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Pressure -

If F is the magnitude of this normal force on the piston of area A then the average pressure P_{av} is defined as the normal force acting per unit area.

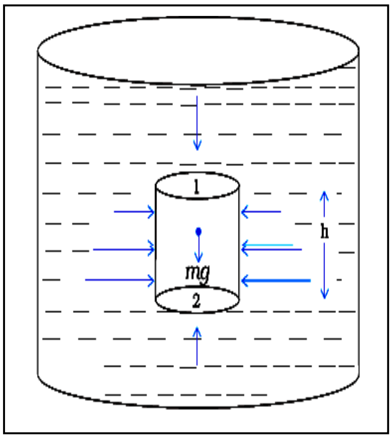
P= F/A ,

Its dimensions are $[ML^{-1}T^{-2}]$.

The SI unit is **N m^{-2}** or **pascal (Pa)**

A common unit of pressure is the atmosphere (atm), i.e. pressure exerted by the atmosphere at sea level is **1 atm = 1.013 ×10^5 Pa**

Variation of Pressure with Depth



Considering a fluid at rest in a container. A point 1 is at height h above a point 2.The pressures at points 1 and 2 are $P_1$and P_2 respectively. Considering a cylindrical element of fluid having area of base A and height h. As the fluid is at rest the resultant horizontal forces should be zero and the resultant vertical forces should balance the weight of the element. The forces acting in the vertical direction are due to the fluid pressure at the top (P_1A) acting downward, at the bottom (P_2A) acting upward.

If mg is weight of the fluid in the cylinder we have $(P_2 – P_1) A= mg$,
if ρ is the mass density of the fluid,

we have the mass of fluid to be $m= \rho V=\rho hA$, so that, $\mathbf{P_2 – P_1= \rho gh}$

Pressure difference depends on the vertical distance h between the points (1 and 2), mass density of the fluid ρ and acceleration due to gravity g.

Liquid pressure is directly proportional to the height of the fluid column or, liquid pressure increases with depth.

Gauge pressure -

Considering a cylindrical element of fluid base area A and height h , whose one surface is open to the atmosphere , on which pressure applied is atmospheric pressure (P_a) and pressure on the lower face inside the fluid is P Then. $\mathbf{P = P_a + \rho g h}$

Thus, the pressure P, at depth below the surface of a liquid open to the atmosphere is greater than atmospheric pressure by an amount ρgh. The excess of pressure, $\mathbf{P – P_a}$, at depth his called a gauge pressure at that point.

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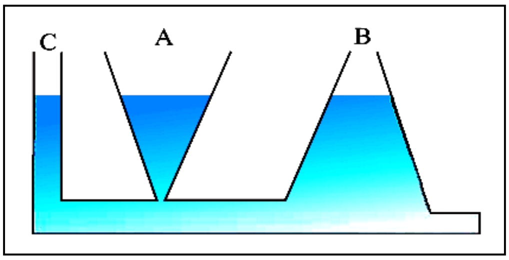
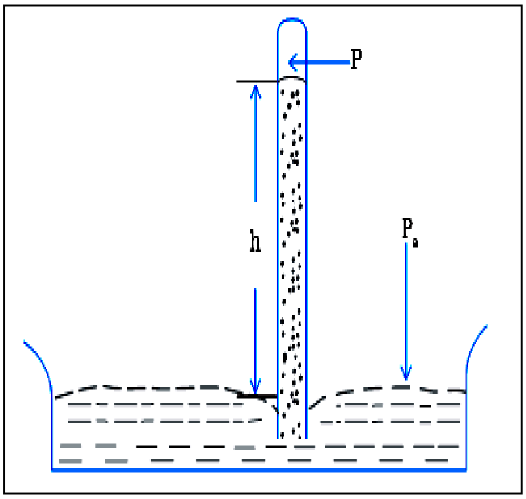
Hydrostatic paradox



The liquid pressure is the same at all points at the same horizontal level i.e. at the same depth. The result is appreciated through the example of hydrostatic paradox. Considering three vessels A, B and C of different shapes. They are connected at the bottom by a horizontal pipe. On filling with water the level in the three vessels is the same though they hold different amounts of water. This is so, because water at the bottom has the same pressure below each section of the vessel.

Atmospheric Pressure and Gauge Pressure



The pressure of the atmosphere at any point is equal to the weight of a column of air of unit cross sectional area extending from that point to the top of the atmosphere.

At sea level it is 1.013×10^5 Pa (1 atm)

Italian scientist Torricelli devised for the first time , mercury barometer ,for measuring atmospheric pressure.

A long glass tube closed at one end and filled with mercury is inverted into a trough of mercury . This device is known as mercury barometer.

The space above the mercury column in the tube contains only mercury vapour of negligible pressure .

The pressure inside the column at point is equal to the

pressure at same level = atmospheric pressure = P_a = ρgh , where ρ is the density of mercury and h is the height of the mercury column in the tube.

In the experiment it is found that the mercury column in the barometer has a height of about 76 cm at sea level equivalent to **one atmosphere (1 atm)**.

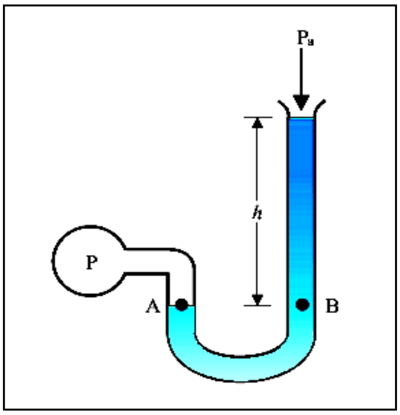
A pressure equivalent of 1 mm is called a torr. **1 torr = 133 Pa**.

The mm of Hg and torr are used in medicine and physiology.

In meteorology, a common unitis the bar & millibar. **1 bar = 10^5Pa**

open-tube manometer –

An open-tube manometer is a useful instrument for measuring pressure differences. It consists of a U-tube containing a suitable liquid of low density liquid for measuring small pressure differences and a high density liquid for large pressure differences. One end of the tube is open to the atmosphere and other end is connected to the system whose pressure we want to measure . Since the density of liquids varies very little over wide ranges in pressure and temperature and we can treat it as a constant for our present purposes .



The pressure P at A = pressure at point B.

So, the gauge pressure= $P - P_a = \rho g h$,

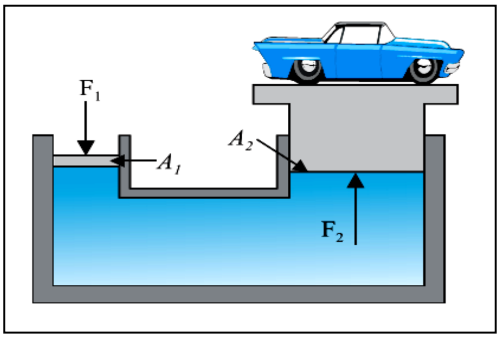
where h is the manometer height

Pascal's law for transmission of fluid pressure- **Whenever external pressure is applied on any part of a fluid contained in a vessel, it is transmitted undiminished and equally in all directions. This is the Pascal's law for transmission of fluid pressure .**

Device based on application of Pascal's law - Hydraulic lift and hydraulic brakes are the devices based on the Pascal's law. In these devices fluids are used for transmitting pressure.

Hydraulic lift:-

In a hydraulic lift as shown in above figure, two pistons are separated by the space filled with a liquid. A piston of small cross sectionA_1 is used to exert a force F_1 directly on the liquid. The pressure **$P = F_1/A_1$** is transmitted throughout the liquid to the larger cylinder attached with a larger piston of area A_2 ,which results in an upward force of **$P \times A_2$**.



Therefore, the piston is capable of supporting a large force like weight of a car, placed on the platform , **$F_2 = PA_2 = F_1 A_2/A_1$.**

By changing the force at A_1, the platform can be moved up or down. Thus, the applied force has been increased by a factor of **A_2/A_1** and this factor is the mechanical advantage of the device.

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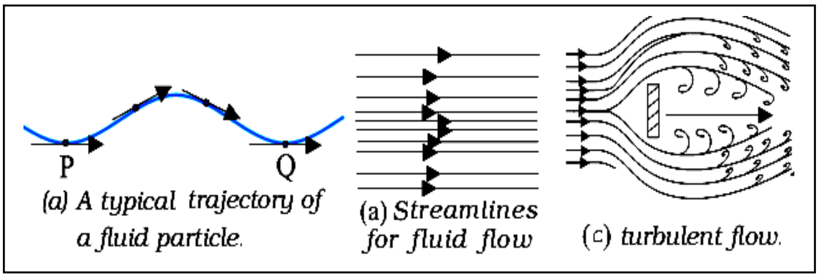
Hydraulic brakes:- In automobiles hydraulic brakes also work on the same principle. When we apply a little force on the pedal with our foot the master piston moves inside the master cylinder, and the pressure caused is transmitted through the brake oil to act on a piston of larger area. A large force acts on the piston and is pushed down expanding the brake shoes against brake lining. In this way a small force on the pedal produces a large retarding force on the wheel. An important advantage of the system is that the pressure set up by pressing pedal is transmitted equally to all cylinders attached to the four wheels so that the braking effort is equal on all wheels.

STREAMLINE FLOW



The study of a fluids in motion is known as fluid dynamics.

The flow of the fluid is said to be steady if at any given point, the velocity of each passing fluid particle remains constant in time.

The velocity of a particular particle may change as it moves from one point to another. That is, at some other point the particle may have a different velocity, but every other particle which passes the second point behaves exactly as the previous particle that has just passed that point.

Each particle follows a smooth path, and the paths of the particles do not cross each other. The path taken by a fluid particle under a steady flow is a streamline.

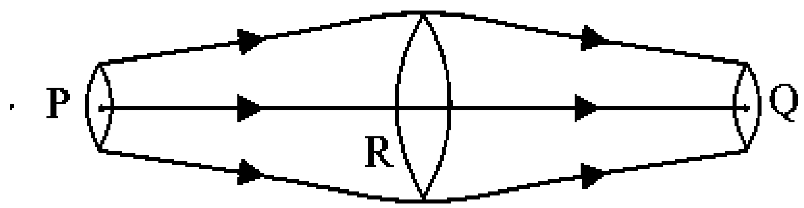
A streamline is defined as a curve whose tangent at any point is in the direction of the fluid velocity at that point.

Turbulent flow –

Steady flow is achieved at low flow speeds. Beyond a limiting value, called **critical speed**, this flow loses steadiness and becomes **turbulent**. One sees this when a fast flowing stream encounters rocks, small foamy whirlpool-like regions called 'white water rapids are formed.

Equation of continuity

According to it ,"**The volume flux or flow rate remains constant throughout the pipe of flow** "



If area of cross-sections at these points are $\mathbf{A_P}$, $\mathbf{A_R}$ and $\mathbf{A_Q}$ and speeds of fluid particles are $\mathbf{v_P}$, $\mathbf{v_R}$ and $\mathbf{v_Q}$, then mass of fluid $\mathbf{\Delta m_P}$ crossing at $\mathbf{A_P}$ in a small interval of time Δt is $\boldsymbol{\rho_P A_P v_P \Delta t}$.

Similarly mass of fluid Δm_R flowing or crossing at A_R in a small interval of time Δt is $\boldsymbol{\rho_R A_R v_R \Delta t}$ and that crossing at A_Q in a small time interval Δt is $\boldsymbol{\rho_Q A_Q v_Q \Delta t}$.

Since the mass of liquid flowing out equals the mass flowing in, holds in all cases , so,

$\rho_P A_P v_P \Delta t = \rho_R A_R v_R \Delta t = \rho_Q A_Q v_Q \Delta t$ (i)

For flow of incompressible fluids $\rho_P = \rho_R = \rho_Q$ ....(ii)

Eqn (i) reduces to, $A_P v_P = A_R v_R = A_Q v_Q$ ...(iii)

which is called the equation of continuity and it is a statement of conservation of mass in flow of incompressible fluids.

In general , **Av = constant .... (iv)**

At narrower portions where the streamlines are closely spaced, velocity increases and its vice versa. From (iv) it is clear that $\mathbf{A_R > A_Q}$ **or** $\mathbf{v_R < v_Q}$, the fluid is accelerated while passing from R to Q . This is associated with a change in pressure in fluid flow in horizontal pipes.

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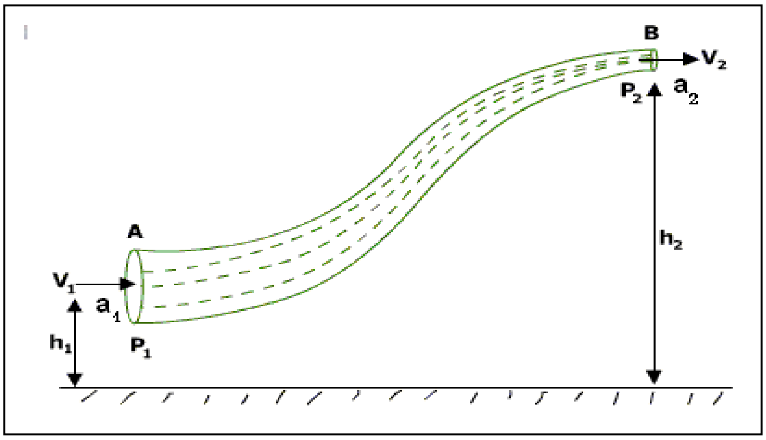
Bernoulli's principle - It relates the pressure difference between two points in a pipe to both velocity changes or kinetic energy and height changes or potential energy .

Statement: **As we move along a streamline the sum of the pressure (P), the kinetic energy per unit volume $\rho v^2/2$ and the potential energy per unit volume (ρgh) remains a constant.**

Proof : Let us consider a tube AB of unequal cross-section through which a non viscous in compressible liquid is flowing steadily. Let a_1 be the cross-sectional area of face A ,which is at a height of h_1 from the horizontal through which liquid is entering with velocity v_1 at liquid pressure P_1 and leaving through face B, which is of cross-sectional area a_2, at a height of h_2 from the horizontal liquid is with a velocity of v_2.



If W_1 and W_2 be the work done on the liquid at face A and B by the liquid pressure , then net work done in moving a volume ΔV of the liquid of mass Δm in time Δt ,

$W = W_1 - W_2 = P_1\Delta V - P_2\Delta V = \Delta V (P_1 - P_2)$

So, increase in Kinetic Energy , $\Delta K = \frac{1}{2}\Delta m\,(v_2^2 - v_1^2) = \frac{1}{2}\Delta V\rho\,(v_2^2 - v_1^2)$

So, increase in Potential energy, $\Delta U = \Delta mg\,h_2 - \Delta mg\,h_1 = \Delta V\rho g\,(h_2 - h_1)$

By work-energy theorem , $W = \Delta K + \Delta U$

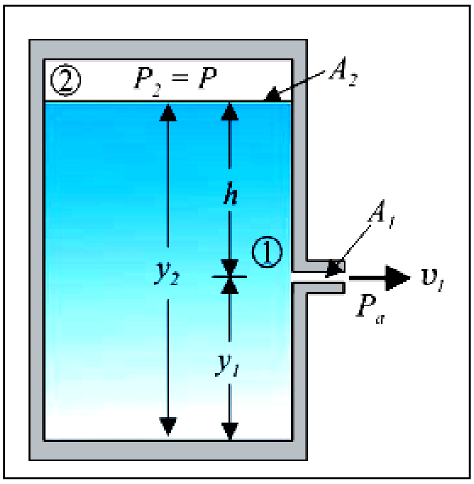
$\Rightarrow \Delta V(P_1 - P_2) = \frac{1}{2}\Delta V\rho\,(v_2^2 - v_1^2) + \Delta V\rho g\,(h_2 - h_1)$

$\Rightarrow P_1 + \frac{1}{2}\rho v_1^2 + \rho g\,h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g\,h_2$

$\Rightarrow P + \frac{1}{2}\rho v^2 + \rho g\,h = \text{Constant}$.........(1) **This is Bernaulli's theorem .**

Speed of Efflux: Torricelli's Law

Efflux means fluid outflow.



Torricelli discovered that the speed of efflux from an open tank is given by a formula identical to that of a freely falling body.

Let us consider a tank containing a liquid of density ρ with a small hole in its side at a height y_1 from the bottom .The air above the liquid, whose surface is at height y_2, is at pressure P.

From the equation of continuity ,

$$a_1 v_1 = a_2 v_2 \quad \text{so} \quad v_2 = a_1 v_1 / a_2$$

If the cross sectional area of the tank A_2 is much larger than that of the hole (**$A_2 >> A_1$**), then we may take the fluid to be approximately at rest at the top, i.e. **$v_2 = 0$**.

Now applying the Bernoulli equation at points 1 and 2 and noting that at the hole **$P_1 = P_a$** ,the atmospheric pressure,

we have from Bernoulli's theorem

$$P_a + \frac{1}{2} v_1^2 + g y_1 = P + g y_2$$

$$\Rightarrow \frac{1}{2} v_1^2 = P - P_a + g y_2 - g y_1$$

$$\Rightarrow v_1^2 = 2(P - P_a) + 2g(y_2 - y_1)$$

Taking $y_2 - y_1 = h$ we have

$$v_1 = \sqrt{2gh + 2(P - P_a)}$$

If the tank is open to the atmosphere, then **$P = P_a$** and then **$v_1 = \sqrt{(2gh)}$** , which is the speed of a freely falling body. This equation is known as **Torricelli's law**.

When $P >> P_a$ and $\sqrt{(2gh)}$ may be ignored, the speed of efflux is determined by the container pressure. Such a situation occurs in rocket propulsion.

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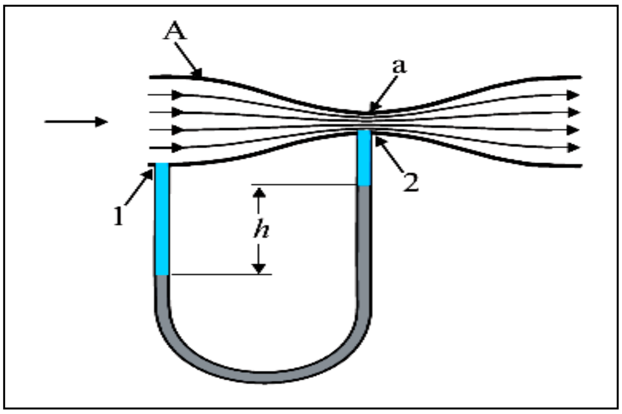
Venturi-meter

The Venturi-meter is a device to measure the flow speed of incompressible fluid.



It consists of a tube with a broad diameter and a small constriction at the middle. A manometer in the form of a U-tube is also attached to it as shown in diagram above . The manometer contains a liquid of density ρ m. The speed v_1 of the liquid flowing through the tube at the broad neck area A is to be measured from equation of continuity and the speed at the constriction becomes

$v_2 = Av_1/a$ …………………1

Then using Bernoulli's equation, we get

$\Rightarrow P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$

$\Rightarrow P_1 - P_2 = \frac{1}{2}\rho (v_1 A/a)^2 - \frac{1}{2}\rho v_1^2$

$\Rightarrow P_1 - P_2 = \frac{1}{2}\rho v_1^2 [(A/a)^2 - 1]$……….2

This pressure difference causes the fluid in the U tube connected at the narrow neck to rise in comparison to the other arm. The difference in height h , measure the pressure difference.

$\Rightarrow P_1 - P_2 = \rho_m g h = \frac{1}{2}\rho v_1^2 [(A/a)^2 - 1]$… 3

So that the speed of fluid at wide neck is

$$v_1 = \sqrt{\left(\frac{2\rho_m g h}{\rho}\right)} \left(\left(\frac{A}{a}\right)^2 - 1\right)^{-1/2} \quad ….4$$

Applications of Bernoulli's principle

(1) The carburetor of automobile has a Venturi channel (nozzle) through which air flows with a large speed. The pressure is then lowered at the narrow neck and the petrol (gasoline) is sucked up in the chamber to provide the correct mixture of air to fuel necessary for combustion.

(2) Filter pumps or aspirators, Bunsen burner, atomisers and sprayers used for perfumes or to spray insecticides work on the Bernoulli's principle.

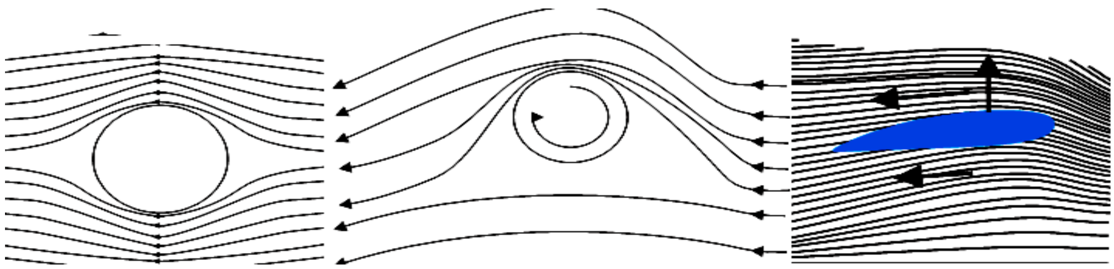
(3) **Blood Flow and Heart Attack**- The artery may get constricted due to the accumulation of plaque on its inner walls. In order to drive the blood through this constriction , the speed of the flow of the blood in this region is raised which lowers the pressure inside and the artery may collapse due to the external pressure. The heart exerts further pressure to open this artery and forces the blood through. If due to the rushing of blood through the opening, the internal pressure may once again drops , which may lead to a repeat collapse. It can result in heart attack.

(4) Dynamic Lift - Dynamic lift is the force that acts on a body, such as airplane wing, a hydrofoil or a spinning ball , due to which ,it deviates from its parabolic trajectory . This can be explained on the basis of Bernoulli's principle.

(i) **Ball moving without spin**: The streamlines around a non-spinning ball moving relative to a fluid is symmetric . So the velocity of air above and below the ball at corresponding points is the same resulting in zero pressure difference. Therefore, no upward or downward force is exerted by air on the ball.

(ii) **Ball moving with spin**: A ball which is spinning drags air along with it. The ball is moving forward ,while the air is moving backwards. Therefore, the velocity of air above the ball relative to it is larger and below it is smaller. The stream lines thus get crowded above and rarified below. This difference in the velocities of air results in the pressure difference between the lower and upper faces and their is a net upward force on the ball. This dynamic lift due to spining is called Magnus effect.

(iii) **Aerofoil or lift on aircraft wing**: An aerofoil, which is a solid piece shaped to provide an upward dynamic lift when it moves horizontally through air. When the aerofoil moves against the wind, the orientation of the wing relative to flow direction causes the streamlines to crowd together above the wing more than those below it. The flow speed on top is higher than that below it. There is an upward force resulting in a dynamic lift of the wings and this balances the weight of the plane.



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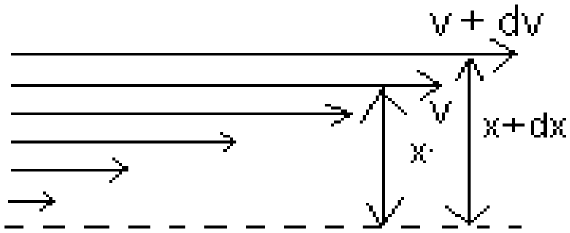
Viscosity

The property of liquid by virtue of which on opposing force arises between two different liquid layers in motion, in order to destroy the relative motion between them is called viscosity.

Viscous Force :- It is defined as the opposing force arising between two moving liquid layers in order to destroy the relative motion between them.

Velocity gradiant :- It is defined as the ratio of change in velocity to the change in distance.



Two liquid layers at a height of x+ dx and x from the bottom from the bottom , are moving with velocity **v + dv** and **v** .

So , velocity gradiant between the two layers. $\frac{v+dv-v}{x+dx-x} = \frac{dv}{dx}$

Expression for Co-efficient of Viscosity

Let P and Q be the two liquid layers of cross-sectional area A , at a height from the bottom of x+ dx and x from the bottom , moving with velocity v + dv and v respectively ,such that velocity gradient between the two layers is **dv/dx**

According to Newton , force of viscosity is

F α A and F α (dv/dx)

Combining , F = η A (dv/dx) ,

Where η is called co-efficient of viscosity.

If A = 1 , **dv/dx =1** , So, **η = F**

The co-efficient of viscosity is defined as the force of viscosity that arises between two moving layers of unit cross-sectional area, to create a unit velocity gradient.

c.g.s unit of η is 1 dyne /cm^2 sec^{-1} = 1 poise.

S.I. unit of η is 1 N / m^2 sec^{-1}= 1 poiseulle or deca poise.

Dimensional formula of η = [$M^1 L^{-1} T^{-1}$]

Stooke's theorem Statement :-

"The force of viscosity (F) acting on a spherical body of radius 'r' moving through a liquid of co-efficient of viscosity η with velocity v is 6π r v η ".

Proof :- Let us consider a spherical body of radius r be moving through a viscous liquid of co-efficient of viscosity η with a velocity v . Then force of viscosity F is found to be

$F \propto r^a$ 1

$F \propto v^b$ 2

$F \propto \eta^c$ 3

Combining $F = K r^a v^b \eta^c$ 4

where k is a dimensional constant.

We know $[F] = [M^1 L^1 T^{-2}]$

$[r] = [M^0 L^1 T^0]$

$[\eta] = [M^1 L^{-1} T^{-1}]$

$[v] = [M^0 L^1 T^{-1}]$

Putting then in (4)

$[M^1 L^1 T^{-2}] = [M^0 L^1 T^0]^a [M^0 L^1 T^{-1}]^b [M^1 L^{-1} T^{-1}]^c$

$[M^1 L^1 T^{-2}] = [M^c L^{a+b-c} T^{-b-c}]$

Comparing the power of M, L, T

c = 1 , a + b - c = 1 , - b - c = -2

a + 1-1 = 1 b + c = 2

a = 1 b + 1 = 2 => **b= 1**

Putting the value of a , b, c in (1)

$F = K r^1 v^1 \eta^1$

Or, $F = K r v \eta$ .... (5)

Stoke experimentally found that K= 6π

So , $F = 6\pi r v \eta$ .... (6).

Terminal velocity –

The uniform velocity with which a spherical body is descending through a viscous liquid , when its weight is balanced by the force of viscosity , is known as terminal velocity.

Let us consider a spherical body of radius r and density ρ be descending through a viscous liquid of density σ co-efficient of viscosity η , under the action of gravity , various forces acting on it.

(i) Its weight : **$W = (4/3)\pi r^3 \rho g$** , acting vertically downward.

(ii) Force of buoyancy: **$U = (4/3)\pi r^3 \sigma g$**, acting vertically upward.

(iii)Force of viscosity ,**$F = 6\pi r \eta v_T$** , acting vertically upward.

Since F is a velocity dependent force, so due to acceleration due gravity , F increases, and a stage will come when no, resultant force is acting on it.

In equilibrium , W - U – F = 0

The body will descent down with a uniform velocity called terminal velocity (V_T).

$W - U = F \Rightarrow (4/3)\pi r^3 \rho g - (4/3)\pi r^3 \sigma g = 6\pi r \eta v_T$

$\Rightarrow (4/3)\pi r^3[\rho - \sigma] g = 6\pi r \eta v_T$

$\Rightarrow v_T = 2r^2(\rho - \sigma) g / 9\eta$

This is the expression for terminal velocity.

Surface Tension

The free surface of a liquid , in a container , possess some additional energy. This phenomenon is known as surface tension.

The property of a liquid surface by virtue of which it behaves like stretched membrance is known as surface tension and it is defined as the force action per unit length of an imaginary line drawn on the liquid surface.

If 'F' be the force acting on a imaginary line of lenght '*l*' then surface tension

$T = F / l$

Unit:- **Nm^{-1}** & dyne cm^{-1}

Dimensional formula [T] = [$M^1L^oT^{-2}$]

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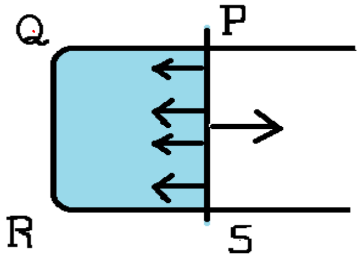
Q..What is surface energy of a liquid flim ? Show that surface energy is numerically equal to surface tension .

Surface energy :- It is defined as the amount of work done in increasing the area of a liquid film by unit amount.



Let us consider a rectangular frame PQRS whose fourth arm is **PS = *l*** movable along PQ & RS. Let it be dipped in a soap solution so that a soap film is form in either side of it. Due to the surface tension arm ps will be moved inward by a force ,

F = T x 2 *l* — (i)

Let PS be pulled out ward by a small distance Δx by doing amount of work done and increasing the surface area of the soap film by an amount

ΔA = 2 (***l* x**Δx) ———— (ii)

The term 2 arises as a soap film has two surfaces

So work done ΔW =F. Δx = T x 2 (***l* x** Δx)

ΔW =T x ΔA ———— (iii)

This is the amount of work done in increasing the area by a small amount.

So surface energy of the liquid film is

$$S=\frac{W}{\Delta A}=\frac{T \times \Delta A}{\Delta A}$$

= > **S = T**

So surface energy is numerically equal to surface tension.

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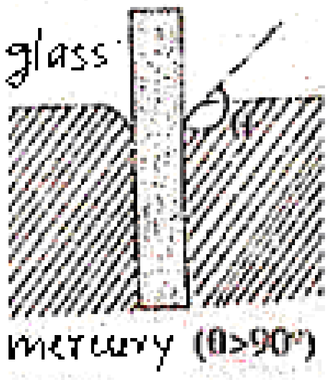
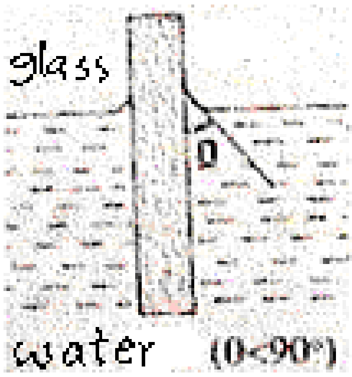
Angle of contact

The angle made by the tangent drawn at the point of contact of the solid and liquid surface with the solid part inside the liquid is known as angle of contact.

For water and glass it is about 4^{O} to 8^{O} i.e, acute

for mercury and glass it is about 130^{O} i.e obtuse.



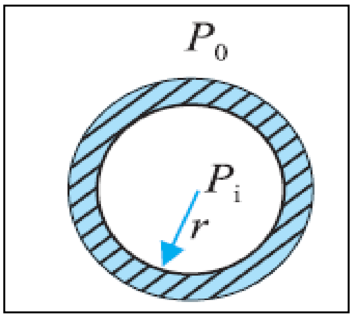


Force of adhesion and force of cohesion

The molecular force of attraction between molecules of simillar types is called force of cohesion.

The molecular force of attraction between molecules of different types is called force of adhesion.

Excess pressure inside a soup bubbles



An interesting consequence of surface tension is that the pressure inside a spherical drop is more than the pressure outside. Let a soap bubble of radius r is in equilibrium. If its radius is increased by Δr, the extra surface energy is

$\mathbf{W = 2[4\pi(r + \Delta r)^2 - 4\pi r^2]\, S}$

$\mathbf{= 2\, S\, [4\pi\, r^2\{1 + (\Delta r/r)\}^2 - 4\pi\, r^2]}$

$\mathbf{= 2\, S\, [4\pi\, r^2 + 8\pi\, r\, \Delta r - 4\pi\, r^2] \;=\; 16\pi r\, \Delta r\, S}$ ....*(i)*

If the drop is in equilibrium this energy cost, is balanced by the energy gain due to expansion under the pressure difference $(P_i - P_o)$ between the inside of the bubble and the outside.

The work done is $W = (P_i - P_o)\, 4\pi\, r^2 \Delta r$ ....(ii)

From (i) and (ii) , $(P_i - P_o)\, 4\pi\, r^2 \Delta r \;=\; 16\pi r\, \Delta r\, S$

$\Rightarrow (P_i - P_o) \;=\; 4\, S\,/r$ ....(iii)

NCERT-XI / Unit- 10 – Properties of Fluids

Q.1. What is capillarity and capillary tube.

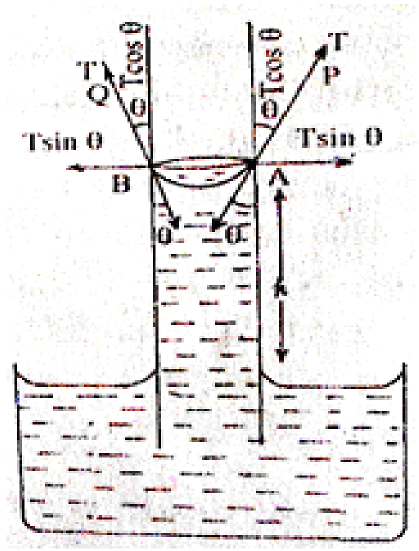
Q.2. Find an expression for capillary rise in a capillary tube ?

Q.3. What is Jurin's law ?

Ans :- The phenomenon by virtue of which liquid rises in tube of very fine bore when dipped in it ,is known as capillarity .

A tube with a very fine bore whose diameter is of order mm is known as capillary tube.

Expression for capillary rise in a capillary tube :-



Let us considered a capillary tube of radius of 'r' be dipped in a liquid of density 'ρ such that water rises in it up to the height 'h' with an upward concave meniscus.

Let 'T' be the surface tension of the liquid with as θ angle of contact. Resolving T.

i) T cos θ , along the wall of the tube.

ii) T sin θ , along a perpendicular direction of the tube.

Since, every T sin θ component will be cancelled out by its diametrically opposite counter part ,so T cosθ will be effective for the rise of the liquid in the tube.

Force acting on the liquid in the tube in upward direction -

$F = 2\pi r T \cos\theta$ ——— (i)   [$T = F / l$]

This force is responsible for the rise of liquid in the capillary tube.

$F = mg \Rightarrow 2\pi r T \cos\theta = \rho V g$

$$\Rightarrow 2\pi \; rT\cos\,\theta = \rho\left[\pi\, r^2(h + r) - \frac{2}{3}\pi\, r^3\right] g$$

$$\Rightarrow 2\pi\ rT\cos\theta = \rho\left[\pi\ r^2 h + \pi r^3 - \frac{2}{3}\pi\ r^3\right] g$$

$$\Rightarrow 2\pi\ rT\cos\ \theta = \rho\ \pi\ r^2 (h + \frac{r}{3})\ g$$

as $h \gg \frac{r}{3}$ neglecting r/3 in comparison to h

we have $2\pi\ r\ T\cos\theta = \rho\pi\ r^3\ hg$

$$\Rightarrow h = \frac{2T\cos\theta}{\rho\ gr} \text{ ——— (ii)}$$

For pure liquid $\theta = 0^o$

$$\Rightarrow h = \frac{2T}{\rho gr} \text{ ——— (iii)}$$

As, T ,ρ &, g are constant ,

$$\Rightarrow h \propto \frac{1}{r} \text{ ——— (iv)}$$

This is known as Jurin's law.

According to which "**rise of a liquid in a capillary tube is inversely proportional to its radius".**