# CH:2 MECHANICAL PROPERTIES OF FLUIDS

**Q.1: Define a fluid. What are properties of an ideal fluid.**

⇒ Any substance that can flow is a fluid. A fluid is a substance that deforms continually under the action of an external force. Fluid is a phase of matter that includes liquid, gases & plasmas. (Plasma consist of gas of ions, free electrons & neutral atoms).

eg. Air, water, flour dough, toothpaste, molten lava etc.

**Properties of ideal fluid:**

1) It is incompressible: It's density is constant.
2) It's flow is irrotational: It's flow is smooth, there are no turbulences in the flow.
3) It is nonviscous: There is no internal friction in the flow.
4) It's flow is steady: It's velocity at each point is constant in time.

**Q.2: Define pressure. State it's S.I. unit & dimensions.**

⇒ A fluid at rest exerts a force on the surface of contact. The normal force (F) exerted by a fluid at rest per unit surface area (A) of contact is called the pressure (P) of the fluid.

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

It is a scalar quantity.

S.I. unit ⇒ $N/m^2$

⇒ Pascal (Pa) ... ($1\ N/m^2 = 1\ Pa$)

Dimensions ⇒ $[L^{-1} M^1 T^{-2}]$

Other common units ⇒ 1 bar $= 10^5\ N/m^2$

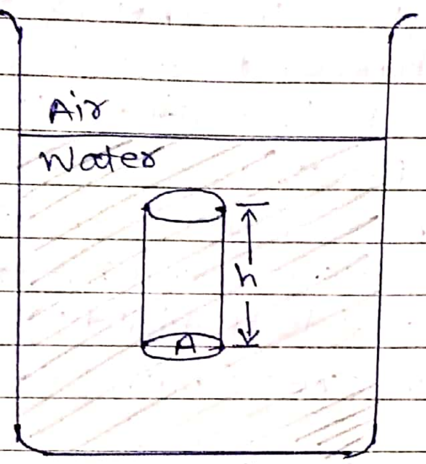
1 hectapascal (h Pa) = 100 Pa, 760 torr = 1 atm

~~1kPa~~ 1 atm = 760 mm Hg = 760 ~~torr~~ =
101.3 kPa = 14.7 psi

1 torr = 1 mm of Hg

**Q.3:** Derive expression for pressure extented by a fluid at rest or Pressure due to a liquid column.

⇒




Consider a vessel filled with a liquid. Consider an imaginary cylinder of cross-sectional area A inside the container. Let the density of fluid be 'ρ' & 'h' be the height of the cylinder.

The force extented by the liquid column on the bottom of cylinder is it's weight.

$\therefore F = mg$

This force acts in the downward direction.

∴ Pressure exerted by liquid column on bottom of cylinder is -

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

$$= \frac{mg}{A}$$

Now, Mass = Volume × Density

$\therefore m = (Ah) \times \rho$

$$\therefore P = \frac{(Ah\rho)g}{A}$$

$$\therefore \boxed{P = h\rho g}$$

This is the pressure exerted by imaginary cylinder of height 'h'. It doesn't depend on area of cylinder.

Q.4: Write a note on atmospheric pressure.

⇒ Earth's atmosphere is made of a fluid called air. It exerts a downward force due to it's weight. The pressure due to this force is called atmospheric pressure.

Thus, at any point, the atmospheric pressure is the weight of a column of air of unit cross-section starting from that point & extending to top of the atmosphere.

It is highest at sea level & decreases as we go above. The pressure at sea level is called normal atmospheric pressure.

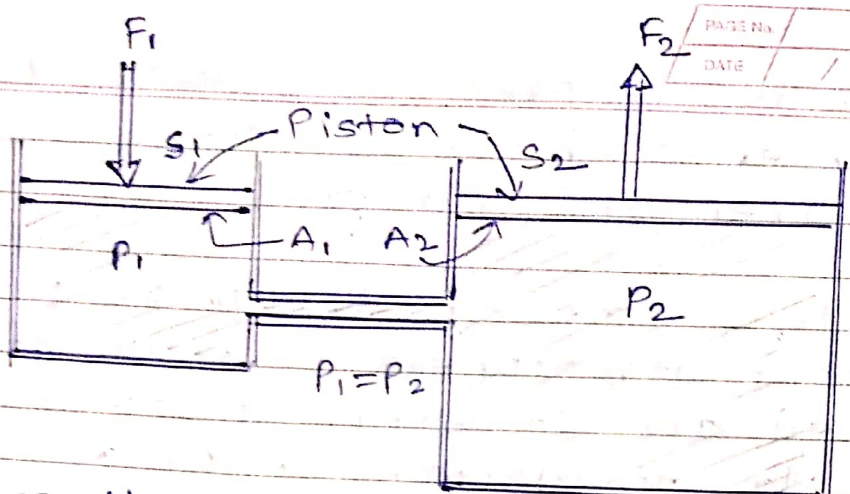
Q.5: State Pascal's law. Explain it's one application.

⇒ It states that the pressure applied at any point of an enclosed fluid at rest is transmitted equally & undiminished to every point of the fluid & also on the walls of the container, provided the effect of gravity is neglected.

Applications:

1) Hydraulic lift: It is used to lift a heavy object using a small force. The working of this machine is based on Pascal's law.

A tank containing a fluid is fitted with two pistons $S_1$ & $S_2$. $S_1$ has



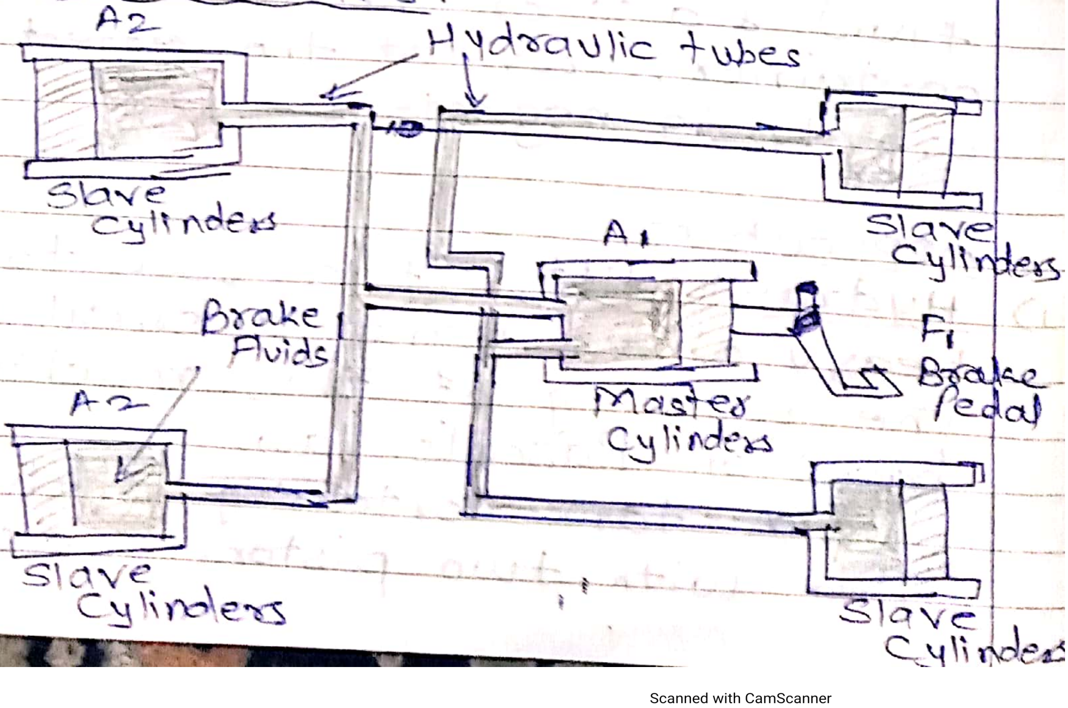

a smaller area of cross-section A1 while $S_2$ has a much larger area of cross-section $A_2$ ($A_2 >> A_1$).

If we apply a force $F_1$ on the smaller piston $S_1$ in downward direction it will generate pressure $P\left(=\frac{F_1}{A_1}\right)$ which will be transmitted undiminished to the bigger piston $S_2$. A force $F_2 = PA_2$ will be exerted upwards on it. $P_1 = P_2$ $\therefore \frac{F_1}{A_1} = \frac{F_2}{A_2}$

$$F_2 = F_1\left(\frac{A_2}{A_1}\right)$$

Thus, $F_2$ is much larger than $F_1$. Thus $S_2$ can lift a very heavy load up & down by applying a small force on $S_1$. This is the principle of hydraulic lift.

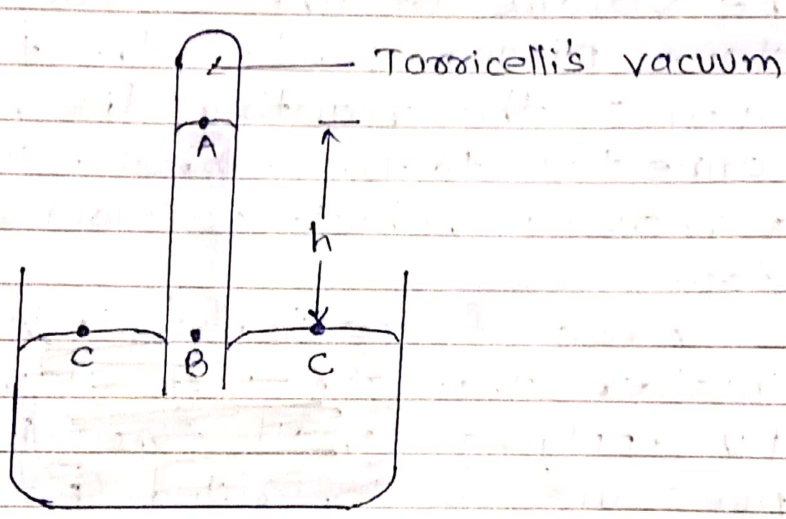
2) Hydraulic brakes:



1) Mercury barometer
2) Open tube manometer.

Q.7: Explain construction & working of Mercury barometer.

⇒ An instrument that measures atmospheric pressure is called a barometer. The mercury barometer is in the form of a glass tube completely filled with mercury & placed upside down in a small dish containing mercury.




A glass tube 1 m long & of diameter 1 cm is filled with mercury upto it's brim. It is then quickly inverted into a small dish containing mercury. As some mercury in the tube spills in the tube, a gap is created at the closed end of the tube. This gap does not contain air & is called Torricelli's vacuum. It does contain some mercury vapors.

Thus pressure at upper end of tub is zero. like at point A.

$\therefore P_A = \text{zero}$ —— (1)

Consider point C on dish surface & point B inside the tube at same horizontal level as that of C.

Since C is open to atmosphere, pressure at C is atmospheric pressure $P_0$. As points B & C are at same level, pressure at both points are same.

$\therefore P_B = P_0$ —— (2)

Suppose point B is at depth 'h' below point A & $\rho$ is density of mercury then

$$P_B = P_A + h\rho g \quad \text{(From (1) \& (2))}$$

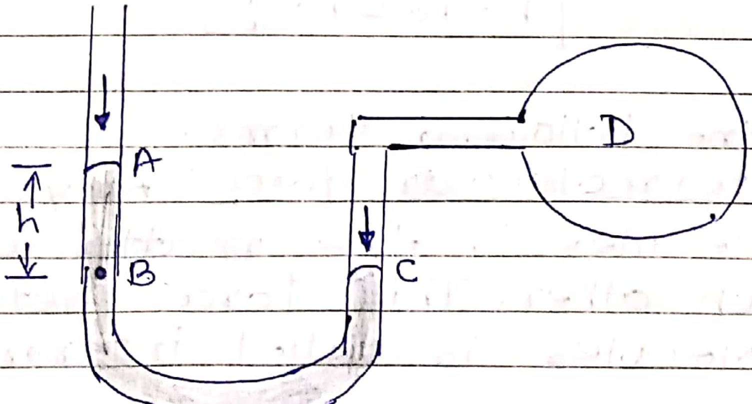
$$\therefore P_0 = 0 + h\rho g \quad (\because P_A = 0 \ \& \ P_B = P_0)$$

$$\therefore \boxed{P_0 = h\rho g}$$

Thus atmospheric pressure can be measured by this instrument.

Q.8: Explain construction & working of Open tube manometer.

⇒ A manometer consists of a U-shaped tube partly filled with a low density liquid such as water or kerosene. This helps in having a larger level difference between the level of liquid in the 2 arms of the manometer.




One arm of the manometer is open to the atmosphere & other is connected to the container 'D' of which the pressure P is to be measured.

Since A is open to atmosphere,

pressure at 'A' is atmospheric pressure $P_0$. We need to find pressure at point 'C'. For this consider point B in the open arm at same level as that of C. Pressure at points B & C are same since they are at same level.

$$\therefore P_C = P_B \quad \text{---(1)}$$

The pressure at point B is

$$P_B = P_0 + h\rho g \quad \text{---(2)}$$

where, $\rho$ is density of liquid in manometer & 'h' is height of column above B.

According to Pascal's law, pressure at C is same as that of D ie. inside the chamber. Therefore, pressure inside container is -

$$P = P_C \quad \text{(from (1) \& (2))}$$
$$= P_0 + h\rho g \quad (\because P_C = P_B \;\&\; P_B = P_0 + h\rho g)$$

As the manometer measures gauge pressure of gas in D, the gauge pressure inside D is

$$\boxed{P - P_0 = h\rho g}$$

Q.9: Define following terms.

1) Intermolecular force: Any two molecules in the matter attract each other. This force between molecules is called intermolecular force.

These are of 2 types-
(1) Cohesive force & (2) Adhesive force.

2) Cohesive force: The force of attraction between the molecules

of the same substance is called cohesive force. This property is called cohesion. It is strongest in solids & weakest in gases. This is the reason why solids have a definite shape & gases do not.

eg. Force of attraction between 2 air molecules or that between 2 water molecules.

3) Adhesive force: The force of attraction between the molecules of different substances is called adhesive force or force of adhesion.

It exists at the liquid-solid, liquid-gas interface. It is weaker than cohesive force.

eg. Force of attraction between glass & water molecule, sticking of chalk particles on blackboard.

4) Range of molecular attraction (force): The maximum distance from a molecule upto which the molecular force is effective is called the range of molecular force.

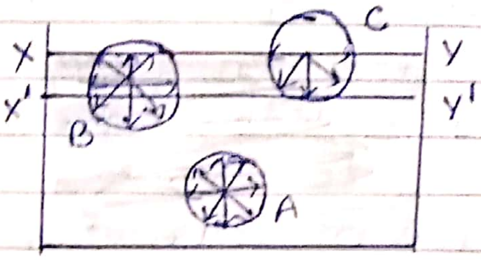
It is effective upto a distance of the order of few nanometer ($10^{-9}$ m) in solids & liquids, so it is called short range force.

5) Sphere of influence: An imaginary sphere with a molecule at it's centre & radius equal to the molecular range is called the sphere of influence of the molecule.

The intermolecular force is effective


only within the sphere of influence.

6) Surface film:




The surface layer of a liquid with thickness equal to the range of molecular force is called the surface film.

This is the layer shown between XY & X'Y' in the figure.

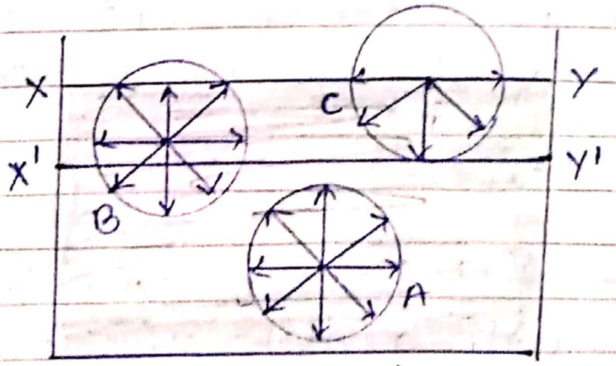
7) Free surface of a liquid: It is the surface of a fluid which does not experience any shear stress. For example, the interface between liquid water & the air above.

In figure, XY is the free surface of the liquid.

Q10: Explain surface tension on the basis of molecular theory.

OR Describe the molecular theory of surface tension.

⇒




1) XY is the free surface of liquid & X'Y' is the inner layer parallel to XY at a distance equal to range of molecular force. Hence,

the section $XX'-Y'Y$ acts as a surface film. Consider three molecules A, B & C such that A is deep inside the liquid, B within surface film & C on the surface of the liquid.

2) Molecule A is deep inside the liquid. ∴ It's sphere of influence is also completely in-side the liquid. As a result, A is acted upon by equal cohesive forces in all directions. Hence, net cohesive force on A is zero.

3) Molecule B lies within the surface layer & below the free surface of liquid. A larger part of it's sphere of influence is inside the liquid & smaller part in air. Thus a strong downward cohesive force acts on it. The adhesive force due to air molecules is negligible. It points upwards. As a result, B gets attracted inside the liquid.

4) Molecule C lies exactly on the free surface of liquid. Half of the sphere of influence is in air & half in liquid. Since density of air is less than liquid, no. of air molecules within sphere of influence is much less than no. of liquid molecules. Thus adhesive force which is upward is much weaker than cohesive force that pull the molecule inside liquid surface. As a result, C also gets attracted inside the liquid.

5) Thus, all molecules in surface film are acted upon by an unbalanced net cohesive force directed into the liquid. Therefore, they are pulled inside the liquid. This minimizes the total no. of molecules in the surface film. As a

Scanned with CamScanner

result, the surface film remains under tension. & it acts as a stretched elastic membrane. This tension is known as surface tension.

6) The force due to surface tension acts tangential to the free surface of a liquid.

**Q.11:** Define surface tension & explain. State it's SI unit & dimensions.

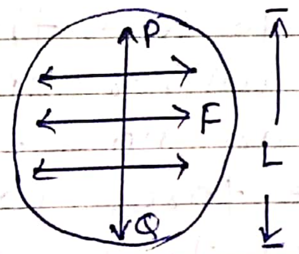
⇒ Surface Tension: It is defined as the tangential force acting per unit length on both sides of an imaginary line drawn on the free surface of liquid.

If F is the force acting on the imaginary line of length (L) then surface tension (T) on liquid is

$$T = \frac{F}{L}$$

S.I. Unit ⇒ N/m

Dimensions ⇒ $[L^0 M^1 T^{-2}]$




The free surface of a liquid in a container acts as a stretched membrane & all the molecules on the surface fiolm experience a stretching force. Imagine a line PQ of length L drawn tangential to the free surface of the liquid as shown.

All the molecules on this line experience equal & opposite forces tangential to surface as if they are tearing the surface apart due to the cohesive forces of molecules lying on either side. This force per unit length is the surface tension.

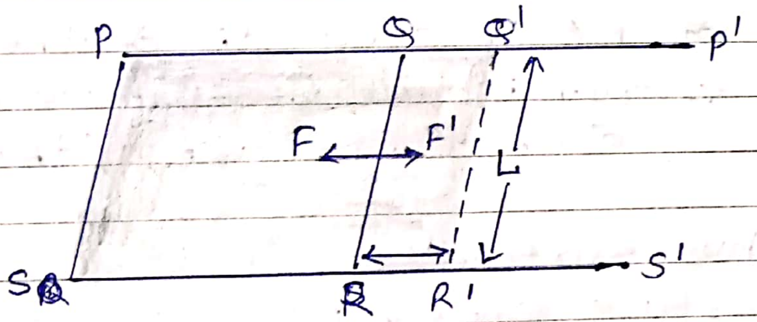
12: What is surface energy? Establish the relation between surface tension & surface energy.

⇒ Surface energy: The surface molecules possess extra potential energy as compared to the molecules inside the liquid. The extra energy of the molecules in the surface layer is called surface energy of the liquid.

S.I. Unit ⇒ joule (J)

Dimensions ⇒ $[L^2 M^1 T^{-2}]$

Relation between surface energy & surface tension:




Consider a rectangular frame of wire P'PSS'. It is fitted with a movable arm QR as shown. This frame is dipped in a soap solution & then taken out. A film of soap solution will be formed within the boundaries PQRS of the frame.

Each arm of the frame experiences an inward force due to the film. Under the action of this force, the movable arm QR moves towards PS so as to decrease area of the film. Suppose length of QR is L. The inward force F acting on it is -

$$F = (T) \times (2L) \quad \text{—— (1)}$$

Since the film has 2 surfaces, upper & lower, the total length over which surface tension acts on QR is 2L.

Imagine an external force F' (equal & opposite to F) applied isothermally to the arm QR to increase surface area of film. QR moves to Q'R' by distance 'dx'. The work done against force F is

$$dW = F' \cdot dx$$

$$= T(2L \cdot dx) \quad \ldots (\text{From (1)})$$

But, $2L \cdot dx = dA$, increase in area of two surfaces of the film.

$$\therefore dW = T(dA)$$

This work done is stored in the form of P.E. in area dA of the film. This energy is called surface energy.

$$\therefore \text{Surface energy} = T(dA)$$

Thus, surface tension is also equal to surface energy per unit area.

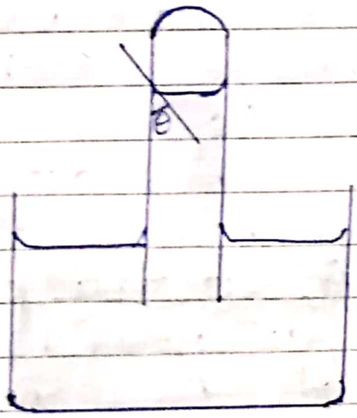
Q.13: What is meant by angle of contact? Explain concave meniscus & convex meniscus. State it's characteristics.

=> When a liquid is in contact with a solid, the angle between tangent drawn to the free surface of the liquid & the surface of solid at the point of contact measured inside the liquid is called angle of contact.

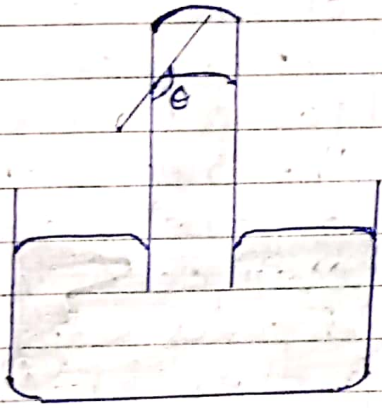
Characteristics:

1) The angle of contact is constant for a given liquid-solid pair.
2) It's value depends upon nature of liquid & solid in contact.
3) It depends upon the medium which exists above the free surface of liquid.
4) It changes due to impurity & temperature

Concave meniscus:




Convex Meniscus




When the angle of contact is acute, the liquid forms a concave meniscus at the point of contact.

eg. Water-glass interface.

When the angle of contact is obtuse, it forms a convex meniscus.

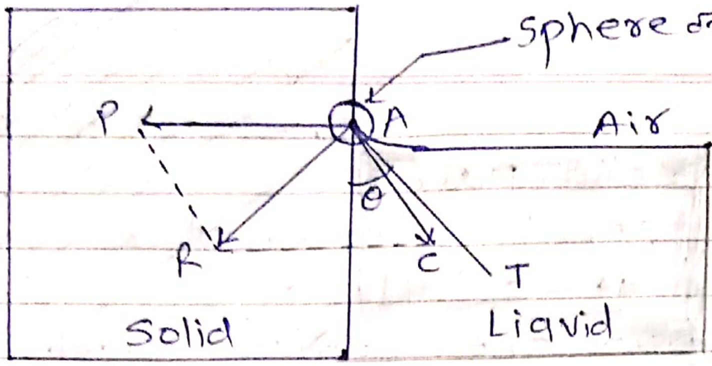
eg. Mercury-glass interface.

The difference between the shapes of menisci is due to the net effect of the cohesive forces between liquid molecules & adhesive forces between liquid & solid molecules.

Q.14: Explain why angle of contact of water-glass pair is acute.

OR why angle of contact of Kerosene in a glass bottle is acute? Explain.

→ Here the liquid wets the solid surface




like kerosene in a glass bottle or water-glass pair.

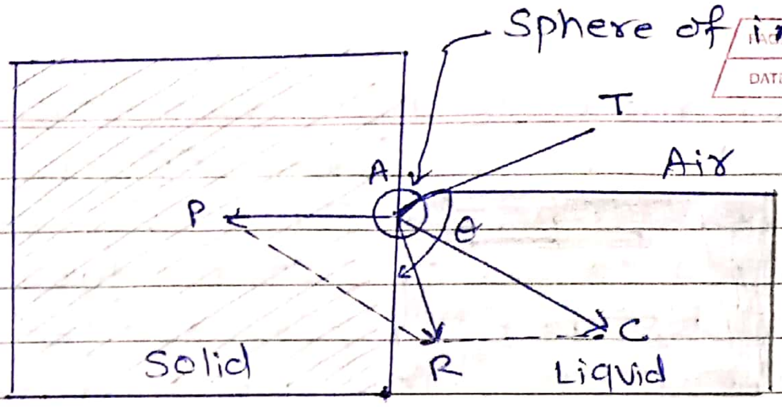
Consider a molecule A on the surface of the liquid near the wall of the container. The molecule experiences both cohesive & adhesive forces. Since the wall is vertical, the net adhesive force ($\vec{AP}$) acting on the molecule A is horizontal. Net cohesive force ($\vec{AC}$) acting on molecule is directed at nearly 45° to either of the surfaces. As adhesive force is stronger, net force ($\vec{AR}$) is directed inside the solid.

In equilibrium state, the tangent AT to the liquid surface must be ⊥er to the resultant force. ∴ Liquid molecules like A creeps upwards on the solid surface. Hence the liquid surface in contact with solid is concave upwards & angle of contact is acute. Thus meniscus is concave.

**Q.15:** Explain why meniscus is convex in case of mercury in a glass bottle.

OR Explain why angle of contact is obtuse in case of mercury & glass pair.

⇒ Here the liquid does not wet the solid surface like mercury in a glass bottle.



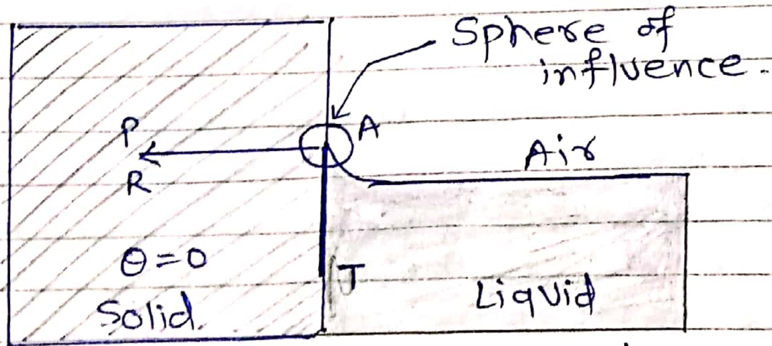

Consider a molecule A on the surface of the liquid near the wall of the container. The molecule experiences both cohesive & adhesive forces. Since the wall is vertical, net adhesive force ($\vec{AP}$) acting on the molecule A is horizontal. As cohesive force is stronger, net force ($\vec{AR}$) is directed inside the liquid.

In equilibrium state, the tangent AT to the liquid surface is ⊥er to the resultant force $\vec{AR}$. ∴ Liquid molecules like A creeps downwards on the solid surface. Hence the liquid surface in contact with solid is convex upwards & angle of contact is obtuse. Thus meniscus is convex.

16: Explain the angle of contact in case of highly pure water with clean glass.

OR Explain the zero angle of contact.

⇒




In case of liquid (eg. highly pure water) which completely wets a solid (eg. clean glass), the resultant adhesive force $\vec{AP}$

acting on molecule A is very strong & resultant cohesive force $\vec{AC}$ is negligible. ie. $\vec{AC} = 0$. Thus net adhesive force itself is the resultant force. ie. $\vec{AP} = \vec{AR}$. Therefore, the tangent AT along the wall within the liquid. & the angle of contact is zero. $\theta = 0°$.

Q.17: What are different factors affecting the angle of contact?

⇒ i) The nature of the liquid & solid in contact.

2) Impurity: Impurities present in the liquid change the angle of contact.

3) Temp. of the liquid: Any increase in the temp. of a liquid decreases it's angle of contact.

Q.18: Explain the effect of impurities & temp. on the surface tension of liquid.

⇒ a) Effect of impurities ::

① When soluble substance like common salt ($NaCl$) is dissolved in water, the surface tension of water increases.

② When a sparingly soluble subtance like phenol or detergent is mixed with water, surface tension of water decreases. Thus detergent powder is mixed with water to wash clothes. Due to this S.T. of water decreases & water makes good contact with the fabric & is able to remove tough stains.

③ When insoluble impurity is added into water, S.T. of water decreases. When impurity is added to liquid,

Scanned with CamScanner

cohesive force of that liquid decreases & which affect angle of contact. If mercury gathers dust then it's S.T. is reduced & it doesn't form spherical droplets until dust is completely removed.

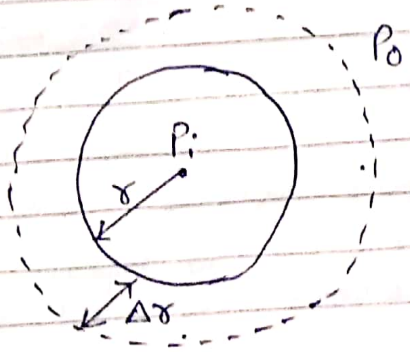
1) Effect of Temp: As temp increases S.T. decreases. eg. New cotton fabric should be washed in cold water. Here, water does not make good contact with the fabric due to it's higher S.T. Thus, the fabric does not lose it's colour. Also, hot water is used to remove tough stains on fabric because of it's lower S.T.

The S.T. of liquid becomes zero at critical temperature.

19) Derive Laplace's law of a spherical membrane.

2) Derive an expression for excess pressure inside a liquid drop.

→ Due to surface tension free liquid drops & bubbles are spherical in shape. Due to spherical shape, the inside pressure will be greater than outside pressure.




Consider a spherical drop as shown.
Let $P_i$ = Inside pressure of drop
$P_o$ = Outside —"—
= Radius of drop

Excess pressure inside drop $= P_i - P_o$

Let the radius of drop increases from $r$ to $(r+\Delta r)$ so that inside pressure remains constant.

Initial surface area $(A_1) = 4\pi r^2$

Final —"— $(A_2) = 4\pi(r+\Delta r)^2$

$\therefore A_2 = 4\pi(r^2 + 2r.\Delta r + \Delta r^2)$

$= 4\pi r^2 + 8\pi r.\Delta r + 4\pi\Delta r^2$

$\because \Delta r$ is very small, $\Delta r^2$ can be neglected.

$\therefore A_2 = 4\pi r^2 + 8\pi r.\Delta r$

$\therefore$ Increase in surface area is -

$dA = A_2 - A_1$

$= 4\pi r^2 + 8\pi r.\Delta r - 4\pi r^2$

$= 8\pi r.\Delta r$ —— (*)

Work done to increase the above surface area is -

$dW = T.dA$

$= T(8\pi r.\Delta r)$ —— ①

But, $dW = F.\Delta r$

$= (P_i - P_o).4\pi r^2.\Delta r$ —② $\{\because P = \frac{F}{A}$, $\therefore F = PA$

From ① & ② ⟹

$(P_i - P_o)4\pi r^2.\Delta r = T(8\pi r.\Delta r)$

$\therefore P_i - P_o = \frac{8\pi r.\Delta r.T}{4\pi r^2.\Delta r}$

$$\therefore \boxed{P_i - P_o = \frac{2T}{r}}$$

This equation gives the excess pressure inside a drop. This is called Laplace's law of a spherical membrane.

For soap bubble, there are 2 free surfaces in contact with air, the inner & outer surface.

$\therefore dA = 2(8\pi r \cdot \Delta r)$ ... From (*)

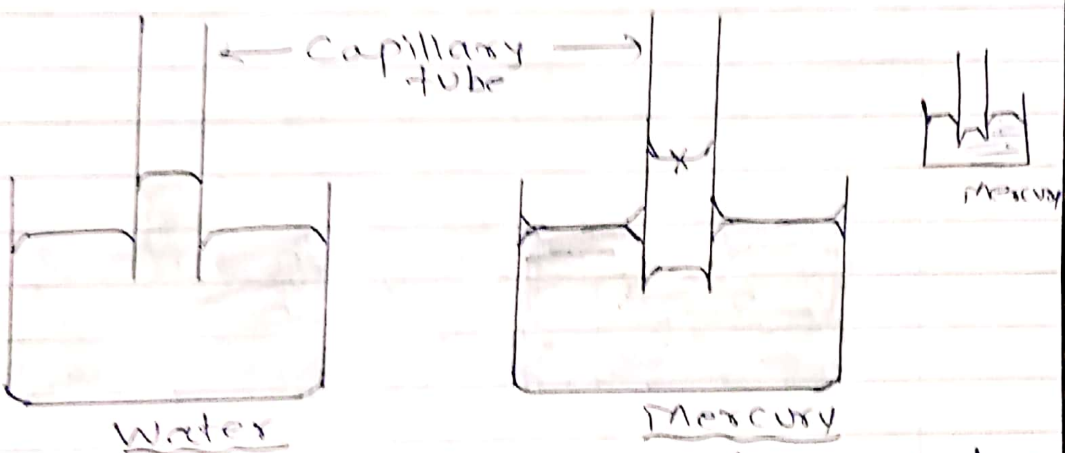
$\therefore dW = T[2(8\pi r \Delta r)] = T(16\pi r \Delta r)$

$\therefore P_i - P_o = \frac{16\pi r \cdot \Delta r \cdot T}{4\pi r^2 \cdot \Delta r}$

$$\therefore \boxed{P_i - P_o = \frac{4T}{r}}$$

Q: What is capillarity? Give some applications of capillarity.

→ A glass tube having a very fine bore (~1mm) is called capillary.




When Capillary tube is dipped in water which wets the capillary, the water level rises inside the capillary tube.

But when the same tube is dipped in mercury which does not wet the capillary, the mercury level in the tube falls below.

Capillarity: The phenomenon of rise or fall of a liquid inside a capillary tube when it is dipped in the liquid is called Capillarity.

Applications:

1) Blotting paper absorbs ink due to

Capillary action.

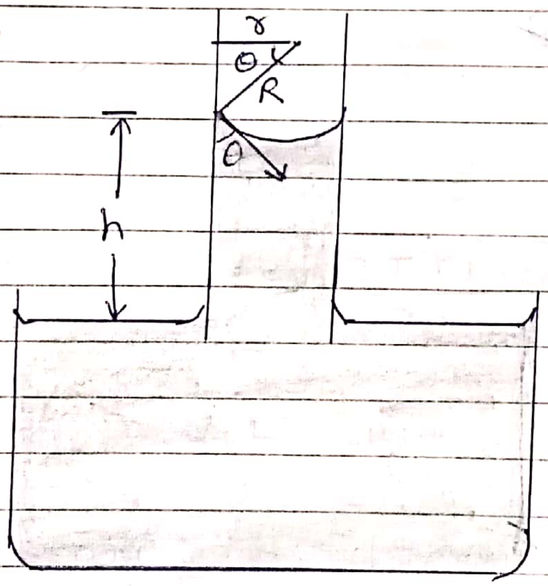
(2) Ink rises in a pen due to capillary action.

(3) Oil rises up in the wick of lamp on account of capillarity.

(4) Sap & water rises even up to the topmost leaves in the tree by capillary action.

Q.21: Obtain an expression for the rise of a liquid (or fall) in a capillary tube using pressure difference method.

⇒ Consider a capillary tube dipped in a liquid which wets the walls of the tube. Therefore, angle of contact is acute & meniscus is concave.




The pressure due to the liquid (water) column of height h must be equal to the pressure difference $\frac{2T}{R}$ due to concavity.

$$\therefore h\rho g = \frac{2T}{R}$$

Where, $\rho$ ⇒ Density of the liquid
g ⇒ Acceln due to gravity
T ⇒ Surface tension of the liquid
R ⇒ Radius of curvature of meniscus.

Let $r$ be the radius of the capillary tube & $\theta$ be the angle of contact of the liquid.
The radius of curvature $R$ of the meniscus is given by -

$$R = \frac{r}{\cos\theta} \quad \cdots \left(\because \cos\theta = \frac{r}{R}\right)$$

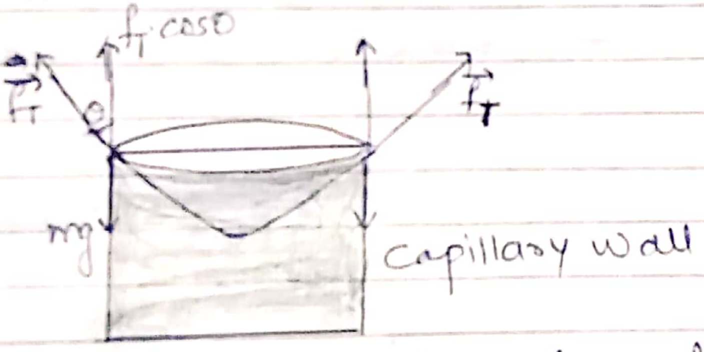
$$\therefore h\rho g = \frac{2T \cdot \cos\theta}{r}$$

$$\therefore \boxed{h = \frac{2T \cdot \cos\theta}{r\rho g}}$$

This equation gives expression for capillary rise (or fall) for a liquid.

22. Obtain an expression for rise (or fall) of liquid in a capillary tube using forces method.

⇒




Consider a capillary tube dipped in a liquid which wets the walls of the tube. Therefore, angle of contact is acute & meniscus is concave.

Rise of water inside a capillary is against gravity. Hence, weight of the liquid column must be equal & opposite to the proper component of force due to surface tension at the point of contact.

The length of liquid in contact inside the capillary $= 2\pi r$ ... (Circumference)

$\therefore$ Force due to S.T. is

$$f_T = (\text{Surface tension}) \times (\text{Length in contact})$$
$$= T \times 2\pi r$$

Direction of this force is along the tangent.
Vertical component of this force is -

$$(f_T)_v = T \times 2\pi r \times \cos\theta \quad \text{--- (1)}$$

Ignoring the liquid in the concave meniscus, the volume of liquid in the capillary rise is -

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

∴ Mass of liquid in capillary rise is -

$$m = V \times \rho$$
$$= \pi r^2 h \rho$$

∴ Weight of liquid is -

$$W = \pi r^2 h \rho g \quad \text{--- (2)} \quad (\because W = mg)$$

This must be equal & opposite to vertical component of force.
∴ Equating eq$^n$ (1) & (2) RHS ⇒

$$T \times 2\pi r \times \cos\theta = \pi r^2 h \rho g$$

$$\therefore h = \frac{T \times 2\pi r \times \cos\theta}{\pi r^2 \rho g}$$

$$\therefore \boxed{h = \frac{2T \cdot \cos\theta}{r \rho g}}$$

This equation gives expression for Capillary rise (or fall).

**Note:** In terms of capillary action, the expression for S.T. is -

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

**Q.23:** Explain the terms:

1) Hydrostatics: The branch of Physics which deals with the properties of fluids at rest is called Hydrostatics.
Pressure is the property of fluid at rest.