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 probably where the term " surface tension " came from . 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 .
Surface tension has the dimension of force per unit length , or of energy per unit area . The two are equivalent , but when referring to energy per unit of area , it is common to use the term surface energy , which is a more general term in the sense that it applies also to solids .
In materials science , surface tension is used for either surface stress or surface free energy .

Causes

The cohesive forces among liquid molecules are responsible for the phenomenon of 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 of zero . The molecules at the surface do not have the same molecules on all sides of them and therefore are pulled inwards . 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 imbalance in cohesive forces of the surface layer . In the absence of other forces , including gravity , drops of virtually all liquids would be approximately spherical . The spherical shape minimizes the necessary " wall tension " of the surface layer according to Laplace 's law .
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 boundary molecules are missing neighbors (compared to interior molecules) and therefore have a higher energy . For the liquid to minimize its energy state , the number of higher energy boundary molecules must be minimized . The minimized quantity of boundary molecules results in a minimal surface area . As a result of surface area minimization , a surface will assume the smoothest shape it can (mathematical proof that " smooth " shapes minimize surface area relies on use of the Euler ? Lagrange equation) . Since any curvature in the surface shape results in greater area , a higher energy will also result . Consequently , the surface will push back against any curvature in much the same way as a ball pushed uphill will push back to minimize its gravitational potential energy .

Effects of surface tension

Water

Several effects of surface tension can be seen with ordinary water :
A. Beading of rain water on a waxy surface , such as 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 .
B. Formation of drops occurs when a mass of liquid is stretched . The animation shows water adhering to the faucet gaining mass until it is stretched to a point where the surface tension can no

longer keep the drop linked to the faucet . It then separates and surface tension forms the drop into a sphere . If a stream of water was running from the faucet , the stream would break up into drops during its fall . Gravity stretches the stream , then surface tension pinches it into spheres .
C. Flotation of objects denser than water occurs when the object is nonwettable and its weight is small enough to be borne by the forces arising from surface tension . For example , water striders use surface tension to walk on the surface of a pond by the following way . Nonwettability of leg of the water strider means no attraction between molecules of the leg and molecules of the water , so when the leg pushes down the water , the surface tension of the water only tries to recover its flatness from its deformation due to the leg . This behavior of the water push the water strider upward so it can stand on the surface of the water as long as its mass is small enough so that the water can support it . 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 and tendency of minimization of surface curvature (so area) of the water pushes the insect 's feet upward .
D. Separation of oil and water (in this case , water and liquid wax) is caused by a tension in the surface between dissimilar liquids . This type of surface tension is called " interface tension " , but its chemistry is the same .
E. Tears of wine is the formation of drops and rivulets on the side of a glass containing an alcoholic beverage . Its cause is a complex interaction between the differing surface tensions of water and ethanol ; it is induced by a combination of surface tension modification of water by ethanol together with ethanol evaporating faster than water .

= = = Surfactants = = =

Surface tension is visible in other common phenomena , especially when surfactants are used to decrease it :
Soap bubbles have very large surface areas with very little mass . Bubbles in pure water are unstable . The addition of surfactants , however , can have a stabilizing effect on the bubbles (see Marangoni effect) . Note that surfactants actually reduce the surface tension of water by a factor of three or more .
Emulsions are a type of solution in which surface tension plays a role . Tiny fragments of oil suspended in pure water will spontaneously assemble themselves into much larger masses . But the presence of a surfactant provides a decrease in surface tension , which permits stability of minute droplets of oil in the bulk of water (or vice versa) .

= = Physics = =

= = = Physical units = = =

Surface tension , usually represented by the symbol ? , is measured in force per unit length . Its SI unit is newton per meter but the cgs unit of dyne per cm is also used .
<formula>

= = = Surface area growth = = =

Surface tension can be defined in terms of force or energy.In terms of force : surface tension <formula> of a liquid is the force per unit length . In the illustration on the right , the rectangular frame , composed of three unmovable sides (black) that form a " U " shape , and a fourth movable side (blue) that can slide to the right . Surface tension will pull the blue bar to the left ; the force <formula> required to hold immobile the movable side is proportional to the length <formula> of the movable side . Thus the ratio <formula> depends only on the intrinsic properties of the liquid (composition , temperature , etc .) , not on its geometry . For example , if the frame had a more complicated shape , the ratio <formula> , with <formula> the length of the movable side and

<formula> the force required to stop it from sliding , is found to be the same for all shapes . We therefore define the surface tension as
<formula> .
The reason for the <formula> is that the film has two sides , each of which contributes equally to the force ; so the force contributed by a single side is <formula> .
In terms of energy : surface tension <formula> of a liquid is the ratio of 1) the change in the energy of the liquid , and 2) the change in the surface area of the liquid (that led to the change in energy) . This can be easily related to the previous definition in terms of force : if <formula> is the force required to stop the side from starting to slide , then this is also the force that would keep the side in the state of sliding at a constant speed (by Newton 's Second Law) . But if the side is moving to the right (in the direction the force is applied) , then the surface area of the stretched liquid is increasing while the applied force is doing work on the liquid . This means that increasing the surface area increases the energy of the film . The work done by the force <formula> in moving the side by distance <formula> is <formula> ; at the same time the total area of the film increases by <formula> (the factor of 2 is here because the liquid has two sides , two surfaces) . Thus , multiplying both the numerator and the denominator of <formula> by <formula> , we get
<formula> .
This work <formula> is , by the usual arguments , interpreted as being stored as potential energy . Consequently , surface tension can be also measured in SI system as joules per square meter and in the cgs system as ergs per cm2 . Since mechanical systems try to find a state of minimum potential energy , a free droplet of liquid naturally assumes a spherical shape , which has the minimum surface area for a given volume . The equivalence of measurement of energy per unit area to force per unit length can be proven by dimensional analysis .

= = = Surface curvature and pressure = = =

If no force acts normal to a tensioned surface , the surface must remain flat . But if the pressure on one side of the surface differs from pressure on the other side , the pressure difference times surface area results in a normal force . In order for the surface tension forces to cancel the force due to pressure , the surface must be curved . The diagram shows how surface curvature of a tiny patch of surface leads to a net component of surface tension forces acting normal to the center of the patch . When all the forces are balanced , the resulting equation is known as the Young ? Laplace equation :
<formula>
where :
?p is the pressure difference , known as the Laplace pressure .
<formula> is surface tension .
Rx and Ry are radii of curvature in each of the axes that are parallel to the surface .
The quantity in parentheses on the right hand side is in fact (twice) the mean curvature of the surface (depending on normalisation) . Solutions to this equation determine the shape of water drops , puddles , menisci , soap bubbles , and all other shapes determined by surface tension (such as the shape of the impressions that a water strider 's feet make on the surface of a pond) . The table below shows how the internal pressure of a water droplet increases with decreasing radius . For not very small drops the effect is subtle , but the pressure difference becomes enormous when the drop sizes approach the molecular size . (In the limit of a single molecule the concept becomes meaningless .)

= = = Floating objects = = =

When an object is placed on a liquid , its weight Fw depresses the surface , and is balanced by the surface tension forces on either side Fs , which are each parallel to the water 's surface at the points where it contacts the object . Notice that the horizontal components of the two Fs arrows point in opposite directions , so they cancel each other , but the vertical components point in the same

direction and therefore add up to balance Fw . The object 's surface must not be wettable for this to happen , and its weight must be low enough for the surface tension to support it .
<formula>

= = = Liquid surface = = =

To find the shape of the minimal surface bounded by some arbitrary shaped frame using strictly mathematical means can be a daunting task . Yet by fashioning the frame out of wire and dipping it in soap @-@ solution , a locally minimal surface will appear in the resulting soap @-@ film within seconds .
The reason for this is that the pressure difference across a fluid interface is proportional to the mean curvature , as seen in the Young @-@ Laplace equation . For an open soap film , the pressure difference is zero , hence the mean curvature is zero , and minimal surfaces have the property of zero mean curvature .

= = = Contact angles = = =

The surface of any liquid is an interface between that liquid and some other medium . The top surface of a pond , for example , is an interface between the pond water and the air . Surface tension , then , is not a property of the liquid alone , but a property of the liquid 's interface with another medium . If a liquid is in a container , then besides the liquid / air interface at its top surface , there is also an interface between the liquid and the walls of the container . The surface tension between the liquid and air is usually different (greater than) its surface tension with the walls of a container . And where the two surfaces meet , their geometry must be such that all forces balance .
Where the two surfaces meet , they form a contact angle , <formula> , which is the angle the tangent to the surface makes with the solid surface . The diagram to the right shows two examples . Tension forces are shown for the liquid @-@ air interface , the liquid @-@ solid interface , and the solid @-@ air interface . The example on the left is where the difference between the liquid @-@ solid and solid @-@ air surface tension , <formula> , is less than the liquid @-@ air surface tension , <formula> , but is nevertheless positive , that is
<formula>
In the diagram , both the vertical and horizontal forces must cancel exactly at the contact point , known as equilibrium . The horizontal component of <formula> is canceled by the adhesive force , <formula> .
<formula>
The more telling balance of forces , though , is in the vertical direction . The vertical component of <formula> must exactly cancel the force , <formula> .
<formula>
Since the forces are in direct proportion to their respective surface tensions , we also have :
<formula>
where
<formula> is the liquid @-@ solid surface tension ,
<formula> is the liquid @-@ air surface tension ,
<formula> is the solid @-@ air surface tension ,
<formula> is the contact angle , where a concave meniscus has contact angle less than 90 ° and a convex meniscus has contact angle of greater than 90 ° .
This means that although the difference between the liquid @-@ solid and solid @-@ air surface tension , <formula> , is difficult to measure directly , it can be inferred from the liquid @-@ air surface tension , <formula> , and the equilibrium contact angle , <formula> , which is a function of the easily measurable advancing and receding contact angles (see main article contact angle) .
This same relationship exists in the diagram on the right . But in this case we see that because the contact angle is less than 90 ° , the liquid @-@ solid / solid @-@ air surface tension difference must be negative :

<formula>

= = = = Special contact angles = = = =

Observe that in the special case of a water @-@ silver interface where the contact angle is equal to 90 ° , the liquid @-@ solid / solid @-@ air surface tension difference is exactly zero .

Another special case is where the contact angle is exactly 180 ° . Water with specially prepared Teflon approaches this . Contact angle of 180 ° occurs when the liquid @-@ solid surface tension is exactly equal to the liquid @-@ air surface tension .

<formula>

= = Methods of measurement = =

Because surface tension manifests itself in various effects , it offers a number of paths to its measurement . Which method is optimal depends upon the nature of the liquid being measured , the conditions under which its tension is to be measured , and the stability of its surface when it is deformed .

du Noüy ring method : The traditional method used to measure surface or interfacial tension . Wetting properties of the surface or interface have little influence on this measuring technique . Maximum pull exerted on the ring by the surface is measured .

Du Noüy @-@ Padday method : A minimized version of Du Noüy method uses a small diameter metal needle instead of a ring , in combination with a high sensitivity microbalance to record maximum pull . The advantage of this method is that very small sample volumes (down to few tens of microliters) can be measured with very high precision , without the need to correct for buoyancy (for a needle or rather , rod , with proper geometry) . Further , the measurement can be performed very quickly , minimally in about 20 seconds . First commercial multichannel tensiometers [CMCeeker] were recently built based on this principle .

Wilhelmy plate method : A universal method especially suited to check surface tension over long time intervals . A vertical plate of known perimeter is attached to a balance , and the force due to wetting is measured .

Spinning drop method : This technique is ideal for measuring low interfacial tensions . The diameter of a drop within a heavy phase is measured while both are rotated .

Pendant drop method : Surface and interfacial tension can be measured by this technique , even at elevated temperatures and pressures . Geometry of a drop is analyzed optically . For details , see Drop .

Bubble pressure method (Jaeger 's method) : A measurement technique for determining surface tension at short surface ages . Maximum pressure of each bubble is measured .

Drop volume method : A method for determining interfacial tension as a function of interface age . Liquid of one density is pumped into a second liquid of a different density and time between drops produced is measured .

Capillary rise method : The end of a capillary is immersed into the solution . The height at which the solution reaches inside the capillary is related to the surface tension by the equation discussed below .

Stalagmometric method : A method of weighting and reading a drop of liquid .

Sessile drop method : A method for determining surface tension and density by placing a drop on a substrate and measuring the contact angle (see Sessile drop technique) .

Vibrational frequency of levitated drops : The natural frequency of vibrational oscillations of magnetically levitated drops has been used to measure the surface tension of superfluid 4He . This value is estimated to be 0 @.@ 375 dyn / cm at T = 0 K.

Resonant oscillations of spherical and hemispherical liquid drop : The technique is based on measuring the resonant frequency of spherical and hemispherical pendant droplets driven in oscillations by a modulated electric field . The surface tension and viscosity can be evaluated from the obtained resonant curves .

= = Effects = =

= = = Liquid in a vertical tube = = =

An old style mercury barometer consists of a vertical glass tube about 1 cm in diameter partially filled with mercury , and with a vacuum (called Torricelli 's vacuum) in the unfilled volume (see diagram to the right) . Notice that the mercury level at the center of the tube is higher than at the edges , making the upper surface of the mercury dome @-@ shaped . The center of mass of the entire column of mercury would be slightly lower if the top surface of the mercury were flat over the entire crossection of the tube . But the dome @-@ shaped top gives slightly less surface area to the entire mass of mercury . Again the two effects combine to minimize the total potential energy . Such a surface shape is known as a convex meniscus .

We consider the surface area of the entire mass of mercury , including the part of the surface that is in contact with the glass , because mercury does not adhere to glass at all . So the surface tension of the mercury acts over its entire surface area , including where it is in contact with the glass . If instead of glass , the tube was made out of copper , the situation would be very different . Mercury aggressively adheres to copper . So in a copper tube , the level of mercury at the center of the tube will be lower than at the edges (that is , it would be a concave meniscus) . In a situation where the liquid adheres to the walls of its container , we consider the part of the fluid 's surface area that is in contact with the container to have negative surface tension . The fluid then works to maximize the contact surface area . So in this case increasing the area in contact with the container decreases rather than increases the potential energy . That decrease is enough to compensate for the increased potential energy associated with lifting the fluid near the walls of the container .

If a tube is sufficiently narrow and the liquid adhesion to its walls is sufficiently strong , surface tension can draw liquid up the tube in a phenomenon known as capillary action . The height to which the column is lifted is given by :

<formula>

where

<formula> is the height the liquid is lifted ,

<formula> is the liquid @-@ air surface tension ,

<formula> is the density of the liquid ,

<formula> is the radius of the capillary ,

<formula> is the acceleration due to gravity ,

<formula> is the angle of contact described above . If <formula> is greater than 90 ° , as with mercury in a glass container , the liquid will be depressed rather than lifted .

= = = Puddles on a surface = = =

Pouring mercury onto a horizontal flat sheet of glass results in a puddle that has a perceptible thickness . The puddle will spread out only to the point where it is a little under half a centimetre thick , and no thinner . Again this is due to the action of mercury 's strong surface tension . The liquid mass flattens out because that brings as much of the mercury to as low a level as possible , but the surface tension , at the same time , is acting to reduce the total surface area . The result of the compromise is a puddle of a nearly fixed thickness .

The same surface tension demonstration can be done with water , lime water or even saline , but only on a surface made of a substance to which water does not adhere . Wax is such a substance . Water poured onto a smooth , flat , horizontal wax surface , say a waxed sheet of glass , will behave similarly to the mercury poured onto glass .

The thickness of a puddle of liquid on a surface whose contact angle is 180 ° is given by :

<formula>

where

In reality , the thicknesses of the puddles will be slightly less than what is predicted by the above formula because very few surfaces have a contact angle of 180 ° with any liquid . When the contact angle is less than 180 ° , the thickness is given by :

<formula>