Applied Physics 1

Surface Tension

1. Concept of Surface Tension

Surface tension is the property of a liquid by virtue of which its free surface behaves like a stretched elastic membrane, tending to contract and occupy the minimum possible surface area. This property arises because the molecules at the free surface of a liquid experience an unbalanced net inward force of attraction from the molecules below and around them, unlike molecules deep within the liquid, which are attracted equally in all directions by neighbouring molecules.

Because of this unbalanced inward pull, surface molecules are drawn slightly inward, resulting in the surface behaving as though it were under tension, always tending to minimise its area. Surface tension is defined quantitatively as the force acting per unit length along the free surface of a liquid, acting perpendicular to an imaginary line drawn on the surface, tending to pull the surface together:

- Surface tension, T = Force / Length

Surface tension is responsible for a wide range of familiar phenomena, including the nearly spherical shape of small liquid drops, the ability of certain small, dense objects (such as a needle) to float on the surface of water, and the rise of liquids in narrow capillary tubes.

2. Units of Surface Tension

Since surface tension is defined as force per unit length, its SI unit is newton per metre (N/m). In the CGS system, the unit of surface tension is dyne per centimetre (dyne/cm).

The dimensional formula of surface tension is $[M^1L^0T^{-2}]$, since it is equivalent to force divided by length, which is $[M^1L^1T^{-2}] / [L^1]$. Surface tension can also be expressed as energy per unit area (J/m^2), since the work done in increasing the surface area of a liquid against the inward pull of surface tension is stored as additional surface energy.

3. Cohesive and Adhesive Forces

The behaviour of a liquid surface, particularly near a solid boundary such as the wall of a container, is governed by two types of intermolecular forces:

Type of Force	Definition	Example

Cohesive Force	Force of attraction between molecules of the same substance	Attraction between water molecules; attraction between mercury molecules
Adhesive Force	Force of attraction between molecules of different substances	Attraction between water molecules and glass; attraction between chalk and a blackboard

The relative magnitudes of cohesive and adhesive forces determine whether a liquid wets a solid surface (spreads over it, as water does on clean glass) or does not wet it (forms beads and does not spread, as mercury does on glass, or as water does on a greasy surface).

4. Angle of Contact

The angle of contact is defined as the angle between the tangent to the liquid surface at the point of contact with a solid surface and the solid surface itself, measured inside the liquid. The value of the angle of contact depends on the relative strengths of the cohesive and adhesive forces acting at that point, as summarised below:

Condition	Angle of Contact	Behaviour of Liquid Meniscus
Adhesive force greater than cohesive force	Acute (less than 90°)	Liquid wets the surface; concave meniscus (e.g. water in a glass tube)
Adhesive force less than cohesive force	Obtuse (greater than 90°)	Liquid does not wet the surface; convex meniscus (e.g. mercury in a glass tube)
Adhesive force equal to cohesive force	Exactly 90°	Meniscus is flat

The angle of contact plays an important role in determining whether a liquid rises or falls in a narrow capillary tube, and by how much, as discussed in the next section.

5. Capillary Rise (Formula Only)

Capillary rise refers to the phenomenon in which a liquid rises (or, in some cases, falls) in a narrow tube, called a capillary tube, when the tube is dipped vertically into the liquid. This occurs due to the combined effect of surface tension, adhesive and cohesive forces, and the angle of contact between the liquid and the material of the tube. Liquids that wet the tube (such as water in a glass capillary) rise in the tube, while liquids that do not wet the tube (such as mercury in a glass capillary) are depressed below the level outside the tube.

The formula for the height h to which a liquid rises (or falls) in a capillary tube of radius r is given by:

- $h = 2 T \cos\theta / (r \rho g)$

where T is the surface tension of the liquid, θ is the angle of contact between the liquid and the tube, r is the radius of the capillary tube, ρ is the density of the liquid, and g is the acceleration due to gravity.

This formula shows that the height of capillary rise is directly proportional to the surface tension of the liquid and inversely proportional to the radius of the tube, which is why capillary rise is much more noticeable in very narrow tubes than in wider ones.

6. Applications of Surface Tension

Surface tension has a wide range of applications and manifestations in daily life, nature, and technology, some of which are summarised below:

Application / Observation	Explanation Based on Surface Tension
Small liquid drops and soap bubbles are spherical in shape	Surface tension acts to minimise surface area, and a sphere has the least surface area for a given volume.
A needle or a small insect can float or walk on the surface of water	The surface behaves like a stretched elastic membrane, supporting small weights without breaking.
Rise of oil in a lamp wick and ink in a fountain pen nib	Capillary action draws the liquid upward through the narrow fibres or tube due to surface tension.
Rise of water from soil to plant roots and upward through narrow stem tubes	Capillary rise in the fine capillary channels of plant tissue helps in the movement of water and nutrients.
Detergents and soaps help in cleaning clothes	They lower the surface tension of water, allowing it to penetrate more easily into the fine fibres of the fabric.
Antiseptics used in medicine spread more easily on wounds	Antiseptic liquids are formulated to have low surface tension so that they spread over a larger area and penetrate small cracks and openings.
Raindrops and dew drops are nearly spherical	Surface tension pulls the liquid surface into the shape with minimum surface area, which is a sphere.

7. Effect of Temperature and Impurity on Surface Tension

The surface tension of a liquid is not a fixed, unchanging quantity; it is affected by both the temperature of the liquid and the presence of impurities dissolved or mixed in it.

Factor	Effect on Surface Tension
Increase in temperature	Surface tension generally decreases with an increase in temperature, and becomes zero at the critical temperature of the liquid, since increased molecular motion weakens the cohesive forces between molecules.
Addition of a soluble impurity (e.g. common salt, sugar) that increases cohesion	Surface tension increases slightly.
Addition of a detergent or soap (surfactant)	Surface tension decreases considerably, since these substances reduce the cohesive forces at the surface.

These effects are of considerable practical importance. For example, the addition of detergents deliberately lowers the surface tension of water to help it penetrate fabric fibres more effectively during washing, while in certain industrial and medical applications, controlling the surface tension of a liquid through temperature or additives is essential for achieving the desired spreading, wetting, or mixing behaviour.

8. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. Surface tension is defined as:

A) The force acting throughout the volume of a liquid
B) The force per unit length acting along the free surface of a liquid, tending to minimise its surface area
C) The weight of a liquid per unit volume
D) The pressure exerted by a liquid on the walls of its container

2. The SI unit of surface tension is:

A) N/m^2
B) N·m
C) N/m
D) N·s

3. Cohesive force is the force of attraction between:

A) Molecules of different substances
B) Molecules of the same substance
C) A solid and a liquid only

D) Charged particles only

4. Adhesive force is the force of attraction between:

A) Molecules of the same substance
B) Molecules of different substances
C) Only gas molecules
D) Only solid molecules

5. When adhesive force is greater than cohesive force, the angle of contact is:

A) Obtuse (greater than 90°)
B) Acute (less than 90°)
C) Always 180°
D) Undefined

6. The angle of contact for mercury in a glass tube is:

A) Acute
B) Obtuse
C) Exactly 0°
D) Exactly 90° always

7. The formula for the height of capillary rise h in a tube of radius r is:

A) $h = 2T\cos\theta / (r\rho g)$
B) $h = r\rho g / (2T\cos\theta)$
C) $h = 2T / (r\rho g\cos\theta)$
D) $h = Tr / (2\rho g\cos\theta)$

8. In the capillary rise formula, T represents:

A) Temperature
B) Surface tension of the liquid
C) Total pressure
D) Time of rise

9. According to the capillary rise formula, the height of rise is:

A) Directly proportional to the radius of the tube
B) Inversely proportional to the radius of the tube
C) Independent of the radius of the tube
D) Independent of surface tension

10. As the temperature of a liquid increases, its surface tension generally:

A) Increases
B) Decreases
C) Remains constant
D) Becomes infinite

11. Adding a detergent to water generally causes its surface tension to:

A) Increase

B) Decrease
C) Remain unchanged
D) Become zero instantly

12. Small drops of liquid tend to be spherical mainly because:
A) Gravity pulls them into a sphere
B) Surface tension minimises the surface area for a given volume
C) Air pressure compresses them into a sphere
D) They lose mass continuously

13. A needle can float on water mainly due to:
A) Buoyant force alone
B) The surface tension of water acting like a stretched membrane
C) The high density of the needle
D) Adhesive force between needle and air

14. Capillary rise of ink in a fountain pen nib is an example of the application of:
A) Viscosity
B) Surface tension
C) Bulk modulus
D) Archimedes' principle

15. The surface tension of a liquid becomes zero at its:
A) Freezing point
B) Boiling point only
C) Critical temperature
D) Room temperature

Answer Key

1. B) The force per unit length acting along the free surface of a liquid, tending to minimise its surface area | 2. C) N/m | 3. B) Molecules of the same substance | 4. B) Molecules of different substances | 5. B) Acute (less than 90°) | 6. B) Obtuse | 7. A) $h = 2T \cos\theta / (r \rho g)$ | 8. B) Surface tension of the liquid | 9. B) Inversely proportional to the radius of the tube | 10. B) Decreases | 11. B) Decrease | 12. B) Surface tension minimises the surface area for a given volume | 13. B) The surface tension of water acting like a stretched membrane | 14. B) Surface tension | 15. C) Critical temperature

9. Broad / Long Answer Questions

1. Define surface tension. State its SI unit and explain why liquids tend to behave as though covered with a stretched elastic membrane at their free surface.

2. Define cohesive force and adhesive force. Explain, with examples, how the relative strength of these forces determines the shape of a liquid surface near a solid boundary.

3. Define angle of contact. Explain the conditions under which the angle of contact is acute and obtuse, giving one example of each.

4. Write the formula for the height of capillary rise of a liquid in a tube, and explain each term used in it.

5. Explain, using the capillary rise formula, why the height of rise of a liquid in a capillary tube is greater in a narrower tube than in a wider one.

6. Explain any four applications of surface tension observed in daily life and technology.

7. Explain how capillary action helps in the upward movement of water in the stem of a plant, relating your answer to the concept of surface tension.

8. Explain the effect of an increase in temperature on the surface tension of a liquid, and state what happens to surface tension at the critical temperature.

9. Explain the effect of impurities, such as soap or detergent, on the surface tension of water, and explain why this effect is useful in cleaning clothes.

10. Explain why small insects are able to walk on the surface of water without sinking, using the concept of surface tension.