Surface Tension of Liquids

What is Surface Tension?

- Surface tension is the phenomenon that occurs when the surface of a liquid is in contact with another phase (it can be a liquid as well).
- Liquids tend to acquire the least surface area possible.
- The surface of the liquid behaves like an elastic sheet.

"Surface tension is the tension of the surface film of a liquid caused by the attraction of the particles in the surface layer by the bulk of the liquid, which tends to minimise surface area".

- Surface tension not only depends upon the forces of attraction between the particles within the given liquid but also on the forces of attraction of solid, liquid or gas in contact with it.
- The energy responsible for the phenomenon of surface tension may be thought of as approximately equivalent to the work or energy required to remove the surface layer of molecules in a unit area. Surface tension may be expressed, therefore, in units of energy (joules) per unit area (square metres).
- Surface tension is typically measured in dynes/cm, the force in dynes is required to break a film of length 1 cm.

Surface tension of various liquids:

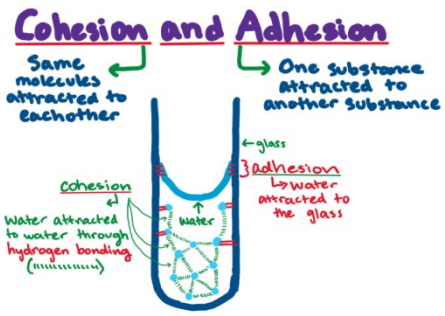
Liquid	Surface Tension (N/m)
Hydrogen	2.4
Helium	0.16
Water	0.072
Ethanol	22.0
Sodium Chloride	114

Cohesive forces

The surface tension of a liquid results from an imbalance of intermolecular attractive forces, the cohesive forces between molecules. The molecules at the surface of this sample of liquid water are not surrounded by other water molecules. The molecules inside the sample are surrounded by other molecules. A molecule in the bulk liquid experiences cohesive forces with other molecules in all directions. A molecule at the surface of a liquid experiences only net inward cohesive forces.

Adhesive Forces

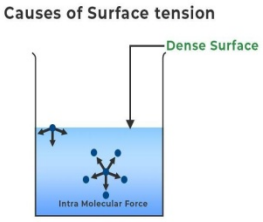
Forces of attraction between a liquid and a solid surface are called adhesive forces. The difference in strength between cohesive forces and adhesive forces determine the behavior of a liquid in contact with a solid surface. Water does not wet waxed surfaces because the cohesive forces within the drops are stronger than the adhesive forces between the drops and the wax. Water wets glass and spreads out on it because the adhesive forces between the liquid and the glass are stronger than the cohesive forces within the water.



What Causes Surface Tension?

The effect known as surface tension is caused by the cohesive forces between liquid molecules. Since the molecules at the surface lack like molecules in both directions, they cohere more closely to those specifically aligned with them on the surface. Intermolecular forces such as Van der Waals force, draw the liquid particles together. Along the surface, the particles are pulled toward the rest of the liquid. This creates a surface "film" that makes moving an object across the surface more difficult than moving it while fully submerged.

Let us assume a jar is filled with water; the water molecules can be found in two positions in this jar: First, beneath the water, and second, on the surface of the water. Since there are no molecules above these molecules, the molecules at the water's surface are unbalanced. As a result, only the molecules below will be attracted. As a result, a thin crust will form on the liquid's upper surface. Because of this thick layer, a form of stress is generated, which is known as Surface Tension. These phenomena can also be explained in terms of energy.



Surface Tension at Molecular Level

Due to the Cohesion force the water molecule tends to stick together. The water molecule at the bottom layer has various molecules above them to stick but the molecule at the top layer does not have various other molecules to cling together. Thus, they attach to each other with a larger force and resist any change in their structure. The molecule inside the body of the liquid experiences the forces from all directions and thus, the net force cancels out each other, whereas the particle at the top layer experiences a strong inward force resulting in the surface tension of the water. Because of this water has one of the highest surface tension among liquids.

Formula for Surface Tension

Mathematically, the surface tension is defined as the force (F) acting on the surface and the length (l) of the surface, so is given as:

$$\mathbf{T = F / l}$$

Also, the ratio of the work done (W) and the change in the area of the surface (A) is termed surface tension.

Unit of Surface Tension

SI Unit	N/m (Newton per Meter)
CGS Unit	dyn/cm

Dimension of Surface Tension

The dimension formula of Force is $[MLT^{-2}]$ whereas the dimension of length is [L] thus, the dimensional formula of **Surface Tension is $[M\ L^{0}\ T^{-2}]$.**

Some Important Examples of Surface Tension

a. Insects Walking on Water

Various insects can easily walk on the surface of the water because the force of their weight is not enough to penetrate the surface of the water

b. Floating Needle

A needle made of steel can easily be made to float on the surface of the water even though it is many times denser than water because of the surface tension of the water.

c. Rise of Liquids in Capillary Tubes

A tube whose radius is very short and uniform is called a capillary tube. When an open capillary is dipped in water. The water rises to some height in the capillary tube.

d. Spherical Shape of Water Droplets

Small droplets of fluid are spherical due to surface tension. The molecules of water tend to stick together due to intramolecular force, and the energy of molecules that are located on the surface of droplets contains higher energy and try to push the other molecule to the centre of the droplet. Due to this the drop makes the shape that contains the least surface area and the spherical shape is best for the least surface area, that's why The droplets of water and raindrops are spherical.

e. Fire Polishing of Glass

The method of polishing glass or thermoplastic with the help of fire or flame is called Fire Polishing. When we heat a glass material in flames, the glass surface starts melting. But due to surface tension, it starts to become soft and smooth which makes the glass very flat and smooth. This method is most applicable to flat external surfaces. Flame polishing is frequently in acrylic plastic fabrication because of its high speed compared to abrasive methods. In this application, an oxyhydrogen torch is typically used, one reason being that the flame chemistry is unlikely to contaminate the plastic.

f. Soaps and Detergents

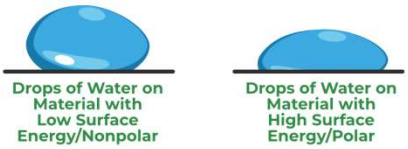
Soaps and Detergents can easily clean clothes because they lower the surface tension of the water and thus allowing it to easily soak the grease and soil particles and then remove them.

What is Surface Energy?

Surface energy measures the breakdown of intermolecular bonds caused by the formation of a surface. Surface-free energy and interfacial-free energy are other names for it. Surface energy is defined as the work done per unit area by the force that forms the new surface. When the free surface area of a liquid is increased, effort must be done against the force of surface tension. This work is stored as potential energy

on the liquid surface. This increased potential energy per unit area of the free surface of the liquid is referred to as surface energy.

The image given below shows the surface of the water molecules.



Mathematically, the surface energy is defined as:

$$\textit{Surface energy} = \textit{Surface tension} \times \textit{Change in the surface area}$$

or

$$E_S = T \times \Delta A$$

where T denotes surface tension and ΔA denotes an increase in surface area.

Therefore, the **SI unit of surface energy is Nm^{-2} and the dimensional formula is $[MT^{-2}]$.**

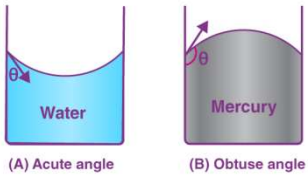
What is Angle of Contact?

The **angle of contact (θ)** is defined as the angle subtended between the tangents drawn at the liquid surface and the solid surface within the liquid at the point of contact.

The angle of contact varies from 0^o to 180^o.

If the adhesive force is greater than the cohesive force, the contact angle is less than 90o. This can be seen between water and glass surfaces.

If the adhesive force is less than the cohesive force, the contact angle is greater than 90o. This can be seen between mercury and glass surfaces.



The angle of contact depends on the following factors:

- The nature of the liquid, the solid with which it comes into contact.
- The medium that exists above the free surface of the liquid.
- As the temperature of the liquid rises, so does the angle of contact.
- When soluble impurities are added to a liquid, the angle of contact drops.

Factors affecting Surface Tension

Various factors which affect the Surface Tension of any liquid are

- **Solubility:** If the solute is highly soluble in the fluid, the surface tension of the fluid would increase. And if the solute is less soluble in the fluid, then the surface tension of the fluid would decrease.

- **Dust particles and lubricants:** If there are dust particles or any lubricant present on the surface of the fluid, the surface tension of the fluid decreases.
- **Temperature :** Increasing the temperature reduces the surface tension of the fluid. And decreasing the temperature increases the surface tension.

Measurement of surface tension:

Various methods can be used to measure the surface tension of any liquid. For example:

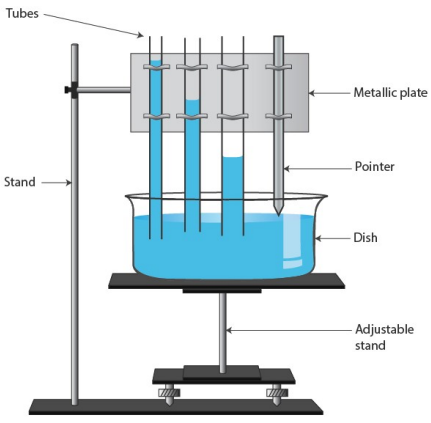
- Capillary Rise Method
- Bubble Pressure Method
- Spinning Drop Method
- Du Noüy–Padday Method
- Du Noüy Ring Method
- Stalagmometric Method
- Sessile Drop Method

Surface Tension by Capillary Rise Method

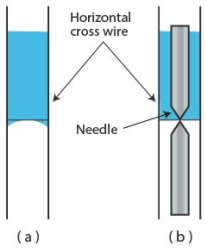
When we experiment with a capillary tube, we observe that when a liquid rises in a capillary tube, the weight of the column of the liquid of density ρ inside the tube is supported by the upward force of surface tension acting along the circumference of the points of contact.

A liquid of density ρ and surface tension σ rises in a capillary of inner radius 'r' to a height 'h' is given by: $h = 2\sigma \cos\theta/\rho g r$

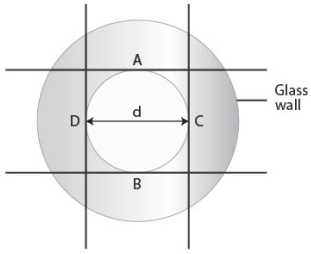
where, θ = The contact-angle made by the liquid meniscus with the surface of the capillary.



Measurement of surface tension by capillary rise



Water meniscus through microscope



Measurement of internal diameter of capillary tube

The surface tension of water is given by the formula

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

where, r is the radius of cross-section, g is the acceleration due to gravity, ρ is the density of the liquid, h is the capillary rise, θ is the contact angle.

Q. Compute the surface tension of a given liquid whose dragging force is 7 N and the length in which the force acts is 2 m?

Solution: *Given,*

- **F** = 7 N
- **L** = 2 m

According to the formula,

T = F/L

⇒ T = 7/2

⇒ T = 3.5 N/m

Q. Why is raindrop spherical?

Presence of cohesive forces between liquid molecules and the surface tension of the liquid.

Q. What happens when a soap bubble is charged?

When a soap bubble is charged, it expands.

Q. What is the dimensional formula of surface tension?

The dimensional formula of surface tension is: $[ML^0T^{-2}]$.

Q. What is the surface tension of water at its boiling point?

The surface tension of water at its boiling point is zero.

Q. Which are the forces behind the origin of surface tension?

The forces behind the origin of surface tension are a cohesive force and adhesive force.

Q. How addition of impurities effects the surface tension of a liquid?

The presence of impurities either on the surface or dissolved in it, affect surface tension of the liquid. Highly soluble substances increase the surface tension of water, whereas sparingly soluble substances reduce the surface tension of water. The surface tension of a liquid decreases with increase in temperature. The surface tension of a liquid becomes zero at its boiling point and vanishes at critical temperature.

Q. What do you mean by capillary action? Explain its importance in brief.

Capillary action is defined as the movement of water within the spaces of a porous material due to the forces of adhesion, cohesion, and surface tension.

Capillary action occurs because water is sticky, due to the forces of cohesion (water molecules like to stay close together) and adhesion (water molecules are attracted and stick to other substances). Adhesion of

water to the walls of a vessel will cause an upward force on the liquid at the edges and result in a meniscus which turns upward. The surface tension acts to hold the surface intact. Capillary action occurs when the adhesion to the walls is stronger than the cohesive forces between the liquid molecules.

Importance and applications:

- Plants and trees couldn't thrive without capillary action. Plants put down roots into the soil which are capable of carrying water from the soil up into the plant. Water, which contains dissolved nutrients, gets inside the roots and starts climbing up the plant tissue. Capillary action helps bring water up into the roots. But capillary action can only "pull" water up a small distance, after which it cannot overcome gravity. To get water up to all the branches and leaves, the forces of adhesion and cohesion go to work in the plant's xylem to move water to the furthest leaf.
- Capillary action is also essential for the drainage of constantly produced tear fluid from the eye. Two tiny-diameter tubes, the lacrimal ducts, are present in the inner corner of the eyelid; these ducts secrete tears into the eye.
- In case of a fountain pen , the ink moves from a reservoir in the body of the pen down to the tip and into the paper (which is composed of tiny paper fibers and air spaces between them), and not just turning into a blob. Of course gravity is responsible for the ink moving downhill to the pen tip, but capillary action is needed to keep the ink flowing onto the paper.
- Not only does water tend to stick together in a drop, it sticks to glass, cloth, organic tissues, soil, and, luckily, to the fibers in a paper towel. When we dip a paper towel into a glass of water, the water tries to climb onto the paper towel. In fact, it will keep going up the towel until the pull of gravity is too much for it to overcome.

Q. Explain why the angle of contact of mercury with glass is obtuse, while that of water with glass is acute.

The adhesive force between glass and water molecules is greater as compared to the cohesive force between water molecules. This makes a concave meniscus for the surface of water. Thus, water makes an acute angle from the glass surface.

The adhesive force between glass and mercury molecules is less as compared to the cohesive force between mercury molecules. This makes a convex meniscus for the surface of mercury. Thus, mercury makes an obtuse angle from the glass surface.

Q. Water on a clean glass surface tends to spread out while mercury on the same surface tends to form drops. Explain.

Water molecules make acute angles with glass. They have a weak force of attraction between themselves and a strong force of attraction toward solids, thus they spread out.
In the case of mercury molecules which make an obtuse angle with glass have a strong force of attraction between themselves and a weak force of attraction toward solids. Hence, they form drop.

Q. Surface tension of a liquid is independent of the area of the surface. Explain.

Surface tension is defined as the force acting per unit length at the interface between the plane of a liquid and any other surface. It depends upon the nature of liquid not on the area of contact.

Q. Water with detergent dissolved in it should have small angles of contact. Explain the reason.

Water with detergent dissolved in it has small angles of contact θ. For a small θ , there is a fast capillary rise of the detergent in the cloth. The capillary rise of a liquid is directly proportional to the cosine of the angle of contact. If θ is small, then $\cos\theta$ will be large and the rise of the detergent water in the cloth will be fast.

Q. A drop of liquid under no external forces is always spherical in shape. Explain.

A liquid tends to acquire the minimum surface area. Since, the surface area of a sphere is minimum for a given volume therefore, under no external forces, liquid drops always take spherical shape.