LECTURE-4
GAS EXCHANGE

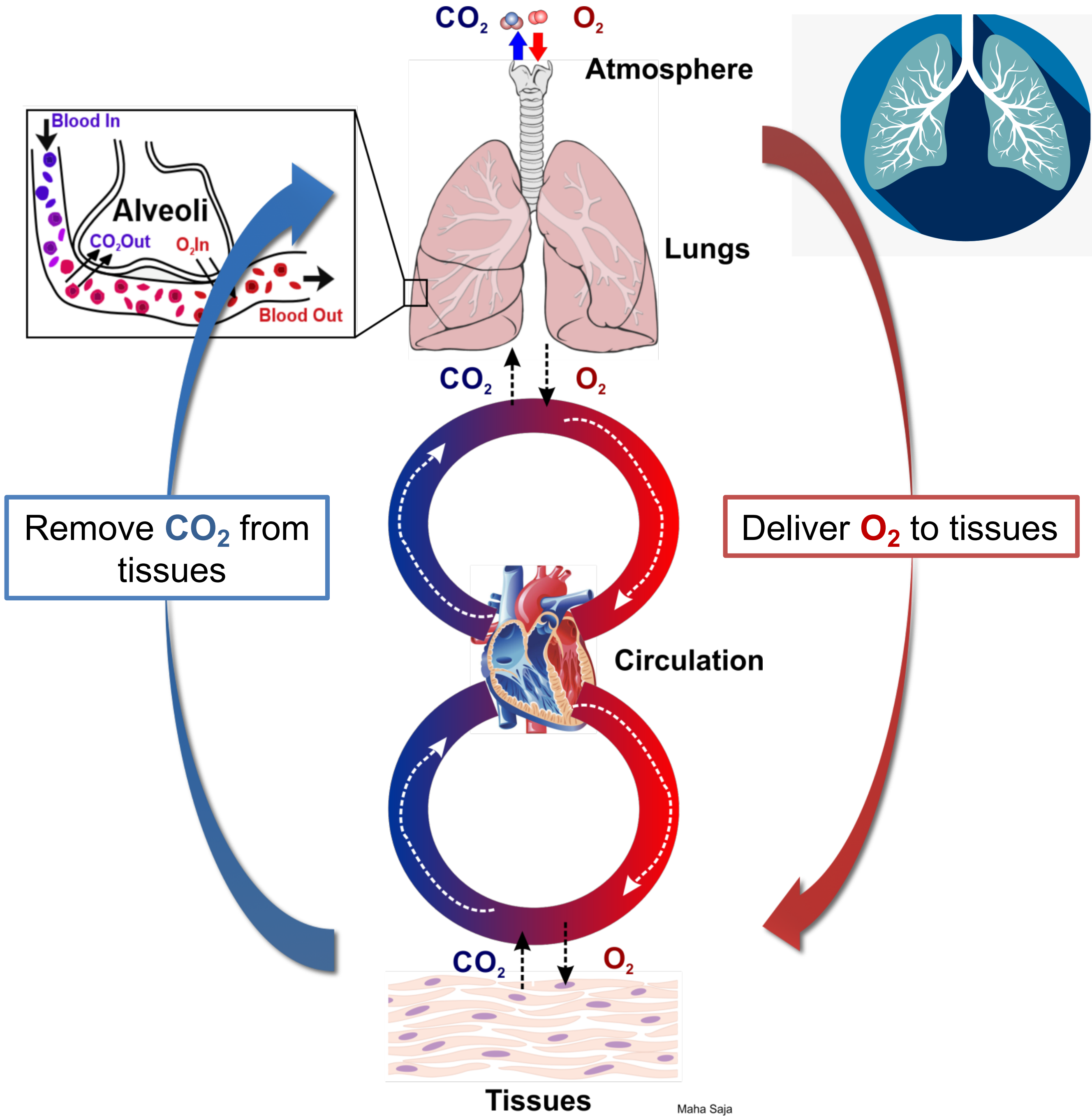
Dr. Maha Saja

Msaja@ksu.edu.sa

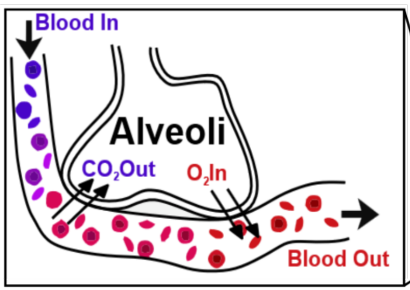
Office no. 8 level 3

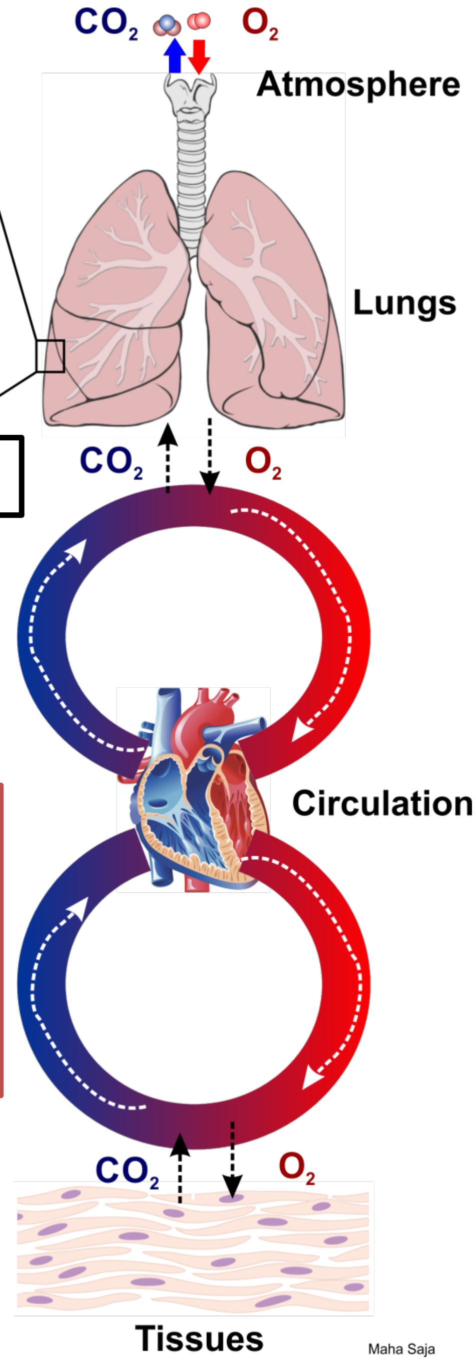
Let’s summarize what have been discussed so far!

What is the aim of respiration?



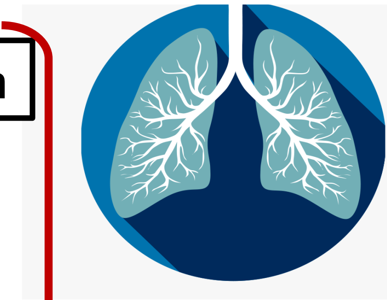
Four *processes* help respiration achieve its goal… What are they?





1 **Pulmonary ventilation**

Inflow & outflow of air between atmosphere & lung alveoli



2 **Gas diffusion**

Movement of O_2 & CO_2 between alveoli & blood

3 **Gas transport**

Transport of O_2 & CO_2 in blood and body fluids to tissue cells

4 **Regulation**

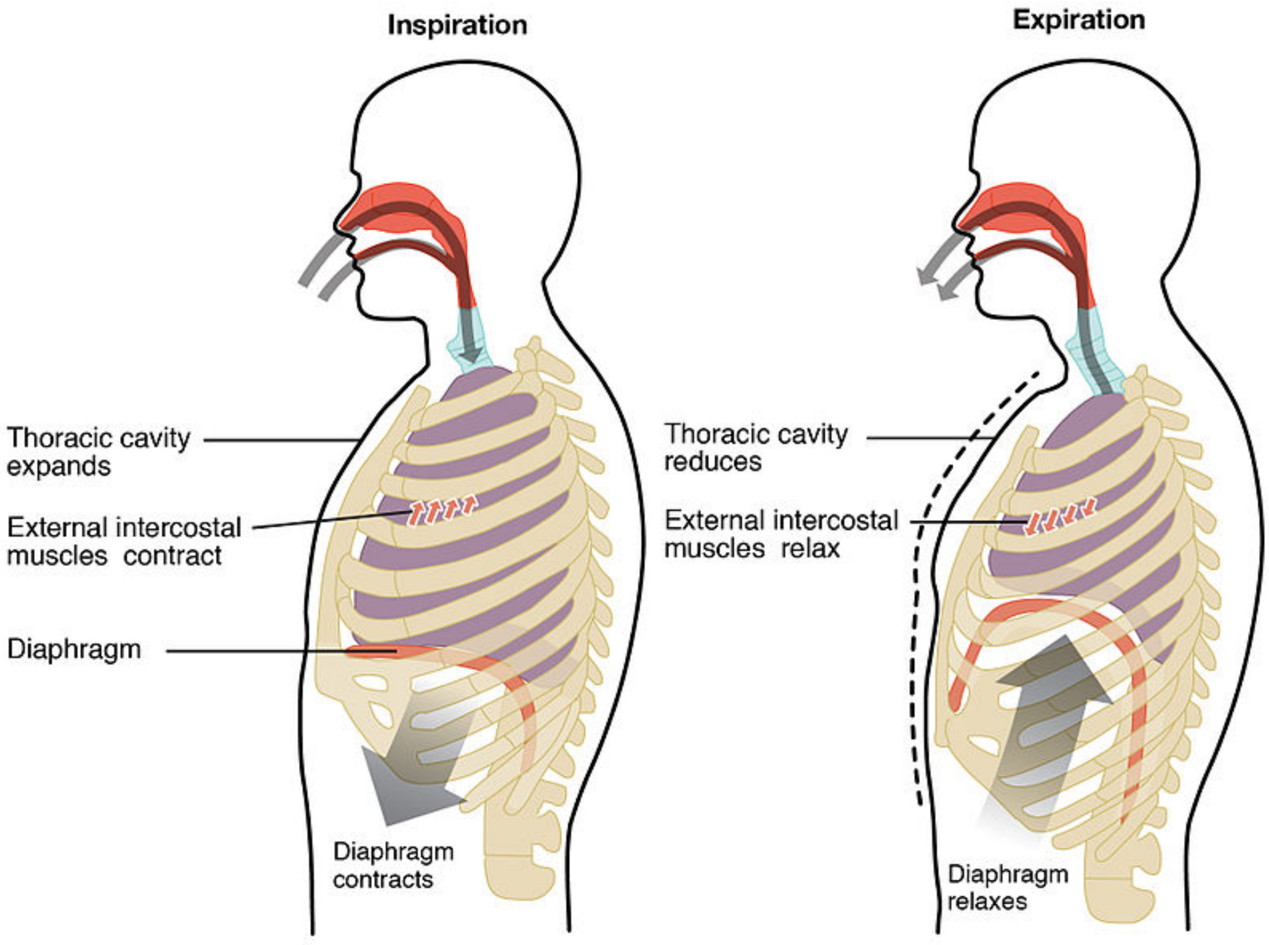
The alveolus is the gas exchange site in respiratory system

In the past 3-4 lectures we discussed the 1st step

Pulmonary ventilation

Let's revise what we know!

Mechanism of Ventilation



Inspiration

Contraction of inspiratory muscles

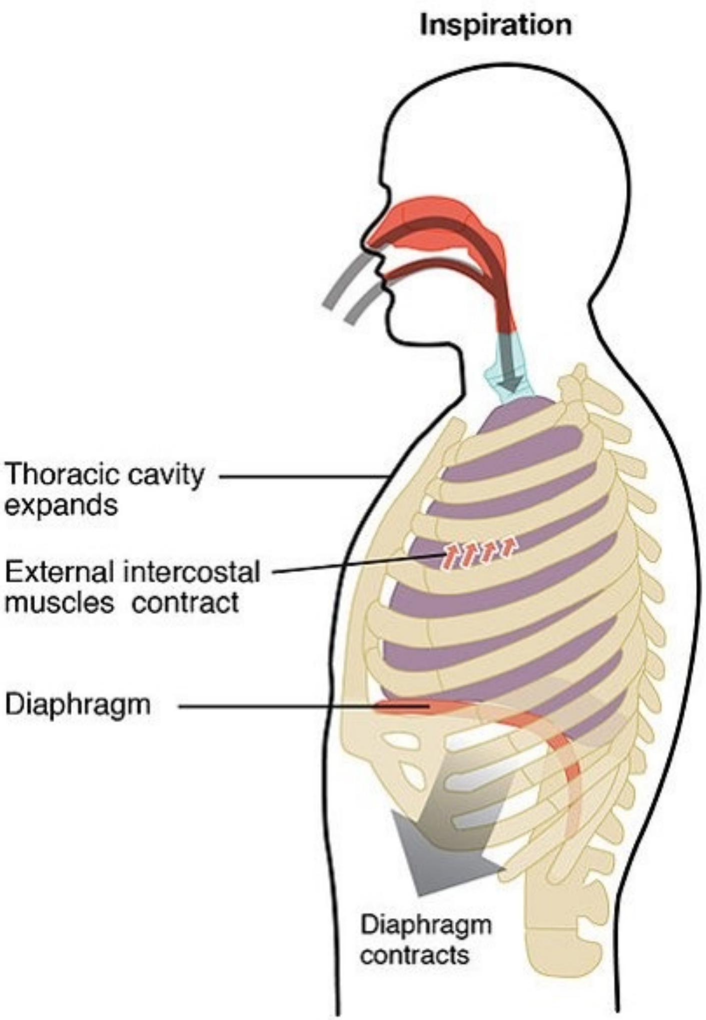
↑ chest volume

↓ IPP (more negative)
-7.5 cm H_2O

↑ TPP
(P_{alv} – IPP = 0-[-7.5]=+7.5 cm H_2O)

Lung (alveoli) expand
(↓ P_{alv} to **-1 cm H_2O**)

$P_B > P_{alv}$
Air moves from atmosphere into the lungs



Expiration

Relaxation of inspiratory muscles

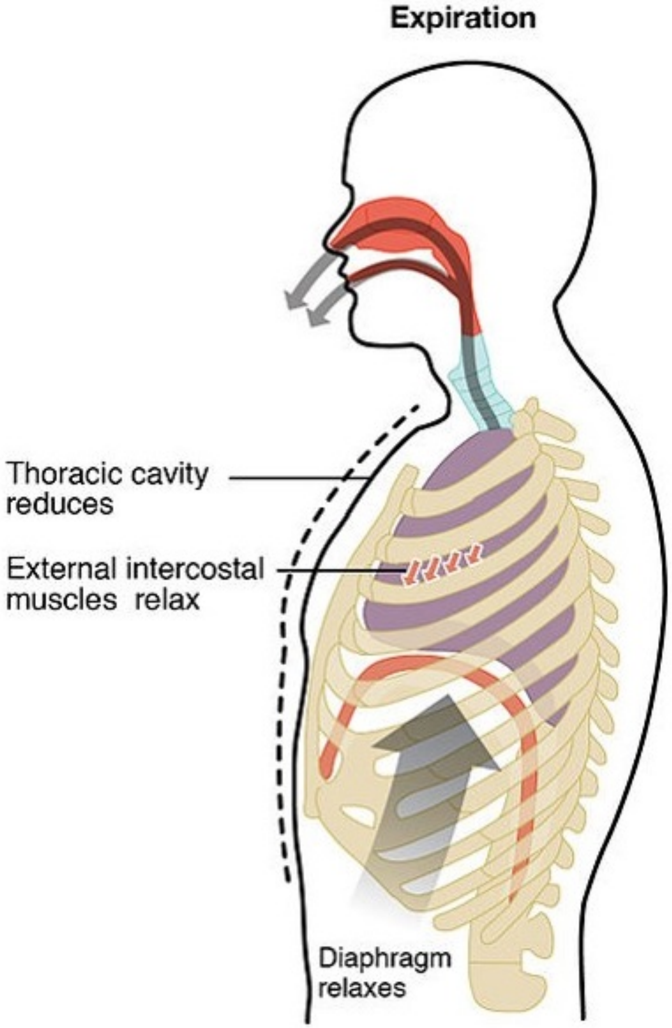
↓ chest volume

↑ IPP (less negative)
-5 cm H_2O

↓ TPP
(P_{alv} – IPP = 0-[-5]=+5 cm H_2O)

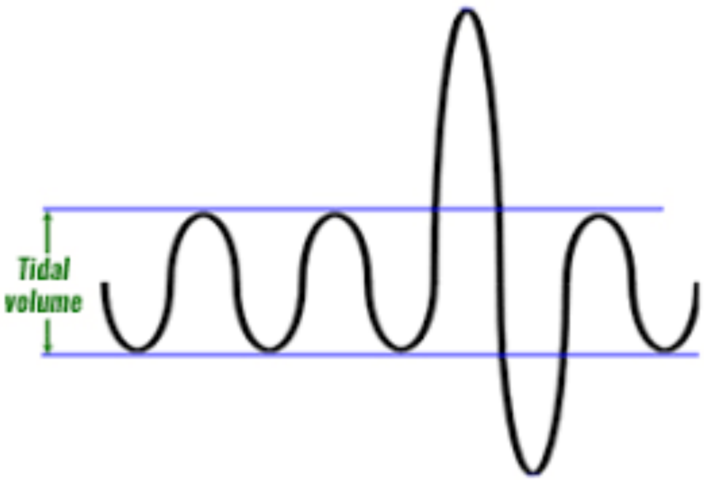
Lung (alveoli) will recoil to preinspiratory volume
(↑ P_{alv} to **+1 cm H_2O**)

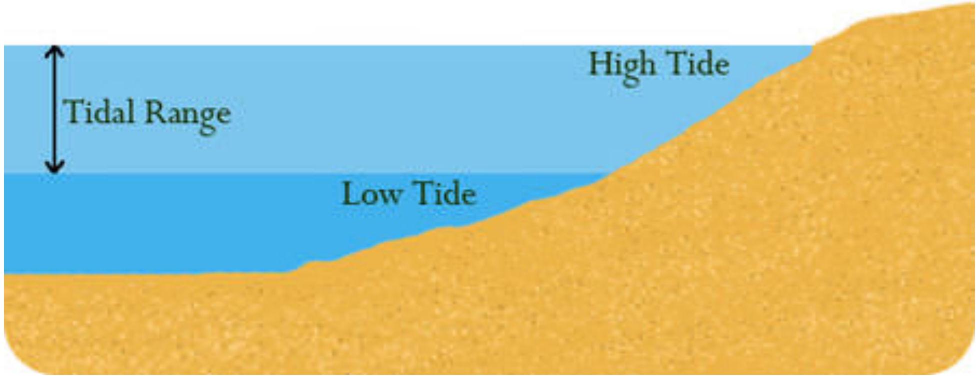
P_{alv} > P_B
Air moves out from lungs into the atmosphere



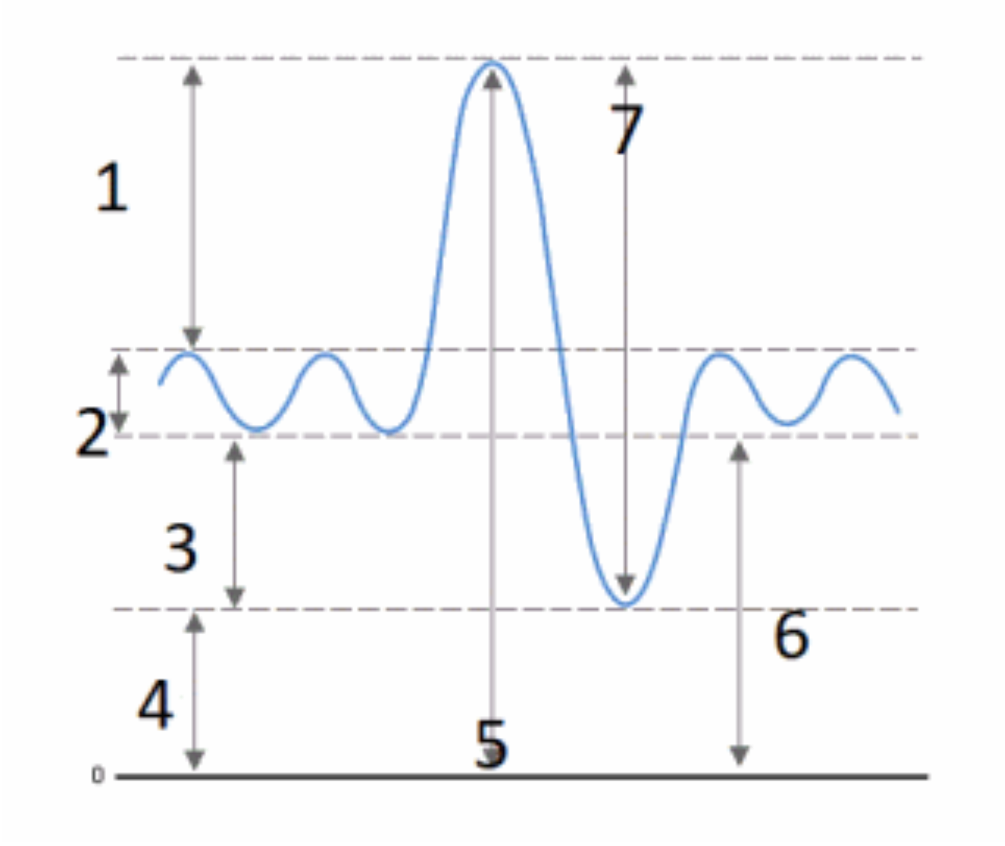
Under normal resting conditions,

How much air moves in or out of the lung during this process (ventilation)?	**500 ml**
What is it called?	Tidal volume





Is the tidal volume the only volume of air that can be breathed in or out of the lungs?



What happens to the TV when it enters the respiratory passages?

Trachea
↓
Bronchi
↓
Terminal bronchiole
Bronchioli ---------- **Alveoli start appearing**
Respiratory bronchiole
↓
Alveolar ducts
↓
Alveolar sacs

Conductive zone: ***No*** **gas exchange**

Respiratory zone: ***Area*** **of gas exchange**

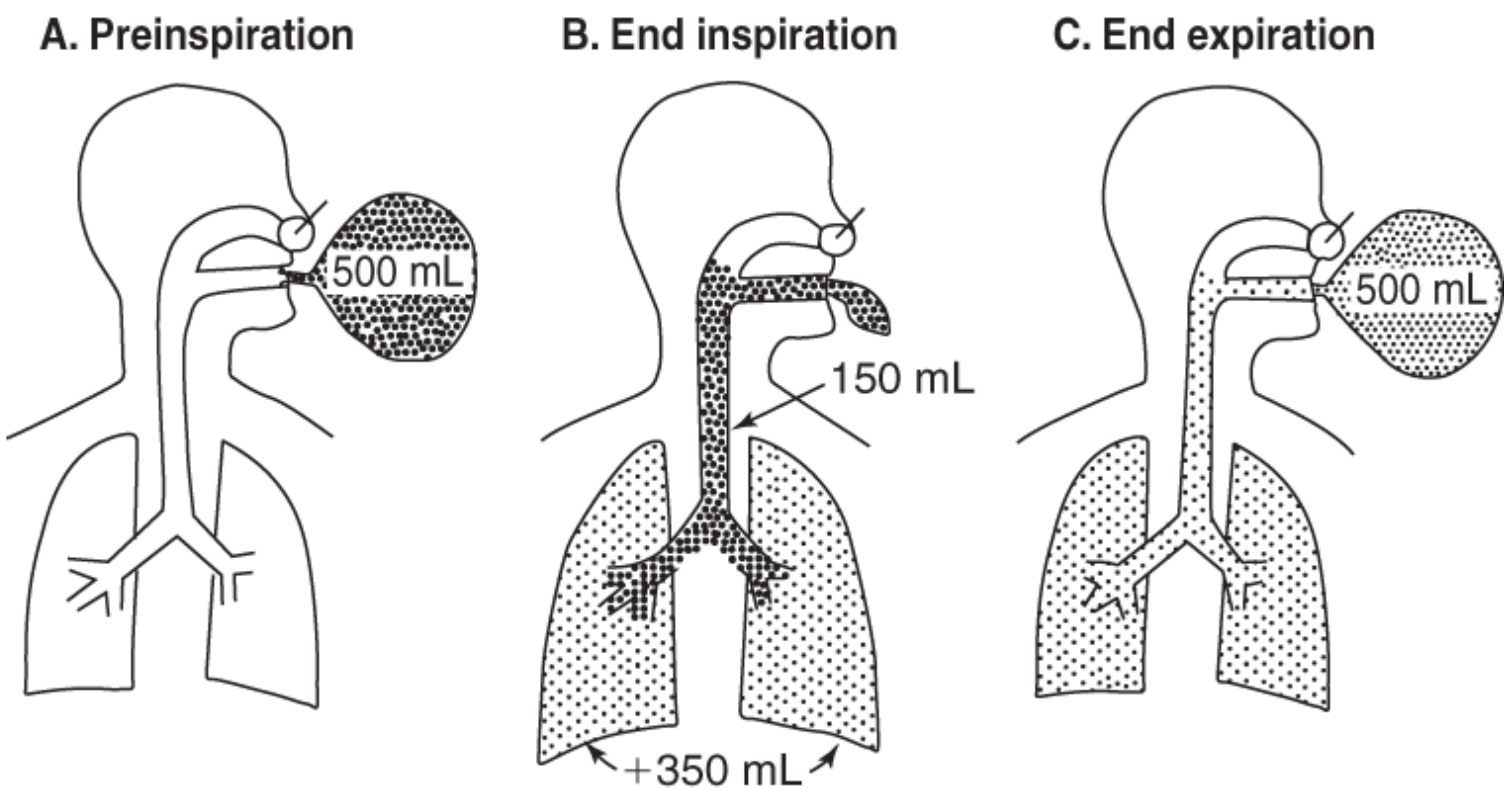
The volume of air occupying the conductive zone is around ***150ml***

This is called "***Anatomical dead space***". V_D

V_A

$$TV = V_D + V_A$$

What happens to the TV when it enters the respiratory passages?



Source: Levitzky MG: *Pulmonary Physiology, Eighth Edition*: www.accessmedicine.com

What are the Partial Pressures of O_2 & CO_2 in Inspired & Expired Air?

- 1st we define pressure.
- ***Pressure*** is force exerted by a fluid (gas/liquid) per unit area.

$$P = \frac{F}{A}$$

- ***Atmospheric pressure*** = the force per unit area exerted by the weight of the atmosphere = 760 mmHg = 1 atm (at sea level).

- Atmospheric dry air is a gas mixture composed of;
  - N_2 = 78.06%
  - O_2 = 20.98% ≈ 21%
  - CO_2 = 0.04%

Partial Pressures of Gases

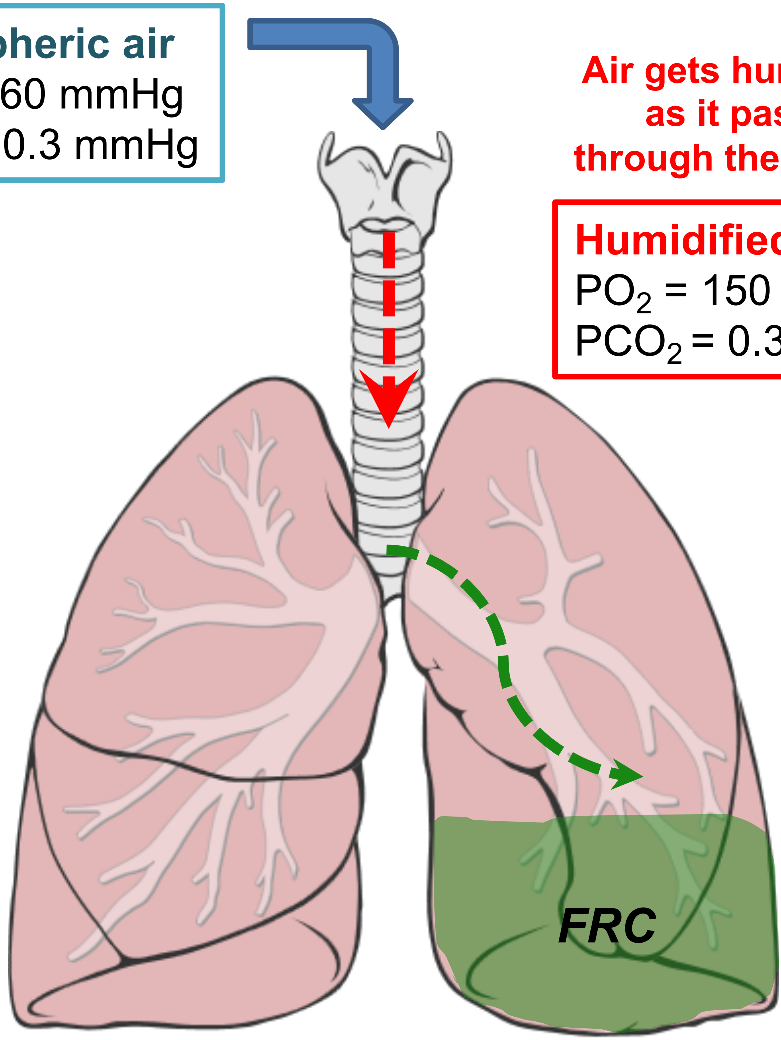
- In a gas mixture, the pressure exerted by any one gas in the mixture is equal to the total pressure of all gases in the mixture X the fractional concentration of that gas in the mixture = ***Partial pressure*** (P)

- PO_2 = 760 mmHg X 21% ≈ 160 mmHg.

- ***Can you calculate the PN_2 and PCO_2 at sea level?***

What Happens to PO_2 and PCO_2 as Inspired Air Passes Through the Respiratory Tract?

Atmospheric air
PO_2 = 160 mmHg
PCO_2 = 0.3 mmHg



Air gets humidified as it passes through the airways

Humidified air
PO_2 = 150 mmHg
PCO_2 = 0.3 mmHg

If you know that water vapour pressure at 37ºC is PH_2O = 47 mmHg, what would happen to PO_2 and PCO_2 flowing in?

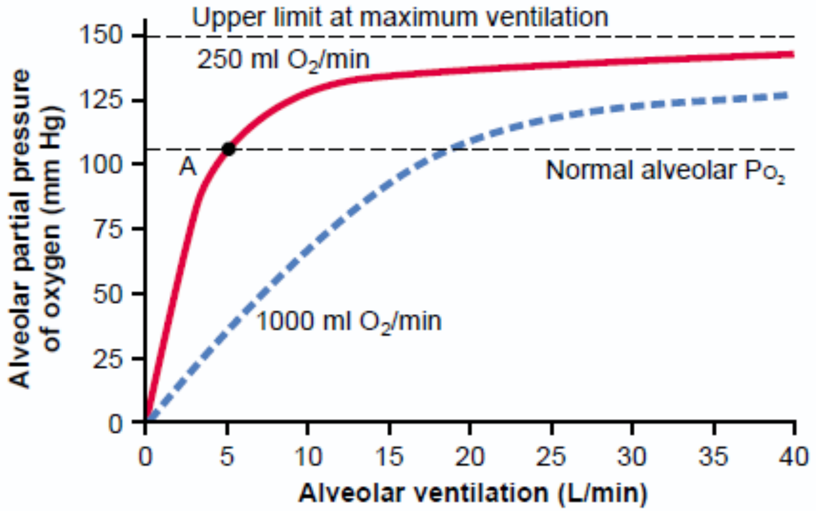
The 350ml of TV that reaches the alveoli mixes with the air present there (FRC)

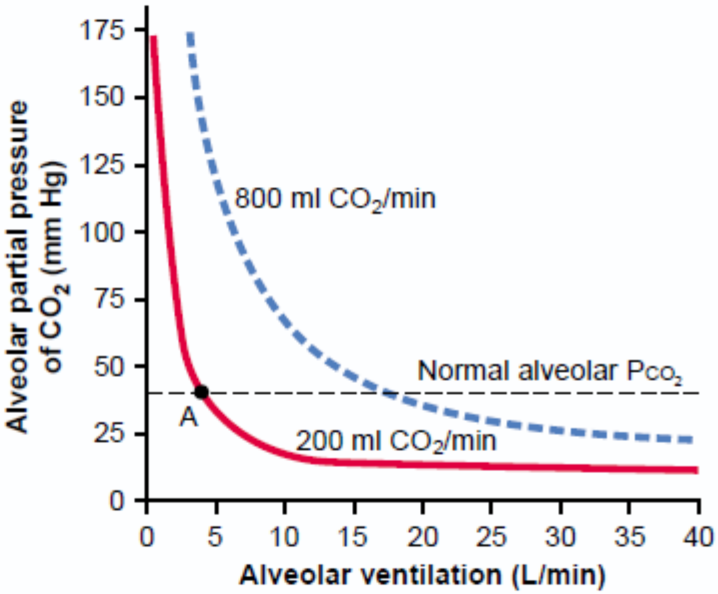
Alveolar air
PO_2 = 104 mmHg
PCO_2 = 40 mmHg

What are the factors affecting alveolar PO_2 and PCO_2?

Factors Affecting Alveolar PO_2 and PCO_2

1. *Rate of alveolar ventilation*





2. *Rate of absorption of O_2 or excretion of CO_2*

At rest, 250ml of ***O_2*** are extracted by tissues at ventilatory rate of 4.2 L/min.

At rest, 200ml of ***CO_2*** are excreted by tissues at ventilatory rate of 4.2 L/min.

Summary

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%)

* On an average cool, clear day.

How do you explain the readings of expired air?!!!

Ventilation is done and air has reached the alveoli

What’s next?

Gas Diffusion from alveoli into the blood

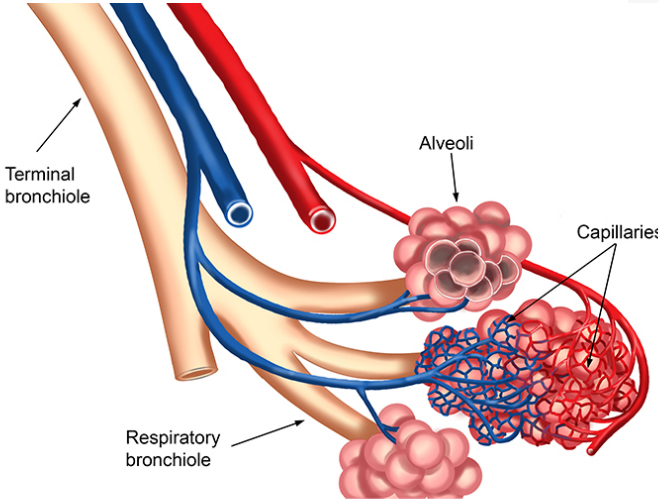
GAS EXCHANGE & GAS TRANSFER

Objectives

- Define partial pressure of a gas, how is influenced by altitude.
- 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)
- Understand that gases in a liquid diffuse from higher partial pressure to lower partial pressure (Henry's Law)
- Describe the factors that determine the concentration of a gas in a liquid.
- Describe the components of the alveolar-capillary membrane (i.e., what does a molecule of gas pass through).
- Identify the various factors determining gas transfer: -
- Surface area, thickness, partial pressure difference, and diffusion coefficient of gas
- 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.

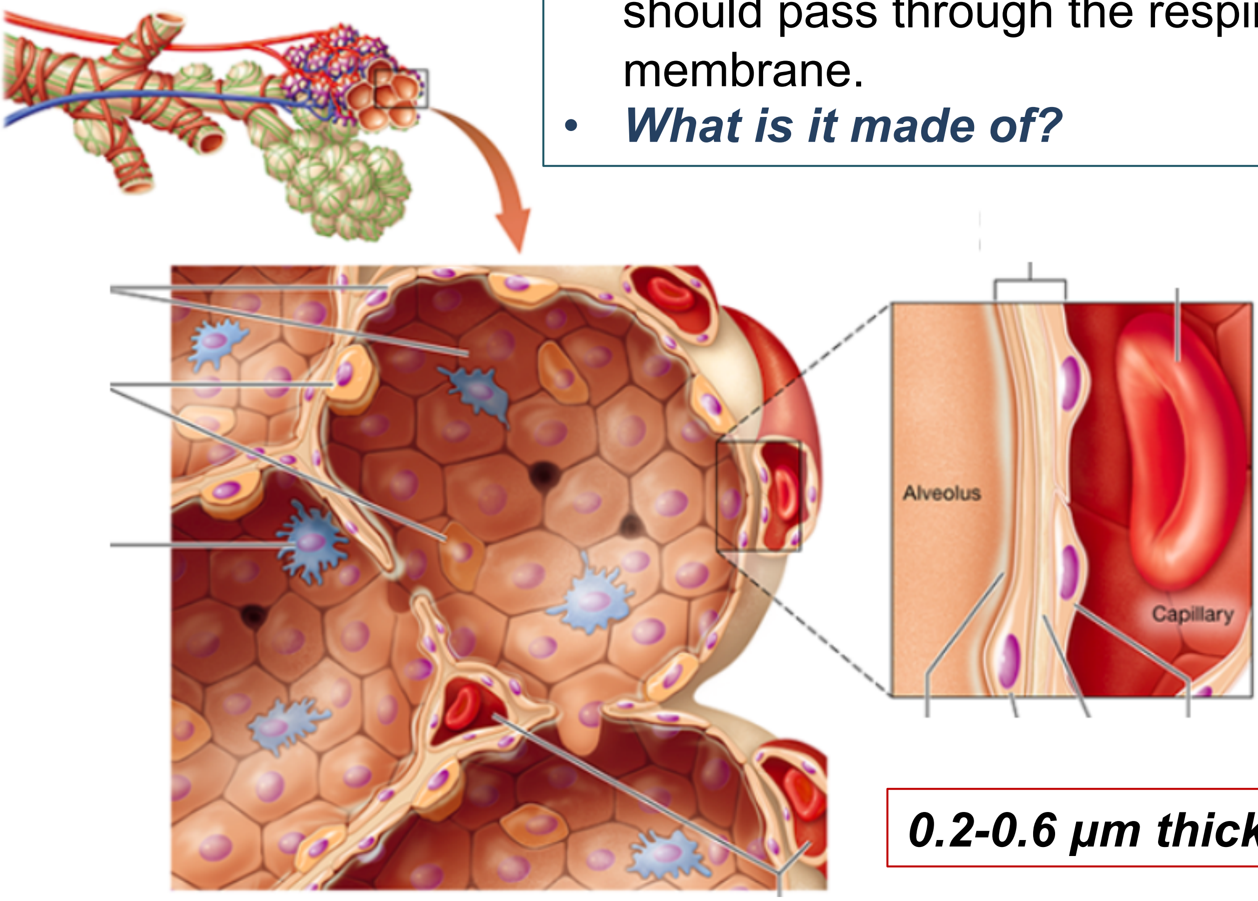
The Respiratory Unit

- Respiratory bronchioles + alveolar ducts + alveoli. The site of gas exchange in the lungs.
- There are around 300 million alveoli in humans.
- The total surface area ≈ $70m^2$ (area of a tennis court).
- The blood present in the capillary bed at any time = 60-140ml.



The Respiratory Membrane

- For gas to diffuse from alveoli to blood, it should pass through the respiratory membrane.
- ***What is it made of?***



1. Layer of fluid.
2. Alveolar epithelium.
3. Epithelial BM.
4. +/- Thin interstitial space.
5. Endothelial BM.
6. Capillary endothelial membrane.

0.2-0.6 µm thick

Factors Affecting Gas Diffusion Across the Membrane

1. Thickness of the membrane.
2. Membrane surface area.
3. Diffusion coefficient of the gas.
   - Depends on: gas solubility and square root of the MW.
4. Partial pressure difference of the gas between the two sides of the membrane.

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

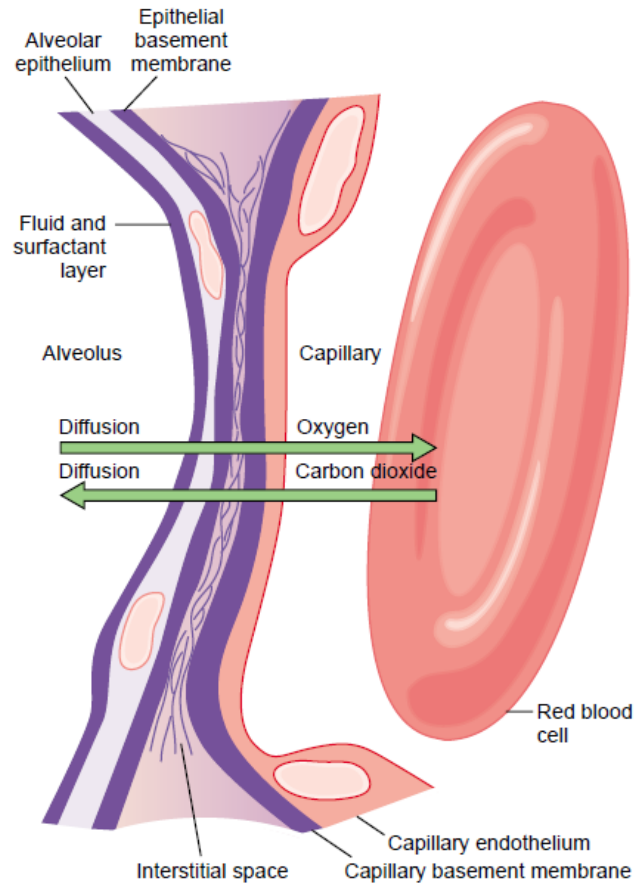


Figure 39–9

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

What Determines the Partial Pressure of a Gas in a Liquid (Blood)

- According to Henry's law;

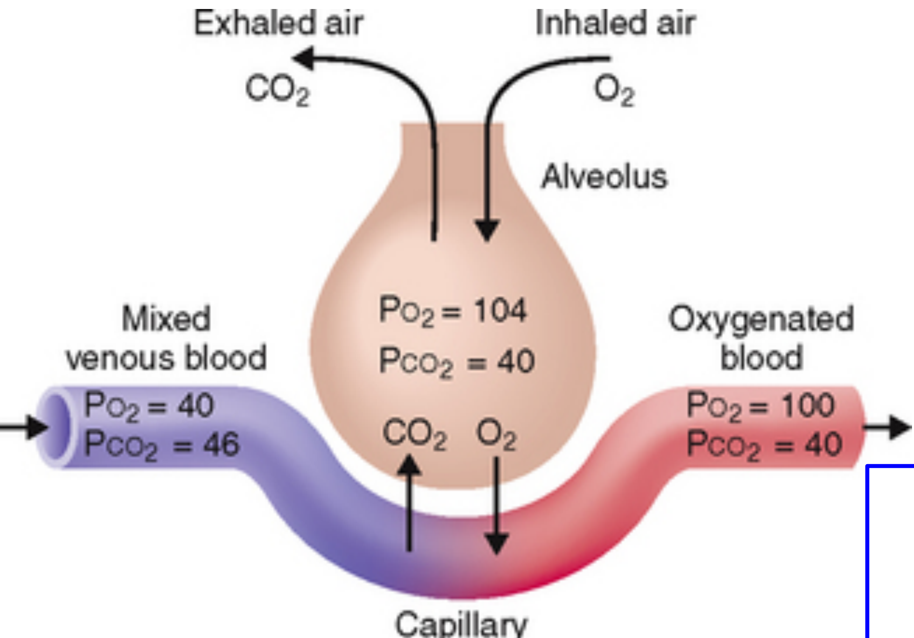
$$\textit{Partial Pressure} = \frac{\textit{Concentration of dissolved gas}}{\textit{Solubility coefficient}}$$

- When a molecule has high solubility, far more can be dissolved without building up excess partial pressure within a solution.

Oxygen	0.024
Carbon dioxide	0.57
Carbon monoxide	0.018
Nitrogen	0.012
Helium	0.008

The solubility coefficient of different gases.
What do you notice?

Diffusion of Oxygen



Diffusion of O_2 from alveoli to pulmonary capillaries

Diffusion of O_2 from tissue capillaries to tissues

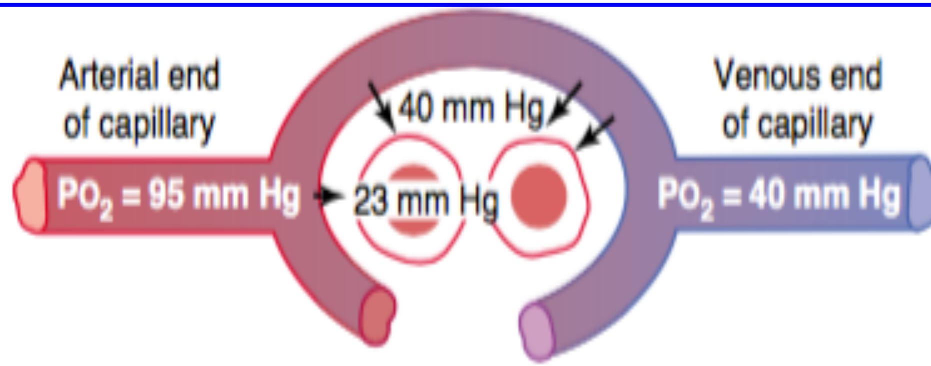


Figure 40–3

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.)

Diffusion of Carbon Dioxide

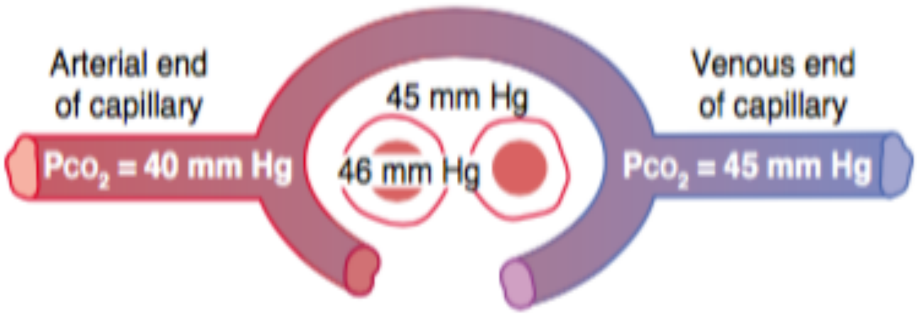
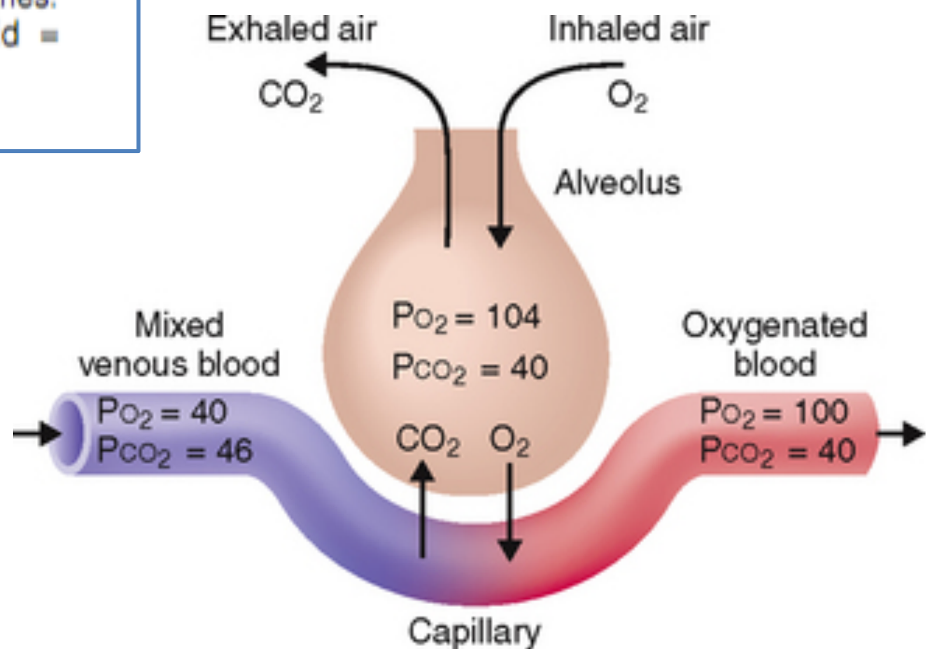


Figure 40–5

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.)

Diffusion of CO_2 from tissues to tissue capillaries

Diffusion of CO_2 from pulmonary capillaries to alveoli



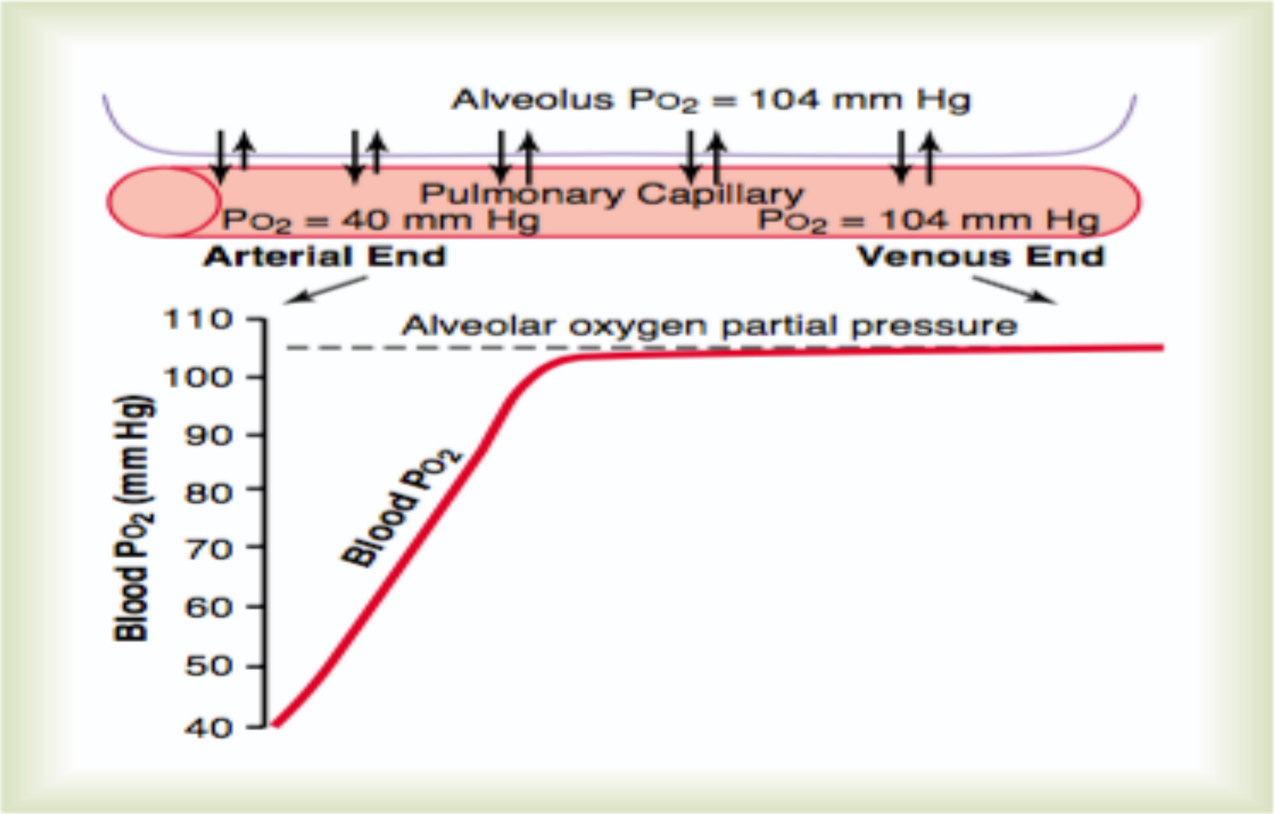


Figure 40–1

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.)

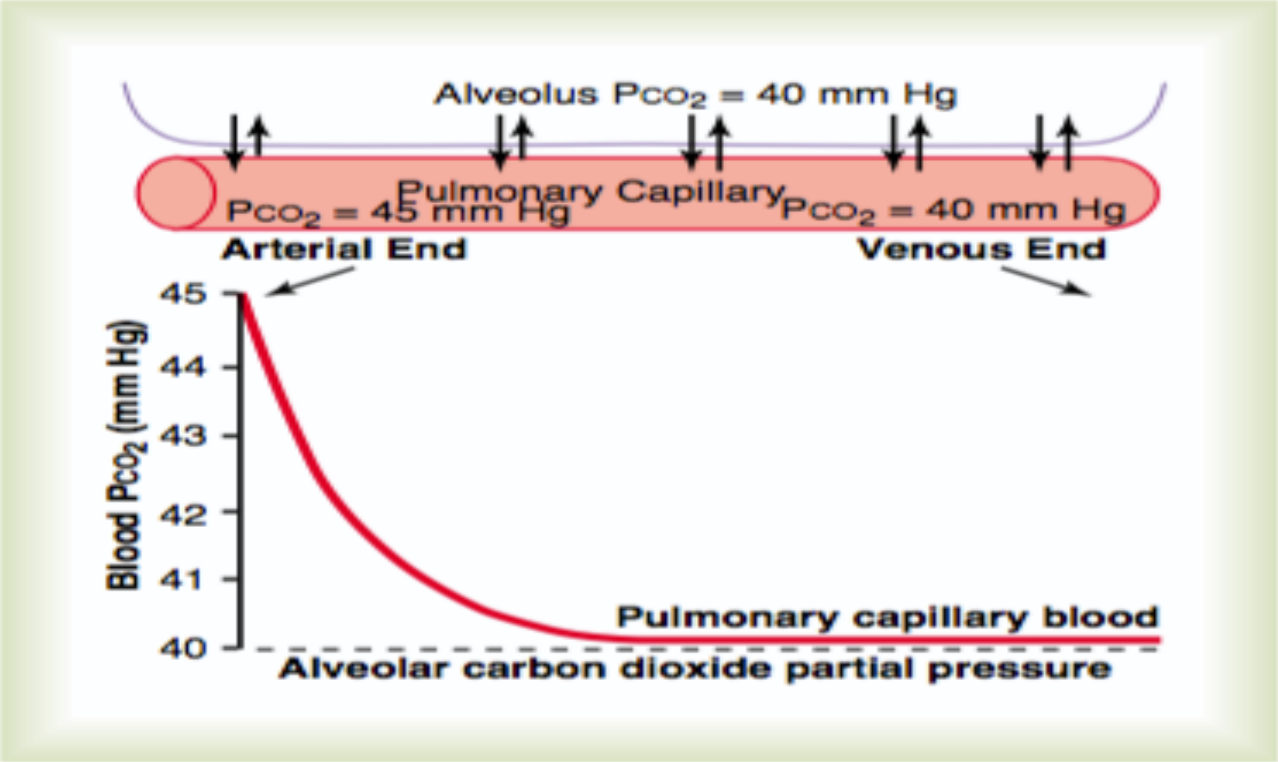
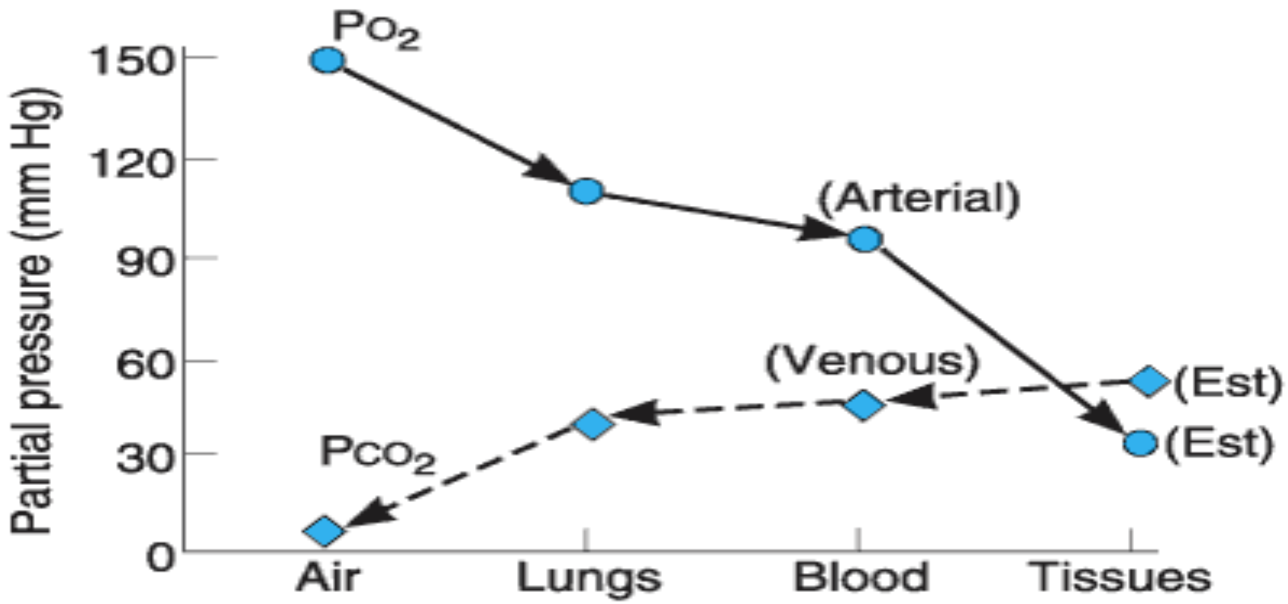


Figure 40–6

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.)

Summary

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.)

Thank you