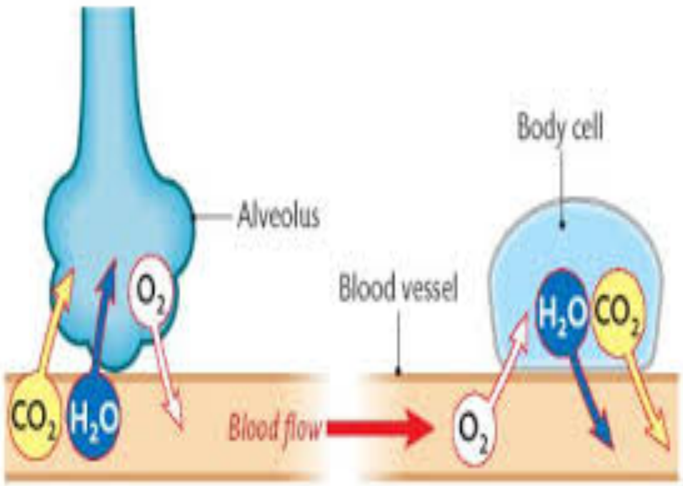
(Diffusion of O2 and CO2)



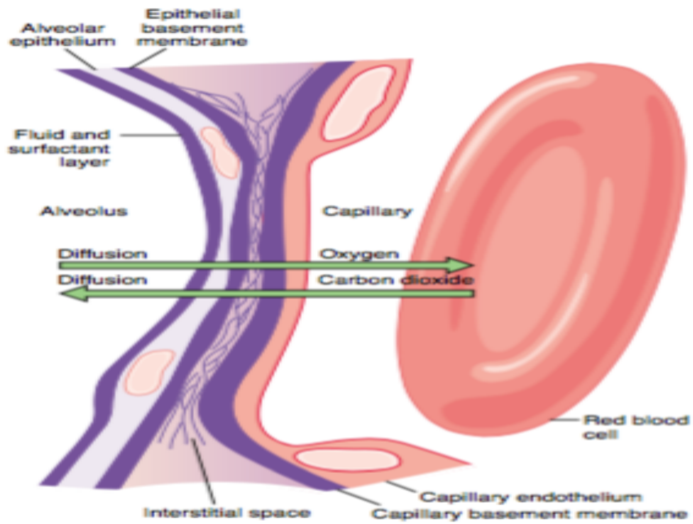


Figure 39–9

Ultrastructure of the alveolar respiratory membrane, shown in cross section.

Dr.Tamir Al-khlaiwi
Department of Physiology
College of Medicine
KSU

Objectives:

1-Define partial pressure of a gas.

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- Identify 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.

Gas exchange through respiratory membrane

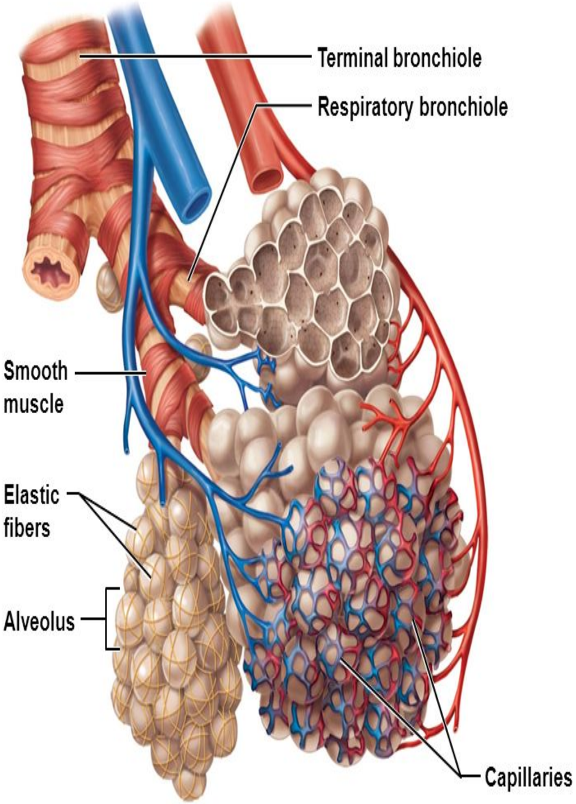
After ventilation of the alveoli with fresh air the next step is the process called Diffusion of oxygen and carbon dioxide across the respiratory membrane.

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

-The total surface area is about 50-100 m2 in the normal adult human male.

-The total quantity of blood in the capillaries of the lungs at any

Figure 22.9a Alveoli and the respiratory membrane.



(a) Diagrammatic view of capillary-alveoli relationships

Respiratory Membrane

1. A layer of fluid containing surfactant that lines the alveolus and reduces the surface tension of the alveolar fluid.

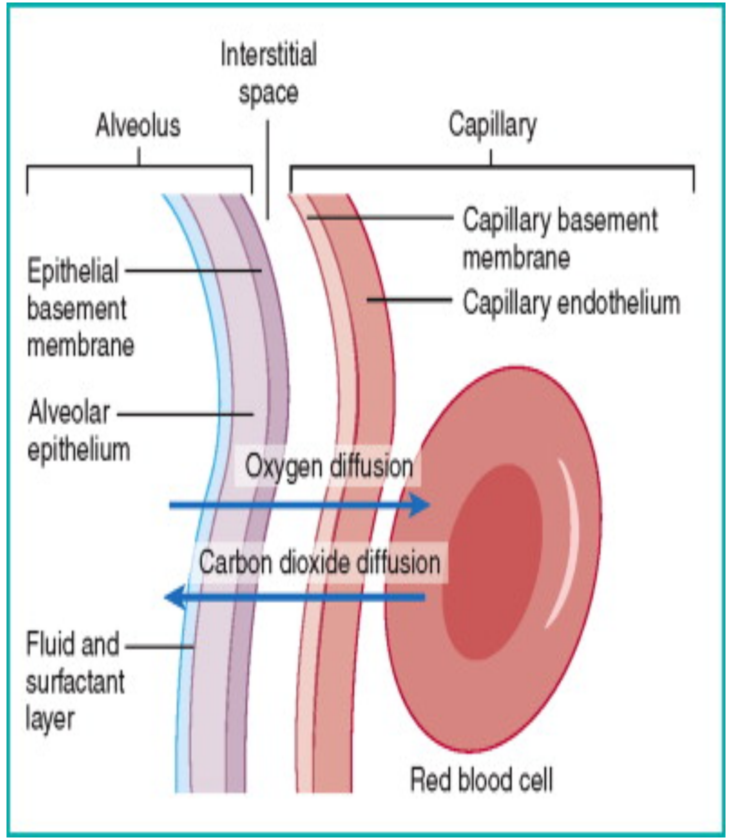
2. The alveolar epithelium, which is composed of thin epithelial cells.

3. An epithelial basement membrane.

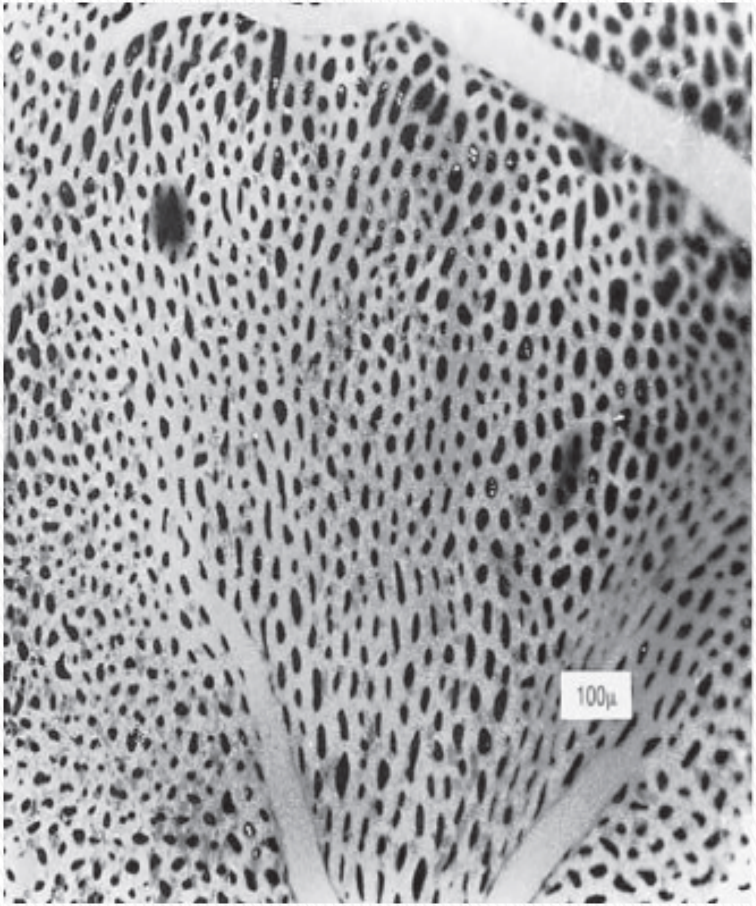
4. A thin interstitial space between the alveolar epithelium and the capillary membrane.

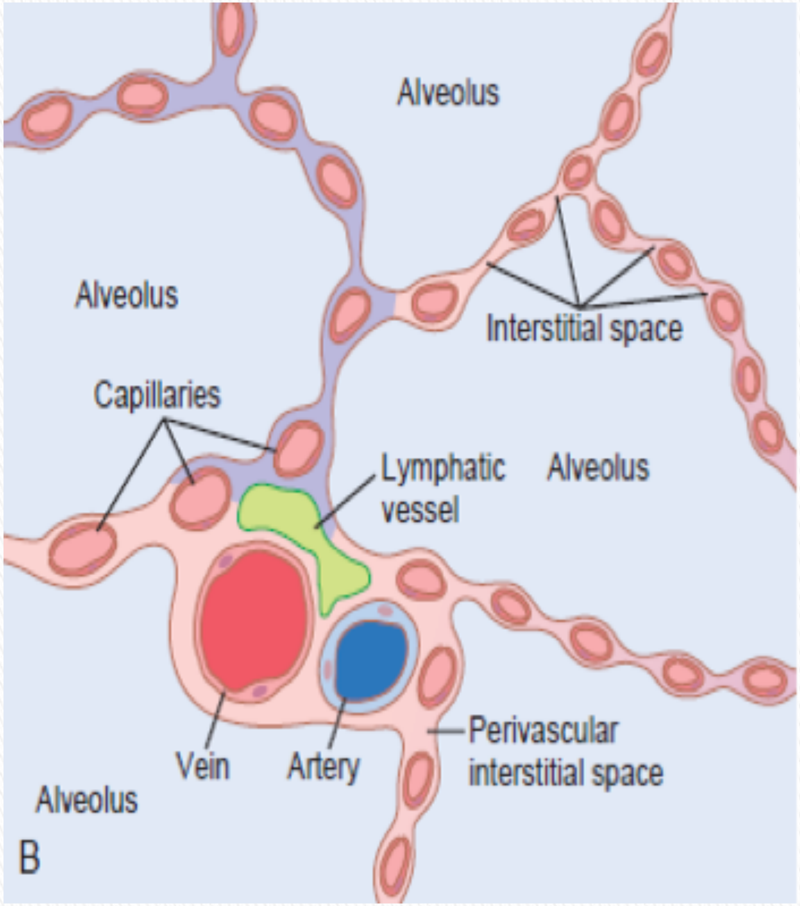
5. A capillary basement membrane that in many places fuses with the alveolar epithelial basement membrane.

6. The capillary endothelial membrane.



Cross-sectional view of alveolar walls and their vascular supply





Partial pressure of gases

- The gases of physiological importance are O2,CO2.
- The rate of diffusion of each of these gases is directly proportional to the pressure caused by this gas alone which is called the partial pressure of the gas
- Pressure is caused by the constant impact of kinetically moving molecules against a surface..

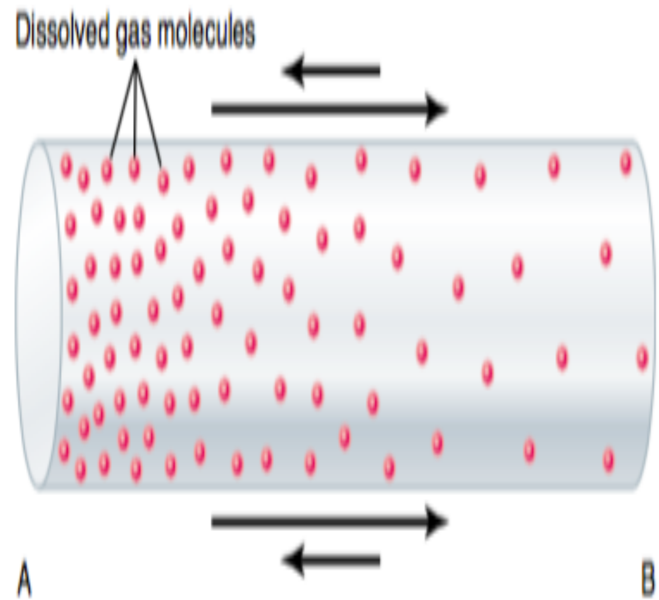


Figure 39-1

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*.

Dalton's Law of Partial Pressures

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 $P_x = P_B \times F$

for humidified gas : $P_X = (P_B - P_{H_2O}) \times F$

P_X = Partial pressure of gas (mm Hg)

P_B = Barometric pressure (760mm Hg)

P_{H_2O} = Water vapor pressure at 37°C (47 mm Hg)

F = Fractional concentration of gas (0.21 no units)

The barometric pressure (P_B) is the sum of the partial pressures of O_2, CO_2, N_2, and H_2O.

The percentages of gases in dry air at a barometric pressure of 760 mm Hg are as follows: O_2= 21% (0.21); N_2= 79% (0.79); and CO_2= 0% (0). Because air is humidified in the airways, water vapor pressure is obligatory and equal to 47 mm Hg at 37°C.

Alveolar air and its relation to atmospheric air

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

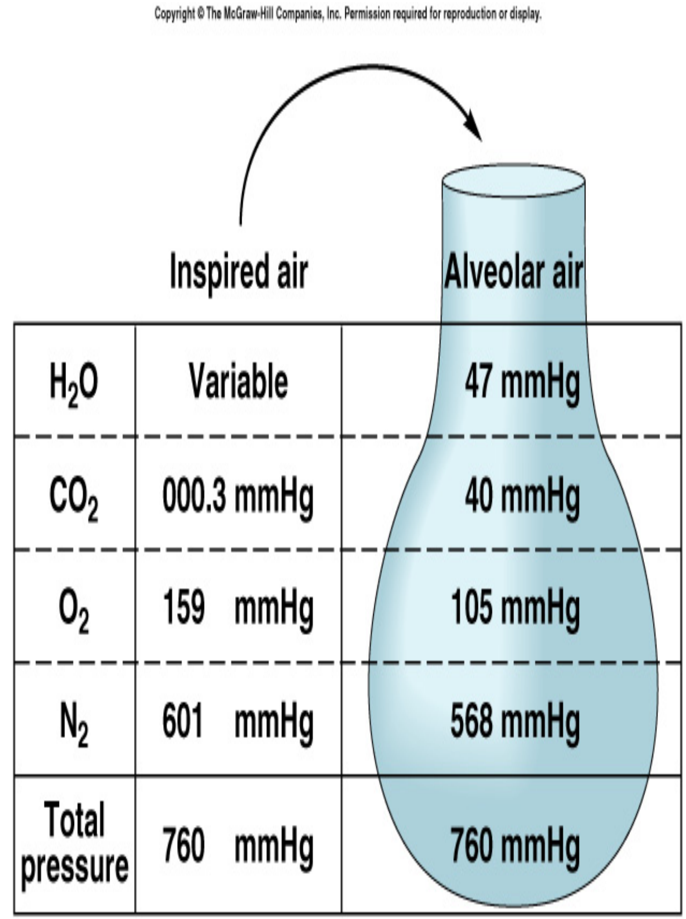
1-The alveolar air is only partially replaced by atmospheric air with each breath {Only 350 milliliters of new air is brought into the alveoli with each normal inspiration, and this same amount of old alveolar air is expired.

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.

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

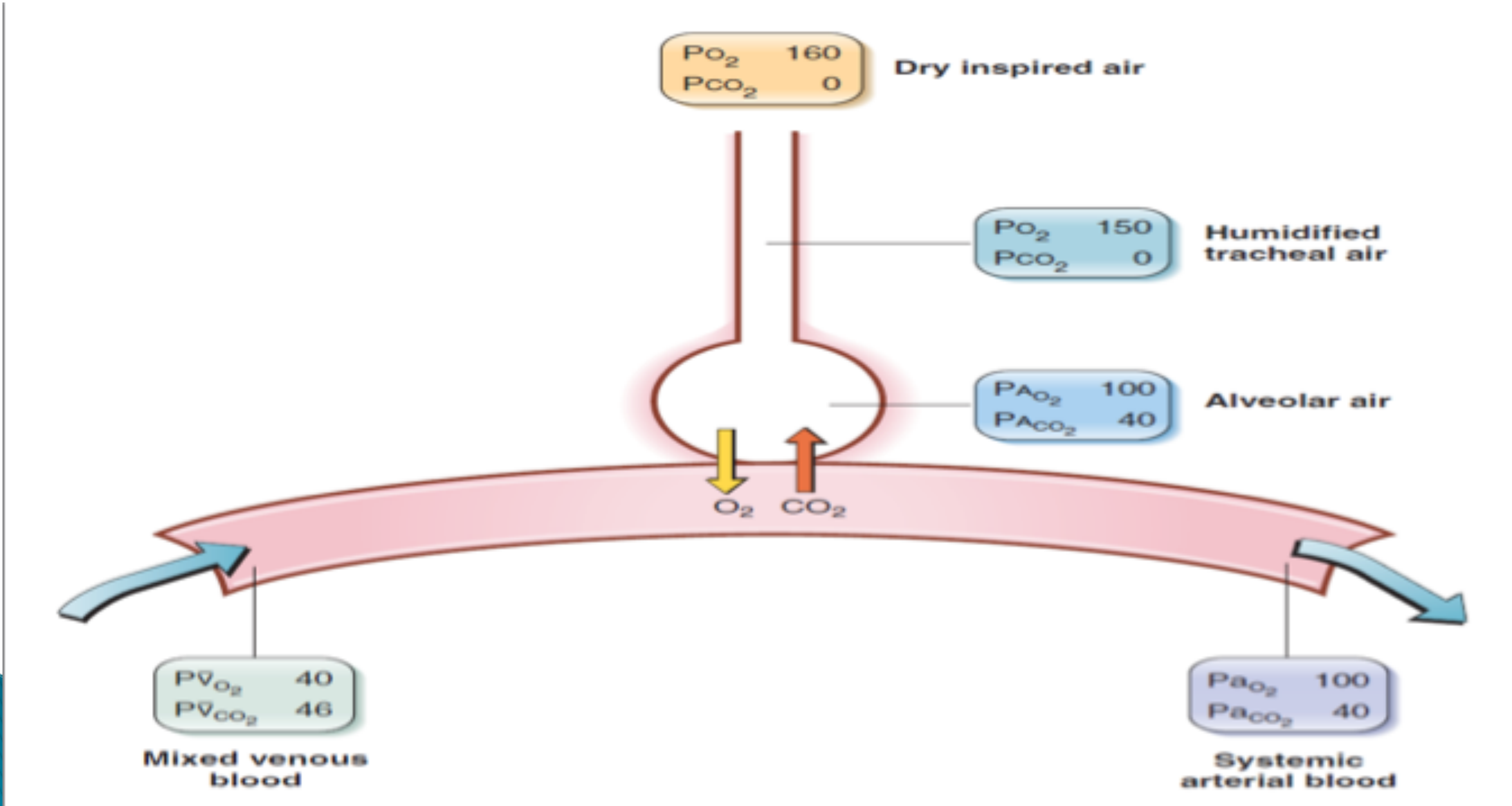


	Inspired air	Alveolar air
H_2O	Variable	47 mmHg
CO_2	000.3 mmHg	40 mmHg
O_2	159 mmHg	105 mmHg
N_2	601 mmHg	568 mmHg
Total pressure	760 mmHg	760 mmHg

Humidification of air in respiratory passages

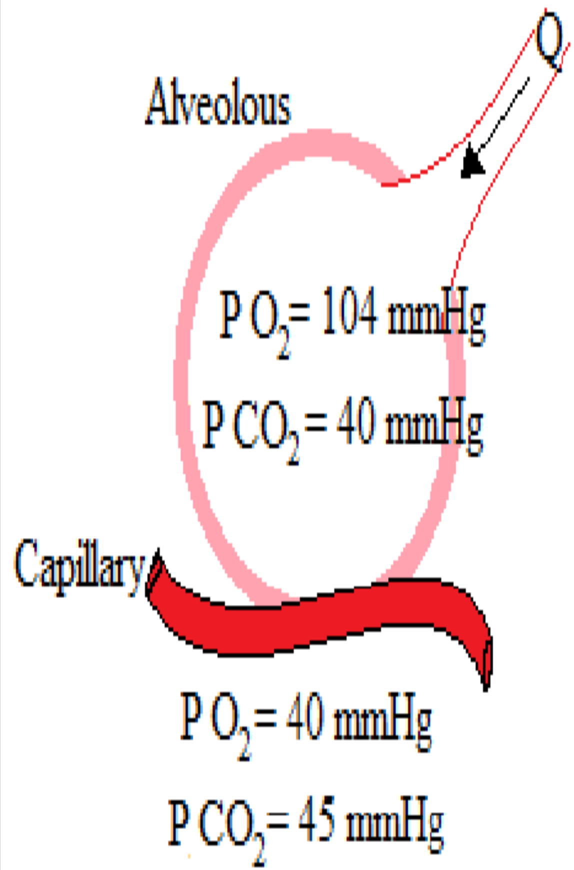
- Atmospheric air is composed almost entirely of nitrogen and O_2; it normally contains almost no CO_2 (???) and little water vapor.
- As soon as the atmospheric air enters the respiratory passages, it is exposed to the fluids that cover the respiratory surfaces.
- Even before the air enters the alveoli, it becomes almost totally humidified.

Values for PO2 and PCO2 in dry inspired, humidified tracheal, alveolar air, and pulmonary blood.



Partial Pressure of O2 and CO2

- Oxygen concentration in the atmosphere is 21%. So, PO2 in atmosphere = 760 mmHg x 21% = 160 mmHg.
- This mixes 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% = 0.3 mm Hg.
- This mixes with high CO2 levels from residual volume in the alveoli to arrive at PCO2 of 40 mmHg in the alveoli.



Factors That Determine the Partial Pressure of a Gas Dissolved in a Fluid.

- The partial pressure of a gas in a solution is determined not only by its **concentration** but 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.

Factors affecting gas diffusion- Fick's law

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

1-P: Partial pressure differences

2-A: Surface area for gas exchange [The total surface area of the respiratory membrane is ≃ 50 to 100 m2 in normal adult.]

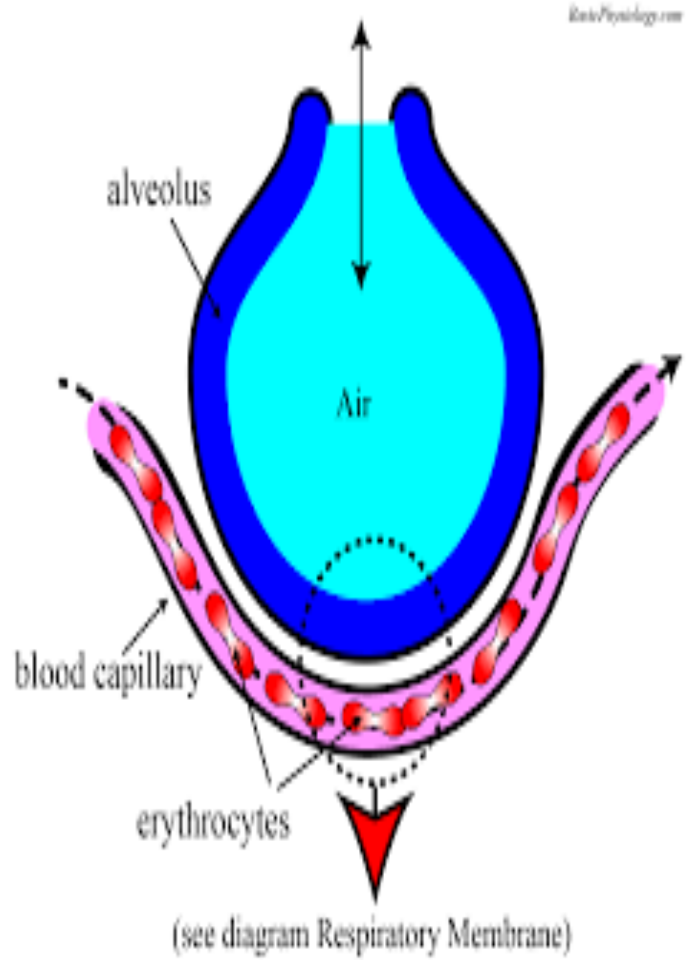
3-D: Diffusion distance [thickness of the respiratory membrane]

4-MW: Molecular weight.

5-S: solubility of gas in the body fluids.

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

6-The temperature of the fluid. In the body, the temperature remains reasonably constant and usually need not to be considered.



Cont…Factors affecting diffusion across the respiratory membrane

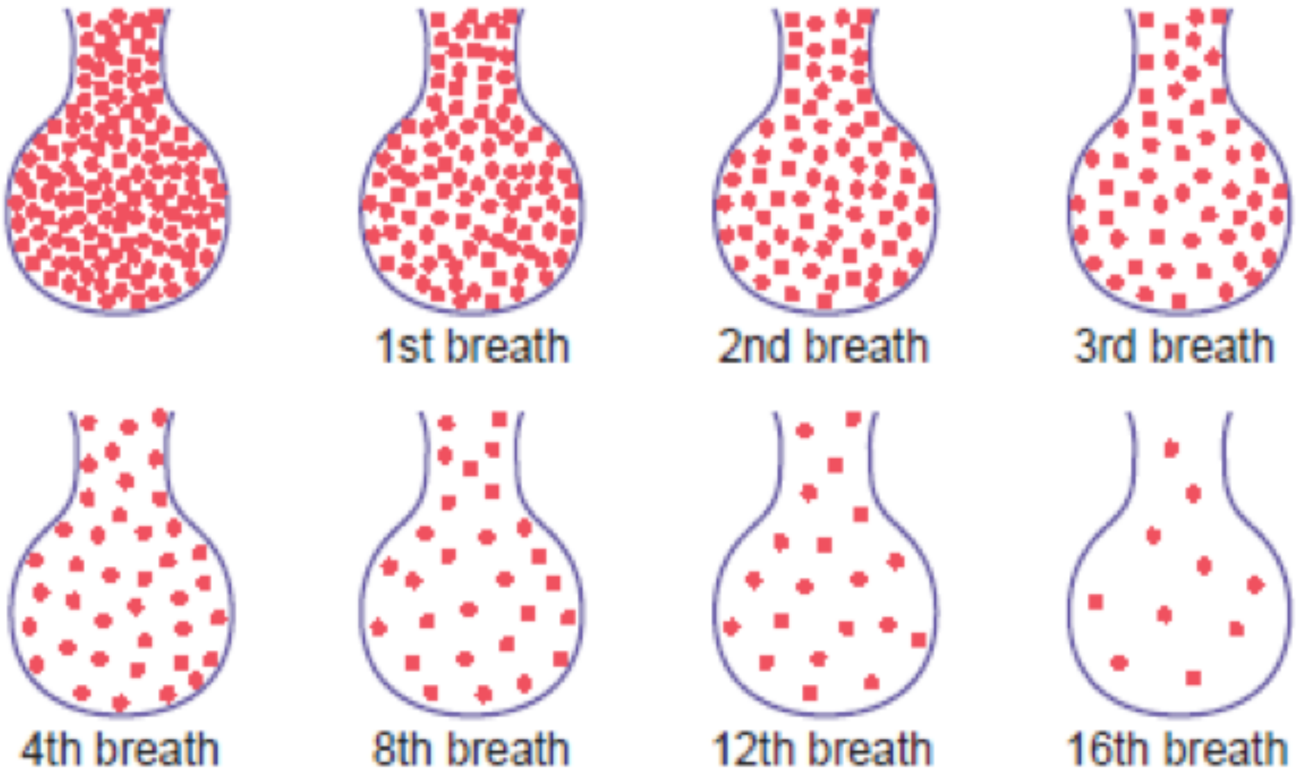
- O_2 has lower molecular weight than CO_2 But CO_2 is 24 times more soluble than O_2
- Net result: CO_2 diffusion approximately 20 times faster than O_2 diffusion.

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

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

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

Exchange of a gas from an alveolus with successive breaths.



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.

Transport of oxygen in the arterial blood

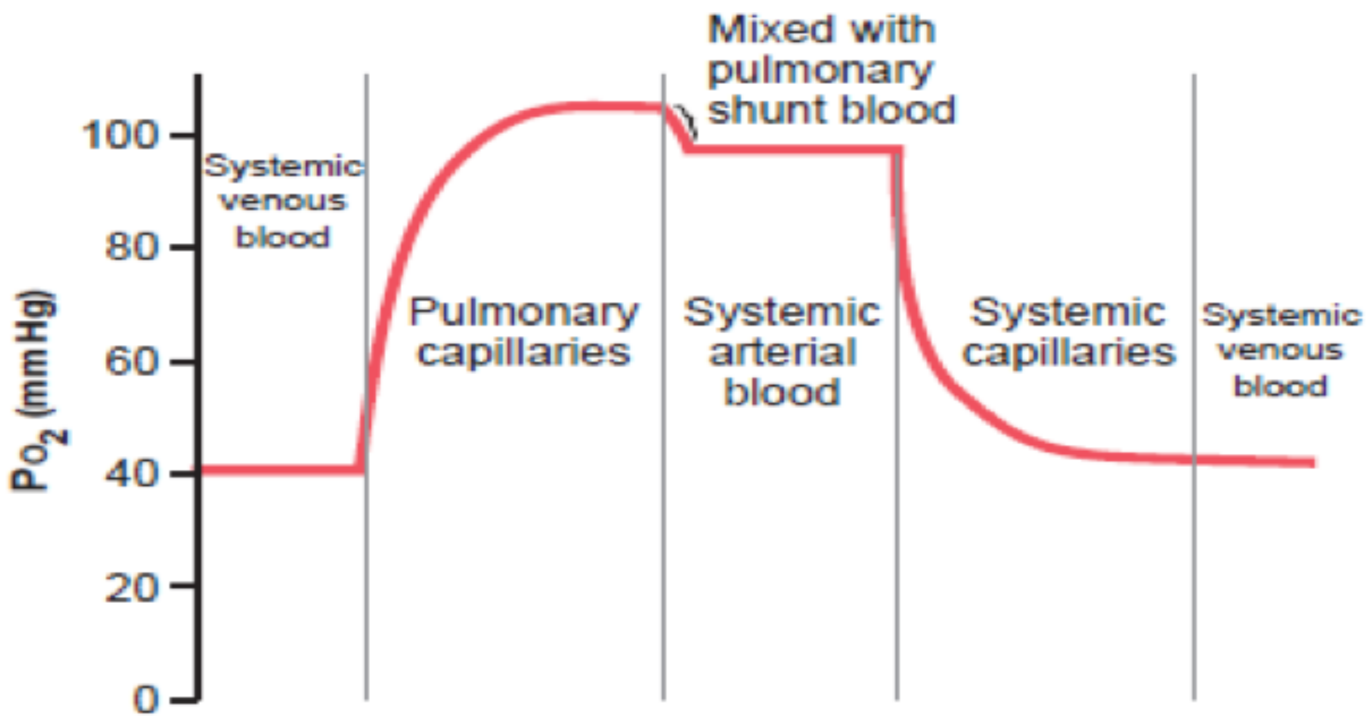
About 98 percent of the blood that enters the left atrium from the lungs has just passed through the alveolar capillaries and has become oxygenated up to a PO2 of about 104 mm Hg.

Another 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.

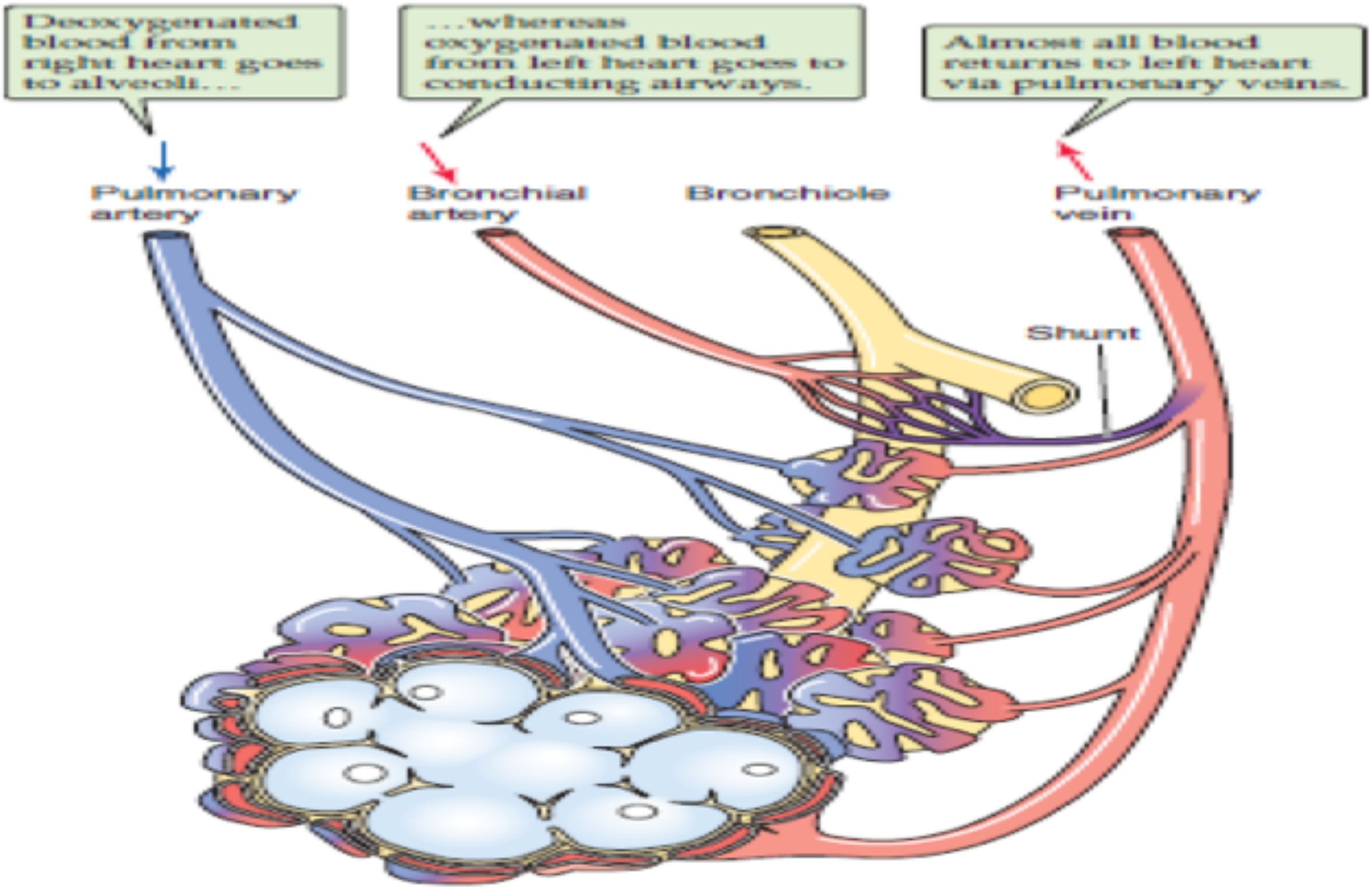
Upon leaving the lungs, the PO2 of the shunt blood is approximately that of normal systemic venous blood—about 40 mm Hg.

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.

Changes in PO2 in pulmonary capillary, systemic arterial, and systemic capillary, and the effect of venous admixture



Pulmonary shunt



Diffusion of Oxygen from Peripheral Capillaries into Tissue Fluid

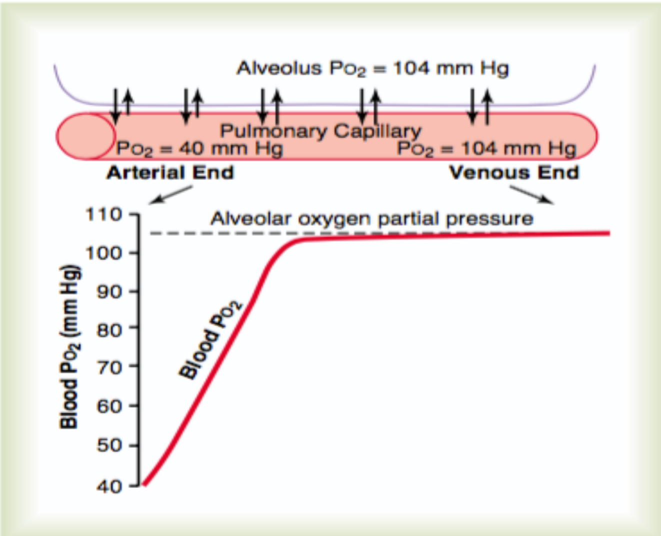


Figure 40–1

Uptake of oxygen by the pulmonary capillary blood. (The curve in this figure was constructed from data in Milhorn HT Jr, Pulley PE Jr: A theoretical study of pulmonary capillary gas exchange and venous admixture. Biophys J 8:337, 1968.)

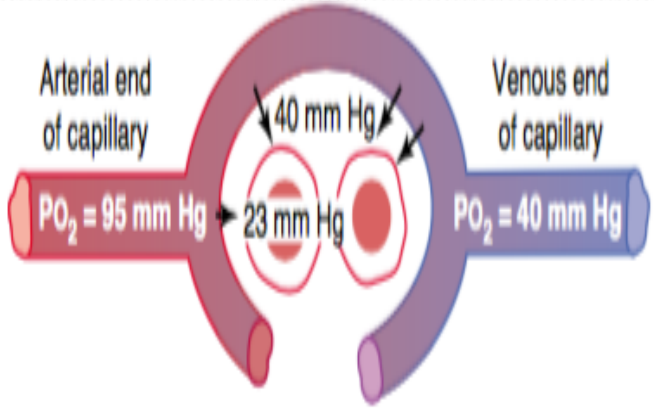


Figure 40–3

Diffusion of oxygen from a tissue capillary to the cells. (Po_2 in interstitial fluid = 40 mm Hg, and in tissue cells = 23 mm Hg.)

From alveoli to pulmonary capillaries

From systemic capillaries to tissues

Diffusion of Carbon Dioxide

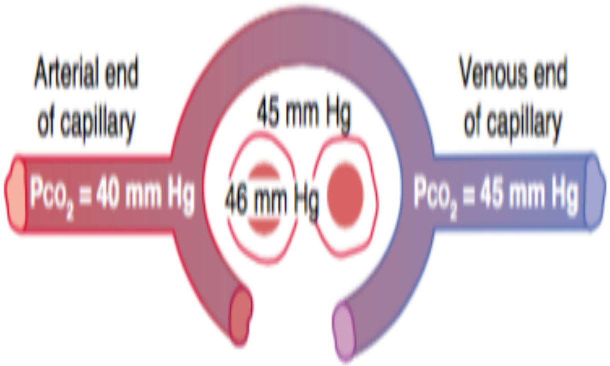


Figure 40-5

Uptake of carbon dioxide by the blood in the tissue capillaries. (P_{CO_2} in tissue cells = 46 mm Hg, and in interstitial fluid = 45 mm Hg.)

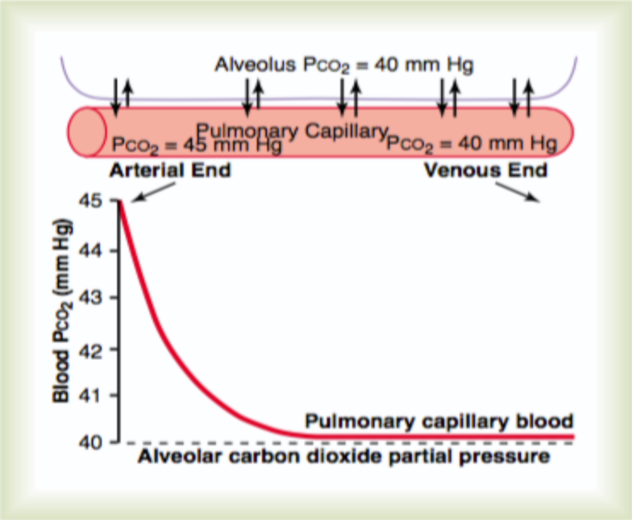


Figure 40–6

Diffusion of carbon dioxide from the pulmonary blood into the alveolus. (This curve was constructed from data in Milhorn HT Jr, Pulley PE Jr: A theoretical study of pulmonary capillary gas exchange and venous admixture. Biophys J 8:337, 1968.)

from the peripheral tissue cells into the Capillaries

from the Pulmonary Capillaries into the Alveoli

PO2 and PCO2 in various potions 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.

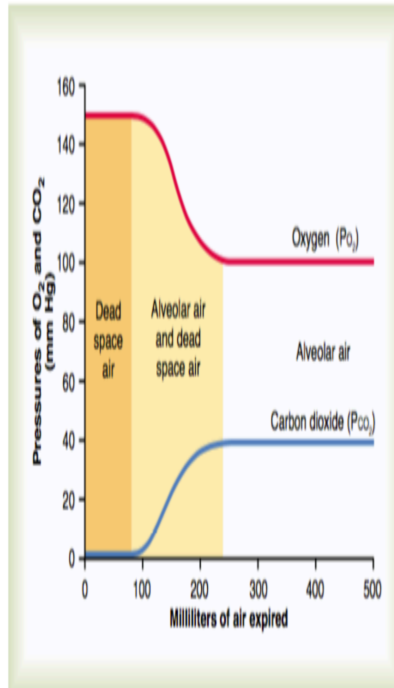
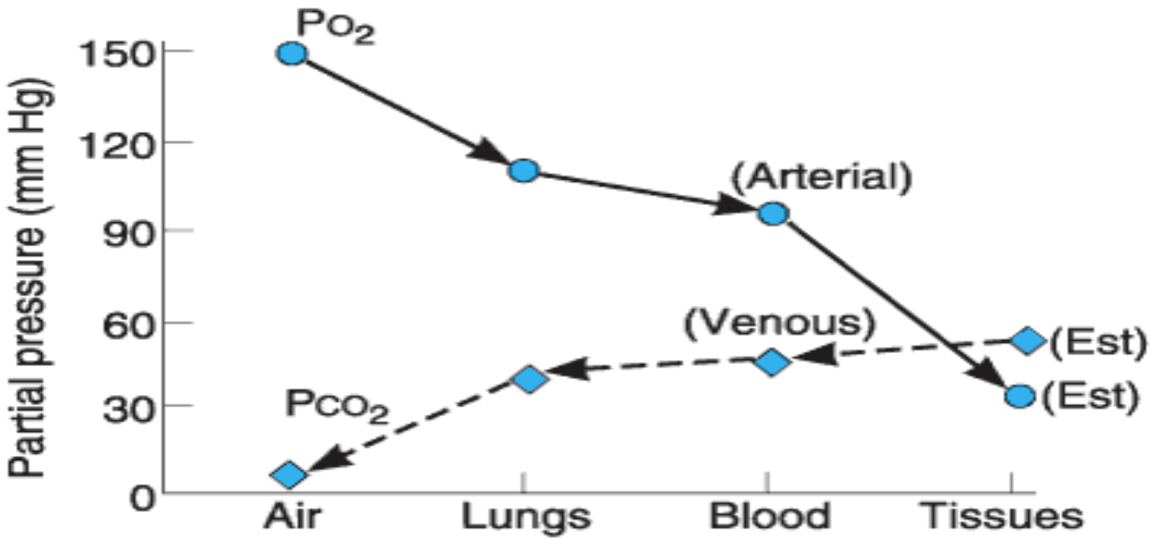


Figure 39-6

Oxygen and carbon dioxide partial pressures in the various portions of normal expired air.

PO2 and PCO2 in air, lung and tissues

Figure 35–1.



Summary of PO_2 and PCO_2 values in air, lungs, blood, and tissues, graphed to emphasize the fact that both O_2 and CO_2 diffuse "downhill" along gradients of decreasing partial pressure. (Redrawn and reproduced, with permission, from Kinney JM: Transport of carbon dioxide in blood. Anesthesiology 1960;21:615.)