Surface Tension

Attractive molecular and atomic forces

Molecules (atoms) exert an attractive force between themselves. These attractive inter-molecular inter atomic forces are of two types :
1. Cohesive force or force of cohesion
2. Adhesive force or force of adhesion.

1. Force of cohesion. The force of attraction between molecules of the same substance, is called force of cohesion.
Force of cohesion is maximum between solid molecules, less between liquid molecules and least (zero in ideal gas) between gas molecules. It is for this reason that solids and liquids have definite volume while gases have no fixed volume. (More cohesive force makes solid hard, less cohesive force makes solid soft).
2. Force of adhesion. The force of attraction between the molecules of the different substances, is called force of adhesion.
It is for this reason that the water sticks to the glass and gum sticks to the paper.

Some useful definitions

1. Molecular range. Molecular attractive forces are short range forces and effective only up to very small distance.
   The maximum distance up to which a molecule can exert its influence (attraction) on other molecules, is called the molecular range of the molecule.
   It is represented by the symbol R. Its order is 10^{-9} m.
2. Sphere of molecular influence. It is a sphere of radius equal to molecular range (10^{-9} m) drawn around a molecule with molecule as centre. All the molecules lying in this sphere are attracted by and also attract the molecule at the centre.
3. Surface film. It is a layer of liquid, at the free surface of a liquid, having thickness equal to molecular range. Liquid molecules in surface film have extra potential energy.
4. Surface energy. The extra potential energy of the liquid molecules in the unit area of the surface film, is called surface energy. It is represented by the symbol E.

Surface tension

Definition. It is the property of a liquid by virtue of which its free surface at rest behaves like an elastic skin or a stretched rubber membrane with a tendency to contract so as to occupy minimum surface area.
This property has been well-explained by molecular theory, in texts.
Measurement. Due to surface tension, liquid molecules in free surface pull each other. Surface tension is measured as the force acting normally per unit length on an imaginary line drawn on the free liquid surface at rest. It is represented by the symbol T (or S). Its S.I. unit is newton per metre (N m^{-1}).
Its dimensional formula is $[M^1L^oT^{-2}]$. Surface energy = surface tension x change in surface area.

Shape of liquid meniscus

Due to surface tension, the free liquid surface (meniscus) is rarely plane.
Three cases arise:

Case I. There is more adhesive force than the cohesive force. The vessel molecules will pull up the liquid molecules in surface in contact with the wall of the vessel. The surface becomes concave upward.
It happens for water in a glass vessel.

Case II. There is more cohesive force than the adhesive force. The liquid molecules will pull down the liquid molecules in surface in contact with the wall of the vessel. The surface becomes convex upward.
It happens for mercury in a glass vessel.

Case III. The cohesive force and the adhesive force (along the wall of the vessel) become balanced. The liquid molecules in surface in contact with the wall of the vessel are neither pulled up nor pulled down. The surface remains plane.
It happens for water in a silver vessel.

Angle of contact

(a) Definition. It is the angle that the tangent to the liquid surface at the point of contact makes with the wall of the vessel inside the liquid. It is represented by the symbol θ.

(b) Different Cases for different angle of contact.
(i) For surfaces concave upward, it is acute (less than 90°).
(ii) For surfaces convex upward, it is obtuse (more than 90°).
(iii) For plane surfaces, it is right angle (90°).

Pressure difference due to curvature in liquid surface

Due to curvature in free liquid surface, its area becomes more. It tends to become flat to minimise the surface area (property of surface tension). Hence pressure is not the same, above and below the surface.
A surface concave upward, has a tendency that its central part tends to rise up to minimise free surface area. Hence pressure above it becomes more than below it.
A surface convex upward, has tendency that its central part tends to move down to minimise free surface area. Hence pressure above it becomes less than below it.
A plane surface does not have above tendency. Hence pressure remains same above and below it. (In the two cases of curved surfaces above, there is more pressure on the side for which surface is concave).

Excess pressure on the concave side

Let a liquid drop of radius R have excess inside (concave side) pressure P. (Fig)

Then total inward excess force becomes $4\pi R^2 P$. If this drop is to be increased in size, an outward force $4\pi R^2 P$ will be needed.

Let the surface of drop be pushed outward by distance dR by external force $4\pi R^2 P$, so that work done becomes $4\pi R^2 P dR$.

This will increase the surface area of drop by amount,

$$4\pi(R + dR)^2 - 4\pi R^2 = 4\pi[(R + dR)^2 - R^2]$$
$$= 4\pi\, 2RdR$$
$$[\text{neglecting } (dR)^2]$$

The energy spent in the work done in increasing size of the drop becomes stored as the surface energy of the increased surface area.

If E be the surface energy, then total surface energy of new surface becomes,

$$= E8\,\pi R\,dR$$

Hence, $$4\pi R^2 P\,dR = E\,8\pi R\,dR$$

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

But since, $$E = \text{Surface tension } (T)$$

Excess pressure, $$P = \frac{2T}{R} \quad ...(1)$$

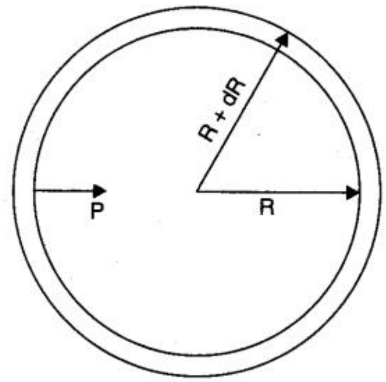

Fig. 11.01. Excess pressure inside a liquid drop.

For a spherical bubble with two surfaces

$$P = \frac{4T}{R} \quad ...(2)$$

For an air bubble inside liquid or liquid drop, $P = \frac{2T}{R}$ **...(3)**

Capillarity

When a capillary tube is dipped in a liquid, the liquid level either rises or falls in the capillary tube.

The phenomena of rise or fall of a liquid level in a capillary tube dipped in it, is called capillarity or capillary action.

Rise of liquid level in a capillary tube (Ascent Formula)

Let a capillary tube be dipped in a liquid which makes concave meniscus in the tube. Due to surface tension, the tube molecules exert a force T on the liquid molecules in the unit length of the circle of contact of the liquid surface with the tube. This force acts at an angle θ (angle of contact) with the wall of the vessel [Fig]. Components T sin θ perpendicular to the wall of the tube cancel for the whole circle. Components T cos θ

along the wall of the tube become added. For the tube of radius r, the circle of contact has circumference $2\pi r$ and the upward force on all molecules becomes $2\pi rT \cos \theta$.
It is this upward force that pulls the liquid upward in the capillary tube. The liquid rises in the capillary tube up to a height till the weight of the liquid risen equals this force.
Let the liquid rise up to a height h (as measured for the lower meniscus B) and let the meniscus ABC have hemispherical shape [Fig].