# *THE BLOOD FLOW*

What is flow rate of blood?

It is volume of blood passing through a vessel per unit time. Flow rate is directly proportional to the pressure gradient and inversely proportional to vascular resistance.

$$\mathbf{F} = \frac{\mathbf{\Delta P}}{\mathbf{R}}$$

Where F: is flow rate of blood through vessel,

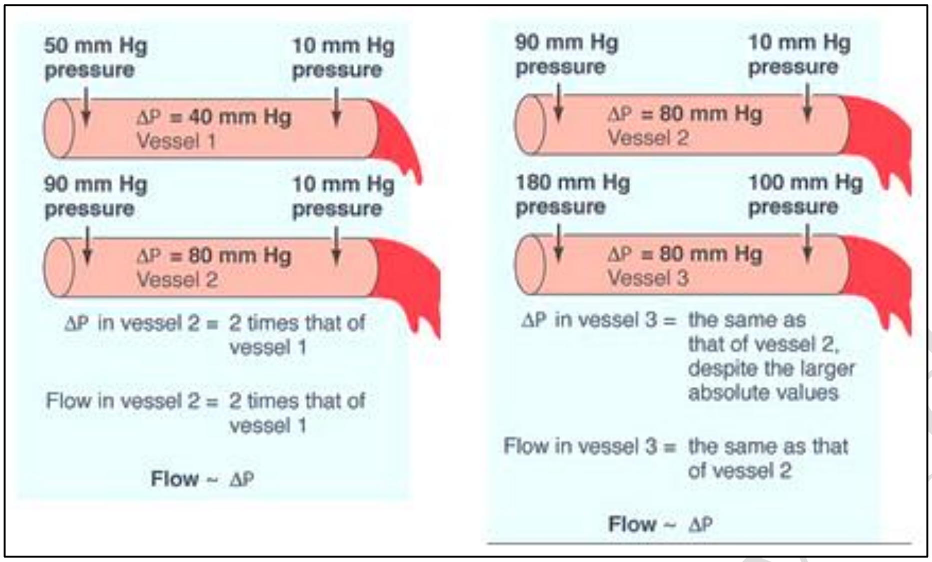
$\Delta P$: is pressure gradient.(which is difference in pressure between the beginning and end of vessel, and blood flow from area of high pressure to an area of low pressure), In practice, this means blood will flow from the arterial end of a vessel to the venous end. This pressure gradient is primarily created by the pumping action of the heart.

$R$: is resistance of blood vessel (caused by friction between the blood in the vessel wall).

If resistance to flow increase, it is difficult for blood to pass through a vessel, therefore, flow rate decrease. When resistance increase, the pressure gradient must increase to maintain the same flow rate.

What is Blood flow through a vessel depends on?

- Directly proportional to Pressure differences.
- Inversely proportional to Vascular resistance.




What is the resistance to blood flow depends on?

1- Viscosity of blood (η): referred to the fluid's resistance to flow, which is caused by a shearing stress within a flowing fluid and between a flowing fluid and its container. For example, syrup has a higher viscosity than water.
   Blood viscosity determined by number of circulating (RBC), and it increased in Polycythemia and decreased in Anemia.

2- Viscosity decrease with increasing temperature.

3-vessel length: greater the length of vessel, more will be resistance.

4-redius of the vessel: it is the most important factor to determine the resistance to flow. The resistance is inversely proportional to the fourth power of the radius.

## ***Medical definition of Poiseuille's law:***

A statement in physics: the velocity of the steady flow of a fluid through a narrow tube (as a blood vessel or a catheter) varies directly as the pressure and the fourth power of the radius of the tube and inversely as the length of the tube and the coefficient of viscosity.

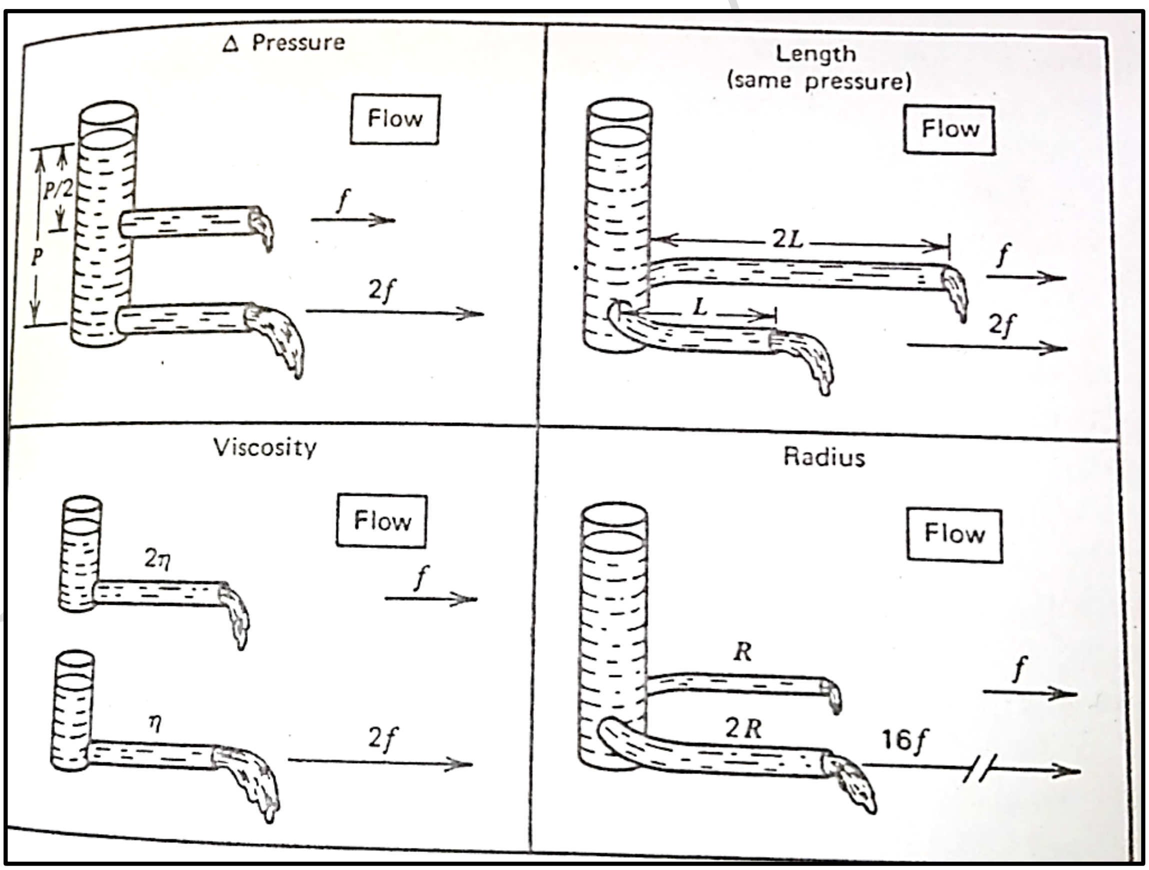
$$\textbf{Flow rate} = \frac{\pi}{8}\frac{\Delta P\, r^4}{\eta\, L}$$

$\Delta P$: pressure gradient (↑pressure gradient= ↑flow).

r: radius (↑radius=↑flow).

$\eta$:viscosity (↑ viscosity=↓flow).

L: length (↑length=↓ flow).

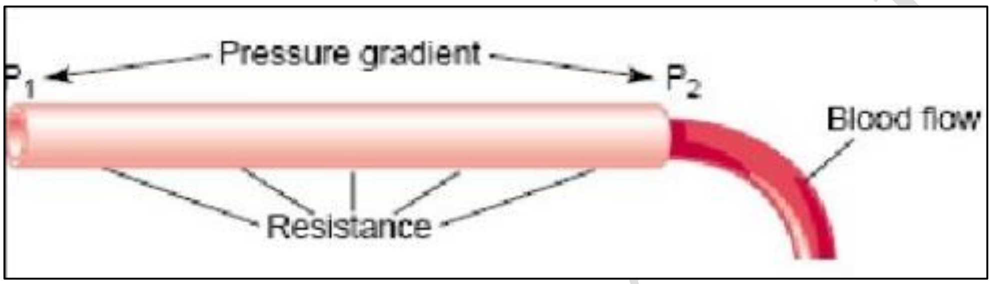


## ***Ohm's Law applied to blood flow:***

To understand the steady flow of blood, we can apply classical hydrodynamic laws. The most important law is analogous to Ohm's law of electricity.

$$I = \frac{\Delta V}{R} \quad (for\ electricity)$$

$$F = \frac{\Delta P}{R} \qquad (for\ liquid)$$




## ***Continuity equation:***

* the continuity equation ties together the relationship between the vessel area, the velocity of blood and the volume of blood flow.

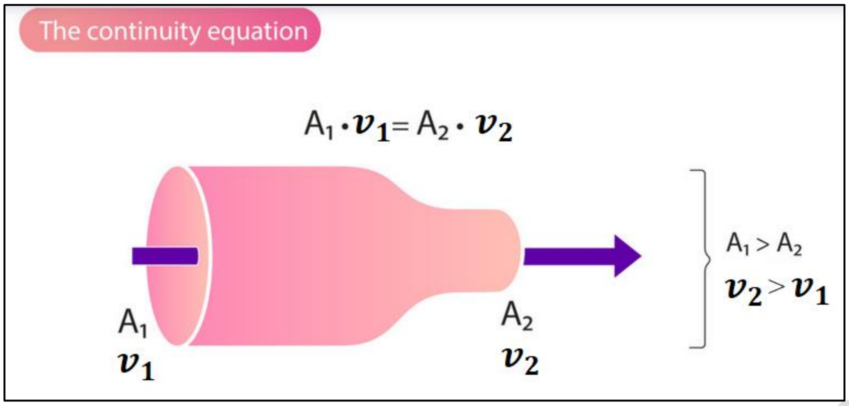
Mass flow rate

From density formula

$$\frac{m}{t} = \frac{\rho\, V}{t} = \frac{\rho\, A\, L}{t} = \rho\, A\, v$$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

*the continuity equation is explained by the fact that the velocity of blood is inversely related to the area of the orifice, velocity increase with diminishing area of the orifice and vice versa.




*Flow of blood is faster in the main artery than in the blood capillaries? Why ? Because the sum of cross-sectional areas of blood capillaries is greater than the cross-sectional area of the main artery and since ($v \propto \frac{1}{A}$) , so , speed of blood decreases in the blood capillaries to allow exchange of oxygen and carbon dioxide gases in the tissues to supply it with food .

Example: the speed of blood in the aorta is (50 cm/sec) and this vessel has a radius of (1cm). if the capillaries have a total cross sectional area of ($3000cm^2$), what is the speed of the blood in them?

Solution:

$$A_1 v_1 = A_2 v_2$$

$$(\pi r_1^2\ )v_1 = A_2 v_2$$

$(3.14 \times 1^2\ ) \times 50 = 3000 \times v_2 \longrightarrow v_2 =$0.052cm/sec

***Example***

An artery with a (3mm) radius is partially blocked with plaque in the constricted region, the effective radius is (2mm) and the average blood velocity is (50cm/sec).

What is the average velocity of the blood in the constricted region?

Solution:

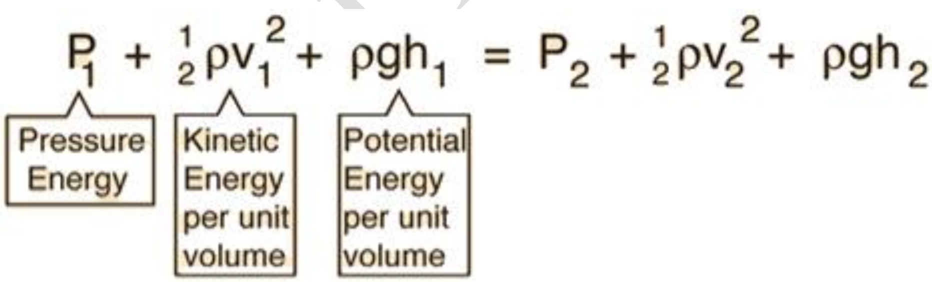
$$r_1 = 3mm, \quad r_2 = 2mm$$

$$A = \pi r^2, \qquad A_1 v_1 = A_2 v_2$$

$$v_1 = \frac{A_2 v_2}{A_1} = \frac{\pi(2 \times 10^{-1})^2 * (50cm/sec)}{\pi(3 \times 10^{-1})^2} = \frac{4}{9} * 50 = 22cm/sec$$

## ***Blood Flow and Heart Attack:***

*Bernoulli's principle says that the sum of potential, kinetic and pressure energy per unit mass of incompressible, non-viscous fluid remains constant.

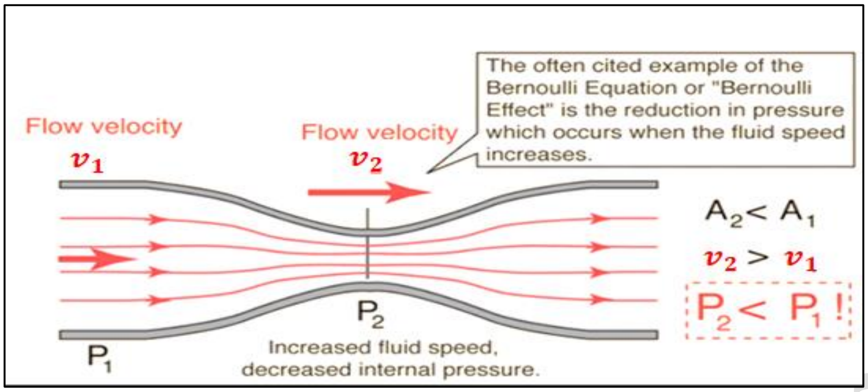



*Bernoulli's principle states that an increase in velocity must be accompanied by a corresponding decrease in pressure.

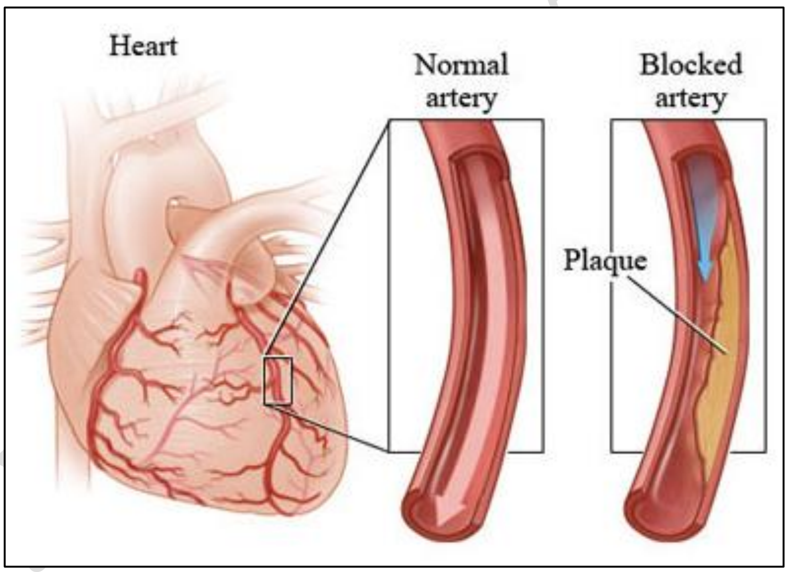
$$v \,\alpha\, \frac{1}{p}$$

* We know if the cross sectional area decreases, the velocity of the blood will increase.

$$v \,\alpha\, \frac{1}{A}$$



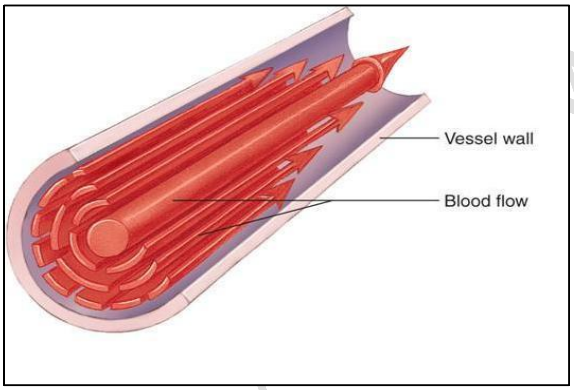

*Bernoulli's principle helps in explaining blood flow in artery. The artery may get constricted due to the accumulation of plaque on its inner walls. This happens because of high cholesterol intake. In order to drive the blood through this constriction a greater demand is placed on the activity of the heart.




* The speed of the flow of the blood in this region is raised which lowers the pressure inside and the artery may collapse due to the external pressure. The heart exerts further pressure to open this artery and forces the blood through. As the blood rushes through the opening, the internal pressure once again drops due to same reasons leading to a repeat collapse. This may result in heart attack.

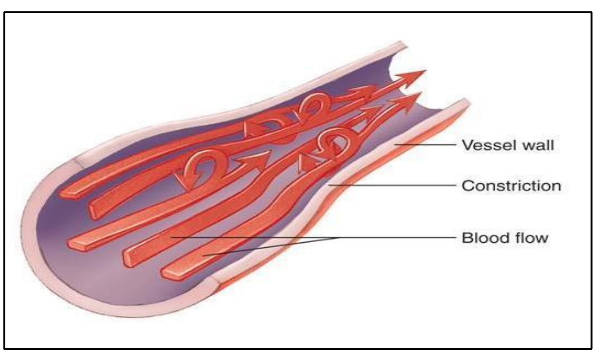
## ***Types of blood flow:***

1) Laminar flow: Also known as streamline flow,
   - Which is present in blood flow through capillaries,
   - Occurs when the flow is slowest near the vessel wall (where there is more friction) and fastest in the center of the blood vessel (where there is less friction).
   - Laminar flow occurs in small diameter pipes in which fluid flows at lower velocities and high viscosity. This type of flow is also called viscous Flow.




2) Turbulent flow:

- The flow is disorderly rather than laminar, with blood flowing crosswise as well as along the vessel.
- Eddy currents form.
- Turbulence is occurs in situations of vessel obstruction.
- Turbulent flow tends to occur in large diameter pipes in which fluid flows with high velocity.



To determine whether flow is laminar or turbulent, calculate the Reynold's number ($N_R$):

$$N_R = \frac{velocity * diameter * density}{viscosity}$$

When $N_R < 2000$ →define laminar flow.

$N_R \geq 2000$ →Define turbulent flow.

Example:

Determine whether the flow is laminar or turbulent if water flows in cooper tube with a flow rate 285 L/min, where diameter is 0.02527m and the area is $5.017\times 10^{-4} m^2$ , $\eta = 4.11 \times 10^{-7} m^2/sec$

## ***Pascal's Law***

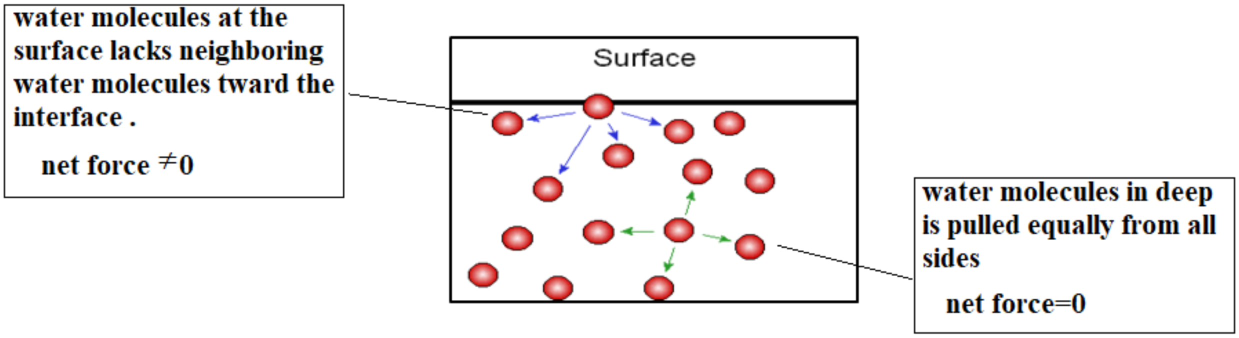
Whenever an external pressure is applied to any confined fluid, the pressure is increased at every point in the fluid by the amount of the external pressure.

$$P_0 = P_i \ , \qquad \frac{F_0}{A_0} = \frac{F_i}{A_i} ,$$

In biological application: is the protection afforded to anything entirely surrounded by a liquid, for example the fetus enclosed in its liquid sac.

## ***Surface tension***

- The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension.
- The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface.
- This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submersed.



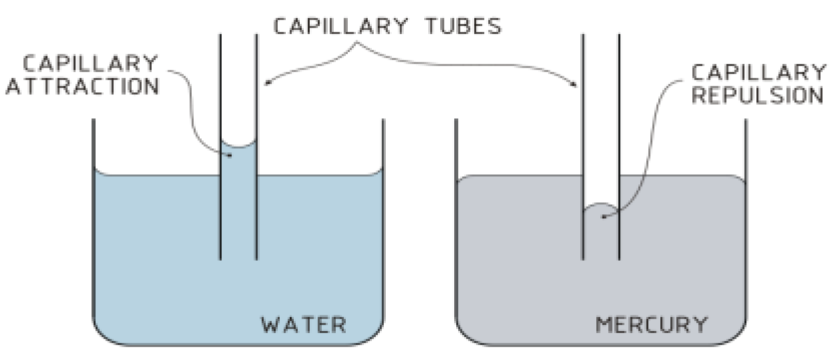

## Capillary action:

- Capillary action is the ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to, external forces like gravity.

- This spontaneous rising of a liquid is the outcome of two opposing forces:

1) Cohesion: the attractive forces between similar molecules or atoms. mercury is characterized by stronger cohesion, and hence its capillarity is much lower.

2) Adhesion: the attractive forces between the particles of the liquid and the particles forming the tube. For example, water in a thin glass tube has strong adhesive forces due to the hydrogen bonds that form between the water molecules and the oxygen atoms in the tube wall.

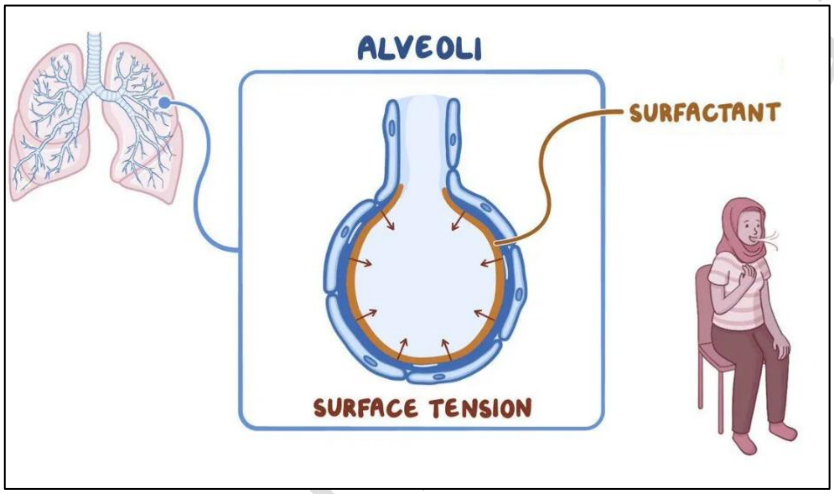


## Surface tension in lung:

Lung compatibility depends on two factors:

First: the capacity of the lung tissue and the chest cavity for stretch ability, this depends on the degree of elasticity. Thus, any defect in this elasticity, such as fibrosis or problems in the chest cavity, reduces compatibility.

Second: is the surface tension of the fluid layer that lining the alveoli. This fluid is called pulmonary surfactant.

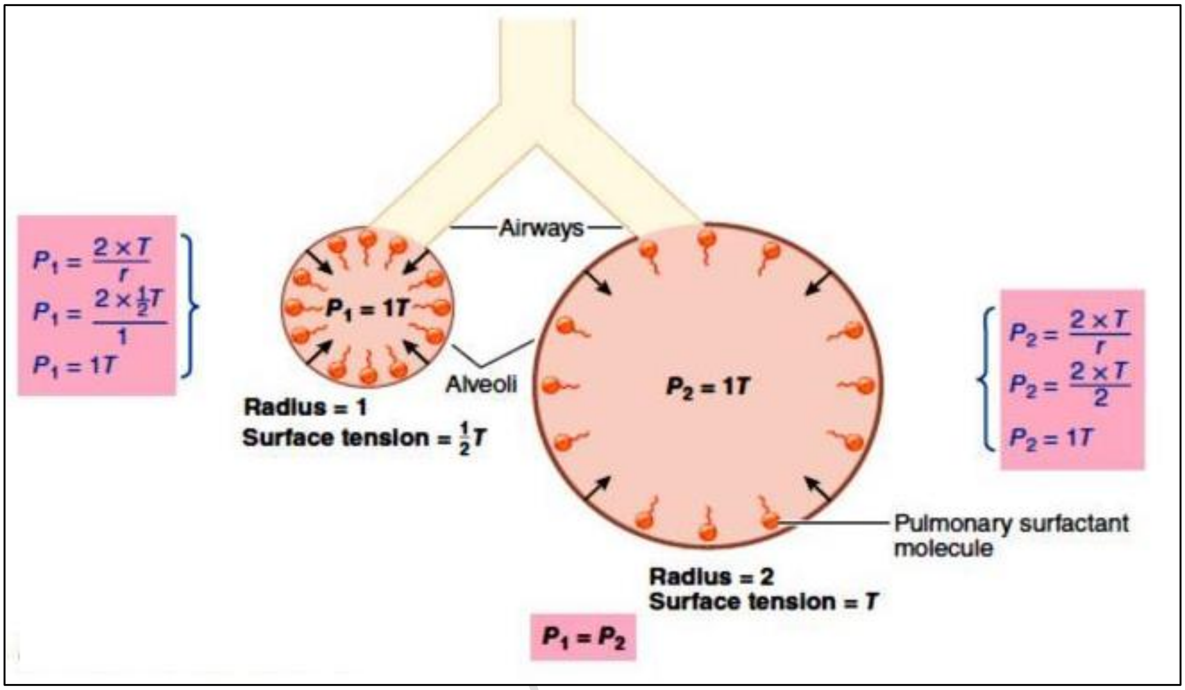



- The high surface tension of pure water would pull the walls of one alveoli to each other (i.e inward) in an attempt to reduce its size and then plate it completely. It helps that the alveoli are subject to **Laplace's law** $\left(P = \frac{2S}{r}\right)$. (Which indicates that the pressure inside spherical structures such as alveoli is directly proportional to the surface tension and inversely proportional to the radius).

- The increase in pressure inside the small alveoli means the necessity of air flowing from them towards the larger sacs so that the pressure in the two is equal,

- and when air flows from them, their diameter becomes smaller again, so their pressure increases and the air flows from them again in favor of the larger alveoli and this series continues until the small alveoli are completely emptied into the large alveoli and this It means that a large number of alveoli are excluded from the gas exchange process.

- But this usually does not happen when the lung is normal and secretes surfactant active substances, as these substances reduce the surface tension of the alveoli, so the pressure inside them decreases, and there is no air flow, which stabilizes the size of the small alveoli, making it easier to inflate.




- The condition can be understood in premature infants, as the alveolar cells of the second type are not mature enough to secrete active substances, which reduces lung compatibility and makes inhalation difficult.