Surface Tension

Molecular Force

As we know that all the substance are made up of small particles, known as molecules. The force of attraction or repulsion betn molecules is known as molecular forces.

There are two types of molecular forces :
① Cohesive force or Force of cohesion.
② Adhesive force or Force of adhesion.

① Cohesive force : The force of attraction between molecules of same substance or material is known as cohesive force.

For Ex : it is difficult to break a drop of mercury into small droplets due to large cohesive forces betn the molecules of mercury.

Cohesive force is maximum in solids and smaller in liquids. This force is very small in gases.

② Adhesive force : The force of attraction betn the molecules of different substance or

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material in Known as adhesive force.

for Ex : Water wets the glass surface due to adhesive force. Adhesive force is diff. for diff. substances.

Molecular Range

The maximum distance up to which a molecule can exert force of attraction on another molecule is known as molecular range.

It is in the order of 10^{-9} m in solids and liquids.

Sphere of Influence

A sphere drawn around a molecule as centre with a radius equal to its molecular range is known as sphere of influence.

The molecule attracts all the other molecules lying in its sphere of influence i.e. A molecule will attract another molecule only if it lies within the sphere of influence.

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Surface film

A thin film of liquid on its free surface having thickness equal to the molecular range for that liquid is known as surface film.

- Practical Examples of Cohesive and Adhesive forces -
A few practical examples of these forces are given below -

(a) The ink sticks on paper. It is because the adhesive force betⁿ ink and paper is greater than the cohesive force of ink molecules.

(b) Water wets the glass. It is because the adhesive force betⁿ water molecules and glass molecules is greater than the force of cohesive force betⁿ water molecules.

(c) Mercury does not wet the glass because the adhesive force betⁿ mercury molecules and glass molecules is less than the cohesive force betⁿ mercury molecules.

(d) We are able to write on the blackboard with a piece of the chalk because the adhesive force b/w chalk molecules and wood molecules is made

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greater than the Cohesive force b/w chalk molecules.

Some facts about molecular forces:

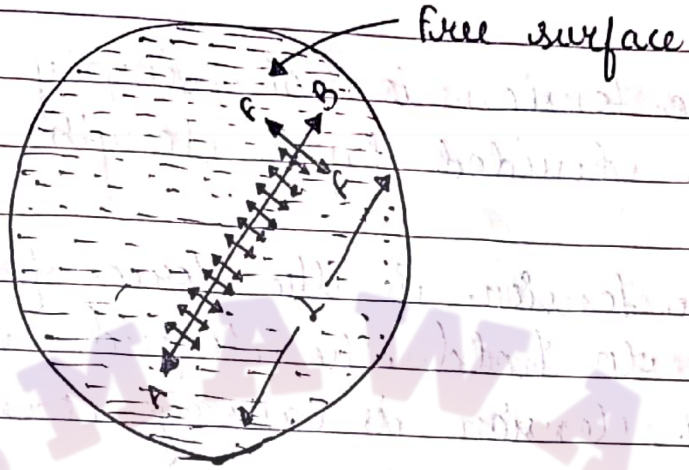
① On the average, the molecules in solids and liquids are separated by a distance of the order of 10^{-9} m.

② The molecules of a liquid or solid attract each other if distance b/w them is 10^{-9} m. or less.

③ If the distance b/w the molecules becomes greater than 10^{-9} m, the attraction b/w the molecules become negligible.

Surface Tension:

The property of a liquid at rest by virtue of which its free surface behaves like a stretched membrane under tension and tries to occupy as small area as possible is called surface tension.



surface tension, $T = \frac{\text{Force on either side of line AB}}{\text{Length of AB}}$

$= \frac{F}{l}$

If $l = 1$, then $T = F$

Thus surface tension of a liquid can be measured as the force per unit length in the plane of the liquid surface acting at right angles on either side of an imaginary line drawn on the liquid surface.

since surface tension T is a force per unit length, its SI unit is Nm^{-1}.

4) Discussion -

① Surface Tension is a scalar quantity because it has no specific direction for a given liquid.

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(2) surface tension is not simply a force but is a force divided by a length ($T = F/l$).

(3) surface tension is the force per unit length needed to hold the liquid surface together. surface tension is always tangent to the liquid surface.

(4) The surface tension of a liquid decrease with the increase in temperature and vice-versa.

Laplace's Molecular Theory of Surface Tension

fig →

Let a glass jar filled with some liquid as shown in fig. Let us consider four molecules A, B, C and D of liquid with their sphere of influence drawn around them. sphere A being well inside the liquid. B near the free

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surface of the liquid. C just on the free surface Molecules D lies above the free surface.

Since the sphere of influence of molecule A lies utterly inside the liquid, it is attracted equally in all direction by the other molecules lying within its sphere of influence. so that there is an no resultant cohesive force on it.

Therefore it merely passes its thermal velocity.

The sphere of influence of molecule B, lies partly outside the liquid and this part contains only gas or vapour molecules. Their number is less. So forces exerted by the air molecules on B will be very small. Major part of sphere of influence is within the liquid. Hence, number of molecules is too large. Hence, a resultant downward force will act on B.

molecule C lies on the surface of the liquid. Upper half of this sphere of influence contains air or vapour molecules whose number is less than the number of liquid molecules of the lower half portion of the sphere of influence. As a result the resultant force on the molecule C will be downward. This downward force exerted per unit area of a liquid surface is called internal, intrinsic or cohesion pressure.

For, the molecule D, above the surface of the liquid, a small part of the sphere of influence lies inside the liquid and its major part lies outside the liquid. In this case, no. of liquid molecules is very-very less than that of air molecules, so, resultant on D will be in the upward direction. Molecule D will evaporate.

If a plane RS is drawn parallel to the free surface PQ of the liquid at a depth equal to the molecular range (distance r), the layers of the liquid betn the planes PQ and RS is called the surface film.

Thus, we find maximum downward force acts only over the surface film of the liquid.

Angle of Contact -

The angle of Contact betn a liquid and a solid is defined as the angle (θ) which the tangent to the liquid surface at the point of contact (i.e, point A makes with the solid surface inside the liquid)

The meniscus of the liquid is concave when angle of contact (θ) is less than 90° and it is convex when θ is greater than 90°. The value of angle of contact depends on the following factors:

1. The nature of the liquid and the solid in contact.
2. The medium that exists above the free surface of the liquid.
3. Impurities present in the liquid; angle of contact θ decreases on adding impurities to the liquid.
4. Temperature; Contact angle increases with the increases in temperature.

when angle of Contact is acute -
shown that angle of Contact betn the liquid (not water) and the solid surface (glass wall) is acute [i.e, θ < 90°]. In this case, the resultant adhesive force is greater than the resultant cohesive force. Therefore, the glass wall pulls up liquid and liquid tends to stick (i.e, wet) to the glass. As a result, the meniscus of the liquid become concave.

When angle of Contact is acute, the:
(a) liquid will wet the solid.
(b) meniscus of the liquid will be concave.
(c) Liquid will rise in the capillary tube made of such a solid.

When the angle of Contact is obtuse -
shown that angle of Contact betn mercury and the solid is obtuse (i.e θ > 90°). In this case, the resultant cohesive force is greater than the resultant adhesive force. Therefore, the mercury gets depressed near the glass wall and mercury surface pulls from the glass wall (i.e mercury does not wet the glass). As a result, the meniscus of memory becomes convex.

when angle of contact is obtuse, then:
(a) Liquid will not wet the solid.
(b) meniscus of the liquid will be convex.
(c) Liquid will get depressed in the capillary tube made of such a solid.

when angle of Contact is zero -
The angle of Contact for pure water and clean glass is zero. In this case, the resultant adhesive force is equal to the resultant cohesive force. Therefore, in the glass tube, the meniscus of water will be exactly hemispherical or horizontal.

NOTE - A surface will be wetted by water if the angle of Contact is less than 90°.
Addition of soap to water reduces the angles of Contact and is, therefore, useful in washing.

Capillarity or Capillary action -

The rise or fall of a liquid in a narrow tube is called capillarity or capillary action.

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Note -
A tube of very small diameter is called a capillary tube. Capillary means hair-like.

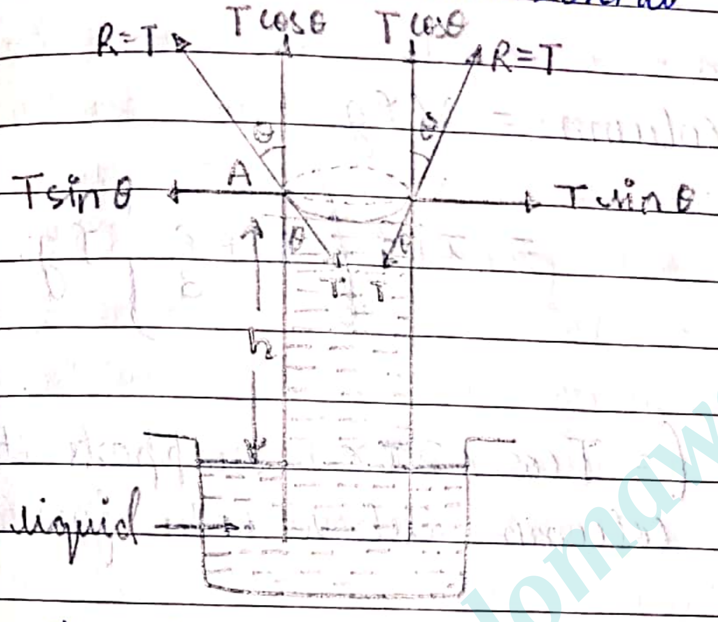
Write few application of Capillarity -

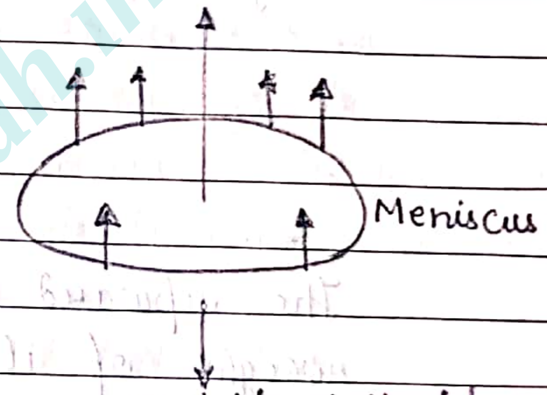
1. The oil in a lamp rise in the wick to its top by capillary action.
2. Sap and water rise upto the top of the leaves of the tree by capillary action.
3. Ink is absorbed by the blotting paper due to capillary action.
4. Sandy soil is more dry than clay. It is because the capillaries betⁿ sand particles are not so line as to draw the water up by capillary action.
5. If one end to the towel dips into a bucket of water and the other end hangs over the bucket, the towel soon becomes wet throughout due to capillary action.

Relation between surface tension, Capillary rise and radius of Capillary -

Let, θ = Angle of Contact
h = Height to which the liquid rises

r = radius (internal) of the tube
ρ = Density of the liquid.
T = Surface tension of the liquid.
g = gravitational acceleration.
$T\cos\theta$ = Vertical component of T
$T\sin\theta$ = Horizontal component of T.





The horizontal components of all around the tube ~~Total chanel~~ cancel out and hence they play no part.

$\therefore$ Total upward force $= T\cos\theta \times 2\pi r$

Volume of liquid in the tube above the free surface of liquid is

V = Volume of Cylinder of height h and radius r + volume of Cylinder of height r and radius r − Volume of hemisphere of radius r.

$$= \pi r^2 h + \pi r^2 \times r - \frac{1}{2}\left[\frac{4}{3}\pi r^3\right]$$

$$= \pi r^2 h + \pi r^3 - \frac{2}{3}\pi r^3$$

$$= \pi r^2 \left[h + \frac{r}{3}\right]$$

Weight of liquid column $= V \rho g$

$$= \pi r^2 \left[h + \frac{r}{3}\right] \rho g.$$

The upward force ($= T\cos \times 2\pi r$) supports the weight of liquid column above the free surface of the liquid.

$$\therefore \quad T\cos\theta \times 2\pi r = \pi r^2 \left[h + \frac{r}{3}\right] \rho g$$

or $$h + \frac{r}{3} = \frac{2T\cos\theta}{r\rho g}$$

or $$h = \frac{2T\cos\theta}{r\rho g} - \frac{r}{3}$$

If the tube is narrow, $r/3$ can be neglected

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as compared to h

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

Dicussion –

① The rise of liquid in the tube is inversely proportional to the radius (or diameter) of the tube. The narrow the tube, the greater is the height to which the liquid rises.

② If θ is less than $90°$, $\cos\theta$ is positive and hence h is positive. This means a liquid whose angle of contact is acute will rise in the tube.

③ If θ is greater than $90°$, $\cos\theta$ is negative and hence h is ~~positive~~ -ve. This means a liquid whose angle of contact is abtuse will suffer capillary depression.

④ If $\theta = 90°$, $h = 0$ and the liquid neither rises nor is depressed.

Effects of Temperature on Surface Tension

With the rise in temperature the surface Tension of liquid decreases as thermal vibration reduces the intermolecular force

i.e. surface tension $\propto \frac{1}{\text{Temperature}}$.

When the liquid is heated the molecules of liquid move with greater velocity. Faster moving molecules of hot liquid are not bounded together as strongly as those in normal temperature. Thus, surface tension of liquid decreases with increase in temperature.

The surface tension of water is about $0.0756\ Nm^{-1}$ at 0°C but it becomes $0.072\ Nm^{-1}$ at 20°C.

Critical Temperature

The temperature at which the surface tension of a liquid becomes zero, is called critical temperature.

For Ex: the surface tension of hot soup is less than that of cold soup. ∴ hot soup will spread over a large area of tongue and hence hot soup is tastier than the cold soup.

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At boiling point, surface tension of a liquid becomes zero whereas at freezing point surface tensions becomes maximum.

Exception : Surface tension of molten cadmium or copper increases with increase in temp.

Effect of impurities on Surface Tension

The effect of impurity on the surface tension may categorised in two types.

(i) Soluble impurities and
(ii) Insoluble or partly soluble impurity.

(i) Effect of soluble impurities on surface tension.

When highly soluble impurities like NaCl (common salt) the solute molecules are attracted more strongly to liquid molecules. This increases the surface tension because the force of attraction of solute molecules exceeds surface energy and hence surface tension i.e, water with salt impurity had the highest surface tension 82m Nm^{-1} followed by sugar impurity.

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(ii) Effect of Insoluble or Partly soluble Impurities-

when a ~~soluble~~ substance which is not readily soluble in the liquid and added to the liquid, the liquid molecules are separated by the impurities. This decreases intermolecular force between the liquid molecules and hence the surface tension.

For example soap, detergent etc.

when insoluble impurities is added to a liquid, the intermolecular forces become very weak and hence reduces ~~to~~ the surface tension.

For example sand in water.

But this happens only when it is added. Once the impurity settled, the surface tension of the liquid regains its original value.

APPLICATION OF SURFACE TENSION

① Soap added to water reduces the surface tension and hence it helps in cleaning by spreading over a large action.

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(2) In construction of thermometer it is used to choose the liquid which should not stick to the wall of thermometer, for example mercury.

(3) It is used to prepare ball bearing or bullets.

(4) The ends of a glass tube become rounded on heating.

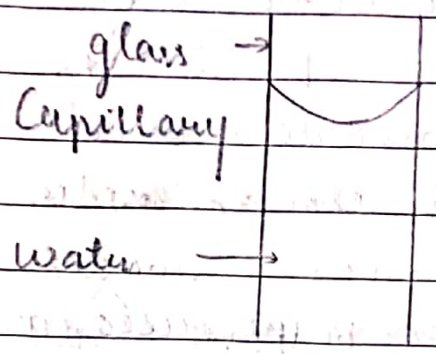
(5) Oils of low surface tension are used as lubricants because they spread more in the parts of machineries.

NOTE [Angle of Contact]

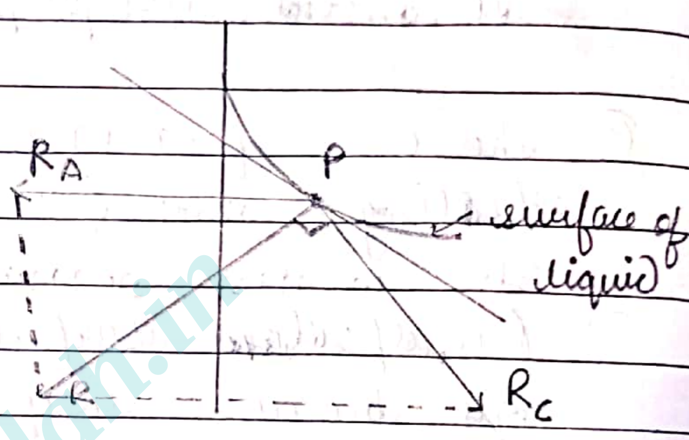
For Pure Water and Perfectly clean glass, the angle of contact is 0°. For ordinary water and glass, it lies between 8° and 18°. For pure water and pure silver, the angle of contact is 90°. When pure water is put in pure silver vessel, the surface of water is flat.

Shape of Meniscus of Water:

(i) Shape of water surface in a glass capillary tube is concave.



(a) The shape of water surface in glass capillary is concave



(b) Diagram explaining why water surface is concave is glass capillary

R_A = Resultant adhesive force
R_C = Resultant cohesive force
R = Resultant of R_A and R_C.

(ii) Shape of mercury in a glass capillary tube is ~~concave~~ convex.

R_A = Resultant adhesive force.
R_C = Resultant cohesive force.
R = Resultant of R_A and R_C.

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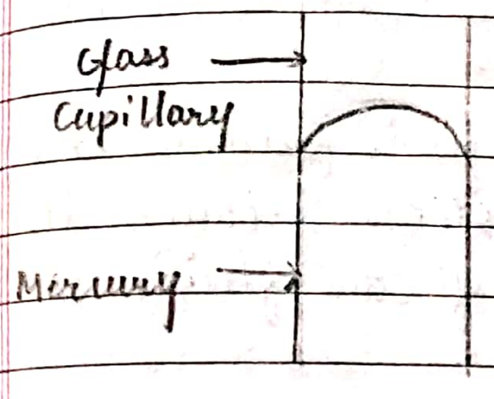
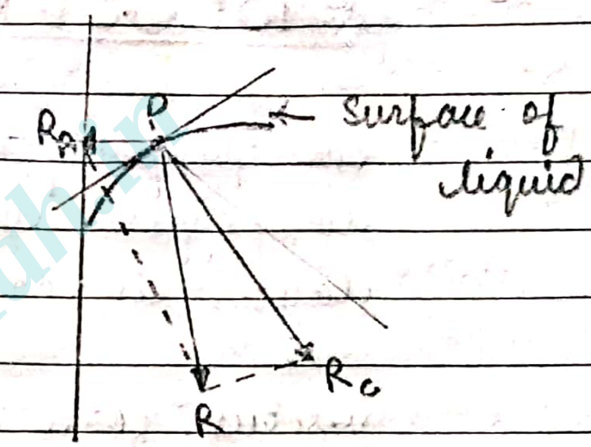


(a) shape of mercury surface in glass capillary is convex.



(b) Diagram explaining why mercury surface is convex in glass capillary.