Measurement of surface tension of a liquid by capillary rise method

Objective:

To determine of the surface tension of a liquid by capillary rise method

Apparatus:

(i) Capillary tubes of different radii, (ii) Experimental liquid (water/soap solution/salt solution), (iii) Beaker, (iv) Travelling microscope, (v) Glass plate to fix the tubes, (vi) A needle, (vii) Laboratory Jack/support base to keep the beaker, (viii) Support stands and clamps.

Theory:

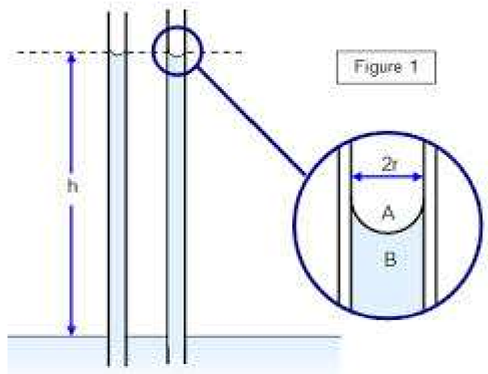
A molecule well within a liquid is surrounded by other molecules on all sides. The surrounding molecules attract the central molecule equally in all directions, leading to a zero net force. In contrast, the resulting force acting on a molecule at the boundary layer on the surface of the liquid is not zero, but points into the liquid. This net attractive force causes the liquid surface to contract toward the interior until the repulsive collisional forces from the other molecules halt the contraction at the point when the surface area is a minimum. If the liquid is not acted upon by external forces, a liquid sample forms a sphere, which has the minimum surface area for a given volume. Nearly spherical drops of water are a familiar sight, for example, when the external forces are negligible.

The surface tension γ is defined as the magnitude F of the force exerted tangential to the surface of a liquid per unit length over which the force acts in order to maintain the liquid film.

$$\gamma = F/l \qquad (1)$$

In this experiment we will determine the surface tension of water by capillary rise method. Capillarity is the combined effect of cohesive and adhesive forces that cause liquids to rise in tubes of very small diameter. In the case of water in a capillary tube, the adhesive force draws it up along the sides of the glass tube to form a meniscus. The cohesive force also acts at the same time to minimize the distance between the water molecules by pulling the bottom of the meniscus up against the force of gravity.

Consider the situation depicted in Fig. 1, in which the end of a capillary tube of radius, r, is immersed in a liquid of density $\boldsymbol{\rho}$. For sufficiently small capillaries, one observes a substantial rise of liquid to height, h, in the capillary, because of the force exerted on the liquid due to surface tension. Equilibrium occurs when the force of gravity on the volume of liquid balances the force due to surface tension. The balance point can be used to measure the surface tension.



Thus, at equilibrium the orce of gravity is given as,

$$\boldsymbol{F_g = \rho h(\pi r^2) g} \qquad \textbf{(2)}$$

where $\boldsymbol{g}$ is the acceleration due to gravity.

Force due to surface tension (see Fig. 2) is along the perimeter of the liquid. Let θ be the angle of contact of the liquid on glass. The vertical component of the force (upward) at equilibrium is given as

$$\boldsymbol{F = \gamma \times 2\pi r \times \cos\theta} \quad \textbf{(3)}$$

Assuming θ to be very small and neglecting the curvature of the liquid surface at the boundary, one can obtain surface tension by equating Eqs. 2 and 3 as follows:

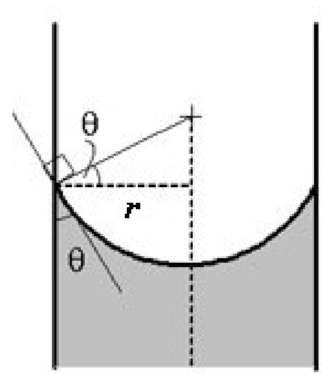


Fig 2

$$\boldsymbol{\gamma = \frac{1}{2}\rho g r h} \quad \textbf{(4)}$$

It should also be noted that surface tension of a liquid depends very markedly upon the presence of impurities in the liquid and upon temperature. The SI unit for surface tension is N/m.

Procedure:

1. Fix the supplied capillary tubes on the glass plate parallel to each other (see Fig. 3). The lower ends of the tubes, which are to be immersed in water, should be nearly at the same level. Fix the needle at about 1 cm away from the capillary tubes.
2. Clamp the glass plate to the support stand and check that the tubes remain perfectly vertical.
3. Keep the beaker filled with water on the support base. Bring the clamp stand near the beaker. Let the tubes immerse in water. Adjust the needle such that the lower tip just touches the water surface.

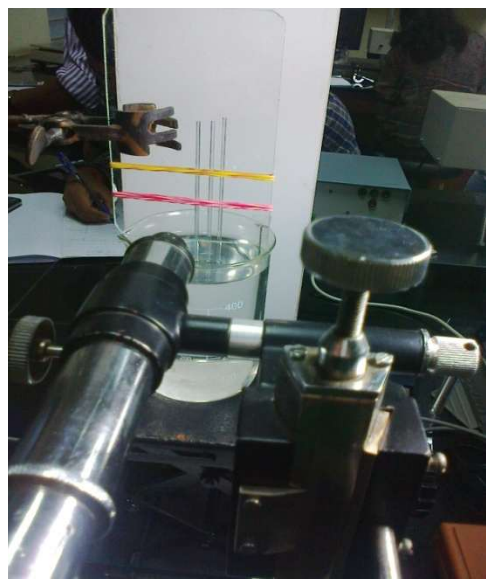


Fig 3. Experiment setup

4. Determine the vernier constant of the travelling microscope to be used.
5. Focus the travelling microscope so that you can see the inverted (convex) meniscus of water. Adjust the horizontal crosswire to be tangential to the convex liquid surface. Note down the readings (say R_1) on the vertical scale.
6. Turn the microscope screws in the horizontal direction to view the next capillary tube and follow the above step to note the position of the liquid surface.
7. After noting the positions of the liquid surface for all the tubes, move the microscope further horizontally and focus on the needle. Now move the microscope vertically and let the lower tip of the needle be focused at the point of intersection of the two cross wires. Note down the readings on the vertical scale (say R).
8. Thus the height of the liquid can be calculated from the difference of the two readings noted above, e.g. (R_1-R).
9. Now to find the radius of the tube, lower the height of the support base and remove the beaker. Carefully rotate the glass plate with the tubes so that the immersed lower ends face towards you.
10. Focus one of the tubes using the travelling microscope to clearly see the inner walls of the tube. Let the vertical crosswire coincide with the left side inner wall of the tube. Note down the reading (say L_1). Turn the microscope screws in the horizontal direction to view the right side inner wall of the tube. Note down the reading (say R_1). Thus the radius of the tube can be calculated as ½(L_1~R_1).
11. Turn the microscope screws in the horizontal direction to view the next capillary tubes and follow the above step to find the radius of each tube.
12. Finally calculate the surface tension and estimate the error in your experiment. Report the result at the noted room temperature.

Observations:

Table# 1

Vernier Constant (v.c.) of the microscope

….. Divisions (say m) of the vernier scale = ………… divisions (say n) of the main scale.

Value of 1 smallest main scale division (l_1)	Value of 1 vernier division ($l_2 = \frac{n}{m} l_1$) (cm)	Vernier constant v.c. = $(l_1 - l_2)$ (cm)
…………	………………	…………………..

Vernier constant (least count) of travelling microscope = ……..

Table # 2: Height of the liquid, *h*

Tube #	Microscope reading for the position of lower meniscus of liquid			Microscope reading for the position of lower tip of the needle			Height of the liquid ***h***
	Main scale reading	Vernier scale reading	Total reading	Main scale reading	Vernier scale reading	Total reading	
1							
2							
3							

Table # 3: radii of the capillary tubes, *r*

Tube #	Microscope reading for the position of inner left wall of the tube			Microscope reading for the position of inner right wall of the tube			Radius of the capillary tube ***r***
	Main scale reading	Vernier scale reading	Total reading	Main scale reading	Vernier scale reading	Total reading	
1							
2							
3							

Table # 4: Surface tension of the liquid, *γ*

Tube #	Height of the liquid ***h***	Radius of the capillary tube ***r***	Surface tension of the liquid, ***γ***	Mean ***γ***
1				
2				
3				

Estimation of error:

Precautions:

(i) Capillary tubes should be perfectly vertical and fixed parallel to each other.
(ii) Presence of impurities in the liquid or the immersed tubes can alter the surface tension. So cleanliness is desired.
(iii) Avoid bubbles in the liquid column.
(iv) Handle the glassware with extreme care.
(v) There should not be too much fluctuation of surrounding the temperature.