# SURFACE TENSION

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**Interatomic force :**

**The force with which the atoms or the molecules attract each other is called interatomic or intermolecular force. And the maximum distance up to which a molecule can attract another molecule is called molecular range.**

**Cohesion:**

**It is the phenomenon of attraction between the molecules of the same substance and the force with which they attract each other is called cohesive force.**

## Adhension

**It is the phenomenon of attraction between the molecules of different substances and the force of attraction between them is called adhesive force.**

## Surface Tension

**It is the property of a liquid by virtue of which its free surface behaves as a stretched elastic membrane so as to occupy the minimum surface area.**

**The force of surface tension is defined as the force per unit length on an imaginary line drawn on the free surface of the liquid which is perpendicular to its length and tangentially to the liquid surface.**

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

**$F$ = Force on either side**
**$l$ = Length of the imaginary line**

**It is represented by $T$ or $\sigma$ and its SI unit is $Nm^{-1}$. Its dimensional formula is $[MT^{-2}]$**

**Surface Film:**

**A very thin film of liquid near its free surface, having thickness equal to the molecular range is called its surface film.**

## Surface Energy

It is defined as the amount of work done in increasing the surface area of its surface film by unity, i.e.

$$\text{Surface energy}\,(S) = \frac{\text{Work done}\,(W)}{\text{Increase in Area}(\Delta A)}$$

It SI unit is $Jm^{-2}$.

## Relation between surface tension and surface energy.

The following figure (1) shows a surface film of a liquid of surface tension *T*.

Let *F* be the external force applied on the wire *AB* in the outward direction so as to increase the surface area of the film without acceleration, i.e.

$$a = 0$$

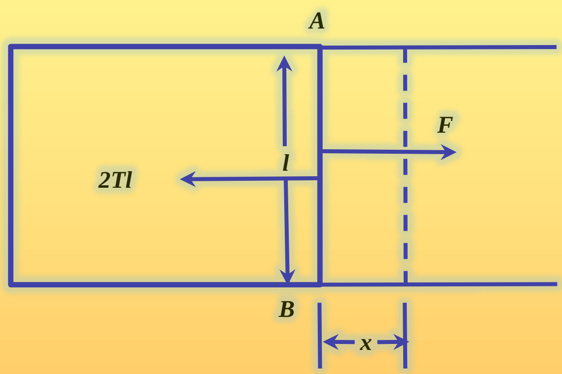



*Fig. (1)*

Net force on length AB of the wire is zero.

$\Rightarrow$ $$F = 2\,T\,l \qquad (1)$$

If the wire moves a distance x in the outward direction, then work done by the external force,

$$W = F\,x$$

**W = 2 T l x (2)**

**Total change in the area of the film,**

**$\Delta$A = 2 *l*x**

**(film has two free surfaces)**

**Then, the surface energy of the film is given by,**

$$S = \frac{W}{\Delta A}$$

**or S = *T***

**This shows that the surface energy of a liquid is numerically equal to the surface tension of the liquid.**

## Shape of the Free Surface of Liquid:

**The shape of the free surface of a liquid may be concave, plane or convex; depending on the direction of the net force on it.**

**(a) It is concave if,**

$$F_0 > F_i$$

or $$P_0 > P_i$$

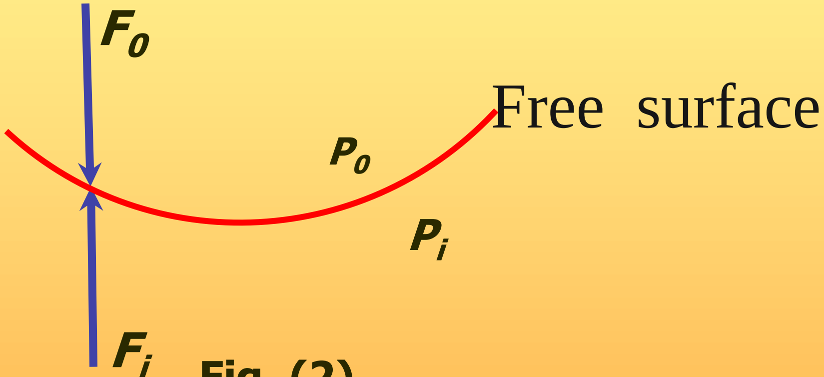



Fig. (2)

where $P_0$ = Pressure just above the free surface
and $P_i$ = Pressure just below the free surface

**(b) It is plane if,**

$$F_0 < F_i$$

or $$P_0 = P_i$$

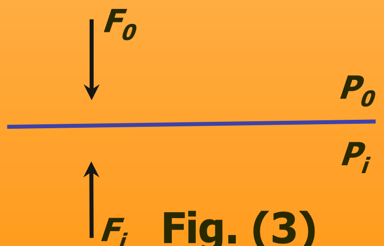



Fig. (3)

**(c) It is convex if,**

$$F_0 < F_i$$

or

$$P_0 < P_i$$

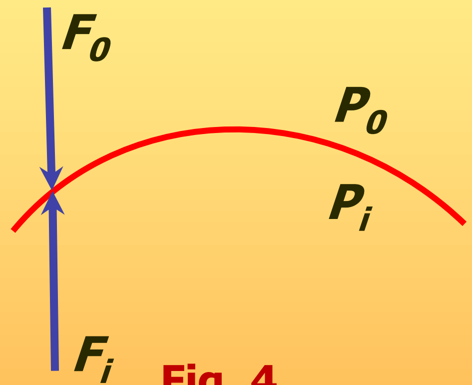



**Fig. 4**

**From the above three cases we conclude that pressure is always found more on the concave side of the free surface.**

**(i) Excess of pressure inside the liquid drop: Consider a liquid drop of radius 'R' and of surface tension *T*.**

**Let $P_i$ and $P_0$ be the pressures inside and outside the drop respectively, then we have, $P_i > P_0$**

**Therefore, net force on the drop is radially outwards and is given by,**

$$F = (P_i - P_0)\, 4\pi R^2 \qquad (1)$$

**If $\Delta R$ be the increase in radius of the drop due to this net force, then work done by this force to increase the radius,**

$$W = F\,\Delta R$$

$$W = (P_i - P_0)\, 4\pi R^2\, \Delta R \qquad (2)$$

**Also, we know that amount of work done in increasing the surface area of a free surface gets stored in it in the form of potential energy, which can also be calculated as,**

$$S = \frac{W}{\Delta A} = T$$

$\Rightarrow$ $W = T\,\Delta A$

or $W = T\,[4\pi\,(R + \Delta R)^2 - 4\,\pi R^2\,]$

$= T\,[8\pi\,R\,\Delta R + 4\pi\,\Delta R^2\,]$

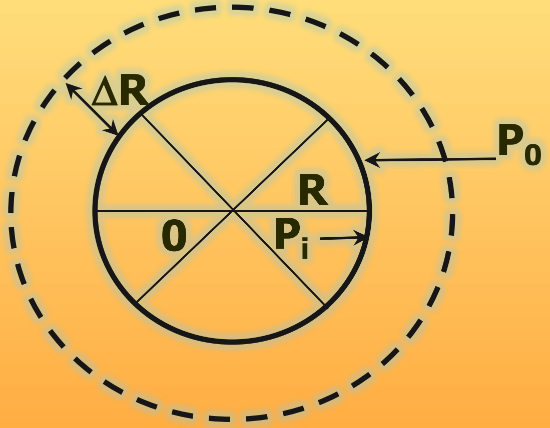



Fig. 5

**$\Delta R$ is very small, therefore, the term of $\Delta R^2$ can be neglected.**

$\therefore \qquad W = 8 \pi RT \Delta R \qquad (3)$

**Now from (2) and (3), we have,**

$$\left(P_i - P_0\right) = \frac{2T}{R}$$

**i.e. Excess of pressure inside a liquid drop is directly proportional to its surface tension and inversely proportional to the radius of the drop.**

**(ii) Excess of pressure inside a liquid bubble:**

**The concept is same as that of liquid drop except one difference that liquid bubble has two free surfaces, therefore, total change in area is double that of (in the case of) drop.**

**Thus,**

$$\left(P_i - P_0\right) = \frac{4T}{R}$$

**(iii) Excess of pressure inside an air bubble:**

**Air bubble is formed inside a liquid, therefore, it also has only one free surface.**

**In the case of air bubble,**

$$\left(P_i - P_0\right) = \frac{2T}{R}$$

**Angle of Contact:**

**The angle of contact between a solid surface and a liquid is defined as the angle made by the tangent drawn to the free surface of the liquid at the point of contract, with the solid surface in contact with liquid.**

**It is represented by θ and depends on the**
**(a) nature of the solid surface and liquid**
**(b) medium above the free surface**
**(c) cleanliness of the solid surface.**

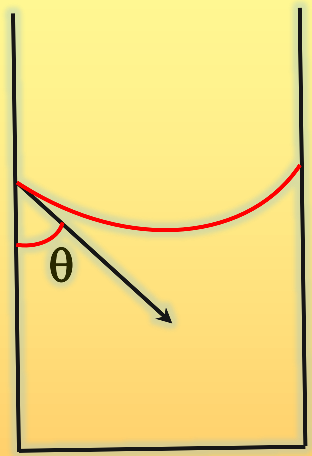



**Fig. 6**

## Capillary Tube

**It is a long glass tube which is open at both ends and has a very fine bore.**

**Capillarity: The process of rising or falling of a liquid in a capillary tube is called capillarity.**

**Expression for the height of a liquid column in a capillary tube (Ascent Formula):** **Consider a capillary tube of radius 'r' dipped in a liquid of surface tension T and density ρ. Let θ be the angle of contact and H be the height by which the level of liquid rises in the tube (Fig. 7).**

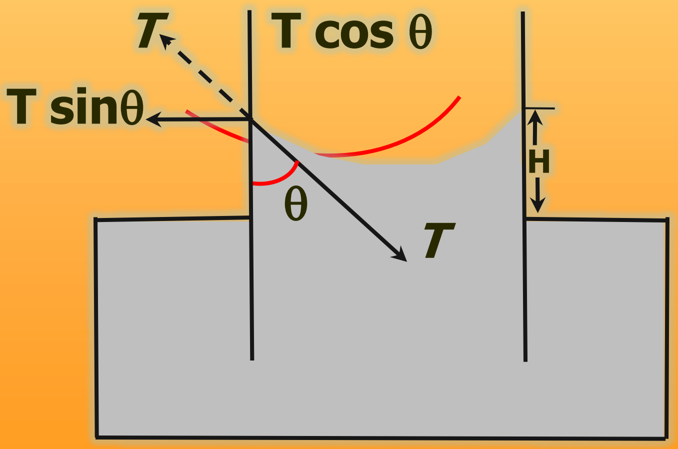



**Fig. 7**

**In equilibrium,**

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

**This shows that if,**

**(a) angle of contact, θ < 90°,**

**cos θ = +ve**

**∴ H= -ve**

**i.e., the liquid rises in the tube.**

**(b) angle of contact θ > 90°,**

**cos θ = +ve**

**∴ H= -ve**

**i.e., the liquid falls in the tube.**

# Point to Remember

- **Work done in bowing a liquid drop**
  **If a liquid drop is blown up from a radius $r_1$ to $r_2$, then work done for that**
  $$W = S(A_2 - A_1) = S.4\pi \left(r_2^2 - r_1^2\right)$$

- **Work done in blowing a soap bubble**
  **As a soap bubble has two free surface, hence, work done in blowing a soap bubble so as to increase its radius from $r_1$ to $r_2$ is given by**
  $$W = S.8\pi\left(r_2^2 - r_1^2\right)$$

- **Work done in splitting a bigger drop into n smaller droplets**
  **If a liquid drop of radius R is splitted up into n smaller**

**droplets, all of same size, then radius of each droplet**

$$r = R.(n)^{-1/3}$$

**and work done** $$W = S.4\pi(nr^2 - R^2)$$
$$= S.4\pi R^2(n^{1/3} - 1)$$

**Coalescence of drops**

**If n small liquid drops radius r each combine together so as to a form a single bigger drop of radius $R = n^{1/3}.\ r$, then in the process energy is released. Release of energy is given by**

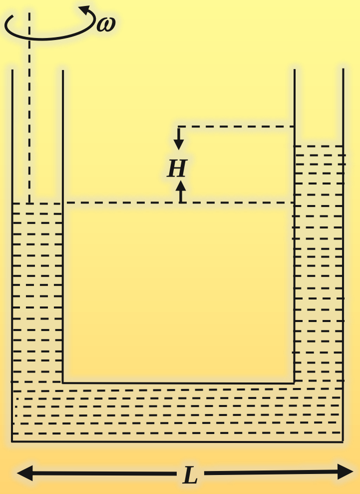
$$\Delta U = S \bullet 4\pi(n\, r^2 - R^2)$$
$$= S \bullet 4\pi r^2 n\,(1 - n^{-1/3})$$

**Effect of Temperature on Surface Tension :**

**Surface tension of a liquid decreases with the increase in temperature. The value of surface tension of a liquid becomes zero at a particular temperature called Critical temperature of that liquid.**

**Example: 1**

A U tube is rotated about one of its limbs with an angular velocity $\omega$. Find the difference in height H of the liquid (density $\rho$) level, where diameter of the tube d < < L.




**Sol.** Consider circular motion of small element dx.

Centripetal force $= (dm)\, x\omega^2$

$(dP) \times A = (\rho A dx) \times x\omega^2$

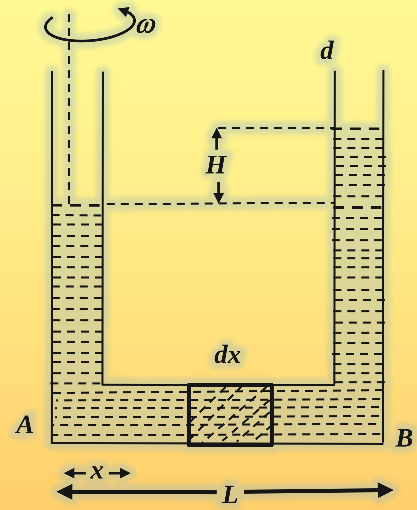
or $dP = \rho\omega^2\, x dx$

$$\text{or} \int_{p1}^{p2} dP = \rho\omega^2 \int_0^L x dx$$

$$\text{or } (P_2 - P_1) = \rho\omega^2 \left[\frac{x^2}{2}\right]_0^L$$

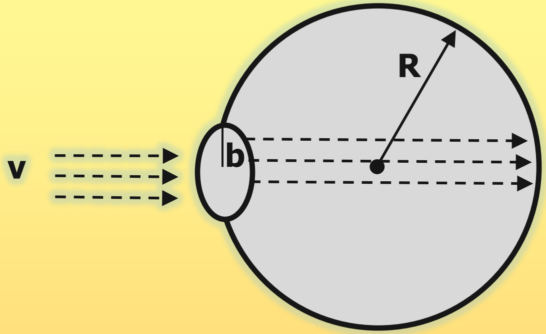
$$\text{or } P_2 - P_1 = \frac{\rho\omega^2 L^2}{2}$$

$$\text{or } \rho g H = \frac{\rho\omega^2 L^2}{2} \text{ or } H = \frac{\omega^2 L^2}{2g}.$$



**Example: 1**

**A bubble having surface tension T and radius R is formed on a ring of radius b (b < < R). Air is blown inside the tube with velocity v as shown.**




**The air molecule collides perpendicularly with the wall of the bubble and stops. Calculate the radius at which the bubble separates from the ring.**

**Solution 1.** **Excess pressure inside a bubble** $= \dfrac{4T}{R}$

**Let area of bubble at wall where air strikes be *A*.**

$\therefore$ **Force due to excess pressure** $= \dfrac{4TA}{R}$

**Let $\rho$ = density of air,**
**Force due to striking air = $\rho A v^2$**
**For bubble to separate from the ring,**

$$\rho A v^2 = \frac{4TA}{R}$$

$$\text{or} \quad \rho A v^2 R = 4TA$$

$$\text{or} \quad R = \frac{4T}{\rho v^2}$$

**Thank You…**