

SURFACE TENSION

Introduction:

Liquids have a definite volume but not shape. When a liquid is poured into a vessel there will be free surface separating the liquid from air in the vessel.

It has been found that there exists a force of attraction between the molecules when the distance between the molecules greater than the normal distance.

Free surface of liquid has a natural tendency to contract so as to assume smallest possible area. The following illustrations show these facts;

1. Rain drops and small quantity of mercury placed on a glass plate forms a spherical shape. So a liquid experience some kind of force, so as to occupy a minimum surface areathis contracting tendency of a liquid surface is known as *surface tension of liquid*.
2. If a sewing needle is placed carefully on water surface, it makes a small depression on the surface and rests there without sinking.
3. A liquid flowing out of a dropper comes out in the form of a fine spherical drop.

The above illustrations are due to the existence of a boundary surface between the liquid and the other substance.

These illustrations justify that surface of a liquid behaves as an elastic membrane, having a natural tendency to contract the liquid surface.

Molecular forces in liquids:

Since the surface tension of a liquid is basically a molecular phenomenon, the forces acting between the molecules of a liquid are molecular in nature. There are two types of molecular forces in liquids, namely

- 1) Adhesive force
- 2) Cohesive force.

1. Adhesive Force:

“The force of mutual attraction between the molecules of different substances is called adhesive force”.

The adhesive force is different for different substances.

Examples:

- i. The force of attraction between the glass molecules of a beaker and molecules of water contained in it.
- ii. The force of attraction between the glue and paper molecules.

2. Cohesive Force:

“The force of mutual attraction between the molecules of same substances is called cohesive force”.

Examples: force of attraction between water and water molecules, mercury and mercury molecules and glass and glass molecules.

This force probably varies inversely as the eighth power of the distance between two molecules and thus decreases rapidly with distance. The magnitude of this force is greater in the case of solids and less in liquids and negligible in gases.

The adhesive and cohesive forces are effective only when the distance between the neighbouring molecules is extremely small. i.e. of the order of $10^{-9}m$.

Molecular range –Sphere of influence:

“The maximum distance up to which a molecule exerts a force of attraction on another is called molecular range”.

Or

“The greatest distance at which the molecules can attract each other is called molecular range”.

It is generally of the order $10^{-9}m$.

Sphere of Influence:

“A sphere drawn around the molecule with the molecule as its centre and the molecular range as its radius is called sphere of influence or sphere of molecular attraction”.

The molecule attracted by all other molecules by sphere of influence.

Surface Tension:

Surface tension of a liquid is defined as *“The force per unit length acting on either side of imaginary line drawn on the liquid surface at rest.”*

Or

“The force per unit length of a line drawn in the liquid surface, acting perpendicular to it at every point and tending to pull the surface apart along the surface.”

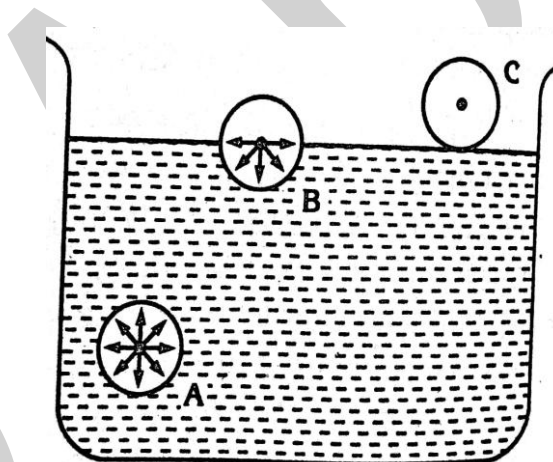
$$\text{Surface tension} = \frac{\text{Force}}{\text{Length}}$$

Units of surface tension: In CGS system is dynes per centimetre (*dyne/cm*) and in SI unit Newton/meter (*N/m*)

Dimension of surface tension: Since it is a ratio of force to the length, its dimensions are $\frac{MLT^{-2}}{L} = MT^{-2}$

Explanation of Surface Tension (Molecular Theory of Surface Tension):

The phenomenon of surface tension can be easily explained by the extension kinetic theory of gases. This was first attempted by **Laplace**.



Consider the molecules A, B and C of a liquid, around each of which a sphere of influence is drawn with the respective molecule being at its centre. The molecule A is well within the liquid and is attracted by all the molecules lying within its sphere of influence as shown in above figure. As a result, there is no net cohesive force acting on the molecule A. The molecule B lies on the surface of the liquid with half of its sphere of influence lying above the surface and the other half within the liquid. The upper part of the sphere of influence contains only a few molecules of the gas or vapour whereas the entire lower part within the liquid contains liquid molecules. Therefore, the resultant force on the molecule B is maximum in the downward direction. This downward force exerted per unit area

of the liquid surface is called its cohesive pressure (it is also called intrinsic or internal pressure). This results in a net downward force on the molecules lying on the liquid surface and the liquid therefore, experiences a downward pull all over its surface. Thus, the surface of the liquid at rest is stretched due to the surface tension and acts like a stretched membrane.

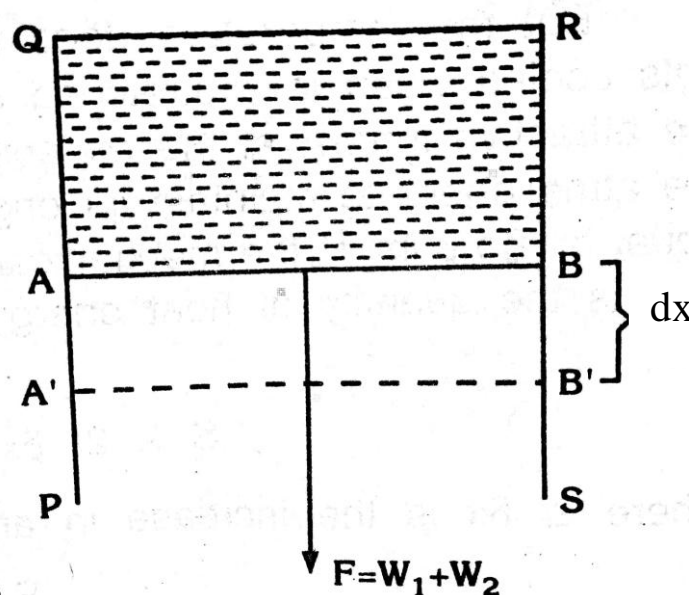
Surface Energy:

When, the surface of a liquid is extended the molecules from the interior of the liquid rise to the surface against the inward cohesive force of attraction. The necessary mechanical work done on the molecules is stored as potential energy in the new surface formed. Further when the surface is extended heat from the surrounding flows into it. Thus the surface possesses potential energy due to mechanical work and also heat energy absorbed from the surrounding. This total energy per unit surface area is called the "Surface energy".

Or

“Increase in potential energy per unit area of the surface film is called surface energy”.

Relation between the Surface tension and Surface energy:



Consider a rectangular frame of wire PQRS, as shown in figure with a horizontal wire AB of weight W_1 placed across the frame. AB is capable of sliding up and down the frame. When this frame is dipped in the soap solution, a soap film is formed across AQRB and the wire AB is pulled up due to the surface tension of the film. To keep the wire AB in equilibrium position, a force has to be

applied downwards, equal to the upward force due to the surface tension of the film.

This is done by hanging a weight W_2 from AB. Then the net downward force $F = W_1 + W_2$ where, W_1 is the weight of the wire, and W_2 be the extra weight to be used.

Let the wire AB be pulled downward to the position A'B', through a distance dx . This increases the area of the film and therefore, the molecules from the interior of the liquid move into the surface layers.

If the temperature is remains constant, then the work done to move AB through a distance dx is given by

$$\text{Work done} = F \times dx \quad \dots\dots (1)$$

Since the film has two surfaces, increase in area takes place on both the sides.

$$\begin{aligned} \text{Then the total increased in the surface area of the liquid film} &= 2 \times \text{Area} \\ &= 2(l \times dx) \end{aligned}$$

Here l is the length of the wire AB.

$$\text{Work done per unit increase in area} = \frac{F \times dx}{2l \times dx} = \frac{F}{2l} \dots\dots (2)$$

This work done per unit area gives the increase in the potential energy per unit area of the film is called surface energy.

$$\text{Therefore, equation (2) becomes Surface energy} = \frac{F}{2l} \dots\dots (3)$$

The force acting on the film due to the surface tension T is given by

$$F = T \times 2l$$

$$T = \frac{F}{2l} \dots\dots (4)$$

Comparing equation (3) and (4), we get

$$\text{Surface energy} = T \text{ (Surface tension)}$$

$$\text{i.e.} \quad \text{Surface energy} = \text{Surface tension}$$

Therefore, **surface tension is numerically equal to the work done per unit area.**

The film gets cooled when it is stretched. Therefore extra energy has to be supplied to restore the original temperature of the film.

Therefore, the surface energy is equal to the sum of the mechanical work done and the heat absorbed from the atmosphere.

Suppose H is the quantity of heat absorbed per unit area from the atmosphere (here H is in units of work). Then,

$$S \times 2l dx = T \times 2l dx + H \times 2l dx$$

$$S = T + H$$

$$T = S - H \dots\dots\dots (2)$$

Where, S is the surface energy and $(S - H)$ is the mechanical part of the surface energy and is also called the free energy of the surface.

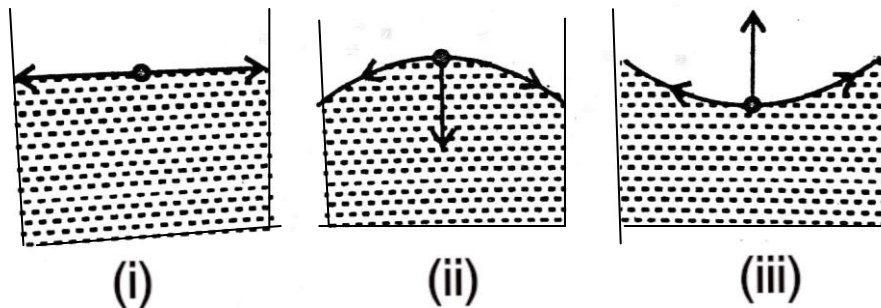
Therefore, the surface tension is equal to mechanical part $(S - H)$ of the surface energy and is also defined as the amount of the work done in increasing the surface area of the film by one unit under isothermal conditions.

If the process is adiabatic, $H = 0$

From equation (2), $T = S$

i.e. Surface tension $T =$ Surface energy S

Pressure difference across a liquid surface:



- i. When the free surface of the liquid is plane, the resultant force due to surface tension on a molecule on the surface is zero as shown in fig.(i).
- ii. When the free surface of the liquid is convex, the resultant force due to surface tension on a molecule on the surface acts vertically inwards or downwards (into the liquid) as shown in fig.(ii).
- iii. When the free surface of the liquid is concave, the resultant force due to surface tension on a molecule on the surface acts vertically upwards (above the surface of liquid) as shown in fig.(iii).

Pressure difference across a Curved liquid surface:

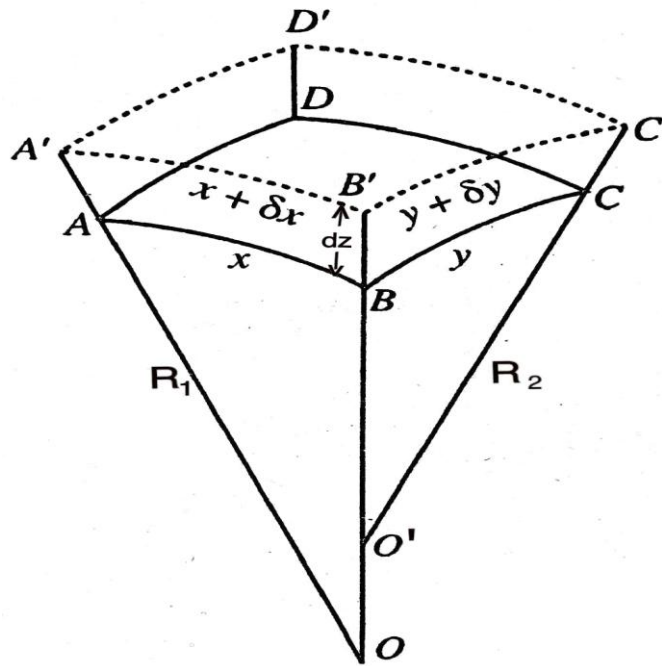


Fig: Curved liquid surface

When the pressure on both sides of a liquid surface is same, then the surface is flat without any curvature. Consider a small curvilinear rectangular element ABCD having radii of curvature R_1 and R_2 respectively of sides AB and BC. This curvilinear rectangular element ABCD will be in equilibrium only if the excess of pressure is acts on the concave side. This excess of pressure balances by the surface tension T on convex side of the membrane.

Let p be the excess pressure inside the liquid surface.

Surface area of the film ABCD = xy

$$AB = x, BC = y, BB' = dz$$

$$A'B' = x + dx, B'C' = y + dy.$$

Let the surface area xy expands, so that the new area occupies the position A'B'C'D' and its displacement be dz .

Let the new sides be $x + dx$ and $y + dy$

$$\begin{aligned} \therefore \text{Increase in the area of the film} &= (x + dx)(y + dy) - xy \\ &= xy + xdy + ydx + dx dy - xy \\ &= xdy + ydx \quad (\because \text{neglecting } dx dy) \end{aligned}$$

Let T be the surface tension of the liquid then,

Work done due to the surface tension T is given by

$$\text{Work done} = T \times (xdy + ydx) \dots\dots\dots (1)$$

Work done by the excess pressure is given by

$$\text{Work done} = pxydz \dots\dots\dots (2)$$

Equating equations (1) and (2), we get

$$pxydz = T \times (xdy + ydx) \dots\dots\dots(3)$$

Consider the triangles ABO and A'B'O' are similar,

$$\frac{A'B'}{OB'} = \frac{AB}{OB} = \frac{A'B' - AB}{OB' - OB}$$

$$\frac{x+dx}{R_1+dz} = \frac{x}{R_1} = \frac{dx}{dz} \{ \because A'B' - AB = x + dx - x = x, OB' - OB = dz \}$$

$$dx = \frac{x}{R_1} dz$$

Similarly it can be proved that for triangles BCO and B'C'O'

$$dy = \frac{y}{R_2} dz$$

Substitute the values of dx and dy in equation (3) we get

$$pxydz = T \left(\frac{xydz}{R_2} + \frac{xydz}{R_1} \right)$$

$$pxydz = xydz T \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

$$P = T \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

Special cases:

1) In case of a spherical liquid drop or an air bubble inside liquid

Then $R_1 = R_2 = R$ it has only one surface therefore above equation becomes

$$P = T \left(\frac{1}{R} + \frac{1}{R} \right)$$

$$P = \frac{2T}{R}$$

2) In case of a spherical soap bubble or liquid bubble

Here there are two surfaces having the same radius of curvature $R_1 = R_2 = R$

$$P = 2T \left(\frac{1}{R} + \frac{1}{R} \right)$$

$$P = \frac{4T}{R}$$

3) In case of cylindrical drop or cylindrical liquid surface

Here one of the radii $R_1 = R$ and the other radius $R_2 = \infty$

$$P = T \left(\frac{1}{R} + \frac{1}{\infty} \right)$$

$$P = \frac{T}{R}$$

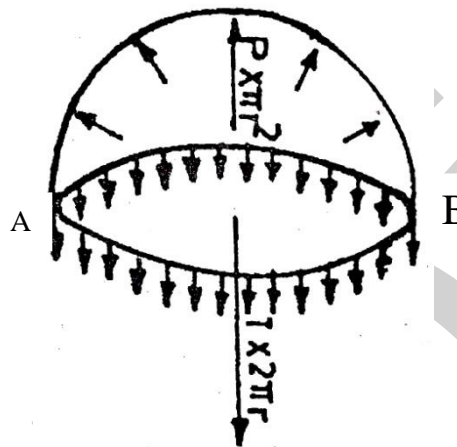
4) In case of a hollow cylindrical film or hollow cylindrical bubble

It has two surfaces hence excess of pressure is given by

$$P = 2T \left(\frac{1}{R} + \frac{1}{\infty} \right)$$

$$P = \frac{2T}{R}$$

Excess of pressure inside a Spherical liquid drop or an air bubble in a liquid:



Consider a spherical liquid drop of radius r (or an air bubble inside a liquid). The molecules on the surface of the drop experiences a resultant force pull inward due to surface tension T .

Therefore, the pressure inside the drop due to surface tension is greater than the pressure outside. This excess of pressure is calculated and it depends upon the surface tension of the liquid and radius of the drop.

Imagine the drop is divided into two equal hemispheres by a horizontal line AB and let us consider the equilibrium of upper half (or upper hemisphere) of the drop as shown in the above figure. Let P be the excess of pressure on the liquid drop and T be the surface tension. The circumference of the circle is $2\pi r$ and the area of the circle is πr^2 . Neglecting the weight of the drop there are two forces acting on it:

1. The out ward force on the plane face AB due to the excess pressure P

i.e. $F_{out} = \text{excess of pressure} \times \text{area of the circle}$

$$F_{out} = P \times \pi r^2$$

2. The inward force due to the surface tension, acting on circumference of the circle AB

i.e. $F_{in} = \text{surface tension} \times \text{circumference of the circle}$

$$F_{in} = T \times 2\pi r$$

Since the hemisphere is considered to be in equilibrium hence the out ward force must be equal to inward force

i.e. $F_{out} = F_{in}$

$$P \times \pi r^2 = T \times 2\pi r$$

$$P = \frac{2T}{r}$$

Forms or shape of a liquid drops:

The shape of the liquid drop depends upon by the action of following two forces

(i) Force of gravity

(ii) Force of surface tension

When a quantity of liquid rests upon a horizontal solid plate, which it doesn't wet, the shape of the drop is determined by surface tension and gravity. For extremely small drops the surface tension effects are great and the gravitational effects are small. So surface tension determines the shape of the drop. Ex: Rain drops, a small quantity of mercury on a glass plate, water drops on leaves all assume spherical shape on account of this.

On increasing the size of the drop, the effects of gravitation becomes greater and that of surface tension is less. Now the effect of gravitation alone would be to make the drop spread out, so that its centre of gravity may be the lowest. Hence a drop of heavy liquid spreads out when placed on a glass plate.

For a small drop the potential energy due to surface tension is too large compare to that gravitation and hence drop takes the spherical shape. For example rain drops, oil drop and small drops of mercury are spherical in shape.

Angle of Contact:

In general, when the free surface of a liquid comes in contact of a solid, it becomes curved near the place of contact this is called capillary curve.

“The angle between the tangent to the liquid surface at the point of contact and the solid surface, inside the liquid is called the angle of contact”

Or

“The angle made by the tangent at the point of contact of the liquid of the liquid surface with solid surface inside the liquid”

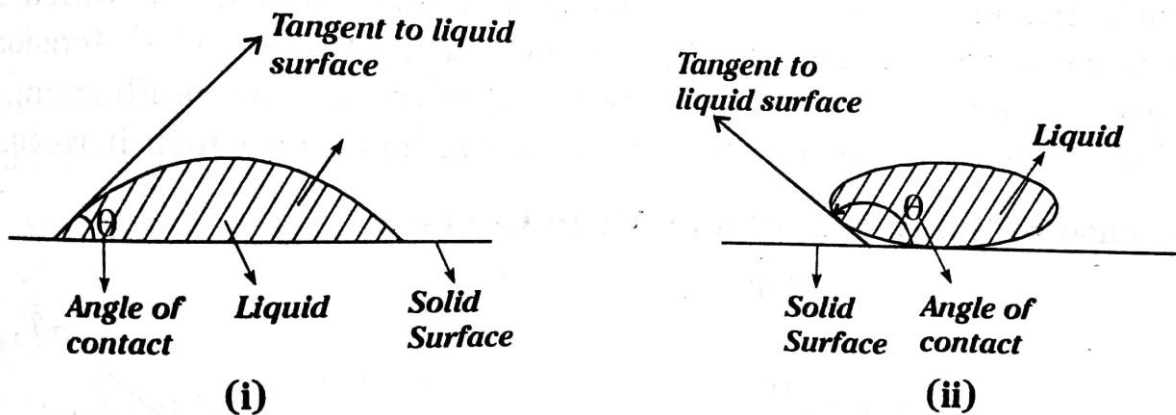


Fig. : Angle of contact

Explanation (angle of contact):

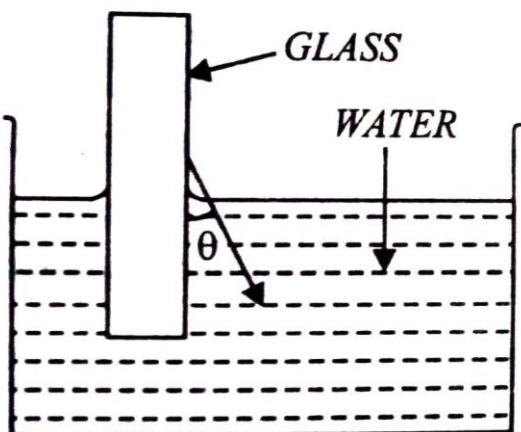


Fig: (i) Glass plate in water

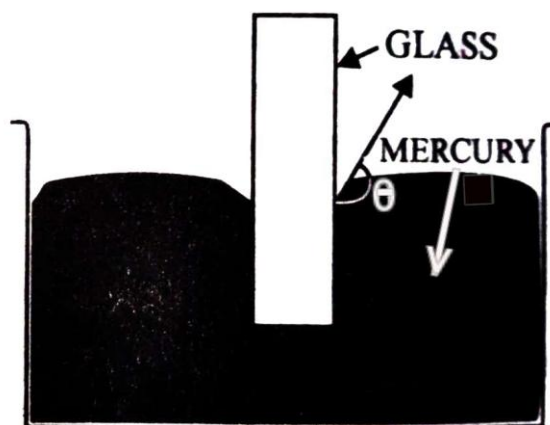


Fig: (ii) Glass plate in mercury

When a glass plate is dipped in water, the water molecules cling to the surface of glass and the water molecules rise along the plate. The shape of water surface is as shown in Fig. (i). The angle of contact is θ . When the glass plate is dipped in Mercury, the mercury molecules cling to the surface and the liquid is depressed along the plate as shown in Fig. (ii)

The angle of contact is θ . Hence, the angle of contact is defined as *the angle made by the tangent at the point of contact of the liquid surface with tangent the solid surface inside the liquid.*

The angle of contact in the case of water is acute (less than 90°) as shown in Fig.(i)

In the case of mercury the angle of contact is obtuse (more than 90°) as shown Fig. (ii)

Note: The angle of contact varies from 0° to 180° .

- i) *If the angle of contact of a liquid is acute ($<90^\circ$), such liquids wet the surface of the plate, such liquids are called **wet able liquids**. Ex: water.*
- ii) *If the angle of contact is obtuse ($>90^\circ$), such liquids do not wet the surface of the plate are called **non wet able liquids**. Ex: mercury.*
- iii) However, the angle of contact for particular pair of solid and liquid is a constant.

The angle of contact is depends upon the following:

1. Nature of the liquid and solid

Ex: For pure water and clean glass the angle of contact is zero.

2. The medium which exist above the free surface of the liquid.

When air is above the mercury, the angle of contact between mercury and glass is different to the angle of contact when there is a layer of water, exists above the mercury.

Interfacial Tension Phenomena:

Several types of interface can exist, depending on whether the two adjacent phases are in the solid, liquid or gaseous state.

For convenience, we shall divide these various combinations into two groups, namely liquid interfaces and solid interfaces.

“The force per unit length existing at the interface between two immiscible liquid phases is called interfacial tension”

Invariably, interfacial tensions are less than surface tensions because an adhesive force, between the two liquid phases forming the interface are greater than when a liquid and a gas phase exist together.

If two liquids are completely miscible, no interfacial tension exists between them.

The interfacial tension is between two immiscible liquids arises as a result of imbalance of forces. It is the force per unit length existing at the interface between two immiscible liquid phases. Although, in the general sense, all tensions may be referred to as interfacial tensions, this term is most often, used for the attractive force between immiscible liquids.

Generally interfacial tensions are less than surface tensions because the adhesive forces between two liquid phases forming an interface are greater than when a liquid and a gas phase exist together.

Units of interfacial tension: In CGS system is dynes per centimetre (*dyne/cm*) and in SI unit Newton/meter (*N/m*)

Dimension of interfacial tension: Since it is a ratio of force to the length, its dimensions are $\frac{MLT^{-2}}{L} = MT^{-2}$

Factors affecting surface tension and Interfacial Tension:

There are various factors that affect surface tension of a liquid such as the presence of impurities, presence of a dissolved substance in the liquid and change of temperature etc.

(i) Presence of impurities:

The presence of any kind of impurity on the surface of a liquid contaminates the liquid surface. The surface tension reacts immediately and little sharply to any contamination of the liquid surface. This brings about a significant

change in the value of its surface tension. The change in surface tension depends on the degree of contamination of the liquid surface. Surface tension of the solution is always less than that of the pure solvent or liquid.

(ii) Presence of dissolved substance in a liquid:

When a substance is dissolved in a pure liquid, the surface tension may be increased or decreased according to the nature of the substance. Many organic substances lower the surface tension when dissolved in water. On the other hand, some substances such as inorganic salts increase the surface tension.

(iii) Variation of Surface Tension with Temperature

The surface tension of all liquids decreases linearly with rise of temperature over small temperature ranges, so that the surface tension T of a liquid at t is given by $T = T_0 (1 - \alpha t)$

Where, T_0 is the value of surface tension at 0°C and α is the temperature coefficient for it.

As temp increases the Surface tension of liquids decreases due to enhance kinetic energy that weakens cohesive force. At critical temp Surface tension is 0.

The End