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, Module11, Effects of Surface Tension Chapter 10, Mechanical Properties of Fluids
Module Id	keph_201006_econtent
Pre-requisites	Students should have knowledge of concept of surface tension. Angle of contact, bulk properties of liquids,
Objectives	After going through this lesson, the learners will be able to: • Know about effects of surface tension in daily life • Explain the concept of excess pressure across a curved liquid surface • Apply the concept of surface tension to drops and bubbles • Define Capillarity • Determine surface tension of water by capillary rise method in the laboratory and study the effect of detergent on surface tension of water and hence capillary rise.
Keywords	Surface tension, Excess pressure, capillarity, action of soaps

2. **Development Team**

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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?**
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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 11

3. WORDS YOU MUST KNOW

Fluids: A fluid is a substance that can flow. This includes both gases and liquids

Liquid: state of matter, intermolecular forces are stronger than that in gases but weaker as compared to solid state

Fluid pressure: fluid pressure is exerted in all directions

Free surface: the topmost surface of a liquid in contact with air. The free surface of a liquid just means the surface that is in contact with air. Like the horizontal surface of water in a glass or the top of the ocean where boats float.

Pressure at appoint within the liquid. = h dg where h is the height of the liquid surface above the point, or h may be defined as the depth of the point below the free surface of the liquid.

Pascal's law: a pressure change occurring anywhere in a confined incompressible fluid is transmitted undiminished throughout the fluid.

Force of cohesion: Interatomic /intermolecular force between similar atoms or molecules is called force of cohesion

Force of adhesion: Interatomic /intermolecular force between dissimilar atoms or molecules is called force of cohesion

Surface tension: the property of a liquid by virtue of which the free surface of the liquid behaves like a stretched membrane and has tendency to contract

Angle of contact: the angle between tangent to the liquid surface at the point of contact and solid surface inside the liquid is called angle of contact

4. INTRODUCTION

You must have noticed that, oil and water do not mix; water wets you and me but not ducks; oil rises up a cotton wick, in spite of gravity, we use soaps or detergents to clean ourselves and wash our clothes. Hair of a paint brush do not cling together when dry or even when dipped in water but form a fine tip when taken out of the water. All these and many more such experiences are related with the free surfaces of liquids, or with the phenomenon of surface tension

https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcS2iQLLeJxdmFvuhar22IOhmkrH60nsthr8O4qb6oybQbpTkML-

You must have blown soap bubbles in your childhood.
Why are drops and bubbles spherical?
What keeps soap bubbles more stable as compared to bubbles of water?

We will answer all these and more such questions in this module

In the previous module, we have learnt about the concept of surface tension now let us understand few of its applications in our day-to-day life.

5. EFFECTS OF SURFACE TENSION IN DAILY LIFE

- Rain water forms beads on the surface of a waxy surface, such as that of a leaf. Water adheres weakly to wax and strongly to itself, so water clusters into drops. Surface tension gives them their near-spherical shape, because a sphere has the smallest possible surface area to volume ratio.

Water beading on a leaf a common sight after rains, watering the garden

- Water striders use surface tension to walk on the surface of a pond. The surface of the water behaves like an elastic film: the insect's feet cause indentations in the water's surface, increasing its surface area.

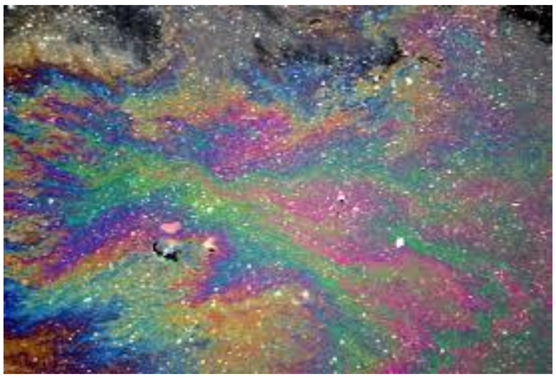
Water striders stay atop the liquid because of surface tension

- Liquid drops and bubbles are spherical in shape.

One consequence of surface tension is that free of liquid drops and bubbles is spherical, if effects of gravity can be neglected. As you have learnt in previous module that a liquid-air interface formed has additional energy, so for a given volume the surface with minimum energy is the one with the least area. The sphere has this property. So, if gravity and other forces (e.g. air resistance) were ineffective, liquid drops would be spherical.

- 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. This is because the water film formed on them tend to occupy minimum area.(try it)

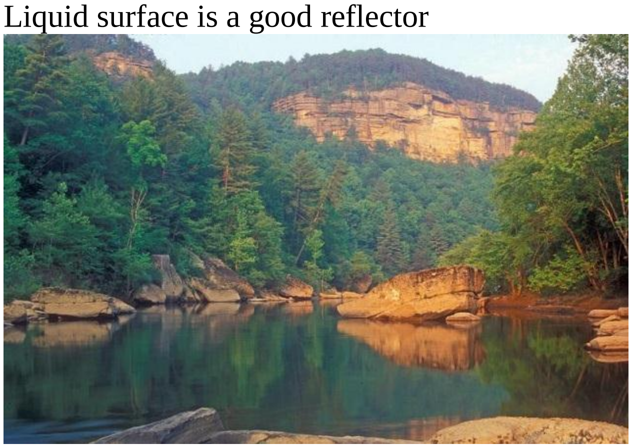
- When an oil drop is put in water, it reaches the top of the surface of water, it spreads out on the water surface because its density is less than water and surface tension of water is greater than that of oil.



This video shows the comparison of surface tension of water and oil.
https://youtu.be/yY-TlcuUOl0

This video shows some fun experiments showing surface tension.
https://youtu.be/7OVB8i0c1bs

- Liquid surface is a good reflector



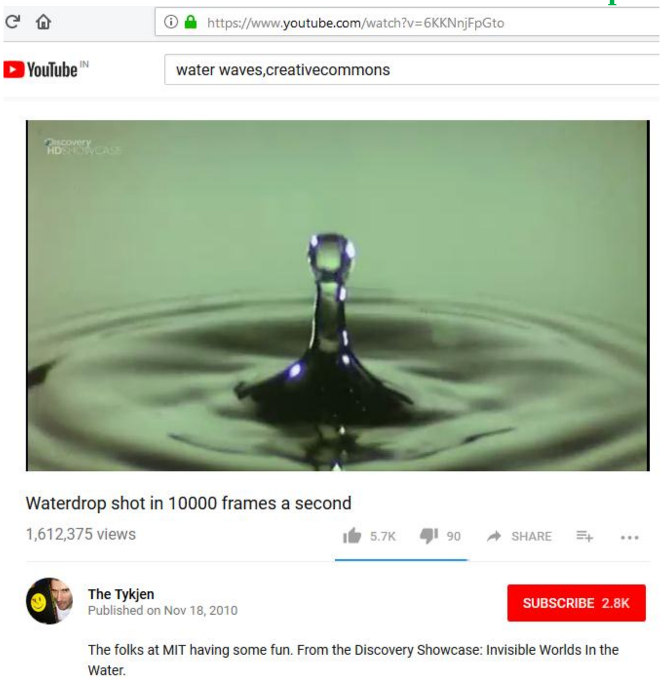
NOTICE the reflection of light confirming the property of surface tension

https://www.nps.gov/common/uploads/stories/images/nri/20161020/articles/E93D92F9-1DD8-B71B-0B20733E1CD3521C/E93D92F9-1DD8-B71B-0B20733E1CD3521C.jpg

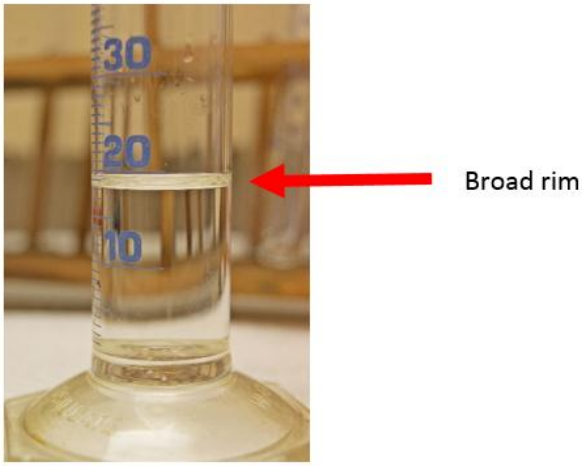
Watch this video

https://www.youtube.com/watch?v=6KKNnjFpGto

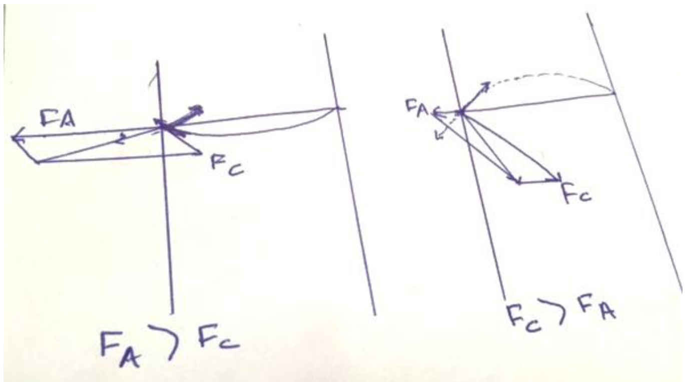
This video shows in slow motion a water drop dropped on a still water surface.



- Water in a glass container has a rim

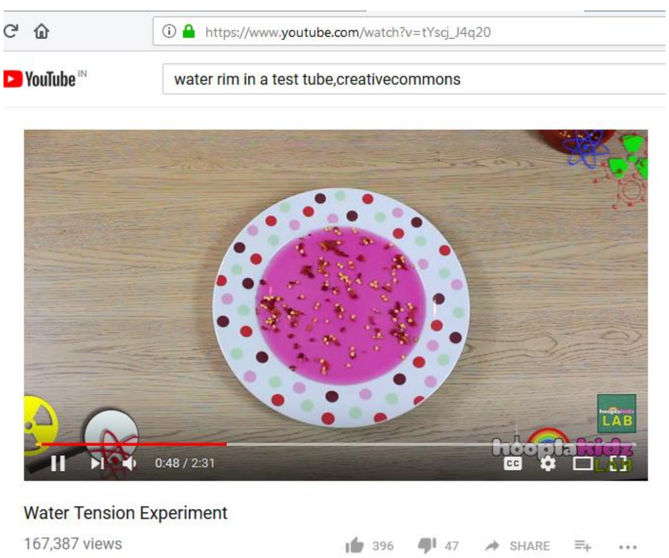


To understand why water climbs on the rim at the points of contact in a glass tumbler



F_A and F_C are forces of adhesion and cohesion

In case $F_A > F_C$
The resultant as shown would pull the molecule at the rim outwards.
The force of surface tension must act perpendicular to the resultant in order to keep the molecule in contact to the rim. This causes the liquid surface to climb the container surface forming a rim.
In case $F_A < F_C$
The resultant as shown would pull the molecule at the rim inwards.
The force of surface tension must act perpendicular to the resultant in order to keep the molecule in contact to the rim. This causes the liquid surface to depress in the container surface forming a rim.



Experiment with the properties of water with HooplaKidzLab, as you do these fun science projects about exploring water tension. This video explores water surface tension. Help your child understand surface tension with the help of this easy experiment with chili flakes and soap!
https://www.youtube.com/watch?v=tYscj_J4q20

- **Water surface is horizontal and can move like a plane**

  - ✓ **Take a transparent glass bottle.**
  - ✓ **Fill it half with water.**
  - ✓ **Place it on a table. Observe the surface of water.**
  - ✓ **Tilt the bottle and watch the surface, it remains horizontal even when it may become oval, it moves like a plane when the bottle is gently tilted back and forth about a vertical line.**

- **Ripples move on the surface of water.**

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

- **Make a water lens between your thumb and forefinger**
  - ✓ wet your hands,
  - ✓ leave some water on the fingers,
  - ✓ observe a drop of water,
  - ✓ gently push the thumb and finger apart and see the curvature change of the droplet.

THINK ABOUT THESE

- **If you fill a glass tumbler with water slowly. Notice 'the water rim' where water is in contact with glass and air on the surface.**
  - **No rim is formed at the center flat part of water surface**
  - **If we fill the glass tumbler to the top and put a little more the water ,surface bulges out (convex surface) before water flows out. How would you explain this phenomenon?**

- **What if glass tumbler is replaced by a stainless steel tumbler, ceramic tumbler, terracotta tumbler (kulhar)**


https://upload.wikimedia.org/wikipedia/commons/f/f8/Water_in_stainless_steel_tumbler.jpg

- **If we take some oil in a metal or a plastic spoon, what kind of surface will be formed concave or convex?**
- **Which of the following should be considered to predict the surface of a liquid in a container?**
  - **Force of cohesion (nature of liquid)**
  - **Force of adhesion (nature of liquid and material of container)**
  - **Relative magnitude of forces of adhesion and cohesion**
  - **Relative magnitude of forces of adhesion and cohesion and temperature**
  - **Relative magnitude of forces of adhesion and cohesion and temperature and surface tension**
- **Is it possible for a liquid surface to climb at the rim in a container and dip in another container?**

6. EXCESS PRESSURE ACROSS A CURVED LIQUID SURFACE

One consequence of surface tension is that free liquid drops and bubbles are spherical if effects of gravity can be neglected.

You must have seen this especially clearly in small drops just formed in a high-speed spray or jet, and in soap bubbles blown by children.

Soap bubbles in a bucket with washing liquid.

https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTwi6z0RuTFUMsiEnDSOomxBs18K7N1tiBQ3ct0_plg8p3Ja1lf

or

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Why are drops and bubbles spherical? What keeps soap bubbles stable?

As we have been saying repeatedly**, a liquid air interface has energy, so for a given volume the surface with minimum energy is the one with the least area.**

The sphere area of a sphere is the least

Hence liquid drops are spherical.

Another interesting consequence of surface tension is that the pressure inside a spherical drop is more than the pressure outside. This is easy to understand as it would not bulge out against atmospheric pressure.

When the free surface of a liquid is curved, there is a difference between the liquid side and vapour side of the surface. Let us consider the three possible liquid surfaces:

Case 1 - When the free surface of a liquid is plane. (Fig a)

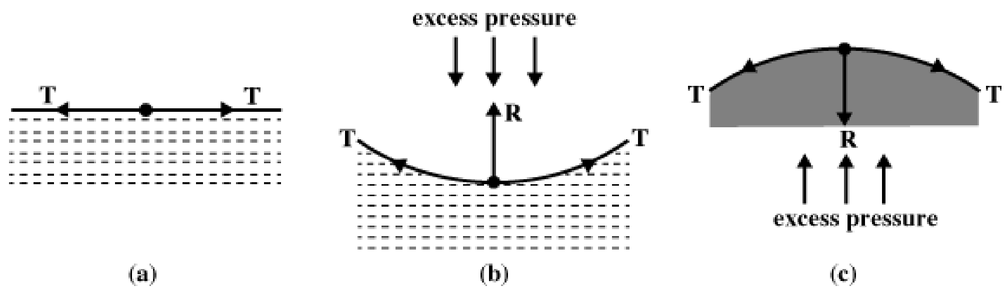
When the free surface of a liquid is plane then the surface tension acts horizontally. It has no component perpendicular to the horizontal surface. As a result, there is no pressure difference between the liquid side and the vapour side.

Case 2 .If the surface of the liquid is concave (Fig. b)

If the surface of the liquid is concave, then the resultant force *R* due to surface tension on a molecule on the surface act vertically upwards. To balance this, an excess pressure acting downward on the concave side is necessary.

Case 3 If the liquid surface is convex (Fig. c),

If the surface is convex the resultant *R* acts downward and there must be an excess pressure on the concave side acting in the upward direction.



Excess of pressure across a liquid surface

Thus, **there is always an excess pressure on the concave side of a curved liquid surface over the pressure on its convex side due to surface tension**

7. APPLICATION OF SURFACE TENSION IDEAS TO DROPS AND BUBBLES

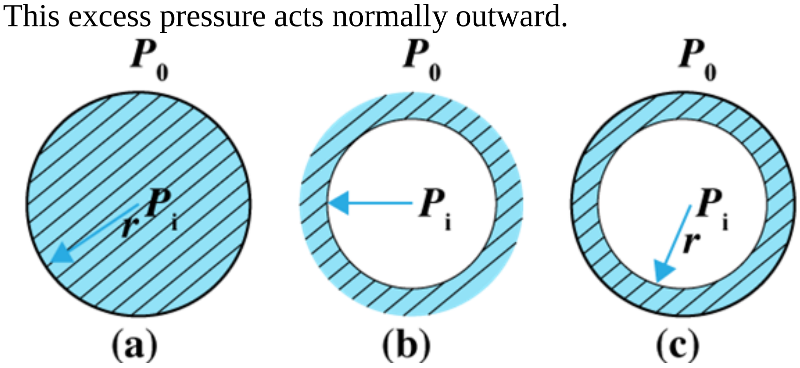
Now, you have understood an interesting consequence of surface tension that **the pressure inside a spherical drop is more than the pressure outside**.

Let us derive an expression for **Excess pressure inside a liquid drop.**

Suppose a spherical drop of radius r is in equilibrium.

Let s be the surface tension of the liquid. Due to its spherical shape, there is an excess pressure inside the drop.

This excess pressure acts normally outward.



Drop, cavity and bubble of radius r.

Let its radius increase by Δr under the excess pressure

The extra surface energy is

$$= \textbf{increase in surface area} \times \textbf{surface tension}$$

$$[4\pi(r+\Delta r)^2 - 4\pi r^2]S_{la} = 8\pi\, r\, \Delta r S_{la}$$

If the drop is in equilibrium this energy cost is balanced by the energy gain due to expansion under the pressure difference ($P_i - P_o$) between the inside of the drop and the outside.

The work done = force x distance

= pressure x area x distance

$$W = (P_i - P_o)4\pi r^2 \Delta\, r$$

We get

$$(\mathbf{P_i} - \mathbf{P_o}) = \left(\frac{\mathbf{2S_{la}}}{\mathbf{r}}\right)$$

EXCESS PRESSURE INSIDE A SOAP BUBBLE

Suppose a soap bubble of radius r is in equilibrium. Let s be the surface tension of the liquid. Due to its spherical shape, there is an excess pressure inside the bubble. This excess pressure acts normally outward. Let its radius increase by Δr under the excess pressure.

The soap bubble has air inside and outside, so that it has two free surfaces

The extra surface energy is =

$$\text{increase in surface area} \times \text{surface tension}$$

$$2 \times [4\pi(r+\Delta r)^2 - 4\pi r^2]S_{la} = 16\pi\, r\, \Delta r S_{la}$$

If the bubble is in equilibrium this energy cost is balanced by the energy gain due to expansion under the pressure difference ($P_i - P_o$) between the inside of the bubble and the outside.

The work done = force x distance

= pressure x area x distance

$$W = (P_i - P_o)4\pi r^2 \Delta\, r$$

This would occur on either side of the soap bubble film.

Hence we consider the two surfaces and the pressure difference due to each, makes it double

We get

$$(\mathbf{P_i} - \mathbf{P_o}) = \left(\frac{\mathbf{4S_{la}}}{\mathbf{r}}\right)$$

EXCESS PRESSURE INSIDE AN AIR BUBBLE INSIDE A LIQUID

Consider an air bubble inside a liquid of radius r that is in equilibrium. Let s be the surface tension of the liquid. Due to its spherical shape, there is an excess pressure inside the air bubble. This excess pressure acts normally outwards. Let its radius increase by Δr under the excess pressure.

The extra surface energy is =

$$\textbf{increase in surface area } \times \textbf{surface tension}$$

$$[4\pi(r + \Delta r)^2 - 4\pi r^2]S_{la} = 8\pi\, r\, \Delta r S_{la}$$

If the drop is in equilibrium this energy cost is balanced by the energy gain due to expansion under the pressure difference ($P_i - P_o$) between the inside of the air bubble and the outside.

The work done = force x distance
= pressure x area x distance

$$W = (P_i - P_o) 4\pi r^2 \Delta\, r$$

We get

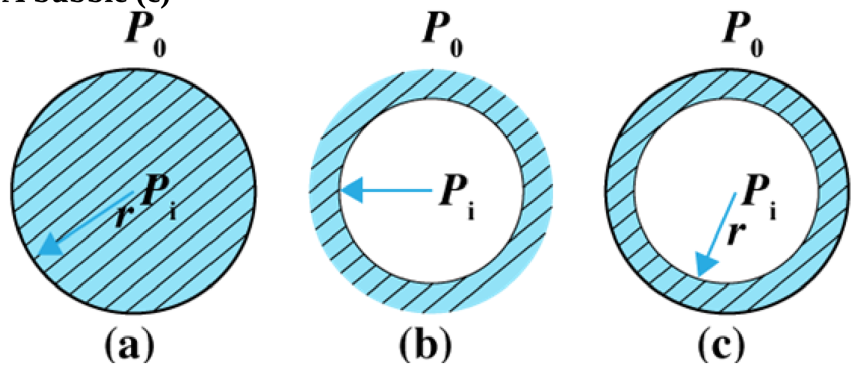
$$(\mathbf{P_i} - \mathbf{P_o}) = \left(\frac{\mathbf{2S_{la}}}{\mathbf{r}}\right)$$

In general, for a liquid-gas interface, the concave side has a higher pressure than the convex side. Let us consider

The drop (a)

Cavity or air bubble (b)

A bubble (c)



Drop, air bubble inside a liquid and bubble of radius r.

So now you know a bubble (c) differs from both a drop and an air bubble inside a liquid; because it has two interfaces.

So for a bubble
$(P_i - P_o) = (4\ S_{la}/\ r)$

This is probably why you have to blow hard, but not too hard, to form a soap bubble.

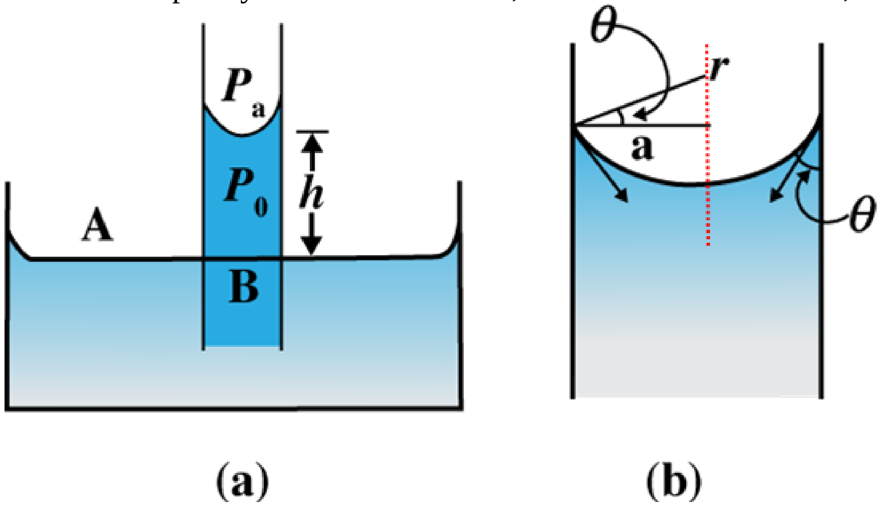
A little extra air pressure is needed inside!

THINK ABOUT THIS
You can make soap bubbles with ease but water bubbles are difficult to make.

8. CAPILLARITY

One consequence of the pressure difference across a curved liquid-air interface is the well-known effect that water rises up in a narrow tube in spite of gravity.

The word capillary means hair in Latin; if the tube were hair thin, the rise would be very large.



Capillary rise, (a) Schematic picture of a narrow tube immersed water. (b) Enlarged picture near interface.

To see this, consider a vertical capillary tube of circular cross section (radius a) inserted into an open vessel of water.

The contact angle between water and glass is acute. Thus the surface of water in **the capillary is concave. This means that there is a pressure difference between the two sides of the top surface. This is given by**

$$(P_i - P_o) = \left(\frac{2S}{r}\right) = \frac{2S}{a\sec\theta} = \left(\frac{2S}{a}\right)\cos\theta$$

Thus the pressure of the water inside the tube, just at the meniscus (air-water interface) is less than the atmospheric pressure.

Here r is the radius of the curvature of the liquid surface
a is the radius of the capillary tube

Consider the two points A and B in Fig. (a). They must be at the same pressure, namely

$$P_0 + h\,\rho\,g = P_i = P_A$$

Where ρ is the density of water and h is called the capillary rise [Fig. (a)].

We have

$$h\,\rho\,g = (P_i - P_o)$$

$$= (2S\cos\theta)/a$$

The rise or fall of liquid in a narrow bore (internal diameter) tube is called callilarity

NOTICE

- **It is clear that the capillary rise is due to surface tension.**
- **It is larger, for a smaller a, typically it is of the order of a few cm for fine capillaries.**
- **θ is the angle of contact for $\theta < 90^0$, $\cos\theta$ varies from $1 - 0$**
  For $\theta = 0$ $\cos\theta = 1$

  $$h = \frac{2S}{\rho\,g\,a}$$

  h , the capillary rise depends upon
  i) surface tension S hence nature of liquid, impurities in it, and temperature
  ii) density of liquid
  iii) acceleration due to gravity (ie place where the experiment is performed)
  iv) diameter of the capillary tube

We can find the surface tension of a liquid by capillary rise method by finding the height h in a capillary of known internal diameter r

$$S = \frac{h\,\rho\,g\,a}{2}$$

EXAMPLE

If a = 0.05 cm, using the value of surface tension for water, find the capillary rise .

SOLUTION

We find that, taking

$$\theta = 0 \; hence \cos\theta = 1$$

$$\mathbf{h} = \frac{\mathbf{2S}}{\boldsymbol{\rho}\,\mathbf{g}\,\mathbf{a}}$$

$$= \mathbf{2.98 \times 10^{-2}} \boldsymbol{m} = \mathbf{2.98}\, \boldsymbol{cm}$$

If the liquid meniscus is convex, as for mercury, i.e., if cos θ is negative then

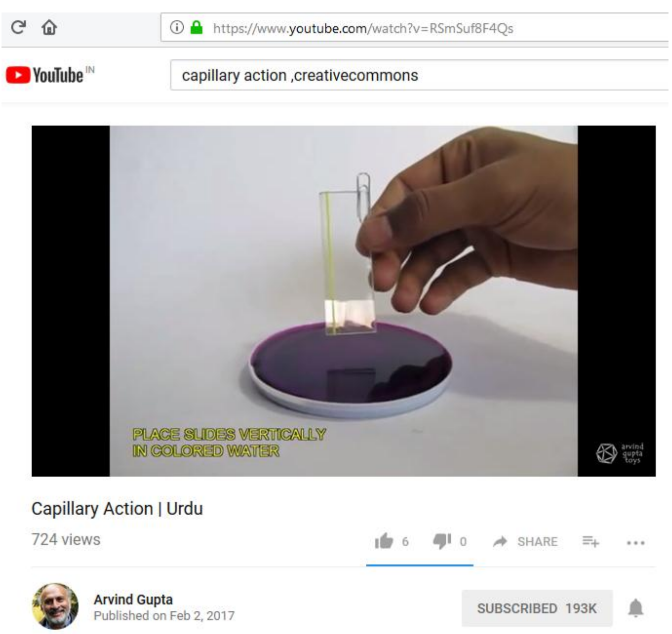
From Eq.

h ρ g = (2S cos θ)/a

It is clear that the liquid will be lowered in the capillary!

DO AN ACTIVITY OR WATCH ON VEDIO

https://www.youtube.com/watch?v=RSmSuf8F4Qs

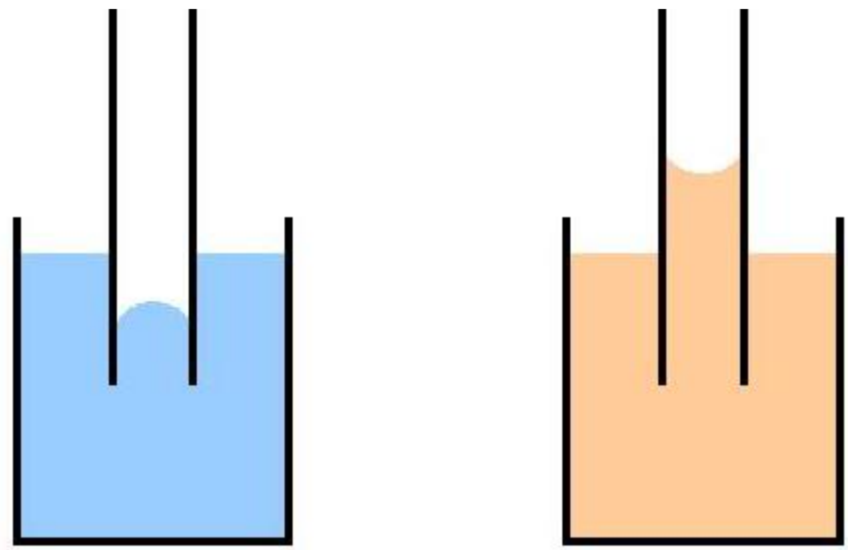


Capillary Action or the Astronomer's Cup is a simple device which you can make using two slides, colored water, a paper clip and a rubber band. Place one slide on top of the other. After aligning the slides place a rubber band along one long edge. Place a paper clip on the other edge. The clip will form a nice wedge between the two slides. Place the slides

vertically in colored water. Water will immediately rise between the slides making a very nice parabolic curve. Where the distance between the slides is narrowest the water level will rise all the way to the top. Towards the broad end the level will be the same level as that of the water. Here the capillary action is pulling the water to the top whereas gravity is pulling it down. As there is no gravity in space the water rises all the way to the top. This is used by astronomers to drink water in space.

THINK ABOUT THIS

- **In the above activity why did the liquid climb between the slides and form a parabolic edge?**



https://upload.wikimedia.org/wikipedia/commons/2/26/Adhesie-Cohesie.jpg

In the two cases shown

- **What role is played by forces of adhesion and cohesion?**
- **Why is the liquid surface inside the capillary convex and concave?**
- **What can you say about the surface outside the capillary tube?**
- **On what factors will the shape of the surface depend upon?**
- **Why do towels have better drying ability?**
- **Why are fried food objects placed on paper to get rid of extra oil?**
- **Why concave side has higher pressure than convex side in a liquid-air interface?**
- **Why is it difficult to fill mercury in the glass tube of a thermometer?**
- **Name the material to make a capillary in which water will descend instead of rising?**
- **Water rises in a capillary tube to a height of 6 cm. Up to which height will the water rise in another capillary tube whose internal radius is 2/3 that of the first capillary tube?**

- **Among the oil, water and milk which will rise to a maximum height in the capillary tube of the same width?**
- **If a capillary tube is dipped in water in a state of weightlessness, how will the rise of water in it be different to that observed in normal conditions?**
- **If normal water rises in a capillary tube up to a height h, the height of water will decrease or increase if we increase the temperature of the water?**

EXAMPLE

The lower end of a capillary tube of diameter 2.00 mm is dipped 8.00 cm below the surface of water in a beaker.
What is the pressure required in the tube in order to blow a hemispherical bubble at its end in water?
Surface tension of water at temperature of the experiment is 7.30×10^{-2} Nm^{-1}.
1 atmospheric pressure = 1.01×10^5 Pa,
Density of water = 1000 kg/m^3,
g = 9.80 ms^{-2}.
Also calculate the excess pressure

SOLUTION

The excess pressure in a bubble of gas in a liquid is given by 2s/r,
where s is the surface tension of the liquid-gas interface.
You should note there is only one liquid surface in this case. (For a bubble of liquid in a gas, there are two liquid surfaces, so the formula for excess pressure in that case is 4S/r.)
The radius of the bubble is r.
Now the pressure outside the bubble P_o equals atmospheric pressure plus the pressure due to 8.00 cm of water column. That is

$$P_o = (1.01 \times 10^5 \;\; P_a + 0.08\, m \;\times 1000 kgm^{-3} \times 9.8\, ms^{-2})$$

= 1.01784×10^5 Pa
Therefore, the pressure inside the bubble is
$P_i = P_o + 2S/r$
= 1.01784×10^5 Pa + ($2 \times 7.3 \times 10^{-2}$ Pa m/10^{-3} m)
= $(1.01784 + 0.00146) \times 10^5$ Pa
= 1.02×10^5 Pa

where the radius of the bubble is taken to be equal to the radius of the capillary tube, since the bubble is hemispherical !
(The answer has been rounded off to three significant figures.) The excess pressure in the bubble is 146 Pa.

EXAMPLE

What is the pressure inside the drop of mercury of radius 3.00 mm at room temperature? Surface tension of mercury at that temperature (20 °C) is 4.65 ×$10^{-1} Nm^{-1}$. The atmospheric pressure is 1.01 × 10^{5}Pa. Also give the excess pressure inside the drop.

SOLUTION

Here, radius of drop, R = 3.0 mm = $3.0 \times 10^{-3} m$

Surface tension of the mercury, T= 4.65 ×$10^{-1} Nm^{-1}$

Pressure outside the mercury drop,

p_0 =Atmospheric pressure = 1.01 × 10^5Pa

If p_i is pressure inside the drop, then excess pressure inside the mercury drop,

$$p_i - p_0 = \frac{2T}{R} = \frac{2 \times 4.65 \times 10^{-1}}{3.0 \times 10^{-3}} = 310\ N\ m^{-2}\ (Pa)$$

Hence, pressure inside the mercury drop,

$$p_i = p_0 + \frac{2T}{R} = 1.01 \times 10^5 + 310 = 1.0131 \times 10^5 Pa$$

EXAMPLE

What is the excess pressure inside a bubble of soap solution of radius 5.00 mm, given that the surface tension of soap solution at the temperature (20 °C) is 2.50 ×10^{-2} N m^{-1}? If an air bubble of the same dimension were formed at depth of 40.0 cm inside a container containing the soap solution (of relative density 1.20), what would be the pressure inside the bubble?

(1 atmospheric pressure is 1.01 × 10^5 Pa).

SOLUTION

Given: surface tension of the soap solution

T = 2.50 ×10^{-2} N m^{-1}

Density of the soap solution, $\rho = 1.2 \times 10^3 kgm^{-3}$

Radius of the soap bubble, R = 5.0 mm = 5.0×10^{-3}m

Now, the excess pressure inside the soap bubble,

$$p_i - p_0 = \frac{4T}{R} = \frac{4 \times 2.5 \times 10^{-2}}{5.0 \times 10^{-3}} = 20\ Pa$$

Also, the excess pressure inside the air bubble,

$$p_i - p_0 = \frac{2T}{R} = \frac{2 \times 2.5 \times 10^{-2}}{5.0 \times 10^{-3}} = 10\ Pa$$

Now, the excess pressure outside the air bubble at a depth of 40 cm i.e. 0.4 m,

p_0 = atmospheric pressure + pressure due to 0.4 m column of soap solution

= $1.01 \times 10^5 + 0.4 \times 1.2 \times 10^3 \times 9.8 = 1.05704 \times 10^5 Pa$

Therefore, pressure inside the air bubble,

$$p_i = p_0 + \frac{2T}{R} = 1.05704 \times 10^5 + 10 = 1.05714 \times 10^5 Pa$$

Let us understand some of the applications of capillarity in our daily life

- We prefer to wear cotton dresses, as in summer because cotton dresses have fine pores which act as capillaries for sweat.
- The absorption of ink by a blotting paper is due to capillary action, as the blotting paper is porous. When it is placed over the ink, the ink raises into the pores.
- **Also rise of oil in the wick of a lamp is due to capillary action.**

https://images.pexels.com/photos/260571/pexels-photo-260571.jpeg?cs=srgb&dl=culture-deepavali-deepawali-260571.jpg&fm=jpg

- If one end of a towel is dipped into a bucket of water and the other end hangs over the bucket, the entire towel soon becomes wet due to capillary action.

- The supply of water to the leaves on the top of plants is through capillary rise, after all we water the roots!!

9. DETERMINATION OF THE SURFACE TENSION OF WATER BY CAPILLARY RISE METHOD IN THE LABORATORY.

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

https://youtu.be/amKHqtcUXvI

10. TO STUDY THE EFFECT OF DETERGENT ON SURFACE TENSION OF WATER BY OBSERVING CAPILLARY RISE (DETERGENTS AND SURFACE TENSION)

We clean dirty clothes containing grease and oil stains sticking to cotton or other fabrics by adding detergents or soap to water, soaking clothes in it and shaking.

Substances that can be used to separate grease, dust and dirt sticking to a surface are called detergents. When added to water detergents lower its surface tension due to additional intermolecular interactions. The lowering of surface tension by addition of detergent in water can be observed by capillary rise method in the laboratory.

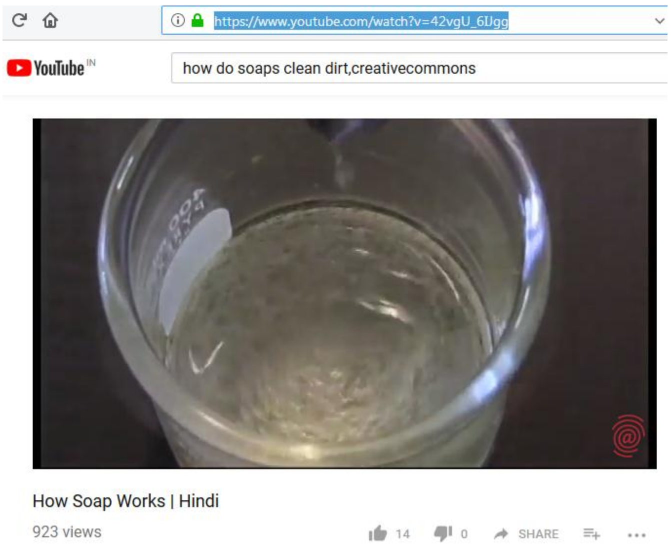
Let us understand this process of cleaning better.

Washing with water does not remove grease stains.

This is because water does **not wet greasy dirt**; i.e., there is very little area of contact between them. If water could wet grease, the flow of water could carry some grease away. Something of this sort is achieved through detergents.

The molecules of detergents are hairpin shaped, with one end attracted to water and the other to molecules of grease, oil or wax, thus tending to form water-oil interfaces. The result is shown in Fig. as a sequence of figures.
In our language, we would say that addition of detergents, whose molecules attract at one end and say, oil on the other, reduces drastically the surface tensions (water-oil).

Watch the video

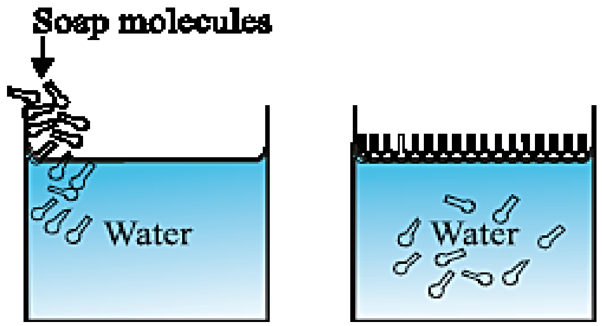


https://www.youtube.com/watch?v=42vgU_6IJgg

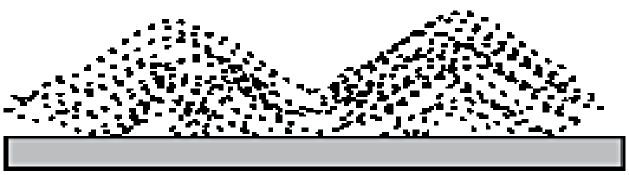
Soap is made by treating oils with a strong alkaline solution. The Babylonians already knew how to make soap almost 5,000 years ago, using ashes and plant oils. Soap molecule has a long nonpolar tail, and a short polar head. The grease on your frying pan is nonpolar, so trying to wash it away with water is ineffective. When we add soap to the grease, the nonpolar tail of the soap molecule attaches to the dirt, forming a micellar bilayer. When we add water to the mix, the polar head of the soap molecule attaches to the water, but the soap acts like a bridge between the water and the dirt, and the resulting mixture is called an emulsion. And now we can easily wash the emulsion away with water. The video is a contextualized and translated version (suitable for Indian audiences) of the original MITK12 video (linked below). The original license allows the use of this video under CC-BY-NC-SA domain of creative commons community.

It may even become energetically favourable to form such interfaces, i.e., globs of dirt surrounded by detergents and then by water. This kind of process using surface active detergents or surfactants is important not only for cleaning, but also in recovering oil, mineral ores etc.

Detergent action in terms of what detergent molecules do.

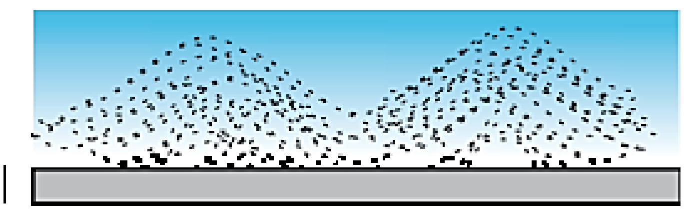


Soap molecules with head attracted to water

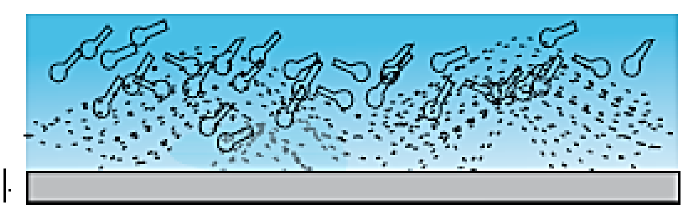


Platter with particles of greasy dirt.

The fig shows how the two ends of a soap molecule get attracted to water
The grease sticks to the container /clothes

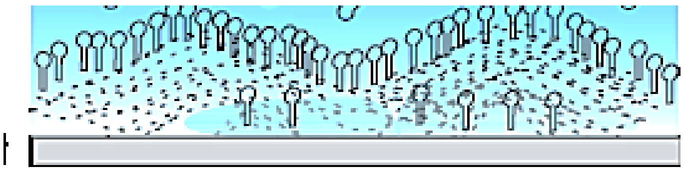


Water is added; dirt is not dislodged.

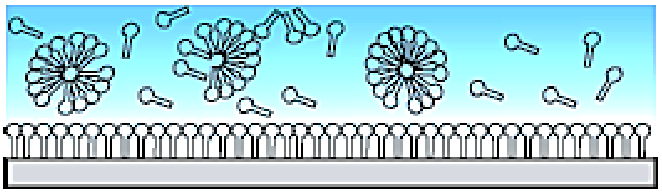


Detergent is added, the 'inert' waxy ends of its molecules are attracted to boundary where water meets dirt.

The fig shows how water is not able to dislodge the grease but when detergent is adde4d to it
The waxy ends of the soap molecules are attracted to the boundary where water meets dirt.



Inert ends surround dirt and the platter dirt can now be dislodged say by moving water.



Dirt is held suspended, surrounded by soap molecules.

The inert dirt can be dislodged by shaking and can be seen suspended in the soap solution

11. SUMMARY

- One consequence of surface tension is that free liquid drops and bubbles are spherical if effects of gravity can be neglected

- There is always an excess of pressure on the concave side of a curved liquid surface over the pressure on its convex side due to surface tension.

- A soap bubble differs from a drop and an air bubble inside a liquid; it has two interfaces. So for a soap bubble
  $(P_i – P_o) = (4\, S_{la}/ r)$

- One consequence of the pressure difference across a curved liquid-air interface is the well-known effect that water rises up in a narrow tube in spite of gravity. The word ‘capilla’ means hair in Latin; if the tube were hair thin, the rise would be very large.