UNIT 4: LIQUID STATE

Capillary Action

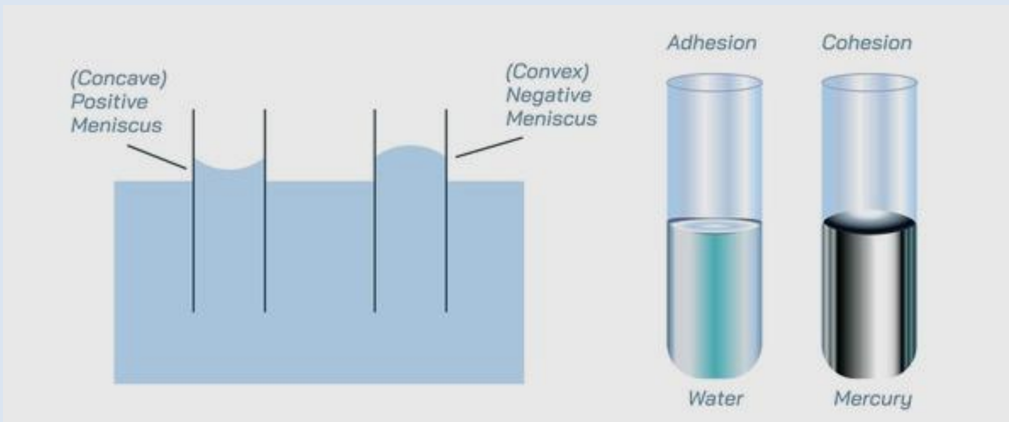
Cohesion: The attraction between the like molecules in liquid is known as cohesion.
Adhesion: The attraction between the liquid and walls of the capillary is known as adhesion.

Case A: if, adhesion > cohesion

The liquid is said to wet the wall. This is happen in case of water and many other liquids. The meniscus is concave.

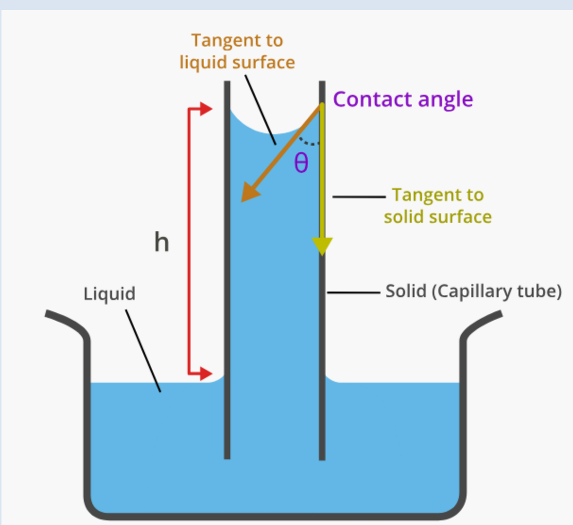
Case B: if, adhesion < cohesion

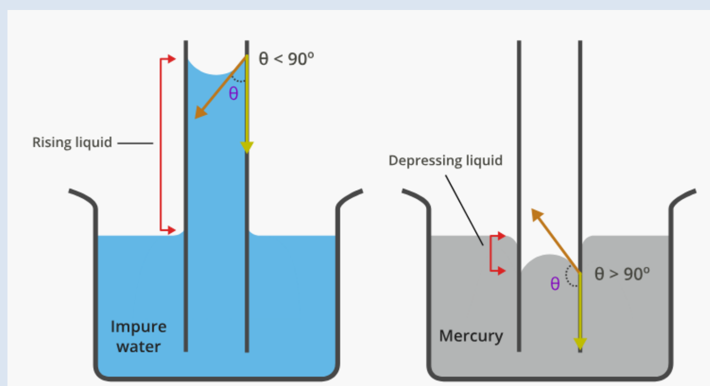
The liquid does not wet the wall. This is happening in case of mercury. The meniscus is convex.



Contact angle or Angle of contact (θ)

The angle between the tangent to the liquid surface at the point of contact and the solid surface inside the liquid is known as the contact angle (θ) for that liquid and solid surface.





θ < 90° = Rising liquids
Adhesion > cohesion
Positive meniscus

θ > 90° = Depressing liquids
Adhesion < cohesion
Negative meniscus

Methods of Surface Tension Measurements: The following methods are used for surface tension measurements.

1. **Capillary rise method**
2. **Stalagmometer method – (i) drop weight method (ii) drop number method**
3. **Torsion method by Tensiometer**

1. Capillary rise method

Let's suppose a liquid of density ρ, rises in a capillary of radius r through a height h.
The total force (F) due to surface tension raising the liquid upward
F= γCosθ x inner circumference of capillary

Where γ- surface tension of the liquid
θ-contact angle

$F = \gamma Cos\theta \times 2\pi r$………………………….. (1)

Force of gravity pulling the liquid downward = weight of the liquid column
$= mg$
$= v\rho g$ where v is the volume of the liquid
$= \pi r^2 h\rho g$ ………(2) $v = \pi r^2 h$

At equilibrium: $\gamma Cos\theta \times 2\pi r = \pi r^2 h\rho g$

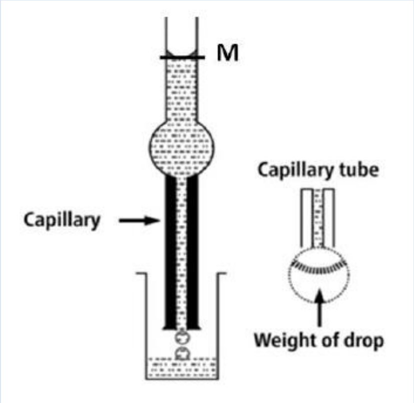
$\gamma Cos\theta \times 2 = rh\rho g$

$\boxed{\gamma = \frac{rh\rho g}{2Cos\theta}}$ …………….. ……….. (3)

If the contact angle, θ=0 then Cos θ=1 so eq (3) becomes $\gamma = \frac{rh\rho g}{2}$

2. Stalagmometer method – (i) drop weight method:

The stalagmometric method is one of the most common methods used for the surface tension determination. In this method the surface tension of unknown liquid is compared to a reference liquid of known surface tension (typically water). Liquid is filled up to the mark M and the number of falling drops counted of both liquids. The drop falls when its weight w just exceeds the force of surface tension.
A weighing tube is placed under stalagmometer and a certain number of drops (say 10) or certain volume of liquid is allowed to fall into it. If m_1 and m_2 are the masses of liquid 1 and 2 respectively then,



For 10 drops or certain volume of two liquids (one is water and other is unkown)

$w_1 = m_1 g = 2\pi r\gamma_1$ ….. (4) (for first liquid i.e. water)

$w_2 = m_2 g = 2\pi r\gamma_2$ ….(5) (for second unknown liquid)

Hence $\frac{w_1}{w_2} = \frac{\gamma_1}{\gamma_2}$ ……….(6)

If the surface tension of one liquid is known that of the other is readily calculated.

Stallagmometer method – (ii) drop number method:

Let n_1 and n_2 be the numbers of drops formed from the same volume V of the two liquids. Then,

Weight of one drop of the liquid 1 = $w_1 = \frac{V\rho_1 g}{n_1}$

Weight of one drop of the liquid 2 = $w_2 = \frac{V\rho_2 g}{n_2}$

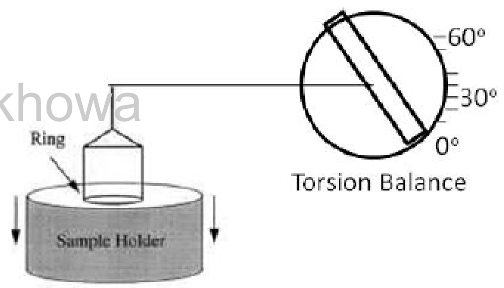
According to eq (6) $\frac{\gamma_1}{\gamma_2} = \frac{w_1}{w_2} = \frac{\frac{V\rho_1 g}{n_1}}{\frac{V\rho_2 g}{n_2}}$

$$\frac{\gamma_1}{\gamma_2} = \frac{n_2\rho_1}{n_1\rho_2} \text{ .... } (7)$$

If the surface tension of one liquid (water) is known that of the other can be easily calculated.

3. Torsion method by Tensiometer: A plate a platinum ring can be used, which is submerged in the liquid. The amount of torsion produced in the ring wires gives a measure of force that is used in detaching the ring from the surface of the liquid (the torsion is given by angle).

If the torsion angle is θ_1 for one liquid and θ_2 for the second liquid, then



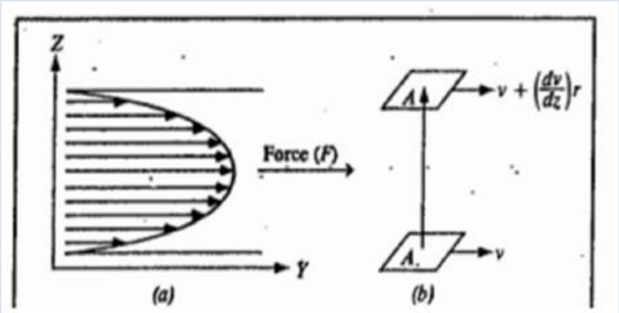
$\theta_1 \propto F_1 = 2x2\pi r\gamma_1$ and $\theta_2 \propto F_2 = 2x2\pi r\gamma_2$ (the surface tension multiplied by 2 because it acts on the two circumference of the ring i.e. inside and outside the ring)

Hence, $\frac{\theta 1}{\theta 2} = \frac{\gamma 1}{\gamma 2}$ Where γ_1 and γ_2 are surface tensions of two liquids. If surface tension of one of the liquid (standard) is known then that of the other can be easily calculated.

Viscosity

Viscosity may be defined as the force of friction between two layers of a liquid moving past one another with different velocities.

Consider the laminar flow of liquid in y direction. The layer in contact with the wall of the tube is stationary. However, the velocity of the successive layers increases as move away from the surface. If the distance between two layers is r and v is the velocity of slow moving layer. As a result velocity gradient is set up along z-direction.



The velocity profile during flow of a liquid in a glass tube.

If we want to maintain the velocity gradient, we must apply an external force along y-axis. This force (*F*) is proportional to common area of two layers (A) and velocity gradient.

$$F \,\alpha\, A\frac{dv}{dz}$$

$$F = -\,\eta A\frac{dv}{dz}$$

Where the proportionality constant η is coefficient of viscosity, $\frac{dv}{dz}$ is velocity gradient. The **minus sign** shows that the viscous force on faster layer is in opposite direction to its motion. The reciprocal of viscosity is called **fluidity**. It is denoted by φ = 1/η

Coefficient of viscosity (η): If A = 1 cm^2, dv = 1 cm/s, dz =1 cm, then **F = η,** Coefficient of viscosity of a fluid is defined as the tangential force per unit area which is required to maintain a unit velocity gradient between its layers.

Unit: The SI unit of viscosity is the pascal-second (Pa s), or equivalently kilogram per meter per second (kg m^{-1} s^{-1}). The CGS unit is the poise (P, or g $cm^{-1}s^{-1}$ = 0.1 Pa s).

Effect of Temperature on Viscosity of Liquid:

The relationship between the coefficient of viscosity and temperature is expressed as:

$$\eta = Ae^{Ea/RT}$$

Where A is constant. Ea is called the activation energy for viscous flow. From the equation it is clear that the viscosity decreases with increase of temperature. Viscosity in liquid is mainly due to the cohesive force (inter molecular force of attraction). Increase in the temperature reduces the cohesive forces between the molecules of liquid and hence the viscosity decreases.

In contrast to liquid the viscosity of gases increases with increasing temperature.

Determination of Viscosity by Ostwald Viscometer: This method is based on Poiseuille's law. The rate of flow of a liquid through a capillary tube with the coefficient of viscosity of the liquid is expressed by the equation:

$\eta = (\pi r^4 tP)/8Vl$ ....*(1)*

Where V is the volume in ml of the liquid flowing in t seconds through a narrow tube of radius r cm and length l cm under hydrostatic pressure P dynes per square centimeter and η is coefficient of viscosity in poises.

since, $P = h\rho g$ ----*(2)*

Then equation (1) becomes:

$\eta = (\pi r^4 t h\rho g)/8Vl$ ....*(3)*

The fixed volume of liquid is filled in bulb A and sucked and then allowed to flow between the mark C and D.

For liquid 1: $\eta_1 = (\pi r^4 t_1 h\rho_1 g)/8Vl$ -----*(4)*

For liquid 2: $\eta_2 = (\pi r^4 t_2 h\rho_2 g)/8Vl$ -----*(5)*

The value of h is same in both cases since equal volume of both liquids are taken.

OSTWLAD VISCOMETER:- I

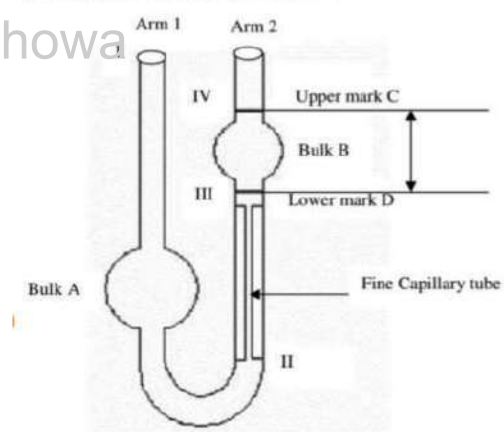


Fig. 1:- Ostwald Viscometer

Hence,

$$\frac{\eta_1}{\eta_2} = \frac{\rho_1 t_1}{\rho_2 t_2}$$

Liquid 1 taken as water, by knowing the *coefficient of viscosity of water (η_1) that of other liquid (η_2), can easily be calculated.*

Question: Benzene takes 46 s to flow through an viscometer while water takes 68 s, at the same temperature. The respective densities are 0.8 and 0.998 g/cm^3. Coefficient of viscosity of water is 1.008 centipoise. Calculate coefficient of viscosity of benzene.

Answer: Let η_1, η_2 coefficient of viscosity of benzene and water, respectively

$$\frac{\eta_1}{\eta_2} = \frac{\rho_1 t_1}{\rho_2 t_2} \text{ or, } \eta_1 = \frac{\eta_2 \rho_1 t_1}{\rho_2 t_2} = \frac{(1.008 \; x \; 10^{-2} dynecm^{-2} s)(0.8 gcm^{-3})(46s)}{(0.998 \; gcm^{-3})(68s)}$$

= 0.0065 dynecm^{-2}s = 0.0065 poise = 0.65 centipoise