# Some Important Results of Surface Tension

1. **Spherical shape of drops**: Surface tension tries to decrease the surface area of the liquid to the minimum. The drops of a liquid (or the bubbles of a gas) are spherical because for given volume, a sphere has minimum surface area. Inward pull of surface tension makes a drop spherical.

2. **Rise of a liquid in a capillary tube**: Suppose one end of a capillary tube is put into a liquid that wets glass (fig.). It is found that the liquid rises into the capillary tube to a certain height. This rise due to inward pull of surface tension acting on the surface which pushes the liquid into the capillary tube. It is because of the same reason that oil rises into the wick of an oil pump or water below the surface of earth rises to the plants through the roots or ink rises in a blotting paper.
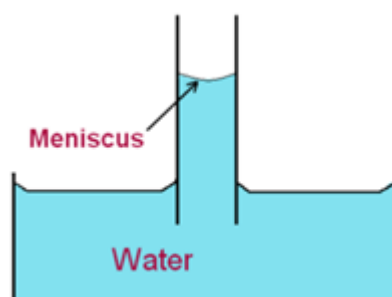
It may be mentioned here that in case of liquid which do not wet glass, e.g. Hg, the level inside the capillary falls below the level outside. Further whereas the upper surface of a liquid that wet glass is concave, that of Hg is convex. Such a surface is therefore, called Meniscus. The angle which the curved surface makes with the wall of the tube is called contact angle and is found by drawing a tangent at that point.

3. **Interfacial Tension**: If two immiscible or partially miscible liquids are taken in a vessel, then the surface tension acting along their surface of separation i.e. along the interface is called the interfacial tension. Its value is generally intermediate between the surface tension of the two liquids but sometimes it is less than both. This is due to fact that at the interface, the molecules of one liquid are attracted by the molecules of the other.

In fact, the surface tension of a liquid is also an interfacial tension, the two phases involved being the liquid and the vapour above it.

4. **Surface Active Agents**: There are certain substances like soaps, certain sulphonic acids and certain other organic compounds like CH_3OH, C_2H_5OH, CH_3COCH_3 etc. which when added to water even in small amount decreases the surface tension of water to a considerable extent. Such substances which lowers the surface tension of water are called as surface active agents. It is for this reason that the soap is acts as detergent.

5. **In the Functioning of Lung**: A biologically relevant issue that is the stability of lung tissue. Lung tissue is composed of small water-lined, air-filled chambers called alveoli. According to Equation ($P_{inner} = P_{outer} + 2\gamma/r$), the pressure difference across the surface of a spherical air-filled cavity is proportional to the surface tension and inversely proportional to the radius of the cavity. Therefore, if two air-filled alveoli, approximated as spheres with radii r and R and for which are interconnected, the smaller alveolus will collapse and the larger alveolus will expand because the pressure within the smaller alveolus is greater than the pressure within the larger alveolus. In theory, due to the surface tension of water that lines the alveoli, these cavities will "coarsen" as smaller alveoli collapse, leaving an ever diminishing number of alveoli of increasing size. Coarsening of the alveoli according to Equations ($P_{inner} = P_{outer} + 2\gamma/r$) will result eventually in the collapse of the lungs. In the alveoli, a lipid surfactant called phosphatidylcholine lowers the surface tension of the water lining the alveoli, thus stabilizing the lungs. But in persons lacking sufficient surfactant in the lining of their lungs, such as prematurely born infants and heavy smokers, the surface tension of the water in the alveoli is not lowered, and as a consequence lung tissue is destabilized by coarsening.

Effect of Temperature on Surface Tension

The surface tension of liquids generally decreases with increase of temperature and becomes zero at critical temperature (when meniscus between the liquid and the vapour disappears). The decrease in surface tension with increase of temperature is due to the fact that with increase of temperature, the kinetic energy of the molecules increases and hence intermolecular attraction decreases.

According to Eotvas 1886:

$$\gamma \, (M/D)^{2/3} = k \, (t_c - t)$$

M = molecular mass of the liquid
D = Density of the liquid at temperature t °C
t_c = Critical temperature of the liquid *i.e.* the temperature at which $\gamma = 0$
γ = Surface tension of the liquid at temperature t °C
k = a constant
M/D = Molar volume of the liquid

If this volume is taken be spherical, then
$(M/D)^{2/3}$ is molar surface of the liquid.
As γ is surface energy of the liquid, therefore
$\gamma \, (M/D)^{2/3}$ is molar surface energy of the liquid.

Further, Ramsay and Shields in 1893 found that
$\gamma \, (M/D)^{2/3}$ is zero at t = t_c but at t = t_c - 6 *i.e.* at temperature 6 °C less than the critical temperature. Hence, they modified the equation as $\gamma \, (M/D)^{2/3} = k \, (t_c - t - 6)$ and will be negative at $t = t_c$. To overcome this difficulty, Katayama suggested a more correct relation $\gamma \, (M/D-d)^{2/3} = k' \, (t_c - t)$.
where d = density of the vapour at temperature t. In this equation $\gamma = 0$ when t = t_c.

Viscosity

A liquid may be considered to be consisting of molecular layers arranged one over the other. When a shearing force is applied to a liquid, it flows. However, the forces of friction between the layers offer resistance to this flow. **Viscosity of a liquid is a measure of its frictional resistance.**

Let us examine a liquid flowing on a glass surface (Fig.5). The molecular layer in contact with the stationary surface has zero velocity. The successive layers above it move with increasingly higher velocities in the direction of the flow.
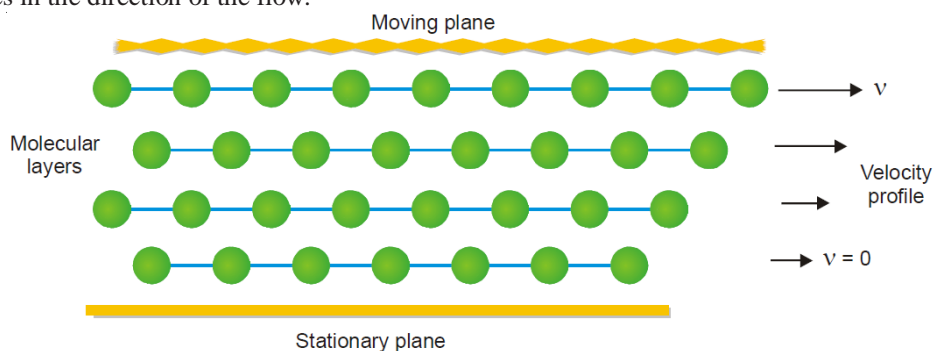

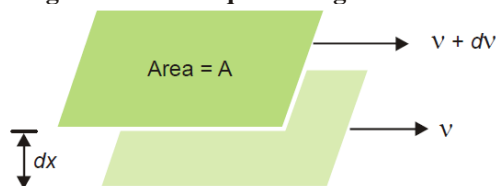
Fig. 5 Flow of a liquid on a glass surface.

Fig. 6 Two parallel layers moving in a liquid.

Now consider two adjacent moving layers of a liquid (Fig.6). Let these be separated by a distance dx and have a velocity difference dv. The force of friction (F) resisting the relative motion of the two layers is directly proportional to the area A and the velocity difference dv, while it is inversely proportional to the distance between the layers.
That is,

$$F \propto A \frac{dv}{dx}$$

or
$$F = \eta A \frac{dv}{dx} \qquad \qquad ...(1)$$

or
$$\eta = \frac{F}{A} \times \frac{dx}{dv} \qquad \qquad ...(2)$$

where η is the proportionality constant. It is known as the **Coefficient of Viscosity** or simply viscosity of a liquid. η has a specific value for a given liquid at the same temperature. It may be defined from equation (2) as: the force of resistance per unit area which will maintain unit velocity difference between two layers of a liquid at a unit distance from each other.

The reciprocal of viscosity is called Fluidity and is denoted by φ.

$$\varphi = 1/\eta$$

Units of Viscosity: The dimensions of the coefficient of viscosity (η) may be derived from equation (2).

$$\eta = \frac{F}{A} \times \frac{dx}{dv} = \frac{\text{force}}{\text{area}} \times \frac{\text{distance}}{\text{velocity}}$$

or
$$\eta = \frac{\text{mass} \times \text{length} \times \text{time}^{-2}}{(\text{length})^2} \times \frac{\text{length}}{\text{length/time}}$$

$$= \text{mass} \times \text{length}^{-1} \times \text{time}^{-1}$$

Thus in CGS system the unit of η is expressed as g cm^{-1} s^{-1}. It is called poise (P). In practice smaller units **centipoise** (10^{-2} poise) and **millipoise** (10^{-3} poise) are used.

The SI unit is kg m^{-1} s^{-1}. One poise is equal to one-tenth of the SI unit *i.e.*

$$1 \text{ poise} = 1 \text{ g cm}^{-1} \text{ s}^{-1} = 0.1 \text{ kg m}^{-1} \text{ s}^{-1}.$$

Measurement of Viscosity - The Ostwald Method:

Viscosity of a liquid can be determined with the help of **Pioseulle's equation.** This expression which governs the flow of a liquid through a capillary may be written as:

$$\eta = \frac{\pi P r^4 t}{8 l V} \qquad \qquad ...(1)$$

where V is the volume of the liquid flowing through capillary in time t, P the pressure-head, r the radius of the tube and l its length. The experimental measurement of P, r, l and V offers considerable difficulty. Therefore, it is not possible to find the absolute coefficient of viscosity (η) straight away from Poiseulle's equation.

Ordinarily, the viscosity of a liquid is determined with respect to that of water. This is called **Relative Viscosity.** Let t_1 and t_2 be the times of flow of a fixed volume (V) of the two liquids through the same capillary. The expression for relative viscosity (η_1/η_2) can be derived from equation (1).

$$\frac{\eta_1}{\eta_2} = \frac{\pi P_1 r^4 t_1}{8 l V} \cdot \frac{8 l V}{\pi P_2 r^4 t_2} = \frac{P_1 t_1}{P_2 t_2} \qquad \qquad ...(2)$$

Since the pressure-head is proportional to density (d) of the liquid, from (2) we have:

$$\frac{\eta_1}{\eta_2} = \frac{d_1 t_1}{d_2 t_2} \qquad \qquad ...(3)$$

Substituting the value of the viscosity coefficient of water (η_2) in (3), we can find the **absolute viscosity** of the given liquid (η_1).

Ostwald Viscometer:

The apparatus commonly used for the determination of relative viscosity of a liquid is known as **Ostwald viscosimeter** *or* **viscometer.** A simple form of it is shown in Fig.7. The left-hand limb is essentially a pipette with two calibration marks A and B. A length of capillary tube joins the pipette to a bulb C in the right-hand limb.
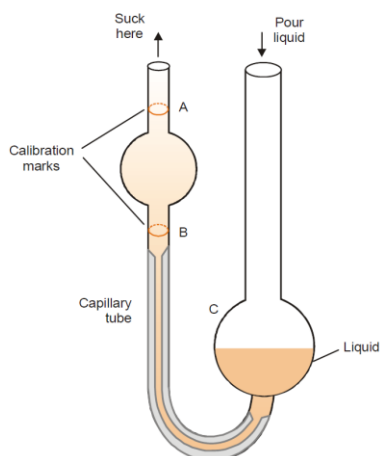
Fig. 7 Ostwald Viscometer.

A definite volume of liquid (say 25 ml) is poured into the bulb *C* with a pipette. The liquid is sucked up near to the top of the left-limb with the help of a rubber tubing attached to it. The liquid is then released to flow back into the bulb *C*. The time (t_1) from *A* to *B* is noted with a stopwatch. Then the apparatus is cleaned and the experiment repeated with water, taking about the same volume. The time of flow of water (t_2) from *A* to *B* is recorded. The density of the liquid (*d*) and water (d_w) are determined with the help of a *pyknometer*. The relative viscosity coefficient is calculated from the expression

$$\frac{\eta}{\eta_w} = \frac{d \; t_1}{d_w \; t_2}$$

Knowing the value of the viscosity coefficient of water (η_w) at the temperature of the experiment, the absolute viscosity coefficient (η) of the given liquid can be found.

Effect of Temperature on Viscosity

The viscosity of a liquid generally decreases with rise in temperature. This decrease is appreciable being about 2% per degree rise of temperature in many cases. This has been explained in terms of **Hole Theory** of liquids.

Hole Theory: According to this theory there are vacancies or holes in a liquid. The liquid molecules keep on moving continuously into these vacancies. As a consequence the vacancies also keep on moving around as otherwise the liquid will not be able to flow. This process however requires energy. A liquid molecule, therefore, needs some activation energy to move into a hole. As the activation energy becomes increasingly available at increasing temperatures, a liquid can flow more easily at higher temperatures. The coefficient of viscosity, thus, falls appreciably with rise in temperature.
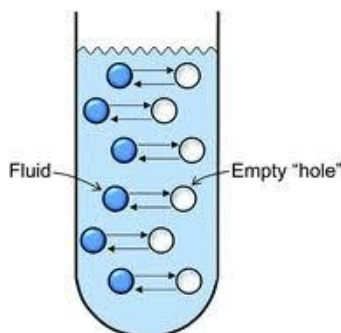
The variation of viscosity (η) with temperature can be expressed by the following relationship

$$\eta = Ae^{-Ea/RT} \quad ....(i)$$

where *A* and E_a are constants for a given liquid.

Taking logarithms on both sides, we get

$$\ln \eta = A + Ea/RT$$

$$\text{or } \ln \eta = E_a/R + 1/T + A ………(ii)$$

comparing equation (*ii*) with
$$y = mx + c \text{ (equation of straight line)}$$
A plot of log η versus 1/T should be a straight line (Fig. 8). It has been verified for a variety of liquids.

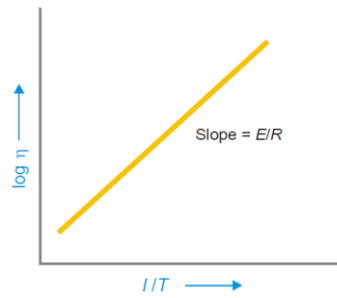**Fig. 8 Plot of log η versus 1/T.**

In contrast to liquid, η increases with increasing temperature in the case of gases.

Effect of Pressure: On increasing pressure viscosity of liquids increases. This is due to fact that decrease in the number of holes as the pressure increases.

Therefore it becomes more difficult for liquid molecules to move around and thus it becomes more difficult for them to flow.