Experiment - 6 : Determine surface tension by capillary rise method and effect of detergents.

Theory

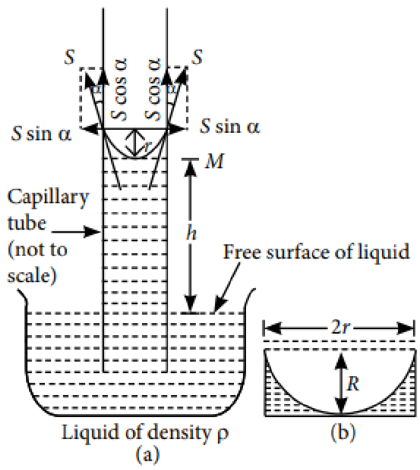
Let a capillary tube be inserted in a liquid of density ρ and surface tension S, partially as shown. It is found that liquid rises up into the tube to a height h above the free surface of the liquid. The surface tension acts tangentially to the meniscus. The vertical component of the surface tension is S cos α where α is the angle of contact. Hence the total force acting vertically upwards is (2πr) × (S cos α) where r is the internal radius of the capillary.

This force holds the weight of the liquid column in the capillary. Now the weight of the liquid column can be calculated in two parts. The vertical column of liquid of height h, excluding the meniscus = (πr 2 h)ρg.

The volume of the meniscus as shown in Fig.(b) can be thought of as cylinder minus hemisphere. (This is true if r is small).

$$\text{Hence its weight} = (\pi r^2 \times r) - \frac{1}{2}\left(\frac{4}{3}\pi r^3\right)$$

$$= \pi r^3 - \frac{2}{3}\pi r^3 = \frac{\pi r^3}{3}$$



$$\Rightarrow \text{Weight of meniscus} = \left(\frac{\pi r^3}{3}\right)\rho g$$

Thus for equilibrium, (2πr)(S cos α)

$$= \pi r^2 h\rho g + \frac{\pi r^3}{3}\rho g$$

$$\Rightarrow S = \frac{r\left(h+\frac{r}{3}\right)\rho g}{2\cos\alpha}$$

For water, α is very small, so cos α ≈ 1, so

$$S = \frac{r\left(h+\frac{r}{3}\right)\rho \cdot g}{2}$$

The height of the meniscus in the liquid column and internal diameter of the capillary are measured using a travelling microscope. The rise in capillary tube decreases with addition of detergent in pure water. With more addition of detergent, rise becomes lesser and lesser. The detergent reduces the surface tension of water.

MCQs Corner

Experiment – 6

26. By how much depth will the surface of a liquid be depressed in a glass tube of radius 0.2 mm if the angle of contact of the liquid is 135° and the surface tension is 0.547 N m^{-1} ? (Density of the liquid is 13.5×10^3 kg m^{-3}).

(a) 2 cm (b) 3 cm (c) 4 cm (d) 5 cm

27. To what height can mercury be filled in a vessel without any leakage if there is a pin hole of diameter 0.1 mm at the bottom of the vessel. (Density of mercury $= 13.6 \times 10^3$ kg m^{-3}, surface tension of mercury $= 550 \times 10^{-3}$ N m^{-1}, Angle of contact with the vessel for mercury = 0°).

(a) 12.5 cm (b) 16.5 cm (c) 18.5 cm (d) 20 cm

28. The amount of energy evolved when eight droplets of mercury (surface tension 0.55 N m^{-1}) of radius 1 mm each combine into one drop, is

(a) 16 μJ (b) 18 μJ (c) 24 μJ (d) 28 μJ

Answer Key

26. (b) 27. (b) 28. (d)

Hints & Explanation

26. **(b) :** $h = \dfrac{2S\cos\theta}{\rho \cdot g \cdot r} = \dfrac{2(0.547)\cos 135^\circ}{(13.5\times10^3)(9.8)(0.2\times10^{-3})}$

$= -0.029$ m $= -2.9$ cm $= -3$ cm

27. **(b) :** Mercury will start leaking when, $\rho g h = \dfrac{2S}{r}$

$h_{min} = \dfrac{2S}{\rho g r} = \dfrac{4S}{\rho \cdot g \cdot d} = \dfrac{4(550\times10^{-3})}{(13.6\times10^3)(9.8)(0.1\times10^{-3})}$

$= 0.165$ m $= 16.5$ cm.

28. **(d) :** Area of 8 droplets $= 8(4\pi r^2) = 32\pi r^2$

When drops combine, volume remains constant.

$\Rightarrow \quad \dfrac{4}{3}\pi R^3 = 8 \times \dfrac{4}{3}\pi r^3$ or $R = 2r$

Area of big drop $= 4\pi(2r)^2 = 16\pi r^2$

Loss of surface area $= 32\pi r^2 - 16\pi r^2 = 16\pi r^2$

$\Rightarrow$ Loss of energy or energy evolved $= (16\pi r^2)S$

$= 16\pi(10^{-3}\text{ m})^2 \cdot (0.55\text{ N m}^{-1}) = 27.6\ \mu\text{J} = 28\ \mu\text{J}$.