6.1 Surface tension on tin basis of motccuiar

Q.l. Define intermolecular force. Write down its two properties.

Ans: Definition:

The force of attraction or repulsion acting between the molecules of substances is called intermolecular force.

This force is more in solids, less in liquids and least in gases.

Properties:

i. These forces do not obey inverse square law.

ii. It is a force of very short range, about 10"[9] m.

***Q.2. What is cohesive force?** **[Feb 2013 old course]**

Ans:

i. *The force of attraction between two molecules of the same substance is called cohesive force. This property is called cohesion.*

ii. The definite shape and rigidity of a solid body is due to cohesion.

iii. It is strongest in solids.

iv. Examples: Force of attraction between two water molecules, force of attraction between two bromine molecules in a container.

***Q.3. What is adhesive force?** **[Feb 2013 old course]**

Ans:

i. *The force of attraction between two molecules of different substances is called adhesive force. This property of substance is called adhesion.*

ii. It exists at the liquid-solid, liquid-gas interface.

iii. It is weaker than cohesive force.

iv. Examples: Sticking of paint on the wall, chalk particles on blackboard, water to the container, etc.

***Q.4. Define the following terms.**

i. **Range of molecular attraction.** **[Feb 2013 old course]**

ii. **Sphere of influence.** **[Feb 2013 old course]**

Ans:

i. **Range of molecular attraction:**

The maximum distance between two molecules upto which the intermolecular forces are effective is called the range of molecular attraction.

It is of the order of 10^{-9} m in solids and liquids, so it is called short range force.

ii. Sphere of influence:

An imaginary sphere drawn with given molecule as centre and radius equal to the molecular range is called the sphere of influence.

The molecule is attracted by other molecule within a range of sphere of influence otherwise it is negligible.

Q.5. Define surface film and free surface of liquid.

Ans: Surface film:

A layer of surface of liquid whose thickness is equal to molecular range of attraction is called surface film.

All the molecules located inside the surface film experience inward attractive force.

Free surface of liquid:

Surface of liquid which is in contact with air is called free surface of liquid.

A free surface always tries to minimise its surface area.

Q.6. Explain the behaviour of free surface of liquid with suitable examples.

Ans: The free surface of liquid behaves as a stretched elastic membrane.

i. Small insects are able to walk on free surface of liquid. It is so because free surface of liquid acts as stretched membrane with maximum surface tension which balances the weight of insect.

ii. If a blade is kept gently on the surface of water, it floats on it. It is so because weight of blade is balanced by surface tension.

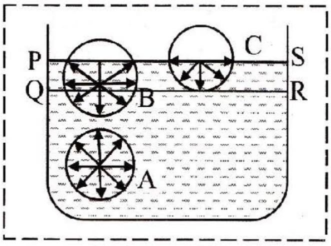
***Q.7. Explain surface tension on the basis of molecular theory. [Mar 04, 05,06, 08]**

Ans: Molecular theory of surface tension:

i. Let PQRS = Surface film of liquid in a container containing liquid.

PQ = SR = Molecular range.

ii. Now consider three molecules A, B and C in a liquid in a vessel such that the molecule A is well inside the liquid, the molecule B within R is just below the free surface of liquid and molecule C is on the free surface as shown in the figure.



i. The sphere of influence of the molecule A is entirely inside the liquid and the molecule is surrounded by its nearest neighbours on all sides. Hence, A is equally attracted from all Sides, so that the resultant cohesive force acting on the molecule A is zero. The molecule A is free to move anywhere within the liquid.

ii. For the molecule B, a part of its sphere of influence is outside surface. This part contains air molecules whose number is negligible compared to the number of molecules in an equal volume of the liquid. Therefore, the molecule B experiences a net cohesive force downward.

iii. For the molecule C, the upper half of the sphere of influence is outside the liquid surface. But number of air molecules in sphere of influence is very small as compared to liquid molecules. Therefore, the resultant cohesive force acting on the molecule C is maximum in downward direction.

iv. Thus, all molecules lying within a surface film experience a net inward puli which depends upon the relative number of molecules between lower and upper halves of sphere of influence.

v. The surface area is proportional to the number of molecules on the surface. To increase the surface area, molecules must be brought to the surface from within the liquid. For this, work must be done against the cohesive forces. This work is stored in the form of potential energy which increases with increase in area. Liquid has a tendency to have minimum potential energy. To attain minimum potential energy, it tries to reduce the number of molecules on the surface so as to have minimum surface area. Thus, liquid behaves like a stretched elastic membrane,

Note:

1. Solids have a definite shape because of largest intermolecular forces. Due to the rigid shape, they resist all kinds of forces.
2. In lubricating machine parts, oil has property of adhesion which prevents them from wear and tear.
3. A liquid wets solid rod due to adhesive force.

<u>**6.2 Surface energy**</u>

Q.8. Define and explain the concept of surface energy. State its unit and dimensions.

Ans: Definition:

The extra energy that a liquid surface holds under isothermal condition is called surface energy.

Explanation:

i. A molecule well within the liquid is surrounded by the similar liquid molecules from all sides and hence there is no resultant force acting on it.

ii. A molecule within surface film is surrounded by similar liquid molecules only on one side of the surface.

iii. On the other side, it may be surrounded by air molecules or molecules of the vapour of the liquid, whose density is much less as compared to density of liquid molecules.

iv. Thus, there is a resultant inward force on a molecule in the surface film. This force tries to pull the molecule into the liquid.

v. Molecules are pulled from the surface layer to the interior of liquid and new molecules from the interior go towards the surface film to the empty space.

vi. When a molecule is taken from the inside to the surface layer work is done against the inward resultant force. This work is stored in the surface of liquid in the form of potential energy.

vii. Potential energy is greater for molecule at the surface film as compared to a molecule well inside the liquid.

viii. This extra potential energy is called the surface energy.

ix. Unit: J in SI system and erg in C.G.S. system.

x. Dimensions: $[M^1L^2T^{-2}]$

Q.9. What is surface energy per unit area?

Ans:

i. *Potential energy per unit area of the liquid surface under isothermal condition is called surface energy per unit area.*

ii. Unit: J/m^2 in SI system and erg/cm^2 in CGS system ($1\ J/m^2 = 10^3\ erg/cm^2$)

iii. Dimensions: $[M^1L^0T^{-2}]$

***Q.10.Why do molecules of a liquid lying in the surface film possess extra energy?**

Ans:

i. Molecules lying in the surface film are surrounded by liquid molecules as well as air molecules,

ii. Thus, there is a resultant downward force of cohesion which increases as we move from bottom to the top of surface film.

iii. To take molecule into surface film from anywhere below it, some work is to be done against the downward force of cohesion.

iv. This work is stored in the form of P.E. Thus, molecules of all liquids lying in the surface film possess extra energy.

6.3 Surface tension :

***Q. 11.Define and explain surface tension. Write down its unit and dimension.**

[Mar 09]

Ans: Definition:

Surface tension is defined as the force per unit length acting at right angles to an imaginary line drawn on the free surface of liquid.

If 'F' is the force acting on the imaginary line of length T then surface tension 'l' is given by,

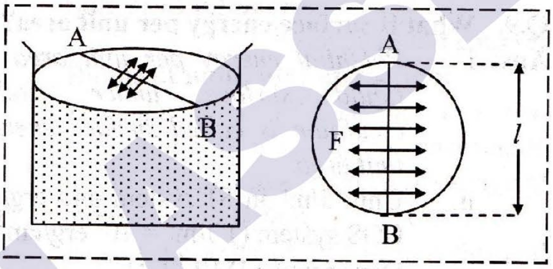
$$T = \frac{F}{l}$$

Explanation:

i. Consider a free surface of liquid in a beaker which acts like a stretched membrane. All the molecules on the surface experience a stretching force.

ii. Imagine a straight line AB drawn on the free surface of the liquid. Molecules of liquid along this line will be acted upon by a force F on each side due to surface tension. This force per unit length of the line AB measures surface tension.

iii. The direction of surface tension is perpendicular to AB and tangential to liquid surface.



iv. Unit: N/m or J/m in SI system and dyne/cm or erg/cm^2 in CGS system.

$1\ N/m = 10^3$ dyne/cm.

v. Dimensions: $[M^1L^0T^{-2}]$

***Q.12. Obtain the dimensions of surface tension.**

Ans:

i. Surface tension, $T = \frac{\text{Force(F)}}{\text{Length}(l)}$

$$\text{Dimensions of } T = \frac{\text{Dimension of force}}{\text{Dimension of length}}$$

$$= \frac{[L^1M^1T^{-2}]}{[L]} = [M^1L^0T^{-2}]$$

ii. Also, surface tension is numerically equal to surface energy per unit area.

\ $T = \frac{E}{A}$

Dimensions of

$$T = \frac{\text{Dimension of surface energy}}{\text{Dimension of area}}$$

$$= \frac{[L^2M^1T^{-2}]}{[L^2]} = [M^1L^0T^{-2}]$$

Dimensions of surface tension is $[M^0L^0T^{-2}]$

***Q.13.What is surface energy? Obtain the relation between surface tension and surface energy.**

[Feb 2013 old course, Oct 08, Oct 10]

OR

Derive the relation between surface tension and surface energy per unit area.

[Feb 13]

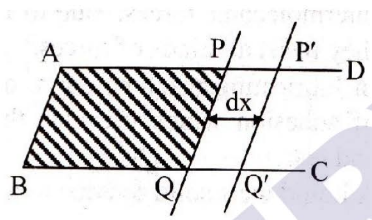
OR

Show that the surface tension of a liquid is numerically equal to the surface energy per unit area. [Oct 13]

Ans: Surface energy: *Refer Q. 8*

Relation between surface tension and surface energy:

i. Let ABCD be an open rectangular frame of wire on which a wire PQ can slide without friction.



ii. The frame held in horizontal position is dipped into soap solution and taken out so that a soap film APQB is formed. Due to surface tension of soap solution, a force ‘F* will act on the wire PQ which tends to pull it towards AB.

iii. Magnitude of force due to surface tension is, $F = 2Tl$ $[\because T = F/l]$

(A factor of 2 appears because soap film has two surfaces which are in contact with wire.)

iv. Let the wire PQ be pulled outwards through a small distance ‘dx’ to the position P’Q’, by applying an external force F’ equal and opposite to F. Work done by this force,

$DW = F'dx = 2T/dx.$

v. But, $2l$dx = DA = increase in area of two surfaces of film.

\ $DW = T DA$

v. This work done is stored in the form of potential energy (surface energy).

Surface energy, $E = TDA$

\ $\frac{E}{Da} = T$

Hence, surface tension = surface energy per unit area,

vii Thus, surface tension is equal to the mechanical work done per unit surface area of the liquid, which is also called as surface energy.

Q.14. How are small insects able to walk on the water surface?

Ans:

i. The free surface of water behaves as stretched membrane due to surface tension.

ii. Due to weight of insect, the membrane is stretched. Thus surface tension acts in an inclined manner.

iii. The vertical component of surface tension balances the weight of the insect.

iv. Hence, insects are able to walk on the surface of water.

Q.15. Explain why oil spreads over the surface of water while water does not do so.

Ans:

i. The surface tension of oil is less than the surface tension of water,

ii. Thus, when oil is dropped on the surface of water, it spreads in all directions due to the higher force of surface tension of water.

Q.16. Explain why the ends of a glass tube become round on heating.

Ans:

i. When the ends of a glass tube are heated, the glass melts.

ii. Due to the surface tension, the molten glass tube tends to have minimum surface area.

iii. The molten glass at all points on the end of tube tends to take spherical shape and as such the ends become round.

Q.17.Explain why surface tension of a liquid is independent of the area of the surface.

(NCERT)

Ans:

i. Surface tension of a liquid is the force acting per unit length on a line drawn tangentially to the liquid.

ii. Since this force is independent of the area of liquid surface; therefore surface tension is also independent of the area of the liquid surface.

Q.18. Give reason for the following.

i. **Hairs of brush when taken out of liquid cling together.**

ii. **Rain drops are spherical.**

iii. **A small irregular piece of camphor dropped on the surface of pure water dances (helter-skelter) above the surface.**

iv. **Oil spreads on cold water but remain as a drop on hot water.**

Ans:

i. As water has no free surface, the tips of the hair of the brush remain spreaded. A thin water film is formed at the tips of the hair. When the brush is taken out of liquid, the surface of the water film occupies minimum possible area due to surface tension and the hairs cling together.

ii. Due to surface tension, the liquid tries to acquire minimum surface area. For a given volume, sphere has minimum surface area, therefore the liquid assumes the shape of a drop.

iii. Irregular shaped camphor dropped on water decreases the surface tension of the water gradually. Because of their irregular shape, the unbalanced forces make it move haphazardly in different directions.

iv. It is due to the fact that surface tension of oil is less than that of the cold water but is greater than that of the hot water.

Note:

1. Force due to surface tension, $F = Tl$
2. For circular thick ring,
   $F = F_1 + F_2 = T \times 2pr_1 + T \times 2pr_2 = 2pT (r_1 + r_2)$
3. For a thin ring, $F = Tl = T \times 2p (r + r) = 4prT$
4. For circular plate, $F = Tl = T \times 2pr = 2p rT$
5. For square frame, $F\ Tl = T \times 2 \times 4l = 8Tl$
6. For square plate, $F = Tl = T \times 4l = 4\ Tl$
7. For rectangular frame, $F = Tl = T (4l + 4 b)$
8. For rectangular plate, $F = Tl = T (2l + 2b)$
9. Work done against force due to surface tension, $W = TDA$
10. Work done in forming a liquid drop of radius r and surface tension T, $W = 4pr^2T$
11. Work done to split a liquid drop of radius R into n identical droplets,
    $W = 4p^2T(n^{1/3} - 1)$
12. Work done to form a bigger drop of liquid by n identical droplets each of radius r,
13. In the case of soap bubble, there are two surfaces.

6.4 Angle of contact

Q.19.*What is meant by an angle of contact? State the main characteristics of angle of contact. [Mar 01,09, Oct 09]

Ans: *When a liquid is in contact with a solid, the angle .between tangent drawn to the free surface of the liquid and the surface of solid at the point of contact measured inside the liquid is called angle of contact.*

Characteristics:

i. The angle of contact is constant for a given liquid-solid pair.

ii. The value of angle of contact depends upon nature of liquid and solid in contact.

iii. It depends upon the medium which exists above the free liquid surface.

iv. The angle of contact changes due to impurity or temperature.

Note:

A small contamination of the surface causes a large change in the angle of contact.

***Q.20.Explain why the free surface of some liquid in contact with a solid is not horizontal.**

OR [Oct 99, Feb 03]

Explain the formation of concave and convex surface of liquid on the basis of molecular forces. [Mar 11]

Ans:

i. To explain the phenomena, suppose a liquid molecule **'A'** is situated in the liquid surface which is in contact with the solid as shown in fig. (a),

ii. Sphere of influence is drawn, which shows that sphere of influence is partly in solid, liquid and air.

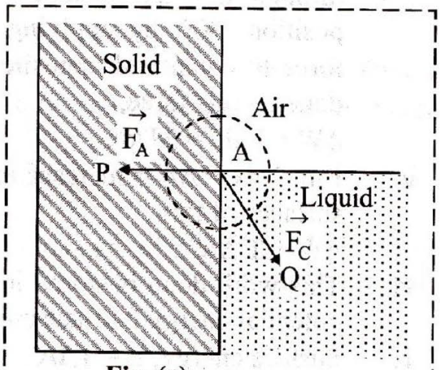


Fig. (a)

iii. The molecule 'A' is acted upon by the following four forces:

a. Net adhesive force exerted by the molecules of the solid $\overline{AP}$ as $\vec{F}_A$.

b. Net cohesive force exerted by the molecules of liquid $\overline{AQ}$ as $\vec{F}_C$.

c. Net adhesive force exerted by the molecules of air, as the number of air inolecule in sphere of influence of molecules 'A' is very small. Hence, resultant adhesive force between air and liquid is neglected.

d. Gravitational force is equal to the weight of the molecule. It is also small and therefore neglected.

iv. So the behaviour of the molecule depends upon two forces $\vec{F}_A$ and $\vec{F}_C$.

Case 1:

In case of liquid which partially wets the solid (e.g. kerosene), resultant adhesive force $\vec{F}_A$ between liquid and solid acting on a molecule A is stronger than resultant cohesive force $\vec{F}_C$ between liquid molecules. Therefore, resultant force F_R lies inside die solid as shown in fig. (b).

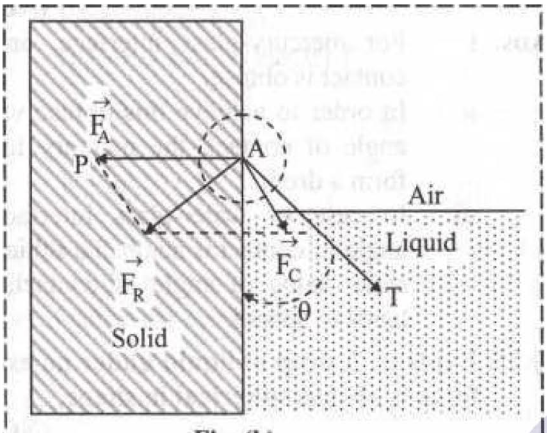


Fig. (b)

Inequilibrium state, the tangent AT to the liquid surface is perpendicular to the resultant force $\vec{F}_R$.

Therefore, liquid creeps upwards on the solid surface. Hence, the liquid surface in contact with solid is concave upward and angle of contact is acute.

Case 2:

In case of the liquid which does not wet the solid (e.g. mercury), the resultant adhesive force $\vec{F}_A$ between liquid and solid on a molecule A is smaller than resultant cohesive force $\vec{F}_C$.

Therefore, their resultant force $\vec{F}_R$ lies inside the liquid as shown in (c).

In equilibrium state, the tangent AT to the liquidsurface is perpendicular to the resultant force $\vec{F}_R$. Therefore, liquid creeps downwards on the solid surface. Hence, the liquid surface in contact with solid is convex upward and angle of contact is obtuse

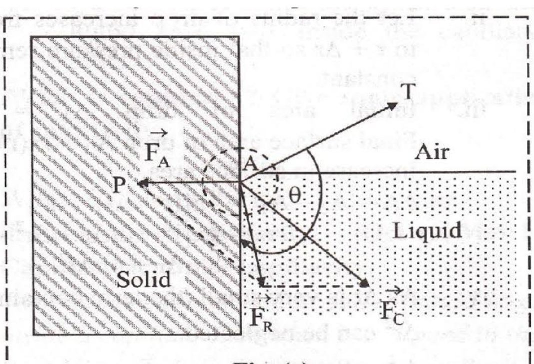


Fig. (c)

Case 3:

In case of the liquid which completely wets the solid (e.g. pure water) the resultant adhesive force

$\vec{F}_A$ acting on molecule A is very strong and resultant cohesive force $\vec{F}_C$ can be neglected. Therefore, their resultant force $\vec{F}_R$ lies along $\vec{F}_A$ as shown in fig. (d). In equilibrium state, the free surface of water is always perpendicular to resultant force F_R acting on molecule A. The only force acting on molecule A is gravitational force acting vertically downwards and thus angle of contact is zero for pure water and clean glass.

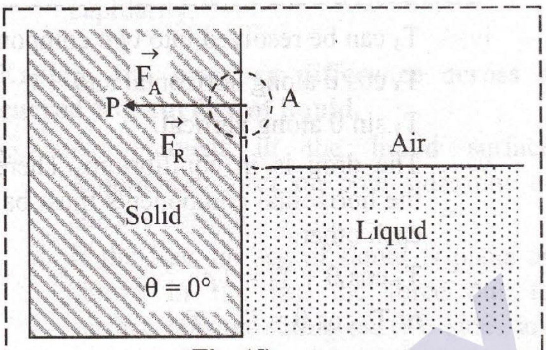


Fig. (d)

***Q.21. Draw labelled diagram to show angle of contact between**

i. **Pure Water and clean glass**

ii. **Mercury and clean glass**

Ans:

i. *Refer Q. 20* (fig. d)

ii. *Refer Q. 20* (fig. c)

***Q.22. "The shape of impure water meniscus is concave whereas the shape of mercury meniscus is convex", explain.**

Ans:

i. Consider a liquid drop at equilibrium on the surface of a glass plate (solid).

ii. Three interfaces are formed:

a. solid-liquid,

b. solid-air and

c. liquid-air

iii. Let,

T_1 = surface tension for the solid-liquid interface.

T_2 = surface tension for the solid-air interface.

T_3 = surface tension for the liquid-air interface.

θ = angle of contact between solid and liquid as shown in fig. (a).

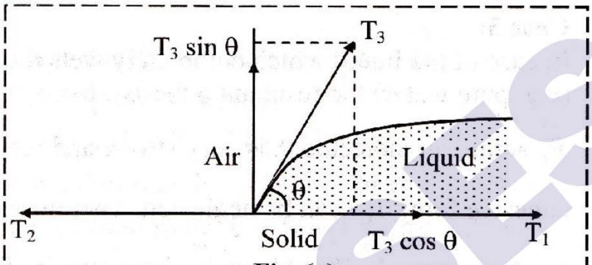


Fig. (a)

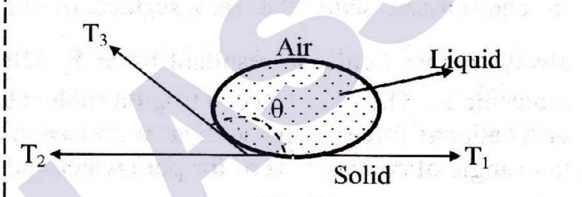


Fig. (b)

iv. T_3 can be resolved into two components: $T_3 \cos\theta$ along horizontal and $T_3 \sin\theta$ along vertical

v. The drop is in equilibrium. Therefore, the horizontal components must balance each other.

∴ $T_3 \cos\theta + T_1 = T_2$

or $T_3 \cos\theta = T_2 - T_1$

∴ $$\cos\theta = \frac{T_2 - T_1}{T_3} \quad \text{....(i)}$$

vi. In case of impure water, $T_2 > T_1$.

∴ cos θ is positive. Hence, angle of contact is acute. Thus, shape of meniscus is concave.

vii. If mercury drops are taken on the glass plate as shown in fig. (b), then $T_2 < T_1$. cos θ is negative.

∴ θ lies between 90° and 180° i.e. angle of contact is obtuse.

Thus, shape of mercury meniscus is convex.

Note:

1. If $T_2 - T_1 = T_3$, cos θ = 1 and 'θ' is nearly equal to zero.

2. If $T_2 - T_1 > T_3$ or $T_2 > T_1 + T_3$; $\cos\theta > 1$ which is impossible, liquid is spread over the solid surface and drop shall not be formed.

***Q.23. Explain why angle of contact of mercury with glass is obtuse while that of water with glass is acute.**
(NCERT) [Oct 05]

Ans:

Refer Q. 22

***Q.24. Explain: Water on a clean glass surface tends to spread out, while mercury on the same surface tends to form a drop.**
(NCERT)

Ans:

i. For mercury-glass interface, angle of contact is obtuse.

ii. In order to achieve this obtuse value of angle of contact, the mercury tends to form a drop.

iii. In case of water-glass interface, the angle of contact is acute. To achieve this acute value of angle of contact, water tends to spread.

Q.25. Explain: A drop of liquid under no external force is always spherical in shape. (NCERT)

Ans:

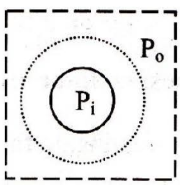
i. In the absence of external forces, the surface of the liquid drop tends to acquire the minimum surface area,

ii. In comparison with other shapes, sphere possesses the least surface area.

Hence, a liquid drop takes the spherical shape.

Q.26. *Explain excess pressure inside a liquid drop and soap bubble OR *Derive Laplace's law for spherical membrane.

Ans: Expression for excess pressure inside a drop:



i. Free surface of drops or bubbles are spherical in shape.

Let,

P_i = inside pressure of a drop or air bubble

P_0 = outside pressure of bubble

r = radius of drop or bubble.

ii. Let the radius of drop increases from r to $r + \Delta r$ so that inside pressure remains constant.

iii. Initial area of drop $A_1 = 4\pi r^2$,

Final surface area of drop $A_2 = 4\pi(r+\Delta r)^2$

Increase in surface area,

$$\Delta A = A_2 - A_1 = 4\pi[(r + \Delta r)^2 - r^2]$$
$$= 4\pi\,[r^2 + 2r\Delta r + \Delta r^2 - r^2]$$
$$= 8\pi r\Delta r + 4\pi\Delta r^2$$

iv. As Δr is very small, the term containing Δr^2 can be neglected.

$\therefore$ $\Delta A = 8\pi r\Delta r$

Work done by force of surface tension,

$dW = T\Delta A = (8\pi r\Delta r)T$ .....(i)

But, $dW = F\Delta r = (P_1 - P_0)\,A\Delta r$

From equation (i),

$(P_i - P_0)\,A\Delta r = (8\pi r\Delta Ar)\,T$

$$\therefore \quad P_i - P_0 = \frac{8\pi r\Delta rT}{4\pi r^2\Delta r} \qquad [\because\ A = 4\pi r^2]$$

$$\therefore \quad P_i - P_0 = \frac{2T}{r} \qquad \text{..... (ii)}$$

Equation(ii) represents excess pressure inside a drop or air bubble. It is also called Laplace's law of spherical membrane.

Note:

In case of soap bubble, there are two free surfaces in contact with air.

$$\therefore \quad \text{Excess pressure, } P_i - P_0 = \frac{4T}{r}$$

6.5 Capillarity and capillary action

Q.27. What is a capillary tube?

Ans:

i. *A glass tube having a very fine bore and uniform cross section is called a capillary tube.*

It is derived from latin word *capilla* which means hair.

Example: Blood capillaries, vascular bundles in plants tissue etc.

ii. If one end of a capillary tube is dipped in liquid, the level of liquid inside capillary either rises or falls as compared to the level of liquid in the outside of capillary in a container.

iii. If a capillary tube is dipped in a liquid ‘Which partially or completely wets the solid then the liquid level rises inside the tube.

iv. If a capillary tube is dipped in a liquid which does not wet the solid, then the liquid level falls inside the capillary tube.

***Q.28. What is capillarity? Give some applications of capillarity.**

OR

What is capillarity? State any ‘two illustrations of capillarity. [Oct 10, Mar 11]

Ans: Capillary action or capillarity:

The phenomenon of rise or fall of liquid level inside a capillary tube when it is dipped in the liquid is called capillary, yction or capillarity.

Applications of capillarity: :

i. Blotting paper contains small pores. These pores act as capillaries and hence quickly absorb ink.

ii. Wick in oil lamp contains threads, which act as capillaries and oil rises up in the wick of the lamp.

iii. Sap and water rise upto the topmost ; leaves in the tree by capillary action.

iv. Towel used in every day life is made up of cotton. It absorbs water or moisture from the body due to capillarity of towel.

v. Piece of sponge retains water, due to capillarity.

Q.29. Explain the pressure difference across a curved free surface of liquid.

Ans:

i. An element in the liquid surface experiences force on both sides due to surface tension.

If the free surface of liquid is plane as shown in fig. (a), the force due to surface tension acting on two sides are equal and opposite, so resultant force is zero and pressure difference on two sides of a plane surface is zero.

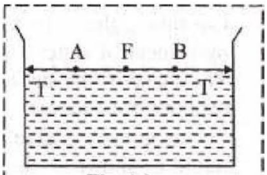


Fig. (a)

If the free surface of liquid is concave as shown in fig. (b),; the force due to surface tension acts vertically upward. Their resultant force also acts vertically upward and the pressure on the concave surface must be greater than the pressure on the other side. (Adhesion force greater than cohesion)

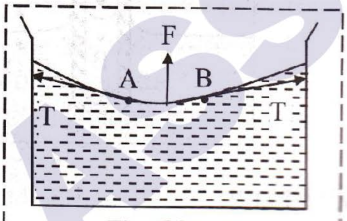


Fig. (b)

iii. If the free surface of liquid is fonvex as shown in fig. (c), the force due to surface tension acts vertically downward. Their resultant force also acts vertically downward. Thus pressure inside the liquid increases, (cohesion force greater than adhesion)

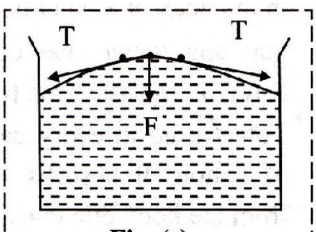


Fig. (c)

ii. From above explanation, it is concluded that

a. if free surface of liquid is Curved, then there' is a difference of pressures on the two sides of the surface. %

h. pressure on concave tide is greater than the pressure on convex side.

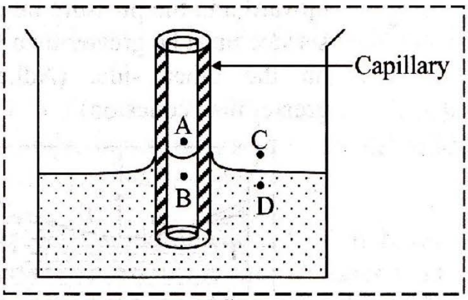
Q.30. Explain the cause of capillary action in a capillary tube.

Ans: Explanation of capillary action:

i. Suppose a capillary tube is dipped into water.

ii. Consider the situation before the movement of water inside the capillary. The shape of the surface of water in the capillary is concave.

iii. Let us consider three molecules in the liquid as shown in the figure. Molecule A is just above the curved surface inside the capillary. B is just below the curved surface inside the capillary. C is just above the plane surface outside the capillary. D is just below the plane surface outside the capillary.



iv. Let PA, PB, Pc and P_D be the pressures at points A, B, C and D respectively.

v. Since pressure on eohcave side of liquid surface is greater than on the convex side.

$P_A > P_B$

As the pressure is same on both sides of a plane surface,

$P_C = P_D$

$P_A = P_C$ = atmospheric pressure

\ PD > PB

vi. Though the points B and D are at same horizontal level in the liquid, the pressure at point D is greater than that at point B. Therefore the liquid cannot remain in equilibrium and it flows into the capillary tube and rises above the point B, till the pressure at B becomes the same as that at D. This is why liquid rises up inside the capillary tube.

vii. For mercury, liquid meniscus is convex, therefore pressure at a point just below the Curved surface is more than the point at same horizontal level outside the capillary, due to which liquid flows outside the capillary and fall of liquid inside the capillary is observed.

***Q.31. Obtain an expression for the rise of liquid in a capillary tube.**

OR

Derive an expression for height of liquid column when a capillary tube is vertically dipped in a liquid. [Oct 09]

Ans: Expression for capillary rise:

i. When glass capillary tube i$ dipped into a liquid, then the liquid rises in the capillary.

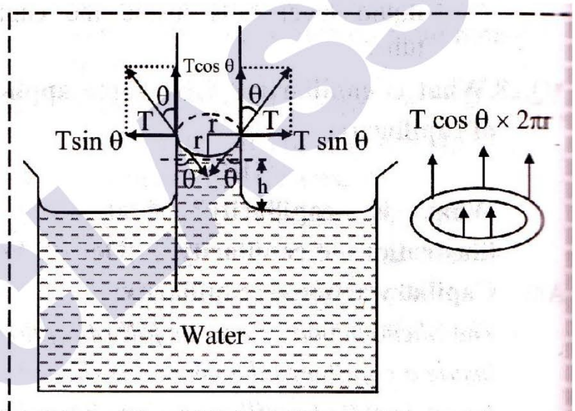
Let, r = radius of capillary tube

h = height of liquid level in the tube

T = surface tension of liquid

r = density of liquid

g = acceleration due to gravity



Rise of liquid in capillary tube

ii. The force of magnitude T acts on unit length of liquid surface which is in contact with wall of capillary tube.

This force can be resolved into two components;

a. T cosq-vertically upward and

b. T sinq-along horizontal

iii. Vertical component is effective. Horizontal component is not responsible for capillary rise.

iv. Total vertical force acting on liquid column = force per unit length x circumference

= T cosq × 2pr

v. Upward force balances weight of liquid column.

It is given by, W = mg = Vrg = pr²hpg where, V = volume of liquid rise in the tube.

v. If liquid in meniscus is neglected, then for equilibrium.,

$2pr\ T \cos q = pr^2\ h\ rg$

\ $T = \dfrac{hrr\ g}{2\cos q}$

\ $h = \dfrac{2T\cos q}{rr\ g}$ ...... (i)

This is the required expression for rise of liquid in capillary tube.

If r and T being given, then h can be easily determined,

vi. From equation (i), it can be concluded that.

a. $h\ \mu\ \dfrac{1}{r}$ b. $h\ \mu\ \dfrac{1}{r}$

c. $h\ \mu\ T$

where, r = constant.

viii. For pure water, $q = 0^0$

\ $\cos 0^0 = 1$, $r = 1$ g/cc

In this case, $T = \dfrac{hrg}{2}$

or $h = \dfrac{2T}{rg}$

Note:

In capillary tube experiment, some liquid rises within the curved surface of liquid. Its volume is neglected. If the small volume of liquid in the meniscus is taken into account,

then h is replaced by $\left(h + \dfrac{r}{3}\right)$.

In this case, $T = \dfrac{rr\ g}{2\cos q}\left(h + \dfrac{r}{3}\right)$

***Q.32. What will happen to the rise of liquid in a capillary tube if its top end is closed?**

Ans:

i. There is a small rise in the capillary tube, if the top of capillary tube is closed.

ii. It is so because the rise of liquid in capillary tube due to surface tension is opposed by the downward force exerted by the compressed air above the liquid in the tube.

iii. This downward force increases with increase in height of liquid column.

iv. Therefore, a small rise of liquid column is possible in a capillary tube with a closed top.

***Q.33. When a chalk piece is immersed in water, bubbles are emitted. Why?**

Ans:

i. When a chalk piece is immersed in water then pores of chalk act as capillaries.

ii. Water begins to rise in these capillaries expelling the air inside it.

iii. Thus, expelled air comes out on the surface of water in the form of bubbles.

Q.34. Explain why water with detergent dissolved in it should have small angle of contact. (NCERT)

Ans:

i. Clothes have narrow, spaces in the form of capillaries.

ii. The rise of liquid in a capillary tube is directly proportional to cos 0.

iii. If 0 is small, cos 0 will be large due to which capillary rise will be more.

iv. Hence, the detergent will penetrate more in clothes.

Note:

1. Excess pressure inside air bubble is
   P = 2T/r

2. Excess pressure inside a soap bubble is P = 4T/r because soap bubble has two free surfaces.

3. Radius of interface when two soap bubbles of different radii are in contact,
   $r = r_1\ r_2 / r_2 - r_1$.

4. If a capillary tube is tilted at an angle a with vertical, then length of liquid column increases inside the tube. It is given by,

   $l = \dfrac{h}{\cos a}$

   where, h = vertical height of liquid column.

***Q.35. "Tents are coated with a thin layer of aluminium hydroxide," Why?**

Ans:-

i. Tents and umbrella cloth are made of tightly -woven fabric so that water with its high surface tension cannot easily penetrate

ii. But falling raindrops can overcome the suface tension and wet the fabric which will then start seeping of water to its other side.

iii. Aluminium hydroxide is water insoluble and water repellent. Thus, it drains off the raindrops before they can wet the fabric.

iv. Hence, tents are coated with a thin layer of aluminium hydroxide.

6.6 Effect of impurities and temperature on surface tension of liquid

***Q.36. Explain the effect of presence of impurities on surface tension of liquid.**

Ans: Effect of impurities on surface tension:

The effect of impurities on surface tension of liquid can be either due to soluble impurities or insoluble impurities on the surface of liquid.

i. **Effect of soluble impurities:**

In the case of highly soluble impurities like common salt, the solute molecules are attracted more strongly to liquid molecules. This results in increase of surface tension because the force of attraction solute molecules exceeds surface energy.

ii. **Effect of insoluble or partly soluble impurities:**

If impurity is insoluble or partly soluble in liquid, surface tension of liquid decreases. This is because liquid molecules move inside the surface of liquid. In place of these molecules, the insoluble or partly soluble impurity added takes up the place. This gives higher concentration of solute molecules in outer layer than in interior of liquid. This results in decrease of surface tension.

Example: Soap or detergent in water decreases the surface tension of water and helps in cleaning of cloths.

Q.37. Explain the effect of temperature on surface tension.

Ans: Effect of temperature on surface tension:

i. In most of the liquids, surface tension decreases with increase in temperature. When the liquid is heated, the molecules of liquid are in random motion with greater velocity.

ii. Faster moving molecules of hot liquid are not bounded together as strongly as those in cooler liquid. Hence, surface tension of the liquid decreases with increase in temperature.

iii. In small range of temperature, surface tension varies as,

$T = T_0 (1 - \alpha\Delta t)$

where, T_0 = surface tension at 0°C,

T = surface tension at t°C,

α = temperature coefficient of liquid,

Δt = temperature difference

Q.38. Define critical temperature. Explain the effect of contamination on surface tension.

Ans: Definition:

The temperature at which surface tension of liquid becomes zero is called critical temperature.

Effect of contamination on surface tension:

The presence of contaminated materials like dust particles or lubricating materials on the liquid surface decreases its surface tension.

***Q.39. A steel blade floats on the surface of pure water but sinks when detergent is added to the water. Why?**

Ans:

i. When a steel blade is kept on pure water gently, then blade starts floating on the water surface. It is so because at the surface film of water, weight of the blade is balanced by vertical component of force due to surface tension.

$\therefore \quad Mg = T \sin\theta \times 2l$

where, M = mass of the blade

ii. By adding detergent in water, surface tension of water reduces.

In this case,

$Mg > T \sin\theta \times 2l$

Hence, steel blade sinks.

Q.40. Explain cleaning action of detergent or soap for washing cloths.

Ans: Cleaning action of detergent or soap:

i. Detergent or soap is added with water. Dirty clothes are soaked and rubbed in it for sometime. This results in reducing surface tension of water.

As a result, water penetrates the pores of cloths easily and cleans the dirt on the cloths.

[r]Q.41. What is the effect of temperature on angle of contact?

Ans: As temperature increases, surface tension decreases thus angle of contact decreases.

Note:

1. Wetting takes place when adhesive force between the molecules of the solid and liquid is large as compared to the cohesive force between the molecules of the liquid.
2. Angle of contact between water and glass is very small but that between mercury and glass is very large i.e. about 135°.

Summary :

1. Surface tension is the property of liquid only. This property tends to minimise the surface area of liquid. Numerically, surface tension is the force per unit length of liquid surface.

$$T = \frac{F}{l}$$

2. Intermolecular forces are of two types; cohesive force and adhesive force. Cohesive force is the attraction of molecules of same substances but adhesive force is the attraction of molecules of different substances.
3. The concept of surface tension can be explained on the basis of molecular theory.
4. If a liquid drop increases its surface area, then work needs to be done. This work is numerically equal to TDA.
5.

i. Excess of pressure inside the liquid drop is,

$$P = P_i - P_0 = \frac{2T}{r}$$

ii. Excess of pressure inside the soap bubble is, $P = P_i - P_0 = \frac{4T}{r}$

6. Angle of contact (i) increases with increase in temperature, (ii) decreases on adding soluble impurity to a liquid and (iii) does not depend upon the inclination of the tube.
7. When angle of contact is 90° (eg. water in a silver capillary tube), the level of liquid in the capillary is horizontal and there will be no rise of liquid in the capillary tube but the liquid will wet the walls of the capillary tube. In this case, cohesive force is equal to adhesive force.
8. If a capillary tube is immersed in a liquid, then there is a rise or fall of liquid level depending upon angle of contact. It is given by $h = \frac{2T\cos q}{rpg}$. If cosq is positive, then liquid level rises but if cosq is negative, then liquid level is depressed.
9. Soap reduces the surface tension of liquid due to which it helps in better cleaning of clothes.

Formula :

1. **Surface tension:**

$$T = \frac{F}{l}$$

2. **Force due to surface tension:**

$F = T \times l$

3. **Surface energy:**

$E = TDA$

4. **Excess pressure inside an air bubble:**

$$P = \frac{2T}{r}$$

5. **Excess pressure inside a soap bubble:**

$$P = \frac{4T}{r}$$

6. **Total pressure in the air bubble at a depth h below the surface of liquid of density r :**

$$P = P_0 + hr g + \frac{2T}{r}$$

7. **Work done in increasing radius of air bubble from r_1 to r_2:**

$W = 4pT\,(r_2^2 - r_1^2)$

8. **Work done in forming soap bubble of radius r:**

$W = 8pr^2T$

9. **Work done in increasing radius of soap bubble from r_1 to r_2:**

$W = 8\kappa T\,(r_2^2 - r_1^2)$

10. **Rise or fall of liquid in capillary tube:**

$$h = \frac{2T \cos q}{rr\, g}$$

11. **Variation of surface tension with temperature:**

$T = T_0 (1 – aDT)$

Solved Problems

Example 1

The surface tension of water is 0.072 N/m. Find the vertical force required to detach a floating pin of length 2.5 cm from the surface of water. ***Solution:***

Given: T = 0.072 N/m,

$l = 2.5 \times 10^{-2}$m

To find: Force (F)

Formula: $T = \frac{F}{l}$

Calculation: The pin has no finite thickness.

The length of line of contact

$l = 2 \times 2.5 \times 10^{-2}$ m $= 5 \times 10^{-2}$ m

From formula,

F=Tl = **0.072** $\times 5 \times 10^{-2}$

F **= 3.6 × lO^{-2}N**

Ans: The vertical force required to detach the floating pin from the surface of water is **3.6 × 10^{-3} N**

Example 2

A thin circular wire ring of platinum has circumference of 8 cm. It floats horizontally on water. An upward force of 1.2 × 10^{-2} N can just detach the ring from water. Find the surface tension of water.

Solution:

Given: Circumference, c = 2pr = 8 cm

$= 8 \times 10^{-2}$ m,

$F = 1.2 \times 10^{-2}$N

To find: Surface tension (T)

Formula: $T = \frac{F}{l}$

Calculation: Length of the line of contact,

$l = 2 \times (2pr) = 2 \times 8 \times 10^{-2}$ m

From formula,

$$T = \frac{1.2\,´\,10^{-2}}{2\,´\,8\,´\,10^{-2}}$$

\ $T = 7.5 \times 10^{-2}$ N/m

Ans: The surface tension of water is 7.5×10^{-2} N/m.

Example. 3

A U-shaped wire is dipped in a soap solution and removed. The thin soap film formed between the wire and the light slider supports a weight of 1.5 × 10^{-2} N (which includes the small weight of the slider). The length of the slider is 30 cm. What is the surface tension of the film ?

Solution:

Given: $F = 1.5 \times 10^{-2}$ N, l = 30 cm = 0.3 m

To find: Surface tension (T)

Formula : $T = \frac{F}{l}$

Calculation : There are two sides of slider acted upon by the force F.

From formula,

$$T = \frac{F}{2l} = \frac{1.5\,´\,10^{-2}}{2\,´\,0.3}$$

\ $T = 2.5 \times 10^{-2}$ Nm^{-1}

Ans: The surface tension of the film is **2.5 × 10^{-2} Nm^{-1}.**

**Example 4*

Calculate the force required to take away a flat circular plate of radius 0.01 m from the surface of water. The surface tension of water is 0.075 N/m.

Solution:

Given: r = 0.01 m, T = 0.075 N/m

To find: Force (F)

Formula: F =T × l

Calculation: The plate is fiat

Force due to surface tension acts on only one face

l = 2pr

From formula,

F = 0.075 (2 × 3.142 × 0.01)

F = 0.150 × 3.142

$F = \mathbf{0.004717}$ **N**

Ans: The force required to take away the flat circular plate from the surface of water is **0.004717 N.**

***Example 5**

A horizontal circular loop of wire of radius 0.02 m is lowered into crude oil and forms a film. The force due to surface tension of the liquid is 0.0113 N. Calculate the surface tension of crude oil.

Solution:

Given: $r = 0.02$ m, $F = 0.0113$ N

To find: Surface tension (T)

Formula: $F = Tl$

Calculation: We have, $l = 2 \times 2\pi r$.

$\therefore$ From formula,

$F = 4\pi rT$

$$\therefore \quad T = \frac{F}{4\pi r}$$

$$\therefore \quad T = \frac{0.0113}{4 \times .142 \times 0.02}$$

Ans: The surface tension of crude oil is **0.04495 N/m.**

***Example 6**

A glass tube has inner diameter 1 mm and outer diameter 1.1 mm. When it is kept vertical and partially dipped in water, calculate the downward pull due to surface tension.

[Surface tension of water = 75 dyne/cm]

Solution:

Given: $d_1 = 1$ mm,

$$\therefore \quad r_1 = \frac{d_1}{2} = \frac{1}{2} = 0.5 \text{ mm} = 0.05 \text{ cm},$$

$d_2 = 1.1$ mm

$$\therefore \quad r_2 = \frac{d_2}{2} = \frac{1.1}{2} = 0.55 \text{ mm} = 0.055 \text{ cm},$$

$T = 75$ dyne/cm

To find: Force (F)

Formula: $F = Tl$

Calculation: $l = 2\pi T(r_1 + r_2)$

From formula,

$F = 2\pi T(r_1 + r_2)$

$= 2 \times 3.142 \times 75\,(0.05 + 0.055)$

$= 2 \times 3.142 \times 75 \times 0.105$

$F = 150 \times 3.142 \times 0.105$

$\mathbf{F = 49.49}$ **dyne**

Ans: The downward pull due to surface tension is **49.49 dyne.**

Example 7

A ring is cut from a platinum tube having 8.6 cm internal and 8.8 cm external diameter and suspended from a pan of a balance so that its lower surface is horizontal. When this surface is brought into contact with water kept in a dish, an extra weight of 3.9 g is required just to pull the ring away from water. Calculate the surface tension of water,

[g = 980 cm/s^2]

Example 8

A capillary tube having inner diameter 1 mm and the outer diameter 4 mm hangs vertically from one arm of the balance. If the lower end of the tube just touches a liquid of surface tension 2×10^{2} N/m, assuming that the liquid wets the tube, find the downward force due to surface tension acting on the tube.

Solution:

Given: $d_1 = 1$ mm, $r_1 = 0.5$ mm $= 0.5 \times 10^{-3}$ m,

$d_2 = 4$ mm, $r_2 = 2$ mm $= 2 \times 10^{-3}$ m,

$T = 3 \times 10^{-2}$ N/m

To find: Force (F)

Formula: $T = \frac{F}{l}$

Calculation: $l = 2\pi r_1 + 2\pi r_2 = 2\pi(r_1 + r_2)$

$= 2\pi(0.5 + 2) \times 10^{-3}$

$= 2\pi \times 2.5\,\pi\,10^{-3}$

$= 5\pi \times 10^{-3}$m

From formula,

$F = 3 \times 10^{-2} \times 5\pi \times 10^{-3}$

$= 15\pi \times 10^{-5} = 15 \times 3.14 \times 10^{-5}$

$\mathbf{F = 4.71 \times 10^{-4}}$ **N**

Ans: The downward force due to surce tension acting on the tube is $\mathbf{4.71 \times 10^{-4}}$ **N**.

Example 9

Calculate the work done when a spherical drop of mercury of radius 2 mm, falls from some height and breaks into a million droplets, each of the same size. The surface tension of mercury is T = 0.5 N/m.

[Mar 10]

Solution:

Given: $R = 2mm = 2 \times 10^{-3}$ m, $n = 10^6$.

To find : Work (W)

Formula : $W = T\Delta A$

Calculation : Volume of a single drop $= \frac{4}{3}\pi R^3$

and Volume of a single droplet $= \frac{4}{3}\pi R^3$.

∴ We have, $\frac{4}{3}\pi R^3 = n \times \frac{4}{3}\pi r^3$ or $R3 = nr^3$

∴ $r = \frac{R}{\sqrt[3]{n}} = \frac{2 \times 10^{-3}}{\sqrt[3]{10^6}} = 2 \times 10^{-5}$ m

From formula,

$W = T(n \times 4\pi r^2 - 4\pi R^2)$

$= 4\pi T(nr^2 - R^2)$

$= 4 \times 3.14 \times 0.5 \times [10^6 \times (2 \times 10^{-5})^2 - (2 \times 10^{-3})^2]$

$= 6.28 \times [(20 \times 10^{-3})^2 - (2 \times 10^{-3})^2]$

$= 6.28 \times (400 \times 4) \times 10^{-6}$

$= 6.28 \times 396 \times 10^{-6}$

∴ $W = 2486.88 \times 10^{-6} = \mathbf{2.486 \times 10^{-3}}$ **J**

Ans: The work done when a spherical drop of merccury falls from some height and breaks into a million droplets is $\mathbf{2.486 \times 10^{-3}}$ **J**.

Example 10

Calculate the surface energy of spherical mercury drop of radius 0.01 m due to surface tension. The S.T. of mercury is 0.46 N/m.

Solution:

Given: $r = 0.01$ m $= 1 \times 10^{-2}$ m,

$T = 0.46$ N/m

To find: Surface energy (E)

Formula: $E = T\Delta A$

Calculation: From formula,

$E = 4\pi r^2 T$ ...[Since $\Delta A = 4\pi r^2$]

∴ $E = 4 \times 3.14 \times (10^{-2})^2 \times 0.46$

$= 12.56 \times 0.46 \times 10^{-4}$

∴ $E = 5.78 \times 10^{-4}$ J

Ans : The surface energy of spherical mercury drop is 5.**78 ×** $\mathbf{10^{-4}}$ **J**.

Example 11

Calculate the work done in increasing the radius of a soap bubble from 1 cm to 2 cm. The surface tension of a soap solution is 30 dyne cm^{-1}.

Solution:

Given: $r_1 = 1$ cm, $r_2 = 2$ cm, $T = 30$ dyne/cm

To find: Work (W)

Formula: $W = T\Delta A$

Calculation: $A_1 = 4\pi r_1^2 = 4\pi \times 1^2 = 4\pi$ cm^2

$A_2 = 4\pi r_2^2 = 4\pi \times 2^2 = 16\pi$ cm^2

$\Delta A = A_2 - A_1 = (16\pi - 4\pi) = 12\pi$ cm^2

Since soap bubble has two surfaces From formula,

$W = 2T \times \Delta A$

$= 2 \times 30 \times 12\pi$

$= 2 \times 30 \times 12 \times 3.14$

∴ $W = \mathbf{2.26 \times 10^3}$ **erg**

Ans: The work done in increasing the radius of the soap bubble is $\mathbf{2.26 \times 10^3}$ **erg.**

Example 12

A drop of water of radius 6 mm breaks into number of droplets, each of radius 1 mm. How many droplets will be formed?

Solution:

Given: Radius of big drop, R = 6 mm,

Radius of smaller drop, r = 1 mm

To find: Number of droplets (n)

Formula:

$$\text{Number of droplets} = \frac{\text{Volume of big drop}}{\text{Volume of small drop}}$$

Calculation: Volume of big drop,

$V_1 = \frac{4}{3}\pi R^3$

Volume of each small drop, $V_2 = \frac{4}{3}\pi R^3$

From formula,

$$n = \frac{V_1}{V_2} = \frac{\frac{4}{3}\pi R^3}{\frac{4}{3}\pi R^3}$$

$$\therefore \quad n = \left(\frac{R}{r}\right)^3 = \left(\frac{6}{1}\right)^3 = \mathbf{216}$$

Ans: 216 droplets will be formed.

Example 13

There is a soap film on a rectangular frame of wire of area 4 × 4 cm². If the area of the frame is increased to 4 5 5 cm², find the work done in the process. [S.T of soap film = 3 × 10⁻²N/m]

Solution:

Given: $A_1 = - 4 \times 4\ cm^2 = 16\ cm^2$

$A_1 = 16 \times 10^{-4}\ m^2$

$A_2 = 4 \times 5\ cm^2 = 20\ cm^2$

$A_2 = 20 \times 10^{-4}\ m^2$

$T = 3 \times 10^{-2}\ N/m$

To find: Work(W)

Formula: $W = T\Delta A$

Calculation: A soap film has two surfaces

$$\therefore \quad W = 2T\Delta A$$
$$= 2T(A_2 - A_1)$$
$$= 2T(20 \times 10^{-4} - 16 \times 10^{-4})$$
$$= 2 \times 3 \times 10^{-2} \times \mathbf{4} \times 10^{-4}$$
$$= 6 \times 4 \times 10^{-6}\ J$$
$$= 24 \times 10^{-6}\ J$$

$\therefore$ Work done, W **= 2.4 x 10⁻⁵ J**

Ans: The work done in the process is

2.4 × 10⁻⁵ J.

***Example 14**

The total energy of the free surface of a liquid drop is 2π times the surface tension of the liquid. What is the diameter of the drop? [Assume all terms in SI unit]

Solution:

Given: $E = 2\pi T$,

To find: Diameter of drop (d)

Formula: $E = T\Delta A$

Calculation: $\Delta A = 4\pi r^2$

From formula,

$E = 4\pi r^2$

$\therefore \quad 2\pi T = 4\pi r^2 T$

$\therefore \quad 2r^2 = 1$

$$\therefore \quad r^2 = \frac{1}{2}$$

$$\therefore \quad r = \frac{1}{\sqrt{2}}$$

$$d = 2r = \frac{2}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = \sqrt{2}$$

d = **1.414 m**

Ans: The diameter of the drop is **1.414 m.**

Example 15

A water drop of radius 10⁻² m is broken into 125 equal droplets. Calculate gain in surface energy.

[Surface tension of water is 0.075 N/m]

Solution:

Given: $R = 10^{-2}$ m, n = 125, T = 0.075N/m

To find: Surface energy (E)

Formula: $\mathbf{E = T\Delta A}$

Calculation:

Let radius of each small droplet = r

Volume of original drop = Volume of 125 droplets

$$\therefore \quad \frac{4}{3}\pi R^3 = 125 \times \frac{4}{3}\pi r^3$$

$\therefore \quad R^3 = 125\ r^3 \qquad \therefore \quad R = 5r$

$$\therefore \quad r = \frac{R}{5} = \frac{10^{-2}}{5} = 2 \times 10^{-3} m$$

Now, $A_1 = 4\pi R^2$ and

$A_2 = 125 \times 4\pi r^2$

$$\therefore \Delta A = 125 \times 4\pi r^2 - 4\pi R^2 = 4\pi\left(\frac{125R^2}{25} - R^2\right)$$

$\Delta A = 16\pi R^2$

From formula,

$E = 0.075 \times 16\pi R^2$

$= 0.075 \times 16 \times 3.14 \times 10^{-4}$

$\therefore \quad E = \mathbf{3.768 \times 10^{-4}\ J}$

Ans: The gain in suface energy is 3.768×10^{-4}J

Example 16

1000 droplets of mercury each of radius 1 mm coalesce into a single drop. Find change in the surface energy. Surface tension of mercury is 0.465 J/m².

Solution:

Given: $n = 1000$, $r = 1$ mm $= 1 \times 10^{-3}$m,

$T = 0.465$ J/m^2

To find: Surface energy (E)

Formula: $E = T\Delta A$

Calculation: Let radius of drop = R

Volume of big drop

= 1000 × Volume of each small droplet

$$\therefore \quad \frac{4}{3}\pi R^3 = 1000 \times \frac{4}{3}\pi r^3$$

$$\therefore \quad R^3 = 1000\, r^3$$

$R = 10\, r = 10 \times 1 \times 10^{-3} = 10^{-2}$ m

Surface area of 1000 small drops,

$A_1 = 1000 \times 4\pi\, r^2$

$= 1000 \text{ x } 4\pi \times (10^{-3})^2$

$= 4\pi \times 10^{-3}$ m^2

Surface area of big drop

$A_2 = 4\pi R^2 \times 4\pi \times (10^{-2})^{-2}$

$= 4\pi \times 10^{-4}$ m^2

$$= 4\pi \times 10^{-3} \left(1 - \frac{1}{10}\right)$$

$= 4\pi \times 9 \times 10^{-4}$

From formula,

$E = 0.465 \times 4\pi \times 9 \times 10^{-4}$

$= 0.465 \times 36 \times 3.14 \times 10^{-4}$

$\mathbf{E = 5.256 \text{ x } 10^{-3} J}$

Ans: The change in the surface energy is **$5.256 \times 10\ ^3$ J.**

***Example 17**

Eight droplets of water, each of radius 0.2 mm, coalesce into a single drop. Find the change in total surface energy.

[Surface tension = 0.072 N/m]

Solution:

Given: $n = 8$, $T = 0.072$ N/m,

$r = 0.2$ mm $= 0.2 \times 10\ ^3$ m $= 2 \times 10^{-4}$ m

R = radius of coalesce drop

To find: Surface energy (E)

Formula: $E = T\Delta A$

Calculation:

Volume of 8 drops of radius 'r' is equal to volume of single drop of radius **'R'**.

$$\therefore \quad \frac{4}{3}\pi r^3 n = \frac{4}{3}\pi R^3$$

$$\therefore \quad nr^3 = R$$

$$\therefore \quad R = r.\sqrt[3]{n} = r\sqrt[3]{8} = 2r$$

$R = 2 \times 2 \times 10^{-4}$ m

Total work done to coalesce the drops

$W = T\Delta A$

This work is equal to change in surface energy.

$\therefore \quad E = T \times 4\pi\,(nr^2 - R^2)$

$= T\Delta\, 4\pi\,[8 \times (2 \times 10^{-4})^2 - (4\ 5\ 10^{-4})^2]$

$= 4 \times 3.14 \times 0.072\ [8 \times 4 \times 10^{-8} - 16 \times 10^{-8}]$

$E = 1.446 \times 10^{-7}$ J

Example 18

A soap bubble of radius 12 cm is blown. Surface tension of soap solution is 30 dyne/cm. Calculate the work done in blowing the soap bubble.

[Oct 13]

Solution:

Given: $r = 12$ cm, $T = 30$ dyne/cm

To find: Work (W)

Formula: $W = T \times \Delta A$

Calculation:

Initial surface area of soap bubble = 0

Final surface area $\Delta A = 2 \times 4\pi r^2$

Increase in surface area $= 2 \times 4\pi^2$

From formula,

$W = 30 \times 8 \times 3.14 \times (12)^2$

$= 108518.4$ erg

$= 108518.4 \times 10^{-7}$ J

$W = 1.085 \times 10^{-2}$ J

Ans: The work done in blowing the soap bubble is **1.085×10^{-2}J.**

EXERCISE

Section A: Practice Problems

1. A needle 5 cm long can just rest on the surface of water without wetting. What is its weight?

   [Surface tension of water = 0.07N/m]

2. A thin wire is bent in the form of a rectangle of length 4 cm and breadth 3 cm. What force due to the surface tension do the sides experience when a soap film is formed in the frame? [S.T of soap solution = 0.030 N/m]

3. A thin and light ring of a material of radius 3 cm is rested flat on a liquid surface. When slowly raised, it is found that the pull required is 0.03 N more before the film breaks than after. Find the surface tension of the liquid.

4. Calculate the work done in order to triple the radius of a water drop of radius 2cm. The surface tension of water is 75 dyne/cm.

5. Calculate the work done in increasing the radius of a soap bubble from 2 cm to 8 cm, the surface tension of soap solution is 30×10^{-3}N/m.

6. A drop of radius 4 cm is broken into 125 equal small drops. Calculate the work done if surface tension of water is 75×10^{-3} N/m.

7. If 216 small identical drops of water combine to form a big drop, then find out the ratio of final surface energy to the total initial surface energy.

8. A capillary tube of radius 0.25 mm is immersed in water. The top end of the capillary tube projects by 10 mm above the surface of the water. Calculate the radius of curvature of the meniscus.

   [S.T. of water = 72 dyne/cm]

9. If the surface tension of water is 0.06 NoT^{1}, then calculate the capillary rise in a tube of a diameter 1 mm assuming $0 = 0°$.

10. A water film is formed between two straigl* parallel wires of 10cm each with separation of 1 cm. If the distance between the wire is increased by 0.1 cm, how much work is done? [T = 0.072 N/m]

11. A ring of glass is cut from a tube having 7.4 cm internal and 7.8 cm external diameter. This ring with its lower side horizontal is suspended from one arm of a balance so that the lower edge is just immersed in a vessel of water. It is found that an additional weight of 3.62g must be placed in the other scale pan to compensate for the pull of surface tension on the ring. Calculate the S. T. of water. [g= 9.8 m/s^{1}]

12. A capillary tube is kept in a vessel containing Hg. The level of Hg in capillary tube is found to be 2 cm, below the level of Hg in the vessel. If the same capillary tube is dipped in water, then calculate the rise of water in it. The angle of contact for water and Hg are respectively 0° and 135° and S.T of water $= 72 \times 10^{-3}$ N/m. S.T. of Hg is 465×10^{-3} N/m.

13. Water rises to a height of 10 cm in a capillary tube, and mercury falls to a depth of 3.42 cm in the same capillary tube. Angle of contact of mercury glass interface is 135°. Calculate the ratio of surface tension for water and mercury.

14. A soap bubble has radius 4 cm. What is the amount of additional work done in increasing its radius further by 2 cm. Surface tension of soap s? 0.03 N/m.

15. Two soap bubbles have radii in the ratio 2:3. Compare the excess of pressure inside these bubbles.

Section B : Theoretical Board Questions

1. What is capillarity? How is it used to determine the surface tension of a liquid which wets the glass? [Mar 96,00, Feb 02]

3. Define Surface tension. Describe Capillary tube experiment to determine the surface tension of a liquid with necessary foririula.

   [Mar 97, 03, Oct 98]

4. What is surface energy? Obtain the relationship between surface tension and surface energy. [Mar 98, Oct 01]

5. Define Molecular Range and Sphere of influence. What do you mean by adhesive and cohesive forces?

6. Define surface tension. State its S.I unit and dimensions. State any two characteristics of angle of contact. State any two applications of capillarity. [Oct 02]

7. Define-Surface tension. Obtain its dimensions. [Feb 03]
8. Explain why the angle of contact is acute for kerosene glass pair and is obtuse for mercury glass pair. [Oct 03]
9. Define range of molecular attraction and sphere of influence. [Oct 04]
10. Define
    i. Surface tension
    ii. Angle of contact. [Oct05]
11. What is angle of contact? Explain why the upper surface of mercury in a glass capillary tube is convex while for kerosene it is concave. [Feb 06]
12. Explain on the basis of molecular theory, why liquid surface in a container are some times.
    i. Convex upwards
    ii. Concave upwards [Oct06]
13. Define the terms:
    (a) Sphere of influence
    (b) Angle of contact. [Mar 08]
14. Define surface tension.
    Explain the effect of impurity on surface tension. [Oct08]
15. Draw a neat diagram for the rise of liquid in a capillary tube showing the components of a surface tension T. [Mar 10]
16. Define angle of contact. State its any two characteristics. [Oct11]
17. Explain why the angle of contact is acute for kerosene glass pair and is obtuse for mercury glass pair. [Mar 12]

Section C : Numerical Board Problems

1. Find the work done in blowing a soap bubble of radius 5 cm. Surface tension of soap solution is 25 dyne/cm. [Mar **96, Oct 00]**
2. A drop of mercury of radius 0.1 cm is broken into 8 droplets of same size. Find the work done if the surface tension of mercury is **540** dyne/cm. **[Mar 98]**
3. A liquid rises to a height of 9 cm in a glass capillary of radius 0.02 cm. What will be the height of liquid column in a glass capillary of radius 0.03 cm? **[Oct 98]**
4. A capillary tube of uniform bore is dipped vertically in water which rises by 7 cm in the tube. Find the radius of the capillary if the surface tension of water is 70 dyne/cm.
   [g = 980 cm/s] **[Mar 99]**
5. Calculate the work done in breaking a mercury drop of radius 1 mm into one thousand droplets of the same size. Surface tension of mercury is 525 x 10^{-3} N/m.
   [Mar 99]
6. A liquid of density 900 kg/m^3 rises to a height of 9 mm in a capillary tube of 2.4 mm diameter. If the angle of contact is 25°, find the surface tension of the liquid,
   [g = 9.8 m/s^2] [Oct 99]
7. Eight droplets of mercury each of radius 1 mm coalesce into a single drop. Find change in the surface energy. Surface tension of mercury is 0. 465 N/m.[Feb **01, Oct 04]**
8. Water rises to a height of 5 cm in a certain capillary tube. In the same capillary tube, mercury is depressed by 1.54 cm. Compare the surface tensions of water and mercury. [Given: Density of water = 1000 kg/m^3, Density of mercury=13600 kg/m^3, Angle of contact for water = 0° and Angle of contact for mercury - 130°] **[Oct 01]**
9. A soap bubble has diameter 2 cm. Calculate the work done to increase its diameter to 6 cm. [Surface tension of soap solution is 35 dynes/cm] [Feb02]
10. A glass plate 9.5 cm long and 0.5 cm thick is suspended in a trough containing water so that its length just touches the water surface. Calculate the downward force due to surface tension acting on the plate. [Surface tension of water -72 dyne/cm| **[Oct 02]**
11. Compare the amounts of work done in blowing two soap bubbles of radii in the ratio
    3 : 5. [Mar 05]
12. A drop of mercury 2 mm in diameter breakes into a million small spherical droplets, all of same size. Calculate the work done. (Surface tension of mercury = 460 × 10^{-3} N/m.)

Section D : Multiple Choice Questions

1. A 10 cm long needle can just rest on the surface of water Without wetting, its weight is [surface tension of water is 0.07 N/m]

(A) 0.014 N (B) 0.14N

(C) 1.4 N (D) 14 N

2. Surface tension is due to

(A) frictional forces between molecules.

(B) cohesive forces between molecules.

(C) adhesive forces between molecules.

(D) gravitational force.

3. Molecules on the surface of the liquid have

(A) maximum kinetic energy

(B) maximum potential energy

(C) minimum kinetic energy

(D) minimum potential energy

4. The spherical shape of rain-drop is due to

(A) density of the liquid

(B) surface tension

(C) atmospheric pressure

(D) gravity

5. The surface tension of a liquid is 5 N/m. If a thin film of the area 0.02 m^2 is formed on a loop, then its surface energy will be

(A) 5×10^{-2} J (B) 2.5×10^{-2} J

(C) 2×10^{-1} J (D) 3×10^{-1} J

6. A 10 cm long wire is placed horizontally on the surface of water and is gently pulled up with a force of 2×10^{-2} N to keep the wire in equilibrium. The surface tension, in Nm^{-1} of water is

(A) 0.1 (B) 0.2

(C) 0.001 (D) 0.002

7. The surface tension of a liquid is T. The increase in its surface energy on increasing the surface area by A is

(A) $\frac{A}{T}$ (B) A^2T

(C) AT (D) A^2T^2

8. Absorption of water by filter paper is due to ______ **[Mar 09]**

(A) cohesion (B) capillarity

(c) adhesion (D) elasticity

9. A soap film of surface tension 3×10^{-2} Nm^{-1} formed in rectangular frame, can support a straw. The length of the film is 10 cm. Mass of the straw the film can support is

(A) 0.06 g (B) 0.6 g

(C) 6 g (D) 60 g

10. Work done in splitting a drop of water of 1 mm radius into 10^6 droplets is [Surface tension of water = $72 \times 10^{-3} J/m^2$]

(A) 9.58×10^{-5}J

(B) 8.95×10^{-5} J

(C) 5.89×10^{-5} J

(D) 5.98×10^{-6} J

11. The smface tension of a liquid is 10^8 dyne/cm. It is equivalent to

(A) 10^5N/m (B) 10^6N/m

(C) 10^7N/m (D) 10^4N/m

12. If T is the surface tension of soap solution, the amount of work done in blowing a soap bubble from a diameter D to 2D is

(A) $2pD^2T$ (B) $4pD^2T$

(C) $6pD^2T$ (D) $8pD^2T$

13. When two soap bubbles of radius r_1 and r_2 ($r_2 > r1$) coalesce, the radius of curvature of common surface is

(A) $r_2 - r_1$ (B) $\frac{r_2 - r_1}{r_1 r_2}$

(C) $\frac{r_1 r_2}{r_2 - r_1}$ (D) $r_2 + n$

14. Hairs of shaving brush cling together when it is removed from water due to

(A) force of attraction between hairs.

(B) surface tension.

(C) viscosity of water.

(D) characteristic property of hairs.

15. It is not possible to write directly on a blotting paper or newspaper with ink pen because of

(A) viscosity (B) inertia

(C) friction (D) capillarity

16. Coatings used on raincoat are waterproof because

(A) water is absorbed by the coating.

(B) cohesive force becomes greater.

(C) water is not scattered away by the coating.

(D) angle of contact decreases.

17. A soap bubble A of radius 0.03 m and another soap bubble B of radius 0.04 ml are brought together so that the combined bubble has a common interface of radius r, then the value ofr is

(A) 0.06 m (B) 0.012 m

(C) 0.12 m (D) 0.035 m

18. Which of the following is incorrect?

(A) Angle of contact, q < 90, if cohesive force < adhesive force.

(B) Angle of contact, q > 90, if cohesive force > adhesive force.

(C) Angle of contact, q = 90, if cohesive force = adhesive force.

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

19. The work done in blowing a soap bubble from initial diameter of 4 cm to final diameter of 40 cm is [S.T of soap bubble is 0.04 N/m]

(A) 398×10^{-2} J (B) 39.8×10^{-2} J

(C) $3.98 \text{ x } 10^{-2}$ J (D) 3981×10^{-2} J

20. A liquid does not wet the sides of a solid, if the angle of contact is

(A) zero (B) 120°

(C) 45° (D) 90°

21. 'n' droplets of equal size of radius r coalesce to form a bigger drop of radius R. The energy liberated is equal to .

(T = Smface tension of water) [Feb 2013]

(A) $4pR^2T[n^{\frac{1}{3}} - 1]$

(B) $4pr^2T[n^{\frac{1}{3}} - 1]$

(C) $4pR^2T[n^{\frac{2}{3}} - 1]$

(D) $4pr^2T[n^{\frac{2}{3}} - 1]$

22. One thousand small water droplets of equal size combine to form a big drop.

The ratio of the final surface energy to the initial surface energy of water droplets is

(A) 1 : 1000 (B) 10 : 1

(C) 1 : 10 (D) 1000 : 1

23. Angle of contact of the liquids with the surface of a body, if the liquid wets the surface is

(A) =90° (B) <90°

(C) >90° (D) =0°

24. The value of surface tension of a liquid at critical temperature is

(A) zero

(B) infinite

(C) between 0 and cc

(D) unpredictable

25. When the temperature increases, the angle of contact of a liquid

(A) increases

(B) decreases

(C) remains unchanged

(D) first increases and then decreases

26. A big drop of radius R is formed from 1000 droplets of water. The radius of a droplet will be: [Oct13]

(A) 10 R (B) $\frac{R}{10}$

(C) $\frac{R}{100}$ (D) $\frac{R}{1000}$

27. Surface tension of soap solution is 2×10^{-2} N/m. The work done in producing a soap bubble of radius 2 cm is

(A) $64p \times 10^{-6}$ J (B) $32\, p \times 10^{-6}$ J

(C) $16p \times 10^{-6}$ J (D) $8p \times 10^{-6}$ J

28. If we draw a graph between the height of liquid in a capillary tube against the reciprocal of radius of the tube for a given liquid then we get

(A) straight line (B) circle

(C) hyperbola (D) parabola

29. When two small bubbles join to form a bigger one, energy is

(A) released

(B) absorbed

(C) first absorbed then released

(D) neither absorbed nor released

30. The angle of contact between glass and mercury is

(A) 0° (B) 30°

(C) 90° (D) 135°

31. Two capillary tubes of different diameters are dipped in water. The rise of water is

(A) greater in tube of smaller diameter.

(B) greater in tube of larger diameter.

(C) same in both.

(D) zero in both.

32. As the length of capillary tube is insufficient, the rise of liquid in it will be up to the top, in the absence of ———

[Feb 2013 old course]

(A) insoluble impurity

(B) soluble impurity

(C) gravity

(D) critical temperature

33. A liquid drop of diameter 'D' breaks into 27 small drops of equal size. If the surface tension of the liquid is 'T', then change in surface energy is

(A) pD^2T (B) $2pD^2T$

(C) $3pD^2T$ (D) $4pD^2T$

34. If the diameter of a capillary tube is doubled, then height of the liquid that will rise is

(A) twice

(B) half

(C) same as earlier

(D) none of these

35. The correct relation is

(A) $r = \frac{2T \cos q}{hr\,g}$ (B) $r = \frac{hr\,g}{2T \cos q}$

(C) $r = \frac{2Thr\,g}{\cos q}$ (D) $r = \frac{T \cos q}{hr\,g}$

36. The lower end of a capillary tube is dipped in a liquid whose angle of contact is 90°. The liquid

(A) will neither rise nor fall inside the tube.

(B) will rise inside the tube.

(C) will rise to the top of tube.

(D) will fall inside the tube.

37. A shell having a hole of radius 'r' is dipped in water. It holds the water upto a depth of 'h' then the value of r is

(A) $r = \frac{2T}{hr\,g}$ (B) $r = \frac{T}{hr\,g}$

(C) $r = \frac{Tg}{hr}$ (D) $\frac{T}{2hr\,g}$

38. The potential energy of a molecule on the surface of a liquid compared to one inside the liquid is

(A) zero (B) smaller

(C) the same (D) greater

39. Due to capillarity, a liquid will rise in a glass tube if angle of contact is

(A) zero (B) acute

(C) obtuse (D) both (A) and (B)

40. Kerosene rises in a wick because of

(A) viscosity of the oil.

(B) evaporation of oil at low temperature.

(C) capillary action.

(D) low density of oil.

41. A drop of oil is placed on the surface of water. Which of the following statements is correct ?

(A) It will remain on it as a sphere.

(B) It will spread as a thin layer.

(C) It will partly be as spherical droplets and partly as thin film.

(D) It will float as distorted drop on the water surface.

42. Chalk-particle cling to the black board due to

(A) capillarity (B) compression

(C) cohesion (D) adhesion

43. If the radius of capillary tube increases, then level of liquid in capillary will

(A) increase

(B) decrease

(C) remain unchanged

(D) none of these

44. Nature of meniscus for liquid of angle of contact 0° will be

(A) plane (B) parabolic

(C) semi-spherical (D) cylindrical

45. 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

(A) 6 h (B) 1/6 h

(C) h (D) zero

46. Oil spreads over the surface of water where as water does not spread over the surface of the oil because

(A) surface tension of water is very high.

(B) surface tension of water is very low.

(C) viscosity of oil is high.

(D) viscosity of water is high.

47. Cohesive force is experienced between

(A) magnetic substances

(B) molecules of different substances

(C) molecules of same substances

(D) atoms. of same substances

48. The surface tension for pure water in a capillary tube experiment is

(A) $\frac{r g}{2hr}$ (B) $\frac{2}{hrr g}$

(C) $\frac{rr g}{2h}$ (D) $\frac{hrr g}{2}$

49. Radius of a capillary is 2×10^{-3} m. A liquid of weight 6.28×10^{-4} N may (remain in the capillary then the surface tension of liquid will be

(A) 5×10^{-3} N/m (B) 5×10^{-2} N/m

(C) 5 N/m (D) 50 N/m

50. Two bubbles A and B (A > B) are joined through a narrow tube, then

(A) size of A will increase.

(B) size of B will increase.

(C) size of B will increase until the pressure becomes equal.

(D) size of A will decrease.

51. When the common salt is dissolved in pure water, the surface tension of the solution is that of pure water. **[Oct 10]**

(A) less than (B) equal to

(C) greater than (D) half

52. A glass capillary tube of radius 1 mm dip into a liquid of density 0.8×10 kg/m^3. The liquid rises to a height of 3 cm and the angle of contact is 5°. The surface tension of liquid is

(A) 0.24 N/m

(B) 0.12 N/m

(C) 1.2×10^{-3}N/m

(D) 1.2×10^{-4} N/m

53. What is the surface tension of boiling water?

(A) Zero

(B) Infinity

(C) 100 times than that at 0°C

(D) None of these

54. Waterproofing agent changes the angle of contact

(A) Jrom, obtuse to acute

(B) from, acute to obtuse

(C) from Qbtuse to p/2

(D) from ^cute to p/2

55. On mixing the-salt in water, the surface tension of water will

(A) increase

(B) remain unchanged

(C) decrease

(D) increase or decrease

Answers

Section A

1. 0.07 N
2. 8.4×10^{-3} N
3. 0.08 N/m
4. 30159.2 erg
5. 45.2×10^{-4} J
6. 6.03×10^{-3}J
7. 1 : 6
8. 0.073 cm
9. 2.45 cm
10. 1.44×10^{-5} J

11. 7.4×10^{-2} N/m

12. 5.96 cm

13. 0.152

14. 1.5×10^{-3} J

15. 3 : 2

Section C

1. 15710 erg
2. 67 : 82 erg
3. 6 cm
4. 0.0204 cm
5. 5.94×10^{-5} J
6. 52.55 dyne / cm
7. 2.337×10^{-5} J
8. $T_w/T_{Hg} = 0.1535$
9. 7034 erg
10. 1440 dyne Wj 16
11. $\frac{W_1}{W_2} = \frac{16}{25}$
12. 2.288×10^{-3}J

Section **D**

1.	(A)	2.	(B)	3.	(B)	4.	(B)
5.	(C)	6.	(A)	7.	(C)	8.	(B)
9.	(B)	10.	(B)	11.	(A)	12.	(C)
13:	(C)	14.	(B)	15.	(D)	16.	(B)
17.	(C)	18.	(D)	19.	(C)	20.	(B)
21.	(A)	22.	(C)	23.	(B)	24.	(A)
25.	(A)	26.	(B)	27.	(A)	28.	(A)
29.	(A)	30.	(D)	31.	(A)	32.	(C)
33.	(B)	34.	(B)	35.	(A)	36.	(A)
37.	(A)	38.	(D)	39.	(D)	40.	(C)
41.	(B)	42.	(D)	43.	(B)	44.	(C)
45.	(A)	46.	(A)	47.	(C)	48.	(D)
49.	(B)	50.	(A)	51.	(C)	52.	(B)
53.	(A)	54.	(B)	55.	(A)		