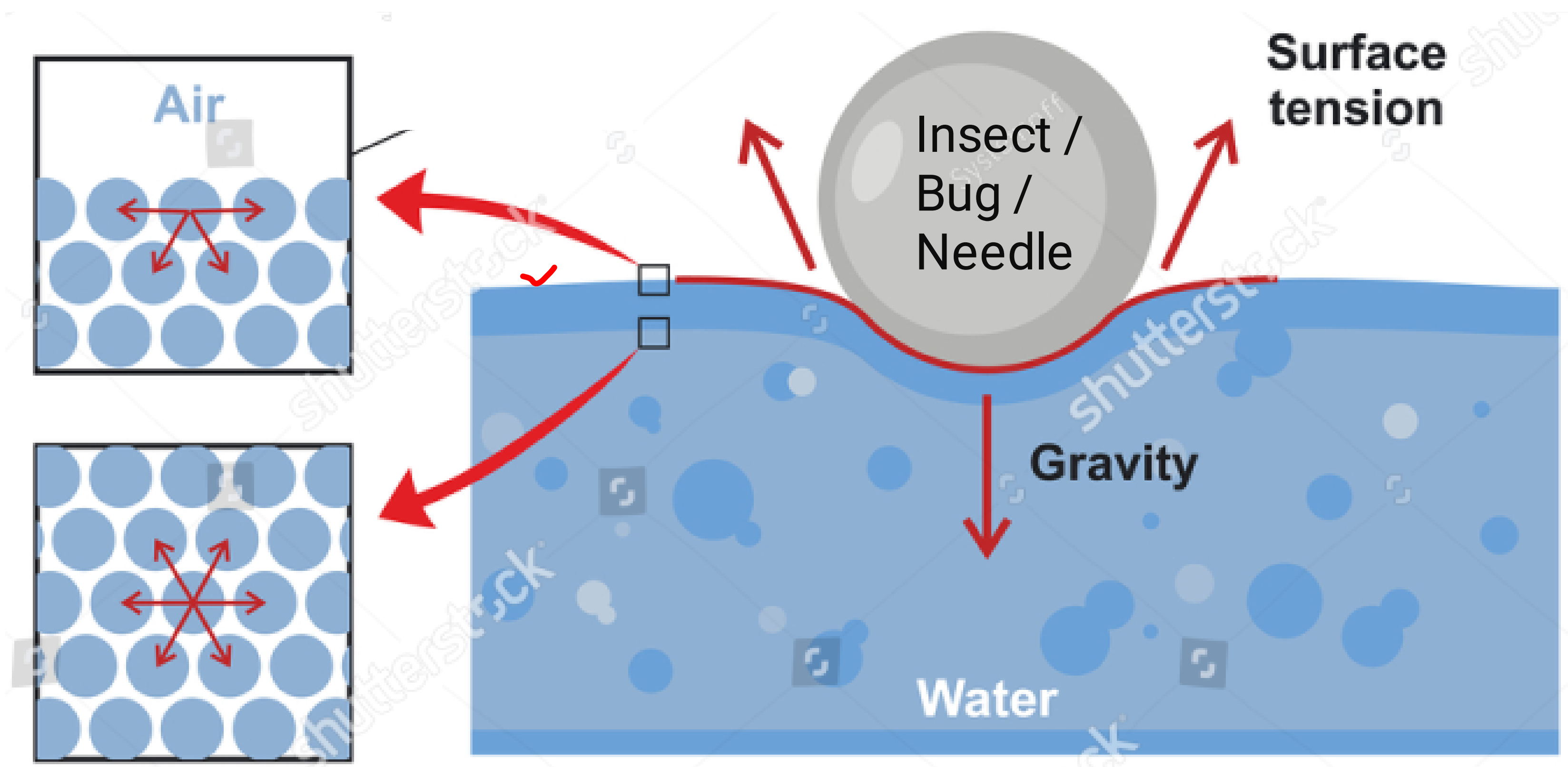
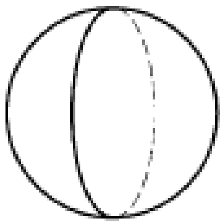
Surface Tension of Liquids

The phenomenon of surface tension arises due to the two kinds of intermolecular forces

➢**Cohesion :** Force of attraction between like molecules, i.e molecules of same liquid

➢**Adhesion :** The force of attraction between unlike molecules, i.e. between the molecules of different liquids (or) between the molecules of a liquid and those of a solid body when they are in contact with each other.





(a) DROPLET

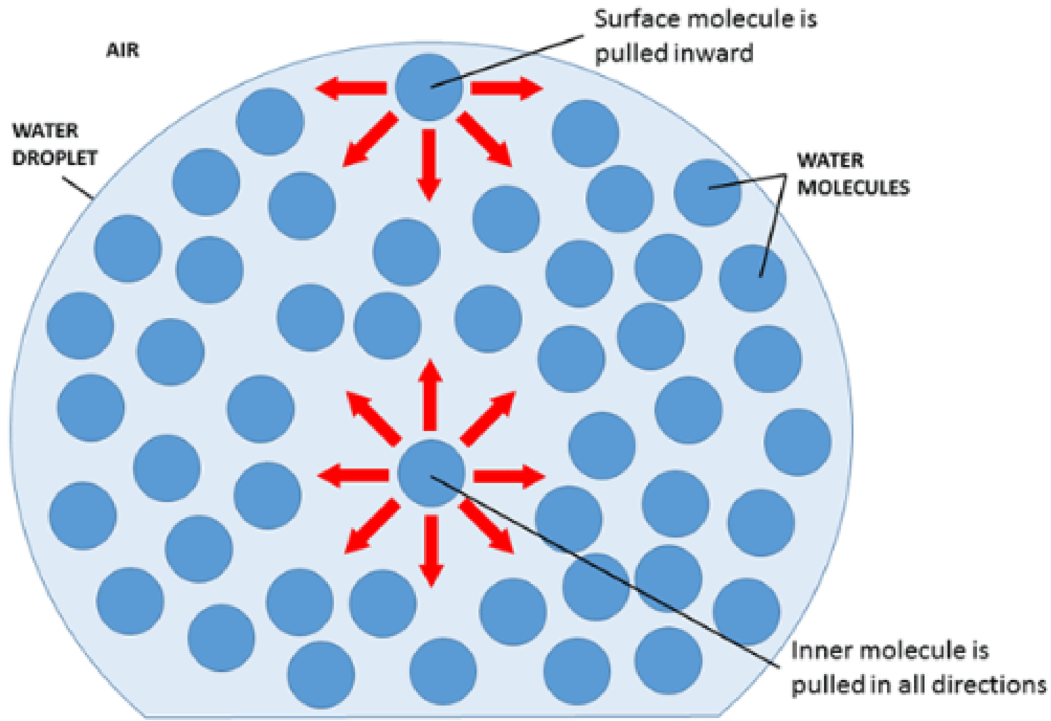
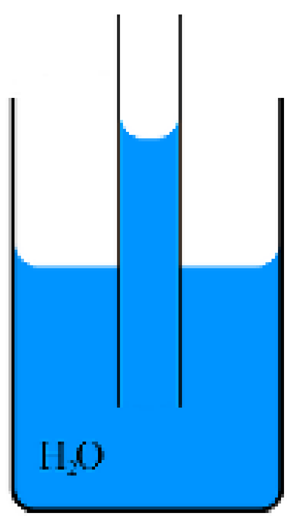


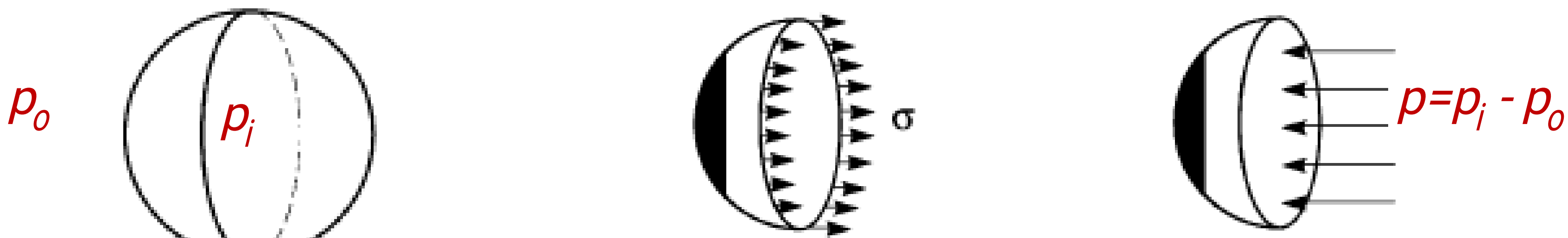
Diagram not to scale

Capillarity



Surface tension on liquid droplet

p is the Excess pressure



(a) DROPLET b) SURFACE TENSION (c) PRESSURE FORCES

Pressure force on droplet cross section area = Force due to Surface tension over droplet circumference

$$p \times \frac{\pi}{4} d^2 = \sigma \times \pi d$$

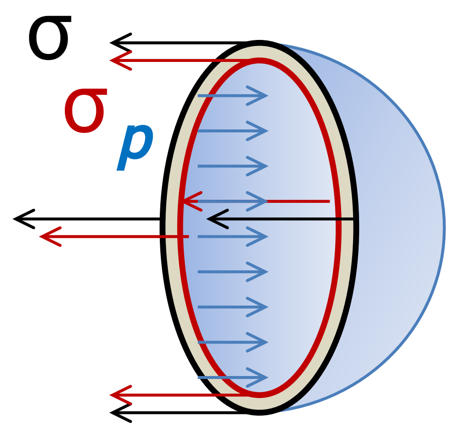
$$p = \frac{\sigma \times \pi d}{\frac{\pi}{4} \times d^2} = \frac{4\sigma}{d}$$

Surface tension on hollow bubble

Soap bubble in air has two contact surfaces, one inside and one outside

$$p \times \frac{\pi}{4} d^2 = 2 \times (\sigma \times \pi d)$$

$$p = \frac{2\sigma\pi d}{\frac{\pi}{4} d^2} = \frac{8\sigma}{d}$$

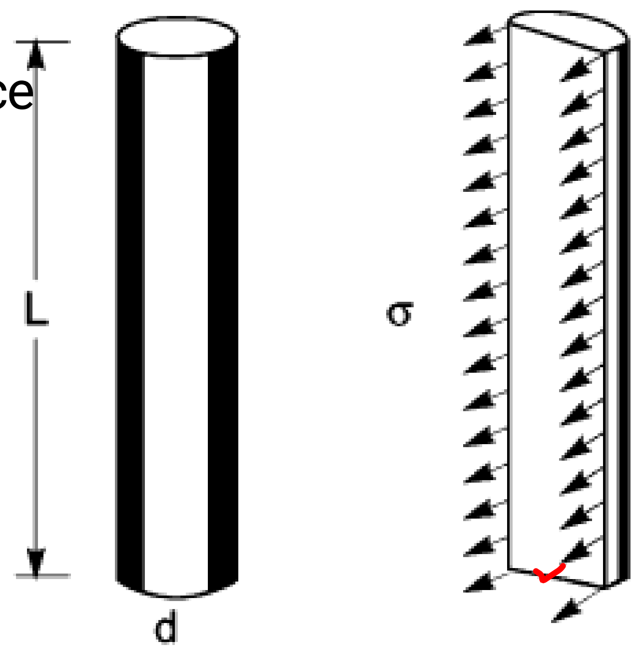


Surface tension on a liquid jet

Pressure force on cut section = surface tension force

$$p \times L \times d = \sigma \times 2L$$

$$p = \frac{\sigma \times 2L}{L \times d}$$



Problem 1:

The surface tension of water in contact with air at 20 deg. C is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm^2 greater than the outside pressure. Calculate the diameter of the droplet of water.

Solution. Given :

Surface tension, $\sigma = 0.0725$ N/m

Pressure intensity, p in excess of outside pressure is

$$p = 0.02 \text{ N/cm}^2 = 0.02 \times 10^4 \frac{\text{N}}{\text{m}^2}$$

Let d = dia. of the droplet

we get $p = \dfrac{4\sigma}{d}$ or $0.02 \times 10^4 = \dfrac{4 \times 0.0725}{d}$

$$d = \frac{4 \times 0.0725}{0.02 \times (10)^4} = .00145 \text{ m} = .00145 \times 1000 = \mathbf{1.45\ mm.\ Ans.}$$

Problem 2:

Find the surface tension in a soap bubble of 40 mm diameter when the inside pressure is 2.5 N/m^2 above the atmospheric pressure

Solution. Given :

Dia. of bubble, $d = 40 \text{ mm} = 40 \times 10^{-3} \text{ m}$

Pressure in excess of outside, $p = 2.5 \text{ N/m}^2$

For a soap bubble, using equation (1.15), we get

$$p = \frac{8\sigma}{d} \quad \text{or} \quad 2.5 = \frac{8 \times \sigma}{40 \times 10^{-3}}$$

$$\sigma = \frac{2.5 \times 40 \times 10^{-3}}{8} \text{ N/m} = \mathbf{0.0125 \text{ N/m. Ans.}}$$

Problem 3:

The pressure outside the droplet of water of diameter 0.04mm is 10.23N/cm^2. Calculate the pressure within the droplet if surface tension is given as 0.0725 N/m of water.

Solution. Given :

Dia. of droplet, $d = 0.04 \text{ mm} = .04 \times 10^{-3} \text{ m}$

Pressure outside the droplet $= 10.32 \text{ N/cm}^2 = 10.32 \times 10^4 \text{ N/m}^2$

Surface tension, $\sigma = 0.0725 \text{ N/m}$

The pressure inside the droplet, in excess of outside pressure is given by equation (1.14)

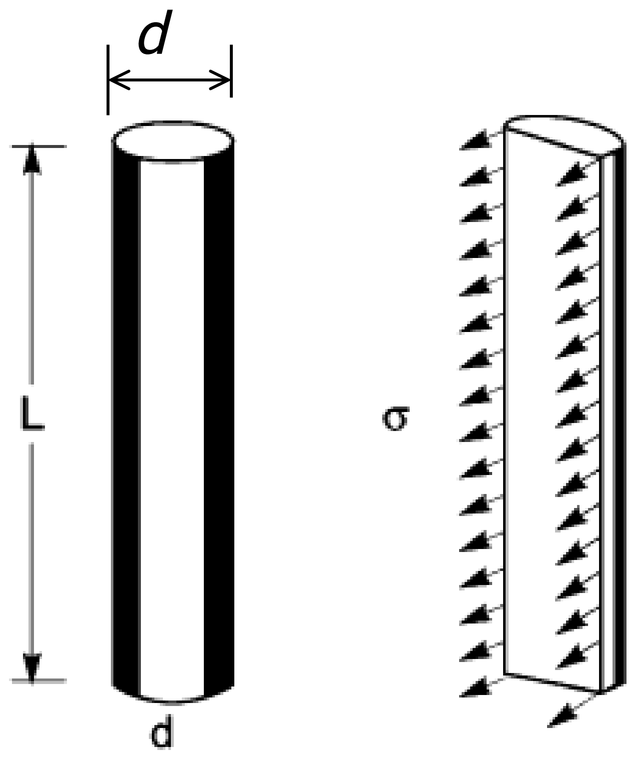
or
$$p = \frac{4\sigma}{d} = \frac{4 \times 0.0725}{.04 \times 10^{-3}} = 7250 \text{ N/m}^2 = \frac{7250 \text{ N}}{10^4 \text{ cm}^2} = 0.725 \text{ N/cm}^2$$

$\therefore$ Pressure inside the droplet $= p +$ Pressure outside the droplet

$= 0.725 + 10.32 = \mathbf{11.045\ N/cm^2}$. **Ans.**

Problem 4:

A 12-mm diameter jet of water discharges vertically into the atmosphere. Due to surface tension the pressure inside the jet will be slightly higher than the surrounding atmospheric pressure. Determine this difference in pressure. Surface tension of water-air interface is 7.34×10^{-2} N/m.



$$p(Ld) = \sigma(2L)$$

$$p = \frac{2\sigma}{d}$$

$\sigma = 7.34 \times 10^{-2}$ N/m

$d = 0.012$ m

$$p = p_i - p_0 = 12.2\,\text{Pa}$$

Capillarity

- Defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is dipped and held vertically in a liquid.

- The interplay of the forces of cohesion and adhesion explains the phenomenon of capillarity

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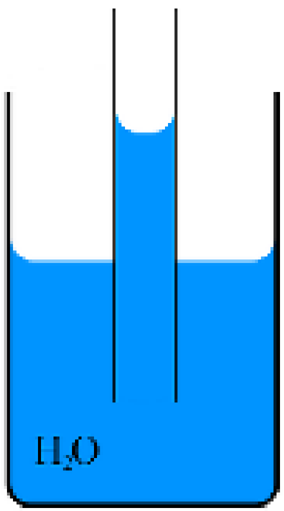
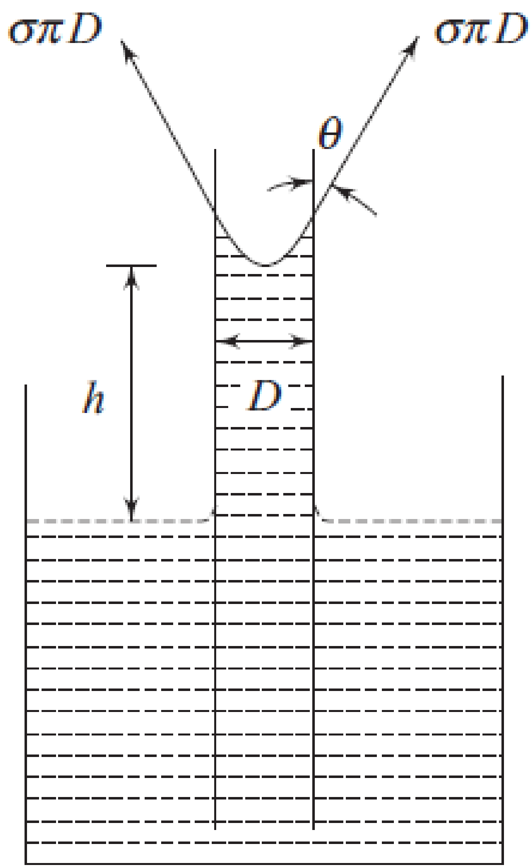
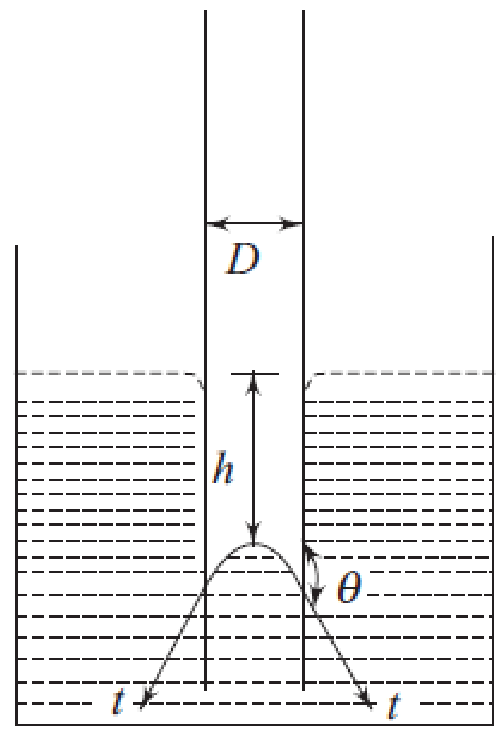




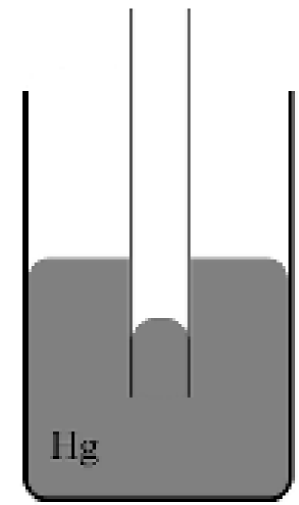
Capillary rise

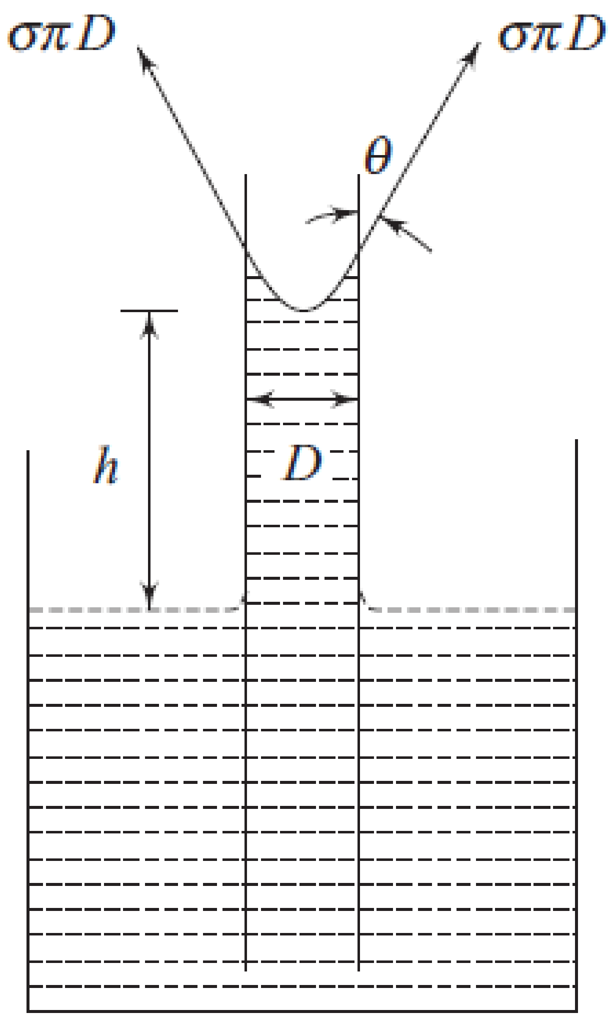
Adhesion > cohesion
liquid wets the surface



Capillary depression

Adhesion < cohesion
liquid stays away from the surface





Capillary rise

Weight of the raised liquid column in the tube = Vertical component of the force due to surface tension

$$\frac{\pi D^2}{4} h \rho g = \sigma \pi D \cos \theta$$

$$h = \frac{4 \sigma \cos\theta}{\rho g D}$$

Equation is same for both capillary rise and capillary depression

Problem 1:

Calculate the capillary effect in a glass tube of 4mm diameter when immersed vertically in (a) water and (b) mercury. Take surface tensions for water as 0.073575 N/m and mercury as 0.51 N/m. The angle of contact of water is zero and for mercury is 130 degrees. Take density of water as 998 kg/m^3 and mercury as 13600 kg/m^3.

Solution. Given :

Dia. of tube, $d = 4 \text{ mm} = 4 \times 10^{-3} \text{ m}$

The capillary effect (*i.e.*, capillary rise or depression) is given by equation (1.20) as

$$h = \frac{4\sigma \cos\theta}{\rho \times g \times d}$$

where σ = surface tension in N/m

θ = angle of contact, and ρ = density

(*i*) Capillary effect for water

$$\sigma = 0.073575 \text{ N/m}, \theta = 0°$$

$$\rho = 998 \text{ kg/m}^3 \text{ at } 20°\text{C}$$

$$\therefore \quad h = \frac{4 \times 0.073575 \times \cos 0°}{998 \times 9.81 \times 4 \times 10^{-3}} = 7.51 \times 10^{-3} \text{ m} = \mathbf{7.51 \text{ mm. Ans.}}$$

(*ii*) **Capillary effect for mercury**

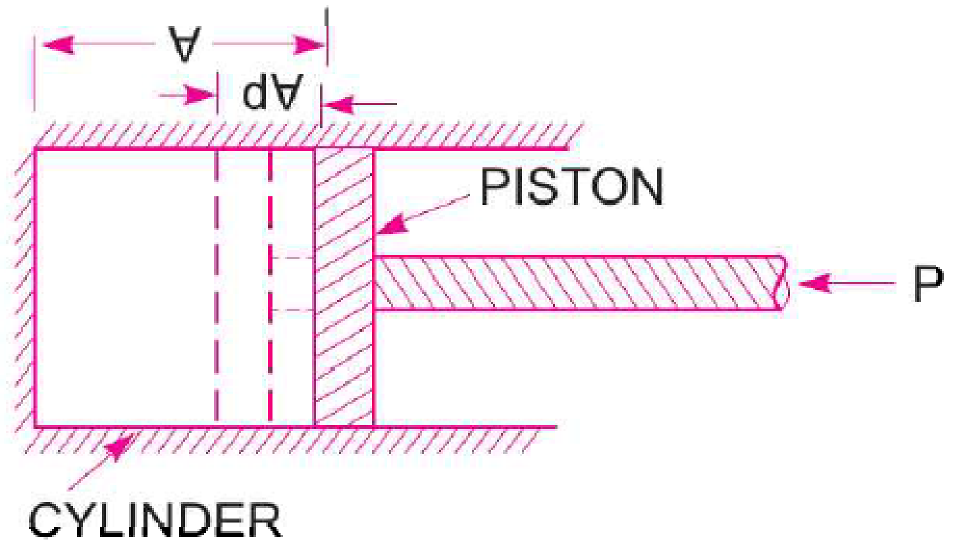
$$\sigma = 0.51 \text{ N/m}, \theta = 130° \text{ and}$$

$$\rho = \text{sp. gr.} \times 1000 = 13.6 \times 1000 = 13600 \text{ kg/m}^2$$

$$\therefore \qquad h = \frac{4 \times 0.51 \times \cos 130°}{13600 \times 9.81 \times 4 \times 10^{-3}} = -2.46 \times 10^{-3} \text{ m} = \mathbf{-2.46 \text{ mm. Ans.}}$$

The negative sign indicates the capillary depression.

Compressibility and bulk modulus



- Bulk modulus of elasticity K is the ratio of the compressive stress to the volumetric strain.
- Compressibility is the reciprocal of the bulk modulus of elasticity K.

$$\therefore \quad \text{Volumetric strain} = -\frac{d\forall}{\forall}$$

– ve sign means the volume decreases with increase of pressure.

$$\therefore \quad \text{Bulk modulus} \quad K = \frac{\text{Increase of pressure}}{\text{Volumetric strain}}$$

$$= \frac{dp}{\frac{-d\forall}{\forall}} = \frac{-dp}{d\forall}\forall$$

$$\text{Compressibility} = \frac{1}{K}$$

<u>For Air</u>: $K = 10^5$ N/m^2

<u>For Water</u>: $K = 0.2 \times 10^{10}$ N/m^2