PART – 2

properties of Matter

1-Elasticity

2- viscosity

3- Surface tension

Elasticity

1-1Hooke’s law

The subject of elasticity deals with the behavior of those substances which have the property of recovering their size and shape when the forces producing deformations are removed. We find this elastic property to some extent in all solid bodies. If we had the time to deal with the subject at length, we would want to look into many things: the behavior of materials, the general laws of elasticity, the general theory of elasticity, the atomic machinery that determine the elastic properties, and finally the limitations of elastic laws when the forces become so great that plastic flow and fracture occur. It would take more time than we have to cover all these subjects in detail, so we will have to leave out some things. For example, we will not discuss plasticity or the limitations of the elastic laws. (We touched on these subjects briefly when we were talking about dislocations in metals.) Also, we will not be able to discuss the internal mechanisms of elasticity—so our treatment will not have the completeness we have tried to achieve in the earlier chapters. Our aim is mainly to give you an acquaintance with some of the ways of dealing with such practical problems as the bending of beams.

When you push on a piece of material, it “gives”—the material is deformed. If the force is small enough, the relative displacements of the various points in the material are proportional to the force—we say the behavior is *elastic*. We will discuss only the elastic behavior. First, we will write down the fundamental laws of elasticity, and then we will apply them to a number of different situations.

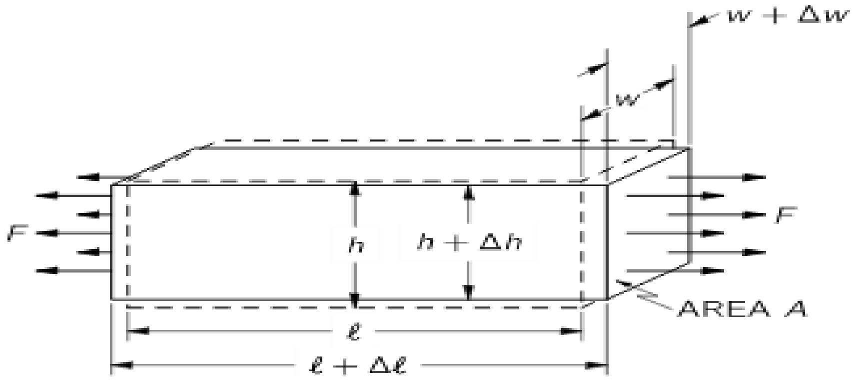


Fig.–1.The stretching of a bar under uniform tension.

Suppose we take a rectangular block of material of length l, width w, and height h, as shown in Fig. (1). If we pull on the ends with a force F, then the length increases by an amount Δl. We will suppose in all cases that the change in length is a small fraction of the original length. As a matter of fact, for materials like wood and steel, the material will break if the change in length is more than a few percent of the original length. For a large number of materials, experiments show that for sufficiently small extensions the force is proportional to the extension

$$F \propto \Delta l. \qquad (1)$$

This relation is known as *Hooke's law*.

The lengthening Δl of the bar will also depend on its length. We can figure out how by the following argument. If we cement two identical blocks together, end to end, the same forces act on each block; each will stretch by Δl. Thus, the stretch of a block of length 2l would be twice as big as a block of the same cross section, but of length l. In order to get a number more characteristic of the material, and less of any particular shape, we choose to deal with the ratio Δl/l of the extension to the original length. This ratio is proportional to the force but independent of l:

$$F \propto \Delta l / l. \qquad (.2)$$

The force F will also depend on the area of the block. Suppose that we put two blocks side by side. Then for a given stretch Δl we would have the force F on each block, or twice as much on the combination of the two blocks. The force, for a given amount of stretch, must be proportional to the cross-sectional area A of the block. To obtain a law in which the coefficient of proportionality is independent of the dimensions of the body, we write Hooke's law for a rectangular block in the form

$$F=YA\Delta l/l. \qquad (3)$$

The constant Y is a property only of the nature of the material; it is known as *Young's modulus*. (Usually you will see Young's modulus called E. But we've used E for electric fields, energy, and emf's, so we prefer to use a different letter.)

The *force per unit area* is called the *stress*, and the stretch per unit length—the *fractional* stretch—is called the *strain*. Equation (3) can therefore be rewritten in the following way:

$$F/A=Y\times\Delta l/l, \qquad (.4)$$

Stress=(Young's modulus)×(Strain).

There is another part to Hooke's law: When you *stretch* a block of material in one direction it *contracts* at right angles to the stretch. The contraction in width is proportional to the width w and also to $\Delta l/l$. The sideways contraction is in the same proportion for both width and height, and is usually written

$$\Delta w/w=\Delta h/h=-\sigma\Delta l/l, \qquad (5)$$

where the constant σ is another property of the material called *Poisson's ratio*. It is always positive in sign and is a number less than 1/2. (It is "reasonable" that σ should be generally positive, but it is not quite clear that it *must* be so.)

The two constants Y and σ specify completely the elastic properties of a *homogeneous isotropic* (that is, noncrystalline) material. In crystalline materials the stretches and contractions can be different in different directions, so there can be many more elastic constants. We will restrict our discussion temporarily to homogeneous isotropic materials whose properties can be described by Y and σ. As usual there are different ways of describing things—some people like to describe the elastic properties of materials by different constants. It always takes two, and they can be related to σ and Y.

The last general law we need is the principle of superposition. Since the two laws (.4) and (5) are linear in the forces and in the displacements, superposition will work. If you have one set of forces and get some displacements, and then you add a new set of forces and get some additional displacements, the resulting displacements will be the sum of the ones you would get with the two sets of forces acting independently.

Now we have all the general principles—the superposition principle and Eqs. (.4) and (.5)—and that's all there is to elasticity. But that is like saying that once you have Newton's laws that's all there is to mechanics. Or, given Maxwell's equations, that's all there is to electricity. It is, of course, true that with these principles you have a great deal, because with your present mathematical ability you could go a long way. We will, however, work out a few special applications.

1-2-What is Stress?

Stress is defined as force per unit area within materials that arises from externally applied forces, uneven heating, or permanent deformation and that permits an accurate description and prediction of elastic, plastic, and fluid behaviour.

Stress is given by the following formula:

$$\sigma = \frac{F}{A}$$

where, σ is the stress applied, ***F*** is the force applied and ***A*** is the area of the force application.

The unit of stress is N/m^2.

Types of Stress

Stress applied to a material can be of two types as follows:

- Tensile Stress

The external force per unit area of the material resulting in the stretch of the material is known as tensile stress.

- Compressive Stress

Compressive stress is the force that is responsible for the deformation of the material, such that the volume of the material reduces.

1-3- What is Strain?

Strain is the amount of deformation experienced by the body in the direction of force applied, divided by the initial dimensions of the body.

Suppose the original length of the object is l_0 and due to stress, the length changes to l_1. The *change* in length is $\Delta l = l_1 - l_0$. The strain ϵ is then given by,

$$\epsilon = \frac{\Delta l}{l_0}$$

The following equation gives the relation for deformation in terms of the length of a solid:

$\epsilon=\Delta l/L_o$

where ε is the strain due to the stress applied, Δl is the change in length and **L_o** is the original length of the material.

The strain is a dimensionless quantity as it just defines the relative change in shape.

Since strain is given by a fraction where the numerator and denominator both have units of length, the strain itself has no units. i.e. it is a “dimensionless quantity”. It is common to see strain expressed in terms of percentages.

Types of Strain

Strain experienced by a body can be of two types depending on stress application as follows:

Tensile Strain

The deformation or elongation of a solid body due to applying a tensile force or stress is known as Tensile strain. In other words, tensile strain is produced when a body increases in length as applied forces try to stretch it.

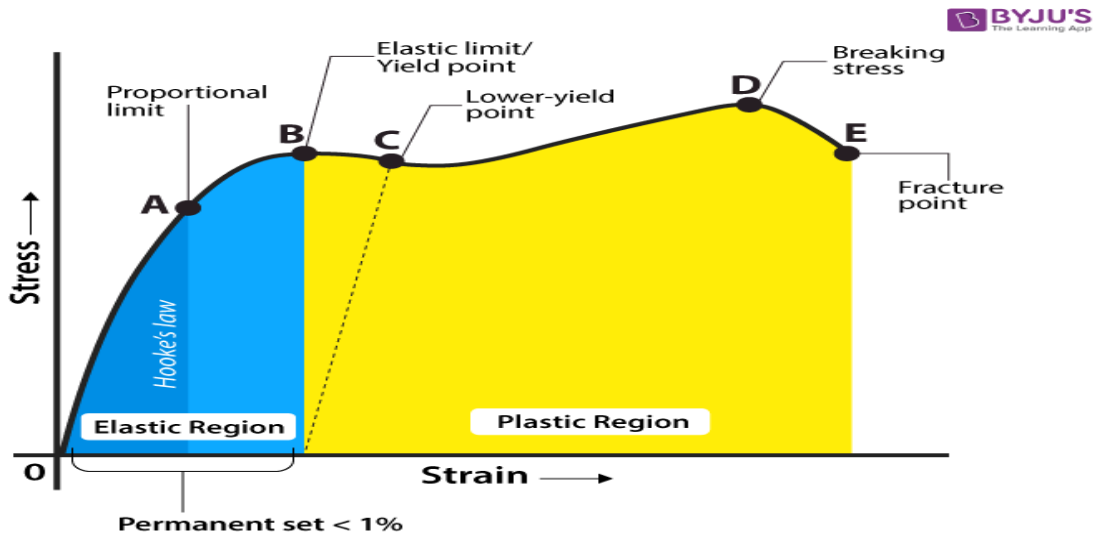
Compressive Strain

Compressive strain is the deformation in a solid due to the application of compressive stress. In other words, compressive strain is produced when a body decreases in length when equal and opposite forces try to compress it.

1=4 - Stress-Strain Curve

When we study solids and their mechanical properties, information regarding their elastic properties is most important. We can learn about the elastic properties of materials by studying the stress-strain relationships, under different loads, in these materials.

The material’s stress-strain curve gives its stress-strain relationship. In a stress-strain curve, the stress and its corresponding strain values are plotted. An example of a stress-strain curve is given below.



Explaining Stress-Strain Graph

The different regions in the stress-strain diagram are:

(i) Proportional Limit

It is the region in the stress-strain curve that obeys Hooke’s Law. In this limit, the stress-strain ratio gives us a proportionality constant known as Young’s modulus. The point OA in the graph represents the proportional limit.

(ii) Elastic Limit

It is the point in the graph up to which the material returns to its original position when the load acting on it is completely removed. Beyond this limit, the material doesn’t return to its original position, and a plastic deformation starts to appear in it.

(iii) Yield Point

The yield point is defined as the point at which the material starts to deform plastically. After the yield point is passed, permanent plastic deformation occurs. There are two yield points (i) upper yield point (ii) lower yield point.

(iv) Ultimate Stress Point

It is a point that represents the maximum stress that a material can endure before failure. Beyond this point, failure occurs.

(v) Fracture or Breaking Point

It is the point in the stress-strain curve at which the failure of the material takes place.

Hooke’s Law

In the 19th-century, while studying springs and elasticity, English scientist Robert Hooke noticed that many materials exhibited a similar property when the stress-strain relationship was studied. There was a linear region where the force required to stretch the material was proportional to the extension of the material, known as Hooke’s Law.

Hooke’s Law states that the strain of the material is proportional to the applied stress within the elastic limit of that material.

Mathematically, Hooke’s law is commonly expressed as:

$F = -k.x$

Where F is the force, x is the extension in length, and k is the constant of proportionality known as the spring constant in N/m.

1-5 -Elastic modulus

An **elastic modulus** (also known as **modulus of elasticity**) is the unit of measurement of an object's or substance's resistance to being deformed elastically (i.e., non-permanently) when a stress is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region:[1] A stiffer material will have a higher elastic modulus. An elastic modulus has the form:

Stress / strain

where *stress* is the force causing the deformation divided by the area to which the force is applied and *strain* is the ratio of the change in some parameter caused by the deformation to the original value of the parameter. Since strain is a dimensionless quantity, the units

of will be the same as the units of stress.[2]

Specifying how stress and strain are to be measured, including directions, allows for many types of elastic moduli to be defined. The three primary ones are:

1. *Young's modulus* (E) describes tensile and compressive elasticity, or the tendency of an object to deform along an axis when opposing forces are applied along that axis; it is defined as the ratio of tensile stress to tensile strain. It is often referred to simply as the *elastic modulus*.
2. The *shear modulus* or *modulus of rigidity* (G or Lamé second parameter) describes an object's tendency to shear (the deformation of shape at constant volume) when acted upon by opposing forces; it is defined as shear stress over shear strain. The shear modulus is part of the derivation of viscosity.

3. The *bulk modulus* (K) describes volumetric elasticity, or the tendency of an object to deform in all directions when uniformly loaded in all directions; it is defined as volumetric stress over volumetric strain, and is the inverse of compressibility. The bulk modulus is an extension of Young's modulus to three dimensions.

Two other elastic moduli are Lamé's first parameter, λ, and P-wave modulus, M, as used in table of modulus comparisons given below references.

Homogeneous and isotropic (similar in all directions) materials (solids) have their (linear) elastic properties fully described by two elastic moduli, and one may choose any pair. Given a pair of elastic moduli, all other elastic moduli can be calculated according to formulas in the table below at the end of page.

Inviscid fluids are special in that they cannot support shear stress, meaning that the shear modulus is always zero. This also implies that Young's modulus for this group is always zero.

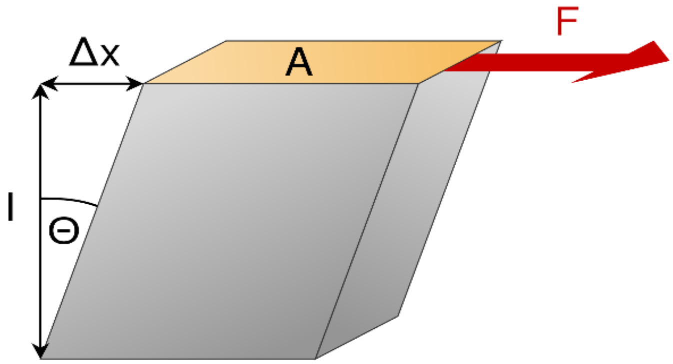
In some texts, the modulus of elasticity is referred to as the *elastic constant*, while the inverse quantity is referred to as *elastic modulus*.

1-7- Shear modulus

n materials science, **shear modulus** or **modulus of rigidity**, denoted by G, or sometimes S or μ, is a measure of the elastic shear stiffness of a material and is defined as the ratio of shear stress to the shear strain:[1]

G = shear stress / shear strain

$G = F/A \; / \; \Delta X/L \; = FL \,/\, A \; \Delta X$



where

F/A = shear stress

F is the force which acts

A is the area on which the force acts

shear strain. In engineering ΔX/L=tam θ, elsewhere =θ

ΔX is the transverse displacement

L is the initial length of the area.

The derived SI unit of shear modulus is the pascal (Pa), although it is usually expressed in gigapascals (GPa) or in thousand pounds per square inch (ksi). Its dimensional form is $M^1L^{-1}T^{-2}$, replacing *force* by *mass* times *acceleration*.

The shear modulus is one of several quantities for measuring the stiffness of materials. All of them arise in the generalized Hooke's law:

- Young's modulus *E* describes the material's strain response to uniaxial stress in the direction of this stress (like pulling on the ends of a wire or putting a weight on top of a column, with the wire getting longer and the column losing height),
- the Poisson's ratio *ν* describes the response in the directions orthogonal to this uniaxial stress (the wire getting thinner and the column thicker),

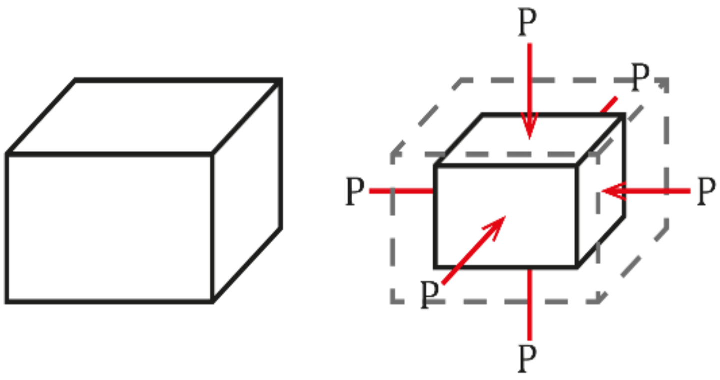
- the bulk modulus K describes the material's response to (uniform) hydrostatic pressure (like the pressure at the bottom of the ocean or a deep swimming pool),
- the **shear modulus** G describes the material's response to shear stress (like cutting it with dull scissors).

These moduli are not independent, and for isotropic materials they are connected via the equations[9]

The shear modulus is concerned with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force (such as friction). In the case of an object shaped like a rectangular prism, it will deform into a parallelepiped. Anisotropic materials such as wood, paper and also essentially all single crystals exhibit differing material response to stress or strain when tested in different directions. In this case, one may need to use the full tensor-expression of the elastic constants, rather than a single scalar value.

> One possible definition of a fluid would be a material with zero shear modulus.

1-8- Bulk modulus



he **bulk modulus** (K or B) of a substance is a measure of how resistant to compression the substance is. It is defined as the ratio of the infinitesimal pressure increase to the resulting *relative* decrease of the volume.[1]

Other moduli describe the material's response (strain) to other kinds of stress: the shear modulus describes the response to shear stress, and Young's modulus describes the response to normal (lengthwise stretching) stress. For a fluid, only the bulk modulus is meaningful. For a complex anisotropic solid such as wood or paper, these three moduli do not contain enough information to describe its behaviour, and one must use the full generalized Hooke's law. The reciprocal of the bulk modulus at fixed temperature is called the isothermal compressibility.

Definition

The bulk modulus K (which is usually positive) can be formally defined by the equation

$$K= -V\, dP/ dV$$

where P is pressure,V is the initial volume of the substance, and dP/ dV denotes the derivative of pressure with respect to volume. Since the volume is inversely proportional to the density, it follows that

$$K= \rho\, dP/ d\rho$$

where ρ is the initial density and dP/ dρ denotes the derivative of pressure with respect to density. The inverse of the bulk modulus gives a substance's compressibility. Generally the bulk modulus is defined at constant temperature as the isothermal bulk modulus, but can also be defined at constant entropy as the adiabatic bulk modulus.

Elastic Moduli of Materials

The following table lists Young’s modulus, shear modulus and bulk modulus for common materials.

Material	**Young’s modulus (E) in GPa**	**Shear modulus (G) in GPa**	**Bulk modulus (K) in GPa**
Glass	55	23	37
Steel	200	84	160
Iron	91	70	100
Lead	16	5.6	7.7
Aluminium	70	24	70

Note: GPa is gigapascal and 1 GPa = 1,00,00,00,000 Pa.

Approximate bulk modulus (*K*) for common materials

Material	**Bulk modulus in GPa**	**Bulk modulus in Mpsi**
Diamond (at 4K) [2]	443	64
Alumina[3]	162 ± 14	23.5

Steel	160	23.2
Limestone	65	9.4
Granite	50	7.3
Glass (see also diagram below table)	35 to 55	5.8
Graphite 2H (single crystal)[4]	34	4.9
Sodium chloride	24.42	3.542
Shale	10	1.5
Chalk	9	1.3
Rubber[5]	1.5 to 2	0.22 to 0.29
Sandstone	0.7	0.1

2 – viscosity

2- 1-What is viscosity?

This question is often best answered by example. Imagine a styrofoam cup with a hole in the bottom. If I then pour honey into the cup I will find that the cup drains very slowly. That is because honey's viscosity is large compared to other liquids' viscosities. If I fill the same cup with water, for example, the cup will drain much more quickly.

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid. A fluidwith large viscosity resists motion because its molecular makeup gives it a lot of internal friction. A fluid with low viscosity flows easily because its molecular makeup results in very little friction when it is in motion.

Gases also have viscosity, although it is a little harder to notice it in ordinary circumstances.

2 -2 - definitions

Informally, viscosity is the quantity that describes a fluid's resistance to flow. Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them.

The dimensions of dynamic viscosity are force × time ÷ area. The unit of viscosity, accordingly, is newton-second per square metre, which is usually expressed as pascal-second in SI units. The dimensional formula of viscosity is $[ML^{-1}T^{-1}]$.

The viscosity of liquids decreases rapidly with
an increase in temperature, and the viscosity of gases increases with an increase in temperature. Thus, upon heating, liquids flow more easily, whereas gases flow more sluggishly. For example, the viscosities of

water at 27 °C (81 °F) and at 77 °C (171 °F) are 0.85 × 10^{-3} and 0.36 × 10^{-3} pascal-second, respectively, but those of air at the same temperatures are 1.85 × 10^{-5} and 2.08 × 10^{-5} pascal-second.

For some applications the kinematic viscosity is more useful than the absolute, or dynamic, viscosity. Kinematic viscosity is the absolute viscosity of a fluid divided by its mass density. (Mass density is the mass of a substance divided by its volume.) The dimensions of kinematic viscosity are area divided by time; the appropriate units are metre squared per second. The unit of kinematic viscosity in the centimetre-gram-second (CGS) system, called the stokes in Britain and the stoke in the U.S., is named for the British physicist Sir George Gabriel Stokes. The stoke is defined as one centimetre squared per second.

2 - 3Viscosity Types

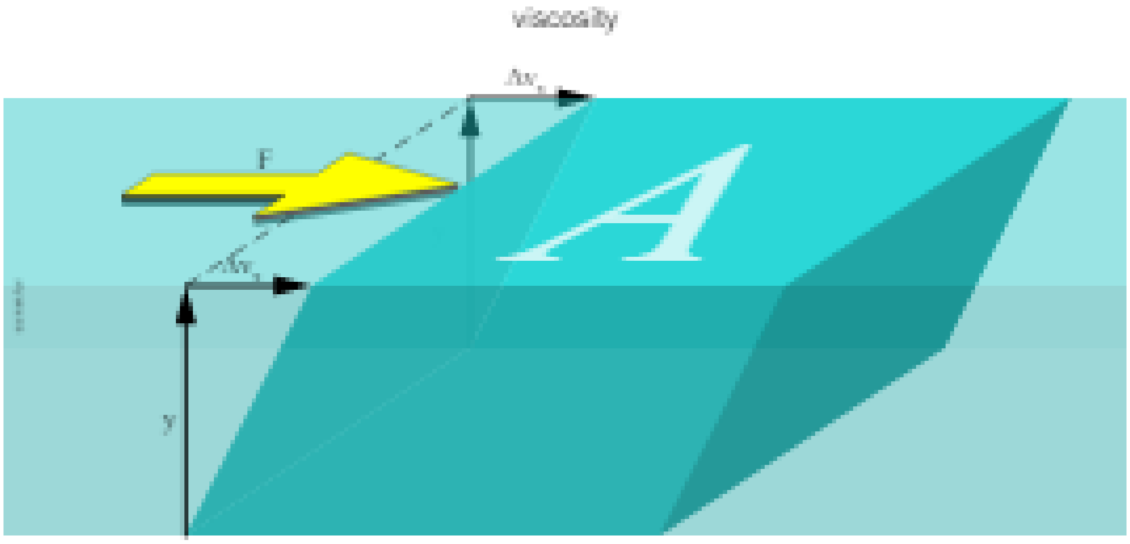
Viscosity is the measure of fluid's friction to its flow. There are two ways to measure the fluid's viscosity as follows:

- Dynamic Viscosity (Absolute Viscosity)
- Kinematic Viscosity

One way is to measure the fluid's resistance to flow when an external force is applied. This is known as Dynamic Viscosity. And the other way is to measure the resistive flow of a fluid under the weight of gravity. We call this measure of fluid viscosity kinematic viscosity.

Many are confused between the two viscosity measures and consider them to be one and the same. In reality, they have significant differences between them. For a few applications, kinematic viscosity is more useful than absolute or dynamic viscosity.

2 – 3-1 (dynamic) viscosity



Formally, *viscosity* (represented by the symbol η "eta") is the ratio of the *shearing stress* (F/A) to the *velocity gradient* ($\Delta v_x/\Delta y$ or dv_x/dy) in a fluid.

$$\eta = \frac{F/A}{\Delta v_x/\Delta y}$$

or

$$\eta = \frac{F/A}{dv_x/dy}$$

The more usual form of this relationship, called *Newton's equation*, states that the resulting shear of a fluid is directly proportional to the force applied and inversely proportional to its viscosity. The similarity to Newton's second law of motion ($F = ma$) should be apparent.

$$\frac{F}{A} = \eta \frac{\Delta v_x}{\Delta y} \quad \Leftrightarrow \quad F = m \frac{\Delta v}{\Delta t}$$

Or if you prefer calculus symbols (and who doesn't)…

$$\frac{F}{A} = \eta \frac{dv_x}{dy} \quad \Leftrightarrow \quad F = m \frac{dv}{dt}$$

The SI unit of viscosity is the *pascal second* [Pa s], which has no special name. Despite its self-proclaimed title as an international system, the International System of Units has had little international impact on viscosity. The pascal second is more rare than it should be in scientific and technical writing today. The most common unit of viscosity is the *dyne second per square centimeter* [dyne s/cm^2], which is given the name *poise* [P] after the French physiologist Jean Poiseuille (1799–1869). Ten poise equal one pascal second [Pa s] making the *centipoise* [cP] and *millipascal second* [mPa s] identical.

1 Pa s = 10 P
1000 mPa s = 10 P
1 mPa s = 0.01 P
1 mPa s = 1 cP

2 – 3 -2 kinematic viscosity

There are actually two quantities that are called viscosity. The quantity defined above is sometimes called *dynamic viscosity*, *absolute viscosity*, or *simple viscosity* to distinguish it from the other quantity, but is usually just called viscosity. The other quantity called *kinematic viscosity* (represented by the Greek letter ν "nu") is the ratio of the viscosity of a fluid to its density.

$$\nu = \frac{\eta}{\rho}$$

Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. It is frequently measured using a device called a capillary viscometer — basically a graduated can with a narrow tube at the bottom. When two fluids of equal volume are placed in identical capillary viscometers and allowed to flow under the influence of gravity, the more viscous fluid takes longer than the less viscous fluid to flow through the tube. Capillary viscometers will be discussed in more detail later in this section.

The SI unit of kinematic viscosity is the *square meter per second* [m^2/s], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the *square centimeter per second* [cm^2/s], which is given the name *stokes* [St] after the Irish mathematician and physicist George Stokes (1819–1903). One square meter per second is equal to ten thousand stokes.

$1\ cm^2/s = 1\ St$

$1\ m^2/s = 10{,}000\ cm^2/s$

$1\ m^2/s = 10{,}000\ St$

Even this unit is a bit too large, so the most common unit is probably the *square millimeter per second* [mm^2/s] or *the centistokes* [cSt]. One square meter per second is equal to one million centistokes.

$1\ mm^2/s = 1\ cSt$

$1\ m^2/s = 1{,}000{,}000\ mm^2/s$

$1\ m^2/s = 1{,}000{,}000\ cSt$

The stokes is a rare example of a word in the English language where the singular and plural forms are identical. Fish is the most immediate example of a aword that behaves like this. 1 fish, 2 fish, red fish, blue fish; 1 stokes, 2 stokes, some stokes, few stokes.

2 – 4 factors affecting viscosity

This part needs to be reorganized.

Viscosity is first and foremost a function of material. The viscosity of water at 20 °C is 1.0020 millipascal seconds (which is conveniently close to one by coincidence alone). Most ordinary liquids have viscosities on the order of 1 to 1000 mPa s, while gases have viscosities on the order of 1 to 10 μPa s. Pastes, gels, emulsions, and other *complex liquids* are harder to summarize. Some fats like butter or margarine are so viscous that they seem more like soft solids than like flowing liquids. Molten glass is extremely viscous and approaches infinite viscosity as it solidifies. Since the process is not as well defined as true freezing, some believe (incorrectly) that glass may still flow even after it has completely cooled, but this is not the case. At ordinary temperatures, glasses are as solid as true solids.

From everyday experience, it should be common knowledge that viscosity varies with temperature. Honey and syrups can be made to flow more readily when heated. Engine oil and hydraulic fluids thicken appreciably on cold days and significantly affect the performance of cars and other machinery during the winter months. In general, the viscosity of a *simple liquid* decreases with increasing temperature. As temperature increases, the average speed of the molecules in a liquid increases and the amount of time they spend "in contact" with their nearest neighbors decreases. Thus, as temperature increases, the average intermolecular forces decrease. The actual manner in which the two quantities vary is nonlinear and changes abruptly when the liquid changes phase.

Viscosity is normally independent of pressure, but liquids under extreme pressure often experience an increase in viscosity. Since liquids are normally incompressible, an increase in pressure doesn't really bring the molecules significantly closer together. Simple models of molecular interactions won't work to explain this behavior and, to my knowledge, there is no generally accepted more complex model that does. The liquid phase is probably the least well understood of all the phases of matter.

While liquids get runnier as they get hotter, gases get thicker. (If one can imagine a "thick" gas.) The viscosity of gases increases as temperature increases and is approximately proportional to the square root of temperature. This is due to the increase in the frequency of intermolecular collisions at higher temperatures. Since most of the time the molecules in a gas are flying freely through the void, anything that increases the number of times one molecule is in contact with another will decrease the ability of the molecules as a whole to engage in the coordinated movement. The more these molecules collide with one another, the more disorganized their motion becomes. Physical models, advanced beyond the scope of this book, have been around for nearly a century that adequately explain the temperature dependence of viscosity in gases. Newer models do a better job than the older models. They also agree with the observation that the viscosity of gases is roughly independent of pressure and density. The gaseous phase is probably the best understood of all the phases of matter.

Since viscosity is so dependent on temperature, it shouldn't never be stated without it.

This is a pretty good model for liquids…

$$\eta = AeB^{/}T$$

$$\ln \eta = \ln A + B \frac{1}{T}$$

$$y = b + mx$$

Where…

$1/T$ = the independent variable, x
$\ln \eta$ = the dependent variable, y
B = the slope, m
$\ln A$ = the y intercept, b

Viscosities of selected materials
(note the variety of unit prefixes)

simple liquids	*T* (°C)	η (mPa s)
alcohol, ethyl (grain)	20	1.1
alcohol, isopropyl	20	2.4
alcohol, methyl (wood)	20	0.59
blood	37	3–4
ethylene glycol	25	16.1
ethylene glycol	100	1.98
freon 11 (propellant)	−25	0.74
freon 11 (propellant)	0	0.54
freon 11 (propellant)	+25	0.42
freon 12 (refrigerant)	−15	?
freon 12 (refrigerant)	0	?
freon 12 (refrigerant)	+15	0.20
gallium	>30	1–2
glycerin	20	1420
glycerin	40	280

simple liquids	*T* (°C)	η (mPa s)
helium (liquid)	4 K	0.00333
mercury	15	1.55
milk	25	3
oil, vegetable, canola	25	57
oil, vegetable, canola	40	33
oil, vegetable, corn	20	65
oil, vegetable, corn	40	31
oil, vegetable, olive	20	84
oil, vegetable, olive	40	?
oil, vegetable, soybean	20	69
oil, vegetable, soybean	40	26
oil, machine, light	20	102
oil, machine, heavy	20	233
propylene glycol	25	40.4
propylene glycol	100	2.75
water	0	1.79
water	20	1.00

simple liquids	*T* (°C)	η (mPa s)
water	40	0.65
water	100	0.28
gases	*T* (°C)	η (μPa s)
air	15	17.9
hydrogen	0	8.42
helium (gas)	0	18.6
nitrogen	0	16.7
oxygen	0	18.1
complex materials	*T* (°C)	η (Pa s)
caulk	20	1000
glass	20	10^{18}–10^{21}
glass, strain pt.	504	$10^{15.2}$
glass, annealing pt.	546	$10^{12.5}$
glass, softening pt.	724	$10^{6.6}$
glass, working pt.		10^{3}
glass, melting pt.		10^{1}
honey	25	10–20

complex materials	T (°C)	η (Pa s)
ketchup	20	50
lard	20	1000
molasses	20	5
mustard	25	70
peanut butter	20	150–250
sour cream	25	100
syrup, chocolate	20	10–25
syrup, corn	25	2–3

2 – 5 capillary viscometer

The mathematical expression describing the flow of fluids in circular tubes was determined by the French physician and physiologist Jean Poiseuille (1799–1869). Since it was also discovered independently by the German hydraulic engineer Gotthilf Hagen (1797–1884), it should be properly known as the *Hagen-Poiseuille equation*, but it is usually just called *Poiseuille's equation*. I will not derive it here (but I probably should someday). For non-turbulent, non-pulsatile fluid flow through a uniform straight pipe, the volume flow rate (q_m) is…

- directly proportional to the pressure difference (ΔP) between the ends of the tube
- inversely proportional to the length (ℓ) of the tube
- inversely proportional to the viscosity (η) of the fluid

- proportional to the fourth power of the radius (r^4) of the tube

$$q_m = \frac{\pi \Delta P r^4}{8 \eta \ell}$$

Solve for viscosity if that's what you want to know.

$$\eta = \frac{\pi \Delta P r^4}{8 q_m \ell}$$

Capillary viscometer… keep writing… sorry this is incomplete.

2 – 6 falling sphere

The mathematical expression describing the viscous drag force on a sphere was determined by the 19th century British physicist George Stokes. I will not derive it here (but I probably should someday in the future).

$$R = 6\pi\eta r v$$

The formula for the buoyant force on a sphere is accredited to the Ancient Greek engineerArchimedes of Syracuse, but equations weren't invented back then.

$$B = \rho_{fluid} g V_{displaced}$$

The formula for weight had to be invented by someone, but I don't know who.

$$W = mg = \rho_{object} g V_{object}$$

Let's combine all these things together for a sphere falling in a fluid. Weight points down, buoyancy points up, drag points up. After a while, the sphere will fall with constant velocity. When it does, all these forces cancel. When a sphere is falling through a fluid it is completely submerged, so there is only one volume to talk about — the volume of a sphere. Let's work through this.

$$\begin{aligned} B \quad + \quad R \quad &= W \\ \rho_{fluid} gV + 6\pi\eta rv &= \rho_{object} gV \\ 6\pi\eta rv &= (\rho_{object} - \rho_{fluid})gV \\ 6\pi\eta rv &= \Delta\rho g \tfrac{4}{3}\pi r^3 \end{aligned}$$

And here we are.

$$\eta = \frac{2\Delta\rho g r^2}{9v}$$

Drop a sphere into a liquid. If you know the size and density of the sphere and the density of the liquid, you can determine the viscosity of the liquid. If you don't know the density of the liquid you can still determine the kinematic viscosity. If you don't know the density of the sphere, but you know its mass and radius, well then you can calculate its density.

3- Surface tension

Surface tension is the tendency of liquid surfaces at rest to shrink into the minimum surface area possible. Surface tension is what allows objects with a higher density than water such as razor blades and insects (e.g. water striders) to float on a water surface without becoming even partly submerged.

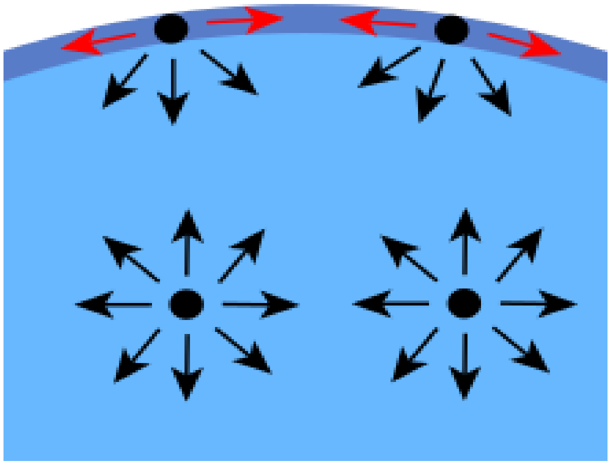
At liquid–air interfaces, surface tension results from the greater attraction of liquid molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion).[1]

There are two primary mechanisms in play. One is an inward force on the surface molecules causing the liquid to contract.[2][3] Second is a tangential force parallel to the surface of the liquid.[3] This *tangential* force is generally referred to as the surface tension. The net effect is the liquid behaves as if its surface were covered with a stretched elastic membrane. But this analogy must not be taken too far as the tension in an elastic membrane is dependent on the amount of deformation of the membrane while surface tension is an inherent property of the liquid–air or liquid–vapour interface.[4]

Because of the relatively high attraction of water molecules to each other through a web of hydrogen bonds, water has a higher surface tension (72.8 millinewtons (mN) per meter at 20 °C) than 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.[4] 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 energy.



Due to the cohesive forces, a molecule located away from the surface is pulled equally in every direction by neighbouring 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 inward. This creates some internal pressure and forces liquid surfaces to contract to the minimum area.[2]

There is also a tension parallel to the surface at the liquid-air interface which will resist an external force, due to the cohesive nature of water molecules.[2][3]

The forces of attraction acting between molecules of the same type are called cohesive forces, while those acting between molecules of different types are called adhesive forces. The balance between the cohesion of the liquid and its adhesion to the material of the container determines the degree of wetting, the contact angle and the shape of meniscus. When cohesion dominates (specifically, adhesion energy is less than half of cohesion energy) the wetting is low and the meniscus is convex at a vertical wall (as for mercury in a glass container). On the other hand, when adhesion dominates (adhesion energy more than half of cohesion energy) the wetting is high and the similar meniscus is concave (as in water in a glass).

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, 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. 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 number of boundary molecules results in a minimal surface area.[5] 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.

3-1Effects 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 (below) 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 were 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.[6]

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.[5] For example, water striders use surface tension to walk on the surface of a pond in the following way. The nonwettability of the water strider's leg means there is no attraction between molecules of the leg and molecules of the water, so when the leg pushes down on 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 pushes the water strider upward so it can stand on the surface of the water as long as its mass is small enough 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[7] 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.

Water
beading on a leaf tension Water striders stay at the top
of liquid because of surface

Surfactants

Surface tension is visible in other common phenomena, especially when surfactants are used to decrease it:

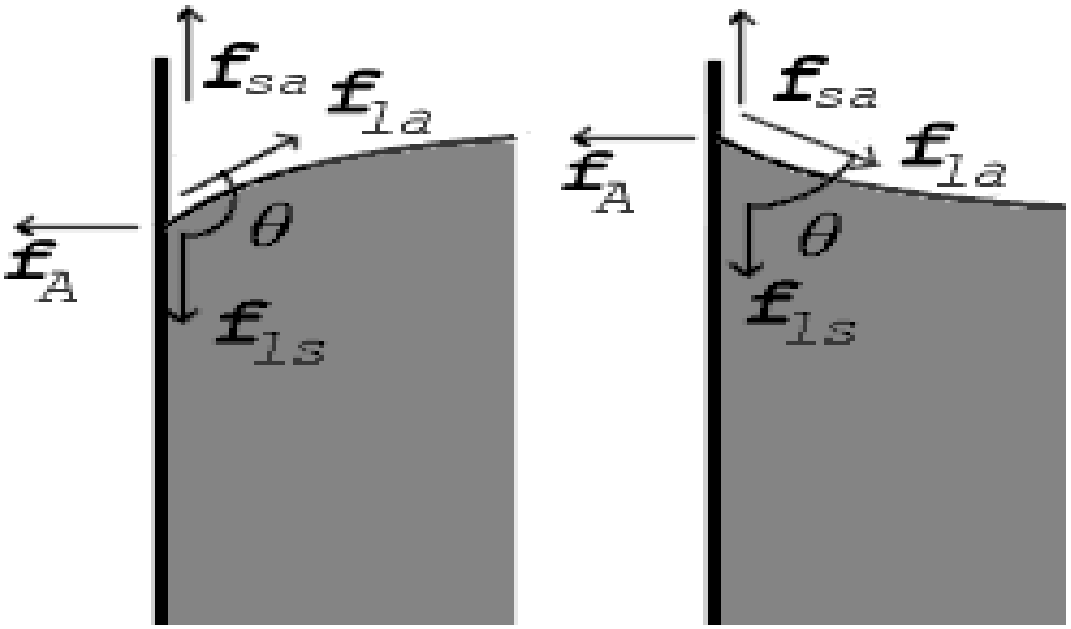
- Soap bubbles have very large surface areas with very little mass. Bubbles in pure water are unstable. The addition of surfactants, however, can have a stabilizing effect on the bubbles (see Marangoni effect). Note that surfactants actually reduce the surface tension of water by a factor of three or more.
- Emulsions are a type of colloid 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).

3-2Physical units

Surface tension, represented by the symbol γ (alternatively σ or T), is measured in force per unit length. Its SI unit is newton per meter but the cgs unit of dyne per centimeter is also used.

3-3Contact angles

- The surface of any liquid is an interface between that liquid and some other medium.[note 1] 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.[10]



Forces at contact point shown for contact angle greater than 90° (left) and less than 90° (right)

Where the two surfaces meet, they form a contact angle, θ, which is the angle the tangent to the surface makes with the solid surface. Note that the angle is measured *through the liquid*, as shown in the diagrams above. 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, $\gamma_{ls} - \gamma_{sa}$, is less than the liquid–air surface tension, γ_{la}, but is nevertheless positive, that is

In the diagram, both the vertical and horizontal forces must cancel exactly at the contact point, known as equilibrium. The horizontal component of f_{la} is canceled by the adhesive force, f_A.[10]

$F_A = Fa_1 \sin\theta$

The more telling balance of forces, though, is in the vertical direction. The vertical component of f_{la} must exactly cancel the difference of the forces along the solid surface, $f_{ls} - f_{sa}$.[10]

$f_{ls} - f_{sa} = - Fa_1 \cos\theta$

Since the forces are in direct proportion to their respective surface tensions, we also have:[11]

$\gamma_{ls} - \gamma_{sa} = - \gamma_{la} \cos\theta$

where

- γ_{ls} is the liquid–solid surface tension,

- γ_{la} is the liquid–air surface tension,
- γ_{sa} is the solid–air surface tension,
- θ 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°.[10]

This means that although the difference between the liquid–solid and solid–air surface tension, $\gamma_{ls} - \gamma_{sa}$, is difficult to measure directly, it can be inferred from the liquid–air surface tension, γ_{la}, and the equilibrium contact angle, θ, 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:

3- 4 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.[11] Contact angle of 180° occurs when the liquid–solid surface tension is exactly equal to the liquid–air surface tension.

Some liquid–solid contact angles[10]

Liquid	Solid	Contact angle

water	soda-lime glass lead glass fused quartz	0°
ethanol		
diethyl ether		
carbon tetrachloride		
glycerol		
acetic acid		
water	paraffin wax	107°
	silver	90°
methyl iodide	soda-lime glass	29°
	lead glass	30°
	fused quartz	33°
mercury	soda-lime glass	140

3-5 What is Capillary Action? (capillary tubes)

We can define capillary action as a phenomenon where ascension of liquids through a tube or cylinder takes place. This primarily occurs due to adhesive and cohesive forces.

The liquid is drawn upward due to this interaction between the phenomena. Narrower the tube, higher will the liquid rise. If any of the two phenomena's i.e. that of surface tension and a ratio between cohesion to adhesion increase the rise will also increase. Although, if the density of the liquid increases, the rise of the liquid in the capillary will lessen.

The amount of water that is held in the capillary also determines the force with which it will rise. The material that surrounds the pores fills the pores also forms a film over them. The solid materials that are nearest to the molecules of water have the greatest adhesion property. The thickness of the film increases as water is added to the pore and the magnitude of capillary force gets reduced.

The film that was formed on the outer surface of the soil molecules also may begin to flow. The capillary action is what causes the movement of groundwater through the different zones of soil. How the fluids are transported inside the xylem vessels of plants is also by the capillary action. As the water evaporates from the surface of the leaves, water from the lower levels that is the roots are drawn up by this phenomenon.

In essence, liquids have the property of being drawn into minute openings such as in between the granules of sands and rising into thin tubes. Solid substances and liquids have an intermolecular force of attraction in between them and due to a result of that capillarity or capillary action takes place. The same thing happens when a sheet of paper is placed on a puddle of water, it absorbs it. This happens because the water gets absorbed into the thin openings between the fibres of the paper.

Application of Newton's Second Law

We will explain the phenomenon by applying Newton’s second law to the liquid column. To apply Newton’s second law this free body is chosen (as shown in figure 1) so that we can define net force on the liquid column contact forces are those exerted by the liquid surrounding the column, these adhesive forces do not act on this body and therefore will not be counted.

Newton’s Laws of Motion

The pressure at the top and bottom of the column is 1 atm and so these forces balance each other. Similarly, horizontal pressure forces along the sides of the liquid column balance each other. So the remaining vertical forces must balance. In the vertical direction weight of the liquid column (mg) acting downward and the force of surface tension acts in the upward direction, which acts along a circle of radius r.

According to Newton’s second law

$\sum Fy=0$
Force by surface tension – mg = 0

$TL - mg = 0$

$T(2\pi r)-mg=0$
Where,

mg – the weight of the liquid

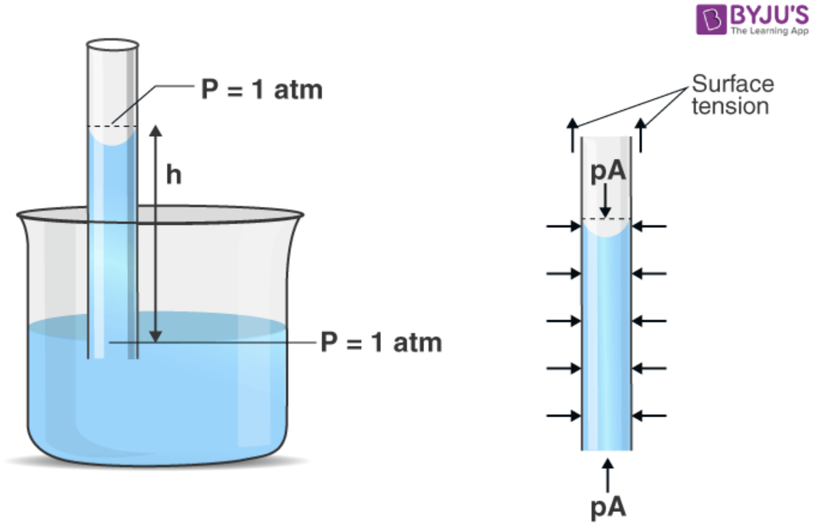
TL – is the surface tension force

$m=\rho v=\rho Ah=\rho\pi r2h$

$T(2\pi r)=(\rho\pi r2h)g$

$2T\rho rg=h$……………..(1)

This is the desired result of the rise of liquid in the capillary tube



Another way we can derive the capillary rise through excess pressure. In order to find the height to which a liquid will rise in a capillary of radius R dipped in a liquid. It is shown in the figure. As the meniscus is concave and nearly spherical. As we know pressure below the concave meniscus will be less than the pressure above the meniscus by

2Tr.
pressure above the meniscus is P and pressure below the concave meniscus is
P0−2Tr
.
Where,

P_0 – is atmospheric pressure

r – is the radius of meniscus

T – is surface tension

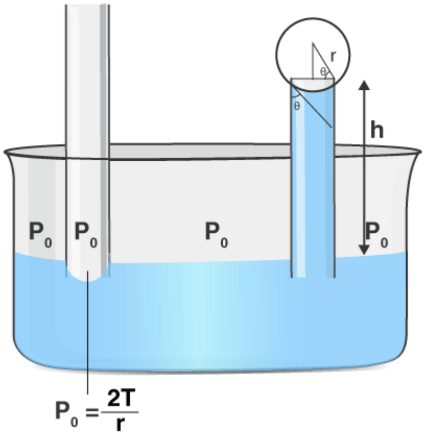
Since,

The liquid will flow from higher to lower pressure and at the same level in liquid pressure must be the same, so the liquid will rise in the capillary till hydrostatic pressure of liquid compensates the decrease in pressure.

$P0=[P0-2Tr]+h\rho g$……………..….(1)
$2Tr=h\rho g$
$2Tr\rho g=h$……………..….(2)
From figure (2), it is found that the relationship between the radius of the meniscus (r) and the radius of the capillary (R) will be;

$Rr=\cos\theta$
$r=R\cos\theta$……………….(3)
Substitute equation (3) in equation (2)

$h=2T\cos\theta R\rho g$……………….(4)



Important Points Regarding Capillarity Action

(i) Capillarity Depends On The Nature Of The Liquid And Solid

(i.e.) T, P, R and Q where,

T – surface tension

ρ – density of liquid

R – Radius of capillary

Q – the angle of contact

If θ > 90°:-

The meniscus is convex, and h will be negative (h = -ve), which means the liquid will falls (descends) in the capillary.

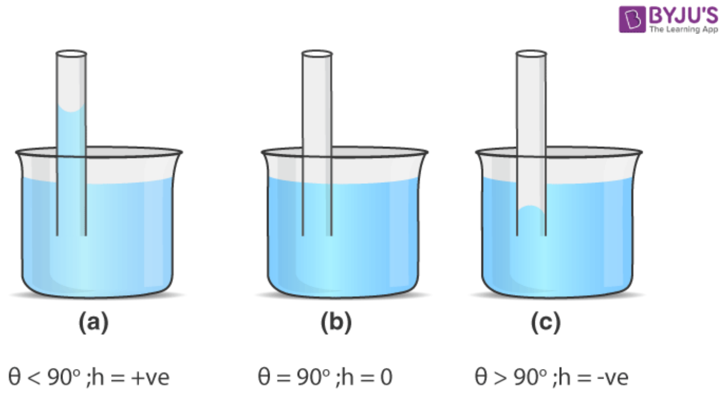
(i.e.) Actually, it happens in the case of mercury in a glass tube.

If θ = 90°:

This means the meniscus is plane, so (h = 0), and there is no capillarity.

If θ < 90°:

The meniscus is concave, and h will be positive (h = +ve). This means the liquid level rises up (ascends) in the capillary, which is shown in figure (3).



Capillary with respect to angle at centre

(ii) Angle of Contact

The angle of contact is defined as the angle between the tangent drawn to the liquid surface at a point of contact of liquid and solid insides the liquid. It depends on the nature of solid and liquid both. For concave meniscus of liquid will be acute and for convex meniscus of liquid, it will be obtuse.

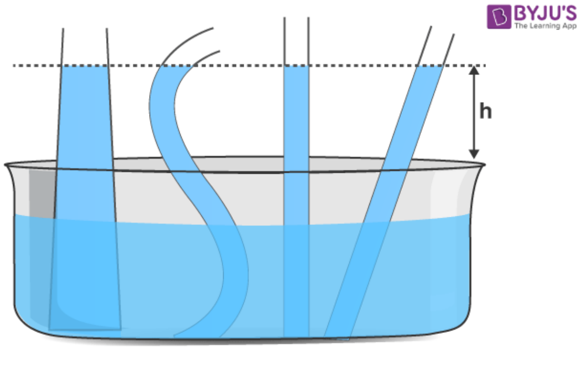
(iii) For A Given Liquid And Solid At A Given Condition P, T, Θ And G Are Constant

H_r = constant ……………….(5)

(i.e.) lesser the radius of capillarity (R) and greater will be the rise and vice-versa.

(iv) Independent of The Shape of Capillary

At equilibrium, the height (h) is independent of the shape of the capillary (if the radius of meniscus remains the same). This is why the vertical height (h) of a liquid column in capillaries of different size and shapes will be same. (If the radius of meniscus remains the same and then vertical height (h) of the capillaries also remains same even for different capillaries). It is given in below figure (4).



Capillary with respect to radius of meniscus

In capillarity, the excess pressure is balanced by hydrostatic pressure and not by the force due to surface tension by weight

In general,

$2Tr=h\rho g$………..…(1)
And

$TL = mg$

$2\pi rT=\pi r2h\rho g$…………(2)
This equation (2) is valid only for cylindrical tubes and cannot be applied to other situations shown in figure (4). But equation (1) is the general case (v). in case of a capillary of insufficient length ($L < h$) (the capillary is less than the excepted rise of liquid) the liquid will neither overflow from the upper end (i.e.) fountain nor will it tickle along the vertical sides of the capillary. The liquid after reaching the upper end will increase the radius of its meniscus without changing nature in such cases.

$hr=Lr'$

Liquid Meniscus in Capillarity

In capillarity liquid meniscus can be:

(i) concave meniscus

(ii) convex meniscus

(iii) plane meniscus

To understand this let us take a liquid drop (or) bubble as we know due to the property of surface tension, every liquid tries to minimize (or) contract its free surface area. Similarly, a liquid drop (or) bubble also tries to compress (contract) its surface and so it compresses the matter enclosed.

Fluid Dynamics

This, in turn, increases the internal pressure of the liquid drop (or) bubble, which prevents further contraction and equilibrium is achieved.

In the equilibrium state, the pressure inside the bubble (or) drop is greater than outside the bubble (or) liquid drop and this difference in pressure between inside and outside the liquid drop (or) bubble is called excess pressure.

In the case of a liquid drop

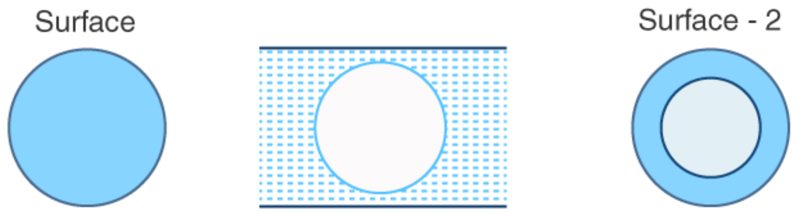
For a liquid drop, excess pressure is provided by the hydrostatic pressure of the liquid.

In the case of a bubble

For the bubble, the excess pressure is provided by the gauge pressure of the gas confined in the bubble.

Relationship Between Excess Pressure And Surface Tension

To derive the relationship between surface tension and excess pressure for a liquid drop ((or) bubble inside the liquid) let us consider a liquid drop of the radius (r) having internal pressure and external pressure are P_i and P_o respectively.



(a)
Liquid drop
1-surface

(b)
Bubble in iquid
1 - surface

(c)
Bubble in Air
2 - surfaces

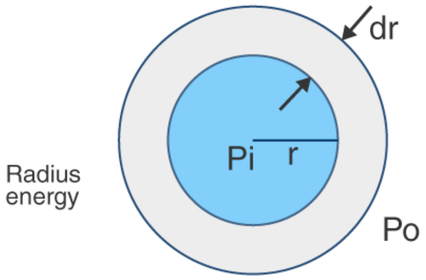
So that excess pressure $P = P_i - P_o$ if we want to change the radius of the drop from r to r + dr, then we have to do external work.

(W) external work is done = F. dr = P A dr ………….(1)

Because,

$P=FA,A=4\pi r2$
$W=4\pi r2Pdr\ldots\ldots\ldots\ldots\ldots(2)$
While changing the radius of the drop from r to r + dr then change in Area will be changed in the area

$dA=4\pi(r+dr)2-4\pi r2$
$dA=8\pi rdr\ldots\ldots\ldots\ldots\ldots(3)$
The work done in changing the area will be very much similar to work done in stretching a rubber sheet. So this work will be stored as potential energy in the surface and the amount of this energy per unit area of the surface under isothermal condition is called “Intrinsic surface energy (or) free surface energy density.”



Liquid drop changing r to r+dr

$W = T\ dA \ldots\ldots\ldots\ldots\ldots(4)$

$WdA=T\ldots\ldots\ldots\ldots\ldots(5)$
Where

W – work done in changing the area

dA – change in the area

T – surface tension

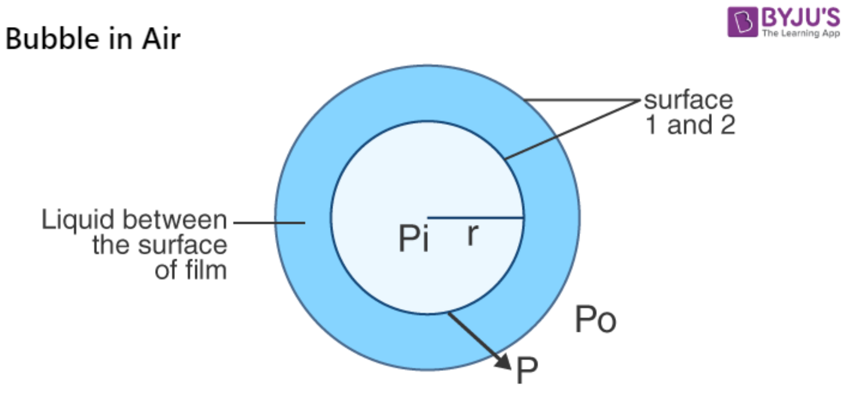
Equation (2) is known as surface energy.

According to surface energy,

$T=WdA=4\pi r2P\ dr8\pi rdr$
$2Tr=P=Pi-Po$……………(6)
This equation (7) is called as excess pressure.

Where P – is known as excess pressure

For Bubble in Air:



Similarly for a bubble in the air, as we know bubbles in the air will have two surfaces. The pressure inside the bubble is Pi, the pressure outside the bubble is P_o and pressure between the two surfaces is P.

So excess pressure will be

$P=Pi-P+P-Po$

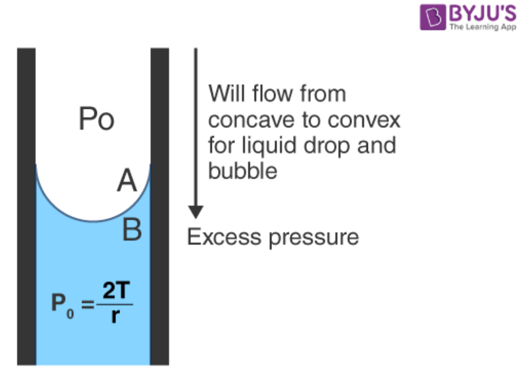
$P=2Tr+2Tr=4Tr$……………..(7)
From equation (6) and (7) it is clear that excess pressure will be inversely proportional to the radius. Which means smaller radius will have more pressure and (vice – versa). This is why when two bubbles of different radii put in communication with each other the air will rush

from smaller radii to larger radii bubbles due to which smaller bubbles will shrink while larger bubbles will expand till the smaller bubble reduces to a droplet.

Excess Pressure-flow Direction

Excess pressure in case of liquid drop (or) bubble in liquid it is directed from inside to outside (inner will be more pressure than outer) [From concave to convex side] this results is true for meniscus of liquids.

(i) Concave Meniscus



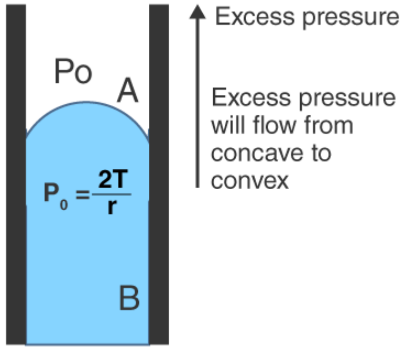
(a) concave meniscus

For concave meniscus pressure below the meniscus will less than the pressure above the meniscus by

$2Tr$.
pressure above the meniscus is P_o and pressure below the meniscus is $Po-2Tr$,
so the excess pressure will be
$PA-PB=2Tr$
Where

$PA=Po$
and
$PB=Po-2Tr$
r – is the radius of meniscus

(ii) For Convex Meniscus

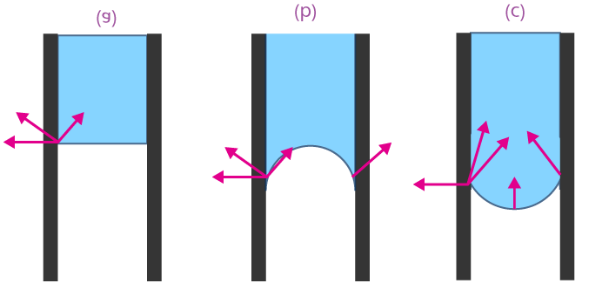


(a) conex meniscus

For convex meniscus pressure below the meniscus will be higher than the pressure below the meniscus. Pressure above the meniscus will be P_o and pressure below the meniscus will be

Po+2Tr
then the pressure difference between above and below the meniscus (excess pressure) will be
P=PB−PA=Po+2Tr−Po=2Tr
Where r – radius of the meniscus.

(iii) Plane Meniscus



For plane meniscus pressure difference between above and below the meniscus will be zero (excess pressure = 0) so there is no capillarity.

Excess pressure P = 0

Difference Between Concave, Convex And Plane Meniscus

Concave meniscus	**Convex meniscus**	**Plane meniscus**
Pressure below the meniscus (Po−2Tr) is less than pressure above the meniscus (P_o)	Pressure below the meniscus will be (Po+2Tr) higher than pressure above the meniscus (P_o)	Pressure below the meniscus = Pressure above the meniscus
Excess pressure will be P=Pabove−Pbelow P=2Tr	Excess pressure (P) P=Pbelow−Pabove P=2Tr	Excess pressure (P) = 0
The angle of contact is acute (θ < 90°)	The angle of contact is obtuse (θ > 90°)	The angle of contact is θ = 90°
Liquid level in the capillary ascends	Liquid level in the capillary descents	No capillarity
The liquid will wet the solid	The liquid will not wet the solid	Critical

3-6Applications Of Capillarity

(a) The oil in the wick of a lamp rises due to the capillary action of threads in the wick.

(b) The action of a towel in soaking up moisture from the body is due to the capillary action of cotton in the towel.

(c) Water is retained in a piece of sponge on account of capillarity.

(d) A blotting paper soaks ink by the capillary action of the pores in the blotting paper.

(e) The root-hairs of plants draw water from the soil through capillary action.

Forces in Capillary Action

Cohesion

The force that exists between the molecules of specific liquids is termed as cohesion. Raindrops, before they fall to the earth, are also kept together by the same force. Surface tension is a phenomenon that most of us are aware of but not many of us know that it is also due to the concept of cohesion. Surface tension allows objects that are denser than the liquids to float on top of them without any support and doesn't let them sink.

Difference Between Adhesion and Cohesion

Adhesion

Another concept that can be understood with this phenomenon is one of adhesion. Adhesion is the force of attraction between two dissimilar substances such as a solid container and a liquid. This is the same force that allows water to stick on the glass.

If the phenomenon of adhesion is more than that of cohesion the liquids wet the surface of the solid it is contacted with and one can also notice the liquid curving upwards towards the rim of the container. Liquids like mercury have more cohesion force than adhesion force and thus can be termed as non-wetting liquids. Such liquids curve inwards when near the rim of the container.

Capillary Action In Everyday Life

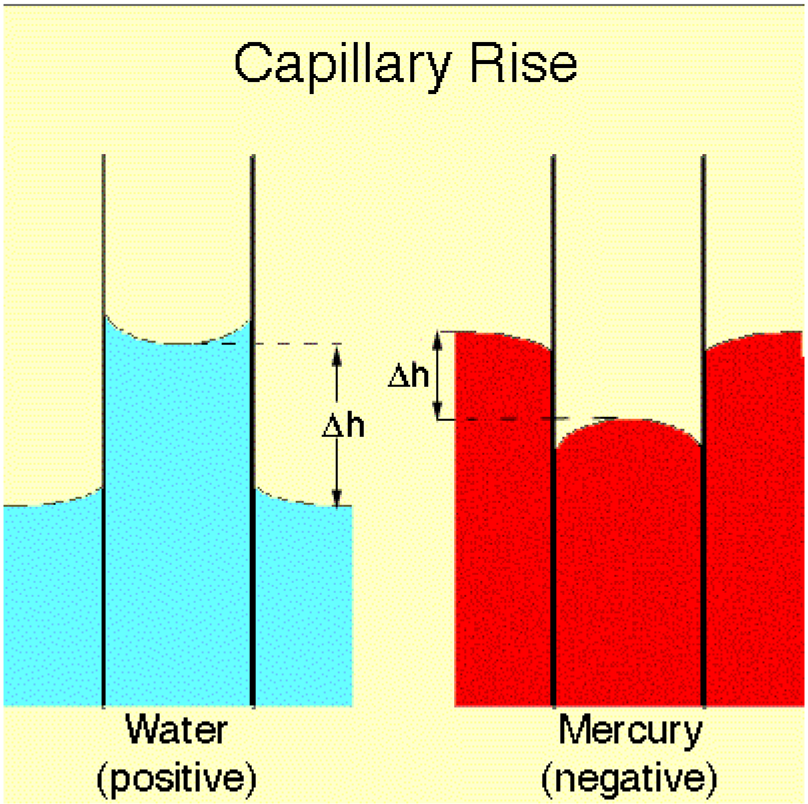
- If you drop a paper towel in water, you’ll see it climb up the towel spontaneously apparently ignoring the gravity. In reality, you see capillary movement, and it is about right that the water molecules crawl up the towel and pull on other water molecules.
- Without capillary action plants and trees will not be able to survive. Plants hold roots in the soil that can bring water from the soil up into the plant.
- Nutrients dissolved in the water get into the roots and starts to climb up the surface of the plant. Capillary activity helps deliver water to the roots.

3-7 Capillary Rise in Water and Mercury

Capillary Rise

This is a close view of two narrow tubes, one containing water and the other containing mercury. The tube containing water exhibits positive capillary rise, where the water adheres to the sides of the tube causing the fluid to rise slightly. The tube containing mercury exhibits negative capillary rise. The fluid is drawn away from the walls of the tube, causing the fluid to sink slightly.

DEFINITION: A rise in a liquid above the level of zero pressure due to a net upward force produced by the attraction of the water molecules to a solid surface, e.g. glass, soil (for those cases where the adhesion of the liquid to the solid is greater than the cohesion of the liquid to itself)


Capillary Rise
Δh
Δh
Water
(positive)
Mercury
(negative)

References

1- **wikipedia.org/wiki/Shear_modulus Elastic modulus**

2- **https://physics.info/viscosity/**

3- **https://www.britannica.com/science/viscosit**

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