Surface tension & Viscosity

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Insects are able to land and
stay on the surface of water

Drops of water do not stick to the leaf and are also generally spherical in nature

Some commonly observed phenomena

- Oil and water do not mix
- Mercury does not wet glass but water sticks to it
- Oil rises up a cotton wick, in spite of gravity
- Sap and water rise up to the top of the leaves of the tree
- Bristles of a paint brush do not cling together when dry and even when dipped in water. They stick together and form a fine tip when taken out of it.

Many such phenomena are related with the free surfaces of liquids. As liquids have a definite volume but no definite shape, they acquire a free surface when poured in a container. These surfaces possess some additional energy. This phenomenon is known as *surface tension*.

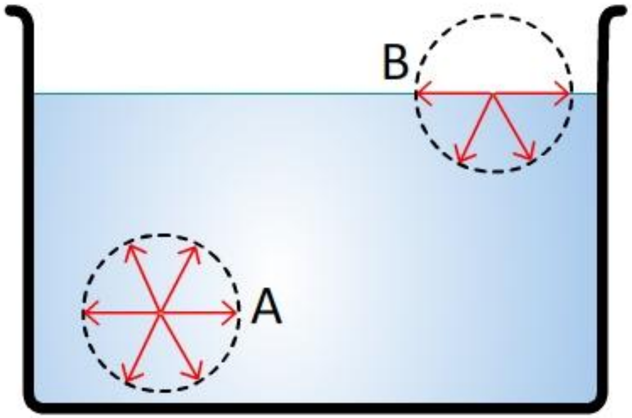
- Surface tension is concerned with liquids only as gases do not have free surfaces.

Surface energy

It is the energy associated with the formation of liquid surface.

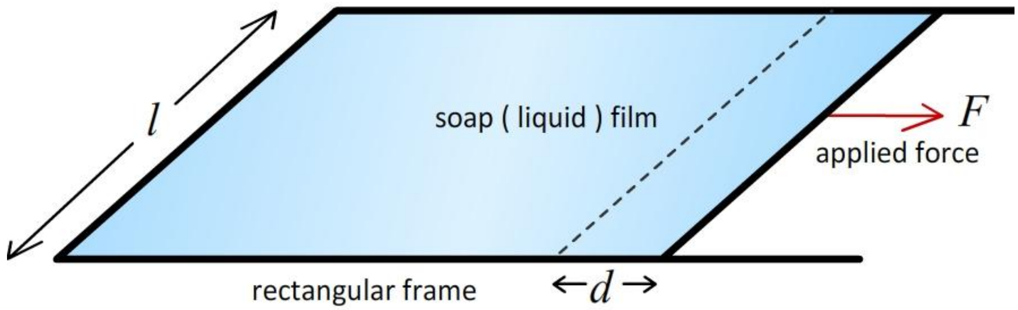
Consider a molecule (A) well inside a liquid. Such a molecule is attracted to all the nearby molecules due to intermolecular forces. This attraction results in a negative potential energy for the molecule, which depends on the number and distribution of molecules around it.

Consider a molecule (B) near the liquid surface. Only lower half of the region around it is surrounded by liquid molecules. Potential energy (negative) of such a molecule is less due to lesser interaction. Thus, molecules on a liquid surface have more energy in comparison to molecules in the interior.



As increasing surface area requires energy, a liquid surface tends to occupy the least surface area.

Surface energy and surface tension



Consider a horizontal liquid film contained in a U shaped frame with a bar at one end, free to slide over parallel guides.

Let the bar be moved by a small distance d. Work done against internal forces in causing this displacement is given by

$$W = F \times d \quad \text{(i)}$$

Additional area formed on surface is

$$A = 2 \times l\, d \quad \text{(ii)}$$

Let S be the surface energy per unit area of the film. Energy associated with formation of this surface is

$$E = S \times 2l\, d \quad \text{(iii)}$$

Using the work energy principle,

$$S \times 2l\, d = F \times d$$

$$\boxed{S = \frac{F}{2l}}$$

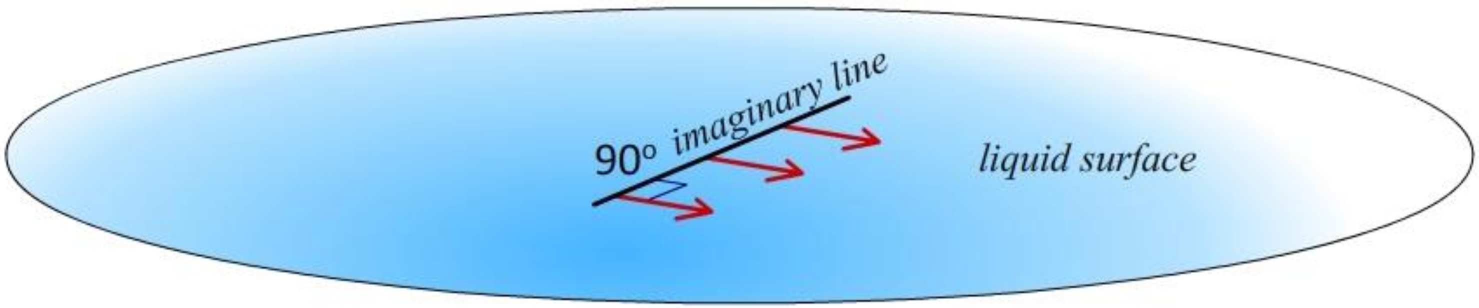
* Factor of 2 is due to upper and lower surface

Surface tension (S) may be defined as

- Surface energy per unit area of the liquid interface
- Force per unit length exerted by the fluid on the movable bar.

Surface tension (S)

Qualitatively, it is the property of a liquid by the virtue of which its surface behaves as a stretched membrane.

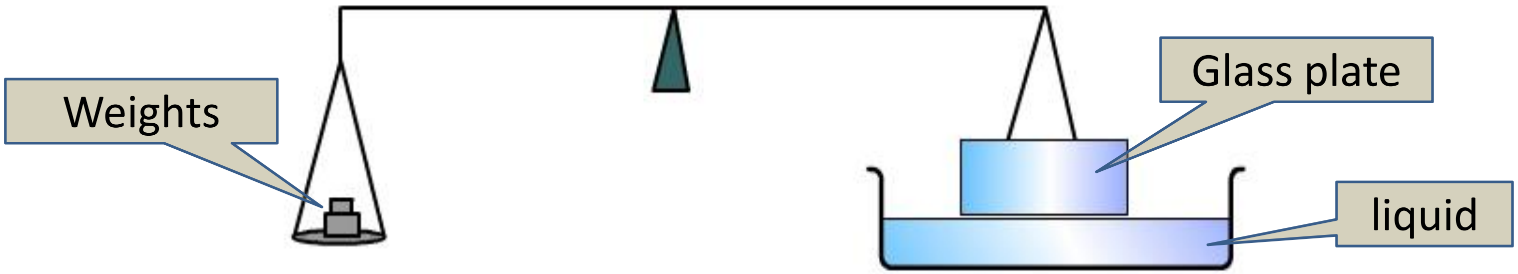


Quantitatively, surface tension is defined as the force acting per unit length on an imaginary line drawn on a liquid surface, tangential to the surface of the liquid and normal to the given line.

$$\boxed{S = \frac{F}{l}}$$

SI unit of surface tension is Nm^{-1} or Jm^{-2}

Experimental determination of surface tension

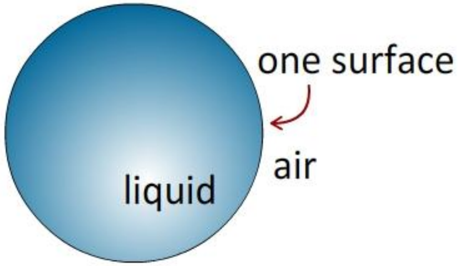


- A glass plate is suspended on a balance.
- A beaker containing the liquid is placed below the glass plate.
- Lower end of the plate is placed just above the liquid surface and the glass plate is supported by sufficient weight ($m_1 g$) on the other arm
- The beaker containing the liquid is raised slightly so that lower edge of the glass plate just touches the liquid surface.
- Weights ($m_2 g$) are added to the other arm gradually until the plate just clears the liquid.
- From difference of weights ($m_2 - m_1$)g, surface tension is obtained using the relation $S = \frac{mg}{2l}$

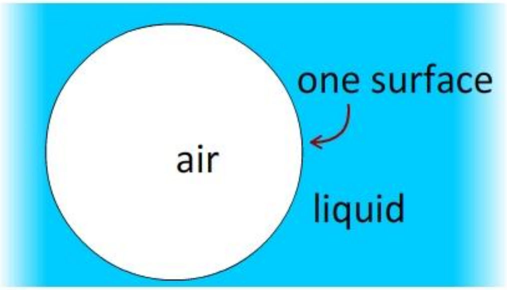
Excess pressure in a liquid drop

$$\boxed{P_{\text{excess}} = \frac{2S}{R}}$$

S Surface tension of the liquid
R Radius of the liquid drop



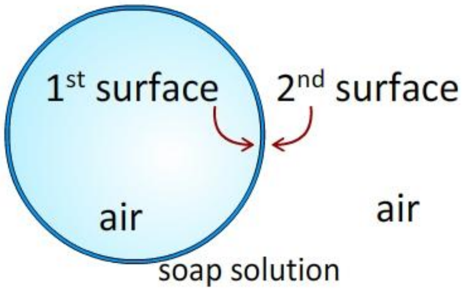
A air bubble formed inside a liquid also has just one surface and hence the above relation is applicable to air bubble in a liquid.



Excess pressure in a soap bubble

$$\boxed{P_{\text{excess}} = \frac{4S}{R}}$$

S Surface tension of soap solution
R Radius of the soap bubble

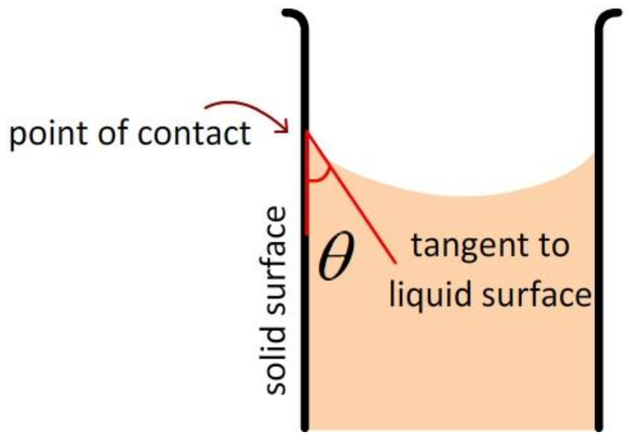


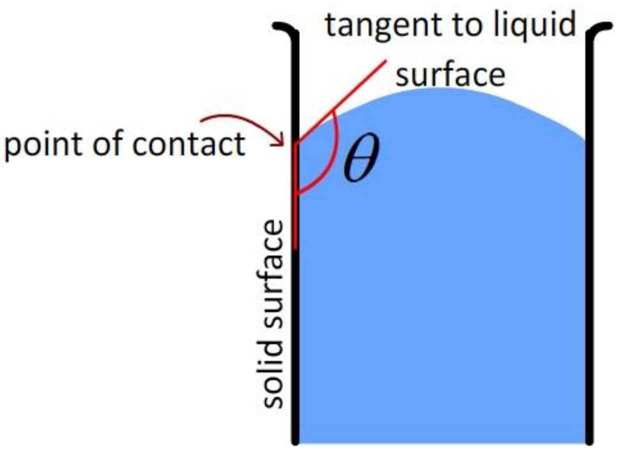
Spherical shape of liquid drops and soap bubbles

Small liquid drops and soap bubbles are spherical in nature. This is because, for a given volume, a spherical structure occupies least surface area and hence energy associated with spherical surface is the minimum.

Angle of contact

It is the angle between the tangent drawn to the surface of liquid, at the point of contact with the solid and the solid surface, inside the liquid.



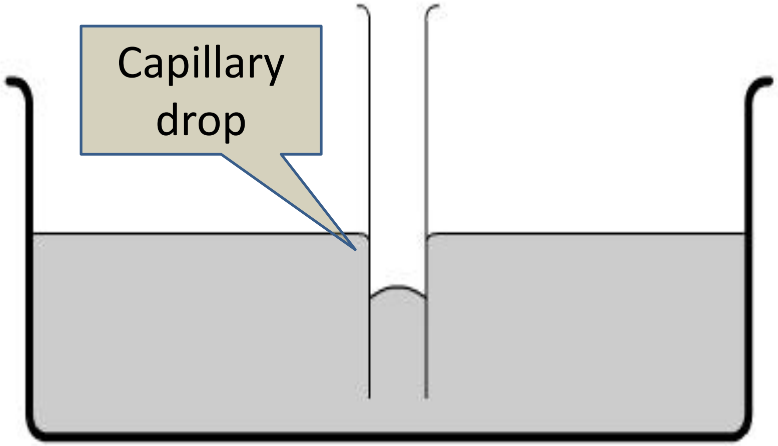


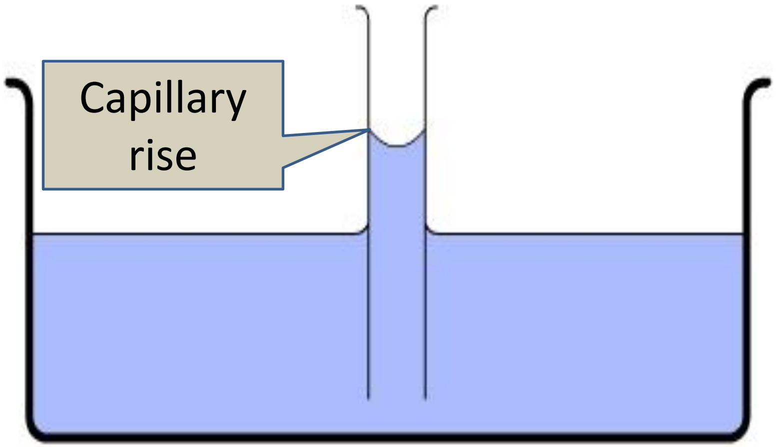
- It is different for different pairs of liquids and solids
- Angle of contact determines whether a liquid spreads on the solid surface or whether it forms droplets on it.
- Examples:

  (a) Water forms droplets on lotus leaf (due to large angle of contact)

  (b) Water spreads over a clean plastic plate (due to small angle of contact)

Angle of contact capillarity and intermolecular forces





- Angle of contact is more than 90^o
- Cohesive forces are stronger than adhesive forces
- Liquid level falls in the capillary tube
- Eg : Mercury and glass

- Angle of contact is less than 90^o
- Adhesive forces are stronger than cohesive forces
- Liquid level raises in the capillary tube
- Eg : Water in glass

Water proofing and water wetting agents

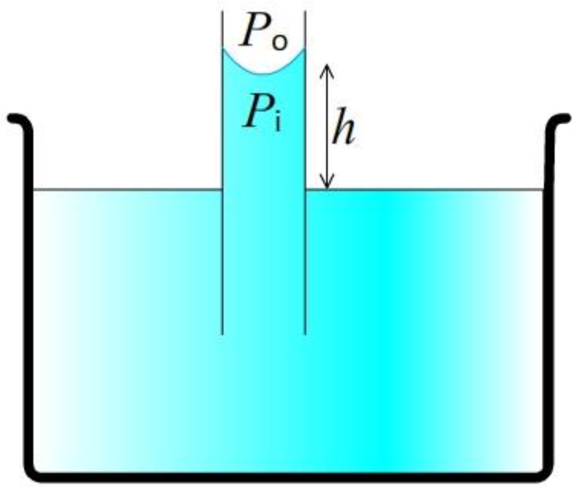
- These are chemicals that can alter the angle of contact of water based on specific purpose
- Soaps, detergents and dying substances are wetting agents.
  When they are added the angle of contact becomes small so that these may penetrate well and become effective.
- Water proofing agents are added to create a large angle of contact between the water and fibers. (example : PVC)

Capillary rise and surface tension

Consider a vertical capillary inserted into an open vessel of water.

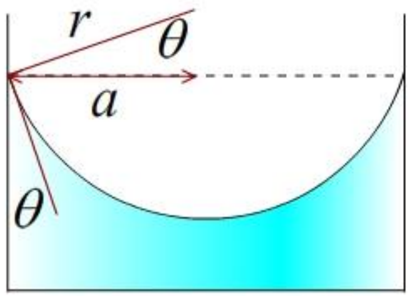
Surface of water in the capillary is concave and the angle of contact is acute. Pressure above the surface is more than the pressure under the surface.

Let r be the radius of curvature of the concave meniscus and a be radius of the capillary tube.



$$P_o - P_i = \frac{2S}{r}$$

From the figure



$$P_o - P_i = \frac{2S}{a}\cos(\theta) \quad \text{i}$$

$$P_i + \rho g h = P_o \quad \text{ii}$$

Substituting this in eq (i) we get

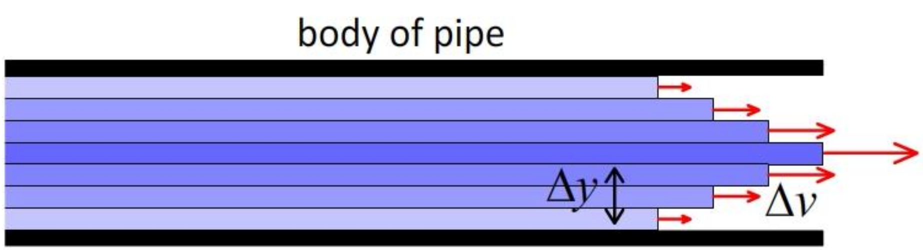
$$\rho g h = \frac{2S}{a}\cos(\theta)$$

$$\boxed{S = \frac{\rho g h a}{2\cos(\theta)}}$$

Viscosity

It is the phenomenon in a fluid by which it tends to oppose relative motion between its adjacent layers.

When a fluid is flowing in a pipe or a tube, then velocity of the liquid layer along the axis of the tube is maximum and decreases gradually as we move towards the walls where it becomes zero.



Change in velocity (Δv) as we move from one layer to another (Δy) is called *velocity gradient*.

Strain in a flowing fluid increases with time continuously and the stress is found experimentally to depend on *rate of change of strain* .

Coefficient of viscosity (η) in liquids is defined as the ratio of shearing stress to rate of change of strain.

$$\boxed{\eta = \frac{F/A}{v/l}}$$

Its SI unit is Nsm^{-2} or poiseiulle (Pl)

- Blood is thicker i.e. more viscous than water.
- Viscosity of liquids decreases with temperature, while it increases in the case of gases.

Stokes law

It is an expression for the viscous force acting on a body moving with certain velocity in a viscous fluid.

$$\boxed{F = 6\pi\eta r v}$$

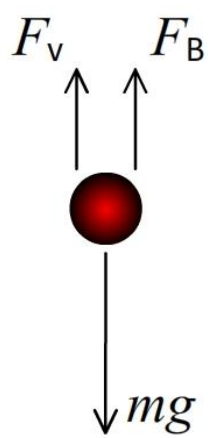
v is velocity of body w.r.t. fluid

r radius of body (assumed to be spherical)

η coefficient of viscosity of fluid

F viscous force

Forces acting on a body moving in a fluid



Terminal velocity

It is the maximum velocity attained by a body, moving through a viscous fluid.

As a body moving through a viscous fluid body attains equilibrium, the upward viscous force and buoyant force is balanced by the downward gravitational force.

$$6\pi\eta r v_T = \frac{4}{3}\pi r^3(\rho - \sigma)g$$

$$\boxed{v_T = \frac{2r^2(\rho - \sigma)g}{9\eta}}$$

From the above relation it is observed that terminal velocity increases with surface area of a body ($4\pi r^2$) .

Reynolds's number (R_e)

It is a dimensionless number which gives an estimate of the velocity at which a stream lined flow of a fluid undergoes transition to turbulent flow.

$$\boxed{R_e = \frac{\rho\, v\, d}{\eta}}\ *$$

v is velocity of fluid

d is a dimension (length / diameter of tube)

ρ is density of fluid

$R_e < 1000$	Fluid flow is streamlined
$1000 < R_e < 2000$	Transition from streamlined to turbulent flow
$R_e > 2000$	Fluid flow is turbulent

Critical value of R_e is the value at which the fluid undergoes transition from streamlined flow to turbulent flow.

Critical value of Reynolds's number is found to be the same for geometrically similar shapes (i.e. independent of density, viscosity etc of the fluid)

Small scale models developed based on Reynolds's number are useful is designing ships, submarines, racing cars etc.

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