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Surface Tension

Surface tension is the property of any liquid by virtue of which it tries to minimise its free surface area.

Surface tension of a liquid is measured as the force acting per unit length on an imaginary line drawn tangentially on the free surface of the liquid.

Surface tension, $S = \frac{\text{Force}}{\text{Length}} = \frac{F}{l} = \frac{\text{Work done}}{\text{Change in area}}$

Its SI unit is Nm^{-1} or Jm^{-2} and its dimensional formula is $[MT^{-2}]$.

It is a scalar quantity. Surface tension is a molecular phenomenon which is due to cohesive force.

Surface tension of a liquid depends only on the nature of liquid and is independent of the surface area of film or length of the line considered.

Small liquid drops are spherical due to the property of surface tension.

Adhesive Force

The force of attraction acting between the molecules of different substances is called adhesive force, *e.g.* the force of attraction acting between the molecules of paper and ink, water and glass etc.

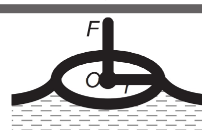
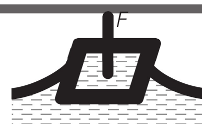
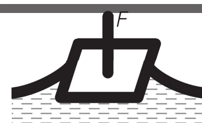
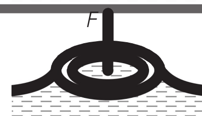
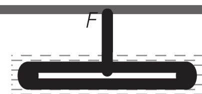
Cohesive Force

The force of attraction acting between the molecules of same substance is called cohesive force, *e.g.* the force of attraction acting between the molecules of water, glass, etc.

Cohesive forces and adhesive forces are van der Waals' forces.

These forces vary inversely as the eighth power of distance between the molecules.

Force of Surface Tension on Different Shape

	Shape	Figure	Force of Surface tension
1.	Thin ring of radius r		$F = 2\pi (r + r) \cdot S + W$ $= 4\pi\, r \cdot S + W$
2.	Circular plate or disc of radius r		$F = 2\pi r \cdot S + W$
3.	Square frame of side a		$F = 8a \cdot S + W$
4.	Square plate of side a		$F = 4aS + W$
5.	Hollow disc of inner radius r_1 and outer radius r_2		$F = 2\pi (r_1 + r_2) \cdot S + W$
6.	Wire of length l		$F = 2 \cdot l \cdot S + W$

Molecular Range

The maximum distance upto which a molecule can exert a force of attraction on other molecules is called molecular range.

Molecular range is different for different substances.

In solids and liquids, it is of the order of 10^{-9} m.

If the distance between the molecules is greater than 10^{-9} m, the force of attraction between them is negligible.

Factors Affecting Surface Tension

(i) Surface tension of a liquid decreases with increase in temperature and becomes zero at critical temperature.

(ii) At boiling point, surface tension of a liquid becomes zero and becomes maximum at freezing point.

(iii) Surface tension decreases when partially soluble impurities such as soap, detergent, dettol, phenol etc are added in water.

(iv) Surface tension increases when highly soluble impurities such as salt is added in water.

(v) When dust particles or oil spreads over the surface of water, its surface tension decreases.

When charge is given to a soap bubble, its size increases because surface tension of the liquid decreases due to electrification.

In weightlessness condition, liquid does not rise in a capillary tube.

Surface Energy

If we increase the free surface area of a liquid, then work has to be done against the force of surface tension. This work done is stored in liquid surface as potential energy.

This additional potential energy per unit area of free surface of liquid is called surface energy.

$$\text{Surface energy } (E) = S \times \Delta A$$

where, S = surface tension and ΔA = increase in surface area.

(i) **Work Done in Blowing a Liquid Drop** If a liquid drop is blown up from a radius r_1 to r_2, then work done for that is

$$W = S \cdot 4\pi(r_2^2 - r_1^2)$$

(ii) **Work Done in Blowing a Soap Bubble** As a soap bubble has two free surfaces, hence work done in blowing a soap bubble so as to increase its radius from r_1 to r_2 is given by

$$W = S \cdot 8\pi(r_2^2 - r_1^2)$$

(iii) **Work Done in Splitting a Bigger Drop into *n* Smaller Droplets**

If a liquid drop of radius R is split up into n smaller droplets, all of same size, then radius of each droplet

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

$$\text{Work done, } W = 4\pi S(nr^2 - R^2) = 4\pi SR^2 (n^{1/3} - 1)$$

(iv) **Coalescance of Drops** If n small liquid drops of radius r each combine together so as to form a single bigger drop of radius $R = n^{1/3} \cdot r$, then in the process energy is released. Release of energy is given by $\Delta U = S \cdot 4\pi(nr^2 - R^2) = 4\pi Sr^2 n(1 - n^{-1/3})$

Excess Pressure due to Surface Tension

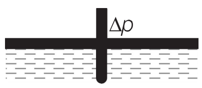
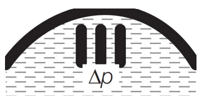
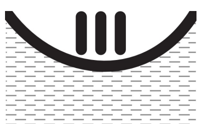
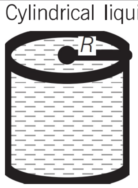
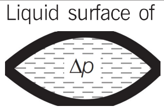
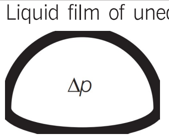
(i) Excess pressure inside a liquid drop $= \dfrac{2S}{R}$

(ii) Excess pressure inside an air bubble in a liquid $= \dfrac{2S}{R}$

(iii) Excess pressure inside a soap bubble $= \dfrac{4S}{R}$

where, S = surface tension and R = radius of drop/bubble.

Excess Pressure in Different Cases

	Nature of Surface	Excess Pressure
1.	Plane surface 	$\Delta p = 0$
2.	Convex surface of radius R 	$\Delta p = \dfrac{2S}{R}$
3.	Concave surface of radius R 	$\Delta p = \dfrac{2S}{R}$
4.	Cylindrical liquid surface of radius R 	$\Delta p = \dfrac{S}{R}$
5.	Liquid surface of unequal radii 	$\Delta p = S\left[\dfrac{1}{R_1} + \dfrac{1}{R_2}\right]$
6.	Liquid film of unequal radii 	$\Delta p = 2S\left[\dfrac{1}{R_1} + \dfrac{1}{R_2}\right]$

- Work done in spraying a liquid drop of radius R into n droplets of radius r = $S \times$ Increase in surface area

$$= 4\pi S R^3 \left(\frac{1}{r} - \frac{1}{R}\right)$$

Fall in temperature, $\Delta\theta = \frac{3S}{J}\left(\frac{1}{r} - \frac{1}{R}\right)$

where, $J = 4.2$ J/cal.

- When n small drops are combined into a bigger drop, then work done is given by

$$W = 4\pi R^2 S\,(n^{1/3} - 1)$$

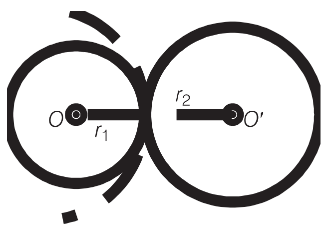
Temperature increase,

$$\Delta\theta = \frac{3S}{J}\left(\frac{1}{r} - \frac{1}{R}\right)$$

- When two bubbles of radii r_1 and r_2 coalesce into a bubble of radius r isothermally, then

$$r^2 = r_1^2 + r_2^2$$

- When two soap bubbles of radii r_1 and r_2 are in contact with each other, then radius r of common interface



Common interface

$$\frac{1}{r} = \frac{1}{r_1} - \frac{1}{r_2} \quad \text{or} \quad r = \frac{r_1 r_2}{r_2 - r_1}$$

Formation of a Single Bubble

- If two bubbles of radius r_1 and r_2 coalesce isothermally to form a single bubble of radius r under external pressure p_0, then surface tension of the liquid

$$S = \frac{p_0\,[r^3 - r_1^3 - r_2^3]}{4\,[r_1^2 + r_2^2 - r^2]}$$

- Pressure inside bubbles are

$$p_1 = \left(p_0 + \frac{4S}{r_1}\right),\ p_2 = \left(p_0 + \frac{4S}{r_2}\right),\ p_3 = \left(p_0 + \frac{4S}{r}\right)$$

Also, $\quad p_1V_1 + p_2V_2 = p_3V_3$

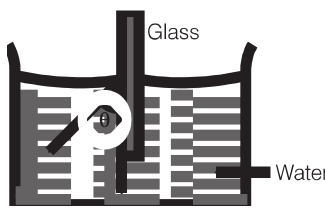
where, p_1, V_1 are pressure and volume of first bubble,
p_2, V_2 are pressure and volume of second bubble
and p_3, V_3 are pressure and volume of new bubble.

Angle of Contact

The angle subtended between the tangents drawn at liquid surface and at solid surface inside the liquid at the point of contact is called angle of contact (θ).

If liquid molecules is in contact with solid (*i.e.* wall of capillary tube), then forces acting on liquid molecules are

(i) Force of cohesion F_c (acts at an angle 45° to the vertical)
(ii) Force of adhesion F_a (acts outwards at right angle to the wall of the tube)



Angle of contact depends upon the nature of the liquid and solid in contact and the medium which exists above the free surface of the liquid.

When wax is coated on a glass capillary tube, it becomes water-proof. The angle of contact increases and becomes obtuse. Water does not rise in it. Rather it falls in the tube by virtue of obtuse angle of contact.

- If θ is acute angle, *i.e.* $\theta < 90°$, then liquid meniscus will be concave upwards.
- If θ is 90°, then liquid meniscus will be plane.
- If θ is obtuse, *i.e.* $\theta > 90°$, then liquid meniscus will be convex upwards.
- If angle of contact is acute angle, *i.e.* $\theta < 90°$, then liquid will wet the solid surface.
- If angle of contact is obtuse angle, *i.e.* $\theta > 90°$, then liquid will not wet the solid surface.

Angle of contact increases with increase in temperature of liquid. Angle of contact decreases on adding soluble impurity to a liquid.

Angle of contact for pure water and glass is zero.

For ordinary water and glass, it is 8°.

For mercury and glass, it is 138°.

For pure water and silver, it is 90°.

For alcohol and clean glass $\theta = 0°$.

Angle of Contact, Meniscus and Shape of liquid surface

Property	Angle of Contact $< 90°$	Angle of Contact $= 90°$	Angle of Contact $> 90°$
Substances	Water and glass	Water and silver	Mercury and glass
Angle of contact	Almost zero, acute angle	Right angle = 90°	Obtuse angle = 138°
Meniscus shape	Concave	Plane	Convex
Capillary action	Liquid rises	No effect	Liquid falls
Sticking to solid	Stick/wets	Does not wet	Does not wet
Relation between cohesive force (F_c) and adhesive force (F_a)	$F_a > \frac{F_c}{\sqrt{2}}$ $F_a > F_c$	$F_a = \frac{F_c}{\sqrt{2}}$	$F_a < \frac{F_c}{\sqrt{2}}$ $F_c > F_a$
Shape of liquid surface	Almost round	Spreads on surface	Flat on interface

Capillarity

The phenomenon of rise or fall of liquid column in a capillary tube is called capillarity.

Ascent of a liquid column in a capillary tube is given by

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

If capillary is very narrow, then

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

where, r = radius of capillary tube, ρ = density of the liquid,

θ = angle of contact and S = surface tension of liquid.

- If $\theta < 90°$, $\cos\theta$ is positive, so h is positive, *i.e.* liquid rises in a capillary tube.
- If $\theta > 90°$, $\cos\theta$ is negative, so h is negative, *i.e.* liquid falls in a capillary tube.
- Rise of liquid in a capillary tube does not violate law of conservation of energy.

Some Practical Examples of Capillarity

(i) The kerosene oil in a lantern and the melted wax in a candle, rise in the capillaries formed in the cotton wick and burns.

(ii) Coffee powder is easily soluble in water because water immediately wets the fine granules of coffee by the action of capillarity.

(iii) The water given to the fields rises in the innumerable capillaries formed in the stems of plants and trees and reaches the leaves.

Zurin's Law

If a capillary tube of insufficient length is placed vertically in a liquid, then liquid never come out from the tube on its own, as

$$Rh = \text{constant} \Rightarrow R_1 h_1 = R_2 h_2$$

where, R = radius of curvature of liquid meniscus

and h = height of liquid column.

When a tube is kept in inclined position in a liquid and the vertical height h remains unchanged, then length of liquid column

$$\cos \alpha = \frac{h}{l} \quad \text{or} \quad l = \frac{h}{\cos \alpha}$$

Liquid rises (water in glass capillary) or falls (mercury in glass capillary) due to property of surface tension

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

where, R = radius of capillary tube, h = height of liquid,
ρ = density of liquid, θ = angle of contact,
S = surface tension of liquid and g = acceleration due to gravity.

Some Phenomena Based on Surface Tension

(i) Medicines used for washing wounds, as dettol, have a surface tension lower than water.

(ii) Hot soup is more tasteful than the cold one because the surface tension of the hot soup is less than that of the cold and so it spreads over a larger area of the tongue.

(iii) Insects and mosquitoes swim on the surface of water in ponds and lakes due to surface tension. If kerosene oil is sprayed on the water surface, the surface tension of water is lowered and the insects and mosquitoes sink in water and are dead.

(iv) If we deform a liquid drop by pushing it slightly, then due to surface tension it again becomes spherical.

(v) The detergents are used for cleaning the dirty clothes. The molecule of detergent can attached with water and dirt molecules and they take away the dirt with them, when we wash the clothes with detergent.