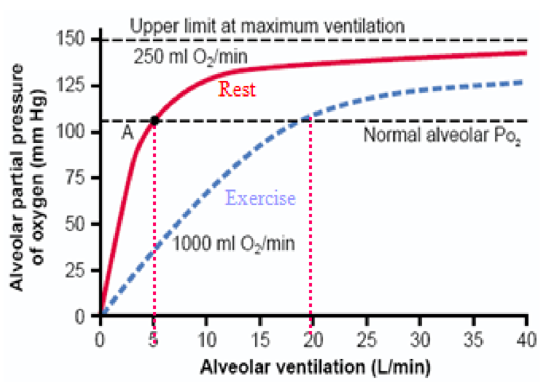
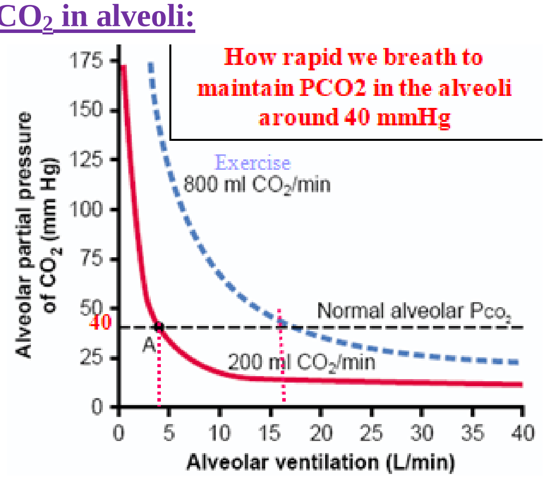
- **Physical principles of gases:**
  - Pressure of a gas is caused by the movement of its molecules against a surface (more concentration of gas molecules = more pressure of that gas).
  - **Partial pressure of a gas dissolved in a fluid is determined by:**
    - ✓ Concentration of that gas.
    - ✓ Solubility coefficient of the gas. Notice that CO_2 is 20 times more soluble than O_2.

      Therefore, partial pressure of a gas = $\frac{Concentration}{Solubility\ coefficient}$
  - Water lines respiratory passages and evaporates to humidify the air which we breath (and this is known as vapor pressure which is equal to 47 mmHg at 37 C).
  - **The rate of gas diffusion in a fluid depends on:**
    - ✓ Its solubility.
    - ✓ Cross-sectional area of the fluid.
    - ✓ The distance through which it diffuses.
    - ✓ Its molecular weight.
    - ✓ Temperature of the fluid.
- **Alveolar air is different from atmospheric air:**
  - Oxygen in alveolar is being constantly absorbed into the blood of pulmonary circulation while CO_2 is constantly diffused from the blood to alveolar air.
  - Humidification of air by water in respiratory passages dilutes oxygen partial pressure from 159 mmHg to 149 mmHg.
  - Notice that only 350 ml of new air is brought to alveoli with each breath (tidal volume = 500 ml but 150 ml is a dead space).
- **Alveolar ventilation and partial pressure of oxygen in alveoli:**
  - To maintain enough partial pressure of oxygen in alveoli (= 104 mmHg). This pressure supplies the body with 250 ml/minute of oxygen. To achieve this goal, we have to breath with a ventilation rate of 4.2 L/minute.
  - During exercise, body needs more than 250 ml/minute of oxygen due to increased oxygen consumption to 1000 ml/minute. To achieve this goal, we have to increase ventilation rate from 4.2 L/minute to 18 L/minute.

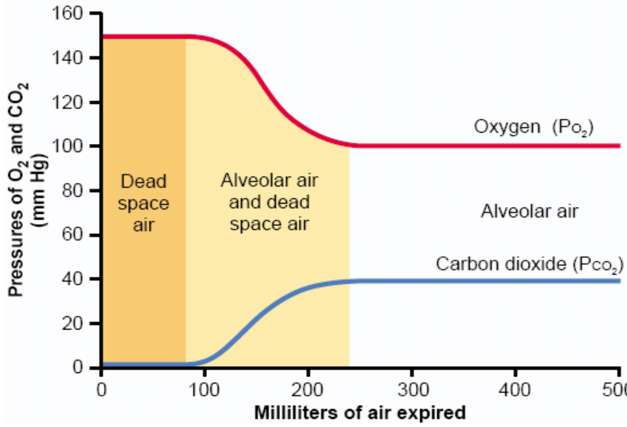


- **Alveolar ventilation and partial pressure of CO_2 in alveoli:**
  - Normal CO_2 excretion is 200 ml/minute. To achieve this, ventilation rate has to be 4.2 L/minute with a CO_2 alveolar partial pressure of 40 mmHg.
  - If CO_2 excretion rate is increased to 800 ml/minute, this needs a ventilation rate of 18 L/minute to produce the same alveolar partial pressure of CO_2 (40 mmHg).

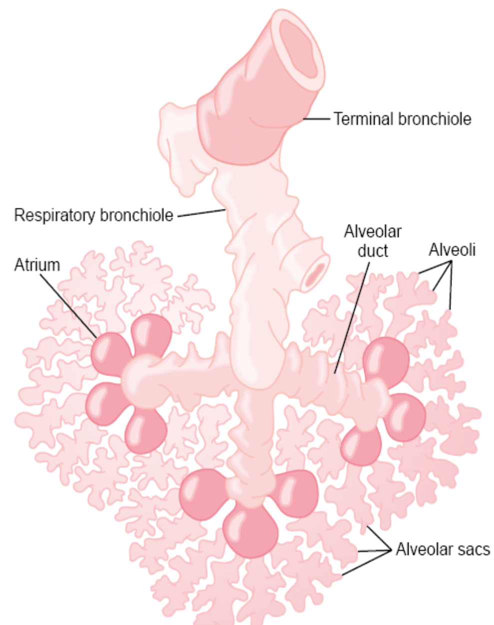


- **Expired air:**
  - First portion of expired air is entirely a dead space of humidified air (very high oxygen and very low CO2). Then, more

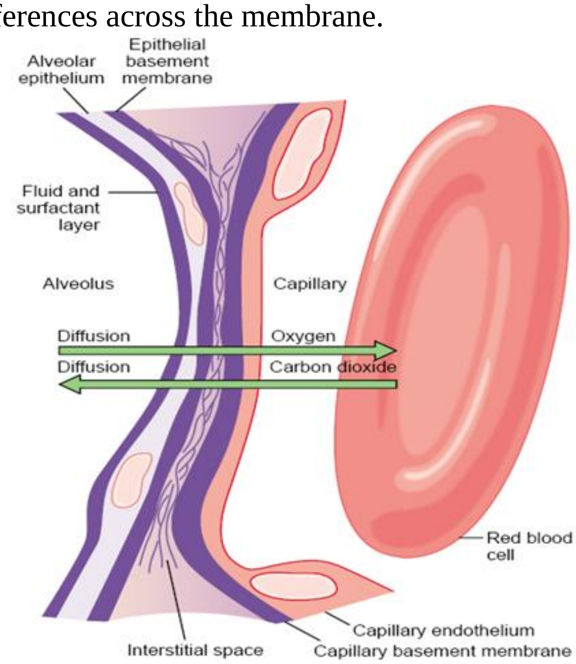
and more alveolar air (more CO2 and less oxygen) becomes mixed with the dead space air until all becoming alveolar air. To test alveolar air, the last portion of the forced expiration volume should be taken.



- **Gas diffusion through respiratory membrane:**

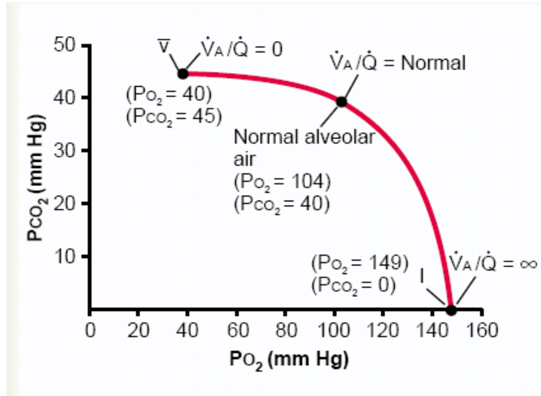


- Gas exchange occurs in: terminal portions of the lung and alveoli.
- **Remember from your anatomy that respiratory unit is composed of:**
  - ✓ Respiratory bronchioles.
  - ✓ Alveolar ducts.
  - ✓ Atria.
  - ✓ Alveoli.
- Surface area of respiratory membrane = 70 m^2 while blood in lung capillaries = 60-140 ml (small quantity of blood over large surface area and this insures rapid gas exchange).
- **Factors which affect gas diffusion:**
  - ✓ Thickness of respiratory membrane.
  - ✓ Surface area of respiratory membrane.
  - ✓ Diffusion coefficient which depends on solubility and molecular weight of the gas.
  - ✓ Pressure differences across the membrane.



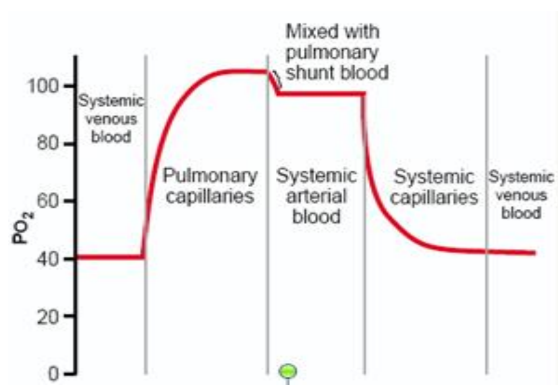
- **Respiratory membrane diffusion capacity:**
  - ✓ Definition: it is the volume of the gas which will diffuse through respiratory membrane each minute.
  - ✓ The diffusion capacity of oxygen = 21 ml/minute/mmHg.

- **Ventilation-perfusion ratio (V_A/Q):**

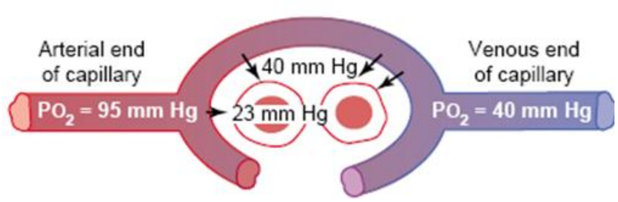


  - It is zero when there is no ventilation. Therefore, partial pressure of gases in alveoli is similar to those in capillaries because there is no gas exchange occurring (oxygen = 40 mmHg; CO_2 = 45 mmHg).
  - It is infinity when perfusion is zero. Therefore, partial pressure of gases in alveoli is similar to those in humidified air (oxygen = 149 mmHg; CO_2 = 0 mmHg).
  - **Normal**: values lie between the atmospheric air and venous blood, so 104 mmHg for oxygen (inspired is 149 and venous 40) and 40 mmHg for CO_2 (inspired zero and venous 45).
  - **Upper and lower parts of the lung:**
    - ✓ Upper part: both (ventilation and perfusion) are less, but blood perfusion is far more reduced. This leads into a V_A/Q ratio of about 2.5 times normal. This results in physiologic dead space (when the V_A is greater than Q, so not all the oxygen coming by good ventilation is taken by the blood).
    - ✓ In lower lung: the perfusion of blood is far more than ventilation. The ratio becomes about 0.6 and this causes physiologic shunt.
  - **In chronic obstructive lung disease, there are two abnormalities seen:**
    - ✓ Some bronchioles are obstructed: no air reach them but they are well perfused. The V_A/Q ratio is approaching zero, so there is Physiologic shunt.
    - ✓ Other bronchioles have destruction of walls, and still there is ventilation which is wasted because of inadequate blood flow. This gives V_A/Q ratio of greater values resulting in physiologic dead space.

- **Transport of oxygen and CO_2:**

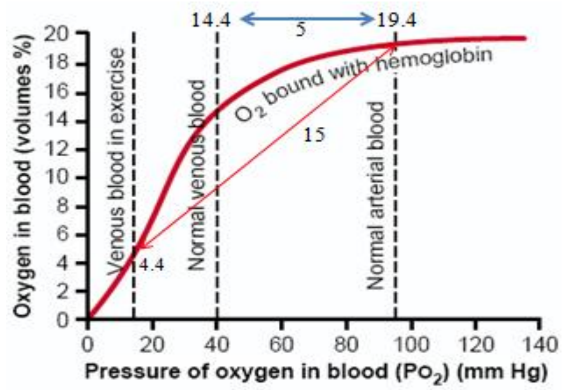


  - Blood passing through capillaries and forming respiratory membrane with air present in alveoli will be oxygenated with a partial pressure of oxygen reaching 104 mmHg but this is going to drop to 95 mmHg after mixing with bronchial blood.
  - The partial pressure of oxygen in arterial blood is 95 mmHg. This is going to drop to 40 mmHg when oxygen diffuses to interstitial fluid which further drops to 23 mmHg when supplying cells with oxygen. Although there is a huge drop as oxygen travels until it reaches the cells, but only partial pressure of oxygen of 1-3 mmHg is needed by cells for their metabolism. Therefore, there will be no problem.

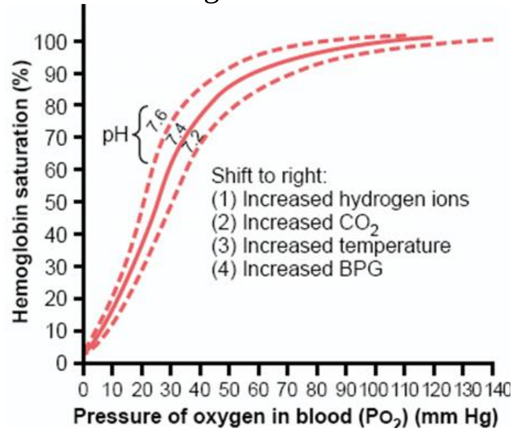


  - Blood passing to the lungs has a partial pressure of CO_2 of 45 mmHg. When CO_2 diffuses from the blood to alveoli to be excreted, partial pressure of CO_2 in blood returning to system circulation is 40 mmHg.
  - As this blood goes to the cells to provide oxygen, CO_2 will diffuse from cells to the blood raising its partial pressure of CO_2 to 45 mmHg and the cycle is repeated.

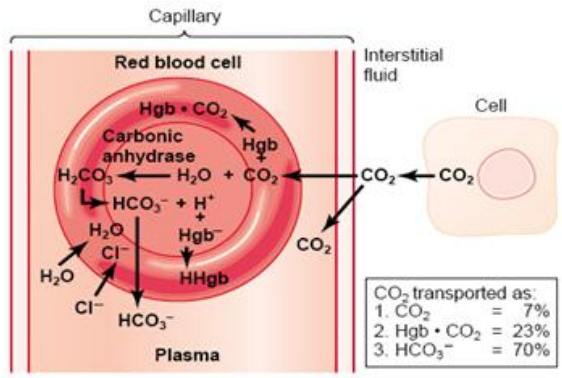
- **Oxygen-hemoglobin dissociation curve:**
  - **How is oxygen carried in the body?**
    - ✓ 97% carried by hemoglobin.
    - ✓ 3% dissolved in plasma.
  - Hemoglobin (Hb) binds oxygen when partial pressure of oxygen is high (95 mmHg in systemic circulation).
  - There is 15 g of Hb in 100 ml of blood. Each gram can carry 1.34 ml of oxygen. Therefore, 100 ml of blood can carry (15 x 1.34 = 20.1 ml of oxygen).
  - Notice that in arterial blood oxygen content is 19.4 ml/100 ml (20.1 is approximated) while oxygen content in venous blood is 14.4 ml/100 ml. Therefore, about 5 ml of oxygen is transported from lungs to tissues by each 100 ml of blood flow.



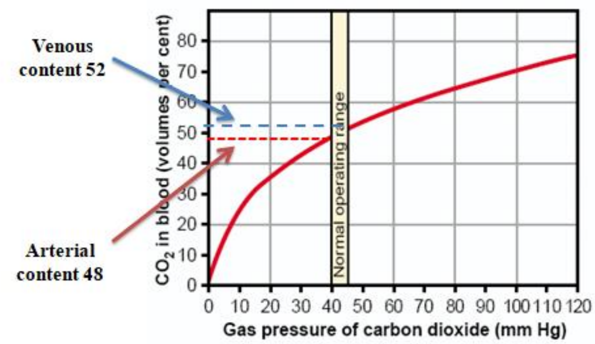
  - In exercise, the interstitial fluid partial pressure of oxygen may drop to 15 mmHg. In such low oxygen partial pressure, only 4.4 ml of oxygen is still bound to Hb/ 100 ml of blood. This means that (19.4- 4.4 = 15 ml of oxygen is delivered to tissues) that is 3 folds more/ 100 ml of blood in exercise.
  - **Bohr effect:**
    - ✓ There is increased delivery of oxygen to tissues when CO_2 and hydrogen ions shift the oxygen-hemoglobin dissociation curve to the right.
    - ✓ BPG (Bi-phospho-glycerate, which shifts the graph to the right) is released in hypoxic conditions that last longer than few hours.



  - **Oxygen transport as dissolved in plasma**: only 0.17 ml/100 ml of blood (compared to 5 ml) of oxygen is transported dissolved in plasma (this represents 3% of the form in which oxygen is carried in the body).
- **Carbon monoxide (CO)-hemoglobin dissociation curve:**
  - CO combines Hb at the same site of oxygen. The curve is similar to oxygen-hemoglobin dissociation curve but notice that CO has higher affinity to bind Hb than oxygen (CO attaches to 1 site of Hb causing 3 remaining sites to retain oxygen tightly, so there will be no hypoxemia).
- **CO_2 transport in the blood:**
  - 30% of CO_2 is carried by combining to Hb (carbaminoHb) and to plasma proteins, but this reaction is much slower than transport of CO_2 as HCO_3 (70%).\

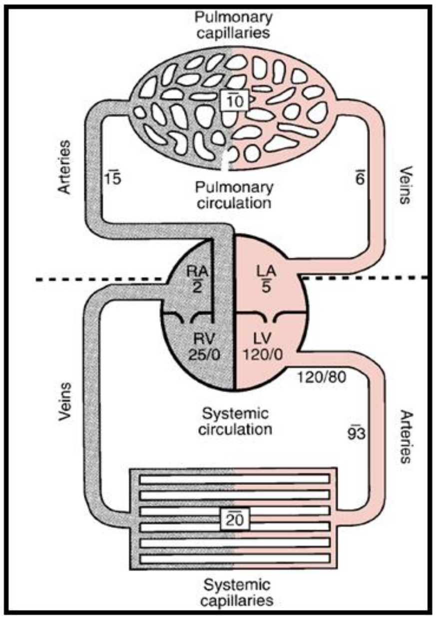


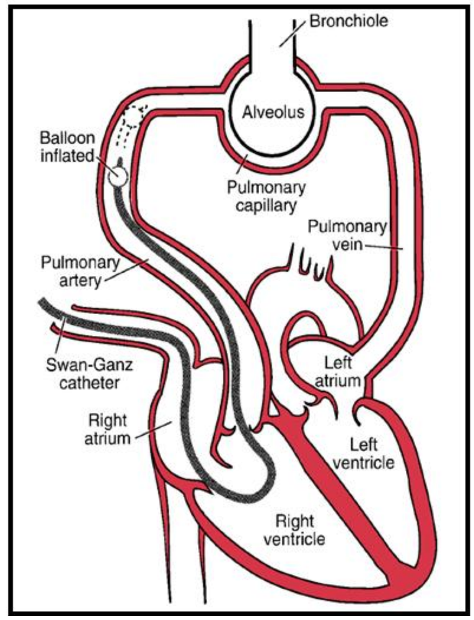
- **<u>CO_2 dissociation curve:</u>**
  - Normal blood Partial pressure of CO_2 ranges between 40 mmHg in arterial and 45 mmHg in venous blood. The volume % content of CO_2 in arterial blood (PCO_2 = 40) is 48 volumes per cent, while the volume % in the venous blood (PCO_2 = 45) is 52 per cent, so only 4 volumes % is exchanged during the transport from the tissues to the lungs.



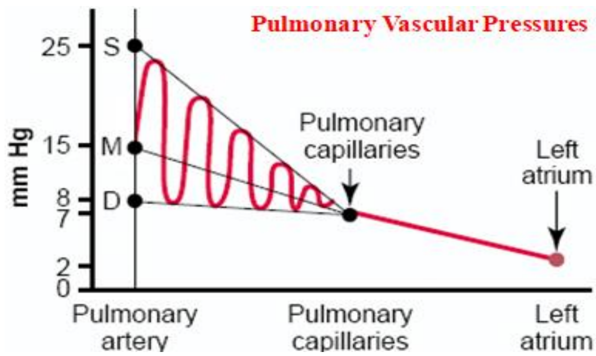
  - **Haldane effect**: it is the reverse of Bohr effect in which binding of oxygen with Hb tends to displace CO_2 from the blood. Haldane effect works by decreasing the tendency of Hb to combine with CO_2
  - **Respiratory exchange ratio (R):**
    - ✓ R= Rate of CO_2 output (4ml) / Rate of oxygen uptake (5ml) = 0.8.
    - ✓ If one eats only carbohydrates then (R) rises to 1 (every oxygen used gives CO_2). If fats are only eaten the R = 0.7 (large number of oxygen combine with H ions from fats to make H_2O instead of CO_2).
- **<u>Pulmonary circulation:</u>**
  - **Pulmonary arteries have large compliance (why?): because they are**
    - ✓ Short branches.
    - ✓ Larger diameters.
    - ✓ Thin and distensible.

    Notice that blood returns to left atrium of the heart by pulmonary veins.
  - **Pressures which you should memorize:**
    - ✓ <u>Right ventricle pressure</u>: 25 mmHg systolic; 0 mmHg diastolic.
    - ✓ <u>Pulmonary artery pressure</u>: 25 mmHg systolic; 8 mmHg diastolic.
    - ✓ <u>Pulmonary capillary pressure</u>: 7 mmHg.
    - ✓ <u>Left atrium pressure</u>: 1-5 mmHg (average 2 mmHg).
  - **Pulmonary wedge pressure**: it is recorded by a catheter introduced through the skin to the right ventricle of the heart. Then passing it through pulmonary artery till it wedges tightly in a small branch. When left atrial pressure rises the pulmonary wedge pressure rises too.
  - **Blood flow through the lungs**: when there is local hypoxia in the lung (area of the lung in which there is ventilation defect), there will be release of vasoconstrictor substances shifting blood flow to more oxygenated part of the lung (thus gas exchange can occur).



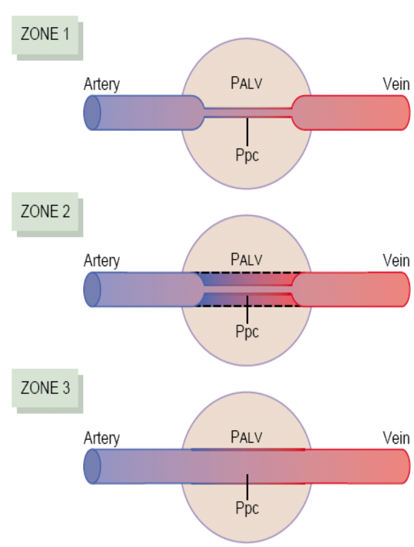


- **Pulmonary vascular pressures**: systolic pulmonary artery pressure averages 25 mmHg, the diastolic pressure is 8 mmHg and the mean pressure is about 15 mmHg. The pulmonary capillary pressure is about 7 mmHg which is higher enough than the left atrial pressure (by about 2 mmHg)



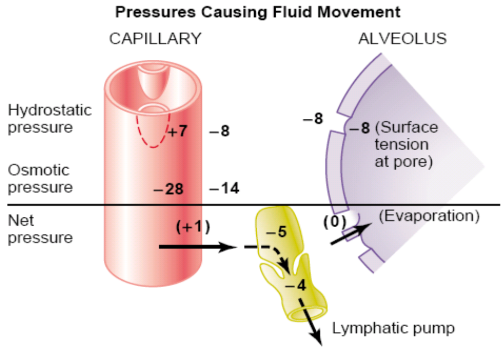
- **The lung acts as a blood reservoir**: the blood volume in the lung is equal to 450 ml (notice that lung can accommodate more volume of blood or provide the body with blood when there is hemorrhage).
- During exercise, the pulmonary blood flow increases a lot (to increase needed oxygenation of blood). This may increase the pulmonary pressure leading into right ventricle strain and pulmonary edema (by increasing the hydrostatic capillary pressure). This is prevented by:
  - ✓ Opening of the normally closed capillaries.
  - ✓ Distending the already opened capillaries.
- **Lung blood flow:**
  - ✓ Zone-1: there is **no blood flow**. Alveolar air pressure (PALV) is greater than pulmonary capillary pressure (Ppc).
  - ✓ Zone-2: **intermittent blood flow**. Pulmonary capillary pressure is only greater than alveolar air pressure during systole.
  - ✓ Zone-3: **continuous blood flow.** Pulmonary capillary pressure is greater than alveolar air pressure in both systole and diastole.

    Notice that normally the apex of the lung is represented by zone-1 while lower part of the lung is represented by zone-3.



- **Fluid movement across respiratory membrane:**
  - ✓ <u>Forces which move fluid out of the capillaries are:</u>
    - ❖ Capillary pressure: 7 mmHg.
    - ❖ Interstitial fluid colloid osmotic pressure: 14 mmHg.
    - ❖ Negative interstitial fluid pressure: 8 mmHg.
    - ❖ Total = 29 mmHg.
  - ✓ <u>Forces which move fluid into capillaries are:</u>
    - ❖ Plasma colloid osmotic pressure: 28 mmHg.

    Notice that a net of 1 mmHg (net filtration pressure) moves the fluid out of capillary.



  - ✓ <u>Normally alveoli are kept DRY because of:</u>
    - ❖ The negative pressures in the lymphatic capillaries and interstitial spaces which sucks all the fluids from the alveoli.
    - ❖ Very little fluid entering alveoli will be evaporated out.
  - ✓ When the left atrial pressure rises more than the colloidal pressure (28 mmHg), fluid leaks into the alveoli causing pulmonary edema. Therefore, the pressure must arise from the normal values of 5 mmHg to as high as 28 mmHg. This is called (safety factor) for pulmonary edema. In chronic conditions, the edema is not fatal and the lung can deal with high pressures (as high as 40 mmHg) because in this case the lymphatics expand greatly and their capability to carry fluid away is big.