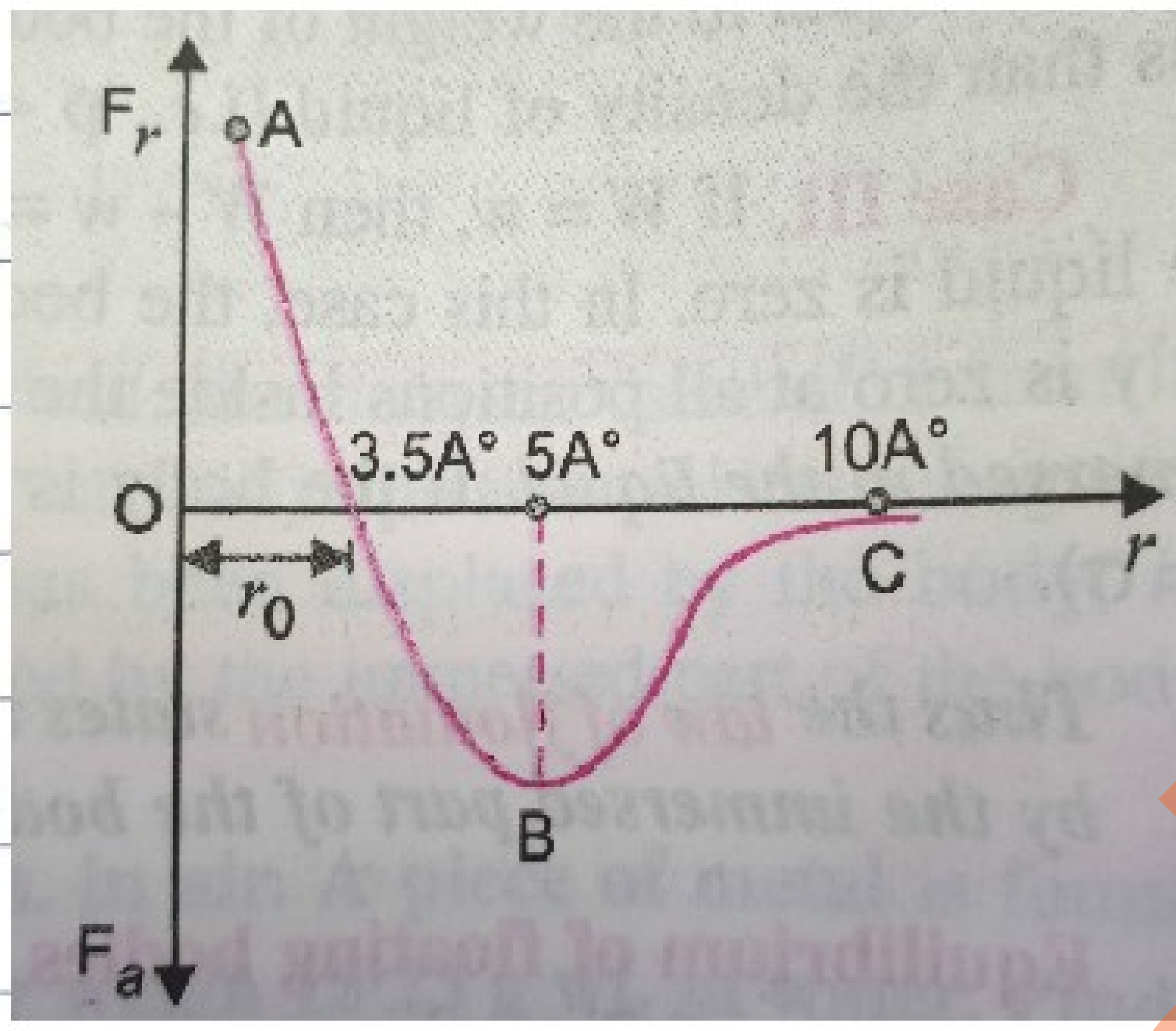
Surface Tension

Inter-molecular forces

The forces betⁿ the molecules of the substances are called intermolecular forces.



- When $r = 10A°$, intermolecular force negligible.
- As 'r' decreases, there develops a force of attraction 'F_a' which increases with decrease in 'r'.
- At $r = 5A°$, F_a - max.
- For $r < 5A°$, F_a decreases & $F_a = 0$ at $r = r_0 = 3.5A°$ (normal or equilibrium distance betⁿ molecules).
- For $r < r_0$, there develops a force of repulsion (F_r) which increases rapidly with decrease in r.

Types of intermolecular forces

① Adhesive force

It is the force of attraction acting between molecules of different substances.

Example :

- Water wets the surface of a glass container because of strong adhesive force betⁿ water & glass molecules.
- Graphite from lead pencils sticks to paper because of adhesive force betⁿ graphite & paper.
- Cement glues 2 surfaces together due to adhesive force.

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② Cohesive force

It is the force of attraction among the molecules of the same substance.

Examples:

- Mercury does not wet the surface of water because the cohesive force among its molecules is greater than the adhesive force betn mercury & glass molecules.
- Solids have a definite shape & size due to strong cohesive force among its molecules.

Some important terms

(i) Molecular range

It is the max. distance upto which a molecule can exert some measurable attraction on other molecules.

(ii) Sphere of influence

- It is an imaginary sphere drawn with a molecule as centre & molecular range as radius
- All the molecules in the sphere attract the molecules at the centre.

(iii) Surface film

It is the top most layer of liquid at rest with thickness equal to molecular range.

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Surface tension (S)

It is the property of the liquid by virtue of which the free surface of liquid at rest tends to have minimum surface area & as such it behaves as if covered with a stretched membrane.

$$S = \frac{F}{l}$$

- Unit - Nm^{-1}
- Dimension - $[MT^{-2}]$
- scalar quantity

Examples

(1) Rain drops are spherical in shape

Reason: Each drop tends to have a minimum surface area due to surface tension & for a given volume, the surface area of sphere is min.

(2) Oildrops spread on cold water & remains as drop on hot-water.

Reason: Surface tension of oil < S.T. of cold water - spreads
" " " > " " hot " - drop remai

(3) Bits of camphor are seen dancing on the surface of water

Reason: As the shape of bits of camphor is irregular, unequal forces of surface tension act on them & so, they move erratically & appear as dancing.

(4) When a shaving brush is dipped in water, its hair spread out.

Reason: When it is taken out, the water film formed betⁿ the hairs tends to make its surface area minimum (due

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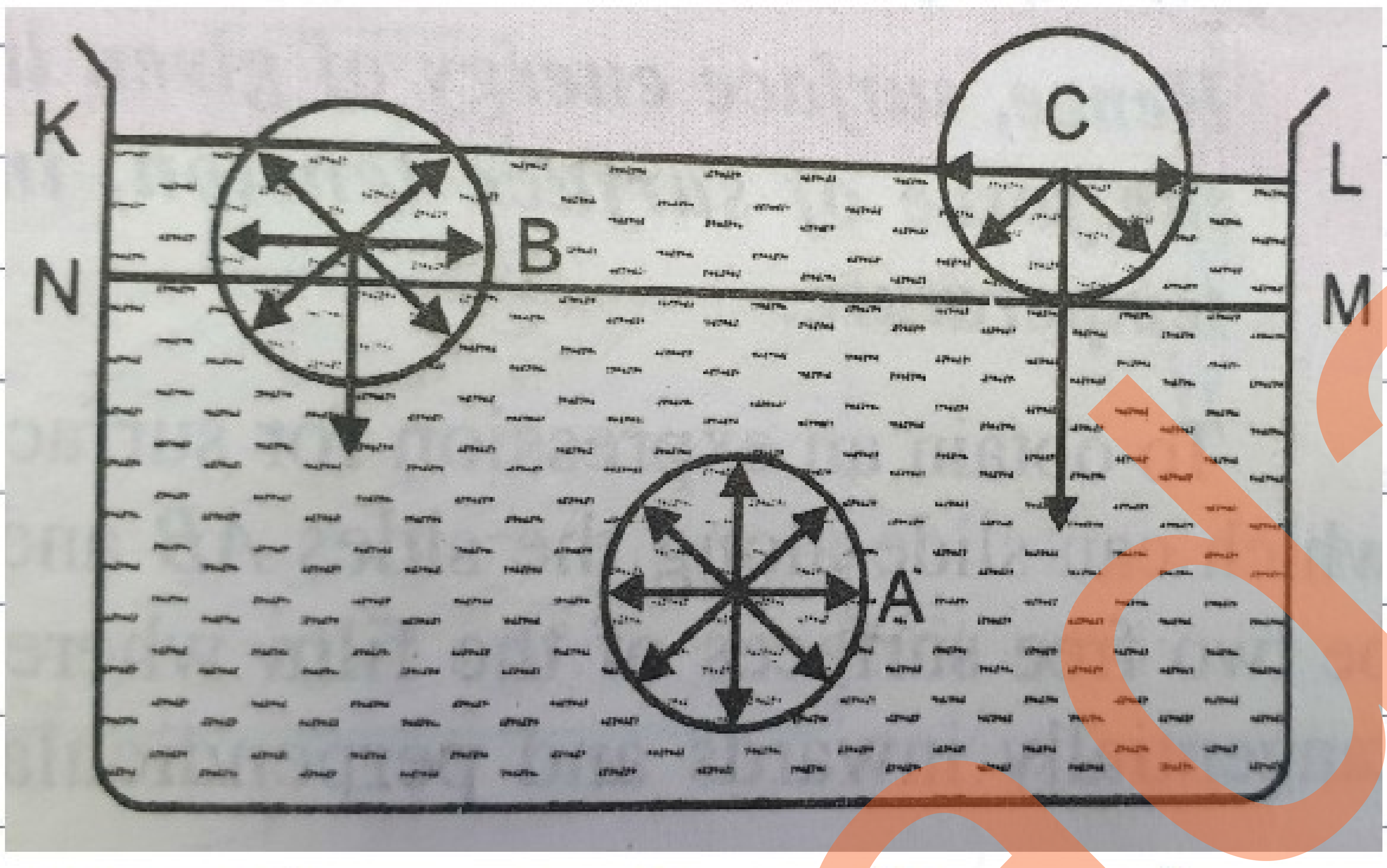
to surface tension) & so it brings the hairs closer to each other. On the other hand, inside water nothing like this occurs & so they spread out.

Molecular theory of surface tension



Let KLMN – surface film of a liquid at rest in a trough

KL = MN – molecular range

A – molecule well inside the liquid

B – " lying in surface film

C – " " at top of " "

For molecule A

no. of molecules in upper half of sphere of influence = no. of molecules in lower half of sphere of influence

⇒ resultant upward force of cohesion = resultant downward force of cohesion

⇒ Net force of cohesion on A = 0

⇒ A has –ve potential energy.

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For molecule B

No. of molecules in upper half of s.o. influence $<$ No. of molecules in lower half of s.o. influence.

$\Rightarrow$ resultant upward force of cohesion $<$ resultant downward force of cohesion

$\Rightarrow$ A resultant downward cohesive force is acting on B.

For molecule C

No. of molecules in upper half of s.o. influence $<<<$ No. of molecules in lower half of s.o. influence.

$\Rightarrow$ resultant upward cohesive force $<<<$ resultant downward cohesive force

$\Rightarrow$ Max. resultant downward force is acting on C.

→ To take a molecule into the surface from anywhere below it, work has to be done against downward cohesive force.

→ This work done appears as additional potential energy of the molecule.

→ So, all the molecules in the surface film possess additional potential energy, & hence the surface film has additional potential energy.

→ In order to attain stable equilibrium, the surface film tends to have min. additional potential energy.

→ For this, the no. of molecules in the surface film should be min.

→ For this, the surface film should have min. volume which will happen when the surface film has min. surface area (as its thickness is fixed)

→ In trying to acquire least surface area, the surface film

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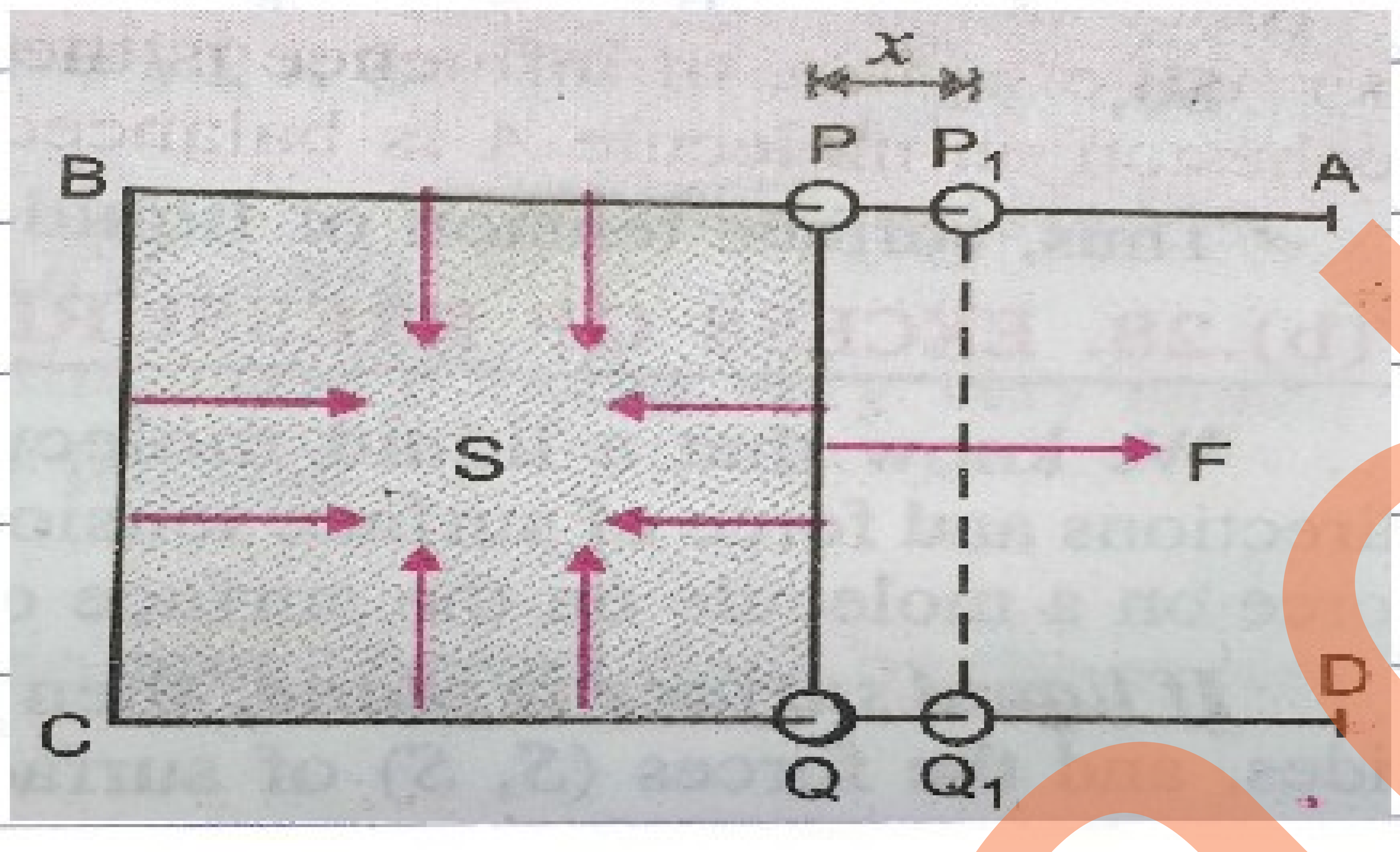
tends to contract & hence behaves as a stretched membrane.

Surface Energy

It is defined as the amount of work done against the force of surface tension, in forming the liquid surface of given area at const. tem.



Consider a rectangular metallic frame ABCD having a wire PQ which slides along AB & CD. Let BCQP be the soap film formed on the frame.

Let S - surface tension of soap solution

l - length of PQ

Since there are 2 free surfaces of the film & surface tension acts on both of them, so total inward force on PQ is

$$F = S \times 2l$$

Let the film be stretched by displacing PQ through small distance 'x' to P_1Q_1

Increase in area of film $PQQ_1P_1 \Rightarrow \Delta A = 2(l \times x)$

The work done in stretching the film is

$$W = Fx$$

$$= S \times 2l \times x = S \times \Delta A$$

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This work done is stored in the film as its surface energy

$$\boxed{E = S \times \Delta A}$$

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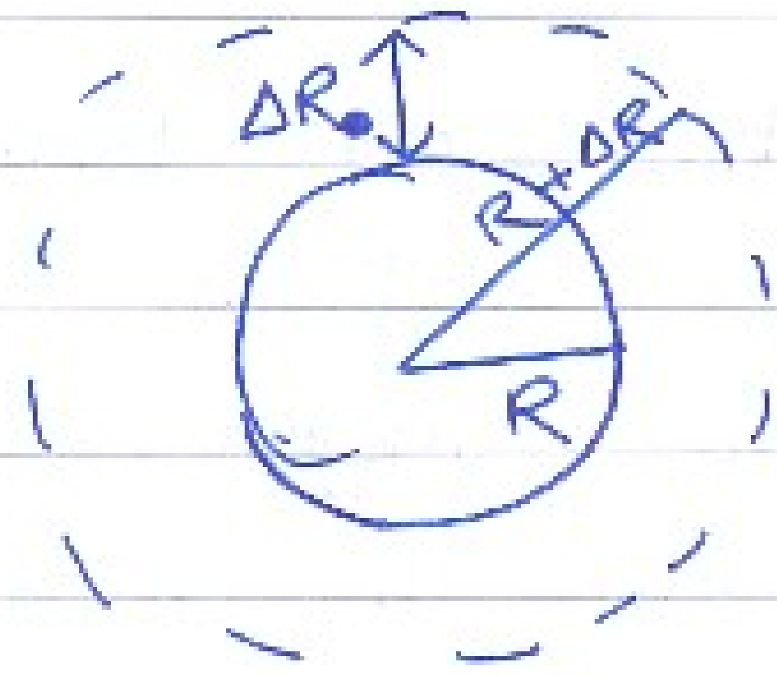
Excess of pressure inside a liquid drop



Consider a liquid drop of surface tension T & radius R.

Let P_i – pressure inside the liquid drop
P_o – " outside " " "

Excess pressure inside the drop $= p_i - p_o$

Suppose the radius of the drop is increased from R to $R + \Delta R$ due to excess pressure.

Small work done in increasing radius

$$dW = F \times \Delta R$$
$$= (P_i - p_o) \times 4\pi R^2 \times \Delta R$$

This work is done by the excess pressure against the force of surface tension & is stored inside the drop as its potential energy.

Now, increase in P.E of liquid drop

$$\Delta U = \text{Surface tension} \times \text{increase in surface area}$$
$$= S\left(4\pi(R+\Delta R)^2 - 4\pi R^2\right)$$
$$= S\left(4\pi\left(R^2 + \Delta R^2 + 2\Delta R \times R\right) - 4\pi R^2\right)$$
$$= 8\pi R \Delta R \times S$$

As the drop is in equilibrium

$$(p_i - p_o)\, 4\pi R^2 \Delta R = 8\pi R \Delta R S \Rightarrow \boxed{p_i - p_o = \frac{2S}{R}}$$

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Excess of pressure inside a soap bubble

→ A soap bubble has air both inside & outside it & so it has 2 free surfaces.

→ If a liquid bubble increases in size from R to R+ΔR then area of its inner as well as outer surface will increase.

So,

increase in P.E of bubble

$$\Delta U = 2S\left[4\pi(R+\Delta R)^2 - 4\pi R^2\right]$$

$$= 16\pi R \Delta R \times S$$

Small work done in increasing radius

$$dW = 4\pi R^2 \Delta R\,(p_i - p_o)$$

As the drop is in equilibrium

$$4\pi R^2 \Delta R\,(p_i - p_o) = 16\pi R \Delta R \times S$$

$$\boxed{p_i - p_o = \frac{4S}{R}}$$

Capillarity

Capillary – A tube of very fine bore

Capillarity – The rise & fall of a liquid in a capillary.

When a capillary tube open at both the ends is dipped in a liquid which

(a) wets the walls of the tube – liquid rises in the tube.

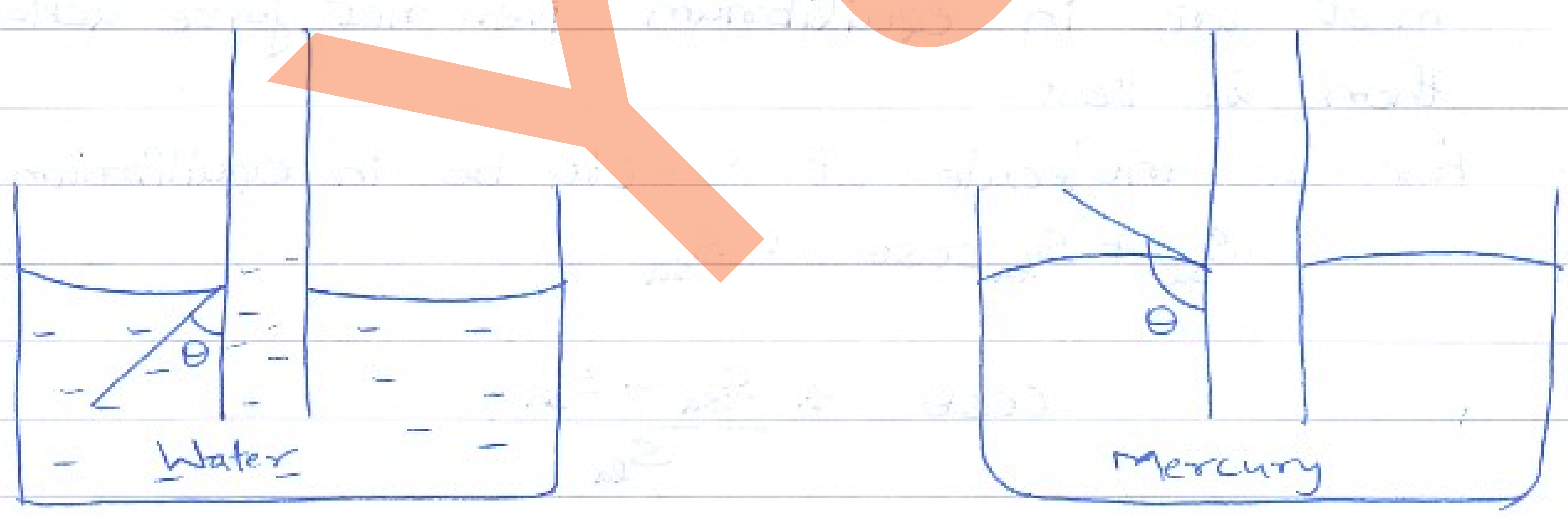
(b) Does not wets " " " " " – liquid depresses below the surface of liquid in the tube.

Practical applications of Capillarity

1. A blotting paper absorbs ink by capillary action
2. Towel soaks water due to capillary action
3. Water reaches every branch of a plant from the stem because of capillary action
4. The tip of the nib of a pen is split to provide capillary action for the ink to rise.

Angle of contact (θ)

The angle which the tangent to the liquid surface at that point of contact makes with the solid surface inside the liquid, is called the angle of contact.



Case 1 Case 2

Case 1 $\theta < 90^\circ$

(i) It happens in case of those liquids which wet the walls of the container.
(ii) meniscus will be concave
(iii) liquid will rise in the capillary

Case 2 $\theta > 90^\circ$

(i) liquids which ~~which~~ do not wet the walls of container.
(ii) meniscus – convex
(iii) liquid will get depressed in the capillary.

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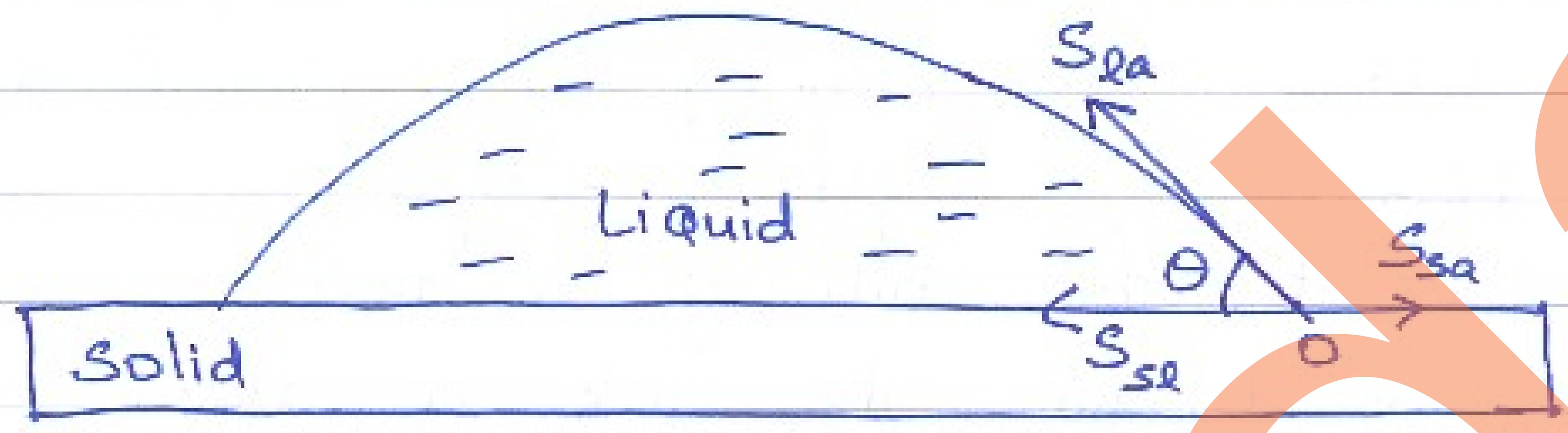
Shape of Drops

- Suppose that a small quantity of a liquid is poured on a plane solid surface.



There are 3 interfaces – solid liquid (sl)
– solid air (sa)
– liquid air (la)

- The molecules in the region where the 3 interfaces meet are in equilibrium i.e. net force acting on them is zero.
- For a molecule at O (to be in equilibrium)

$$S_{sl} + S_{la}\cos\theta = S_{sa}$$

$$\cos\theta = \frac{S_{sa} - S_{sl}}{S_{la}}$$

(i) $S_{sa} > S_{sl}$, $\cos\theta = +ve$ θ – acute
condition is fulfilled when molecules of liquid are strongly attracted to those of solid.

(ii) $S_{sa} < S_{sl}$, $\cos\theta = -ve$ θ – obtuse
condition is fulfilled when molecules of liquid are strongly attracted among themselves.

(iii) $(S_{sl} + S_{la}\cos\theta) > S_{sa}$ – no equilibrium
– liquid spreads.

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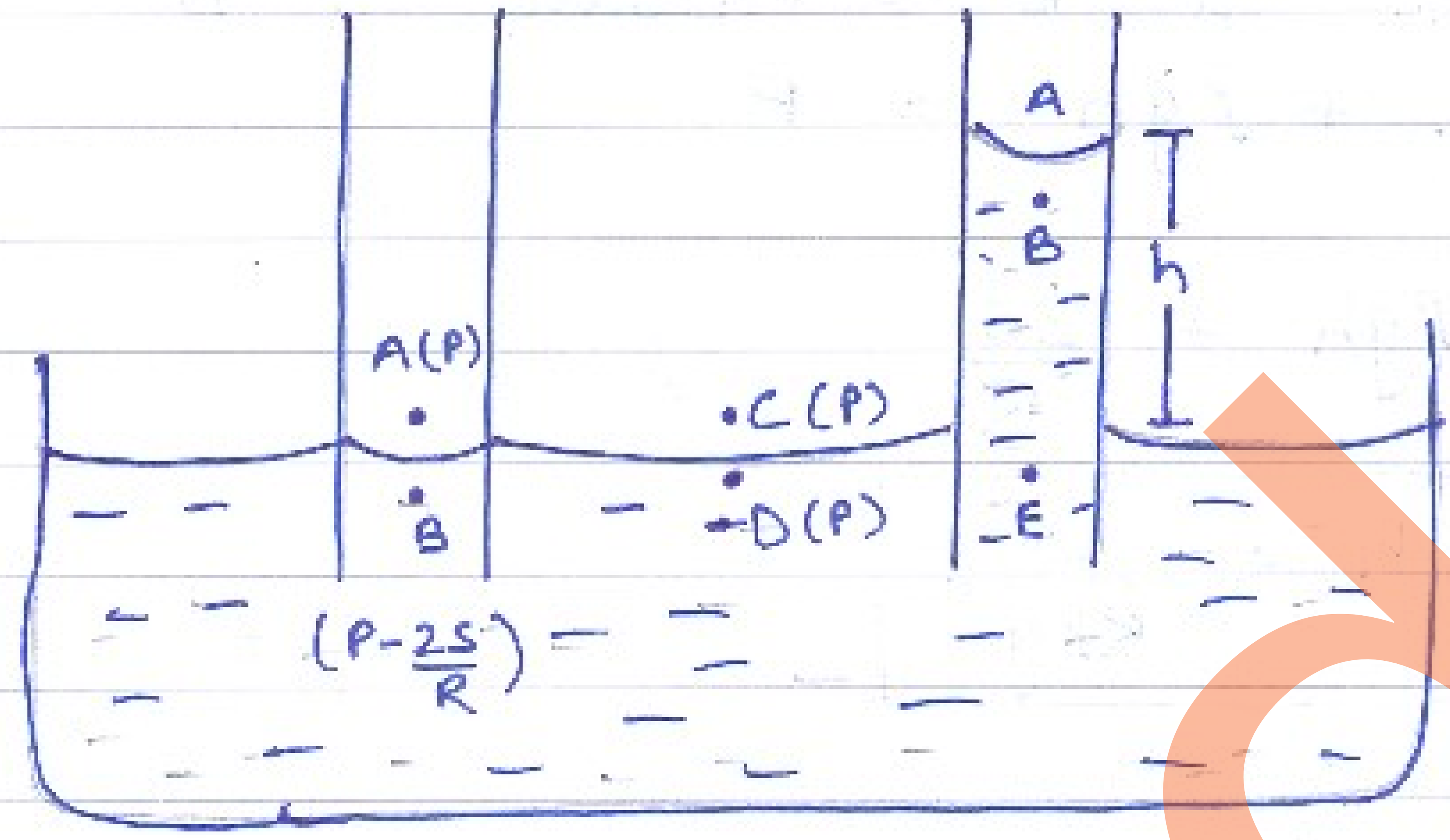
Rise of liquid in a capillary tube (Ascent formula)



Let one end of a capillary tube of radius 'r' is immersed into a liquid of density 'ρ' which wets the sides of a capillary tube.

Let R - radius of curvature of liquid meniscus
P - atmospheric pressure
S - surface tension of liquid

Pressure at pt. A = P

" " " B = $P - \frac{2S}{R}$

C & D = P

Pressure at points B & D is different so there is no equilibrium.
In order to maintain equilibrium, the liquid level rises in the capillary tube upto height 'h' so that pressure at D & E (which are at same level in liquid) may become equal.

Pressure at E = Pressure at B + Pressure due to height h

$$= P - \frac{2S}{R} + h\rho g$$

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As there is equilibrium

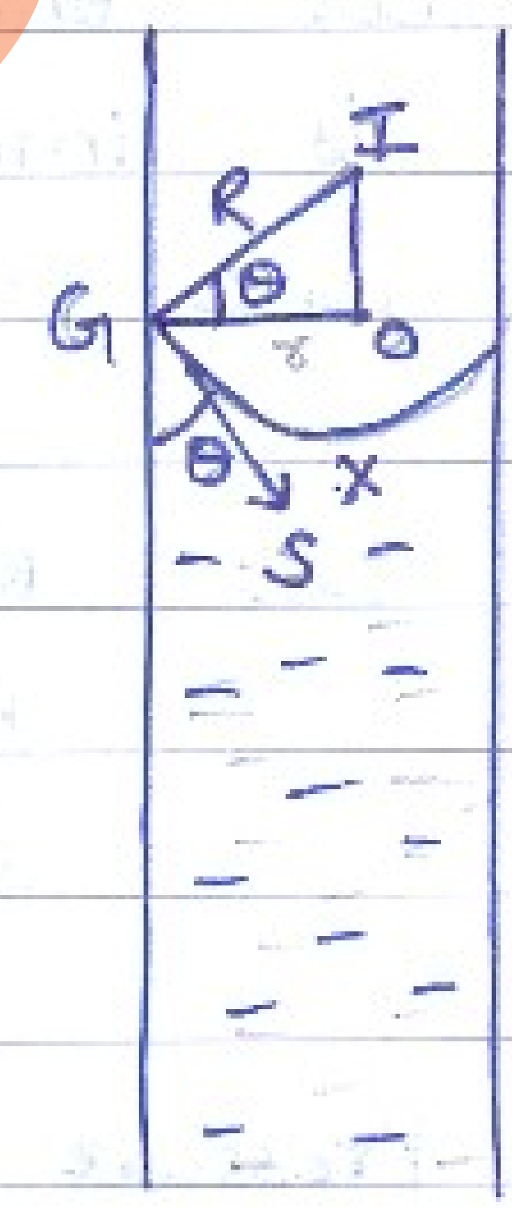
Pressure at E = Pressure at D

$$P - \frac{2S}{R} + \rho g h = P$$

$$\rho g h = \frac{2S}{R}$$

$$\boxed{h = \frac{2S}{R\rho g}}$$

Calculation of R



Let I - c. of curvature of liquid meniscus GXY in the tube

GS - tangent to the liquid surface at G.

GI = R

GO = r

θ - angle of contact

In ΔIGO, $\cos\theta = \frac{r}{R}$ $\Rightarrow R = \frac{r}{\cos\theta}$

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

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

- Smaller is value of r, larger will be value of h & vice-versa
- Thus, liquid rises more in a narrow tube & less in wider tube.

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