكلها الغاز بالضغط الجوي الكلي

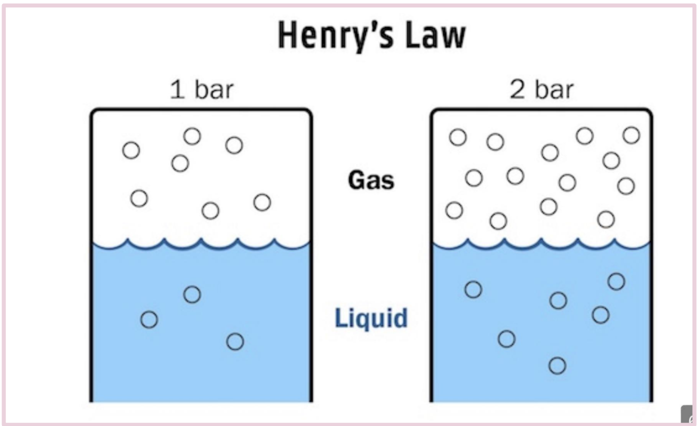
Henry's law

How to determine the partial pressure of a gas dissolved in a fluid (blood)?

by its concentration, also by the solubility coefficient of the gas.
These relations are expressed by the following formula,which is Henry's law:-

$$\text{Partial pressure} = \frac{\text{Concentration of dissolved gas}}{\text{Solubility coefficient}}$$

- Carbon dioxide is more than 20 times as soluble as oxygen.
- Therefore, the partial pressure of carbon dioxide (for a given concentration) is less than one twentieth that exerted by oxygen.

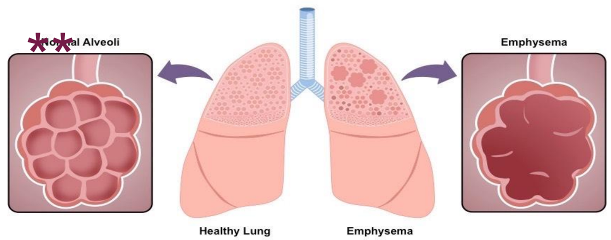


$$D \propto \frac{\Delta P \times A \times S}{d \times \sqrt{MW}}$$

Factors affecting gas diffusion-Fick's law

- **ΔP: Partial pressure difference between the gases in the two sides of the membrane.**
- **A: Surface area for gas exchange.**
- **S: solubility of gas in the body fluids.**
- **MW: Molecular weight.**

- The total surface area of the respiratory membrane is ~ 50 to 100 m2 in normal adult.
- The total surface area is about 70 m2 in the normal adult human male.
- From Guyton
- The surface area of the respiratory membrane can be greatly **decreased** by many conditions. For instance:
  1- removal of an entire lung decreases the total surface area to one-half normal.
  2- **in emphysema, many of the alveoli coalesce (combine) , with dissolution of many alveolar walls. Therefore, the new alveolar chambers are much larger than the original alveoli, but the total surface area of the respiratory membrane is decreased because of loss of the alveolar walls
  3-and increase during exercise because there are more open capillaries and thus more surface area for diffusion.



Cont..Factors affecting gas diffusion

d: Diffusion distance [thickness of the respiratory membrane]:

- Thickness of the respiratory membrane is 0.2 -0.6 micrometer.

  -from Guyton

  when The thickness of the respiratory membrane increases:

  1- as a result of edema fluid in the interstitial space of the membrane and in the alveoli.

  2-some pulmonary diseases cause fibrosis of the lungs, which can increase the thickness of some portions of the respiratory membrane.

The temperature of the fluid

In the body, the temperature remains reasonably constant and usually need not be considered.

S/ √MW: diffusion coefficient

Will discuss in the next slide

diffusion coefficient

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

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

-Assuming that the diffusion coefficient for O2 is 1, the relative diffusion coefficients for different gases of respiratory importance in the body fluids are as follows:

- Oxygen= 1.0
- carbon dioxide = 20.0
- nitrogen=0.53

$$D \propto \frac{\text{Solubility}}{\sqrt{MW}}$$

O2 has lower molecular weight than CO2 But CO2 is 24 times more soluble than O2 so the Net result is that CO2 diffusion is approx 20 times faster than O2 diffusion.

If we have respiratory failure which gas will be affected first? O_2

ثاني أكسيد الكربون مهما تأثر ال Respiratory membrane ماراح يتأثر والسبب ان وجوده بكثرة في جسمنا أخطر من عدم قدرة دخول الأكسجين ف لذالك خروج ثاني أكسيد الكربون أسهل من دخول الأكسجين حتى في الوضع الطبيعي

Composition of alveolar air-its relation to Atmospheric air

Alveolar air concentrations of gases are different from the atmospheric air due to several reasons:

1)The alveolar air is only partially replaced by atmospheric air with each breath “Only 350 milliliters of new air is brought into the alveoli with each normal inspiration, and this same amount of old alveolar air is expired” i.e The volume of alveolar air replaced by new atmospheric air with each breath is only one seventh of the total.

2)Oxygen is being absorbed into the pulmonary blood from the alveolar air

3)Carbon dioxide is diffusing from the pulmonary blood into the alveoli.

نفاذيته أعلى ب٢٠ مرة من الأكسجين

4)Dry atmospheric air is humidified even before it reaches the alveoli.

	Inspired air	Alveolar air
H2O	Variable	47mmHg
CO2	0.3mmHg	40mmHg
O2	159mmHg	105mmHg
N2	601mmHg	568mmHg
Total Pressure	760mmHg	760mmHg

Humidification of the air

Air humidifies when it passes through the airways

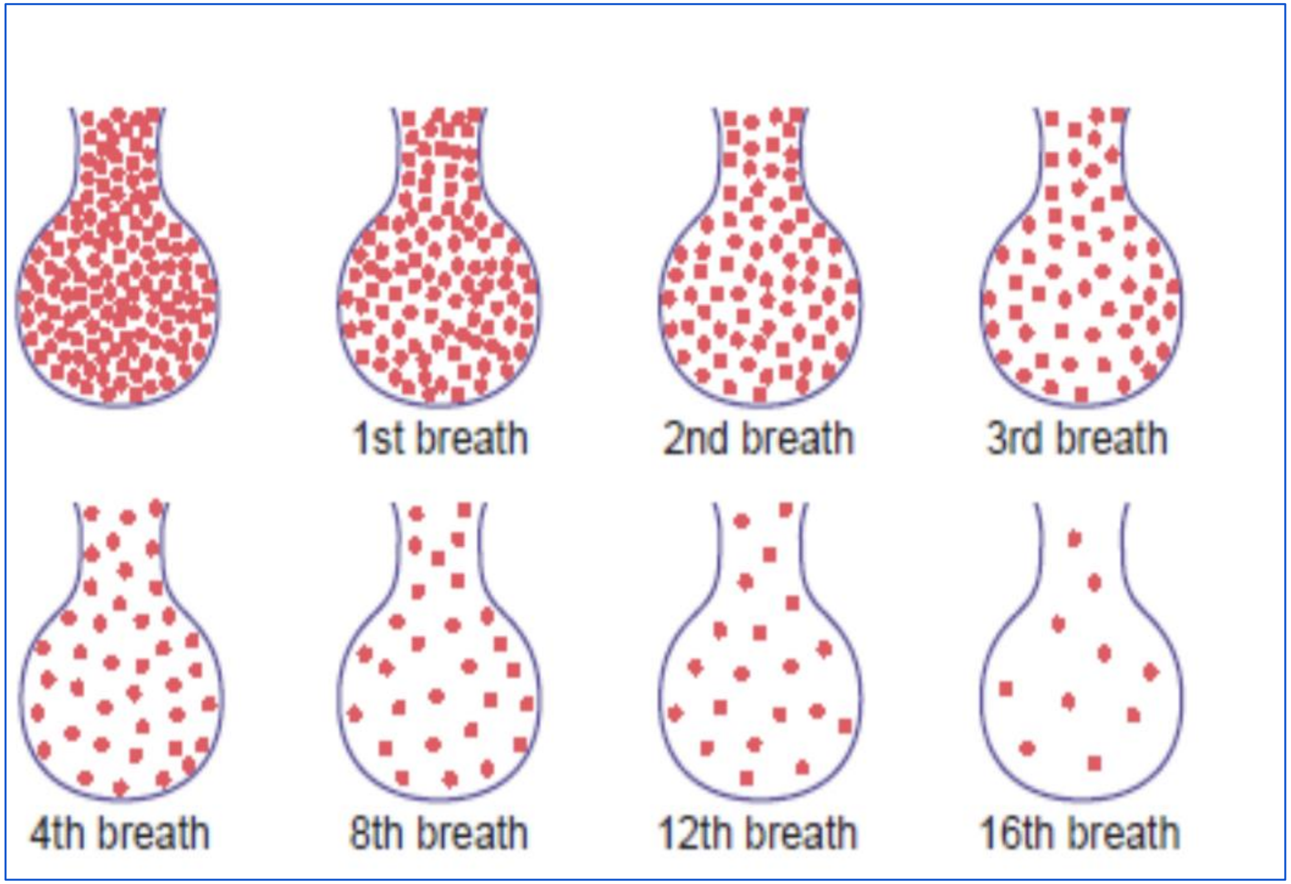
Atmospheric air is composed almost entirely of nitrogen and O2; it normally contains almost no CO2 and little water vapor.
Water vapor:It is one state of water within the hydrosphere.

As soon as the atmospheric air enters the respiratory passages, it is exposed to the fluids that cover the respiratory surfaces.

Even before the air enters the alveoli, it becomes almost totally humidified.

Only in boys slide

expiration of a gas from an alveolus with successive breaths



From Guyton
Air is expired. Therefore, the volume of alveolar replaced by new atmospheric air with each breath only one seventh of the total ,so multiple breaths required to exchange most of alveolar air.this figure shows this slow rate of renewal of the alveolar air.in the first alveolus of the figure , excess gas is present in the alveoli but note that even at the end of 16 breaths the excess gas still has not been completely removed from alveoli

Importance of the slow Replacement of alveolar air

The slow replacement of alveolar air is of particular importance in preventing sudden changes in gas concentrations in the blood.

This makes the respiratory control mechanism much more stable than it would be, and it helps prevent excessive increases and decreases in tissue oxygenation, tissue CO_2 concentration, and tissue pH when respiration is temporarily interrupted

Only in boys slide

Transport of oxygen in the arterial blood

2 percent of the blood

has passed from the aorta through the bronchial circulation, which supplies mainly the deep tissues of the lungs and is not exposed to lung air. This blood flow is called "shunt flow," meaning that blood is shunted and bypass the gas exchange areas.

يتجاوز مناطق تبادل الغاز.

Upon leaving the lungs, the PO2 of the shunt blood is approximately that of normal systemic venous blood—about 40 mm Hg.

98 percent of the blood

that enters the left atrium from the lungs has just passed through the alveolar capillaries and has become oxygenated up to a PO2 of about 104 mm Hg.

When this blood combines in the pulmonary veins with the oxygenated blood from the alveolar capillaries, this so-called venous admixture of blood causes the PO2 of the blood entering the left heart and pumped into the aorta to fall to about 95 mm Hg.

بمعنى ان ال Bronchial circulation هو اللي يوفر الأكسجين للرئة لكنه يتجاوز منطقة تبادل الغازات ف مايصير له oxygenation وتقريبًا قيمته نفس قيمة systemic venous blood لكن مجرد ما يصب في ال pulmonary vein يصير مكس عجيب اسمه venous admixture blood وهذا المكس يقلل الPo2 إلى 95 in pulmonary vein and in the systemic arterial blood

These changes in blood PO2 at different points in the circulatory system are shown in this Figure

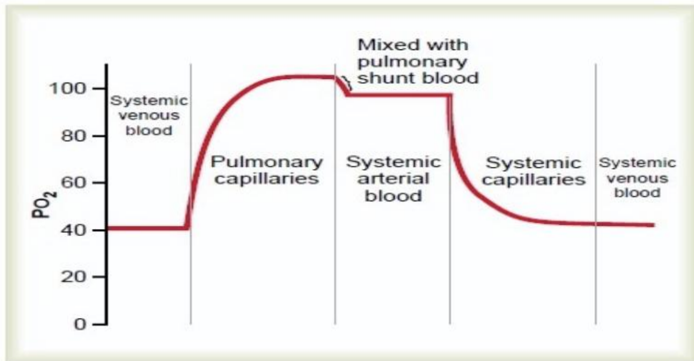
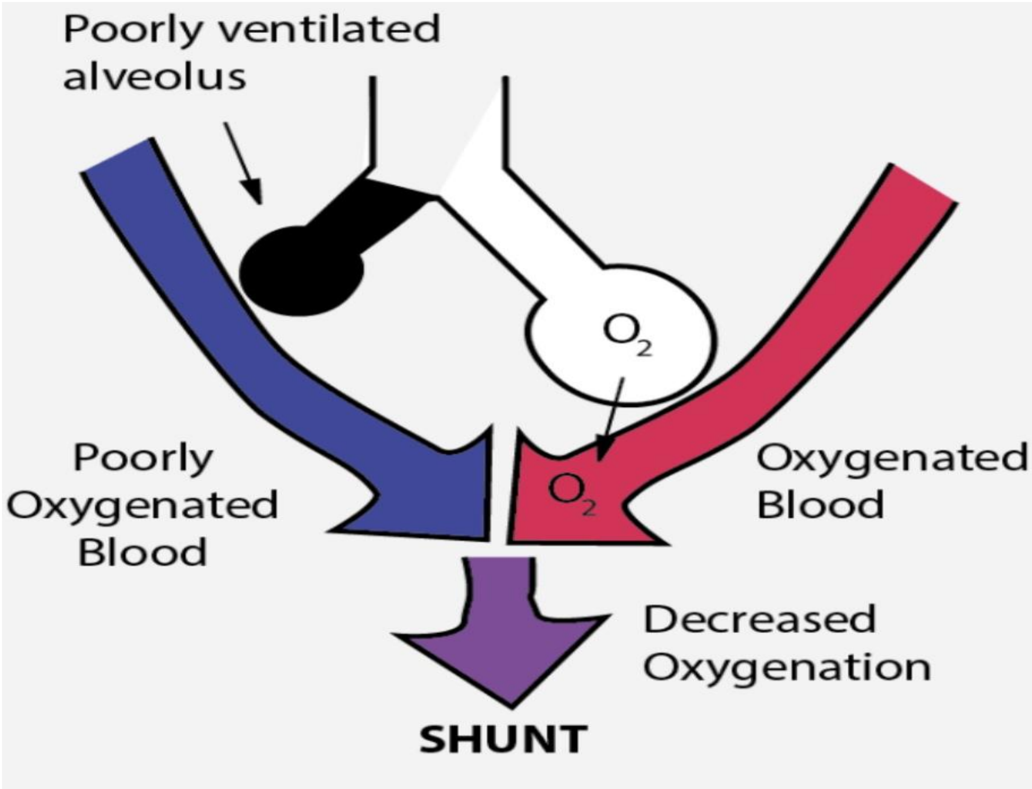


Figure 40–2

Changes in Po_2 in the pulmonary capillary blood, systemic arterial blood, and systemic capillary blood, demonstrating the effect of "venous admixture."

Pulmonary shunt

Helpful video



A pulmonary shunt is a pathological condition which results when the alveoli of the lungs are perfused with blood as normal, but ventilation (the supply of air) fails to supply the perfused region In other word, Blood flowing past poorly ventilated alveoli doesn't pick up additional oxygen. This poorly oxygenated blood returns to the heart and mixes with oxygenated blood coming from other areas of the lungs that are ventilated. The mixture lowers the total oxygen content of the arterial blood, producing hypoxemia. The larger the shunt, the lower the oxygen content.
the ventilation/perfusion ratio (the ratio of air reaching the alveoli to blood perfusing them) is zero.

For better understanding study ventilation perfusion lecture

O2 concentration in the alveoli

In girl's slides only

- At resting condition **250** ml of oxygen are extracted by the tissues at ventilatory rate of **4.2** L/min.
- During exercise **1000** ml of oxygen is extracted by the tissues per minute→the rate of alveolar ventilation must increase **4** (**250*4**) times to maintain the alveolar PO2 at the normal value of **104** mmHg.
- Oxygen concentration in the alveoli, and its partial pressure is controlled by:

1. The rate of absorption of oxygen into the blood.
2. rate of alveolar ventilation (The rate of entry of new oxygen into the lungs by the ventilatory process).

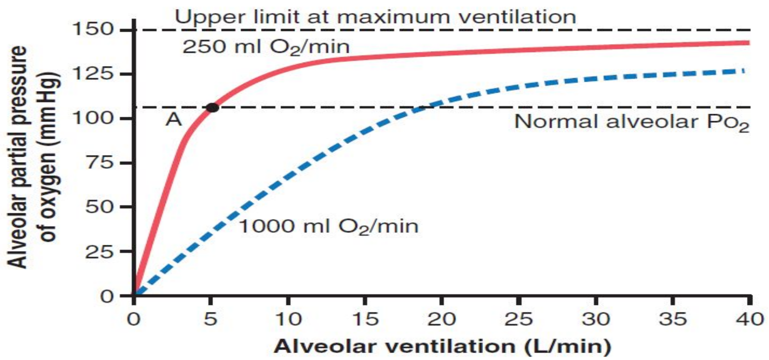


Figure 40-4. Effect of alveolar ventilation on the alveolar partial pressure of oxygen (*Po_2*) at two rates of oxygen absorption from the alveoli—250 ml/min and 1000 ml/min. Point *A* is the normal operating point.

Explanation:

This graph shows the ventilation, absorption through the alveoli, and Oxygen alveolar pressure.

if the absorption increases from 250 to 1000 ml O_2/min , the alveolar pressure would drop. so the body accommodates by increasing the ventilation.

CO2 concentration in the alveoli

-Normal rate of CO2 excretion (at rest) is **200** ml/min, at normal rate of alveolar ventilation of **4.2** L/min.

Carbon dioxide concentration in the alveoli, and its partial pressure is controlled by:

1. alveolar PCO2 increases directly in proportion to the rate of carbon dioxide excretion. as represented by the fourfold elevation of the curve (when 800 milliliters of CO2 are excreted per minute).
2. alveolar PCO2 decreases in inverse proportion to alveolar ventilation.

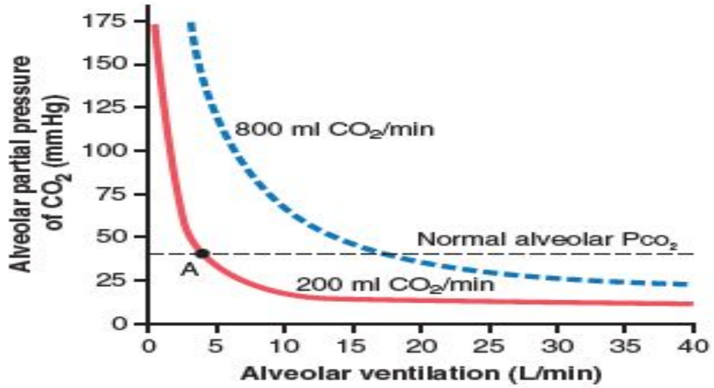


Figure 40-5. Effect of alveolar ventilation on the alveolar partial pressure of carbon dioxide (*Pco_2*) at two rates of carbon dioxide excretion from the blood—800 ml/min and 200 ml/min. Point *A* is the normal operating point.

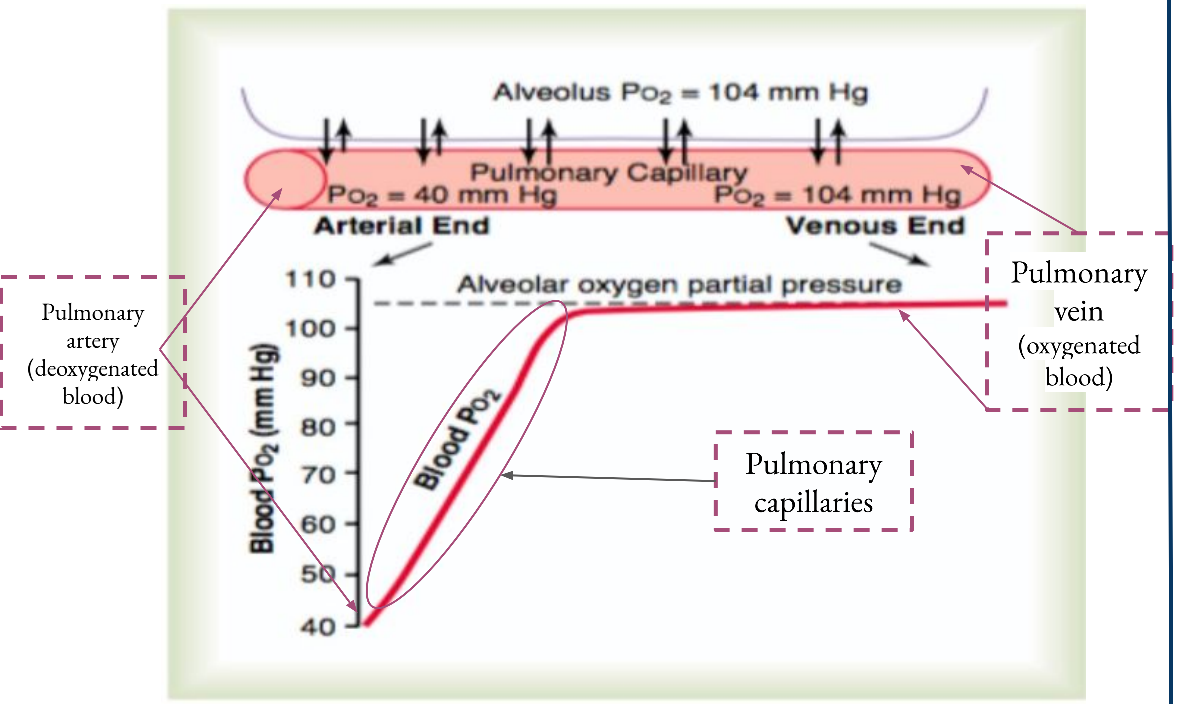
Explanation:

This graph demonstrates excretion, ventilation, and CO_2 pressure in the alveoli.

the more excretion, the higher the CO_2 pressure will be in the alveoli. so the body accommodates by increasing ventilation to get rid of the excess CO_2.

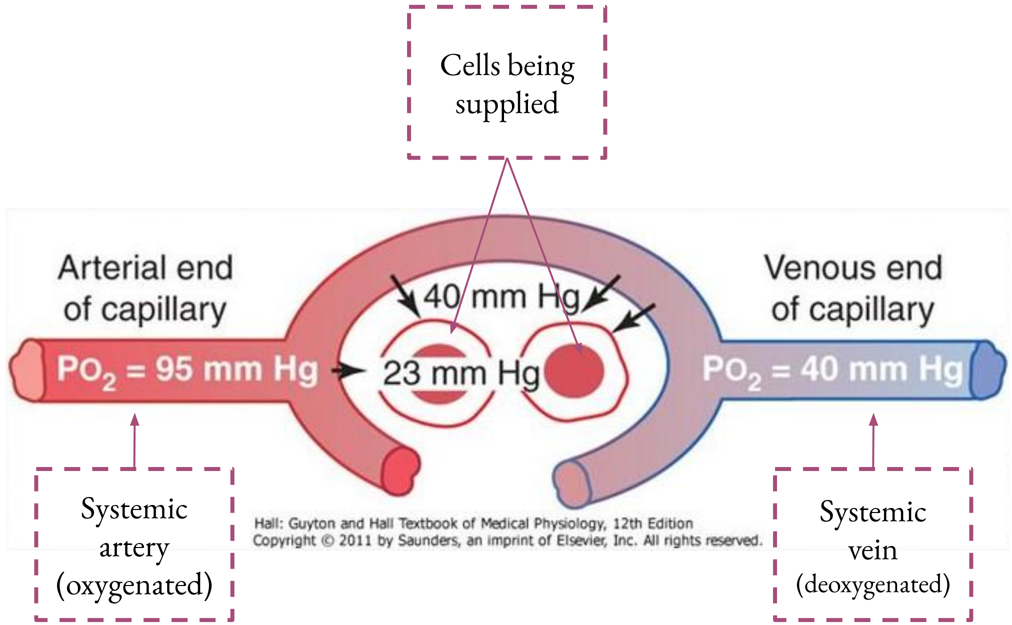
Diffusion of O2 from the peripheral (systemic) capillaries into the tissue fluid

1 The chart below represents the diffusion of O2 from the **alveoli** to **the pulmonary capillaries.**



Explanation: Because the pressure of O2 in the blood coming from the pulmonary artery is less than that of the alveoli there will be oxygen diffusion from the alveoli to the blood.

2 The picture below represents the diffusion (supply) of O2 from the **systemic capillaries** to **cells or tissues.**

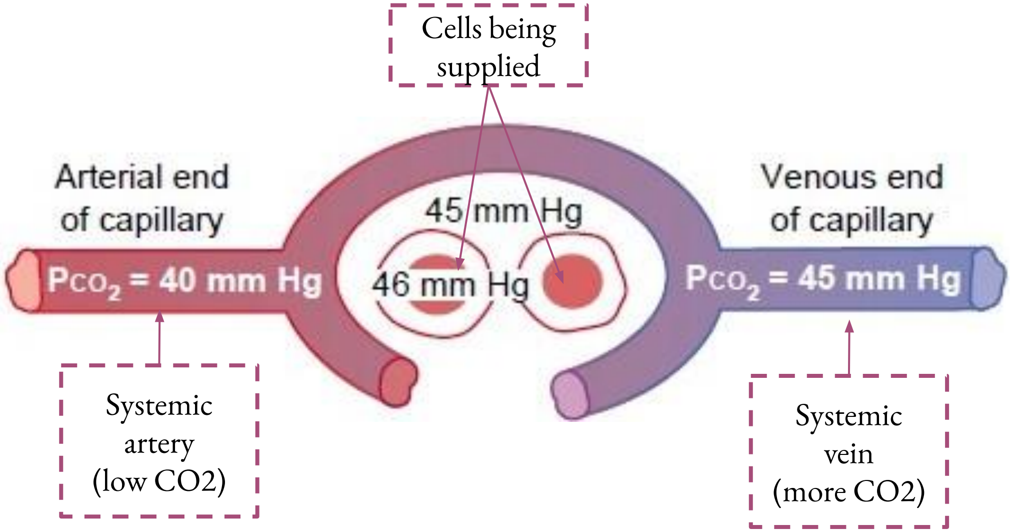


Explanation: Because the pressure of O2 in the blood coming from the systemic artery is higher than that of the cells the oxygen will diffuse from the blood to the cells.

notes:
1-All the arteries in the body are oxygenated except pulmonary artery.
2-All veins in the body are deoxygenated except the pulmonary vein.

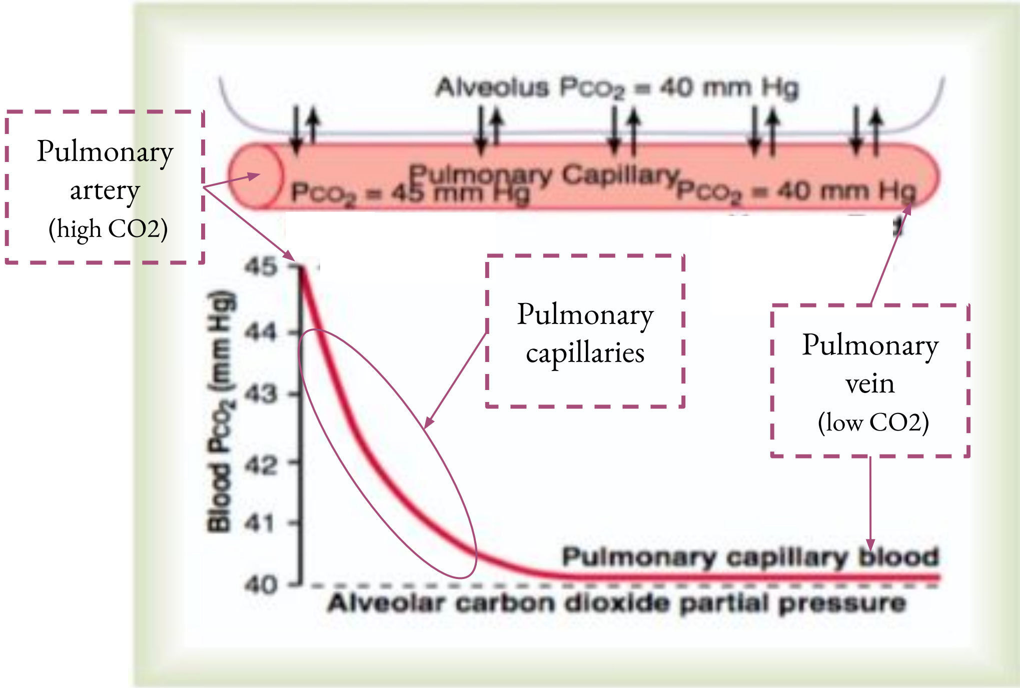
Diffusion of CO2 from the the tissue fluid into peripheral (systemic) capillaries

1 The picture below represents the diffusion (removal) of CO2 from the **cells** to **systemic capillaries.**



Because the pressure of CO2 in the blood coming from the systemic artery is less than that of the cells there will be CO2 diffusion from the cells to the blood.

2 The chart below represents the diffusion of CO2 from **the pulmonary capillaries** to the **alveoli**.



Because the pressure of CO2 in the blood coming from the pulmonary artery is more than that of the alveoli there will be CO2 diffusion from the blood to the alveoli.

PO2 and PCO2 in various portions of normal expired air

- Normal expired air, containing both dead space air and alveolar air.

- It has gas concentrations and partial pressures that is between those of alveolar air and humidified atmospheric air.

- PO2 in expired air (= 120 mmHg) is more than alveolar because dead space volume (airway humidified air) has high PO2.
- PCO2 in expired air (= 27 mmHg) is less than alveolar because it gets diluted when mixing with dead space volume that has low PCO2.

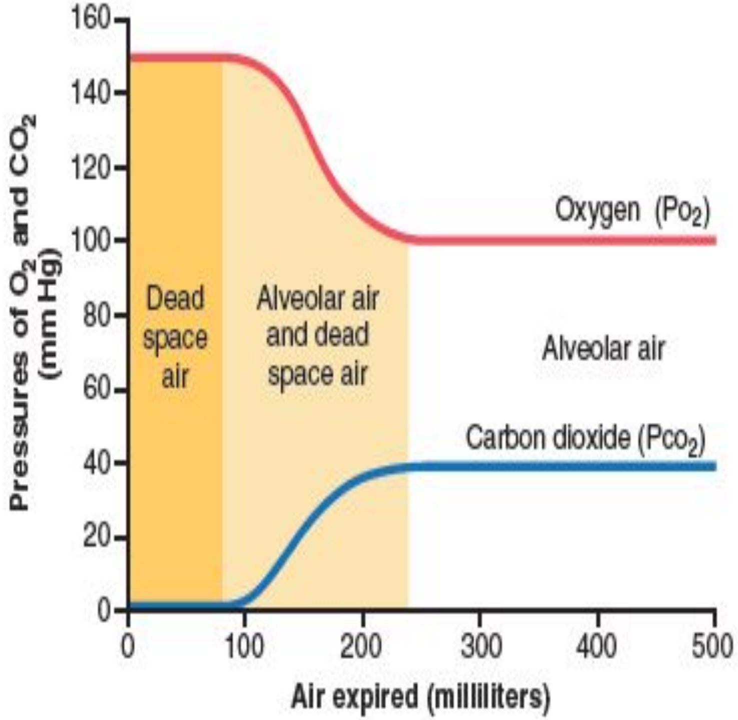
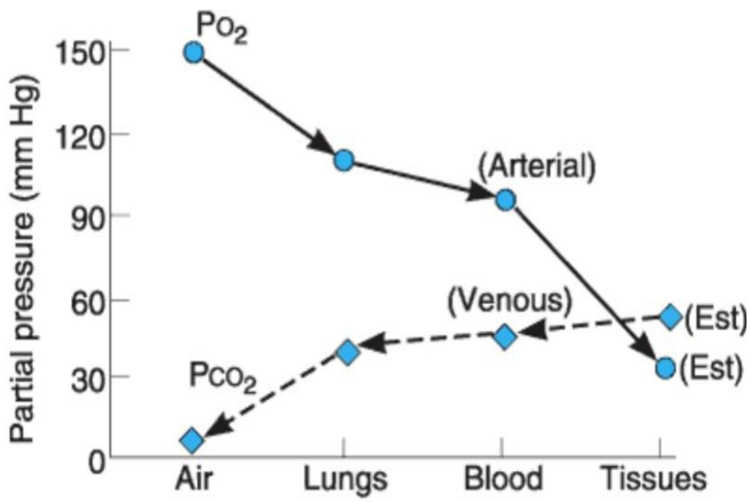
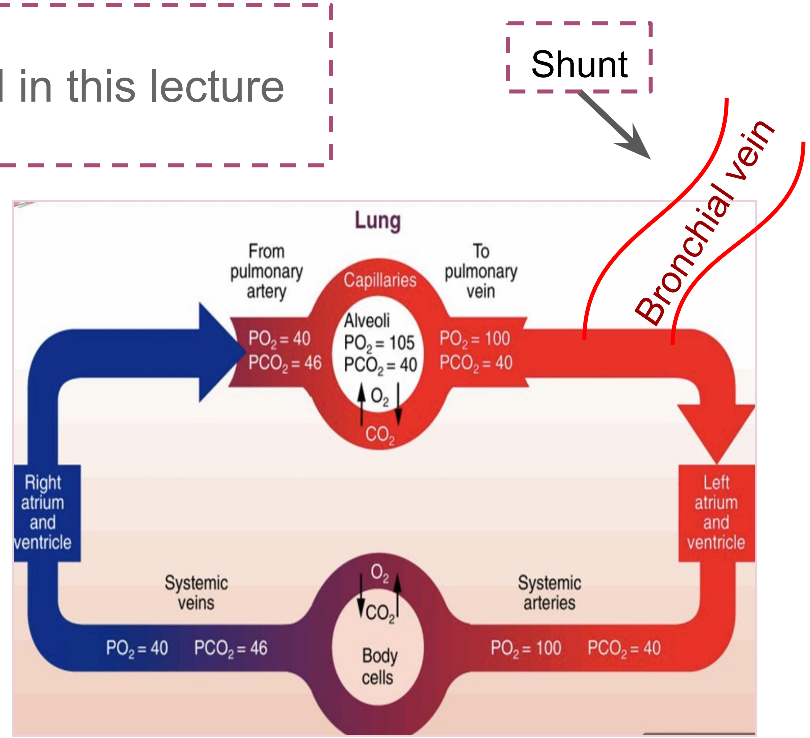


Figure 40-6. Oxygen and carbon dioxide partial pressures (*Po_2* and *Pco_2*) in the various portions of normal expired air.

Let's summarize what we discussed in this lecture





-The atmospheric air has (PO2= 159mmHg and PCO2= 0.3mmHg) so, when a human inspires this air it get humidified in the dead space or conducting zone and becomes PO2= 149.3mmHg and PCO2= 0.3mmHg. Then in the alveoli the level of PO2 is Decreased into (100-105mmHg) and level of PCO2 is increased into (40mmHg) due to several reasons including: partial replacement of alveolar air, continuous diffusion of O2 and continuous diffusion of CO2.

-Now let's go the blood's point of view. After supplying all the tissues, blood returns deoxygenated (PO2= 40mmHg and PCO2= 45-46) to the right heart draining into the right atrium who will pump it the right ventricle. The right ventricle pumps this deoxygenated blood to the alveoli through the pulmonary artery. When the blood arrives to the alveoli, gas exchange occur between the alveoli (which has
PO2= 100-105mmHg and PCO2= 40mmHg) and the pulmonary artery. The result of gas exchange is blood having PO2= 100-105mmHg and
PCO2= 40mmHg. After that, blood drains into the pulmonary vein which will deliver it the left atrium who will pump it to the left ventricle.

-The left ventricle will pump the blood to the hole body supplying the tissues through the systemic arteries. One of the important arteries in the systemic circulation is the bronchial artery which is a branch of the thoracic aorta. This artery supplies the lung then drain into the bronchial veins which plays a role in determining the PO2 levels of blood going to the systemic circulation as I will demonstrate.

-lest's go back to the point where blood get oxygenated (PO2= 100-105mmHg and PC2= 45-46mmHg) and drains into the pulmonary vein. Before it reaches the left heart, there will be a SHUNT "anatomical shunt" (deoxygenated blood drainage by the bronchial vein into the pulmonary vein) which will reduce the PO2 level to become=95mmHg but the PCO2 level will stay = 40mmHg. So, the left ventricle is pumping blood having PO2= 95mmHg and PCO2= 40mmHg to the hole body through systemic arteries..

-Blood runs in the systemic arteries until it reaches systemic capillaries where gas exchange occur between it and the targeted cells which have PO2= 23mmHg and
PCO2 = 46mmHg. After gas exchange, blood drains into the pulmonary veins having PO= 40mmHg and PCO2= 45-46mmHg. The pulmonary veins will deliver the dexygentaed blood to the right heart and circulation start again.

Values

Table 39–1

Partial Pressures of Respiratory Gases as They Enter and Leave the Lungs (at Sea Level)

	Atmospheric Air* (mm Hg)		Humidified Air (mm Hg)		Alveolar Air (mm Hg)		Expired Air (mm Hg)	
N_2	597.0	(78.62%)	563.4	(74.09%)	569.0	(74.9%)	566.0	(74.5%)
O_2	159.0	(20.84%)	149.3	(19.67%)	104.0	(13.6%)	120.0	(15.7%)
CO_2	0.3	(0.04%)	0.3	(0.04%)	40.0	(5.3%)	27.0	(3.6%)
H_2O	3.7	(0.50%)	47.0	(6.20%)	47.0	(6.2%)	47.0	(6.2%)
TOTAL	760.0	(100.0%)	760.0	(100.0%)	760.0	(100.0%)	760.0	(100.0%)

Quiz

1- the Alveolar air concentrations of gases are different from the atmospheric due to?

A. Partial replacement of alveolar air
B. O_2 and CO_2 diffusion
C. Humidification
D. All of the above

2- The forces governing the diffusion of a gas through a biological membrane include the pressure difference across the membrane (ΔP), the cross-sectional area of the membrane (A), the solubility of the gas (S), the distance of diffusion (d), and the molecular weight of the gas (MW). Which changes increase the diffusion of a gas through a biological membrane? According to (Fick's Law)

	ΔP	A	S	d	MW
A.	Increase	Increase	Increase	Increase	Increase
B.	Increase	Decrease	Increase	Increase	Increase
C.	Increase	Increase	Increase	Decrease	Decrease
D.	Increase	Decrease	Decrease	Increase	Increase

3.Which of the following partial pressures of O_2 are correct?
ATM-Humidification-alveoli-pulmonary vein-shunt tissues

A. 160-150-104-94-40 mmHg
B. 150-104-94-55-40 mmHg
C. 160-104-94-40-104 mmHg
D. 150-140-104-94-40 mmHg

4.which of the following partial pressures of CO_2 are correct?

Tissues-Systemic veins-Pulmonary vein

A.46-45-40 mmHg
B.46-40-40 mmHg
C.40-45-46 mmHg
D.40-40-46 mmHg

1)D 2)C 3)A 4)A

SAQS

1- how will an increase in the respiratory rate change PO_2 in the alveoli?

2- (O_2-CO_2) which has a higher rate of diffusion and why?

3- what is the importance of the slow replacement of alveolar air?

1. It will increase PO_2.

2.O_2 has lower molecular weight than CO_2 But CO_2 is 24 times more soluble than O_2 so the Net result is that CO_2 rate of diffusion is approx 20 times faster than O_2 rate of diffusion.

3.prevent sudden changes in gas concentrations in the blood.(stabilization of RCM), this will prevent excessive increase or decrease in tissue oxygenation, tissue CO_2 concentration and tissue PH.

Test yourself

RCM: Respiratory control mechanism

Team leaders :

TeiF Almutiri

Abdulaziz Alkraida

Team Members

- Mishal Althunayan
- Basel Fakeeha
- Ibrahim altamimi
- Abdulaziz Alsuhaim
- Mohammad Alkatheri
- Bassam alasmari
- Morshed Alharbi
- Ahmad Al Khayat
- Mohammod alghedan
- Nawaf alghamdi
- Raed alntaifi
- Homoud alghadeb
- Mishal alhamed
- Musab alamri
- Fayez altbaa
- Khalid altowijeri
- Mohammed alsalman
- Renad Alhomaidi
- Aseel alshehri
- Noura abdulaziz
- Yasmin Al Qarni
- Alaa Alsulmi
- Farah Albakr
- Muneerah alsadhan
- Sarah alobaid
- Farrah alsaid
- Noura almsaud
- Hessah alalyan
- Rema alhdleg
- Raghad alsweed
- Raghad asiari
- Ghadah alouthman
- Haya alanazi
- Asma alamri
- Rania Almutiri
- Yara alasmari

Reviewed by

- Ghada alothman
- homoud Algadheb

Contact us

The Subleader :
Sarah alQhtani