SURFACE TENSION
SURFACE ENERGY

POINTS TO REMEMBER

1. Every surface of a liquid behaves like a stretched elastic membrane and thereby develops surface tension.
2. The force acting on the surface of the liquid per unit length on its either side is called

   Surface tension. $T = \frac{Force(F)}{length(l)}$

   Unit = N/m & $DF = [MT^{-2}]$
3. **Applications of surface tension**
   a) Manufacture of lead shots b) Oils and paints - hence they spread easily and uniformly
   c) Destruction of mosquito breed.
4. The forces between the molecules are of two types (i) cohesive forces (ii) adhesive forces.
5. The force of attraction between the molecules of the same substance is called cohesive force.
6. The force of attraction between the molecules of different substances is called adhesive force.
7. **Surface Energy:** The surface energy of a liquid film is the work done to increase the surface area of the film by unit amount $W = T(A_2 - A_1)$ or $T = \frac{W}{A}$ J/m^2
8. **Angle of contact**: The angle between the tangent to the liquid surface at the point of contact and the solid surface, inside the liquid is called angle of contact
9. Angle of contact does not depend on the angle of inclination of the solid at the liquid.
10. Angle of contact decreases with the increase of temperature.
11. Wetting agents decrease the angle of contact below 90°. Ex: detergents.
12. Non-wetting agents (water proofing) increase the angle of contact above 90°.Ex: rain coats.
13. The surface energy and surface tension of a liquid decreases with the increase of temperature. At critical temperature the surface tension of a liquid is zero.

SHORT ANSWER QUESTIONS

1. **What is surface tension? How do you explain surface tension on the basis of molecular theory?**

Ans: **Surface tension:** Surface tension is defined as the tangential force per unit length acting at right angles on either side of an imaginary line drawn on the free liquid surface in equilibrium.

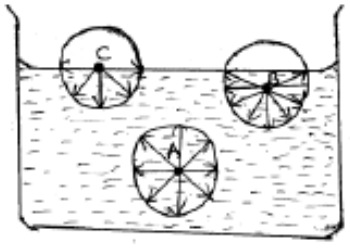
If F is the force perpendicular to the imaginary line of length, then

Surface tension $= \frac{\text{force}}{\text{length}} \quad \Rightarrow \quad T = \frac{F}{l}$

Unit: N/m.

Molecular theory of surface tension: Consider three molecules A,B and C of a liquid so that A is completely inside the liquid, B is just below the surface and C exactly on the surface.
For the molecule A cohesive forces act in all directions equally which balance each other. Hence there is no resultant force on the molecule A.

For the molecule B upward cohesive forces are lesser than that of downward cohesive force and hence there exists a resultant downward force on B. For the molecule C the upward cohesive forces are absent and hence it experiences a maximum downward force. Due to this downward force, the



liquid surface behaves like a stretched elastic membrane. Liquid surface tends to acquire minimum surface area in order to have minimum potential energy and greater stability. This tendency is called surface tension.

VERY SHORT ANSWER QUESTIONS

1) Define Surface Tension and give its dimensional formula? (March 2007, 03, 02)

A) The tangential force acting per unit length of an imaginary line drawn on the surface and perpendicular to the length is called Surface Tension.
Surface Tension = Force / Length
Dimensional formula: $M^1L^0T^{-2}$

2) What are units of Surface Tension?

A) S.I. unit: Nm^{-1} (or) Jm^{-2}

3) Explain why rain drops are Spherical in Nature? (March 03)

A) For a given volume, sphere has minimum surface area due to surface tension. Hence small rain drops are spherical in nature.

4) Define 'angle of contact' what are its values for pure water and Mercury? (March 2001)

A) It is defined as the angle measured inside the liquid between solid surface and the tangent drawn to the surface of the liquid at that point of contact.
For pure water and glass angle of contact is 0^o
For pure Mercury and glass angle of contact is 140^o

5) What are Cohesive and adhesive forces?

A) **Cohesive force:** The force of attraction between the molecules of same substance is called cohesive force.
Adhesive force: The force of attraction between the molecules of different substances is called adhesive force

6) To Increase the wetting nature of water what should be done.

A) When wetting agents like detergent or soap is added to water to increase the wetting nature of water.

7) What is the effect of temperature on Surface Tension? (May 05, June 2002)

A) As temperature increases, surface tension decreases due decrease of cohesive forces.

8) A steel needle placed on the Surface of water floats. Why?

A) The surface of water behaves like a stretched elastic membrane due to Surface Tension. A steel needle placed on the Surface of water floats.

9) When a glass rod is dipped vertically in Mercury, the angle of contact is 140^o. If the same rod is dipped at an angle in Mercury, what is the angle of contact?

A) Angle of contact remains the same because it does not depend on angle at which the glass rod is dipped in the mercury.

10) Mention some examples to show that the surface of a liquid behaves as a stretched elastic membrane?

A) 1. Mosquito can crawl on the surface of water. The surface of water of behaves like a stretched elastic membrane due to surface Tension.
2. A steel needle placed on the Surface of water floats, since The surface of water behaves like a stretched elastic membrane due to Surface Tension.

11) Define surface energy. What is its relation with surface tension?

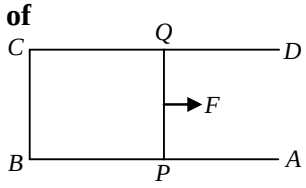
A) The surface energy of a liquid film is the work done to increase the surface area of the film by unit amount $W = T(A_2 - A_1)$ or $T = \frac{W}{A}$ J/m^2

12) A small quantity of oil is used in preparation of Toilet soap. Is there any importance to it in relation to the Surface Tension?

A) In order to increase wetting nature, oil is used in preparation of Toilet soap.

SOLVED EXAMPLES

1. A wire PQ of length 5 cm which is free to move to and fro is attached to a rectangular frame ABCD as shown in figure. When this frame is dipped in a soap solution and raised find the force 'F' required to keep the wire PQ in equilibrium. Surface tension of soap = 4×10^{-2} N/m.



Sol: L = 5 cm = 5×10^{-2} m ; T = 4×10^{-2} Nm^{-1}

F = T × 2L= $(4\times10^{-2}) \times 2 \times (5\times10^{-2}) = 40 \times 10^{-2} = 4 \times 10^{-3}$N

2. A water drop of radius 1cm is broken-up into tiny droplets of water, each of radius 1mm (assume isothermal conditions). Surface tension of water is 7×10^{-2} Nm^{-1}.
i) Find the number of tiny drops formed.
ii) Calculate the increase in the surface area in this process.
iii) Calculate the work done in breaking this big drop into tiny drops.

Sol: i) R = 1cm = 10^{-2} m ; r = 1mm = 10^{-3}m

Volume of the big water drop = $\frac{4}{3}\pi R^3$

Volume of the tiny water drop = $\frac{4}{3}\pi(r)^3$

If 'n' is the number of tiny water drops formed then $\frac{4}{3}\pi R^3 = n \times \frac{4}{3}\pi r^3$

$$\therefore n = \left(\frac{R}{r}\right)^3 = \left(\frac{10^{-2}}{10^{-3}}\right)^3 = 1000$$

ii) Surface area of the big water drop = $4\pi R^2 = 4\pi \times \left(10^{-2}\right)^2 = 4\pi \times 10^{-4} m^2$

Surface area of 1000 tiny water drops = $1000 \times 4\pi r^2 = 1000 \times 4\pi \times \left(10^{-3}\right)^2 = 4\pi \times 10^{-3} m^2$

$\therefore$ Increase in the surface area $= 4\pi \times 10^{-3} - 4\pi \times 10^{-4} = 11.31 \times 10^{-3} m^2$

iii) work done = Increase in surface area × surface tension

$= (4\pi \times 10^{-4} - 4\pi \times 10^{-3}) \times 7 \times 10^{-2} = 79.17 \times 10^{-5} J$

3. A circular ring is cut from a platinum tube 8.5cm internal diameter and 8.7 cm external diameter and supported horizontally from the pan of a balance, so that it comes in contact with the water in a glass vessel. If an extra weight of 3.97 g is required to pull it away from water, calculate the surface tension of water.

Sol: $R_1 = \frac{8.5}{2} cm = 4.25 \times 10^{-2} m; R_2 = \frac{8.7}{2} cm = 4.35 \times 10^{-2} m.$; m =3.97g = 3.97×10^{-3} kg; g = 9.8 m/s^2;

Downward pull on the inner circumference of the ring = $2\pi R_1 \times$ T where R_1 is the internal radius.

Downward pull on the outer circumference of the ring = $2\pi R_2 \times$ T where R_2 is the external radius.

Total downward pull = $T \times 2\pi(R_1 + R_2)$

If 'm' is the mass of the load required to pull it away, $mg = T \times 2\pi\left(R_1 + R_2\right)$

$$T = \frac{mg}{2\pi\left(R_1 + R_2\right)} \Rightarrow \quad T = \frac{3.97\times10^{-3}\times9.8}{2\pi\left(4.25+4.35\right)\times10^{-2}} = 0.07199 \text{ N/m.}$$

4. A circular ring of radius 7 cm is supported horizontally from the pan of a balance, so that it comes in contact with the water in a glass vessel. What force will be required to detach it from the surface of water? (Surface tension of water = 0.072 N/m.)

Sol: T = 0.072 N/m; r = 7cm = 7×10^{-2} m.

Net downward force on the ring $= T \times 2\pi\left(R+R\right) = T\times4\pi R$

Force required to detach it from the water surface is

$$F = T\times 4\pi R = 0.072 \times 4\times\frac{22}{7}\times10^{-2} = 6.336\times10^{-2}\,N$$

5. A circular disc of radius $7/\pi$ cm is placed horizontally on the surface of water. Find the vertical force required to separate it from the water surface. (Surface tension of water = 0.070 N/m.)

Sol: If R is the radius of the circular disc , then vertical force required to separate it from the water surface is given by $F=T\times2\pi R$

T = 0.070 N/m; $R = \frac{7}{\pi}cm = \frac{7}{\pi}\times10^{-2}\,m.$

$$\therefore F = 0.070\times2\times\pi\times\frac{7}{\pi}\times10^{-2} = 9.8\times10^{-2}\,N.$$

6. A water drop of diameter 2 mm is split up into 10^9 identical water drops. Calculate the work done in this process. The surface tension of water is 7.3×10^{-2} Nm^{-1}.

Sol: Let a water drop of radius R be split up into 10^9 identical water drops each of radius r. Then

$$\frac{4}{3}\pi R^3 = 10^9\left(\frac{4}{3}\pi r^3\right)$$

$R = 1mm = 1\times10^{-3}\,m$; T= 7.3×10^{-2} Nm^{-1}

$$\frac{4}{3}\pi\left(1\times10^{-3}\right)^3 = 10^9\times\frac{4}{3}\pi\times r^3 \Rightarrow r = 10^{-6} \text{ m}$$

Work done $= \left[10^9\times4\pi r^2 - 4\pi R^2\right]T = 4\pi\left(10^9 r^2 - R^2\right)\times T$

$$= 4\times\frac{22}{7}\times\left[10^9\times\left(10^{-6}\right)^2 - \left(10^{-3}\right)^2\right]\times7.3\times10^{-2} = 9.17\times10^{-7}\,J$$

7. Find the weight of water supported by surface tension in a capillary tube with a radius of 0.2 mm. Surface tension of water is 0.072 Nm^{-1} and angle of contact of water is 0^0.

Sol: T = 0.072 Nm^{-1} ; $\theta = 0^0$; r = $0.2mm = 0.2\times10^{-3}m$

$$F = 2\pi r\left(T\cos\theta\right) = 2\times\frac{22}{7}\times0.2\times10^{-3}\times0.072\times1 = 90.51\times10^{-6}\,N.$$

8. Calculate the work done in blowing a soap bubble of radius 2 cm. Surface tension of soap solution is 7×10^{-2} Nm^{-1}.

Sol: r = 2cm = 2×10^{-2}m ; T = 7×10^{-2} Nm^{-1}

Work done $= 2\times4\pi r^2\times T = 2\times4\times\frac{22}{7}\times\left(2\times10^{-2}\right)^2\times7\times10^{-2} = 7.04 \times 10^{-4}$ J.

9. Find the radius of the soap bubble if 44×10^{-6} J of work is done in blowing the soap bubble. Surface tension of soap solution = 7×10^{-2} Nm^{-1}.

Sol: Work done W = 44×10^{-6} J

If 'r' is the radius of the soap bubble surface area of the soap bubble $= 2\times 4\pi r^2 = 8\pi r^2$.
Work done in blowing soap bubble (w) = surface area of the bubble ×surface tension

$w = 8\pi r^2 T$

$$\Rightarrow r = \sqrt{\frac{w}{8\pi T}} = \sqrt{\frac{44\times10^{-6}}{8\times\frac{22}{7}\times7\times10^{-2}}} \Rightarrow r = 0.05m$$

10. A soap bubble is blown to a radius of 3 cm. If it is to be further blown to a radius of 4 cm. What is the work done? (Surface tension of soap solution = 3.06×10^{-2} Nm^{-1}.)

Sol: $R_1 = 3cm = 3\times10^{-2}$ m ; $R_2 = 4cm = 4\times10^{-2}$ m

$$W = 8\pi\left(R_2^2 - R_1^2\right)T = 8\times\frac{22}{7}\times3.06\times10^{-2}\times(16-9)\times10^{-4} = 538.56\times10^{-6}\,J$$

EXERCISE 1

1. Calculate the work done, in blowing a soap bubble of diameter 0.6 cm against the surface tension forces. Surface Tension of soap solution is equal to 2.5 $\times10^{-2}$ N/m. (March 2003)

Sol. D = 0.6 cm ; r = 0.3 cm $=0.3\times10^{-2}$ m ; $T = 2.5\times10^{-2}$ N/m

$$W = 2TA = 2T\times 4\pi r^2 = 2\times2.5\times10^{-2}\times4\times3.14\times(0.3\times10^{-2})^2 = 5.65\times10^{-6}\text{ J}$$

2. The surface tension of water is 0.07 N/m. Find the weight of water supported by surface tension in a capillary tube of radius 0.1 mm. Angle of contact is 0º.

Sol: T = 0.07 N/m ; r = 0.1 mm $= 0.1\times10^{-3}$ m

$$mg = 2\pi rT\cos0^0 \Rightarrow W = 2\times\frac{22}{7}\times0.1\times10^{-3}\times0.07 = 44\text{ X }10^{-6}\text{ N}$$

3) A liquid drop of diameter 20 mm is split into 1000 small droplets. If these droplets are identical then calculate the work done during the process. Surface tension of water is 72×10^{-3} Nm^{-1}.

Sol: D = 20mm ; R = 10mm $= 10\times10^{-3}$ m ; n = 1000 ; $T = 72\times10^{-3}$ Nm^{-1}

Work done $W = 4\pi R^2 T\left(n^{1/3} - 1\right)$

$$W = 4\times3.14(10\times10^{-3})^2\times72\times10^{-3}\left((1000)^{1/3} - 1\right) = 8.14\times10^{-4}\text{ J}$$

4. A straight piece of wire 5 cm long is placed horizontally on the surface of water and gently pulled up. It is found that a force of 7 $\times10^{-3}$ N in addition to weight of wire is required for that purpose. What is the surface tension of water?

Sol : L = 5 cm $= 5\times10^{-2}$ m ; $F = 7\times10^{-3}$ N

$$T = \frac{F}{2L} = \frac{7\times10^{-3}}{10\times10^{-2}} = 7\times10^{-2}\,Nm^{-1}$$

5. The material of a wire has specific gravity 8. If it is not wetted by water, what is the maximum diameter of the wire that will float on the surface of water (T = 7 $\times10^{-2}$ Nm^{-1})

Sol : Weight of the wire is balanced by surface tension of water.

$Mg = T\times2l \Rightarrow V\times d\times g = T\times2l \Rightarrow \pi r^2 ldg = T\times2l$

$$\therefore r^2 = \frac{2T}{\pi dg}$$

$$\therefore d = 8\times10^3\,kgm^{-3} = \frac{2\times7\times10^{-2}}{3.14\times8\times10^3\times10}$$

$\Rightarrow r^2 = 0.5573\times10^{-6} \Rightarrow r = 0.75\times10^{-3} m$

Diameter D = 2r = $2\times0.75\times10^{-3} = 1.5\times10^{-3} m = 1.5mm$

6. What is the work done by an agent in splitting a water drop of radius R into n identical droplets? (T is surface tension of water)

Sol : $\frac{4}{3}\pi R^3 = n.\frac{4}{3}\pi r^3 \quad \Rightarrow \quad r = \frac{R}{n^{1/3}}$

$W = T.4\pi\left[n.r^2 - R^2\right] = T4\pi\left[R^2.n^{1/3} - R^2\right]$

Work done $W = T.4\pi R^2\left[n^{1/3} - 1\right]$

7. If the work done by an agent to form a bubble of radius R is W, then how much energy is required to increase its radius to 2 R.

Sol : $R_1 = R \;\; ; \;\; R_2 = 2R$,

$W_1 = W, W_2 = ?, W_2 - W_1 = ?$

$W = 4\pi R^2 T\left(n^{1/3} - 1\right) \Rightarrow W \propto R^2$

$\frac{W_1}{W_2} = \left(\frac{R_1}{R_2}\right)^2 \Rightarrow W_2 = \left(\frac{R_2}{R_1}\right)^2 W_1 \qquad \Rightarrow W_2 = \left(\frac{2R}{R}\right)^2 W$

$W_2 = 4W \Rightarrow W_2 - W_1 = 4W - W = 3W$

ASSESS YOURSELF

1. What is the behavior of a camphor boat when placed in water?

Ans: It moves from one place to another place randomly since the surface tension of water decreases when camphor dissolves in it and it moves from a place of lower surface tension to a place of higher surface tension.

2. What happens when a hot needle is placed between two match sticks placed on the surface of water?

Ans: The match sticks move away from each other as the surface tension decreases due to increase in temperature.

3. When work is done to pull the surface of a soap film to increase its surface area, do you think its surface tension also increases.

Ans: No. surface tension is constant for a given liquid. It is independent of surface area.

4. Tooth paste contains a small quantity of oil. Is it for any reason connected with the surface tension?

Ans: Yes, surface tension of water decreases with addition of oil in the tooth paste. Hence the water or the foam easily spreads over the mouth and cleans the teeth.

5. Why rain drops are spherical in nature?

Ans: Due to surface tension the surface area of the water drop is minimum. For a given volume, since the surface area of sphere is minimum, rain drops assume spherical shape.

6. Is there any advantage of washing clothes with warm water than cold water? Why?

Ans: Surface tension of water decreases with the increase in temperature of water. Hence warm water easily spreads over the clothes and cleans easily.

7. When a few water drops placed between two glass plates, it is difficult to separate the glass plates? Why?

Ans: Due to surface tension.

8. When large number of small drops of liquid coalesces into a large drop will there be increase or decrease in temperature?

Ans: There will be increase in temperature.

9. What are the angles of contact for wetting and non wetting liquids?

Ans: Less than 90^0, more than 90^0

10. Why is it that the meniscus of a liquid surface is concave or convex?

Ans: Concave surface is due to the adhesive forces dominating the cohesive forces. Convex surface is due to the cohesive forces dominating adhesive forces.

11. Why the excess pressure in a soap bubble is more than that of in a water drop?

Ans: Since it has two surfaces.