SHORT ANSWERS QUESTIONS

Q.1. What are laws of pressure of a liquid ?

Ans. The laws are

(*a*) A liquid at rest exerts pressure equally in all directions.

(*b*) Pressure at two points on the same horizontal line in a liquid at rest is the same.

(*c*) Pressure exerted at a point in a confined liquid at rest is transmitted through the liquid equally in all directions.

Q.2. What are force of cohesion and force of adhesion ?

Ans. ***Force of Cohesion*** : The force of attraction between two molecules of same substance is called force of cohesion. The force between two water molecules is a cohesive force.

Force of Adhesion : The force of attraction between two molecules of different substances is called force of adhesion. Thus force between water molecule and glass molecule is an adhesive force.

Q.3. What is molecular range ?

Ans. ***Molecular range*** : The distance upto which a molecule can attract another molecule is called molecular range. It is of the order of 10^{-7} cm.

Q.4. What is sphere of influence ?

Ans. ***Sphere of influence*** : If a sphere is drawn with a molecule as centre and radius equal to molecular range, then the sphere is called sphere of influence. All the molecules within the sphere of influence are attracted by the molecule at the centre.

Q.5. What is surface film ?

Ans. If a plane is drawn at a distance equal to the molecular range from the free surface of a liquid, then the layer of liquid between the free surface and the plane drawn is called surface film.

Q.6. Why is sand drier than clay ?

Ans. Sand has minute pores between its particles. Hence water from below the sand rises due to capillary action and gets evaporated. But in case of clay, no such capillary action takes palce. Hence sand is drier than clay.

Q.7. Oil is contained in the reservoir at the bottom of a lamp while it burns at the top. Why is it so ?

Ans. Oil rises into the wick of the lamp due to the action of capillary where each pore of the wick serves as a fine capillary.

Q.8. Why does oil spread over the surface of water while water does not do so on the oily surface ?

Ans. This is due to the difference of forces of surface tension of water and oil. Surface tension of water is greater than that of oil.

Q.9. Why are the smaller mercury drops spherical ?

Ans. Surface tension tends to make the surface area of the liquid minimum by making it spherical. In the case of smaller drops, the force of surface tension dominates the weight and thus makes the drops spherical.

Q.10. What is streamline or laminar flow ?

Ans. Flow of liquid is said to be streamlined if the velocity of a liquid molecule at any point coincides with that of the preceding one. The paths of the molecule in such a flow is called a streamline.

Q.11. What is turbulent flow ?

Ans. Whenever the velocity of a fluid is very high or if the body rushes past an obstacle so that there is a sudden change of direction of motion, the motion of the fluid becomes irregular. This type of motion is called turbulent flow.

Q.12. Why is it dangerous to stand very close to the track of a fast moving railway track ?

Ans. In that case, the air in between the man and the train moves faster than air behind the man. This results in a decrease of pressure in between man and train. As a result, the man will receive a push towards the train.

Q.13. How does a parachute act ?

Ans. When the parachute opens out, the pressure of air above drops. So an upward thrust comes into play to balance the weight of the parachutist.

Q.14. It is found that a liquid flows faster and more smoothly from a sealed can when two holes are punctured in the can than when one hole is made. Explain.

Ans. When two holes are made, the velocity of flow through each is much less than the velocity of flow when there is only one hole. Hence the flow becomes streamline with two holes. That is why a liquid flows more smoothly and faster with two holes.

Q.15. Two row beats moving parallel to one another in same direction are pulled towards one another. Why ?

Ans. When they are close to each other, the velocity of water between them increases resulting in a fall of pressure there according to Bernoulli's theorem. The pressures from the sides push them closer.

Q.16. Liquids leak through a pin hole at the bottom of a vessel. Will kerosene leak faster than water ?

Ans. Both will leak at the same speed. The velocity of efflux does not depend on the density of liquid. The velocity of efflux is $\sqrt{2gh}$, where h is the height of the liquid.

Q.17. Why does a flag flutter in a strong wind ?

Ans. Due to wind on the two sides of flag, the difference of pressure produces 'folds' in the flag according to Bernoulli's theorem.

Q.18. Do rain drops of different sizes reach the earth with the same velocity ?

Ans. No. Raindrops of different sizes reach the earth with different velocity. The terminal velocity acquired by a drop is proportional to the square of its radius.

Q.19. Why one has to blow over a piece of paper rather than under it, to keep it horizontal?

Ans. When air is blown over the paper, there is a drop in pressure and the atmospheric pressure from below balances the weight of the paper.

Q.20. Very often a sinking ship turns over as it gets immersed in water- why ?

Ans. To pass to the equilibrium position.

LONG ANSWER TYPE QUESTIONS

Q.1. What is fluid pressure ? Derive an expression for fluid pressure. On what factors the pressure due to fluid depends ?

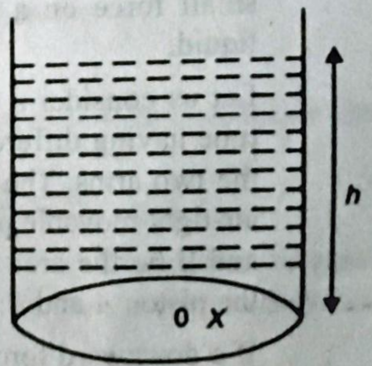
Ans. ***Pressure*** : The pressure exerted by a fluid (liquid) at a point is defined as the force acting per unit area normally around the point.

Let a force F be acting normally on an area A, the pressure at a point on the area is given by

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

The unit of pressure in c.g.s. system is dyne/cm^2 and in S.I. system is N/m^2 or Pascal (Pa). The dimensional formula of pressure is $[M^1L^{-1}T^{-2}]$.

Expression for pressure : Let us consider a liquid of density ρ taken in a cylindrical vessel of base area A. If h is the depth of the liquid, then



Volume of liquid $= Ah$

Mass of liquid $= Ah\rho$

Weight of liquid $= Ah\rho g$.

This weight acts on the area A. Hence the pressure at the point X on the bottom of the vessel is given by

$$p = \frac{Ah\rho g}{A}$$

$$\therefore \quad p = h\rho g.$$

The pressure at a point depends on,

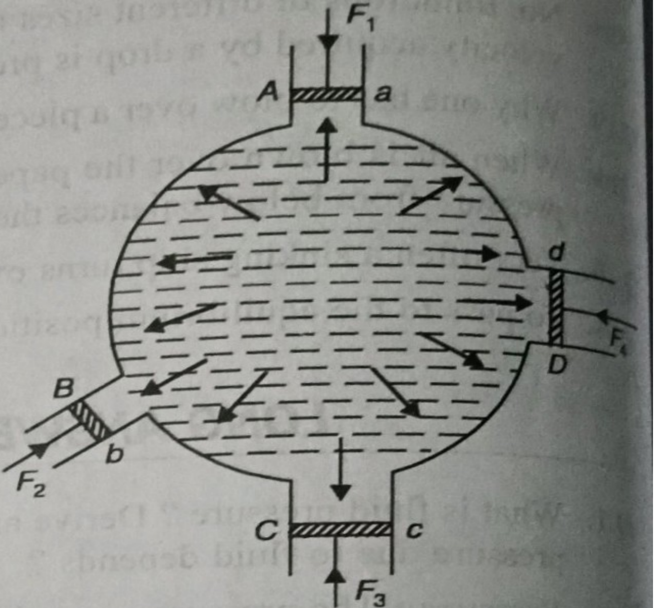
(*i*) the depth '*h*' of the point from the free surface of the liquid.

(*ii*) the density 'ρ' of the liquid and

(*iii*) acceleration due to gravity '*g*'.

Q.2. State and explain Pascal's law of transmission of liquid pressure.

Ans. ***Pascal's law*** : The law states that the pressure exerted anywhere in a confined mass of a liquid is transmitted through the liquid in all directions with undiminished magnitude and acts normally on the wall of the container.



Let us consider a liquid taken in a spherical vessel fitted with airtight movable pistons *A*, *B*, *C* and *D*. Let *a*, *b*, *c* and *d* be the area of cross-section of the pistons respectively.

If the piston *A* is pushed inward by a force F_1, then it is seen that the other pistons tend to move outwards. This shows that the pressure is transmitted in all directions.

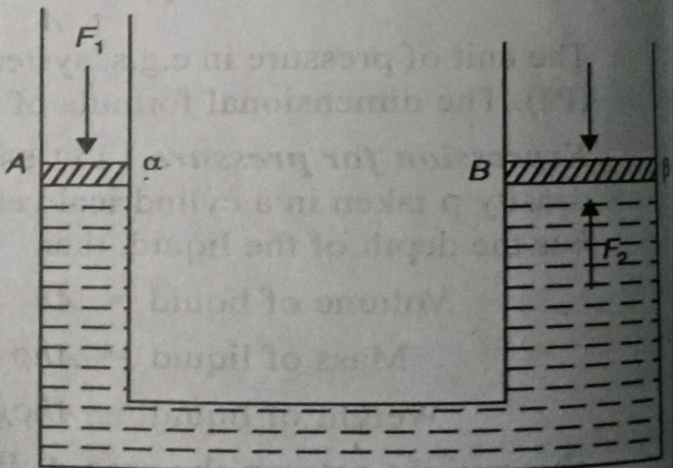
If F_2, F_3 and F_4 are the forces required to keep the pistons *B*, *C* and *D* in position, then it is found that

$$\frac{F_1}{a} = \frac{F_2}{b} = \frac{F_3}{c} = \frac{F_4}{d}$$

Thus, the pressure is transmitted with undiminished magnitude.

Q.3. State and explain the law of multiplication of force.

Ans. ***Principle of multiplication of force*** : According to this principle, a large force can be obtained by applying a small force on a confined mass of a liquid.



Let us consider a liquid taken in a U-tube having different cross-sections of the two arms. The arms are fitted with air-tight movable piston *A* and *B*. Let α and β be the area of cross-sections of the piston *A* and *B*.

If a downward force F_1 is applied. On the piston *A*, then the pressure exerted on the liquid is

$$P = \frac{F_1}{\alpha}$$

According to Pascal's law, this pressure is transmitted through the liquid and acts on the piston B in the upward direction. If F_2 is the upward force on the piston B, then

$$P = \frac{F_2}{\beta}$$

$$\therefore \quad \frac{F_1}{\alpha} = \frac{F_2}{\beta}$$

is

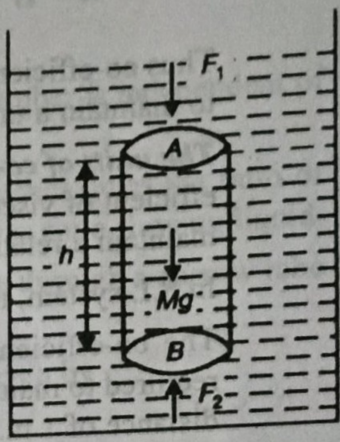
$$\frac{F_2}{F_1} = \frac{\beta}{\alpha}$$

As $\beta > \alpha$, so $F_2 > F_1$

Thus by applying a smaller force, we can get a larger force.

Q.4. What is the effect of Gravity on liquid pressure ?

Ans. Let us consider a liquid of density ρ taken in a vessel. Let A and B be two points inside the liquid at a vertical distance h. We imagine a cylinder of liquid of cross-sectional area A and length h such that A and B lie at the two ends of the cylinder.



The mass of liquid in the imaginary cylinder is

$$M = A\,h\,\rho$$

weight of this liquid $= W = Mg = A\,h\,\rho\,g$.

Let P_1 and P_2 be the pressures of liquid at the points A and B respectively. The forces acting on the liquid cylinder are the followings.

(*i*) Force $F_1 = P_1 A$, acting vertically downward.

(*ii*) Weight $= A\,h\,\rho\,g$, acting vertically downward.

(*iii*) Force $F_2 = P_2 A$, acting vertically upward.

As the liquid is at rest, so

$$F_1 + A\,h\,\rho\,g - F_2 = 0$$

$$\Rightarrow \quad P_1A + Ah\rho g - P_2A = 0$$

$$\Rightarrow \quad P_2 - P_1 = h\,\rho\,g$$

If the points A and B lie at the same level of the liquid, then $h = 0$.

$$\therefore \quad P_1 = P_2$$

This shows that in the presence of gravity, pressure is same at all points inside the liquid lying at the same horizontal plane.

Q.5. What is viscosity ? Define co-efficient of viscosity. What are its units ?

Ans. ***Viscosity*** : The property of a fluid (liquid or gas) by virtue of which an internal frictioinal force comes into play which tends to destroy the relative motion between its different layers is called viscosity.

Co-efficient of viscosity **: Let us consider a liquid moving over an area A. The viscous force F acting between two layers of liquid moving with relative velocity dv separated by an distance dx is given by,**

$$F \propto A$$

$$\propto -\frac{dv}{dx}$$

$$\therefore \quad F = -\eta A \frac{dv}{dx}$$

where η is the constant of proportionality and is called co-efficient of viscosity of the liquid. The negative sign means that the direction of viscous force is opposite to that of velocity.

If $\quad A = 1, \frac{dv}{dx} = 1, \quad \text{then} \quad \eta = F$

Thus co-efficient of viscosity is defined as the tangential force required per unit area to maintain a unit relative velocity between two layers separated by unit distance.

The units of co-efficient of viscosity : In c.g.s. system, the unit of η is poise. The co-efficient of viscosity is said to be one poise if a force of one dyne/cm^2 is required to maintain a relative velocity of 1 cm/sec between two layers separated by 1 cm.

In S.I. system, the unit of η is deca poise.

The co-efficient of viscosity is said to be 1 deca poise if a force of 1 N/m^2 is required to maintain a relative velocity of 1 m/sec between two layers separated by a distance of 1 m.

Q.6. What is critical velocity ? Derive it from dimensional analysis.

Ans. ***Critical velocity*** : The critical velocity is that velocity of liquid flow upto which the flow is streamlined and above which the flow becomes turbulent.

The critical velocity v_c of a liquid flowing through a tube depends on the co-efficient of viscosity η of the liquid, density ρ of the liquid and the radius r of the tube

i.e.

$$v_c \propto \eta^a$$

$$\propto \rho^b$$

$$\propto r^c$$

$$\therefore \quad v_c = K \eta^a \rho^b r^c \qquad \text{... (1)}$$

where K is a dimensionless constant. Taking dimensions,

$$[M^0L^1T^{-1}] = [M^1L^{-1}T^{-1}]^a\,[M^1L^{-3}T^0]^b\,[L^1]^c$$

$$= [M^{a+b}\,L^{-a-3b+c}\,T^{-a}]$$

Applying the principle of homogeneity,

$$a + b = 0$$

$$-a - 3b + c = 1$$

$$-a = -1$$

$\therefore$ $a = 1$

$b = -1$

$c = -1$

Hence from (1), $v_c = K \frac{\eta}{\rho r}$

Here the constant K is called Reynold's number.

Q.7. What is Reynold's number ? What is the physical significance of Reynold's number ?

Ans. Reynold's number is a pure number that determines the nature of flow of liquid throgh a pipe.

According to Reynold, the critical velocity v_c of a liquid of density ρ and viscous co-efficient η flowing through a tube of diameter D is given by

$$v_c = \frac{R\eta}{\rho D} \quad i.e. \quad R = \frac{\rho D v_c}{\eta}$$

Here, R is called Reynold's number. The value of Reynold number is independent of system of units.

Physical significance of Reynold's number : Reynold's number gives the ratio of the inertial force per unit area to the viscous force per unit area for a flowing liquid.

Let us consider a liquid of density ρ flowing with a velocity v through a narrow tube of cross-section A.

The mass of liquid flowing per second through the tube is given by

$$m = A v \rho$$

$$\text{Inertial force per unit area} = \frac{\text{Rate of change of momentum}}{\text{area}}$$

$$= \frac{mv}{A} = \frac{(A v \rho)\, v}{A} = v^2 \rho$$

$$\text{viscous force} = \eta A \frac{v}{r}$$

$$\text{viscous force per unit area} = \frac{\eta A v}{A r}$$

$$= \frac{\eta v}{r}$$

Thus, $\text{Reynold's number} = R = \frac{v^2 \rho}{\eta v / r}$

i.e. $$R = \frac{v \rho r}{\eta}.$$

Q.8. What is terminal velocity ? Derive an expression for terminal velocity using stoke's law.

Ans. ***Terminal velocity*** : It is the maximum constant velocity acquired by a body falling freely through a viscous medium.

Let us consider a spherical body of radius r and density ρ falling under gravity through a medium of density σ and viscous co-efficient η.

Then,

$$\text{weight of the body} = mg = \frac{4}{3}\pi r^3 \rho g$$

$$\text{Bouyancy} = \frac{4}{3}\pi r^3 \sigma g$$

$$\text{Resultant downward force} = \frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \sigma g$$

$$= \frac{4}{3}\pi r^3 (\rho - \sigma) g$$

If v is the terminal velocity then from Stoke's law,

$$\text{upward viscous force} = 6\pi\eta r v$$

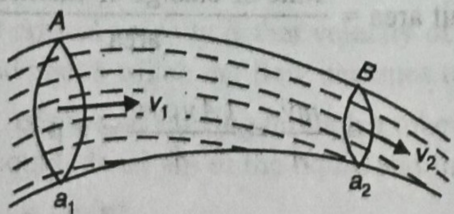
Hence,

$$6\pi\eta r v = \frac{4}{3}\pi r^3 (\rho - \sigma) g$$

$$\therefore \quad v = \frac{2r^2(\rho - \sigma) g}{9\eta}$$

Q.9. Derive the equation of continuity.

Ans. Let us consider the flow of a liquid through a tube of varying cross-section.



Let

a_1 and a_2 = area of cross-section of the tube at A and B respectively.

v_1 and v_2 = velocity of flow of liquid A and B respectively.

Then, Volume of liquid entering per second at $A = a_1 v_1$

Volume of liquid flowing out per second at $B = a_2 v_2$

If ρ_1 and ρ_2 are the densities of liquid at A and B, then

mass of liquid entering per sec at $A = a_1 v_1 \rho_1$

mass of liquid going out per sec at $B = a_2 v_2 \rho_2$

If the flow is steady, then

$$a_1 v_1 \rho_1 = a_2 v_2 \rho_2$$

As liquids are incompressible, so $\rho_1 = \rho_2$

$\therefore \quad a_1 v_1 = a_2 v_2$

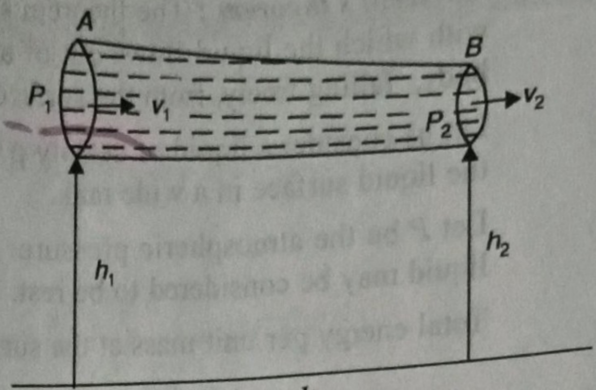
i.e. $\quad a\,v = \text{constant}$ ... (1)

This is known as equation of continuity.

Q.10. State and prove Bernoulli's theorem.

Ans. ***Bernoulli's theorem*** : The theorem states that for the streamline flow of an incompressible, non-viscous liquid, the total energy per unit mass remains constant throughout the displacement.

Let a liquid be flowing in streamline with a velocity v_1 at the section A at a pressure P_1. Let velocity of flow be v_2 and pressure P_2 at B. The cross-sections of the tube are S_1 and S_2 at A and B. If S_1 is larger than S_2, then v_1 will be smaller than v_2. Thus the liquid will be accelerated as it flows from A towards B. This is possible only if P_1 is greater than P_2.



Let a small mass m of the liquid enter the tube at A and moves through a distance v_1 in a small time dt.

The work done on the liquid will be

$$W_1 = S_1 P_1 v_1 \, dt$$

Similarly, work done on the liquid of mass m in time dt at B will be

$$W_2 = S_2 P_2 v_2 \, dt.$$

Hence net work done by the pressure in driving the liquid through the tube is,

$$W = W_1 - W_2 = (S_1 P_1 v_1 - S_2 P_2 v_2)\, dt$$

If h_1 and h_2 are the heights of the sections at A and B during the flow of liquid, then

Change in potential energy $= mg\,(h_2 - h_1)$

Again as $v_2 > v_1$ so

Increase in K.E $= \frac{1}{2} m\,(v_2^2 - v_1^2)$

Total gain of energy of the liquid

$$= mg\,(h_2 - h_1) + \frac{1}{2} m\,(v_2^2 - v_1^2)$$

Hence, we must have,

$$(S_1 P_1 v_1 - S_2 P_2 v_2)\, dt = mg\,(h_2 - h_1) + \frac{1}{2} m\,(v_2^2 - v_1^2)$$

$$\Rightarrow \quad m\left(\frac{P_1}{\rho} - \frac{P_2}{\rho}\right) = mg\,(h_2 - h_1) + \frac{1}{2} m\,(v_2^2 - v_1^2)$$

$$\left[S_1 v_1\, dt = S_2 v_2\, dt = \frac{m}{\rho}\right]$$

$$\Rightarrow \quad \frac{P_1}{\rho} - \frac{P_2}{\rho} = gh_2 - gh_1 + \frac{1}{2}v_2^2 - \frac{1}{2}v_1^2$$

$$\Rightarrow \quad \frac{P_1}{\rho} + gh_1 + \frac{1}{2}v_1^2 = \frac{P_2}{\rho} + gh_2 + \frac{1}{2}v_2^2$$

$$\therefore \quad \frac{1}{2}v^2 + gh + \frac{P}{\rho} = \text{Constant}$$

This is Bernoulli's theorem.

1. **State and prove Torricelli's theorem.**

ns. ***Torricelli's theorem*** : The theorem states that the velocity of efflux *i.e.* the velocity with which the liquid flows out of an orifice is equal to the velocity acquired by a body, falling freely, from the surface of the liquid to the orifice.

Let us consider a liquid of density ρ coming out of an orifice '*O*' at a depth *h* below the liquid surface in a wide tank.

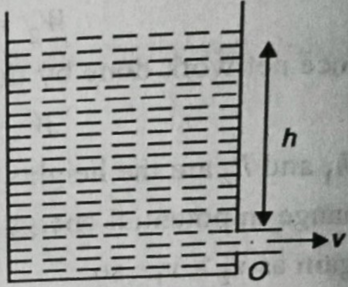
Let *P* be the atmospheric pressure. As the tank is wide, so the free surface of the liquid may be considered to be rest.

Total energy per unit mass at the surface of liquid is

$$E_1 = gh + \frac{P}{\rho} \qquad \text{... (1)}$$

If *v* is the velocity of efflux, then total energy per unit mass at the orifice is

$$E_2 = \frac{1}{2}v^2 + \frac{P}{\rho} \qquad \text{... (2)}$$



Applying Bernoulli's theorem, $E_1 = E_2$

i.e. $$gh + \frac{P}{\rho} = \frac{1}{2}v^2 + \frac{P}{\rho}$$

$$\therefore \quad v = \sqrt{2gh}$$

If a body falls freely under gravity from rest through a height *h*, then the velocity acquired by the body is given by

$$v = \sqrt{2gh}\,.$$

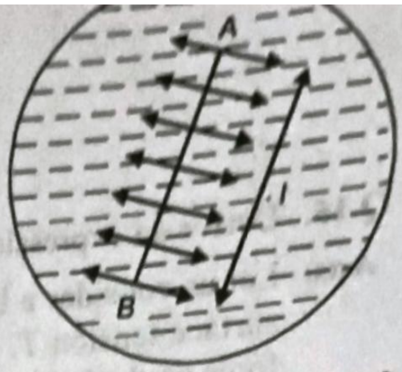
Hence velocity of efflux is equal to velocity of free fall.

Q.12. What are surface tension and surface energy ? What are their units ? Show that surface tension and surface energy are dimensionally equal.

Ans. ***Surface tension*** : The property of a liquid by virtue of which its free surface behaves like a stretched membrane and has a tendency to contract is called surface tension.

The force of surface tension is defined as the force acting tangentially over the liquid surface per unit length on either side of an imaginary line drawn over the liquid surface.

urface tension $= T = \frac{F}{l}$



of surface tension in c.g.s. system is dyne/cm system is N/m.

nergy : The potential energy per unit area of e film is called surface energy. It is measured rk done to increase the surface area by unity.

of surface energy in c.g.s. system is erg/cm^2 and in S.I. system is joule/m^2.

ns of surface tension :

$$T = \frac{F}{l} = \left[\frac{M^1L^1T^{-2}}{L^1}\right] = [M^1L^0T^{-2}]$$

on of surface energy :

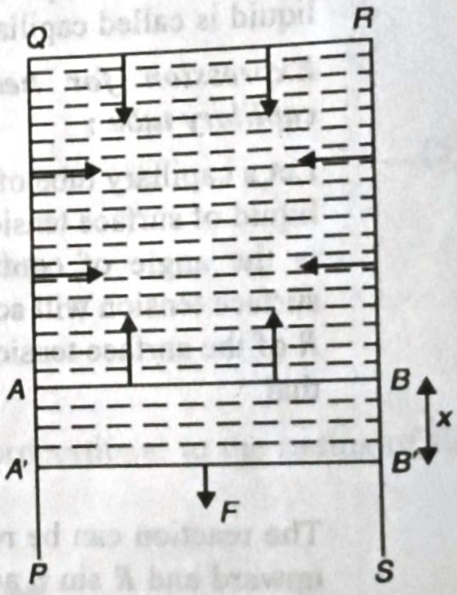
$$E = \frac{\text{Energy}}{\text{area}} = \left[\frac{M^1L^2T^{-2}}{L^2}\right] = [M^1L^0T^{-2}]$$

Surface tension and surface energy are dimensionally equal.

the relation between surface tension and surface energy.

ke a rectangular frame $PQRS$ having a wire AB of length l capable of sliding Q and SR.

ilm $AQRB$ is made by dipping the frame solution. If T is the surface tension of ution, then a force $2\ T$ (there are two) will act on AB in the upward direction.



re AB is pulled slowly through a distance B′ without breaking the film, then the ne is given by

$$W = 2\,T\,lx$$

rease in surface area $= 2\,Lx$

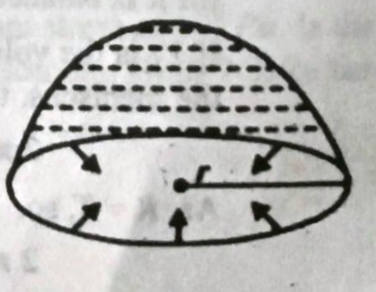
the surface energy is given by

$$E = \frac{2\,T\,lx}{2\,lx} = T$$

urface tension and surface energy are cally equal.

an expression for excess pressure inside a drop.

consider a drop of radius 'r' of a liquid of surface T. The force of surface tension acts inward. The n the drop due to surface tension is $2\,\pi\,rT$. The cts on an area $\pi\,r^2$. Hence the excess pressure on

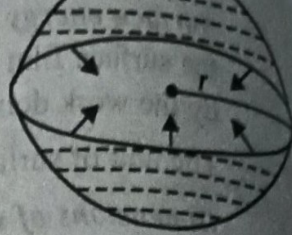


the drop is given by

$$P = \frac{2\pi r T}{\pi r^2}$$

$$\therefore \quad P = \frac{2T}{r}$$

Q.15. Derive an expression for excess pressure inside bubble.

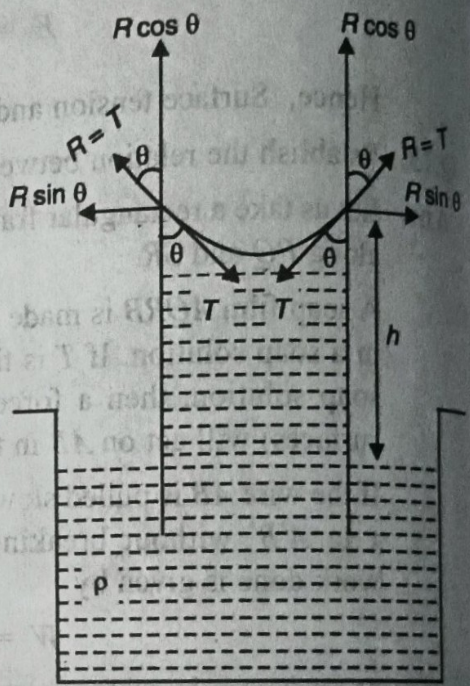


Ans. Let us consider a bubble of radius r of soap solution of surface tension T. As a bubble has two surfaces, so the force on the bubble due to surface tension is $2 \times 2\pi rT = 4\pi rT$. This force acts on an area πr^2. Hence the excess pressure inside the bubble is given by

$$P = \frac{4\pi r T}{\pi r^2}$$

$$\therefore \quad P = \frac{4T}{r}$$

Q.16. What is capillary ? Derive an expression for the height of a liquid in capillary tube. Hence define Jurin's law.



Ans. ***Capillarity*** : The phenomenon in which there is a difference of the levels of liquid inside and outside a capillary tube dipped in the liquid is called capillarity.

Expression for height of liquid in a capillary tube :

Let a capillary tube of radius r be dipped in a liquid of surface tension T and density ρ. If θ is the angle of contact, then the force of surface tension will act inwards. The reaction R of the surface tension will act outwards, so that

$$R = T$$

The reaction can be resolved in two components, namely $R \cos\theta$ acting vertically upward and $R \sin\theta$ acting horizontally outward. Considering the whole meniscus, the total upward force is $2\pi r R \cos\theta$. This force pulls up the liquid through the tube till it is balanced by the weight of the liquid in the tube.

If V_1 is the volume of liquid upto the meniscus and V_2 is the volume of the liquid in the meniscus, then

$$2\pi r R \cos\theta = (V_1 + V_2)\rho g$$

As $R = T$, so,

$$2\pi r T \cos\theta = (V_1 + V_2)\rho g \quad \text{... (1)}$$

...he liquid meniscus, then

$$V_1 = \pi r^2 h$$

$$V_2 = \pi r^2 \cdot r - \frac{1}{2}\frac{4}{3}\pi r^3 = \frac{1}{3}\pi r^3$$

$$T\cos\theta = \left(\pi r^2 h + \frac{1}{3}\pi r^3\right)\rho g$$

$$T = \frac{\pi r^2\left(h + \frac{1}{3}r\right)\rho g}{2\pi r\cos\theta}$$

$$T = \frac{r\left(h + \frac{1}{3}r\right)\rho g}{2\cos\theta} \quad \text{... (2)}$$

$$h = \frac{2T\cos\theta}{r\rho g} - \frac{1}{3}r \quad \text{... (3)}$$

..., so, $h + \frac{1}{3}r = h$, from (2)

$$T = \frac{rh\rho g}{2\cos\theta}$$

$$h = \frac{2T\cos\theta}{r\rho g} \quad \text{... (4)}$$

...of contact $\theta = 0°$, then

$$h = \frac{2T}{r\rho g} \quad \text{... (5)}$$

...cular liquid, ρ and T are constants. Therefore

$$h \propto \frac{1}{r}$$

...height of the liquid column is inversely proportional to the radius of the ...s is called Jurin's law.

NUMERICAL PROBLEMS

...al off-shore structure is built to withstand a maximum stress of 10^9 *Pa*. Is the ...e suitable for putting upon top of an oil well in Bombay High ? Take the ...of the sea to be 3 Km and ignore ocean currents.

maximum stress $= 10^9\ Pa$

depth $= h = 3\text{ Km} = 3 \times 10^3$ m