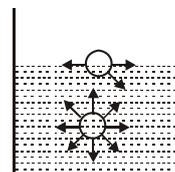


SURFACE TENSION

Synopsis :

1. The properties of a surface are quite different from the properties of the bulk material.
2. A molecule well inside a body is surrounded by similar particles from all sides. But a molecule on the surface has particles of one type on one side and of different type on the other side.
3. The attractive forces between the molecules of a substance are called cohesive forces.
4. The attractive forces between the molecules of a different substances are called adhesive forces.
5. A molecule of water well inside the bulk experiences cohesive forces but a molecule at the surface experiences both cohesive and adhesive forces. This asymmetric force distribution is responsible for surface tension.
6. The maximum distance upto which the cohesive force between two molecules exists is called the molecular range and of the order 10^{-9} m or 1 nm.
7. An imaginary sphere drawn around a molecule with a radius of molecular range is called the sphere of influence of that molecule.
8. Intermolecular force of attraction varies inversely as the eighth power of the intermolecular distance.
9. The surface of the liquid behaves like a stretched rubber sheet. Surface tension is due to cohesion between the molecules of the liquid.



10. Surface tension is the force per unit length of a line drawn on the liquid surface and acting perpendicular to it.

$$T = \frac{F}{l} \quad \text{S.I unit is N/m.}$$

11. Force required to pull a circular ring of radius r from the surface of water of surface tension T is $F=4\pi rT$.
12. Force required to pull a rectangular plate of length ' l ' and thickness ' t ' from the surface of water of surface tension T is $F = 2(l + t)T$.
13. Force required to pull a circular disc of radius R with hole of radius r from the surface of water of surface tension T is $F=2\pi (R + r)T$.
14. A slide is suspended from one arm of a balance and is counter balanced. Now the slide is lowered into a beaker of water until it just touches the surface of water. If m is the additional mass to keep the balance beam horizontal, then $T = \frac{mg}{2(l + b)}$. Where l is length and t is thickness of slide.

15. When a cylindrical glass tube is closed at one end and it is made heavy such that it floats in the vertical position. If the depth of heavy end is h below liquid surface, then $h = \frac{2\pi rT + mg}{\pi r^2 dg}$.

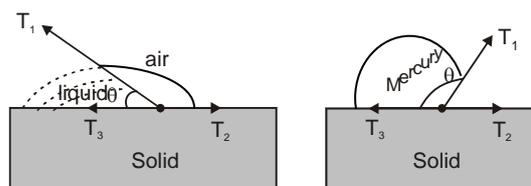
16. Drops of liquid of density d_1 are floating half immersed in a liquid of density d_2 . If the surface tension of liquid is T , then the radius of the drop will be $r = \sqrt{\frac{3T}{(2d_1 - d_2)g}}$.

17. A molecule in the surface has greater potential energy than a molecule well inside the liquid. The extra energy that a surface layer has is called the surface energy.
18. Surface tension of a liquid is also equal to the surface energy per unit surface area. Unit is J/m.
19. Surface energy is defined as the quantity of work done in increasing the surface area of the liquid through unity (also equal to the surface tension of liquid)

$$\text{surface energy} = \frac{\text{work}}{\text{area}} = \frac{\text{energy}}{\text{area}}$$

20. Work done = surface tension x increase in surface area.
21. At constant temperature, liquid surface does not obey Hooke's law, and surface tension is independent of the surface area.
22. The free liquid surface tries to attain minimum surface area. This is the reason for a free liquid drop (like rain drop) to attain a spherical shape.
23. The work done (W) in blowing a soap bubble of radius r is $W = 8\pi r^2T$.
24. Work done in increasing the area of circular soap film from radius r_1 to r_2 ; $W = 2\pi T[r_2^2 - r_1^2]$.

25. Work done in increasing the radius of a bubble from r_1 to r_2 is given by $W = 8\pi(r_2^2 - r_1^2)T$.
26. When a number of small liquid drops coalesce to form a large drop, energy is released (since surface area decreases).
27. Energy is required to break a liquid drop into smaller drops (since surface area increases).
28. The work done by an agent to split a liquid drop of radius R into 'n' identical drops is $W = 4\pi R^2 T(n^{1/3} - 1)$ where T is surface tension.
29. The amount of energy evolved when 'n' droplets of a liquid of radius 'r' combine to form a large drop is $E = 4\pi r^2 T(n - n^{2/3})$.
30. 'n' drops each of radius 'r' combine to form a big drop of radius 'R'. Then the work done (or) the energy expended is $4\pi T(nr^2 - R^2)$.
31. **Factors influencing surface tension :**
- a) **Temperature :** Usually it decreases with increase of temperature. When temperature of liquid increases K.E. of its molecules also increase. Hence cohesive forces between the molecules become weak. At critical temperature the interface between liquid and its vapour disappear and so surface tension of a liquid becomes zero. The surface tension of molten cadmium and molten copper increases with increase of temperature. Surface tension of a liquid is zero at its boiling point.
- b) **Impurities :** If the liquid surface is contaminated by impurities, its surface tension decreases. e.g. when oil or kerosene is sprayed on water surface, its surface tension decreases. Mosquito breed floating on water can be destructed using this technique. Surface tension increases when an inorganic substance (highly soluble) is dissolved in water. e.g. When NaCl, ZnSO₄ are dissolved, surface tension of water increases. Surface tension decreases when an organic substance is dissolved (weakly soluble) in water. e.g. When soap is mixed with water surface tension decreases. Surface tension of soap solution is about 32 dy cm^{-1} .
32. Of all liquids, mercury has maximum surface tension.
33. **Angle of contact :** It is the angle between the tangent drawn at the point of contact of a solid and liquid and the surface of solid within the liquid.
34. The angle of contact may assume any value between 0° and 180° .
35. The angle of contact depends on solid-liquid pair, temperature and impurities.
36. The angle of contact is not altered by the amount of inclination of solid object in the liquid.
37. θ is independent of manner of contact i.e. glass plate in a liquid or liquid drop on a plate or liquid in a solid vessel.
38. Angle of contact increases with increase in temperature.
39. For pure water and glass, the angle of contact is zero.
40. Angle of contact decreases on adding soluble impurity, detergent and wetting agent to a liquid.
41. For mercury and glass, angle of contact is about $140^\circ \approx 139^\circ\text{C}$.
42. (a) For Ag and H₂O angle of contact is 90° .
(b) For ordinary water θ lies between 8° and 18° .
(c) Angle of contact of chromium with water is as high as 160° .
43. If a liquid wets the solid, then the angle of contact is less than 90° and if the liquid doesn't wet the solid, then the angle of contact is greater than 90° .
44. **Angle of contact in case of solid, liquid and air in contact :**

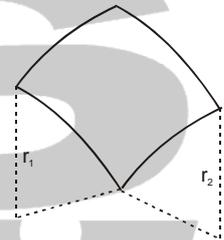


Let T_1 is surface tension for air-liquid surface, T_2 for air-solid and T_3 for liquid-solid surfaces respectively. If θ be the angle of contact of the liquid with the solid, then

$$\cos \theta = \frac{T_2 - T_3}{T_1}$$

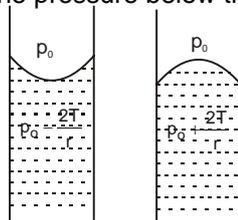
- a) If T_2 is greater than T_3 , $\cos \theta$ will be positive i.e., θ will be less than 90° .
 - b) If T_2 is less than T_3 , $\cos \theta$ will be negative i.e., θ will be between 90° and 180° .
 - c) If $T_2 > T_1 + T_3$, there will be no equilibrium, and the liquid will spread over the solid.
45. **Capillarity** : The property of rise or depression of the liquid due to surface tension in a tube is known as capillarity.
 46. Oil ascends in a wick due to capillarity.
 47. Flow of ink through a nib is due to capillarity.
 48. A painter's brush under water has its hair spread but on withdrawal from water they adhere to each other due to surface tension.
 49. Ploughing of land brings moisture to the top by capillary action.
 50. The addition of a detergent decreases the surface tension and angle of contact.
 51. Wetting agents are used in detergents in order to clean clothes.
 52. The addition of a water proofing agent like waxy substance to a liquid increases angle of contact.
 53. If the angle of contact (θ) is acute ($\theta < 90^\circ$), there will be capillary rise. e.g. : water in glass capillary.
 54. If the angle of contact (θ) is obtuse ($\theta > 90^\circ$), there will be capillary depression. e.g. : mercury in capillary.
 55. If the angle of contact is 90° , there will be neither rise nor fall. e.g. : water in silver capillary.
 56. **Rise of liquid in tubes of insufficient length** : If a liquid can rise upto a height 'h' in the tube but its total length outside the water surface is less than 'h' the liquid will not overflow out of the tube. Instead of it, the liquid will rise to the top of the tube.
 57. Excess pressure in a drop of liquid of radius r is given by $P = 2T/r$.
 58. Excess pressure in a soap bubble of radius r is given by $P = 4T/r$.
 59. Excess pressure inside a soap bubble present in a liquid $P = 2T/r$, where r is radius and T is surface tension.
 60. If the surface be curved in two directions and radii of the two curvatures be r_1 and r_2 respectively the total difference of pressure on the two sides of the surface will be

given by $P = T \left[\frac{1}{r_1} + \frac{1}{r_2} \right]$.



61. Pressure difference across a surface film :
 - a) When free surface of the liquid is plane (fig a), the surface tension acts horizontally and its normal component is zero, thus no extra pressure is communicated to the inside or outside.
 - b) When free surface is convex, the forces due to surface tension acting on both sides of a line on the surface have components acting downwards which gives excess pressure inside the liquid.
 - c) Similarly when free surface is concave, the pressure inside the liquid is decreased.
 - d) Thus there is always an excess pressure on the concave side.
62. In case of concave meniscus the pressure below the meniscus is lesser than above it by

$$\left(\frac{2T}{r} \right).$$

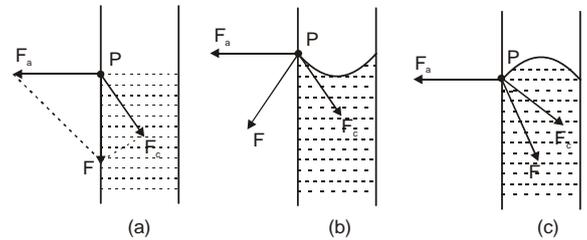


63. In case of convex meniscus the pressure below the meniscus more than above it by $\left(\frac{2T}{r} \right)$.
64. The spherical surface of the liquid in the tube is called **meniscus**.
65. If the adhesive force is large compared with cohesive force, the liquid has concave meniscus upwards. e.g. water and glass tube.

66. If the adhesive force is less than cohesive force, the liquid has a convex meniscus. e.g. mercury and glass tube.

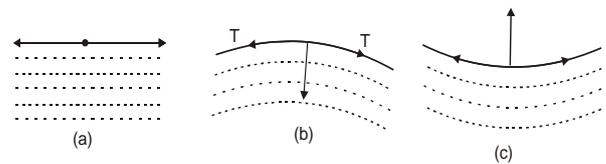
67. **Shape of liquid meniscus in a capillary tube :**

For a liquid molecule at P, force of adhesion F_a acts at right angles to the tube at the point P, force of cohesion F_c acts at an angle of 45° to the vertical. The resultant force on it will be the resultant of these two forces of adhesion and cohesion.



a) When $F_c = \sqrt{2}F_a$, i.e., the cohesive force is $\sqrt{2}$ times the adhesive force the molecules of the liquid are neither raised nor lowered and the liquid surface remains flat or plane (fig a)

b) When $F_c < \sqrt{2}F_a$, i.e., the cohesive force is less than $\sqrt{2}$ times the adhesive force, the molecules of the liquid near the walls of the tube are raised up against the tube making the liquid surface concave upwards as in the case of water. (fig b)



c) When $F_c > \sqrt{2}F_a$, i.e., the cohesive force is greater than $\sqrt{2}$ times the adhesive force, the liquid molecules near the walls of the tube are depressed making the surface convex upwards as in case of mercury. (fig c)

68. When a charge either positive or negative is given to a soap bubble, it expands due to repulsions among the charges.

69. Surface tension by capillary rise method.

$$T = \frac{rdg(h+r/3)}{2 \cos \theta} \approx \frac{rdhg}{2 \cos \theta} \text{ if } h \gg r$$

In the case of pure water, $T = \frac{rdhg}{2}$.

70. In capillary rise the force due to surface tension in upward direction is equal to the weight of liquid column $2\pi r T \cos \theta = mg$.

71. If the radii of the two limbs of a U tube are r_1 and r_2 , then the difference between the levels of a liquid poured in it is $h = \frac{2T}{dg} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$ (here $r_2 > r_1$), d is density and T is surface tension of the liquid.

72. If a vessel has a small hole of radius 'r' at its bottom then the maximum height of water that can be filled into it so that it does not leak out through the hole is $h = \frac{2T}{rdg}$.

73. **Jurin's law** : According to Jurin's law, inversely the height of the liquid (h) risen in capillary tube is proportional to the radius (r) $rh = \text{constant}$

74. A graph between h and r is a rectangular hyperbola.

75. If a liquid rises to a height 'h' in a capillary tube and the tube is inclined at an angle ' α ' to the vertical, the length of the liquid column inside the tube increases but the vertical height to which the liquid rises remains the same.

$$L = \frac{h}{\cos \alpha} \text{ where } L = \text{length of the liquid column inside the tube.}$$

76. If a capillary tube is dipped in water in a satellite, the water level will rise to the full length of the tube.

77. For the liquids of low surface tension wetting property is more.

78. **Critical temperature** : The temperature at which surface tension of the liquid becomes zero is known as critical temperature.

79. In case of molten copper and molten cadmium T increases with increase of temperature.

80. Surface tension of liquid metals is very very high.

81. ST of a liquid is zero at its boiling point.

82. Over small ranges of temperature, the surface tension of a liquid decreases linearly with the rise of temperature.
83. $T = T_0(1 - \alpha t)$ where T is surface tension at $t^\circ\text{C}$, T_0 is the surface tension at 0°C and α is the coefficient of surface tension.
84. When two soap bubbles of radii a and b coalesce under isothermal condition, the resultant bubble has a radius R such that $R = \sqrt{a^2 + b^2}$.
85. If two soap bubbles of radii a and b coalesce ($a > b$), then the radius of curvature of the interface between the two bubbles will be $\left(\frac{ab}{a-b}\right)$.
86. A spherical soap bubble of radius r_1 is formed inside another of radius r_2 . The radius of the single soap bubble which maintains the same pressure difference as inside the smaller and outside the larger soap bubble is $\left(\frac{r_1 r_2}{r_1 + r_2}\right)$.
87. If a small drop of water is squeezed between two plates so that a thin layer of large area is formed, then the pressure inside the water layer is less than the pressure on the plates. The force pushing the two plates together is given by
 $F = \text{excess pressure} \times \text{area of the layer.}$
 $F = \frac{2T}{d} \times \text{area}$
 where $d = \text{thickness of layer.}$
88. If m is mass of water drop, $F = \frac{2Tm}{\rho d^2}$ (ρ - density of water).
89. When two soap bubbles of different sizes are in communication with each other, the air passes from the smaller one to the larger one and the larger one grows at the expense of the smaller one. i.e., size of smaller bubble decreases and that of larger bubble increases. This is because excess pressure inside the smaller bubble (smaller radius) is greater than that in the larger bubble (greater radius).
90. Energy required to raise a liquid in a capillary tube:
 When a capillary tube is depressed vertically into a liquid which wets the walls of the tube, there is a rise of the liquid inside the tube. The energy required to raise the liquid in the capillary tube is obtained from the surface energy of the air glass surface.