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General Properties of Matter Lab
PH29001

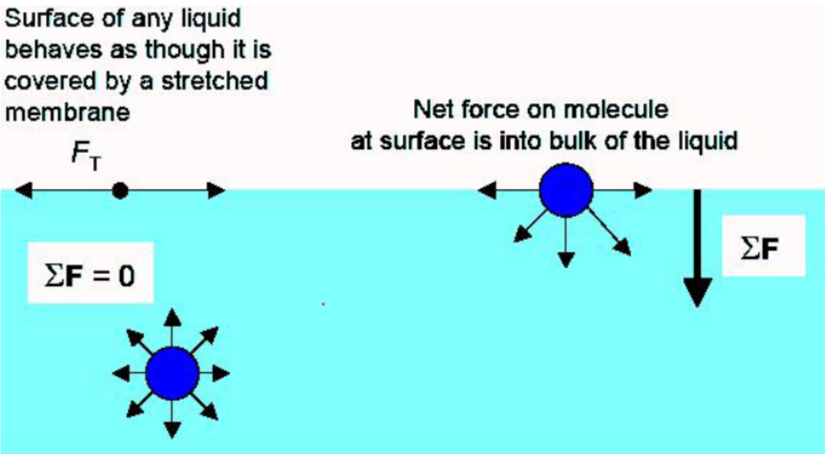
EXPERIMENT-5
Measurement of surface tension of a liquid by capillary rise method

Aim: To determine the surface tension of a liquid by the 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 divided by the length l of the line over which the force acts in order to maintain the liquid film.

$$\gamma = F/l \qquad \text{... (1)}$$



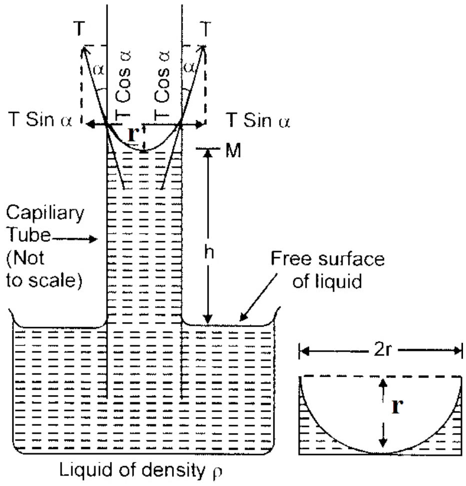
In this experiment, we will determine the surface tension of water by the capillary rise method. Capillarity is the combined effect of cohesive and adhesive forces that cause liquids to rise in tubes of very small diameters. In the case of water in a capillary tube, the adhesive force draws it up along 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 ρ. 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.
At equilibrium force of gravity is given as:

$$F_g = \rho g\left[(h+r)\pi r^2 - \frac{4}{3}\frac{\pi r^3}{2}\right] = \pi r^2 \left(h+\frac{r}{3}\right)\rho g, \quad \ldots \quad \textbf{(2)},$$

where g is the acceleration due to gravity.



(a) **Fig 1** (b)

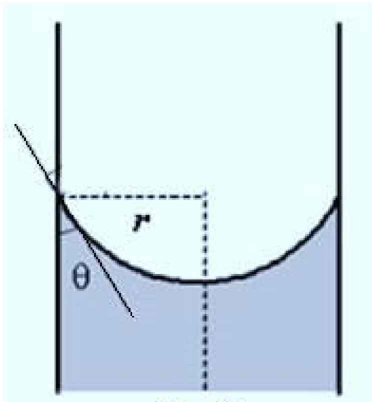


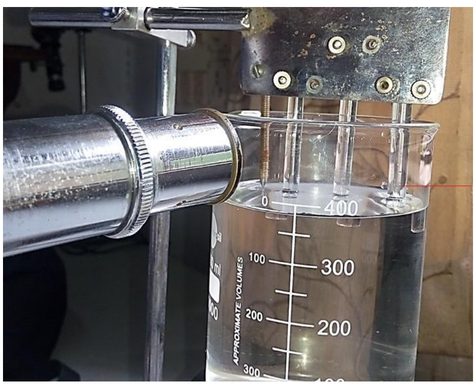
Fig. 2

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-

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

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

$$\gamma \times 2\pi R \times \cos\theta = \pi r^2 \left(h+\frac{r}{3}\right)\rho g \longrightarrow \gamma = \frac{\rho g r\left(h+\frac{r}{3}\right)}{2\cos\theta} \approx \frac{\rho g r\left(h+\frac{r}{3}\right)}{2} \quad \ldots \textbf{(4)}$$



Observations:

Vernier constant of travelling microscope = 0.001 cm and temperature of the laboratory while taking the measuring the values of the parameters = 35°C.

Table-1-

For radii (r) of the capillary tube

Tube	Microscope reading for the position of the inner left wall of the tube (R_1)				Microscope reading for the position of the inner right wall of the tube (R_2)				Radius of tube (cm) r = $\frac{(R_1 - R_2)}{2}$
	Main scale reading (cm)	Vernier scale reading	Total reading(cm)	Average Reading of R_1 (cm)	Main scale reading (cm)	Vernier scale reading	Total reading (cm)	Average Reading of R_2 (cm)	
1	0.85	3	0.853	0.856	0.6	30	0.630	0.634	0.111
	0.85	7	0.857		0.6	35	0.635		
	0.85	10	0.860		0.6	36	0.636		
2	0.60	1	0.601	0.602	0.4	35	0.435	0.435	0.0835
	0.60	5	0.605		0.4	38	0.438		
	0.60	0	0.600		0.4	32	0.432		
3	0.50	16	0.516	0.519	0.3	47	0.347	0.346	0.0865
	0.50	20	0.520		0.3	43	0.343		
	0.50	22	0.522		0.3	49	0.349		

Table-2-

For the height of the liquid column

Tube	Microscope reading for the position of the lower meniscus of liquid (H)				Microscope reading for the position of the lower tip of the needle (H_0)				Height of liquid column (cm) $h = H-H_0$
	Main scale reading (cm)	Vernier scale reading	Total reading (cm)	Average Reading of H (cm)	Main scale reading (cm)	Vernier scale reading	Total reading (cm)	Average reading H_0 (cm)	
1	9.65	17	9.667	9.666	8.25	17	8.267	8.265	1.401
	9.65	20	9.67		8.25	15	8.265		
	9.65	11	9.661		8.25	12	8.262		
2	10.30	6	10.306	10.306	8.25	17	8.267	8.265	2.042
	10.30	2	10.302		8.25	15	8.265		
	10.30	9	10.309		8.25	12	8.262		
3	9.70	1	9.701	9.702	8.25	17	8.267	8.265	1.438
	9.70	3	9.703		8.25	15	8.265		
	9.70	2	9.702		8.25	12	8.262		

Table-3-

Surface tension of the liquid, γ at the temperature 35°C

The surface tension of the liquid γ can be calculated using the formula given below-

$$\gamma = \frac{\rho g r\left(h+\frac{r}{3}\right)}{2\cos\theta} \approx \frac{\rho g r\left(h+\frac{r}{3}\right)}{2}$$

Tube	Height of the liquid column, h (cm)	The radius of the capillary tube, r (cm)	Surface tension of the liquid, γ $(dyne/cm)$	Mean γ $(dyne/cm)$
1	1.401	0.111	78.3	74.7
2	2.042	0.083	84.7	
3	1.438	0.086	62.2	

Error Analysis-

$$\gamma = \frac{\rho g r\left(h+\frac{r}{3}\right)}{2\cos\theta} \approx \frac{\rho g r\left(h+\frac{r}{3}\right)}{2}$$

Let $k = \frac{\rho g}{2}$ = constant, then $\gamma = \frac{\rho g r(h+\frac{r}{3})}{2}$

By the Multiplication/Division Rule: Relative errors of each parameter will be added.

$$\frac{\delta\gamma}{\gamma} = \frac{\delta r}{r} + \frac{\delta(h+\frac{r}{3})}{h+\frac{r}{3}}$$

By summation/subtraction rule, absolute errors of each parameter will be added -

$$\delta(h + \frac{r}{3}) = \delta h + \frac{\delta r}{3}$$

$$\frac{\delta\gamma}{\gamma} = \frac{\delta r}{r} + \frac{\delta h + \frac{\delta r}{3}}{h+\frac{r}{3}}$$

For tube-1, $r = 0.111cm,\ h = 1.401cm, \delta h = 0.001cm\ and\ \delta r = 0.001cm$ −

$$\frac{\delta\gamma}{\gamma} = \frac{0.001}{0.111} + \frac{0.001+\frac{0.001}{3}}{1.401+\frac{0.111}{3}} = 0.01$$

$$\frac{\delta\gamma}{\gamma} \times 100 = 1\%$$

$\delta\gamma = 0.01 \times 74.7 = 0.747 \approx 0.75\ (dyne/cm)$

Therefore, for tube-1, the maximum percentage error in the surface tension is 1%.

For tube-2, $r = 0.084cm,\ h = 2.042cm, \delta h = 0.001cm\ and\ \delta r = 0.001cm$ −

$$\frac{\delta\gamma}{\gamma} = \frac{0.001}{0.084} + \frac{0.001+\frac{0.001}{3}}{2.042+\frac{0.084}{3}} = 0.01269 \approx 0.013$$

$$\frac{\delta\gamma}{\gamma} \times 100 = 1.3\%$$

$\delta\gamma = 0.013 \times 74.7 = 0.9711 \approx 0.97(dyne/cm)$

Therefore, for tube-2, the maximum percentage error in the surface tension is 1.3%.

For tube-3, $r = 0.087cm,\ h = 1.438cm, \delta h = 0.001cm\ and\ \delta r = 0.001cm$ −

$$\frac{\delta\gamma}{\gamma} = \frac{0.001}{0.087} + \frac{0.001 + \frac{0.001}{3}}{1.438 + \frac{0.087}{3}} = 0.01253 \approx 0.013$$

$$\frac{\delta\gamma}{\gamma} \times 100 = 1.3\%$$

$$\delta\gamma = 0.01 \times 74.7 = 0.9711 \approx 0.97(dyne/cm)$$

Therefore, for tube-3, the maximum percentage error in the surface tension is 1.3%.

Result-

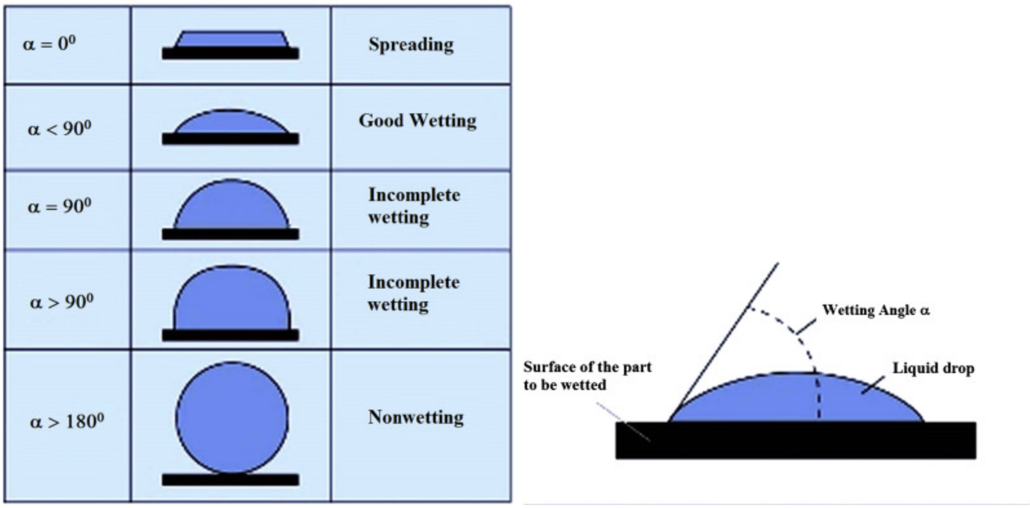
1. The value of γ for water at 35°C = 74.7 $(dyne/cm)$.
2. For tube-1, the maximum percentage error in the surface tension is 1%.
3. For tube-2, the maximum percentage error in the surface tension is 1.3%.
4. For tube-3, the maximum percentage error in the surface tension is 1.3%.

Precautions-

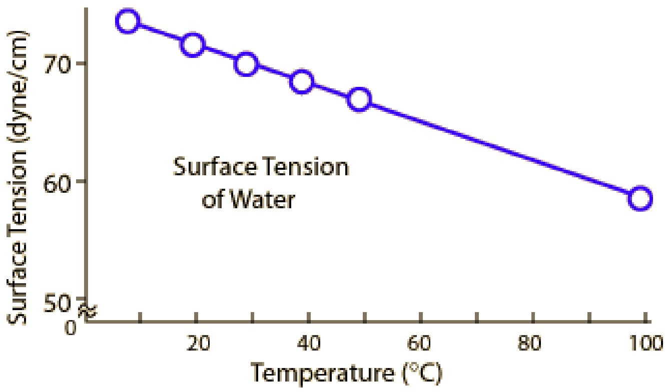
1. Capillary tubes should be perfectly vertical and fixed parallel to each other.
2. The temperature of the laboratory must be noted as the value of surface tension is very sensitive to the temperature.
3. The presence of impurities in the liquid or the immersed tubes can alter the surface
4. Tension, hence cleanliness is desired.
5. Bubbles should be avoided in the liquid column.
6. The glassware must be handled with extreme care.
7. There should not be too much fluctuation of the surrounding temperature.
8. To reduce statistical error in measurements, at least 3-5 readings must be taken.
9. Zero error must be noted in the measuring instruments.
10. Parallax and back-lash errors during measurement must be avoided.
11. A magnifying glass can be used to avoid errors while noting the readings from the travelling microscope.

Discussions-

1. The contact angle is a measure of the ability of a liquid to wet the surface of a solid.
2. The shape that a drop takes on a surface depends on the surface tension of the fluid and the nature of the surface. At the boundary between droplets and the gaseous environment, the surface tension causes a curved contour.



3. Surface tension is the tendency of liquid surfaces at rest to shrink into the minimum surface area possible. It allows objects with a higher density than water such as razor blades and insects to float on a water surface without becoming even partly submerged.
4. Surface tension could be defined as the property of the surface of a liquid that allows it to resist an external force, due to the cohesive nature of the water molecules.
5. Surface tension has a strong dependence on temperature. Hence, it's a good pratice to note down the temperature of the laboratory where the experiment is being performed. Throughout this experiment, it has been assumed that the temperature of the laboratory is same as that of the liquid used in the experiment.
6. Surface tension decreases when temperature increases because cohesive forces decrease with an increase of molecular thermal activity.



7. At significant temperature Surface tension: Zero. Surface tension increases with contamination.