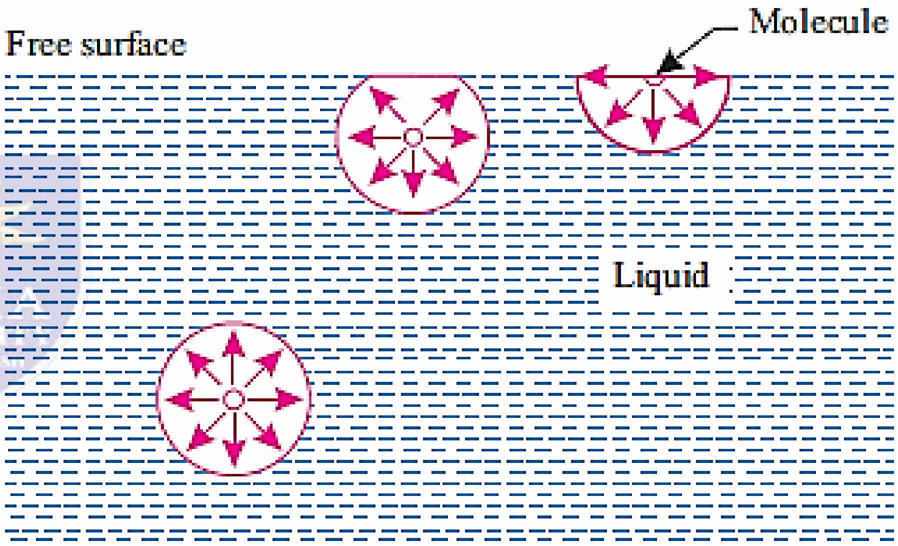
Fluid Properties-Surface Tension

- Cohesion. Cohesion means intermolecular attraction between molecules of the same liquid. It enables a liquid to resist small amount of tensile stresses. Cohesion is a tendency of the liquid to remain as one assemblage of particles. “Surface tension” is due to cohesion between particles at the free surface
- Adhesion. Adhesion means attraction between the molecules of a liquid and the molecules of a solid boundary surface in contact with the liquid. This property enables a liquid to stick to another body. Capillary action is due to both cohesion and adhesion.
- Some important examples of phenomenon of
- surface tension are as follows:
- (i) Rain drops (A falling rain drop becomes spherical due to cohesion and surface tension).
- (ii) Rise of sap in a tree.
- (iii) Bird can drink water from ponds.
- (iv) Capillary rise and capillary siphoning.
- (v) Collection of dust particles on water surface.
- (vi) Break up of liquid jets.



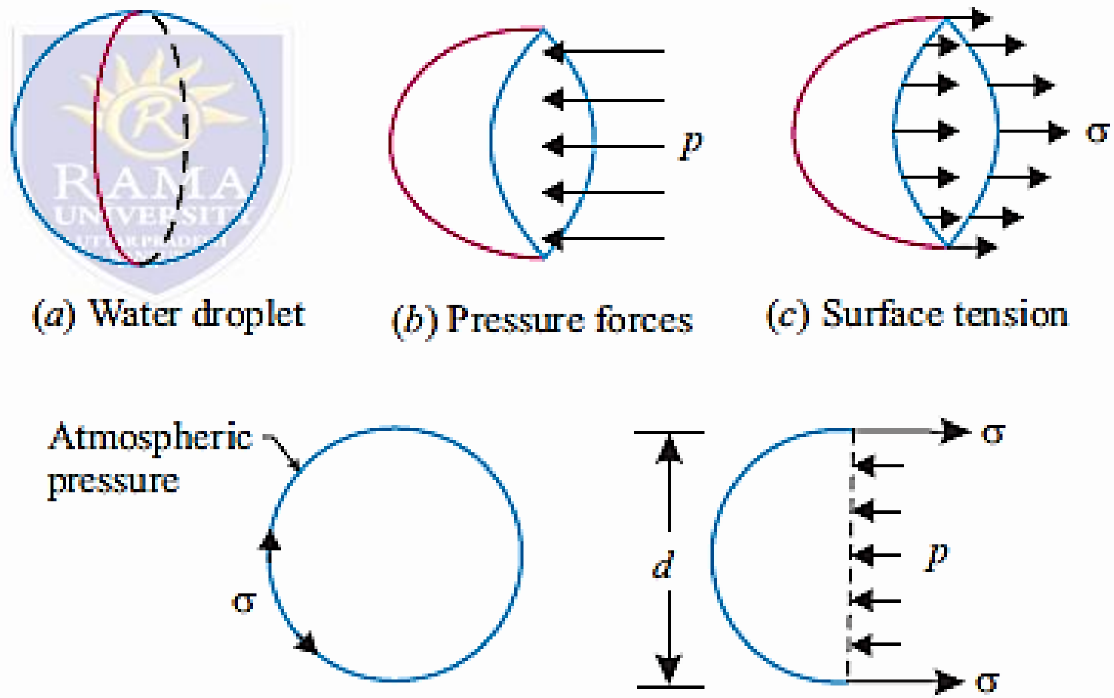
- Pressure Inside a Water Droplet, Soap Bubble and a Liquid Jet Case I. Water droplet:
- Let, p = Pressure inside the droplet above outside pressure (i.e., Δp = p – 0 = p above
- atmospheric pressure) d = Diameter of the droplet and
- σ = Surface tension of the liquid.
- From free body diagram (Fig. 1), we have:

(i) Pressure force = $p \times \frac{\pi}{4} d^2$, and

- (ii) Surface tension force acting around the circumference = σ × π d.
- Under equilibrium conditions these two forces will be equal and opposite,

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

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



(a) Water droplet (b) Pressure forces (c) Surface tension

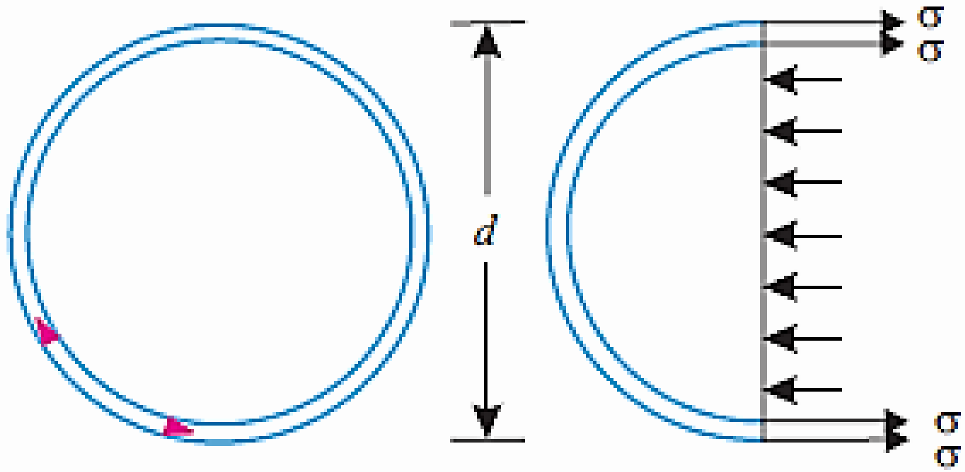
(d) Free body diagram

Fluid Properties

- Case II. Soap (or hollow) bubble:
- Soap bubbles have two surfaces on which surface tension σ acts.
- From the free body diagram (Fig.), we have

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

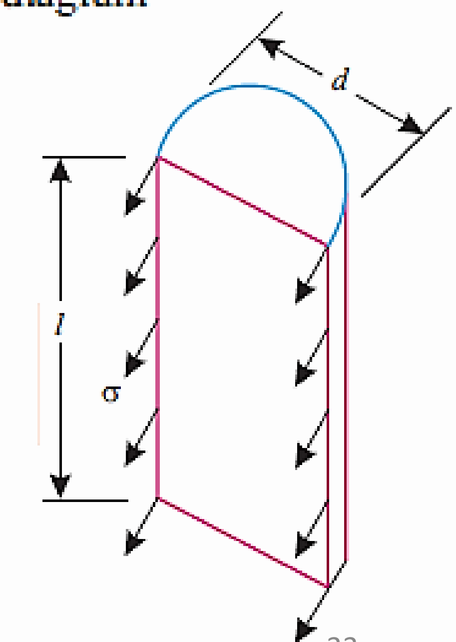
$$\therefore \qquad p = \frac{2\sigma \times \pi d}{\frac{\pi}{4} d^2} = \frac{8\sigma}{d}$$



Free body diagram

- Since the soap solution has a high value of surface tension σ, even with small pressure of
- blowing a soap bubble will tend to grow larger in diameter (hence formation of large soap bubbles
- Case III. A Liquid jet:
- Let us consider a cylindrical liquid jet of diameter d and length l. Fig. 1.21 shows a semi-jet.
- Pressure force = p × l × d
- Surface tension force = σ × 2l
- Equating the two forces, we have:
- p × l × d = σ × 2l

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



Semi-jet

Fluid Properties – Numerical

- If the surface tension at air-water interface is 0.069 N/m, what is the pressure difference between inside and outside of an air bubble of diameter 0.009 mm? 30.667 kN/m2 or kPa (Ans.)

Solution. *Given:* $\sigma = 0.069$ N/m; $d = 0.009$ mm

An air bubble has only one surface. Hence,

$$p = \frac{4\sigma}{d}$$

$$= \frac{4 \times 0.069}{0.009 \times 10^{-3}} = 30667 \text{ N/m}^2$$

$$= \mathbf{30.667 \text{ kN/m}^2 \text{ or kPa (Ans.)}}$$

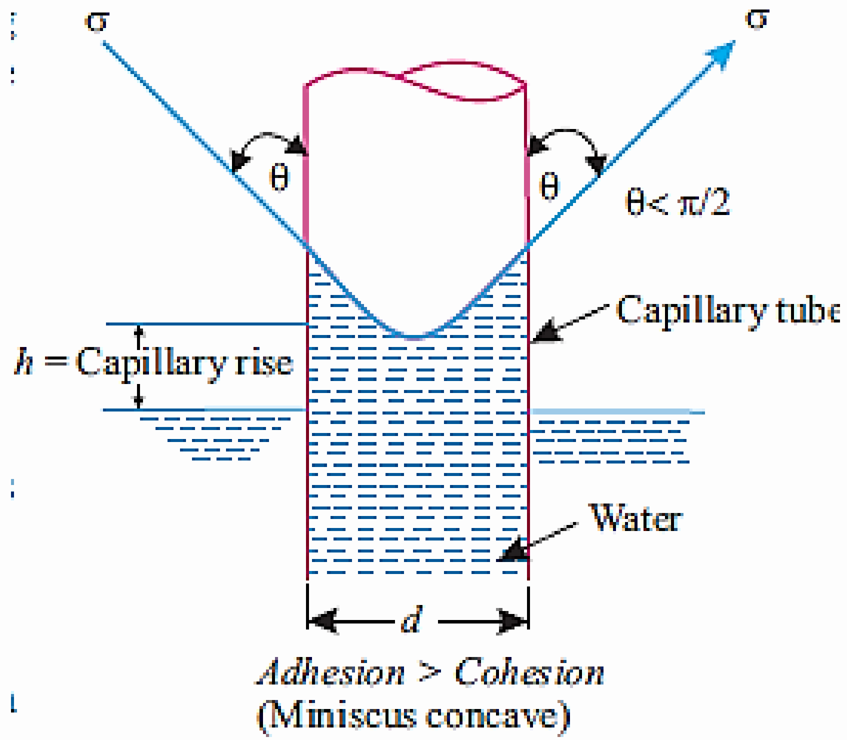
- If the surface tension at the soap-air interface is 0.09 N/m, calculate the internal pressure in a soap bubble of 28 mm diameter. = 25.71 N/m2 (above atmospheric pressure) (Ans.)
- In order to form a stream of bubbles, air is introduced through a nozzle into a tank of water at 20°C. If the process requires 3.0 mm diameter bubbles to be formed, by how much the air pressure at the nozzle must exceed that of the surrounding water? What would be the absolute pressure inside the bubble if the surrounding water is at 100.3 kN/m2? Take surface tension of water at 20°C = 0.0735 N/m.
- 98 N/m2 (Ans.), pads 100.398 kN/m2 (Ans.)
- A soap bubble 62.5 mm diameter has an internal pressure in excess of the outside pressure of 20 N/m2. What is tension in the soap film? 0.156 N/m (Ans.)
- What do you mean by surface tension? If the pressure difference between the inside and outside of the air bubble of diameter 0.01 mm is 29.2 kPa, what will be the surface tension at air-water interface? 0.073 N/m (Ans.)

Fluid Properties- Capillarity

- Capillarity is a phenomenon by which a liquid (depending upon its specific gravity) rises into a thin glass tube above or below its general level. This phenomenon is due to the combined effect of cohesion and adhesion of liquid particles.
- phenomenon of rising water in the tube of smaller diameters.
- Let, d = Diameter of the capillary tube,
- θ = Angle of contact of the water surface,
- σ = Surface tension force for unit length, and
- w = Weight density (ρg). Now, upward surface tension force (lifting
- force) = weight of the water column in the tube (gravity force)

$$\pi d.\sigma \cos\theta = \frac{\pi}{4} d^2 \times h \times w$$

$$\therefore \quad h = \frac{4\sigma \cos\theta}{wd}$$

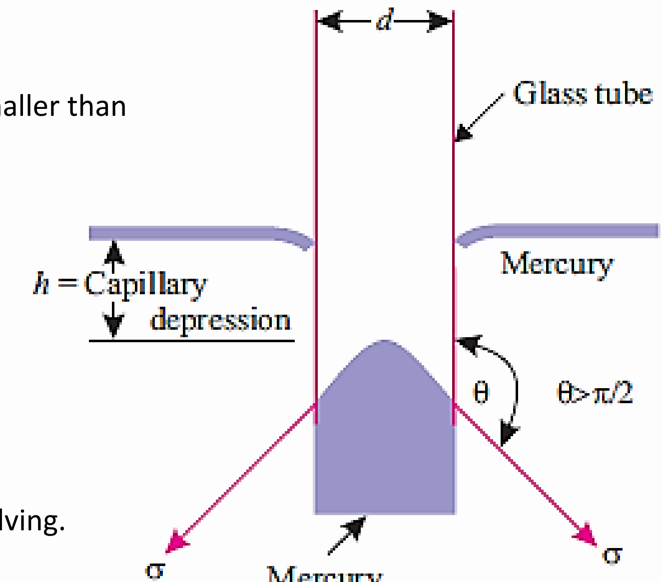


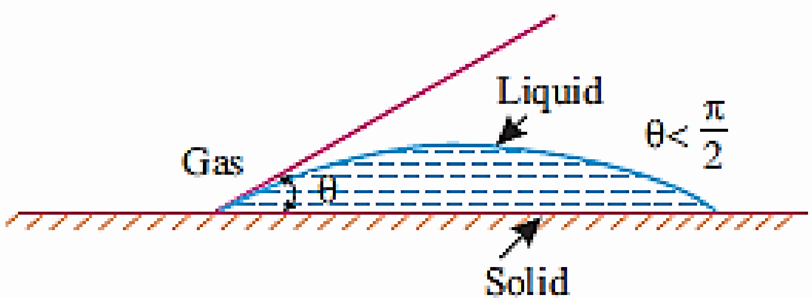
- For water and glass: θ = 0. Hence the capillary rise of water in the glass
- tube, $h = \frac{4\sigma}{wd}$

- In case of mercury there is a capillary depression as shown in Fig. , and the angle of depression is
- θ ⍰ 140°. (It may be noted that here cos θ = cos 140°
- = cos (180 – 40°) = – cos 40°, therefore, h is negative
- indicating capillary depression).

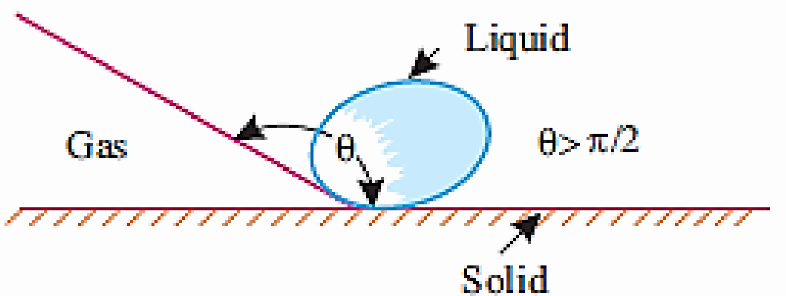
Fluid Properties- Capillarity

- Following points are worth noting:
- (i) Smaller the diameter of the capillary tube, greater is the capillary rise or depression.
- (ii) The measurement of liquid level in laboratory capillary (glass) tubes should not be smaller than
- 8 mm.
- (iii) Capillary effects are negligible for tubes longer than 12 mm.
- (iv) For wetting liquid (water): $\theta < \pi/2$. For water:
- $\theta = 0$ when pure water is in contact with clean glass.
- But θ becomes as high as 25° when water is slightly
- contaminated.
- For non-wetting liquid (mercury): $\theta > \pi/2$. (For mercury: θ varies between 130° to 150°)
- Refer Fig. 1 which illustrates the liquid gas interface with a solid surface.
- (v) The effects of surface tension are negligible in many flow problems except those involving.
- — capillary rise;
- — formation of drops and bubbles;
- — the break up of liquid jets, and
- — hydraulic model studies where the model
- or flow depth is small.





(a) Wetting liquid (water).



(b) Non-wetting liquid (mercury).