PHYSIOLOGY TEAM 435

6 Gas Transfer (Diffusion of O2 and CO2)

- Very important
- Extra information
- Terms

Once you replace negative thoughts with positive ones, you'll start having positive results.

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Objectives

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

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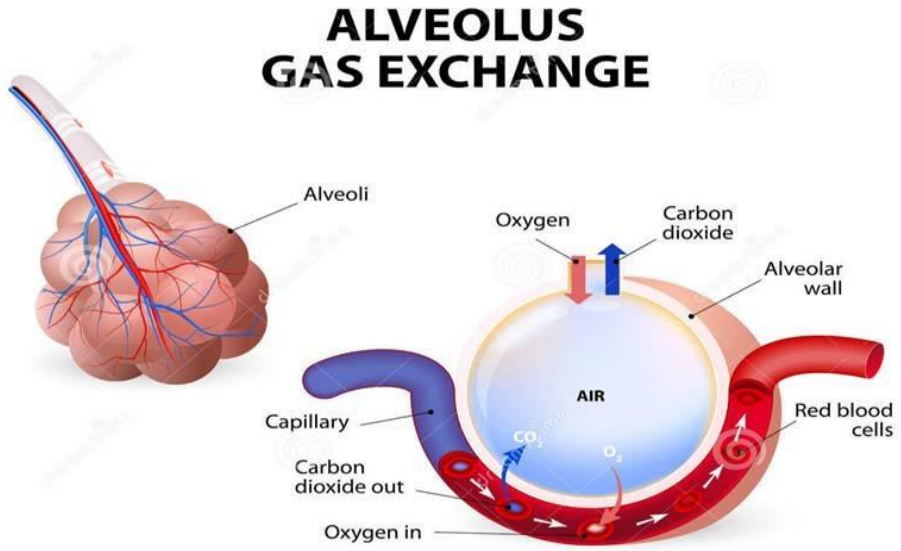
Gas exchange

- After ventilation of the alveoli with fresh air the next step is the process called <u>diffusion</u> of oxygen(O_2) from the alveoli into the pulmonary blood and diffusion of carbon dioxide(CO_2) in opposite direction .

- Partial pressure of the gas is The rate of diffusion of each of these gases is directly proportional to the pressure caused this gas alone.

- Pressure is caused by the constant impact of <u>kinetically moving molecules against a surface</u>.



<u>How does gas has pressure?</u>

Gases in form of molecules ,these molecules have (Kinetic motion/movement) so, they're in "Constant motion".This motion cause Impact of gas molecules ,the force of this collisions collected together then will called "Pressure"

-No differences in pressures > No gases movement >No gas exchange.

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Factors affecting gas diffusion

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

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

-O2 has lower molecular weight (31.99) than CO2 (40)
- But CO2 is 24times more soluble than O2.

Net result :CO2 diffusion approx. 20 times faster thanO2 diffusion.

Delta P: **(Increase partial pressure > Increase Diffusion)**
(Alveolar – Capillaries membrane = Respiratory membrane)
For example :
- Increase PO2 In alveoli > Increase diffusion in the direction of pulmonary capillaries.
-Increase PO2 In pulmonary capillaries > Increase diffusion in the direction of alveoli.

Surface area (A): **(Increase surface area > Increase Diffusion)**
So, How the surface area will Decrease ?
In alveoli :
1- By Trypsin (As we said in lecture one which is lysis the respiratory wall)
2- By Obstruction of some bronchioles or bronchi by mucous or tumor.
In pulmonary capillaries :
1- By thrombus or blood clot.
2- Loss of "Perfusion" = No blood flow.
3- Loss of "Ventilation"

Solubility (S): **(Increase the solubility of gas > Increase the diffusion of it)**
-CO2 is 20 times soluble than O2.
-CO2 More "Diffusible" than O2.

Distance (d) : **(Distance = Thickness of respiratory membrane)**
(Increase Distance > Decrease Diffusion)
How do we increase the thickness of respiratory membrane?
1- By accumulation of fibrous tissue. People who have "Interstitial Pulmonary fibrosis" They have problem with diffusion of gases.
2- By increase "ECF" between alveoli or even inside the alveoli. People who have "Pulmonary Edema"

Molecular weight (MW): **EX: MW = 9 .. √MW = 3**
(Increase √MW of diffusing molecules > Decrease the diffusion)

Factors affecting gas diffusion Cont…

S / √MW: is called <u>the diffusion coefficient of</u> the gas.

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

يعني لو خليت الفرق بين الضغوط عند الRespiratory membrane نفسه لكل الغازات ،اللي رح ينفذ أول هو ثاني أكسيد الكربون ثم الأوكسجين ثم النيتروجين تبعاً للجدول ↓.

Gas	Diffusion Coefficient
Nitrogen	0.53
Oxygen	1
Carbon dioxide	20

WHY do we have this parameter ?
Solubility and Molecular weight. These two factors because they're a unique features for each gas.
-O2 has its own solubility and its own MW , also CO2.
We know that :
<u>1- O2 Less MW than CO2 "That's mean More diffusible!"</u>
<u>2- CO2 More soluble than O2 "That's mean More diffusible!"</u>

So ,Why they said CO2 more diffusible not O2? ..
على أي أساسا حكموا ؟
عشان هاللخبطة اللي صارت قرروا يتعاملون مع حاصل قسمة الصفتين بوقت واحد وليس مع كل صفة على حدا. فاستخدموا هذا القانون وطلع أن ثاني أكسيد الكربون أعلى بالتالي من هنا حكموا أنه أكثر نفاذية من الأكسجين.

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Composition of respiratory air

Component	Inhaled air	Exhaled air
Nitrogen	79%	79%
Oxygen	20%	16%
Carbon dioxide	trace[1]	4%

[1] trace : a very small quantity

Why N2 inhaled and exhaled in same conc.?
Because it's from inner gases that's only take place in our body with any function.
There's no diffusion of N2 in our bodies.

From where this 4% of CO2 came ?
And why the O2 conc. Reduced to 16%?
-Because of "Aerobic metabolism" **HOW?**
We know that :
Food stuff + O2 (4%) → ATP +H2O +Urea +CO2(4%)
The main goal of this process is producing energy for the muscles ,But while I producing ATP there's another product which is CO2. This CO2 is exhaled in the same conc. of the used O2 conc. in this metabolic process.
And the O2 will reduced to 16% from 20%.
SO, **The O2 is helping in producing CO2.**

Partial pressure of O_2 and CO_2

•**Oxygen concentration in the atmosphere is 21% (1 atmosphere = 760 mmHg) So:**
PO2 in atmosphere = 760 mmHg x 21% (0.21) = 160 mmHg
(This mixed with "Old" air already present in alveolus to arrive at PO2 of 104 mmHg in alveoli)

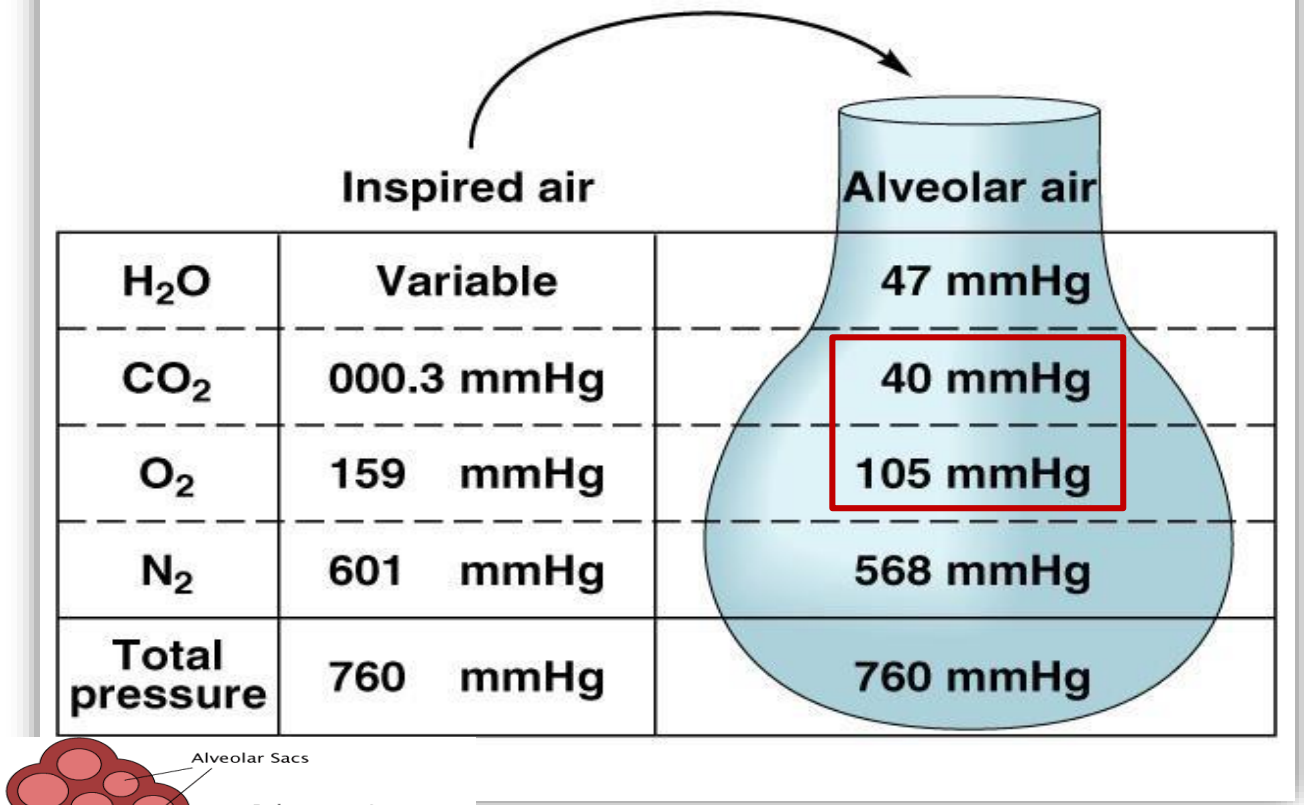
•**Carbon dioxide concentration in the atmosphere is 0.04% So :**
PCO2 in atmosphere = 760 mmHg x 0.04% (0.0004) = 0.3 mmHg
(This mixed with high CO2 levels from residual volume or (FRC) in the alveoli to arrive at PCO2 of 40 mmHg in the alveoli)

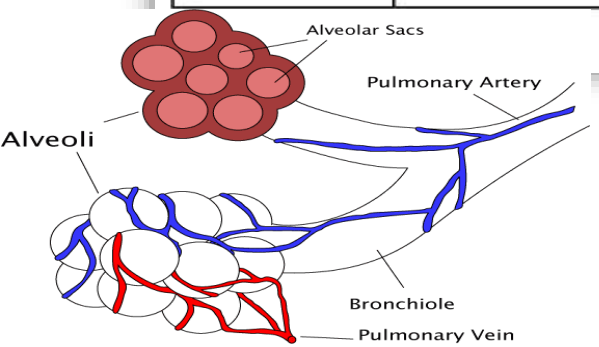
- And that is why the O2 enter the body because the PO2 outside = 160 mmHg Higher than inside (in alveoli) = 104 mmHg .
- So as a result, **the O2 will move from high pressure to low pressure.**

-	In Atm (Inspired air)	In alveoli
PO2	21% .. 160 mmHg	104 mmHg
PCO2	0.04% .. 0.3 mmHg	40 mmHg

Partial pressure of O_2 and CO_2

➢ **BOYS NOTES**



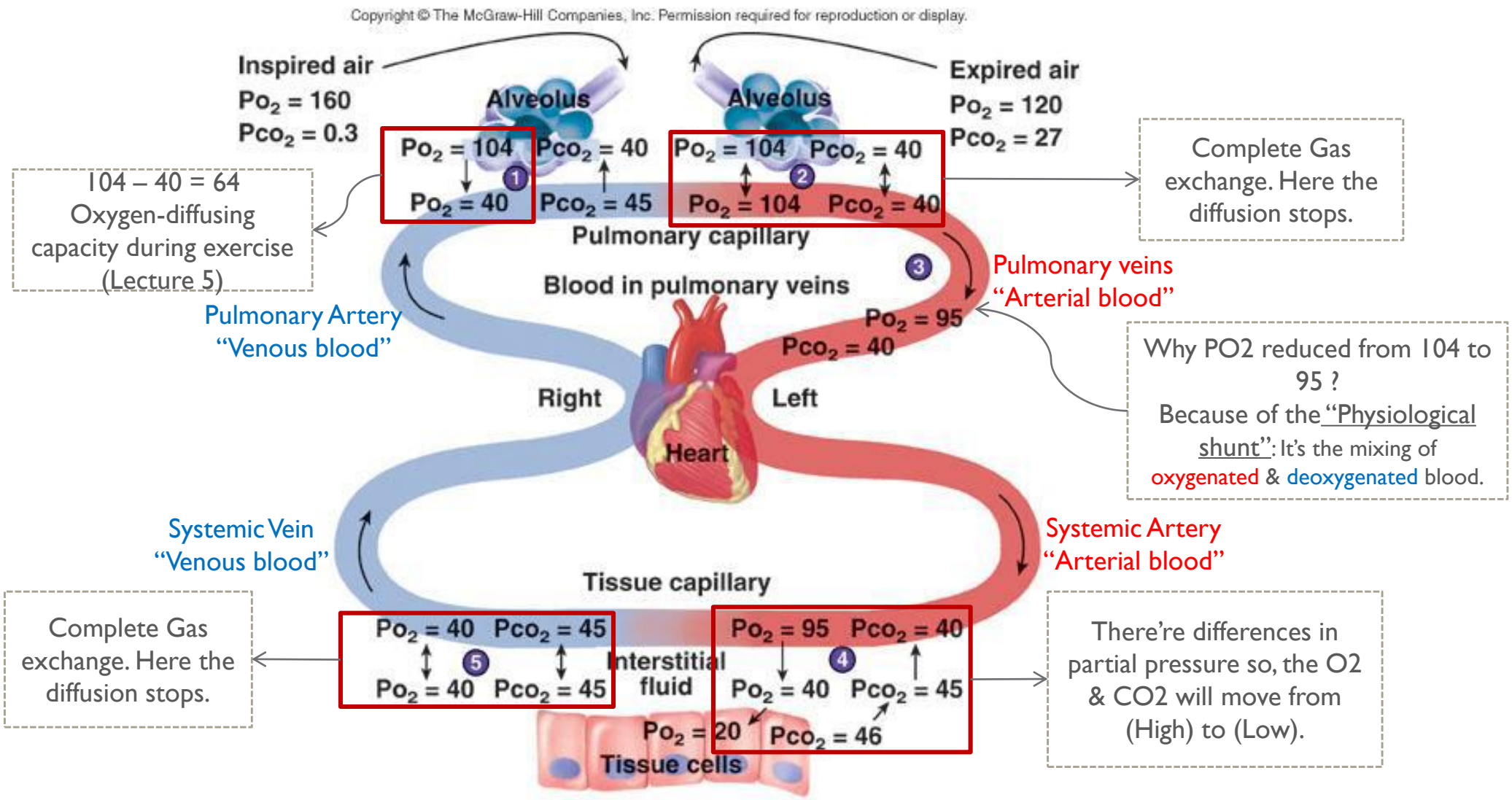


The blood in alveolus are resemble to the blood in "Pulmonary Veins" which contain "Arterial blood"
-Rich > O2
-Poor > CO2
Also, in alveolus more O2 than CO2.

- Consider air, which has an approximate composition of 79% N_2 and 21% O_2.
-The total pressure of this mixture at sea level averages 760 mm Hg. 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 mm Hg is caused by N_2(600 mmHg) and 21%by O_2 (160 mmHg).
-Thus, the "partial pressure" of nitrogen in the mixture is 600 mm Hg, and the "partial pressure" of oxygen is 160 mm Hg.

-The total pressure is 760 mmHg, the sum of the individual partial pressures.
- **The partial pressures** of individual gases in a mixture are designated by the symbols PO_2 , PCO_2 , PN_2, PH, and so forth.

Partial pressure of O_2 and CO_2



104 – 40 = 64
Oxygen-diffusing capacity during exercise (Lecture 5)

Complete Gas exchange. Here the diffusion stops.

Why PO2 reduced from 104 to 95 ?
Because of the "Physiological shunt": It's the mixing of oxygenated & deoxygenated blood.

Complete Gas exchange. Here the diffusion stops.

There're differences in partial pressure so, the O2 & CO2 will move from (High) to (Low).

Oxygen journey: Atmosphere -> Alveoli -> Pulmonary capillary blood -> Arterial blood -> Peripheral capillaries -> Tissue fluid -> Cells

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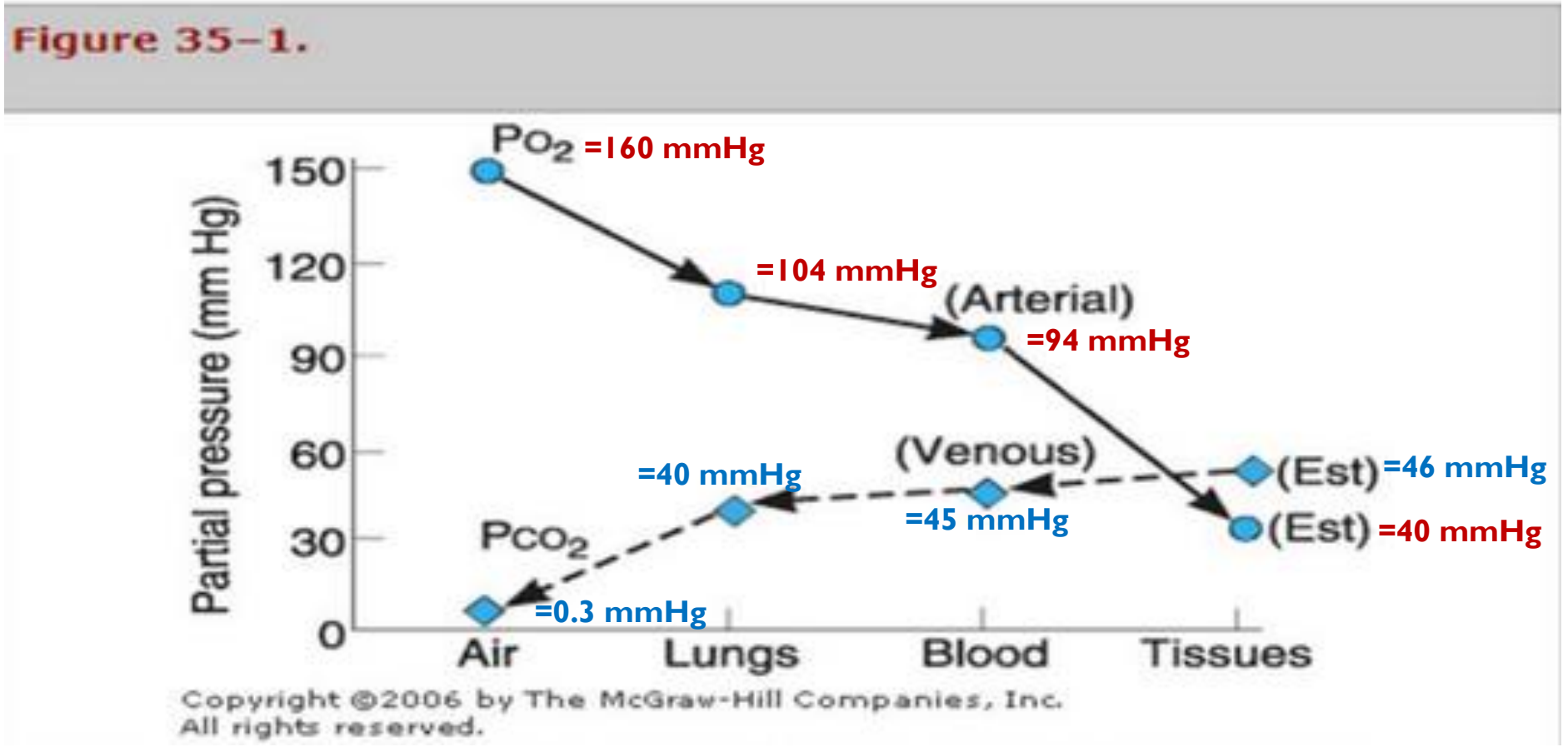
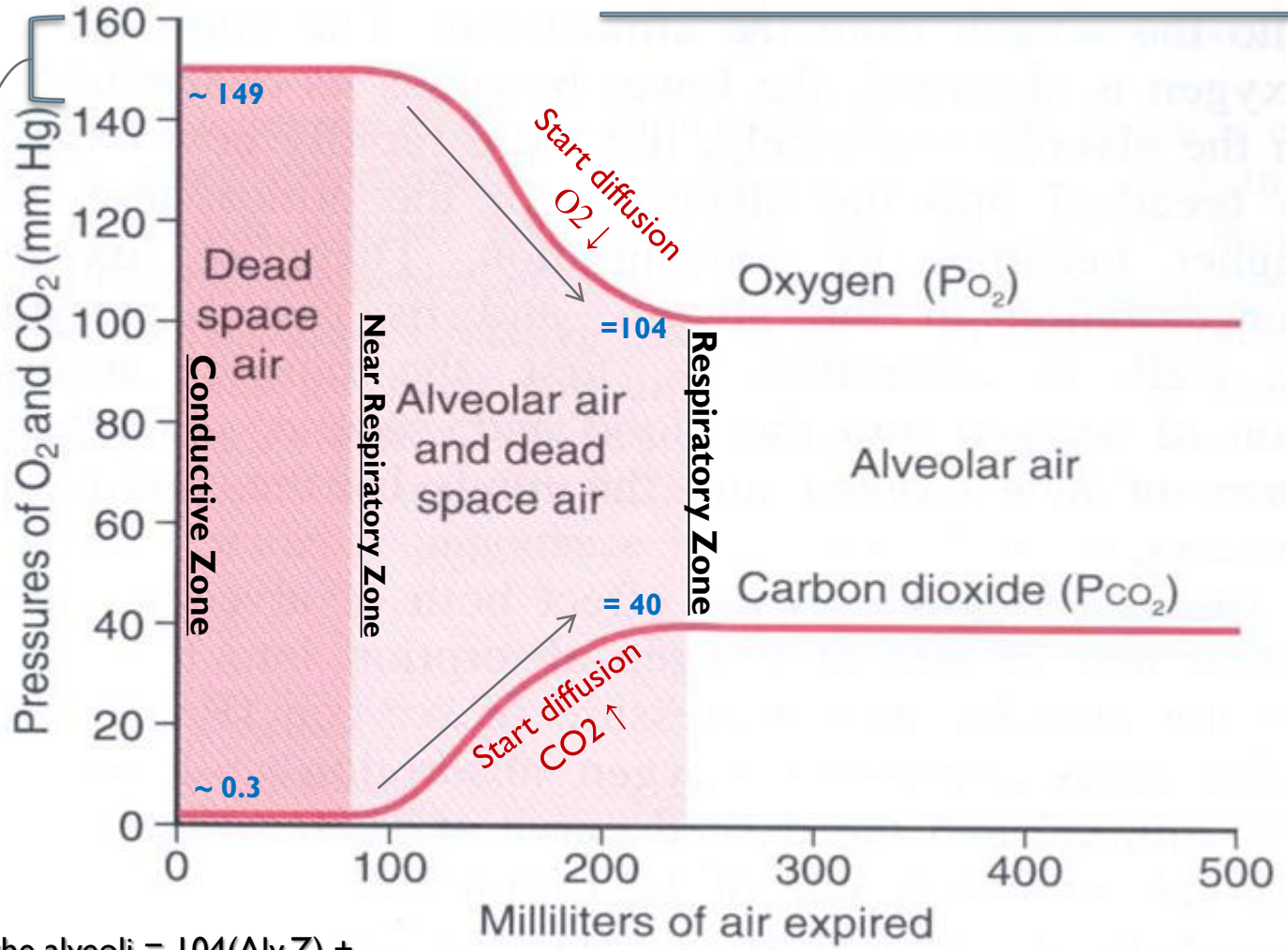
PO2 and PCO2 in air, lung and tissues



PO_2 and PCO_2 in various portions of normal expired air

Why the PO2 reduced from 160 to ~ 149?
We know there's no diffusion in the conductive zone, the reduced O2 used in "Humidification" and warming the inspired air.
الأوكسجين يدخل في تركيب الماء ويساعد في ترطيب الهواء بالتالي يقل تركيزه.



Inspiration
The PO2 will enter the alveoli = 104 mmHg

The PO2 will leave the alveoli = 104(Alv.Z) + 149(Con.Z) = 253mmHg (RICH IN O2)
عشان كذا التنفس الصناعي مفيد (Pulmonary resuscitation)

Expiration

O_2 and CO_2 Concentration in the alveoli

- **At resting** condition **250 ml** of O_2 enter the pulmonary capillaries/min At ventilation rate 4.2 L/min.

- **During exercise** **1000 ml** of O_2 is absorbed by the pulmonary capillaries/min

So the rate of alveolar ventilation must be increased 4 times to maintain the alveolar PO_2 at the normal value of 104 mmHg.

- Normal rate of CO_2 excretion is **200 ml/min** ,At normal rate of alveolar ventilation of 4.2 L/min.

➢BOYS NOTES

- Oxygen is continually being absorbed from the alveoli into the blood of the lungs, and new oxygen is continually being breathed into the alveoli from the atmosphere.

- The more rapidly oxygen is absorbed, the lower its concentration in the alveoli becomes; conversely, the more rapidly new oxygen is breathed into the alveoli from the atmosphere, the higher its concentration becomes.
Therefore, oxygen concentration in the alveoli, as well as its partial pressure, is controlled by:
(1) the rate of absorption of oxygen into the blood and
(2) the rate of entry of new oxygen into the lungs by the ventilatory process.

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7

Oxygen and Carbon dioxide Transport

- Very important
- Extra information
- Terms

A strong positive self-image is the best possible preparation for success.

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Objectives

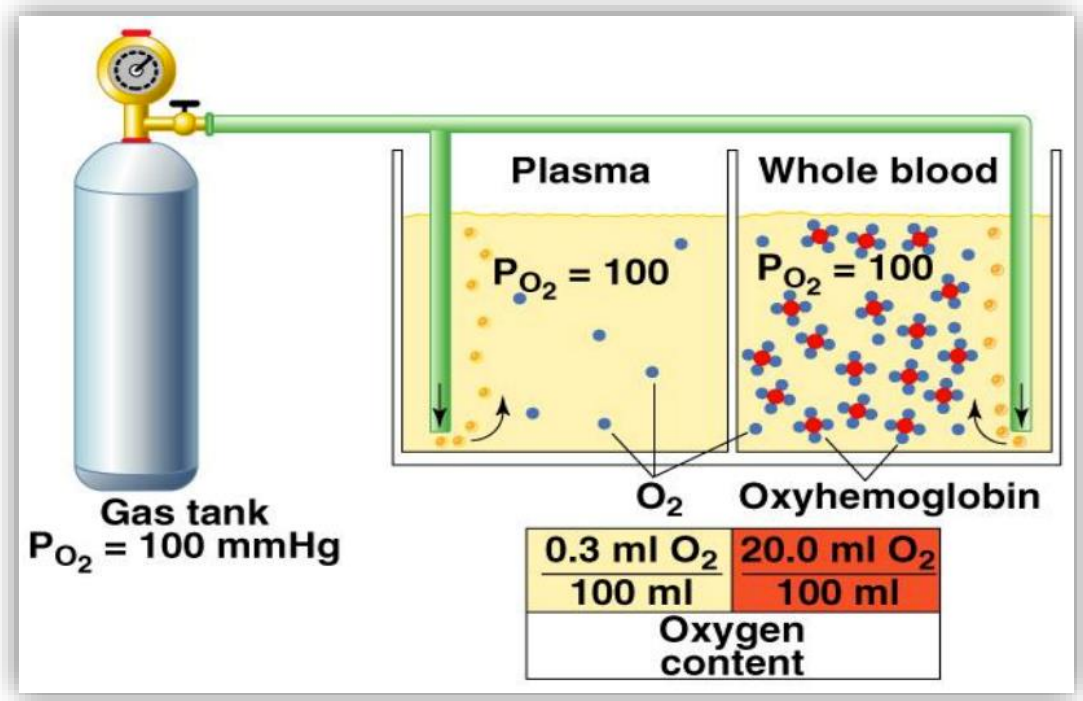
1. Understand the forms of oxygen transport in the blood, the importance of each.
2. Differentiate between O2 capacity, O2 content and O2 saturation.
3. Describe (Oxygen- hemoglobin dissociation curve)
4. Define the P50 and its significance.
5. How DPG, temperature, H+ ions and PCO2 affect affinity of O2 for Hemoglobin and the physiological importance of these effects.
6. Describe the three forms of carbon dioxide that are transported in the blood, and the chloride shift.

Forms of O_2 Transport

Normally O2 in blood in two forms :

(Dissolved) 3%
This form soluble in water of plasma.

(Oxyhemoglobin) 97%
This form bind with Hb.
1Hb can bind to 4O2



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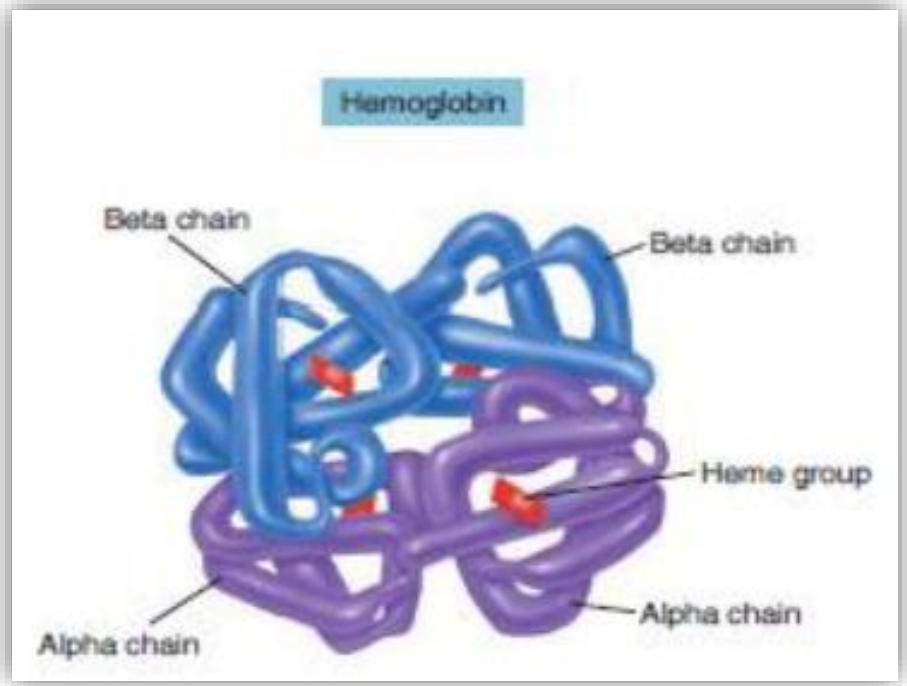
Transport of O2 and Co2 in the blood and body fluids

- O2 is mostly transported in the blood bound to hemoglobin .
- If the PO2 increases Hb binds O2 .
- If PO2 decreases Hb releases O2 .
- O2 binds to the heme group on hemoglobin, with 4 oxygens /Hb.



- Whenever PO2 increase, the binding between Hb and O2 will increase.
- The alveoli have the place of the highest **PO2 = 104 mmHg.**
- The tissues have the place of the lowest **PO2 = 40 mmHg.**
- PO2 ↑ > More O2 bind with Hb↑>Batter transport of O2.
- PO2 ↓ > Less O2 bind with Hb ↓ > Hb release O2 easily.
- Always the place of binding O2 with Hb is in the lung (Alveoli)
- When the hemoglobin bind with four O2 called **"Fully saturated"**
- When the hemoglobin bind with less than four O2 called **"Partial saturated"**

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Terminology

O_2 content

- The mount of O_2 in blood. (mL O_2 /100 mL blood).

O_2 –binding capacity

- The maximum amount of O_2 bound to hemoglobin (mL O_2 /100 mL blood) measured at 100% saturation.

EXAMPLE

mL O2	Venous blood	Arterial blood
For ex. 20 "reference point'	15/20 = 75% "Partially saturated with O2"	20 / 20 = 100% "Fully saturated with O2"

Percent saturation

- % of heme groups bound to O_2
- % Saturation of Hb: $\frac{\text{Oxygen content}}{\text{Oxygen capacity}} \times 100$

Dissolved O_2

- Unbound O_2 in blood (mL O2/100 mL blood)

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Transport of Oxygen In Arterial Blood

100 ml Blood→	100% saturated with O2	97% saturated with O2
Hb →	15 g Hb	Decrease saturation > Decrease the O2 content from 20ml to 19.4ml/100ml in blood.
each gram of Hb carry→	1.34 ml O2	
O2 – content →	15 x 1.34 = 20ml/100ml blood.	

- Amount of oxygen released from the hemoglobin to the tissues is 5ml O_2 per each 100ml blood.
- **At rest:**

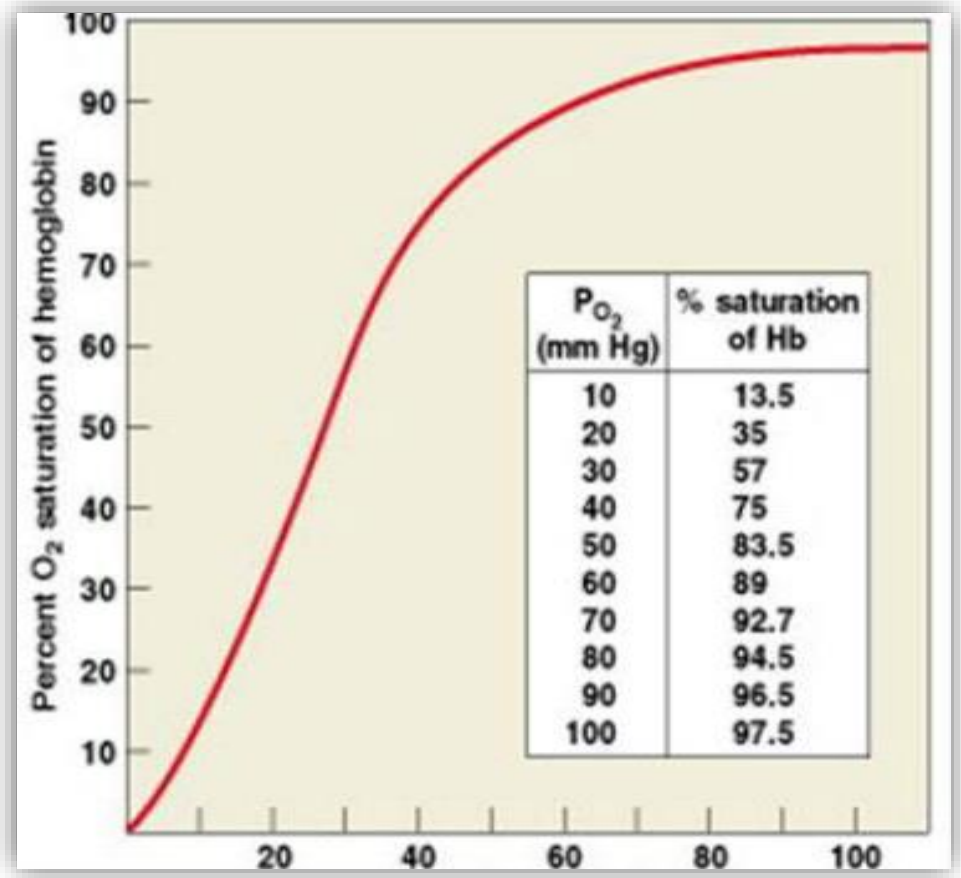
O2 content in arterial blood	O2 released in tissue	So, O2 content iv venous blood
19.4ml O2/ 100ml	5ml O2/100ml	19.4 – 5 = 14.4ml O2/100ml

- **At rest tissues consume 250 ml O_2 /min and produce 200ml CO_2.**
- **During strenuous exercise :**

O2 content in arterial blood	O2 Uptake by the tissue increase "3 folds"	So, O2 content iv venous blood
19.4ml O2/ 100ml	5 x 3 = 15ml O2/100ml	19.4 – 15 = 4.4ml O2/100ml

Oxygen Transport In Blood

- Higher PO2 $_2$ results in greater Hb saturation.
- The relation between PO2 and Hb-O2 is not linear.
- The curve is called Oxyhemoglobin Saturation Curve.
- Which is S-shaped or sigmoid.



P_{O_2} (mm Hg)	% saturation of Hb
10	13.5
20	35
30	57
40	75
50	83.5
60	89
70	92.7
80	94.5
90	96.5
100	97.5

- هذا الكيرف يبين العلاقة بين PO2 وال Saturation% ،يعني كم من الهيموقلوبين رح يكونون مشبعين بالأوكسجين ،مشبع بمعنى كل ١ هيموقلوبين مرتبط فيه أربعة من الأوكسجين.
- ↑ PO2 > ↑Binding O2 to Hb > ↑Saturation of Hb.

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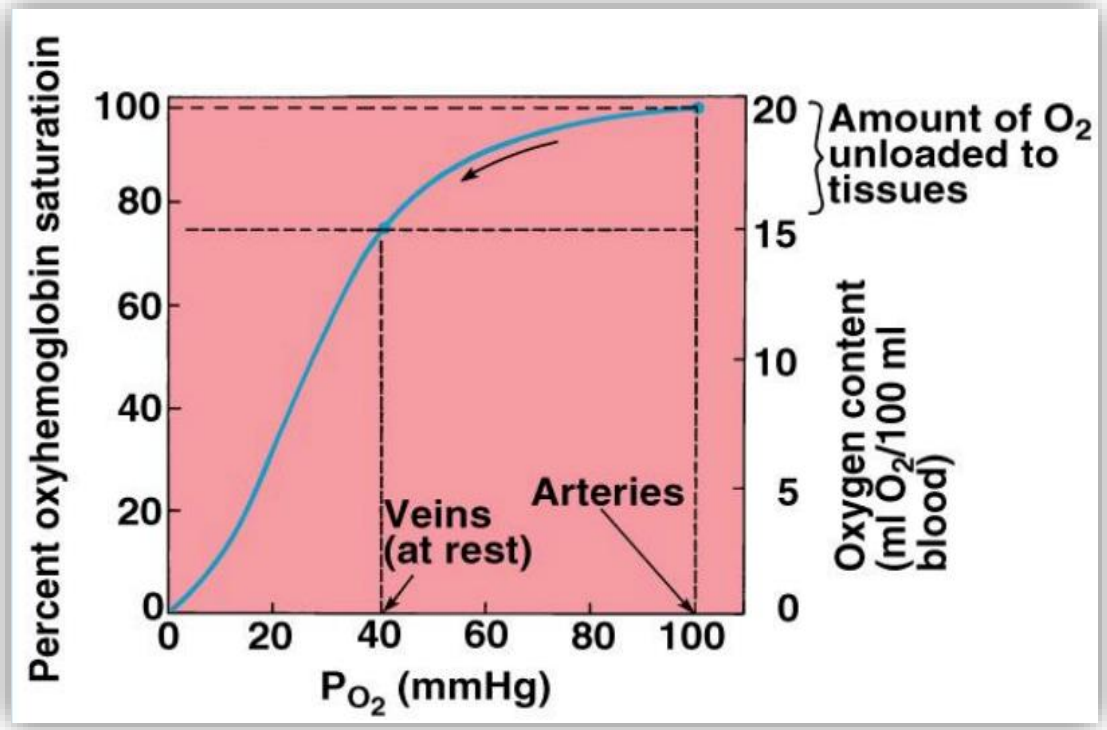
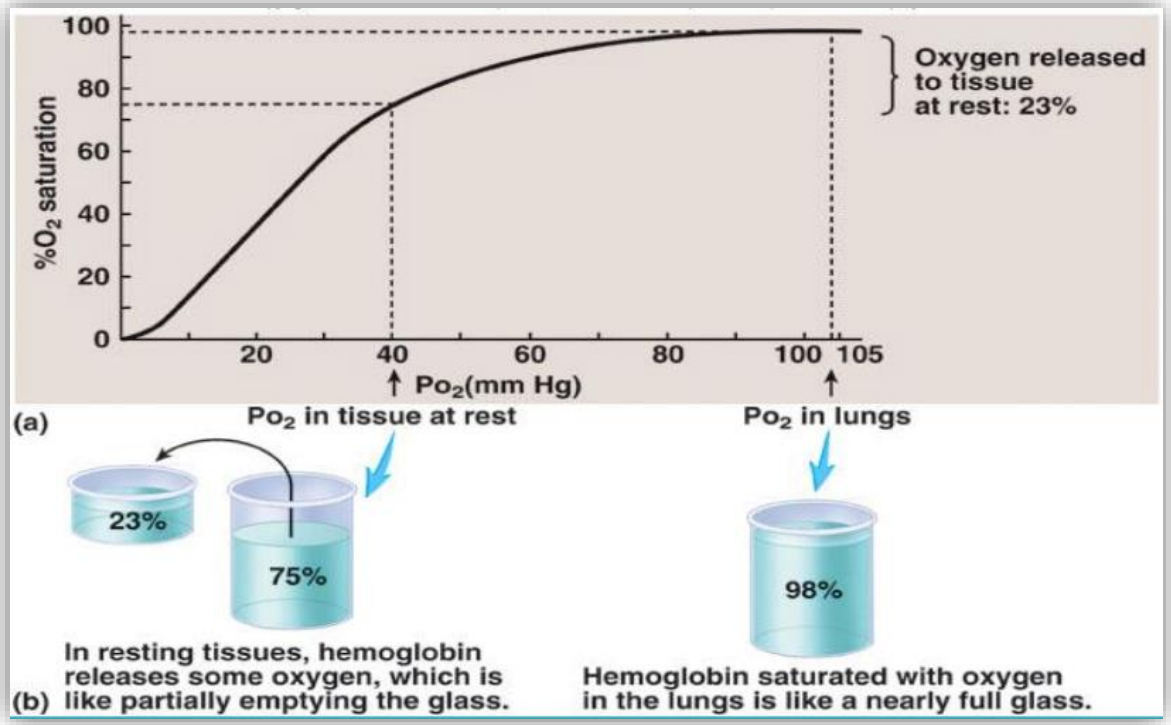
Oxyhemoglobin Dissociation Curve





YouTube Very Helpful.

Factors that shift the o_2-Hb dissociation curve

- The position of the dissociation curve can be determined by measuring the P50.
- P50: The arterial PO_2 at which 50% of the Hb is saturated with O_2, normally P50= 26.5
- **Decreased P50** means increased affinity of Hb to O_2 or shift of the curve to left.
- **Increased P50** means decreased affinity or shift of the curve to right.

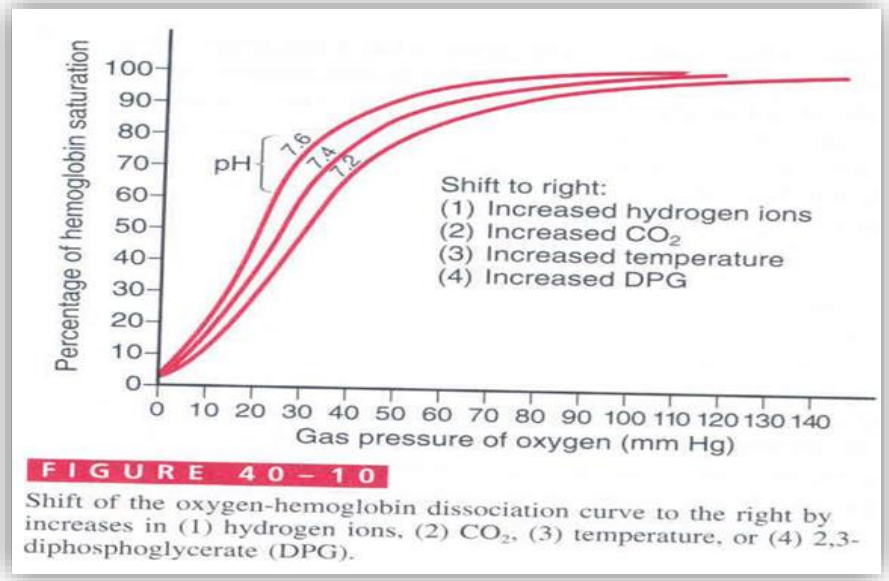
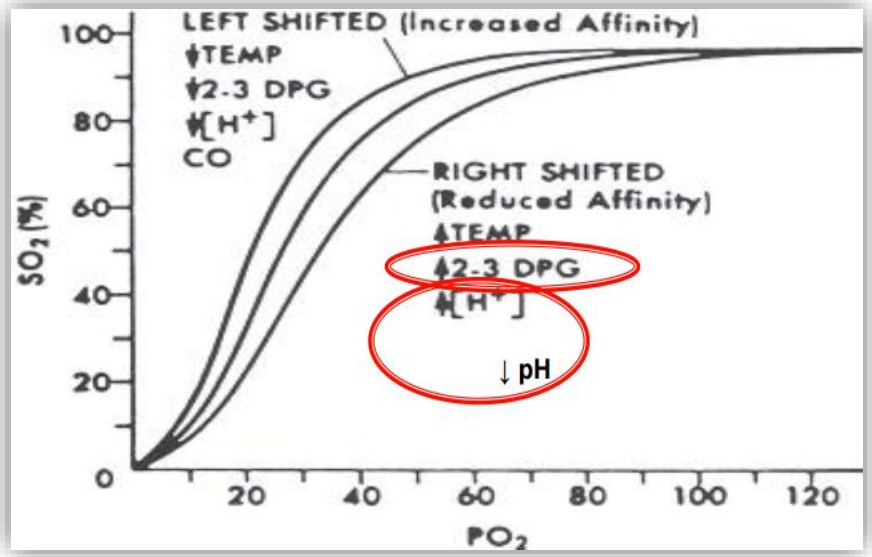


FIGURE 40–10

Shift of the oxygen-hemoglobin dissociation curve to the right by increases in (1) hydrogen ions, (2) CO_2, (3) temperature, or (4) 2,3-diphosphoglycerate (DPG).

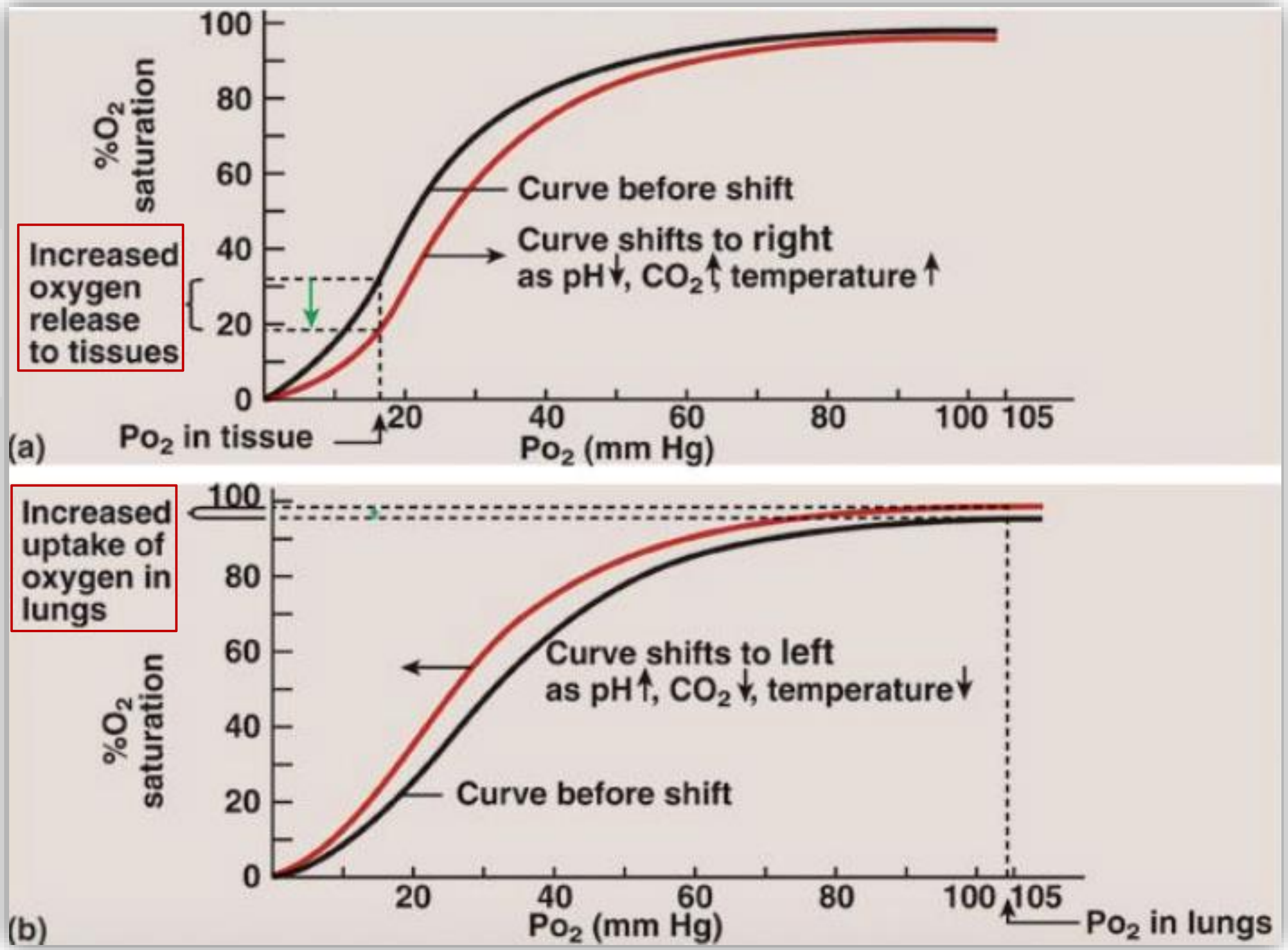


- Where is the normal curve from these 3 curves? To know that, you have to measure the P50! P50 means how many PO2 I need to arrive 50% saturation hemoglobin with O2 ,which is the normal.
- So, we need PO2 = 26.5 to saturate the hemoglobin with O2 in 50%.
- P50 = PO2 = 26.5
- For example ; a person everything is normal with no anemia when he exposed to PO2 = 27 ,this enough for % saturation = 50.
- At this normal stage the affinity between Hb and O2 is the "reference point"

Oxyhemoglobin Dissociation Curve

لأنه مرتبط مع الهيموقلوبين بجاذبية قليلة فيزيد إطلاقه في الأنسجة.

بما أن الجاذبية بين الهيموقلوبين والأوكسجين قوية جداً بالتالي لا يُطلق بالأنسجة ،فأحتاج زيادة معدل أخذ الأوكسجين من الخارج لأغذي به الأنسجة.



The Right Shift

"Right Shift"

means the oxygen is unloaded to the tissues from Hb.

The factors that Shift the curve to the right:

Increased 2,3DPG, H+, Temperature , PCO2.

- 2,3DPG is synthesized in RBCs from the glycolytic pathway , it binds tightly to reduced Hb.
- increased 2,3 DPG facilitate the oxygen release and shifts the dissociation curve to Rt.
- 2,3 DPG increases in the RBCs in anemia and hypoxemia, and thus serves as an important adaptive response in maintaining tissue oxygenation.

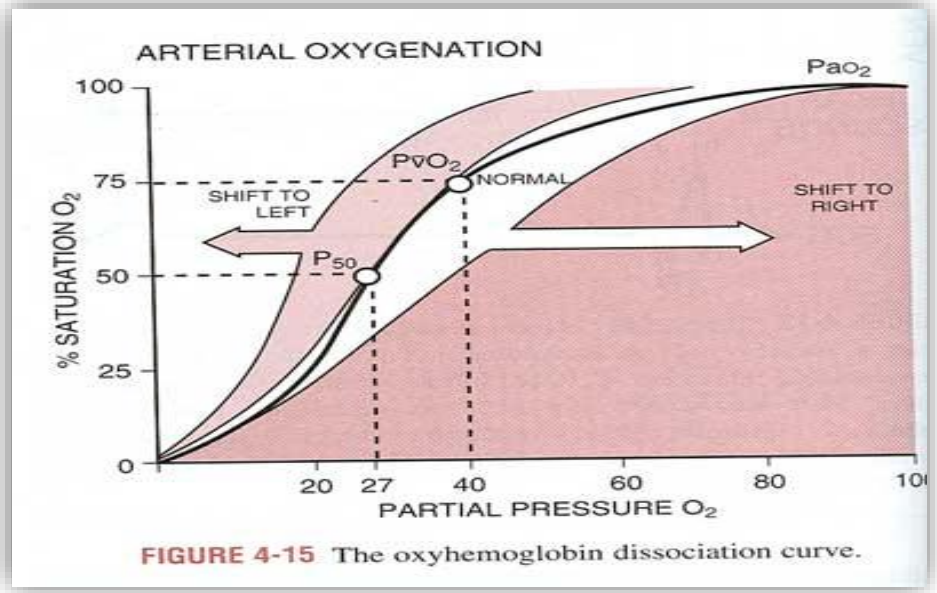


FIGURE 4-15 The oxyhemoglobin dissociation curve.

- Mainly "Right shift" occurs during exercise.

During exercise, we need more O2 so, the PO2 will increased to make the affinity low between O2 & Hb to facilitate the releasing of O2 to the tissue. This process shift the curve to the Right.

- 2,3DPG = **2,3-diphosphoglycerate.** He loves binding to Hb which doesn't have O2 binding to it "Reduced Hb" or "Deoxygenated Hb" so, the O2 can't bind to this Hb which leads to "Decrease affinity".
- Hypoxemia >> In people who live in High altitude.
- من رحمة الله تعالى بمرضى الأنيميا أن هذه المادة 2,3DPG تزيد عندهم ! بما أن الهيموجلوبين عندهم يكون قليل جداً بالتالي لو كانت الجاذبية بينه وبين الأوكسجين عالية مارح يكون فيه أوكسجين يطلق بالانسجة !! فتزيد هذه المادة عشان تقلل من الجاذبية ويطلق أوكسجين أكثر في الأنسجة لتغذيتها.
- In Anemia > Increase 2,3DPG > Decrease Affinity > Increase releasing O2 in tissue > Shift to Righ.

The Left Shift

"Left Shift"
means the oxygen is loading or attachment to Hb.
Fetal Hb: has a P50 of 20 mmHg in comparison to 27 mmHg of adult Hb.

Low PO2 = 20 > Low P50 > High affinity > Shift to the left.

- The fetal Hb has high affinity with O2 maybe "Up to normal" > lead to decrease releasing O2 in tissue > Low O2 conc. In tissue "Hypoxia".

To solve this problem !

- The fetus's kidney will release "Erythropoietin" which stimulate RBC's formation > Increase RBC's > Increase Hb > So, increase releasing of O2 in tissue.

After birth:
The fetal Hb will be HbA (No hypoxia)

- الRBC's الزايدة يكسرها للتخلص منها.

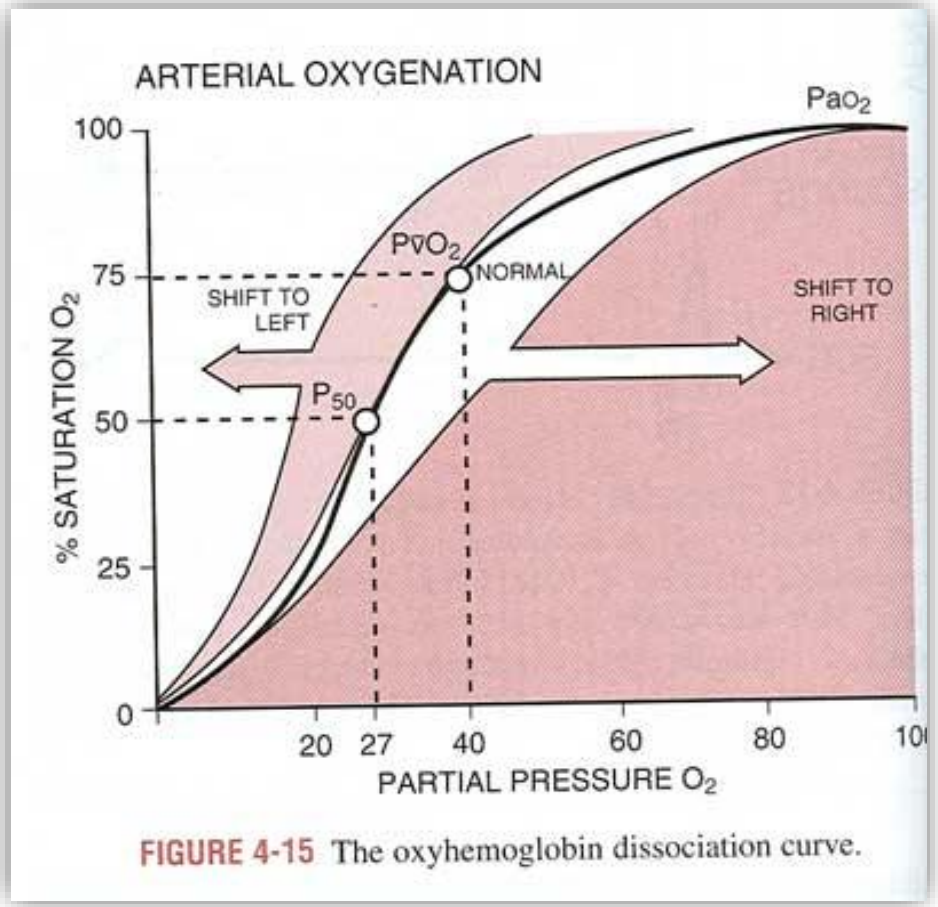


FIGURE 4-15 The oxyhemoglobin dissociation curve.

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Shift Of Dissociation Curve During Exercise

- Exercise increases Temp, H+, 2,3 DPG and shift the curve to Right.
- Utilization Coefficient : The percentage of the blood that gives up its oxygen as it passes through the tissues capillaries is called :

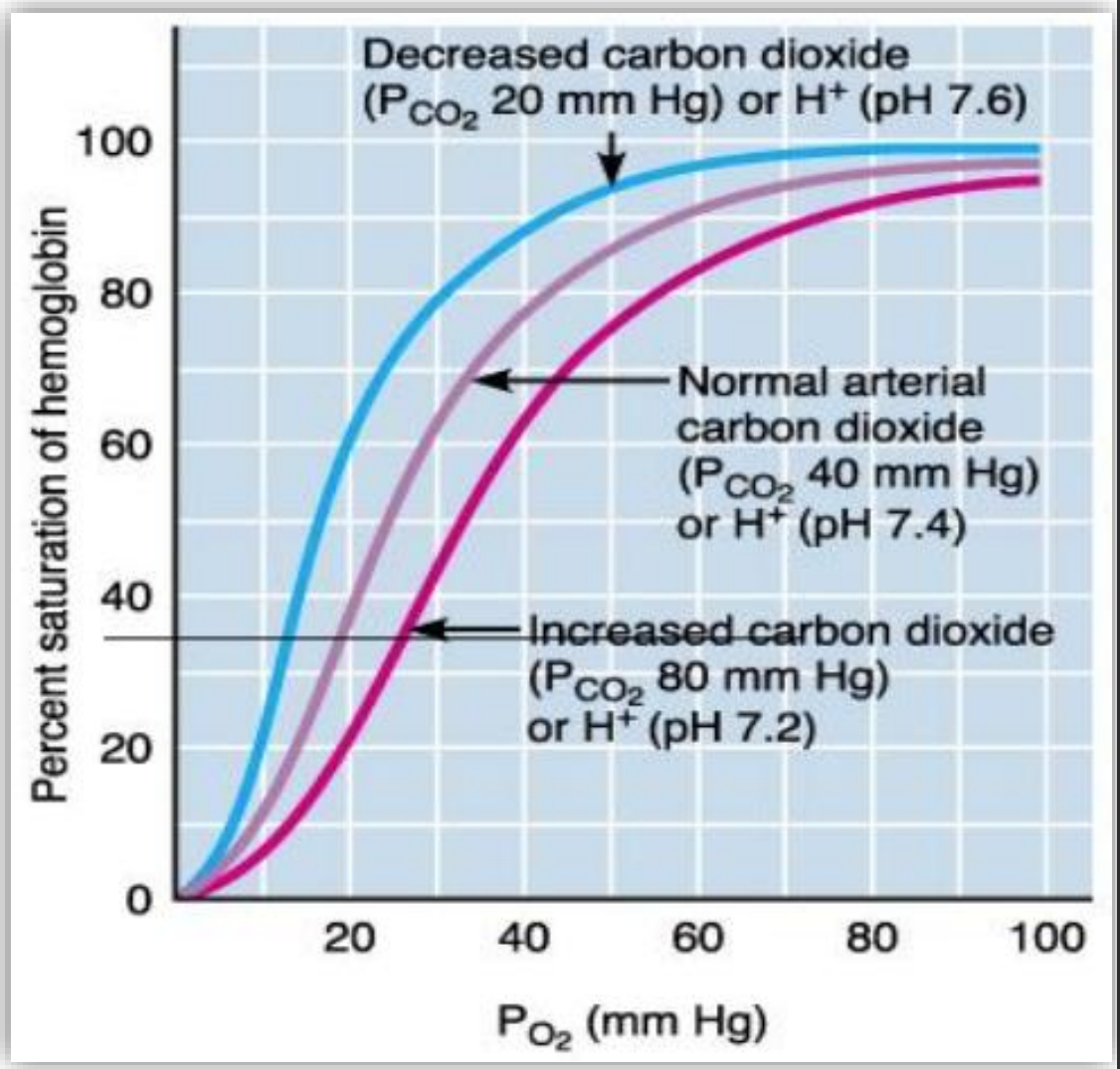
$$\text{Utilization coefficient} = \frac{O_2 \text{ delivered to the tissues}}{O_2 \text{ content of arterial blood}}$$

- Normally at rest = 5ml/20 ml= 25%.
- During exercise it = 15 ml/20 ml= 75 % - 85%

- We know that 5ml O2 from 100ml blood goes to the tissue. This 5ml = ¼ called "Utilization coefficient" .معامل الإستهلاك
- At normal/rest state Utilization coefficient = 25%
- But, During exercise will increase to 50% or 75%.

Bohr Effect

- Effect of carbon dioxide and hydrogen ions on the curve (Bohr effect)
- **At lung:** movement of CO_2 from blood to alveoli will decrease blood CO_2 &H+ →shift the curve to left and increase O_2 affinity to Hb allowing more O_2 transport to tissues.
- **At tissues:** the reverse occur.



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Transport of oxygen in the dissolved state

- Only 3% of O_2 is transported in the dissolved state.
- At normal arterial PO_2 of 95 mmHg , about 0.29 ml of oxygen is dissolved in each 100ml of blood.
- When the PO_2 of the blood falls to 40 mmHg in tissue capillaries, only 0.12 of oxygen remains dissolved.
- 0.17 ml of oxygen is normally transported in the dissolved state to the tissues per each 100 ml of blood.

- Hb-O2 State (Storage O2 in tissue) = 20%
- Dissolved-O2 State (actually used by tissue) = 3% only 0.17 to tissue. "The only form that tissue can used directly"
- When we measuring the PO2 we are measuring the "Dissolved form"

Combination of Hb with CO, Displacement of Oxygen

- CO combines with Hb at the same point on the Hb molecule as does oxygen.
- It binds with Hb about 250 times as much as O_2 (affinity of Hb to CO is very high (250 times) that to O_2.
- It causes Left shift of the O_2- Hb curve.

Transport of Carbon Dioxide in The Blood

- Dissolved CO_2 7%
- Bicarbonate ions 70 %
- Carbaminohemoglobin (with Hb) 23%.
  Each 100 ml of blood carry 4 ml of CO_2 from the tissues/min .

Why is cause Left shift NOT Right shift?

- بوجود ال CO عندنا مشكلة مع ترابط الأوكسجين للهيموجلوبين ،فنحاول نزيد من جاذبية الأكسجين بالتالي تحصل الإزاحة لليسار، يعني لو فيه عدد قليل من الO_2 مرتبط مع الHb بتكون الجاذبية بينهم جداً عالية.
- بشكل عام لو قارنا تجاذب الO_2 اللي ماعندها CO بالأوكسجين اللي عنده CO يتنافس معه نلقى الثاني جاذبيته وقوته أكثر يعني شفت لليسار.

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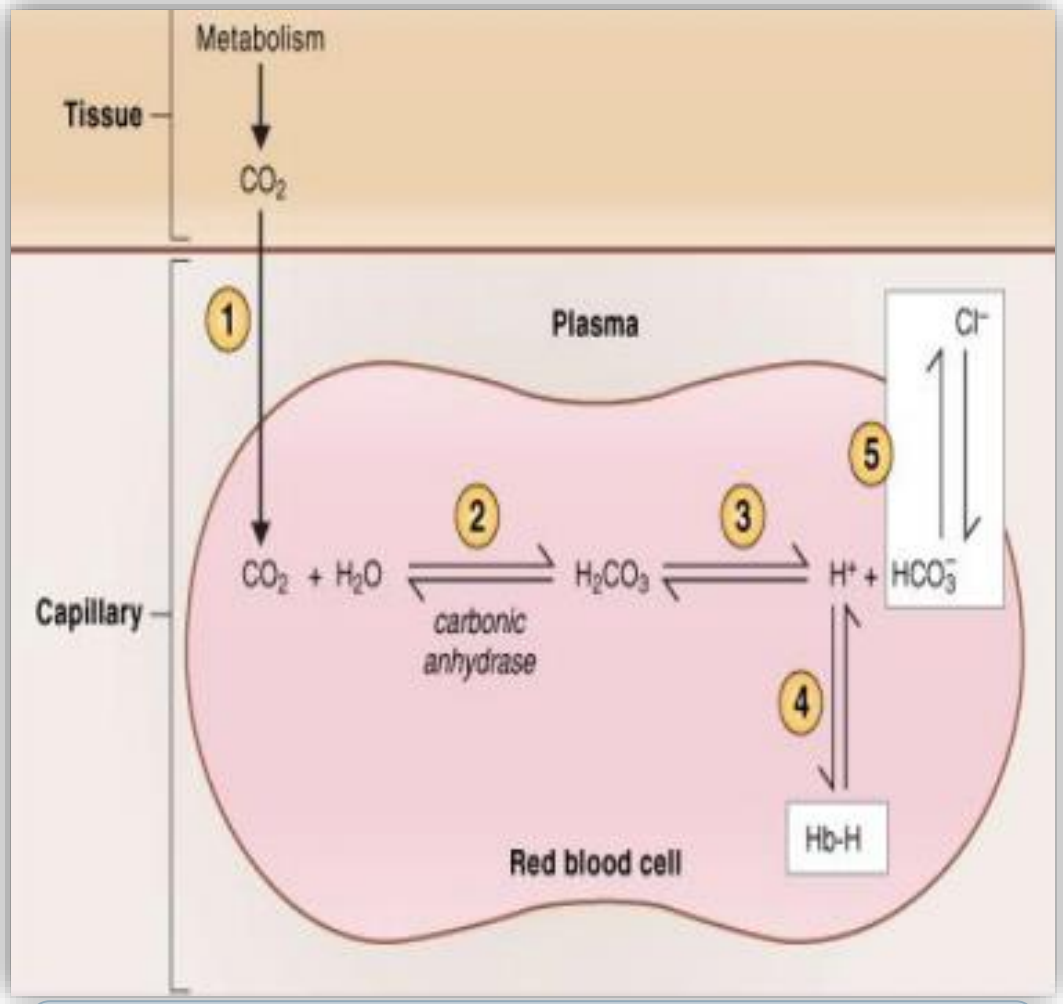
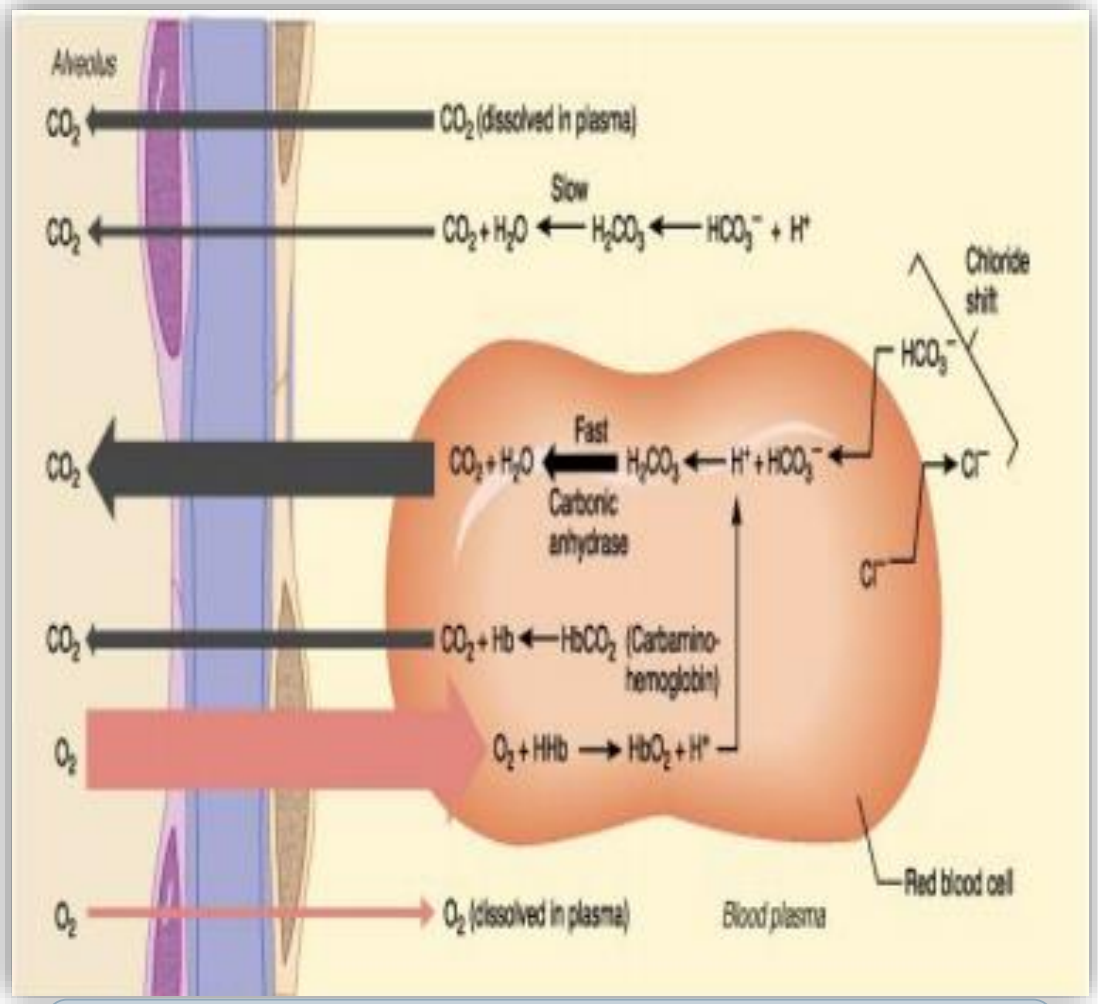
Formation of HCO_3 and Chloride Shift



In Tissues



In Pulmonary Capillaries

The Haladane Effect

- When oxygen binds with hemoglobin, carbon dioxide is released - to increase CO_2 transport.
- Binding of Hb with O_2 at the lung causes the Hb to become a stronger acid and , this in turn displaces CO_2 from the blood and into the alveoli.
- Change in blood acidity during CO_2 transport.

  Arterial blood has a PH of 7.41 that of venous blood with higher PCO_2 falls to 7.37 (i.e change of 0.04 unit takes place)

Respiratory Exchange Ratio

$$R = \frac{\text{Rate of carbon dioxide output}}{\text{Rate of oxygen uptake}}$$

- Normally it is 4/5= 82% .
- When Carbohydrate diet is used R = 1
- When fats only is used R=0.7
- A person on normal diet R=0.825

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Video

Partial Pressure:
https://www.youtube.com/watch?v=yEK6LdwYunQ

Quiz

https://www.onlineexambuilder.com/lecture-7/exam-57809

Quiz

https://www.onlineexambuilder.com/physiology-6th/exam-57596

PHYSIOLOGY TEAM 435

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THANK YOU FOR CHECKING OUR WORK

For any correction, suggestion or any useful information,
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