Surface Tension

1. Intermolecular Force

The force of attraction or repulsion acting between the molecules are known as intermolecular force. The nature of intermolecular force is electromagnetic.

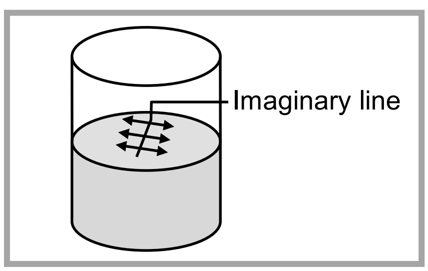
The intermolecular forces of attraction may be classified into two types.

Cohesive force	Adhesive force
The force of attraction between molecules of same substance is called the force of cohesion. This force is lesser in liquids and least in gases.	The force of attraction between the molecules of the different substances is called the force of adhesion.
Ex. (i) Two drops of a liquid coalesce into one when brought in mutual contact. (ii) It is difficult to separate two sticky plates of glass welded with water. (iii) It is difficult to break a drop of mercury into small droplets because of large cohesive force between the mercury molecules.	Ex. (i) Adhesive force enables us to write on the blackboard with a chalk. (ii) A piece of paper sticks to another due to large force of adhesion between the paper and gum molecules. (iii) Water wets the glass surface due to force of adhesion.

Note : Cohesive or adhesive forces are inversely proportional to the eighth power of distance between the molecules.

2. Surface Tension

The property of a liquid due to which its free surface tries to have minimum surface area and behaves as if it were under tension some what like a stretched elastic membrane is called surface tension. A small liquid drop has spherical shape, as due to surface tension the liquid surface tries to have minimum surface area and for a given volume, the sphere has minimum surface area.



Surface tension of a liquid is measured by the force acting per unit length on either side of an imaginary line drawn on the free surface of liquid, the direction of this force being perpendicular to the line and tangential to the free surface of liquid. So if F is the force acting on one side of imaginary line of length L, then T = (F/L)

(1) It depends only on the nature of liquid and is independent of the area of surface or length of line considered.

(2) It is a scalar as it has a unique direction which is not to be specified.

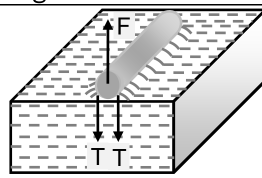
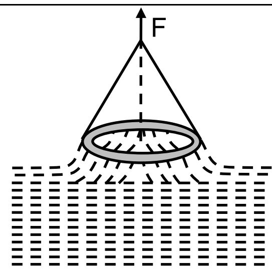
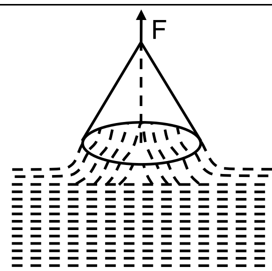
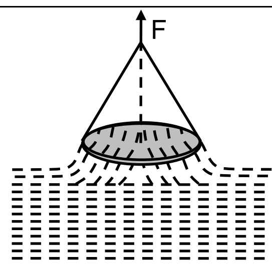
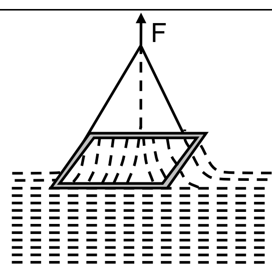
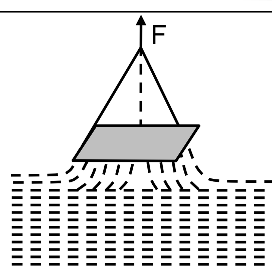
(3) Dimension : $[MT^{-2}]$. (Similar to force constant)

(4) Units : N/m (S.I.) and Dyne/cm [C.G.S.]

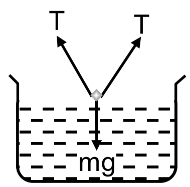
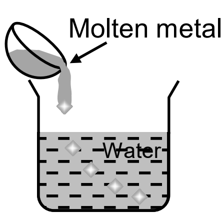
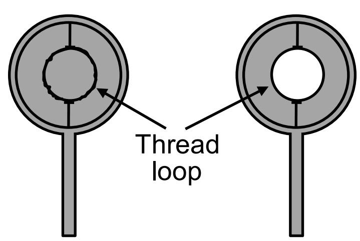
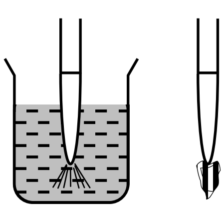
(5) It is a molecular phenomenon and its root cause is the electromagnetic forces.

3. Force Due to Surface Tension

If a body of weight W is placed on the liquid surface, whose surface tension is T. If F is the minimum force required to pull it away from the water then value of F for different bodies can be calculated by the following table.

Body	Figure	Force
Needle (Length = l)		$F = 2l\,T + W$
Hollow disc		$F = 2\pi (r_1 + r_2)T + W$
Thin ring (Radius = r)		$F = 2\pi (r + r)\,T + W$ $F = 4\pi rT + W$
Circular plate or disc (Radius = r)		$F = 2\pi r\,T + W$
Square frame (Side = *l*)		$F = 8lT + W$
Sqaure plate		$F = 4lT + W$

4. Examples of Surface

(1) When mercury is split on a clean glass plate, it forms giobules. Tiny globules are spherical on the account of surface tension because force of gravity is negligible. The bigger globules get flattened from the middle but have round shape near the edges, figure 	(2) When a greased iron needle is placed gently on the surface of water at rest, so that it does not prick the water surface, the needle floats on the surface of water despite it being havier because the weight of needle is balanced by the vertical components of the forces of surface tension. It the water surface is pricked by one end of the needle, the needle sinks down. 
(3) When a molten metal is poured into water from a suitable height, the falling stream of metal breaks up and the detached portion of the liquid in small quantity acquire the spherical shape.  	(4) Take a frame of wire and dip it in soap solution and take it out, a soap film will be formed in the frame. Place a loop of wet thread gently on the film. It will remain in the form, we place it on the film according to figure. Now, piercing the film with a pin at any point inside the loop, It immediately takes the circular form as shown in figure. 
(5) Hair of shaving brush/painting brush when dipped in water spread out, but as soon as it is taken out, its hair stick together. 	(6) If a small irregular piece of camphor is floated on the surface of pure water, it does not remain steady but dances about on the surface. This is because, irregular shaped camphor dissolves unequally and decreases the surface tension of the water locally. The unbalanced forces make it move haphazardly in different directions.

5. Factors Affecting Surface Tension

(1) Temperature : The surface tension of liquid decreases with rise of temperature. The surface tension of liquid is zero at its boiling point and it vanishes at critical temperature. At critical temperature, intermolecular forces for liquid and gases becomes equal and liquid can expand without any restriction. For small temperature differences, the variation in surface tension with temperature is linear and is given by the relation

$$T_t = T_0(1 - \alpha t)$$

where T_t, T_0 are the surface tensions at t°C and 0°C respectively and is the temperature coefficient of surface tension.

Examples :

(i) Hot soup tastes better than the cold soup.
(ii) Machinery parts get jammed in winter.

(2) Impurities : The presence of impurities either on the liquid surface or dissolved in it, considerably affect the force of surface tension, depending upon the degree of contamination. A highly soluble substance like sodium chloride when dissolved in water, increases the surface tension of water. But the sparingly soluble substances like phenol when dissolved in water, decreases the surface tension of water.

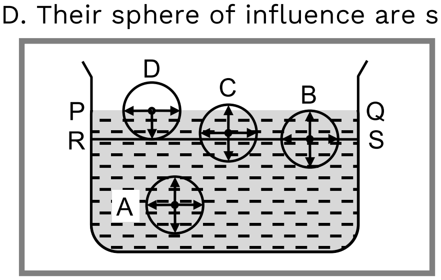
6. Applications of Surface Tension

(1) The oil and grease spots on clothes cannot be removed by pure water. On the other hand, when detergents (like soap) are added in water, the surface tension of water decreases. As a result of this, wetting power of soap solution increases. Also the force of adhesion between soap solution and oil or grease on the clothes increases. Thus, oil, grease and dirt particles get mixed with soap solution easily. Hence clothes are washed easily.
(2) The antiseptics have very low value of surface tension. The low value of surface tension prevents the formation of drops that may otherwise block the entrance to skin or a wound. Due to low surface tension, the antiseptics spreads properly over wound.
(3) Surface tension of all lubricating oils and paints is kept low so that they spread over a large area.
(4) Oil spreads over the surface of water because the surface tension of oil is less than the surface tension of cold water.
(5) A rough sea can be calmed by pouring oil on its surface.
(6) In soldering, addition of 'flux' reduces the surface tension of molten tin, hence, it spreads.

7. Molecular Theory of Surface Tension

The maximum distance upto which the force of attraction between two molecules is appreciable is called molecular range ($\approx 10^{-9}$ m). A sphere with a molecule as centre and radius equal to molecular range is called the sphere of influence. The liquid enclosed between free surface (PQ) of the liquid and an imaginary plane (RS) at a distance r (equal to molecular range) from the free surface of the liquid form a liquid film.

To understand the tension acting on the free surface of a liquid, let us consider four liquid molecules like A, B, C and D. Their sphere of influence are shown in the figure.



(1) Molecule A is well within the liquid, so it is attracted equally in all directions. Hence the net force on this molecule is zero and it moves freely inside the liquid.
(2) Molecule B is little below the free surface of the liquid and it is also attracted equally in all directions. Hence the resultant force on it is also zero.
(3) Molecule C is just below the upper surface of the liquid film and the part of its sphere of influence is outside the free liquid surface. So the number of molecules in the upper half (attracting the molecules upward) is less than the number of molecule in the lower half (attracting the molecule downward). Thus the molecule C experiences a net downward force.
(4) Molecule D is just on the free surface of the liquid. The upper half of the sphere of influence has no liquid molecule. Hence the molecule D experiences a maximum downward force.
Thus all molecules lying in surface film experiences a net downward force. Therefore, free surface of the liquid behaves like a stretched membrane.

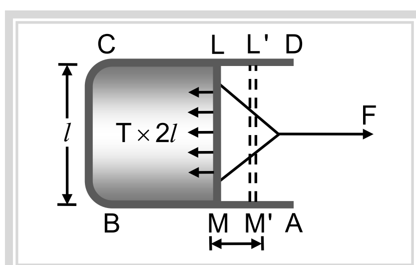
8. Surface Energy

The molecules on the liquid surface experience net downward force. So to bring a molecule from the interior of the liquid to the free surface, some work is required to be done against the intermolecular force of attraction, which will be stored as potential energy of the molecule on the surface. The potential energy of surface molecules per unit area of the surface is called surface energy.

Unit : Joule/m^2 (S.I.) erg/cm^2 (C.G.S.)

Dimension : $[MT^{-2}]$

If a rectangular wire frame ABCD, equipped with a sliding wire LM dipped in soap solution, a film is formed over the frame. Due to the surface tension, the film will have a tendency to shrink and thereby, the sliding wire LM will be pulled in inward direction. However, the sliding wire can be held in this position under a force F, which is equal and opposite to the force acting on the sliding wire LM all along its length due to surface tension in the soap film.



If T is the force due to surface tension per unit length, then F = T × 2l

Here, l is length of the sliding wire LM. The length of the sliding wire has been taken as 2l for the reason that the film has got two free surfaces.

Suppose that the sliding wire LM is moved through a small distance x, so as to take the position L'M'. In this process, area of the film increases by 2l × x (on the two sides) and to do so, the work done is given by

W = F × x = (T × 2l) x = T (2lx) = T × A

W = T × A

[ΔA = Total increase in area of the film from both the sides]

If temperature of the film remains constant in this process, this work done is stored in the film as its surface energy.

From the above expression $T = \frac{W}{\Delta A}$ or T = W [If Δ A = 1]

i.e. surface tension may be defined as the amount of work done in increasing the area of the liquid surface by unity against the force of surface tension at constant temperature.

9. Work Done in Blowing a Liquid Drop or Soap Bubble

(1) If the initial radius of liquid drop is r_1 and final radius of liquid drop is r_2 then

$W = T$ Increment in surface area

$W = T \times 4\pi\ [r_2^2 - r_1^2]$

[drop has only one free surface]

(2) In case of soap bubble

$W = T \times 8\pi\ [r_2^2 - r_1^2]$

[$\because$ Bubble has two free surfaces]

10. Splitting of Bigger Drop

When a drop of radius R splits into n smaller drops, (each of radius r) then surface area of liquid increases. Hence the work is to be done against surface tension.

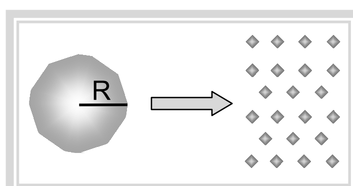
Since the volume of liquid remains constant therefore $\frac{4}{3}\pi R^3 = n\frac{4}{3}\pi r^3 \quad \therefore\ R^3 = nr^3$

Work done = $T \times \Delta A$ = T [Total final surface area of n drops – surface area of big drop]

$= T[n4\pi r^2 - 4\pi R^2]$

Various formulae of work done			
$4\pi T[nr^2 - R^2]$	$4\pi R^2 T[n^{1/3} - 1]$	$4\pi T r^2 n^{2/3}[n^{1/3} - 1]$	$4\pi T R^3\left[\frac{1}{r} - \frac{1}{R}\right]$

If the work is not done by an external source then internal energy of liquid decreases, subsequently temperature decreases. This is the reason why spraying causes cooling.



By conservation of energy, Loss in thermal energy = work done against surface tension

JQ = W

$\Rightarrow \quad JmS\Delta\theta = 4\pi T R^3\left[\frac{1}{r} - \frac{1}{R}\right]$

$\Rightarrow \quad J\frac{4}{3}\pi R^3 d S\Delta\theta = 4\pi R^3 T\left[\frac{1}{r} - \frac{1}{R}\right]$

[As $m = V \times d = \frac{4}{3}\pi R^3 \times d$]

$\therefore$ Decrease in temperature $\Delta\theta = \frac{3T}{JSd}\left[\frac{1}{r} - \frac{1}{R}\right]$

where J = mechanical equivalent of heat, S = specific heat of liquid, d = density of liquid.

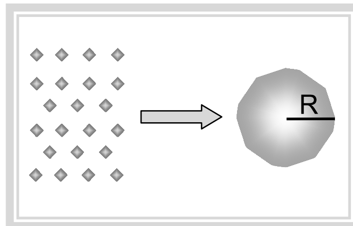
11. Formation of Bigger Drop

If n small drops of radius r coalesce to form a big drop of radius R then surface area of the liquid decreases.

Amount of surface energy released = Initial surface energy - final surface energy

$E = n4\pi r^2 T - 4\pi R^2 T$

Various formulae of released energy			
$4\pi T[nr^2 - R^2]$	$4\pi R^2T[n^{1/3} - 1]$	$4\pi Tr^2n^{2/3}[n^{1/3} - 1]$	$4\pi TR^3\left[\frac{1}{r}-\frac{1}{R}\right]$



(i) If this released energy is absorbed by a big drop, its temperature increases and rise in temperature can be given by $\Delta\theta = \frac{3T}{JSd}\left[\frac{1}{r}-\frac{1}{R}\right]$

Example 1:

The work done in blowing a soap bubble of 10cm radius is (surface tension of the soap solution is $\frac{3}{100}N/m$)

(1) 75.36×10^{-4}J (2) 37.68×10^{-4}J (3) 150.72×10^{-4}J (4) 75.36 J

Solution:

(1) $W = 8\pi R^2T = 8\pi(10\times10^{-2})^2 = 75.36 \times 10^{-4}$J

Example 2:

The work done in increasing the size of a soap film from 10cm × 6cm to 10cm × 11cm is 3×10^{-4} J. The surface tension of the film is

(1) $1.5\times10^{-2}\ Nm^{-1}$ (2) $3.0\times10^{-2}\ Nm^{-1}$ (3) $6.0\times10^{-2}\ Nm^{-1}$ (4) $11.0\times10^{-2}\ Nm^{-1}$

Solution:

(2) $A_1 = 10\times6 = 60cm^2 = 60\times10^{-4}m^2$, $A_2 = 10\times11 = 110cm^2 = 110\times10^{-4}m^2$

As the soap film has two free surfaces

$\therefore W = T\times2\Delta A$ $\Rightarrow W = T\times2\times(A_2 - A_1)$ $\Rightarrow T = \frac{W}{2\times50\times10^{-4}} = \frac{3\times10^{-4}}{2\times50\times10^{-4}}$ $= 3\times10^{-2}$ N/m

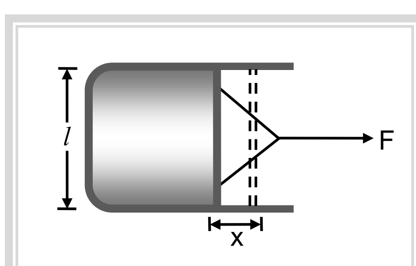
Example 3:

A film of water is formed between two straight parallel wires of length 10cm each separated by 0.5cm. If their separation is increased by 1 mm while still maintaining their parallelism, how much work will have to be done (Surface tension of water = 7.2×10^{-2} N/m)

(1) 7.22×10^{-6} J (2) 1.44×10^{-5} J (3) 2.88×10^{-5} J (4) 5.76×10^{-5} J

Solution:

(2)

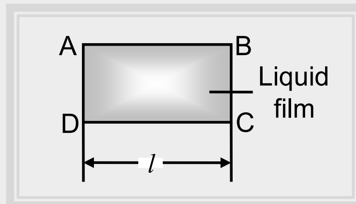


As film have two free surfaces W = T × 2ΔA

$W = T \times 2l \times x = 7.2 \times 10^{-2} \times 2 \times 0.1 \times 1 \times 10^{-3} = 1.44 \times 10^{-5}$ J

Concept Builder-1

Q.1 A liquid film is formed over a frame ABCD as shown in figure. Wire CD can slide without friction. The mass to be hung from CD to keep it in equilibrium is



(1) $\frac{Tl}{g}$ (2) $\frac{2Tl}{g}$ (3) $\frac{g}{2Tl}$ (4) $T \times l$

Q.2 Two small drops of mercury, each of radius R, coalesce to form a single large drop. The ratio of the total surface energies before and after the change is

(1) $1 : 2^{1/3}$ (2) $2 : 1^{1/3}$ (3) 2 : 1 (4) 1 : 2

Q.3 Radius of a soap bubble is increased from R to 2R work done in this process in terms of surface tension is

(1) $24\ \pi r^2 S$ (2) $48\ \pi r^2 S$ (3) $12\ \pi r^2 h$ (4) $36\ \pi r^2 h$

Q.4 A drop of mercury of radius 2mm is split into 8 identical droplets. Find the increase in surface energy. (Surface tension of mercury is 0.465 J/m^2)

(1) 23.4 μJ (2) 18.5 μJ (3) 26.8 μJ (4) 16.8 μJ

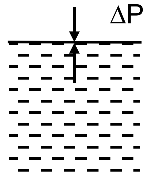
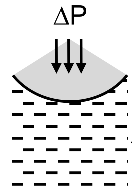
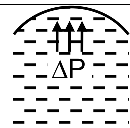
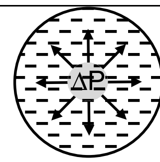
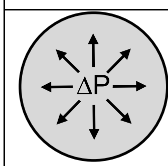
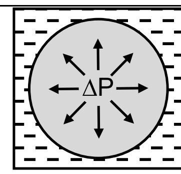
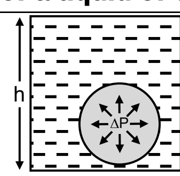
Q.5 If the work done in blowing a bubble of volume V is W, then the work done in blowing the bubble of volume 2V from the same soap solution will be

(1) W/2 (2) $\sqrt{2}$ W (3) $\sqrt[3]{2}$ W (4) $\sqrt[3]{4}$ W

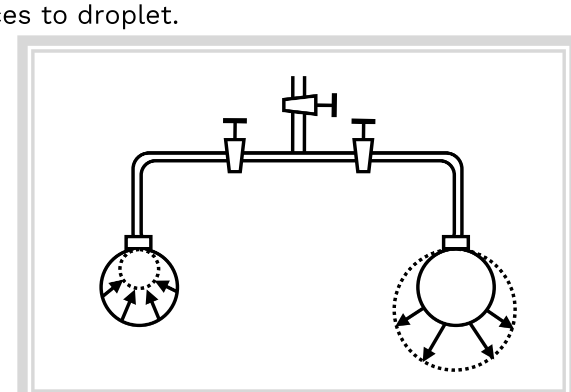
12. Excess Pressure

Due to the property of surface tension a drop or bubble tries to contract and so compresses the matter enclosed. This in turn increases the internal pressure which prevents further contraction and equilibrium is achieved. So in equilibrium the pressure inside a bubble or drop is greater than outside and the difference of pressure between two sides of the liquid surface is called excess pressure. In case of a drop excess pressure is provided by hydrostatic pressure of the liquid within the drop while in case of bubble the gauge pressure of the gas confined in the bubble provides it.

Excess pressure in different cases is given in the following table :

Plane surface	**Concave surface**
 $\Delta P = 0$	 $\Delta P = \frac{2T}{R}$
Convex surface	**Drop**
 $\Delta P = \frac{2T}{R}$	 $\Delta P = \frac{2T}{R}$
Bubble in Air	**Bubble in Water**
 $\Delta P = \frac{4T}{R}$	 $\Delta P = \frac{2T}{R}$
Bubble at a depth h from the free surface of a liquid of density d	
 $\Delta P = \frac{2T}{R}$	

Note : Excess pressure is inversely proportional to the radius of bubble (or drop), i.e., pressure inside a smaller bubble (or drop) is higher than inside a larger bubble (or drop). This is why when two bubbles of different sizes are put in communication with each other, the air will rush from smaller to larger bubble, so that the smaller will shrink while the larger will expand till the smaller bubble reduces to droplet.



Example 4:

The pressure inside a small air bubble of radius 0.1mm situated just below the surface of water will be equal to (Take surface tension of water and atmospheric pressure = $1.013 \times 10^{5}\ Nm^{-2}$)

(1) 2.054×10^{3}Pa (2) 1.027×10^{3}Pa (3) 1.027×10^{5}Pa (4) 2.054×10^{5}Pa

Solution:

(3) Pressure inside a bubble when it is in a liquid $= P_o + \frac{2T}{R} = 1.013 \times 10^5 + 2 \times \frac{70 \times 10^{-3}}{0.1 \times 10^{-3}}$

$= 1.027 \times 10^5$ Pa.

Concept Builder-2

Q.1 If the radius of a soap bubble is four times that of another, then the ratio of their excess pressures will be

(1) 1 : 4 (2) 4 : 1 (3) 16 : 1 (4) 1 : 16

Q.2 Pressure inside two soap bubbles are 1.01 and 1.02 atmospheres. Ratio between their volumes is

(1) 102 : 101 (2) $(102)^3 : (101)^3$ (3) 8 : 1 (4) 2 : 1

Q.3 The excess pressure inside an air bubble of radius r just below the surface of water is P_1. The excess pressure inside a drop of the same radius just outside the surface is P_2. If T is surface tension then

(1) $P_1 = 2P_2$ (2) $P_1 = P_2$ (3) $P_2 = 2P_1$ (4) $P_2 = 0, P_1 \neq 0$

13. Shape of Liquid Meniscus

We know that a liquid assumes the shape of the vessel in which it is contained i.e. it can not oppose permanently any force that tries to change its shape. As the effect of force is zero in a direction perpendicular to it, the free surface of liquid at rest adjusts itself at right angles to the resultant force.

When a capillary tube is dipped in a liquid, the liquid surface becomes curved near the point of contact. This curved surface is due to the resultant of two forces i.e. the force of cohesion and the force of adhesion. The curved surface of the liquid is called meniscus of the liquid.

If liquid molecule A is in contact with solid (i.e. wall of capillary tube) then forces acting on molecule A are

(i) Force of adhesion F_a (acts outwards at right angle to the wall of the tube).

(ii) Force of cohesion F_c (acts at an angle 45° to the vertical).

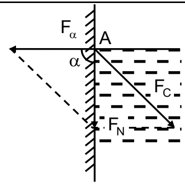
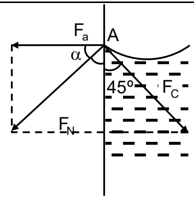
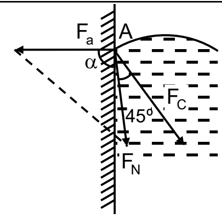
Resultant force F_N depends upon the value of F_a and F_c.

If resultant force F_N make an angle with F_a.

Then

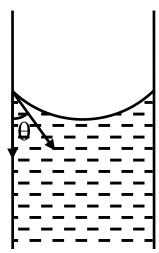
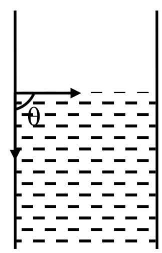
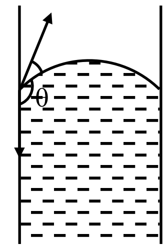
By knowing the direction of resultant force we can find out the shape of meniscus because the free surface of the liquid adjust itself at right angle to this resultant force.

If $F_C = \sqrt{2} F_a$	$F_C < \sqrt{2} F_a$	$F_C > \sqrt{2} F_a$
$\tan \alpha = \infty \therefore \alpha = 90°$ i.e. the resultant force acts vertically downwards. Hence the liquid meniscus must be	$\tan\alpha$ = positive $\therefore \alpha$ is acute angle i.e. the resultant force directed outside the liquid. Hence the liquid meniscus	$\tan\alpha$ = negative $\therefore \alpha$ is obtuse angle i.e. the resultant force directed inside the liquid. Hence the liquid meniscus

horizontal.	must be concave upward.	must be convex upward.
		
Example : Pure water in silver coated capillary tube.	Example : Water in glass capillary tube.	Example : Mercury in glass capillary tube.

14. Angle of Contact

Angle of contact between a liquid and a solid is defined as the angle enclosed between the tangents to the liquid surface and the solid surface inside the liquid, both the tangents being drawn at the point of contact of the liquid with the solid.

$\theta < 90°$ $F_a > \frac{F_C}{\sqrt{2}}$  concave meniscus. Liquid wets the solid surface	$\theta = 90°$ $F_a = \frac{F_C}{\sqrt{2}}$  plane meniscus. Liquid does not wet the solid surface.	$\theta > 90°$ $F_a < \frac{F_C}{\sqrt{2}}$  convex meniscus. Liquid does not wet the solid surface.

Important points

(i) Its value lies between 0° and 180°

$\theta° = 0$ for pure water and glass, $\theta° = 8°$ for tap water and glass, $\theta° = 90°$ for water and silver

$\theta° = 138°$ for mercury and glass, $\theta° = 160°$ for water and chromium

(ii) It is particular for a given pair of liquid and solid. Thus the angle of contact changes with the pair of solid and liquid.

(iii) It does not depends upon the inclination of the solid in the liquid.

(iv) On increasing the temperature, angle of contact decreases.

(v) Soluble impurities increases the angle of contact.

(vi) Partially soluble impurities decreases the angle of contact.

15. Capillarity

If a tube of very narrow bore (called capillary) is dipped in a liquid, it is found that the liquid in the capillary either ascends or descends relative to the surrounding liquid. This phenomenon is called capillarity.

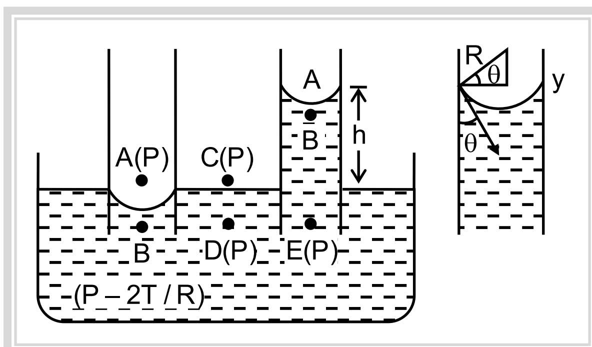
The root cause of capillarity is the difference in pressures on two sides of (concave and convex) curved surface of liquid.

Examples of Capillarity

(i) Ink rises in the fine pores of blotting paper leaving the paper dry.
(ii) A towel soaks water.
(iii) Oil rises in the long narrow spaces between the threads of a wick.
(iv) Wood swells in rainy season due to rise of moisture from air in the pores.
(v) Ploughing of fields is essential for preserving moisture in the soil.
(vi) Sand is drier soil than clay. This is because holes between the sand particles are not so fine as compared to that of clay, to draw up water by capillary action.

16. Ascent Formula

When one end of capillary tube of radius r is immersed into a liquid of density d which wets the sides of the capillary tube (water and capillary tube of glass), the shape of the liquid meniscus in the tube becomes concave upwards.



R = radius of curvature of liquid meniscus.
T = surface tension of liquid
P = atmospheric pressure

Pressure at point A = P, Pressure at point B = $P - \frac{2T}{R}$

Pressure at points C and D just above and below the plane surface of liquid in the vessel is also P (atmospheric pressure). The points B and D are in the same horizontal plane in the liquid but the pressure at these points is different.
In order to maintain the equilibrium the liquid level rises in the capillary tube upto height h.
Pressure due to liquid column = pressure difference due to surface tension

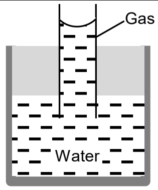
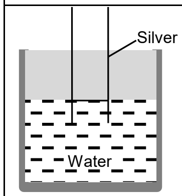
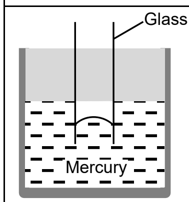
$$\Rightarrow \quad hdg = \frac{2T}{R}$$

$$\therefore \quad h = \frac{2T}{Rdg} = \frac{2T\cos\theta}{rdg} \qquad \left[\text{As } R = \frac{r}{\cos\theta}\right]$$

Important Points

(i) The capillary rise depends on the nature of liquid and solid both i.e. on T, d, θ and R.
(ii) Capillary action for various liquid-solid pair.

	Meniscus	Angle of contact	Level

	Concave	$\theta < 90°$	Rises
	Plane	$\theta = 90°$	No rise no fall
	Convex	$\theta > 90°$	Fall

(iii) For a given liquid and solid at a given place

$h \propto \frac{1}{r}$ [As T, θ, d and g are constant]

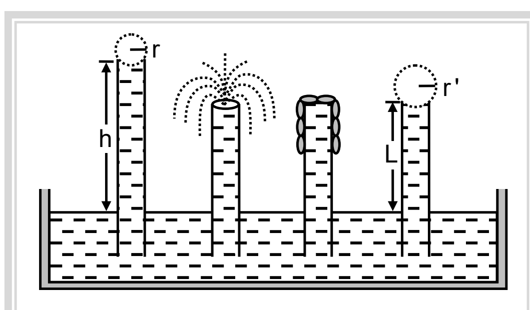
i.e. lesser the radius of capillary greater will be the rise and vice-versa. This is called Jurin's law.

(iv) If the weight of the liquid contained in the meniscus is taken into consideration then more accurate ascent formula is given by

$$h = \frac{2T\cos\theta}{rdg} - \frac{r}{3}$$

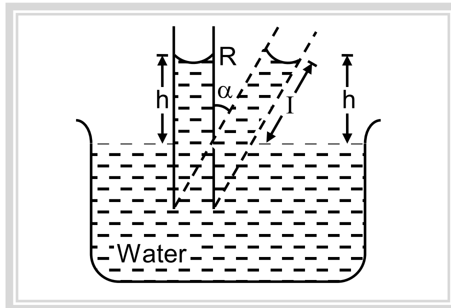
(v) In case of capillary of insufficient length, i.e., L < h, the liquid will neither overflow from the upper end like a fountain nor will it tickle along the vertical sides of the tube. The liquid after reaching the upper end will increase the radius of its meniscus without changing nature such that :

$hr = Lr'$ $\because$ Q $L < h \therefore r' > r$

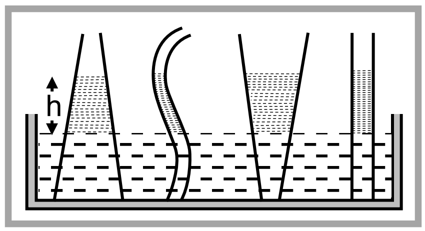


(vi) If a capillary tube is dipped into a liquid and tilted at an angle from vertical, then the vertical height of liquid column remains same whereas the length of liquid column (l) in the capillary tube increases.

$h = l\cos\alpha$ or $I = \frac{h}{\cos\alpha}$



(vii) It is important to note that in equilibrium the height h is independent of the shape of capillary if the radius of meniscus remains the same. That is why the vertical height h of a liquid column in capillaries of different shapes and sizes will be same if the radius of meniscus remains the same.



Example 5:

Water rises in a vertical capillary tube upto a height of 2.0 cm. If the tube is inclined at an angle of 60° with the vertical, then upto what length the water will rise in the tube

(1) 2.0 cm (2) 4.0 cm (3) $\frac{4}{\sqrt{3}}$ cm (4) $2\sqrt{2}$ cm

Solution:

(2) The height upto which water will rise $\ell = \frac{h}{\cos\alpha} = \frac{2cm}{\cos 60^\circ}$ = 4cm. [h = vertical height, α = angle with vertical]

Example 6:

Water rises to a height h in a capillary at the surface of earth. On the surface of the moon the height of water column in the same capillary will be

(1) 6h (2) $\frac{1}{6}$h (3) h (4) Zero

Solution:

(1) $h = \frac{2T\cos\theta}{rdg} \therefore h \propto \frac{1}{g}$

[If other quantities remains constant]

$\frac{h_{moon}}{h_{earth}} = \frac{g_{earth}}{g_{moon}} = 6 \Rightarrow h_{moon} = 6h$

[As $g_{earth} = 6g_{moon}$]

Example 7:

If the surface tension of water is 0.06 N/m, then the capillary rise in a tube of diameter 1mm is (θ = 0°)

(1) 1.22 cm (2) 2.44 cm (3) 3.12 cm (4) 3.86 cm

Solution:

(2) $h = \frac{2T\cos\theta}{rdg}$,

[$\theta = 0$, $r = \frac{1}{2}mm = 0.5\times10^{-3}m$, $T = 0.06N/m$, $d = 10^3 kg/m^3$, $g = 9.8\ m/s^2$]

$h = \frac{2\times0.06\times\cos\theta}{0.5\times10^{-3}\times10^3\times9.8}$ $= 0.0244m = 2.44cm$

Concept Builder-3

Q.1 Water rises to a height of 10cm in a capillary tube and mercury falls to a depth of 3.5cm in the same capillary tube. If the density of mercury is 13.6 gm/cc and its angle of contact is 135° and density of water is 1 gm/cc and its angle of contact is 0°, then the ratio of surface tensions of the two liquids is

(1) 1 : 14 (2) 5 : 34 (3) 1 : 5 (4) 5 : 27

Q.2 Two capillary tubes of same diameter are kept vertically one each in two liquids whose relative densities are 0.8 and 0.6 and surface tensions are 60 and 50 dyne/cm respectively. Ratio of heights of liquids in the two tubes $\frac{h_1}{h_2}$ is

(1) $\frac{10}{9}$ (2) $\frac{3}{10}$ (3) $\frac{10}{3}$ (4) $\frac{9}{10}$

Q.3 A capillary tube of radius R is immersed in water and water rises in it to a height H. Mass of water in the capillary tube is M. If the radius of the tube is doubled, mass of water that will rise in the capillary tube will now be

(1) M (2) 2M (3) M/2 (4) 4M

Q.4 Two capillaries made of same material but of different radii are dipped in a liquid. The rise of liquid in one capillary is 2.2cm and that in the other is 6.6cm. The ratio of their radii is

(1) 9 : 1 (2) 1 : 9 (3) 3 : 1 (4) 1 : 3

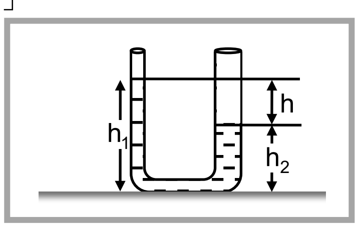
Q.5 Water rises in a capillary tube to a certain height such that the upward force due to surface tension is balanced by 75×10^{-4} N force due to the weight of the liquid. If the surface tension of water is 6×10^{-2} N/m, the inner circumference of the capillary must be

(1) $6\times10^{-2}\,N/m$ (2) $0.50\times10^{-2}\,m$ (3) $5.0\times10^{-2}\,m$ (4) $12.5\times10^{-2}\,m$

17. Useful Facts and Formulae

(1) The difference of levels of liquid column in two limbs of u-tube of unequal radii r_1 and r_2 is

$$h = h_1 - h_2 = \frac{2T\cos\theta}{dg}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$$



(2) A large force (F) is required to draw apart normally two glass plate enclosing a thin water film because the thin water film formed between the two glass plates will have concave surface all around. Since on the concave side of a liquid surface, pressure is more, work will have to be done in drawing the plates apart.

$F = \frac{2AT}{t}$ where T= surface tension of water film, t= thickness of film, A = area of film.

(3) When a soap bubble is charged, then its size increases due to outward force on the bubble.

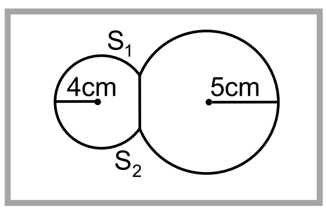
(4) The materials, which when coated on a surface and water does not enter through that surface are known as water proofing agents. For example wax etc. Water proofing agent increases the angle of contact.

(5) Values of surface tension of some liquids.

Liquid	**Surface tension (Newton/metre)**
Mercury	0.465
Water	0.075
Soap solution	0.030
Glycerin	0.063
Carbon tetrachloride	0.027
Ethyl alcohol	0.022

Example 8:

Two soap bubbles of radii r_1 and r_2 equal to 4cm and 5cm are touching each other over a common surface S_1S_2 (shown in figure). Its radius will be



(1) 4 cm (2) 20 cm (3) 5 cm (4) 4.5 cm

Solution:

(2) Radius of curvature of common surface of double bubble $r = \frac{r_2 r_1}{r_2 - r_1} = \frac{5 \times 4}{5 - 4} = 20\text{cm}$

Concept Builder-4

Q.1 The radii of two soap bubbles are r_1 and r_2. In isothermal conditions, two meet together in vacuum. Then the radius of the resultant bubble is given by

(1) $R = (r_1 + r_2)/2$ (2) $R = r_1(r_1 r_2 + r_2)$ (3) $R^2 = r_1^2 + r_2^2$ (4) $R = r_1 + r_2$

Q.2 On dipping one end of a capillary in liquid and inclining the capillary at an angles 30° and 60° with the vertical, the lengths of liquid columns in it are found to be l_1 and l_2 respectively. The ratio of l_1 and l_2 is

(1) $1 : \sqrt{3}$ (2) $1 : \sqrt{2}$ (3) $\sqrt{2} : 1$ (4) $\sqrt{3} : 1$

ANSWER KEY FOR CONCEPT BUILDERS

CONCEPT BUILDER-1

1.	(2)	**2.**	(2)	**3.**	(1)
4.	(1)	**5.**	(4)		

CONCEPT BUILDER-2

1.	(1)	**2.**	(3)	**3.**	(2)

CONCEPT BUILDER-3

1.	(2)	**2.**	(4)	**3.**	(2)
4.	(3)	**5.**	(4)		

CONCEPT BUILDER-4

1.	(3)	**2.**	(1)

Exercise - I

1. Spiders and insects move and run about on the surface of water without sinking because :
(1) Elastic membrane is formed on water due to property of surface tension
(2) Spiders and insects are lighter
(3) Spiders and insects swim on water
(4) Spiders and insects experience up-thrust

2. The additional force required to lift a flat circular disc of radius 5 cm from the surface of water with surface tension 75 dynes/cm, will be-
(1) 750π dyne (2) 750 dyne
(3) 30 dyne (4) 60 dyne

3. If the temperature of a liquid is increased then its surface tension-
(1) decreases
(2) increases
(3) remains the same
(4) increase and then decreases

4. The value of the surface tension of a liquid is 70 dyne/cm. What will be its value in N/m-
(1) 70 N/m (2) 7×10^{-2} N/m
(3) 7×10^{2} N/m (4) 7×10^{3} N/m

5. The force of cohesion is-
(1) maximum in solids
(2) maximum in liquid
(3) same in different matters
(4) maximum in gases

6. Surface tension of a soap liquid is 2×10^{-2} N/m. Work done to form a bubble of 1 cm. radius will be-
(1) $4\pi \times 10^{-6}$ J (2) $8\pi \times 10^{-6}$ J
(3) $12\pi \times 10^{-6}$ J (4) $16\pi \times 10^{-6}$ J

7. A soap bubble (S.T. 30 dyne/cm) has radius of 1 cm. The work done in doubling its radius would be
(1) 96 erg (2) 113.5 erg
(3) 20 erg (4) 2261 erg

8. At which of the following temperatures, the value of surface tension of water is minimum-
(1) 4°C (2) 25°C
(3) 0°C (4) 75°

9. Work done in increasing the radius of soap bubble from r to 2r at given temperature will be-
(1) $24\ T\pi r^2$ (2) $12\ T\pi r^2$
(3) $6\ T\pi r^2$ (4) $4\ T\pi r^2$

10. Spherical shape of a water drop is due to-
(1) surface tension (2) adhesion
(3) gravity (4) density

11. If the surface tension of liquid is T, the work required to be done to increase its surface area by A, is-
(1) A × T (2) $\frac{A}{T}$
(3) 2A × T (4) $A^2 \times T$

12. The unit of surface tension is-
(1) N/cm (2) N/cm^2
(3) N/cm^3 (4) none of these

13. A liquid drop of diameter D breaks into 27 tiny drops. The resultant change in energy is :
(1) $2\pi\ TD^2$ (2) $4\pi\ TD^2$
(3) $\pi\ TD^2$ (4) None of these

14. If work done in blowing a bubble of volume V is W, then the work done in blowing another bubble of volume 2V will be-
(1) 2W (2) W
(3) $\sqrt{2}$ W (4) $2^{2/3}$W

15. The amount of work done in forming a soap bubble (S.T. = 30×10^{-3} N/m) of radius 5 cm is-
(1) 1.88×10^{-3} J (2) 1.88×10^{1} J
(3) 1.88×10^{-1} J (4) 1.88×10^{3} J

16. 8000 identical water drops are combined to form a big drop. Then the ratio of final surface energy to the initial surface energy of all the drops together is-

(1) 1 : 10 (2) 1 : 15

(3) 1 : 20 (4) 1 : 25

17. If 10^6 small droplets are formed from one big droplet of water of radius 1 mm and of surface tension for water is 72×10^{-3} N/m then work done will be-

(1) 89.5×10^{-5} J (2) 8.95×10^{-5} J

(3) 895×10^{-5} J (4) none

18. Two small drops of mercury, each of radius R, coalesce to form a single large drop. The ratio of the total surface energies before and after the change is

(1) $1 : 2^{1/3}$ (2) $2^{1/3} : 1$

(3) 2 : 1 (4) 1 : 2

19. Many small mercury droplets are joined to form a big drop. Temperature of mercury-

(1) Increases

(2) Decreases

(3) Remains same

(4) None of the above

20. The pressure just below the meniscus of water -

(1) is greater than just above it

(2) is lesser than just above it

(3) is same as just above it

(4) is always equal to atmospheric pressure

21. Excess pressure inside a soap bubble is-

(1) $\propto 1/r$

(2) $\propto r$

(3) $\propto \sqrt{r}$

(4) Independent of r

22. A spherical drop of water has radius 1 mm. If surface tension of water is 70×10^{-3} N/m, difference of pressure between inside and outside of the spherical drop is-

(1) 35 N/m^2 (2) 70 N/m^2

(3) 140 N/m^2 (4) zero

23. By blowing air in a soap bubble, the radius is increased from r to 3r. Then the percentage increase in the surface energy of the bubble is-

(1) 90% (2) 80%

(3) 800% (4) 900%

24. A water drop and a soap bubble have the same radius. If the surface tension of soap solution is half that of water, then the ratio of excess pressure inside the water drop and that inside the soap bubble is-

(1) 1 : 2 (2) 2 : 1

(3) 1 : 1 (4) 1 : 4

25. The excess pressure inside one soap bubble is p and that inside a second soap bubble is 3p. Then the ratio of the volumes of the two bubbles is-

(1) 1 : 27 (2) 27 : 1

(3) 1 : 9 (4) 9 : 1

26. Ratio of radii of two soap bubbles is 2 : 1 then the ratio of their excess pressures will be-

(1) 2 : 1 (2) 4 : 1

(3) 1 : 4 (4) 1 : 2

27. If two soap bubbles of different radii are connected by a tube-

(1) there is no flow of air

(2) air flows from bigger bubble to the smaller bubble till the sizes are interchanged.

(3) air flows from the smaller bubble to the bigger.

(4) air flows from the bigger bubble to the smaller bubble till the sizes become equal.

28. A soap bubble in vacuum has a radius of 3 cm and another soap bubble in vacuum has a radius of 4 cm. If the two bubbles coalesce under isothermal condition then the radius of the new bubble is-

(1) 2.3 cm (2) 4.5 cm

(3) 5 cm (4) 7 cm

29. Two soap bubbles with radii r_1 and r_2 coalesce to form a bigger bubble. The radius of the new bubble will be-

(1) $r = \frac{r_1 + r_2}{2}$ (2) $r = \sqrt{r_1 r_2}$

(3) $r = \sqrt{\frac{r_1}{r_2}}$ (4) $r = \sqrt{r_1^2 + r_2^2}$

30. If more air is pushed in a soap bubble, the pressure in it :

(1) decreases (2) increase

(3) remains same (4) becomes zero

31. A false statement is:

(1) Angle of contact $\theta < 90°$, if cohesive force < adhesive force × $\sqrt{2}$

(2) Angle of contact $\theta > 90°$, if cohesive force > adhesive force × $\sqrt{2}$

(3) Angle of contact $\theta = 90°$, if cohesive force = adhesive force × $\sqrt{2}$

(4) If the radius of capillary is reduced to half, the rise of liquid column becomes four times

32. Mercury does not stick to glass or wood rod. It indicates that the cohesive force of mercury is-

(1) less than adhesive force

(2) equal to adhesive force

(3) more than adhesive force

(4) zero

33. Water from inside the earth rises through the trunk of a big tree to leaves high up. The main reason for this is-

(1) Capillary action

(2) High viscosity of water

(3) Gravitational force

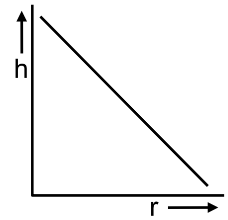
(4) Evaporation of water

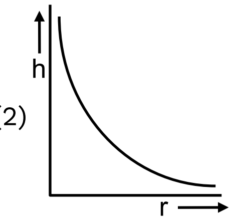
34. The correct relation is-

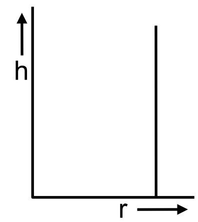
(1) $r = \frac{2T\cos\theta}{hdg}$ 2) $r = \frac{hdg}{2T\cos\theta}$

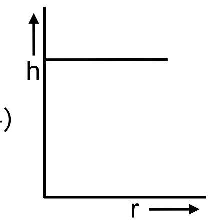
(3) $r = \frac{T\cos\theta}{2hdg}$ (4) $r = \frac{T\cos\theta}{2hdg}$

35. The correct curve between the height of depression h of liquid in a capillary tube and its radius is-

(1)


(2)


(3)


(4)


36. If the surface tension of water is 0.06 Nm^{-1} then the capillary rise in a tube diameter 1 mm is-

(1) 1.22 cm (2) 2.44 cm

(3) 3.12 cm (4) 3.86 cm

37. The lower end of a capillary tube touches a liquid whose angle of contact is 90°. The liquid-

(1) will neither rise nor will fall inside the tube

(2) will rise inside the tube

(3) will rise to the top of the tube

(4) will be depressed inside the tube

38. Water rises to a height of 16.3 cm in a capillary of height 18 cm. If the tube is cut at a height of 12 cm-

(1) Water will come as a fountain from the capillary

(2) Water will stay at a height of 12 cm in the capillary tube

(3) The height of water in the tube will be 10.3 cm

(4) Water will flow down the sides of the capillary tube

39. Two capillaries of the same material but of different diameter are dipped in a liquid. In one of the capillary the liquid rises to a height of 22mm and in the other to 66mm, Then the ratio of their diameters is-

(1) 1: 3 (2) 3 : 1

(3) 1 : 9 (4) 9 : 1

40. If a capillary of radius r is dipped in water, the height of water that rises in it is h and its mass is M. If the radius of the capillary is doubled the mass of water that rises in the capillary will be:

(1) 4M (2) 2M

(3) M (4) $\frac{M}{2}$

41. In a surface tension experiment with a capillary tube water rises up to 0.1 m. If the same experiment is repeated on an artificial satellite which is revolving round the earth, water will rise in the capillary tube up to a height of

(1) 0.1 m

(2) 0.98 m

(3) 9.8 m

(4) full length of capillary tube

42. If angle of contact is 90° and capillary experiment is performed in vacuum then level of liquid:

(1) will rise (2) will remain same

(3) will fall (4) rise to the top

43. If the liquid falls in a capillary, then radius of capillary will be-

(1) Increase

(2) Decrease

(3) Remain constant

(4) None of the above

44. When a capillary is dipped in water, water rises 0.015m in it. If the surface tension of water is 75×10^{-3} N/m, the radius of capillary is-

(1) 0.1 mm (2) 0.5 mm

(3) 1 mm (4) 2 mm

45. If water rises in a capillary tube upto 3 cm. What is the diameter of capillary tube- (Surface tension of water = 7.2×10^{-2} N/m)

(1) 9.6×10^{-4} m (2) 9.6×10^{-3} m

(3) 9.6×10^{-2} m (4) 9.6×10^{-1} m

46. What is the shape of meniscus when a capillary tube is placed in a non wetting liquid-

(1) concave upward

(2) convex upward

(3) concave downward

(4) convex downward

47. Water rises up to a height h in a capillary tube of certain diameter. This capillary tube is replaced by a similar tube of half the diameter. Now the water will rise to the height of-

(1) 4h (2) 3h

(3) 2h (4) h

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	1	1	1	2	1	4	4	4	1	1	1	1	1	4	1	3	2	2	1	2	1	3	3	3	2
Que.	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47			
Ans.	4	3	3	4	1	4	3	1	1	2	1	1	2	2	2	4	2	3	3	1	2	3			

Exercise - II

1. If 'M' is the mass of water that rises in a capillary tube of radius 'r', then mass of water which will rise in a capillary tube of radius '2r' is :

(1) 4M (2) M

(3) 2M (4) $\frac{M}{2}$

2. The ratio of surface tensions of mercury and water is given to be 7.5 while the ratio of thier densities is 13.6. Their contact angles, with glass, are close to 135° and 0°, respectively. It is observed that mercury gets depressed by an amount h in a capillary tube of radius r_1, while water rises by the same amount h in a capillary tube of radius r_2. The ratio, (r_1/r_2), is then close to :

(1) 2/3 (2) 3/5

(3) 2/5 (4) 4/5

3. An air bubble of radius 0.1 cm is in a liquid having surface tension 0.06 N/m and density 10^3 kg/m^3. The pressure inside the bubble is 1100 Nm^{-2} greater than the atmospheric pressure. At what depth is the bubble below the surface of the liquid? (g = 9.8 ms^{-2})

(1) 0.1 m (2) 0.15 m

(3) 0.20 m (4) 0.25 m

4. On dipping a capillary of radius 'r' in water, water rises upto a height H and potential energy of water is u_1. If a capillary of radius 2r is dipped in water, then the potential energy is u_2. The ratio $\frac{u_1}{u_2}$ is :

(1) 2 : 1 (2) 1 : 2

(3) 4 : 1 (4) 1 : 1

5. Two thin wooden sticks are floating on the surface of water close to each other. A hot needle touches the water between them. Then the sticks will-

(1) come closer (2) move apart

(3) stay as before (4) move erratically

6. Two small drops of mercury, each of radius R, coalesce to form a single large drop. The ratio of the total surface energies before and after the change is

(1) $1.2^{1/3}$ (2) $2^{1/3}$: 1

(3) 2 : 1 (4) 1 : 2

7. A large ship can float but a steel needle sinks because of :

(1) Viscosity (2) Surface tension

(3) Density (4) None of these

8. Wax is coated on the inner wall of a capillary tube and the tube is then dipped in water. Then, compared to the unwaxed capillary, the angle of contact θ and the height h upto which water rises change. These changes are

(1) θ decreases and h also decreases

(2) θ increases and h decreases

(3) θ increases and h also increases

(4) θ decreases and h increases

ANSWER KEY

Que.	1	2	3	4	5	6	7	8
Ans.	3	3	1	4	2	2	4	2

Exercise – III (Previous Year Question)

1. The wettability of a surface by a liquid depends primarily on **[NEET 2013]**

(1) surface tension
(2) density
(3) angle of contact between the surface and the liquid
(4) viscosity

2. Water rises to height 'h' in capillary tube. If the length of capillary tube above the surface of water is made less than 'h', then- **[NEET 2015]**

(1) water does not rise at all.
(2) water rises upto the tip of capillary tube and then starts overflowing like a fountain.
(3) water rises upto the top of capillary tube and stays there without overflowing
(4) water rises upto a point a little below the top and stays there.

3. A wind with speed 40 m/s blows parallel to the roof of a house. The area of the roof is 250 m^2. Assuming that the pressure inside the house is atmospheric pressure., the force exerted by the wind on the roof and the direction of the force will be: $(\rho_{air} = 1.2\ kg/m^3)$ **[NEET 2015]**

(1) 4.8×10^5 N, upwards
(2) 2.4×10^5 N, upwards
(3) 2.4×10^5 N, downwards
(4) 4.8×10^5 N, downwards

4. A cubical copper block has each side 2.0 cm. It is suspended by a string and submerged in oil of density 820 kg/m^3. The tension in the string is : (density of copper 8920 kg/m^3, g = 10 m/s^2): **[NEET 2015]**

(1) 0.648 N
(2) 0.712 N
(3) 0.066 N
(4) 1.37 N

5. A rectangular film of liquid is extended from (4 cm × 2 cm) to (5 cm × 4 cm). If the work done is 3×10^{-4} J, the value of the surface tension of the liquid is : **[NEET 2016]**

(1) 0.2 Nm^{-1}
(2) 8.0 Nm^{-1}
(3) 0.250 Nm^{-1}
(4) 0.125 Nm^{-1}

6. Three liquids of densities ρ_1, ρ_2 and ρ_3 (with $\rho_1 > \rho_2 > \rho_3$), having the same value of surface tension T, rise to the same height in three identical capillaries. The angles of contact θ_1, θ_2 and θ_3 obey : **[NEET 2016]**

(1) $\frac{\pi}{2} < \theta_1 < \theta_2 < \theta_3 < \pi$
(2) $\pi > \theta_1 > \theta_2 > \theta_3 > \frac{\pi}{2}$
(3) $\frac{\pi}{2} > \theta_1 > \theta_2 > \theta_3 \geq 0$
(4) $0 \leq \theta_1 < \theta_2 < \theta_3 < \frac{\pi}{2}$

7. A soap bubble having radius of 1 mm, is blown from a detergent solution having a surface tension of 2.5×10^{-2} N/m. The pressure inside the bubble equals at a point Z_0 below the free surface of water in a container. Taking g = 10 m/s^2, density of water = 10^3 kg/m^3, the value of Z_0 is : **[NEET-2019]**

(1) 1 cm
(2) 0.5 cm
(3) 100 cm
(4) 10 cm

8. A liquid does not wet the solid surface if angle of contact is : **[NEET_Covid_2020]**

(1) equal to 45°

(2) equal to 60°

(3) greater then 90°

(4) zero

9. If a soap bubble expands, the pressure inside the bubble: **[NEET-2022]**

(1) decreases

(2) increases

(3) remains the same

(4) is equal to the atmospheric pressure

ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9
Ans.	3	3	2	1	4	4	1	3	1