10.10 SURFACE TENSION

A carefully placed sewing needle floats on the surface of water. The needle floats without sinking eventhough the density of steel is about eight times that of water. A razor blade also floats in water. An insect walks on the water surface. When a glass tube with very small diameter is dipped in water, water rises in the tube, but if this tube is dipped in mercury, the mercury gets depressed. Small mercury drops take spherical shape when placed on glass plate. All these phenomena are associated with the existence of a boundary surface between a liquid and some other surface. This indicates that a liquid surface can be considered to be on a state of stress. This property of liquid surface is called surface tension.

10.10.1 Molecular Theory of Surface Tension

In order to understand the origin of surface tension, let us consider a molecule A well within the liquid. This molecule exerts force of attraction (Cohesive force) on other molecules upto a certain distance. This maximum distance is called molecular range. With the molecule as centre and molecular range as radius, we can imagine a sphere which is known as sphere of influence. For molecule like A, the sphere of influence is well inside the liquid. The net force on A is zero, because it is attracted equally in all directions. The case of a molecule like B is different. The molecule B lies on the surface of the liquid and it is pulled towards the interior of the liquid.
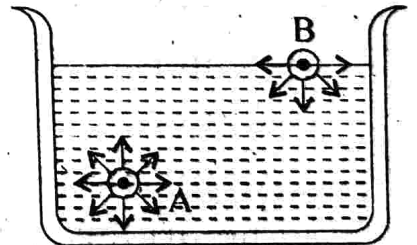

Fig. 18

From this we can conclude that there is a resultant downward force for molecules lying on the liquid surface. The net effect of this pull on all the surface molecules is to make the liquid surface contract and consequently minimize the surface area of the liquid and remains in a state of tension. In trying to do so, the liquid surface behaves like a stretched membrane. This property of liquid surface is called surface tension.

Thus *surface tension* is the property of a liquid by virtue of which the free surface of a liquid at rest, tends to have a minimum surface area and acts like a stretched membrane under tension.

10.10.2 Measurement of Surface Tension

All surface phenomena indicate that a liquid surface can be considered to be in a state of stress. For any imaginary line drawn on the liquid surface is pulled on either sides. This pull lies on the plane of the liquid surface and perpendicular to the line drawn. If l is the length of this line and F is the pulling force, then surface tension of the liquid (S or T) is

$$S = \frac{F}{l} \quad \text{................} \quad (1)$$

Hence **Surface tension** is defined as the force acting over unit length of a line (imaginary) drawn on the free surface of a liquid; the force being perpendicular to the line and tangential to the liquid surface.

Unit

In S.I. - Nm^{-1}

Dimensional formula - $[M^1L^0T^{-2}]$

Surface tension of some liquids are given below

TABLE 3

Liquids in contact with air	Temperature in °C	Surface Tension $\times 10^{-3} \ Nm^{-1}$
Benzene	20	28.9
Ethyl Alcohol	20	22.3
Glycerin	20	63.0
Mercury	20	465.0
Olive Oil	20	32.0
Soapy water	20	25.0
Water	0	75.6
Water	20	73.0
Water	100	59.0

The arrangement for the determination of surface tension of a liquid (water) is as shown in the figure. The glass plate is hanged vertically down from the balance. The glass plate is balanced by placing weights on pan, with the horizontal surface of the plate just above the liquid (water). The vessel containing the liquid is slowly raised until the liquid just touches the lower surface of the glass plate and pulls it down a little due to surface tension. Now

additional weights are placed on the pan till the glass plate just clears the liquid. Let W be the additional weights placed. Let 'l' be the length of the edge of the plate touching the liquid surface.

Balance

String

Glass plate

Liquid (water)

Platform

Fig. 19

Weights

The force pulling down the plate = Additional weights placed on the pan ie., F = W

By the definition of surface tension, $F = S . 2l$

$$\therefore S . 2l = W \qquad \therefore S = \frac{W}{2l} \quad .... (2)$$

$W = mg$, where 'm' is the additional mass added.

$$S = \frac{mg}{2l} \quad .... (3)$$

Thus S.T (S) of the liquid can be found out.
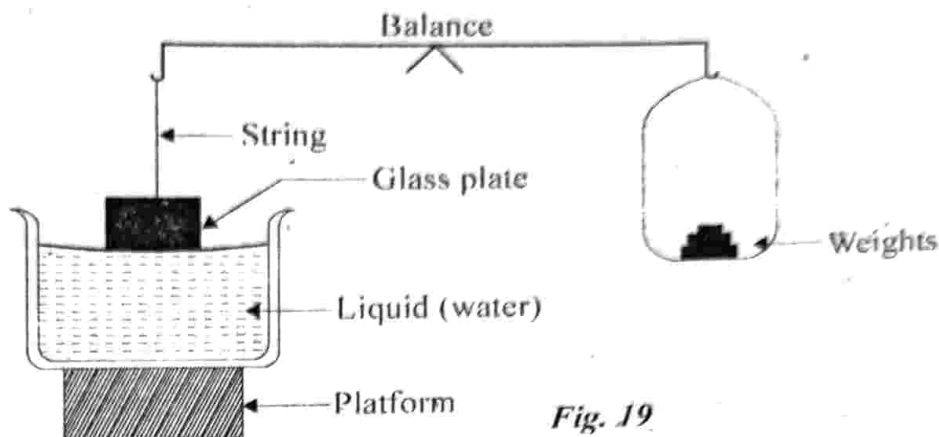
10.10.3 Surface Energy

We have already seen that the free surface of a liquid at rest has a tendency to have minimum surface area due to surface tension. To increase the surface area of a liquid some work has to done against the force due to surface tension. The amount of work done appears as potential energy in the liquid surface and is called surface energy.

Surface energy is defined as the work done to produce unit area on the surface.

10.10.4 Surface Energy and Surface Tension

We can show that surface tension is numerically equal to its surface energy.

Take a rectangular wire frame ABDC with CD movable along the arms AC and BD. Dip the rectangular frame in a soap solution so that a soap film is formed. The pull due to surface tension acting on both sides of the film balances the weight of the wire CD. Let S be the surface tension of the soap solution. Since the film has two surfaces, the pull due to surface tension is $S \times 2\ CD = 2\ lS$ .... (4)
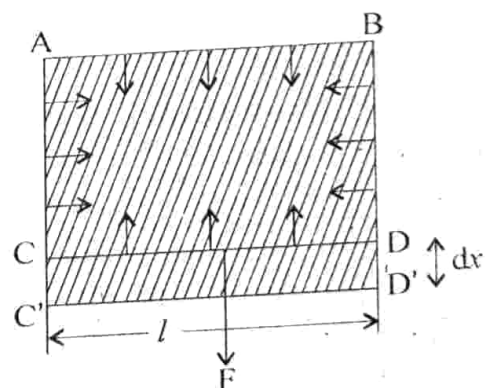

Fig. 20

To increase the area of the surface film, pull the wire CD downwards with a force F. The force so applied should not break the film. The wire gets displaced to C'D' through a small distance CC' = dx (say)

Then, increase in surface area of the film $= \Delta A = 2\ (l . dx)$ .... (5)

Work done to do so = $\Delta W = 2\ lS . dx$

This amount of work done is stored as potential energy in the increased area

Hence Surface energy $= \dfrac{\text{Work done}}{\text{Increase in Area}}$ i.e., $E = \dfrac{2lS\,dx}{2l\,dx}$

$$E = S \ \text{......... (6)}$$

Hence *surface tension of a liquid is also defined as **numerically equal to** surface energy.*

10.10.5 Cohesion and Adhesion

The molecules of a substance generally experience strong intermolecular forces.

The forces between like molecules are called **cohesive forces.**

For example, the molecules of a water droplet are held together by cohesive forces.

The forces between unlike molecules are called **adhesive forces.**

e.g. The force between water molecules and the walls of the container.

The cohesive forces between the molecules well within a liquid are shared with neighbouring molecules. Since there is no molecules of liquid above those molecules on the liquid surface, they exhibit attractive forces between their nearest neighbours. This enhancement of the intermolecular forces at the surface is known as surface tension.

10.10.6 Angle of Contact

Angle of contact is associated with the phenomenon of wetting. A liquid drop on a solid surface is spherical if it does not wet the surface and gets flattened or spreads out on the surface indicating the wetting [Fig 21a and 21b].

Fig. 21a   Fig. 21b

*The **angle of contact** is the angle drawn to the curved liquid surface in contact with the solid and solid inside the liquid.*

In figure 21a, the liquid drop is some what spherical. 'θ' is the angle of contact and is greater than 90°. For a non-wetting fluid $\theta > 90$. In figure 21b, for a wetting fluid, the angle of contact $\theta < 90°$. If the drop is exactly spherical, then the angle of contact is 180° and if it is perfectly flat, then the angle of contact is 0°.

Similarly if we dip a glass rod in water, the angle of contact is within the water as shown in figure 22. In this case the angle of contact $\theta < 90°$. We know that water wets the glass surface.

If the glass rod is dipped in mercury, there is a depression on the surface of mercury near the glass rod, (fig.23). In this case the angle of contact is $\theta > 90°$. We know that mercury does not wet the glass surface.
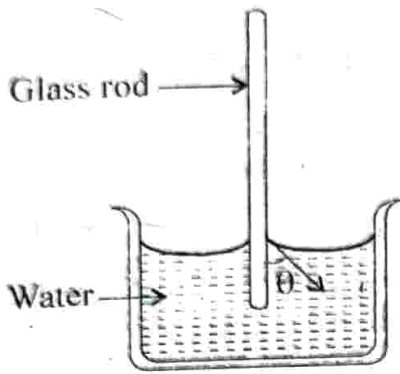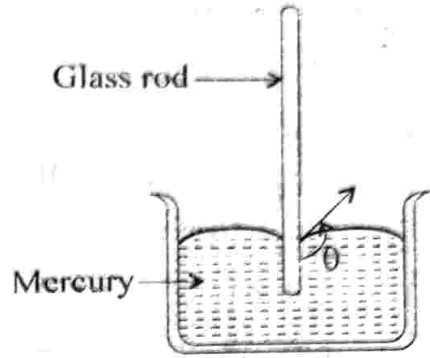
Fig. 22

Fig. 23

For water the angle of contact is very nearly equal to zero on a glass surface and for mercury the angle of contact is about 140°.

Water forms drops on a lotus leaf. It is because water does not wet the surface of lotus leaf.

The value of the angle of contact depends on the following factors.

i. Nature of the liquid and solid in contact

ii. The medium which exists above the free surface of a liquid.

The angle of contact also determines the shape of the liquid meniscus in a container. For liquids whose angle of contact is less than 90° will have a concave meniscus and those having angle of contact greater than 90° will have a convex meniscus.

If impurities are added to a liquid, angle of contact changes considerably.

10.10.7 Drops and Bubbles

10.10.7a Excess Pressure Inside a Liquid Drop

A surface under tension has a tendency to contract until it has the minimum area. For a given volume, a sphere has smaller or minimum surface area than any other geometric shape. Hence liquid drops take spherical shape (gravity and other forces are neglected). Then the pressure inside the drop is greater than the outside pressure. Thus there is an excess pressure inside a liquid drop.

Fig. 24

Consider a liquid drop of radius 'R' and surface tension 'S'. Let 'p' be the excess pressure inside the drop. Due to this excess pressure let us suppose that there is a small increase in its radius by an amount, say, dR. Hence work done by the force due to excess pressure is

dW = force × increase in radius

$= $ excess pressure × Area × dR = p. $4 \pi R^2$ dR .... (1)

Initial surface area of the drop $= 4 \pi R^2$

Final surface area of the drop $= 4 \pi (R + dR)^2$
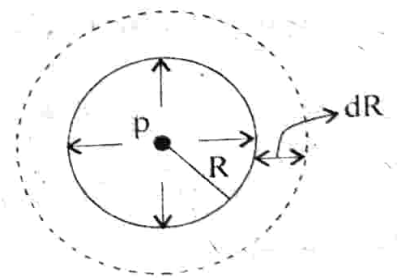
∴ Increase in surface area = $\Delta A = 4\pi(R+dR)^2 - 4\pi R^2$

$= 4\pi(R^2 + 2R\,dR + dR^2 - R^2) = 4\pi(2R\,dR + dR^2)$

$(dR)^2$ being very small, it can be neglected.

∴ $\Delta A = 4\pi \times 2R\,dR = 8\pi R\,dR$

Increase in surface energy or work done to increase the surface area is

dW = Surface Tension × Increase in area $= S \times \Delta A = 8\pi R\,dR.S$ .... (2)

Hence, $p\,4\pi R^2\,dR = 8\pi R\,dR.S$

$$p = \frac{2S}{R} \quad \text{........ (3)}$$

10.10.7b Excess Pressure Inside a Bubble

Since the bubble has two surfaces, we have,

Work done by excess pressure = dW = $p.4\pi R^2 dR$ and

Work done to increase the surface area = dW = $S \times 2(\Delta A) = 2S.8\pi R\,dR$

Hence $p\,4\pi R^2 dR = 2S.8\pi R\,dR$

$$\therefore \quad p = \frac{4S}{R} \quad \text{......... (4)}$$

Note: An air bubble in a liquid has only one surface and so excess pressure,

$$p = \frac{2S}{R} \quad \text{......... (5)}$$