1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 02 (Physics Part-2, Class XI)
Module Name/Title	Unit 7, Module10, Surface Tension Chapter 10, Mechanical Properties of Fluids
Module Id	Keph_201005_econtent
Pre-requisites	Students should have knowledge of bulk properties of matter, properties of fluids, interatomic forces, and intermolecular forces.
Objectives	After going through this lesson, the learners will be able to: • Describe the concept of Surface energy • Define Surface tension and angle of contact • Measure surface tension of water in the laboratory
Keywords	Surface energy, surface tension, angle of contact , force of adhesion, force of cohesion

2. Development Team

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	Central Institute of Educational Technology, NCERT, New Delhi
Programme Coordinator	Dr. Mohd. Mamur Ali	Central Institute of Educational Technology, NCERT, New Delhi
Course Coordinator / PI	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Subject Matter Expert (SME)	Vandita Shukla	Kulachi Hansraj Model School Ashok Vihar, New Delhi
Review Team	Associate Prof. N.K. Sehgal (Retd.) Prof. V. B. Bhatia (Retd.) Prof. B. K. Sharma (Retd.)	Delhi University Delhi University DESM, NCERT, New Delhi

TABLE OF CONTENTS

1. UNIT SYLLABUS

UNIT 7: PROPERTIES OF BULK MATTER:

Chapter–9: Mechanical Properties of Solids:

Elastic behaviour, Stress-strain relationship, Hooke's law, Young's modulus, bulk modulus, shear, modulus of rigidity, Poisson's ratio, elastic energy.

Chapter–10: Mechanical Properties of Fluids:

Pressure due to a fluid column; Pascal's law and its applications (hydraulic lift and hydraulic brakes). Effect of gravity on fluid pressure. Viscosity, Stokes' law, terminal velocity, streamline and turbulent flow, critical velocity, Bernoulli's theorem and its applications. Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, application of surface tension ideas to drops, bubbles and capillary rise

Chapter–11: Thermal Properties of Matter:

Heat, temperature, thermal expansion; thermal expansion of solids, liquids and gases, anomalous expansion of water; specific heat capacity; Cp, Cv - calorimetry; change of state - latent heat capacity. Heat transfer-conduction, convection and radiation, thermal conductivity, qualitative ideas of Blackbody radiation, Wien's displacement Law, Stefan's law, Greenhouse effect.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 17 Modules

Module 1	• Forces between atoms and molecules making up the bulk matter • Reasons to believe that intermolecular and interatomic forces exist • Overview of unit • State of matter • Study of a few selected properties of matter • Study of elastic behaviour of solids • Stationary fluid property: pressure and viscosity • Stationary liquid property: surface tension • Properties of Flowing fluids • Effect of heat on matter
Module 2	• Idea of deformation by external force • Elastic nature of materials • Elastic behaviour • Plastic behaviour • Tensile stress • Longitudinal Stress and longitudinal strain • Relation between stress and strain • Hooke's law • Young's modulus of elasticity 'Y'
Module 3	• Searle's apparatus • Experiment to determine Young's modulus of the material of a wire in the laboratory • What do we learn from the experiment?
Module 4	• Volumetric strain • Volumetric stress • Hydraulic stress • Bulk modulus K • Fish, aquatic life on seabed ,deep sea diver suits and submarines
Module 5	• Shear strain • Shear stress • Modulus of Rigidity G • Poisson's ratio • Elastic energy • To study the effect of load on depression of a suitably

	clamped meter scale loaded at i)its ends ii)in the middle • Height of sand heaps , height of mountains
Module 6	• Fluids-liquids and gases • Stationary and flowing fluids • Pressure due to a fluid column • Pressure exerted by solid , liquids and gases • Direction of Pressure exerted by solids, liquids and gases
Module 7	• Viscosity- coefficient of viscosity • Stokes' Law • Terminal velocity • Examples • Determine the coefficient of viscosity of a given viscous liquid by measuring terminal velocity of a given spherical body in the laboratory
Module 8	• Streamline and turbulent flow • Critical velocity • Reynolds number • Obtaining the Reynolds number formula using method of dimensions • Need for Reynolds number and factors effecting its value • Equation of continuity for fluid flow • Examples
Module 9	• Bernoulli's theorem • To observe the decrease in pressure with increase in velocity of a fluid • Magnus effect • Applications of Bernoulli's theorem • Examples • Doppler test for blockage in arteries
Module 10	• Liquid surface • Surface energy • Surface tension defined through force and through energy • Angle of contact • Measuring surface tension
Module 11	• Effects of surface tension in daily life • Excess pressure across a curved liquid surface • Application of surface tension to drops, bubbles • Capillarity • Determination of surface tension of water by capillary rise

	method in the laboratory • To study the effect of detergent on surface tension of water through observations on capillary rise.
Module 12	• Thermal properties of matter • Heat • Temperature • Thermometers
Module 13	• Thermal expansion • To observe and explain the effect of heating on a bi-metallic strip • Practical applications of bimetallic strips • Expansion of solids, liquids and gases • To note the change in the level of liquid in a container on heating and to interpret the results • Anomalous expansion of water
Module 14	• Rise in temperature • Heat capacity of a body • Specific heat capacity of a material • Calorimetry • To determine specific heat capacity of a given solid material by the method of mixtures • Heat capacities of a gas have a large range • Specific heat at constant volume C_V • Specific heat capacity at constant pressure C_P
Module 15	• Change of state • To observe change of state and plot a cooling curve for molten wax. • Melting point, Regelation, Evaporation, boiling point, sublimation • Triple point of water • Latent heat of fusion • Latent heat of vaporisation • Calorimetry and determination of specific latent heat capacity
Module 16	• Heat Transfer • Conduction, convection, radiation • Coefficient of thermal conductivity • Convection

Module 17	• **Black body** • **Black body radiation** • **Wien's displacement law** • **Stefan's law** • **Newton's law of cooling,** • **To study the temperature, time relation for a hot body by plotting its cooling curve** • **To study the factors affecting the rate of loss of heat of a liquid** • **Greenhouse effect**

MODULE 10

3. WORDS YOU MUST KNOW

Fluids: A fluid is a substance that can flow. This includes both gases and liquids.
Potential energy: The energy of a body or a system with respect to the position of the body or the arrangement of the particles of the system.
Kinetic energy: energy possessed by a body due to its motion
Inter atomic forces: force between atoms of a material. it can be both attractive or repulsive in solids and attractive in fluids. The origin of this force is due to tendency of systems of atoms or molecules to acquire the least possible energy at any t4mperature
Intermolecular forces force between molecules of a material. it can be both attractive or repulsive in solids and attractive in fluids. The origin of this force is due to tendency of systems of molecules to acquire the least possible energy at any t4mperature
Bulk properties: the behaviour of bulk matter in response to external changes of temperature pressure heat etc.
Surface the boundary between two dissimilar materials forms a surface. A surface may also be formed in a material if, the layers have different densities, refractive indices or orientation of atoms and molecules making up the system.

4. INTRODUCTION

Have you observed a rain drop on a leaf?

A soap bubble?

Many observations around us are due to an interesting **liquid surface phenomenon**.

Water drop on a leaf

https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTu5Exe2p8An1mZFsybhTZwXVSXS7x3bY44UqKTHKTmRDeqKyHZ

You may have seen shiny water droplets clinging to stems, glass panes, taps, your fingers after a hand wash



Droplets on the tips of the fern, droplets on window pane, drop falling on surface of water created ripples

You must have noticed that oil and water do not mix; water wets you but not ducks; mercury does not wet glass but water sticks to it, , hair of a paint brush do not cling together when dry and even when dipped in water but form a fine tip when taken out of it.

A bee "walking on water"

https://upload.wikimedia.org/wikipedia/commons/4/4a/Bee_in_water_%285997003760%29.jpg

the surface of a liquid behaves like a stretched membrane.

In our earlier consideration with liquids/fluids, we considered the phenomenon arising within the bulk of the liquid /fluid material. These were related to pressure, flow, and viscosity.

All these and many more such experiences are related with **the free surfaces of liquids**.

By free surface we mean the surface of the liquid in contact with air, like open water bodies river sea ponds lakes or water in a bottle, glass, bucket etc

By Shalom Jacobovitz - SJ1_8558, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=9511582

https://cdn.pixabay.com/photo/2018/03/21/11/36/a-glass-of-water-3246432_960_720.png

a glass of water, observe the shiny top surface the horizontal surface of water in the glass appears to behave like a stretched membrane

In this module, you will learn about **surface tension and surface energy** and their applications in our day to day life.

Before we talk about surface tension and surface energy let us understand the meaning of **cohesive and adhesive forces.**

5. COHESIVE AND ADHESIVE FORCES

Children blow soap bubbles and play in the spray of a fountain or a sprinkler on a hot summer day.

A technician draws blood into a syringe (small-diameter tube) just by touching it to a drop on a pricked finger. All these activities are dominated by the attractive forces between atoms and molecules —both within a liquid, and between the liquid and its surroundings.

Attractive forces among molecules of the same type are called **cohesive forces**.

Liquids can, be held in open containers because cohesive forces hold the molecules together.

Attractive forces among molecules of different types are called **adhesive forces**. Because of adhesive forces -liquid drops cling to window panes.

You can try this

Fill a glass bottle with water, so that it is only half full

Now add two table spoon of oil in it. The oil will float on water why? The oil layer completely spreads uniformly why?

Now shake the bottle and let it stand on a table

Your observation will show that the inner wall of the, bottle will get some oil on it and some water will stick to it due to forces of adhesion between water and oil molecules

Suppose you eat some fried food, without washing your hands you hold a glass of water, it is the force of adhesion between oil and glass surface that makes the glass dirty,

This video shows the cohesive and adhesive forces

Watch

https://www.youtube.com/watch?v=_JAKshBr0eI

You can do this very exciting experiment on Surface Tension with ordinary things. Fill the glass with color water. Cover it with a plate and then invert the glass on the plate. Now gently tilt the glass on its edge and quickly wedge a coin between the glass and the plate. Mop up the water and wedge more coins. Despite the gap between the glass rim and the plate water does not flow out because of surface tension.
http://www.arvindguptatoys.com/toys/a... This work was supported by IUCAA and Tata Trust. This film was made by Ashok Rupner TATA Trust: Education is one of the key focus areas for Tata Trusts, aiming towards enabling access of quality education to the underprivileged population in India. To facilitate quality in teaching and learning of Science education through workshops, capacity building and resource creation, Tata Trusts have been supporting Muktangan Vigyan Shodhika (MVS), IUCAA's Children's Science Centre, since inception. To know more about other initiatives of Tata Trusts, please visit www.tatatrusts.org

Can we do the same with liquids other than water?

THINK ABOUT THESE

- **What makes cohesive forces so strong in liquid?**
- **Are the forces of attraction among the molecule of liquids and gases of the same type?**
- **Up to what distance a cohesive force acts between two molecules?**
- **What is the range of adhesive forces between the molecules of different materials?**
- **If we increase the quantity of matter will the cohesive or adhesive forces also increase?**

We know that liquids have no definite shape but have a definite volume. They acquire a free surface when poured in a container. This surface possesses some additional energy.

Surface tension is the elastic tendency of a fluid surface which makes it acquire the least surface area possible.

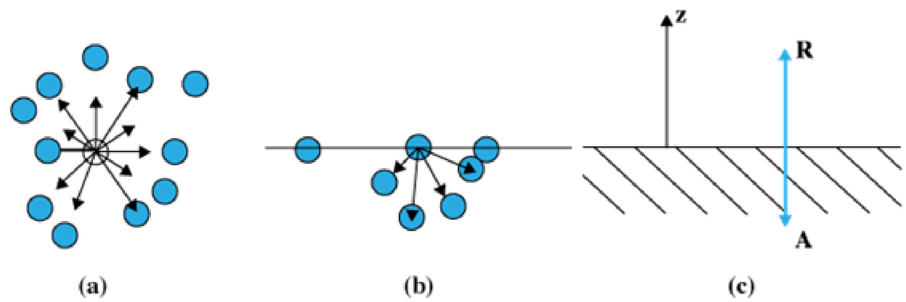
Surface tension allows insects (e.g. water strides), usually denser than water, to float and stride on a water surface.

This phenomenon is known as surface tension and it is concerned with only liquids as gases do not have free surfaces.

Let us now understand this phenomenon.

6. SURFACE ENERGY

A liquid stays together because of attraction among molecules. Consider a molecule well inside a liquid.



Schematic picture of molecules in a liquid, at the surface and balance of forces (a) Molecule inside a liquid. Forces on a molecule due to others are shown. Direction of arrows indicates attraction or repulsion. (b) Same, for a molecule at a surface. (c) Balance of attractive (A) and repulsive (R) forces.

The intermolecular distances are such that it is attracted to all the surrounding molecules [Fig. (a)]. This attraction results in a negative potential energy for the molecule, which depends on the number and distribution of molecules around any chosen one. But the average potential energy of all the molecules is the same. This is supported by the fact that to take a collection of such molecules (the liquid) and to disperse them far away from each other in order to evaporate or vaporise, the heat of evaporation required is quite large. For water, it is of the order of 40 kJ/mol.

Let us consider a molecule near the surface Fig. (b). only lower half side of it is surrounded by liquid molecules. There is some negative potential energy due to these, but obviously it is less than that of a molecule in bulk, i.e., the one fully inside. Approximately it is half of the latter.

Thus, molecules on a liquid surface have some extra energy in comparison to molecules in the interior.

A liquid thus tends to have the least surface area which external conditions permit.

Increasing surface area requires additional energy. This fact explains most liquid surface phenomenon.

How much energy is required to hold a molecule on the surface?

As mentioned above, roughly it is half the energy required to remove it entirely from the liquid i.e., half the heat of evaporation.

Finally, **what is a surface?** Since a liquid consists of molecules moving about, there cannot be a perfectly sharp surface. The density of the liquid molecules drops rapidly to zero around z = 0 as we move along the direction indicated Fig (c) in a distance of the order of a few molecular sizes.

This video shows molecular theory of surface tension.

https://youtu.be/bPlPK298M_8

THINK ABOUT THESE

- **Why is the potential energy of a molecule surrounded by other molecules negative?**
- **If the molecules at the surface have some extra energy in comparison to the molecules in the interior, then why does liquid tend to have the least surface area?**
- **If a drop of liquid breaks in to small drops then what will be the change in the surface energy?**
- **Does the principle of conservation of energy govern the property of fluids to acquire minimum surface area?**
- **Among the liquid-air, liquid-liquid and liquid-solid interface which has maximum surface energy?**

7. SURFACE TENSION

Cohesive force among molecules cause the surface of a liquid to contract to the smallest possible surface area. This general effect is called **surface tension**.

Surface Tension is the property of a liquid by virtue of which the free surface of the liquid behaves like a stretched elastic membrane having a tendency to contract.

Molecules on the surface are pulled inward by cohesive forces, reducing the surface area. Molecules inside the liquid experience zero net force, since they have neighbors on all sides.

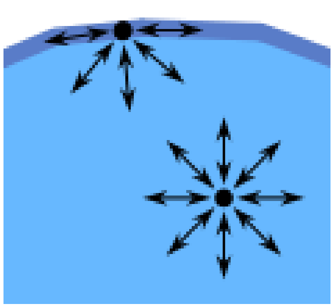


Diagram of the forces on molecules in liquid

Surface tension prevents the paper clip from submerging.

The cohesive forces among the liquid molecules cause surface tension.

- In the bulk of the liquid, each molecule is pulled equally in every direction by neighboring liquid molecules, resulting in a net force zero.
- The molecules at the surface do not have other molecules on all sides of them and therefore are pulled inwards. So the net force of cohesion above the surface is lesser as compared to that on a molecule well inside the liquid. **What about the force of adhesion between liquid vapour molecules and air molecules?**
- This creates some internal pressure and forces liquid surfaces to contract to the minimal area.
- Surface tension is responsible for the shape of liquid droplets. Although easily deformed, droplets of water tend to be pulled into a spherical shape by the cohesive forces of the surface layer. In the absence of other forces, including gravity, drops of virtually all liquids would be perfectly spherical.
- Force of adhesion between the liquid molecules and the molecules of the container are important, we will consider the force of adhesion on liquid surface in the next module.

Another way to view surface Tension is in terms of energy.

A molecule in contact with a neighbor is in a lower state of energy than if it were alone (not in contact with a neighbor).

The interior molecules have as many neighbors as they can possibly have, but the surface molecules are missing neighbors (compared to interior molecules).

So, **the surface molecules have a higher energy**. For the liquid to minimize its energy state, the number of higher energy surface molecules must be minimized. The minimized number of surface molecules results in a minimized surface area.

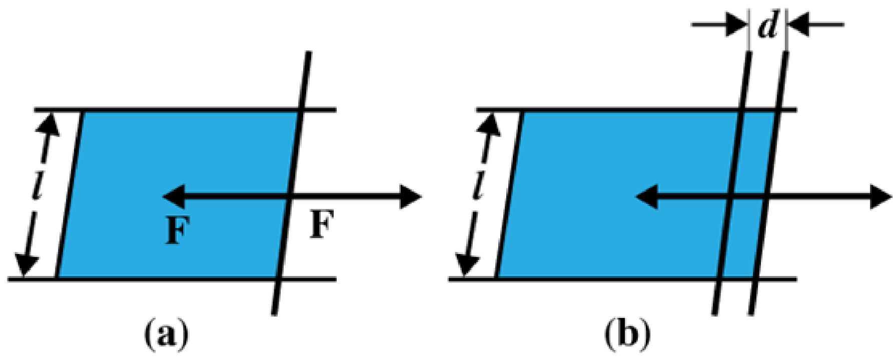
As a result of surface area minimization, a surface will assume the smoothest shape it can. Any curvature in the surface shape results in greater area and a higher energy.

So, the surface will push back against any curvature in much the same way as a truck pushed uphill will push back to minimize its gravitational potential energy.

8. SURFACE ENERGY AND SURFACE TENSION

As we have discussed that an extra energy is associated with surface of liquids, the creation of more surface (spreading of surface), keeping other things like volume fixed, requires additional energy.

To appreciate this, consider a horizontal liquid film ending in bar free to slide over parallel guides Fig.



Stretching a soap film. (a) A film in equilibrium; (b) The film stretched an extra distance.

Suppose that we move the bar by a small distance d as shown. Since the area of the surface increases, the system now has more energy. This means that some work has been done against an internal force.
Let this internal force be F, the work done by the applied force is F.d = Fd.

From conservation of energy, this is stored as additional energy in the film.

If the **surface energy of the film is S per unit area,** the extra area is 2dl.

A film has two sides and the liquid in between, so there are two surfaces and the extra energy is

$$S\ (2dl) = F\ d$$

$$\text{Or,} S = \frac{F.d}{2dl}$$

$$\mathbf{S = \frac{F}{2l}}$$

This quantity **S surface energy per unit area, has the magnitude of surface tension.**

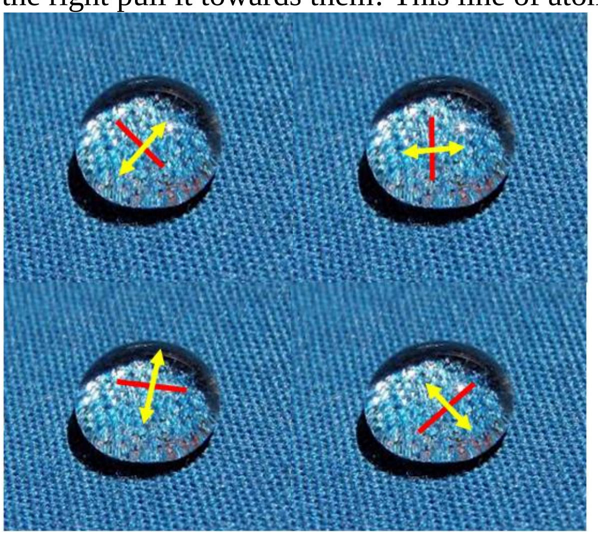
It is equal to the surface energy per unit area of the liquid interface and is also equal to the force per unit length exerted by the fluid on the movable bar.

So far we have talked about the surface of one liquid. More generally, we need to consider fluid surface in contact with gas, liquid or solid.
The surface energy depends on the materials on both sides of the surface. For example, if the molecules of the materials attract each other, surface energy is reduced while if they repel each other the surface energy is increased. Thus, more appropriately, the surface energy is the energy of the interface between two materials and depends on both of them.

We make the following observations from above:

(i) **Surface tension of a liquid is force per unit length (or surface energy per unit area) acting in the plane of the interface between the plane of the liquid and any other substance**; it also is the extra energy that the molecules at the interface have as compared to molecules in the interior(within the interior).

(ii) At any point on the interface besides the boundary, we can draw a line and imagine equal and opposite **force F per unit length due to the surface tension** of the line acting perpendicular to the line, in the plane of the interface. The line is in equilibrium. To be more specific, imagine a line of atoms or molecules at the surface. The atoms to the left pull the line towards them; those to the right pull it towards them! This line of atoms is in equilibrium under tension.



The figure of four liquid drops on a blue surface above, helps you imagine the red line as the imaginary line and the yellow double sided arrow as the force of surface tension the red line may be drawn anywhere on the surface with any orientation.

The force of surface tension keeping the surface stretched can be imagined as acting perpendicular to any line on the surface of the liquid

Surface tension can be defined as the force per unit length with a unit of Nm^{-1}

Table gives the surface tension of various liquids. The value of surface tension of a liquid depends on temperature. **Like viscosity, the surface tension of a liquid usually falls with temperature.**

Surface tension of some liquids at the temperatures indicated with the heats of the vaporisation

Liquid	Temp (°C)	Surface Tension (N/m)	Heat of vaporisation (kJ/mol)
Helium	–270	0.000239	0.115
Oxygen	–183	0.0132	7.1
Ethanol	20	0.0227	40.6
Water	20	0.0727	44.16
Mercury	20	0.4355	63.2

THINK ABOUT THESE

- **How will surface tension of the liquid change in, if its density decreases?**
- **An oil drop is perfectly spherical in water-alcohol mixture; why? (density of mixture is equal to the density of oil)**
- **Why will surface tension change with temperature?**
- **If oil is poured on water, then it will spread on surface of water. What will be change in the surface energy of water surface just below the oil surface?**
- **Is surface tension of a liquid constant?**
- **A floatable plastic bottle cover and pieces of straw are spread on the surface of pure water filled in a vessel. On dropping a piece of sugar in water, the straw come nearer to the bottle cap, but on dropping a piece of soap they go away from it; why? Do you think the surface tension changes with the addition of sugar and soap?**
- **Oil is sprinkled on sea waves to calm them. Why?**
- **At what temperature surface tension of the liquid will be zero**
- **Evaporation and boiling are two ways of vaporization. Since the thermal motion of a molecule of liquid must be sufficient to overcome the surface tension and evaporate. Do you think heat of vaporization is affected by surface tension?**
- **When we walk on a muddy road our shoes and slippers tend to stick and we find it difficult to walk. Why?**

- **A lizard can walk on the ceiling of a room upside down but it cannot walk on wet surfaces. why?**
- **Surface Tension of soap solution in water is T, how much work will be done in the formation of a soap bubble of radius r.**
  HINT: $W=\Delta T$; $W=8\pi r^2 T$

9. MEASURING SURFACE TENSION

FEELING THE SURFACE TENSION FORCE

Let us consider a way to experience the surface tension force.

Take two glass slides, the type you get in the biology lab. Clean them. Put a drop of water on one of them

Place the other slide to cover the first

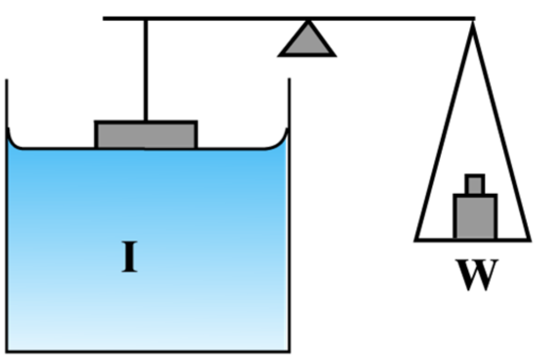
Now try to take the slides apart. The force of surface tension is what you experience.

A fluid will stick to a solid surface if the surface energy between fluid and the solid is smaller than the sum of surface energies between solid-air, and fluid-air.

Now there is adhesion between the molecules of the solid surface and those of the liquid. It can be directly measured experimentally.

A flat vertical glass plate, below which a vessel of some liquid is kept, forms one arm of the balance. The plate is balanced by masses on the other side, with its horizontal edge is just over water.

The vessel is raised slightly till the liquid just touches the glass plate and pulls it down a little because of surface tension. Masses are added till the plate just clears water.



Schematic arrangement to show a method for measuring Surface Tension.

Then, the surface tension of the liquid-air interface is

$$S_{la} = \frac{W}{2l}$$

$$= \frac{mg}{2l}$$

where m is the extra mass added and l is the length of the plate edge in contact with water. The total surface length on either side of the glass plate =2l

The subscript (la) emphasizes the fact that the liquid-air interface tension is involved.
Watch
https://www.youtube.com/watch?v=YzG7po1F5hE
Surface Tension:-
Surface tension is the elastic tendency of a fluid surface which makes it acquire the least surface area possible. Surface tension allows insects (e.g. water striders), usually denser than water, to float and stride on a water surface.

At liquid-air interfaces, surface tension results from the greater attraction of liquid molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion). The net effect is an inward force at its surface that causes the liquid to behave as if its surface were covered with a stretched elastic membrane. Thus, the surface becomes under tension from the imbalanced forces, which is called Surface tension. Surface tension has the dimension of force per unit length, or of energy per unit area. Because of the relatively high attraction of water molecules for each other through a web of hydrogen bonds, water has a higher surface tension (72.8 millinewtons per meter at 20 °C) compared to that of most other liquids. Surface tension is an important factor in the phenomenon of capillarity.

This video explains how to determine the surface tension of water by capillary rise method

EXAMPLE

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

Due to surface tension, the soap film tries to make its surface minimum. As it has two free surfaces, the total force due to surface tension on the slider will be

$$F = 2(T \times l)$$

In equilibrium, the total force due to surface tension on the slider will be equal to its weight i.e.

$$2(T\times l) = M\,g$$

Here, $M\,g = 1.5\times 10^{-2} N$; $l = 30\ cm = 30\times 10^{-2} m$

$$T = \frac{M\,g}{2l}$$

$$= \frac{1.5\times 10^{-2}}{2\times 30\times 10^{-2}}$$

$$= \mathbf{0.025\ N\ m^{-1}}$$

10. ANGLE OF CONTACT

Why does water form beads on a waxed paper but not on a newspaper?

The answer is that the adhesive forces between water and wax are much smaller than those between water and newspaper.

Competition between the forces of adhesion and cohesion are important in the macroscopic behavior of liquids.

An important factor in studying the role of these two forces is the angle θ (inside the liquid) between the tangent to the liquid surface and the solid surface.

The contact angle θ is directly related to the relative strength of the cohesive and adhesive forces. The larger the strength of the cohesive force relative to the adhesive force, the larger θ is, and the more the liquid tends to form a droplet. The smaller θ has, the smaller the relative strength, so that the adhesive force is able to flatten the drop.

The surface of liquid near the plane of contact, with another medium is in general curved.

The angle between tangent to the liquid surface at the point of contact and solid surface inside the liquid is termed as angle of contact. It is denoted by θ. It is different at interfaces of different pairs of liquids and solids. The value of θ determines whether a liquid will spread on the surface of a solid or it will form droplets on it.

For example,
Angle of contact for water droplets on lotus leaf as shown in Fig. (a)

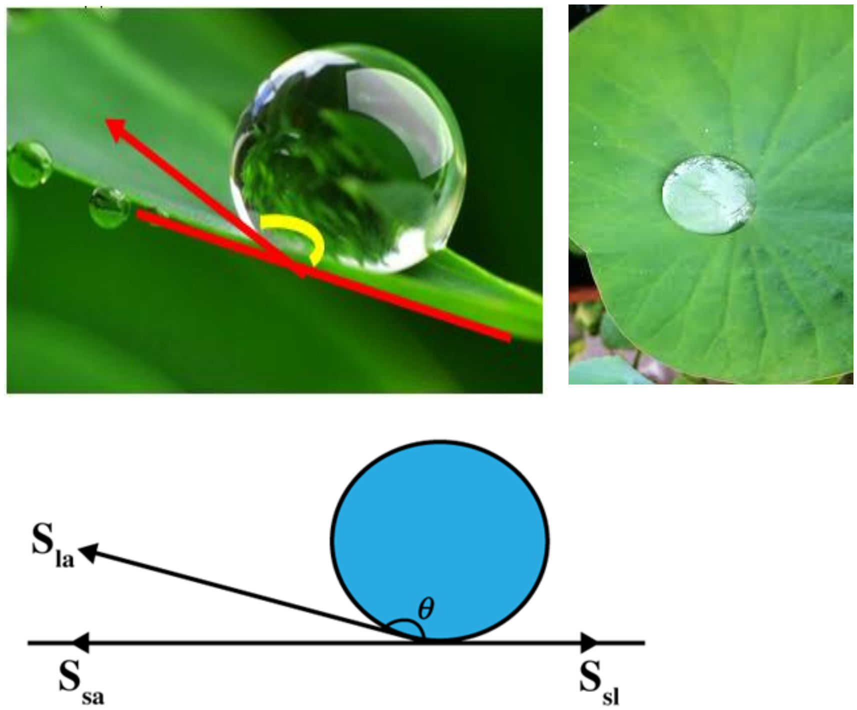
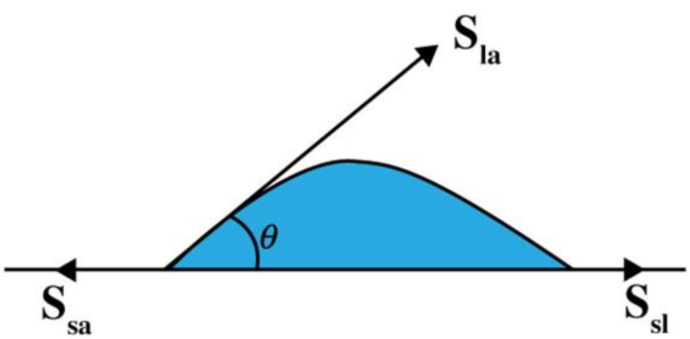


Fig (a)

Water spreads over a clean plastic plate as shown in Fig. (b).



(b)

Different shapes of water drops with interfacial tensions

(a) on a lotus leaf

(b) on a clean plastic plate.

We consider the **three interfacial tensions at all the three interfaces**,

- liquid-air,
- solid-air and
- solid-liquid

denoted by S_{la}, S_{sa} & S_{sl} respectively as given in Fig. (a) and (b).

At the line of contact, the surface forces between the three media must be in equilibrium.

From Fig.(b), the following relation is easily derived.

$$S_{la} \cos \theta + S_{sl} = S_{sa}$$

The angle of contact is an obtuse angle if $S_{sl} > S_{la}$ as in the case of water-leaf interface while it is an acute angle if $S_{sl} < S_{la}$ as in the case of water-plastic interface.

However, it may be a right angle also, as in the case of silver-distilled water interface, formed by filling a tube made of silver, with distilled water.

When θ is an obtuse angle then molecules of liquids are attracted strongly to themselves and weakly to those of solid, it costs a lot of energy to create a liquid-solid surface, and liquid then does not **wet the solid**. Like the water drop on a lotus leaf

This is what happens with water on a waxy or oily surface, and with mercury on any surface.

On the other hand, if the molecules of the liquid are strongly attracted to those of the solid, this will reduce S_{sl} and therefore, cos θ may increase or θ may decrease. In this case θ is an acute angle. This is what happens for water on glass or on plastic and for kerosene oil on virtually anything (it just spreads).

Soaps, detergents and dyeing substances are wetting agents. When they are added the angle of contact becomes small so that these may penetrate well and become effective.
Water proofing agents on the other hand are added to create a large angle of contact between the water and fibers.

THINK ABOUT THESE

- **Will the angle of contact between the oil drop and iron surface be equal to the angle of contact between the oil drop and glass surface?**
- **Can angle of contact of a particular fluid be different with different surfaces?**
- **Why the angle of contact of a water drop is different for a lotus leaf and for a clean glass surface? Think of a reason for your answer**
- **Why should the angle of contact be measured inside of the liquid?**
- **If we want to wet a piece of cloth with a liquid, then what are those necessary condition which will allow wetting?**

- **While using water colors to paint we keep dipping the brush in clean water.**

11. SUMMARY

- Surface tension causes the liquid surface to behave like a stretched membrane.
- Surface tension is force per unit length (or surface energy per unit area) acting in the plane of interface between the liquid and the bounding surface.
- It is the extra energy that the molecules at the interface have as compared to the interior
- Surface tension arises due to excess potential energy of the molecules on the surface in comparison to their potential energy in the interior. Such a surface energy is present at the interface separating two substances at least one of which is a fluid. It is not the property of a single fluid alone
- Surface Tension decreases with temperature.
- The angle inside the liquid, between tangent to the liquid surface at the point of contact and solid surface is termed as angle of contact. It is denoted by θ.
- Angle of contact determines whether the liquid would spread on a surface.
- Laboratory methods to determine surface tension