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NEPAL ENGINEERING COUNCIL
LICENSE EXAM PREPARATION COURSE

FOR

CIVIL ENGINEERS

3. Basic Water Resources Engineering

3.1 Fluids and their properties

Sub topics

- Types of fluids
- Fluid properties

Fluid

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What is fluid?

- Fluid is a substance which can flow.
- Liquid and gas comes under this category

Major types

- Ideal Fluid
    - Incompressible, zero cohesion
- Real Fluid
    - compressible, has cohesion

Solid

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Solid

If we apply some external shear force on solid it undergoes finite deformation ($d\theta$) or breaks.

For solid $\tau \alpha\, d\theta$ where $d\theta$ is finite deformation (or) finite shear strain.

If we remove external shear force depending on deformation (elastic or plastic) solid may or may not regain original shape.

Fluid

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No slip condition

Fluid

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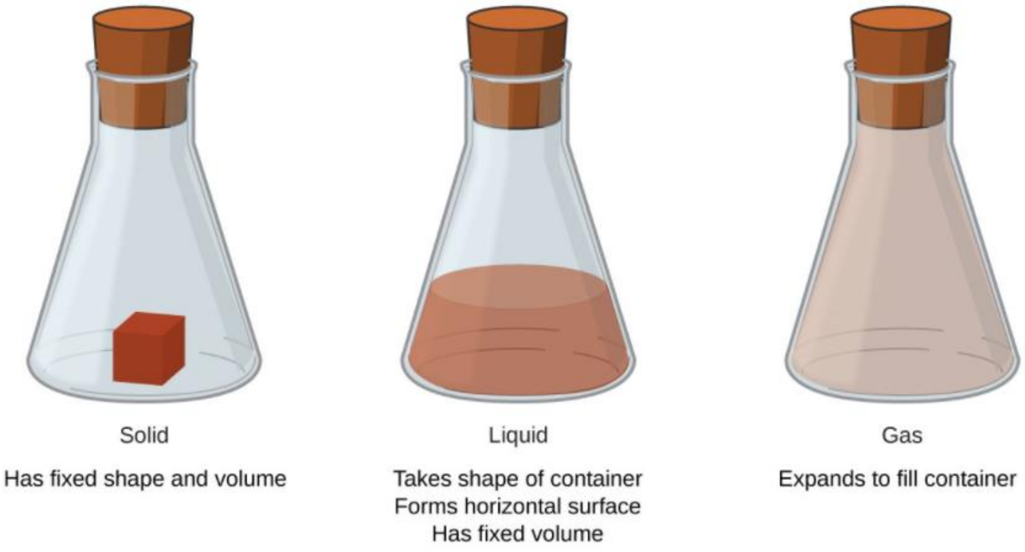
If we apply some external shear force on fluid it undergoes continuous deformation ($d\theta$). This continuous deformation is called flow.

For fluid $\tau \alpha\ d\theta/dt$ where $d\theta/dt$ is finite deformation rate (or) shear strain rate.

If we remove external shear force fluid not regain original shape.

Fluid

Solid: Has a definite shape and volume.
Liquid: Has a definite volume, but take the shape of the container and has a free surface.
Gas: Has no definite shape or volume



MCQs

A substance which deforms continuously under the action of shear stress is called

a) fluid

b) gas

c) liquid

d) solid

MCQs

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An ideal fluid is

a) is very viscous

b) obeys Newtons law of viscosity

c) is similar to gas

d) is frictionless and incompressible

Fluid

Properties of fluid

Extrinsic properties do depend on the size of a sample

- Mass, volume, weight

Intrinsic properties do depend on the size of a sample

- Melting point, boiling point, temperature, pressure density, odor, and color

Mass density/ Density

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Its mass per unit volume

$$\rho = \frac{m}{V}$$

Density represents heaviness of fluid physically.
Dimension: ML^{-3}
The SI unit of density is kg/m^3
The cgs unit of density is g/cm^3

$$1 g/cm^3 = 1000 \ kg/m^3$$

Mass density/ Density

Effect of changes in temperature.

$$\rho = \frac{m}{V}$$

Density decreases on increasing temperature
Density increases on decreasing temperature

Exception: Anomalous behaviour of water

Mass density/ Density

Exception: Anomalous behaviour of water

Water (0°C)	999.8
Water (4°C)	1000
Water (20°C)	998.2
Water (100°C)	958.4

$$\rho = \frac{m}{V}$$

Mass density/ Density

Exception: Anomalous behaviour of water

$$\rho = \frac{m}{V}$$

Common Fluids	Density
Water	1000
Air	1.225
Mercury	13600
oil	800

Specific volume

The specific volume (v) is the volume per unit mass.

$$v = \frac{1}{\rho}$$

Dimension: $M^{-1}L^3$

Weight density/ Specific weight

Its weight per unit volume

$$\gamma = \rho g$$

Dimension: $ML^{-2}T^{-2}$

The SI unit of density is N/m^3, $\frac{\mathrm{kg}}{\mathrm{m}^2 s^2}$
The cgs unit of density is dyne/cm^3

1dyne/cm^3 = 10 N/m^3

Weight density/ Specific weight

Effect of changes in temperature.

$$\gamma = \rho g$$

Specific wt and Density decreases on increasing temperature
Specific wt and Density increases on decreasing temperature

Effect of location
Specific wt and Density increases on increase of value of g

$$\gamma_{pole} > \gamma_{equator} \; as \; R_{pole} < R_{equator}$$

Specific gravity

Specific gravity is defined as the ratio of the density of the material to the density of water at 4.0°C and one atmosphere of pressure. Determines if one object will float or sink in water.

$$\text{Specific gravity} = \frac{\text{Density of material}}{\text{Density of water}}.$$

Dimension: $M^0L^0T^0$

For gasses standard material is H_2 or air at 15^0C and 1 atm pressure

Relative density

Relative density is defined as the ratio of the density of the one material to the density of other.

Specific gravity is also relative density.

Dimension: $M^0L^0T^0$

Determines if one object will float or sink

MCQs

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If the volume of a liquid weighing 3000 kg is 4 cubic meters, then 0.75 is its

a) Specific weight

b) Specific mass

c) Specific gravity

d) none

Viscosity

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Resistance of a fluid (liquid or gas) to a change in shape, or movement of neighbouring portions relative to one another.

Viscosity denotes opposition to flow.

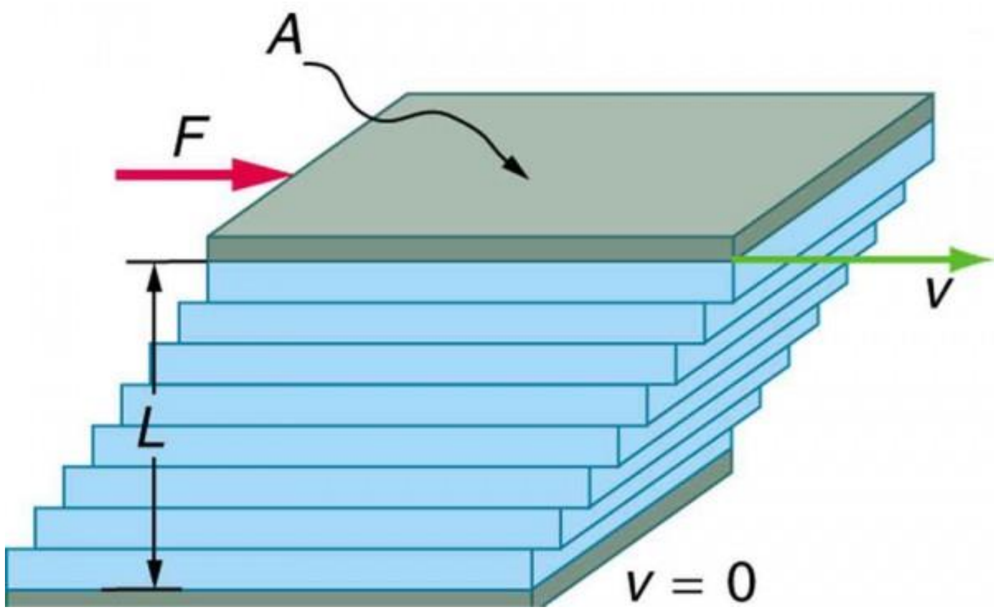
The reciprocal of the viscosity is called the fluidity, a measure of the ease of flow

Viscosity

What leads to viscosity in liquid?

Fluid layers has internal resistance to motion due to cohesion.

Viscosity denotes opposition to flow or opposes relative motion between layers of fluid layer.



Viscosity

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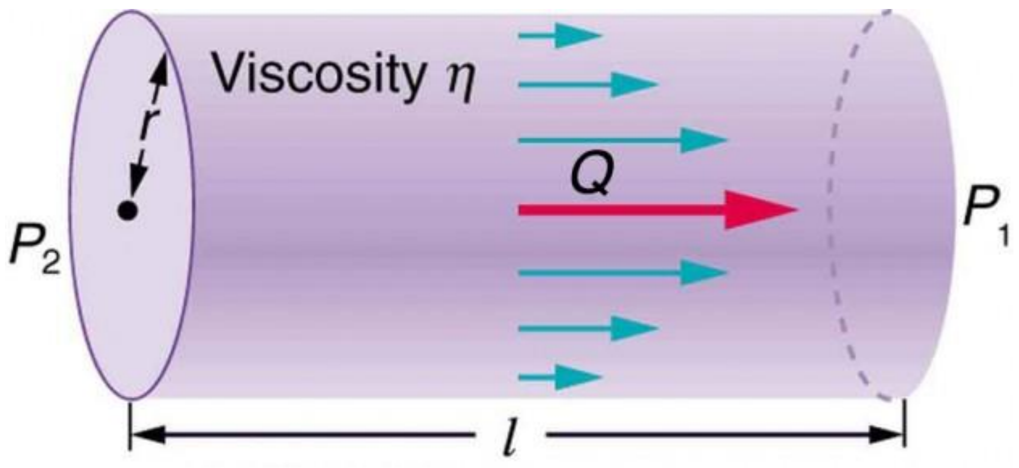
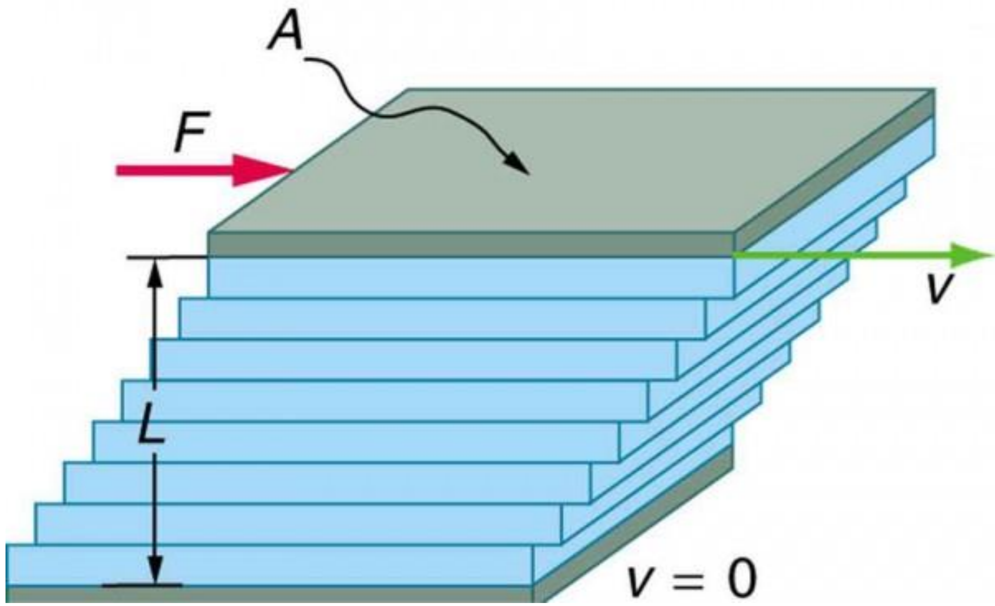




Newton's law of Viscosity

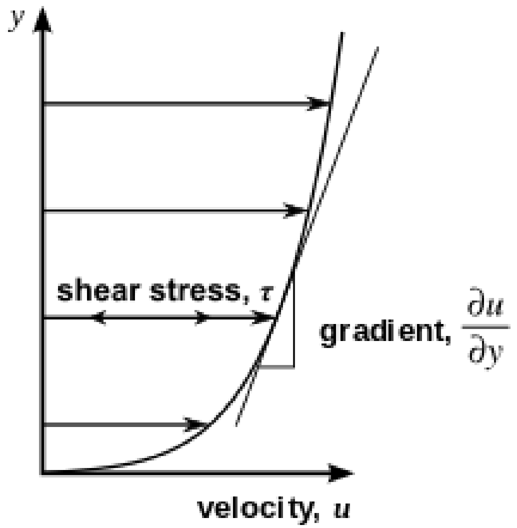
For fluid flow, shear strain rate (deformation rate) is equal to velocity gradient in y direction

$$\tau \propto \frac{d\theta}{dt} \propto \frac{du}{dy}$$

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

$$\mu = \frac{\tau}{du/dy}$$



Viscosity

$$\mu = \frac{\tau}{du/dy}$$

Coefficient of viscosity, absolute viscosity, dynamic viscosity, simple viscosity

SI Unit: $Ns/m^2, Pa\ s,\ kg/ms$

CGS Unit: Poise or dyne. s/cm^2

1 poise =0.1 Ns/m^2

Commonly used unit : Centipoise = 0.01 poise = 0.001 Ns/m^2

Viscosity

SI Unit: $Ns/m^2, Pa\ s,\ kg/ms$

CGS Unit: Poise (P) or dyne. s/cm^2

1 poise =0.1 Ns/m^2

Commonly used unit : Centipoise = 0.01 poise = 0.001 Ns/m^2

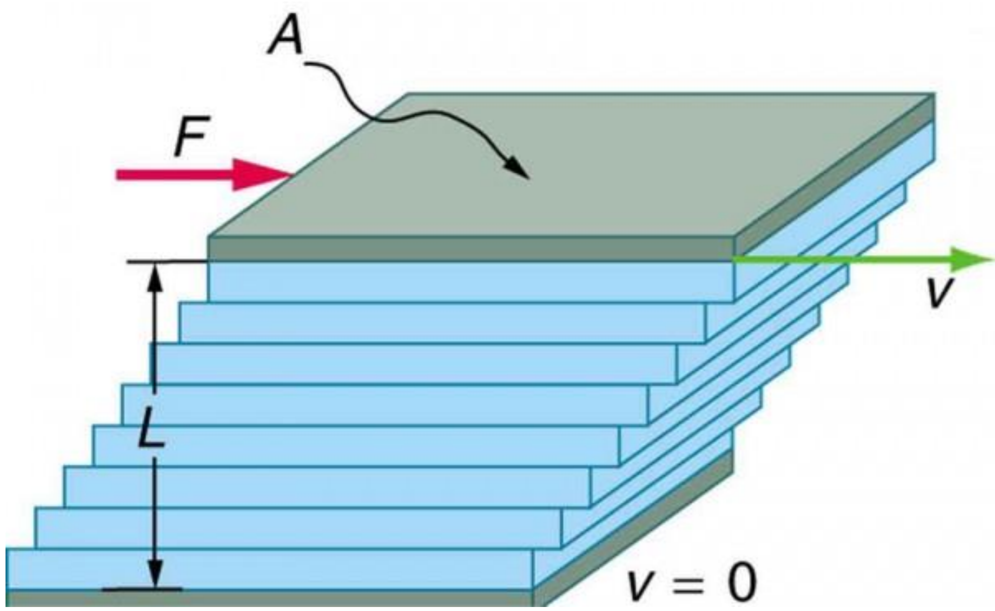
Viscocity of water at 20°C is about 1cP

Viscosity

What leads to viscosity in gasses?

Molecular colision

Viscosity denotes opposition to flow or opposes relative motion between layers of fluid layer.



Viscosity

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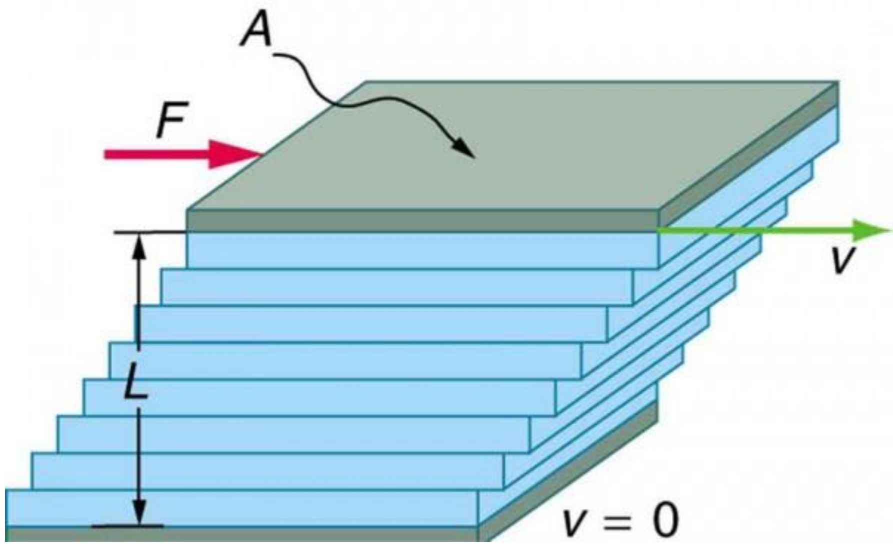
Viscosity in ideal fluid : zero , no cohesion
Viscosity at rest or relative rest: zero, no motion

Effect of Pressure?
No effect founds in experiments



Viscosity

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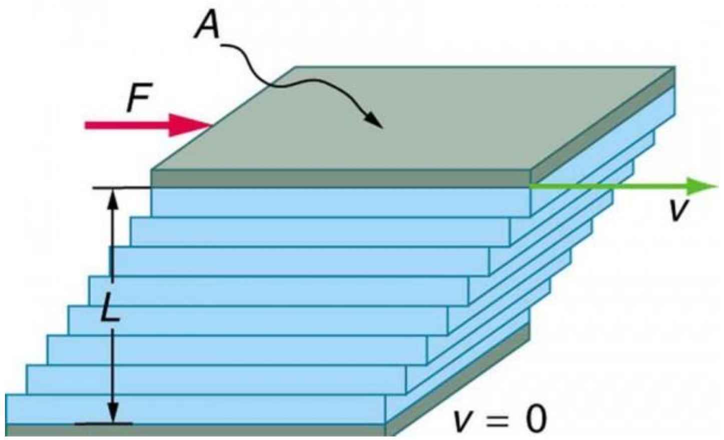
Effect of Temperature

In liquid:

Temperature increase increases volume, increases distance between molecules in liquid thus decreases cohesion.



Increasing temperature decreases viscosity in liquid

$$\mu = a \times 10^{\frac{b}{T-c}}$$

Viscosity

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Effect of Temperature

In gasses:

Temperature increase, increases randomness in molecules.

Increasing temperature increases viscosity

$$\mu = \frac{a\sqrt{T}}{1 + b/T}$$

Viscosity

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Viscosity

Common Fluids	Viscosity at 20°C in cP
Water	1
Air	1/55
Mercury	1.6
oil	300

Viscosity

Viscosity act like friction
Opposes motion, reduces velocity with time

We need to supply power continuously to make steady velocity
$P=Fv$

Viscosity

A square plate 0.1 m side moves parallel to second plate with a velocity of 0.1 m/s, both plates being immersed in water. If the viscous force is 0.002 N and the coefficient of viscosity 0.001 poise, what is the distance between the plates?

Kinematic Viscosity

The kinematic viscosity is defined as the absolute viscosity of a liquid divided by its density at the same temperature.

A measure of a fluid's internal resistance to flow under gravitational forces

$$\nu = \mu/\rho$$

Kinematic Viscosity

SI Unit: m^2/s,

CGS Unit: stoke , cm^2/s

1 stoke =0.0001 m^2/s

Kinematic Viscosity

Effect of temperature

$$\nu = \mu/\rho$$

For liquid
Kinematic viscosity decreases with increase in temperature as rate of decrease of dynamic viscosity is more that rate of decrease of density.

For gas
Kinematic viscosity increases with increase in temperature as dynamic viscosity increases and density decreases.

Rate of increase of ν is more than μ in gasses.

Kinematic Viscosity

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Effect of Pressure

$$\nu = \mu/\rho$$

For liquid

Kinematic viscosity does not change with pressure as dynamic viscosity and density remains same.

For gas

Kinematic viscosity decreases with increase in pressure as dynamic viscosity remains same but density increases.

Kinematic Viscosity

Kinematic viscosity of water is about 15 times than that of water at 20°C

Surface Tension

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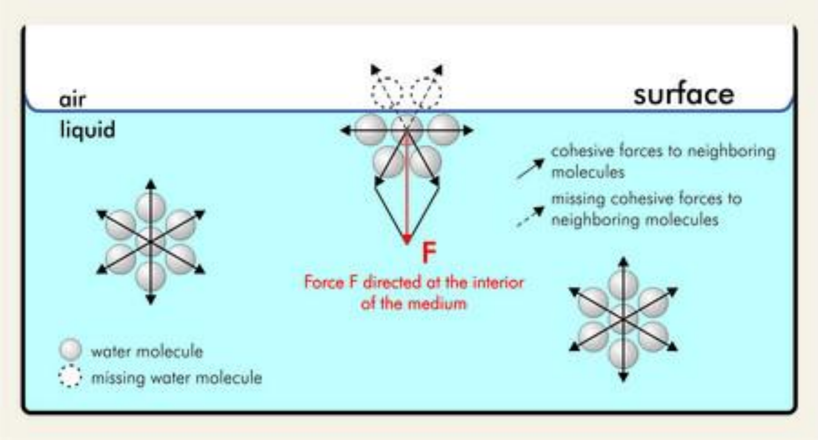
Cohesion can be described as attractive (cohesive) forces or ‘stickiness’ between molecules of liquids.

Cohesive forces are those that hold the body of a liquid together with minimum surface area.

Ideal fluid has no surface tension.

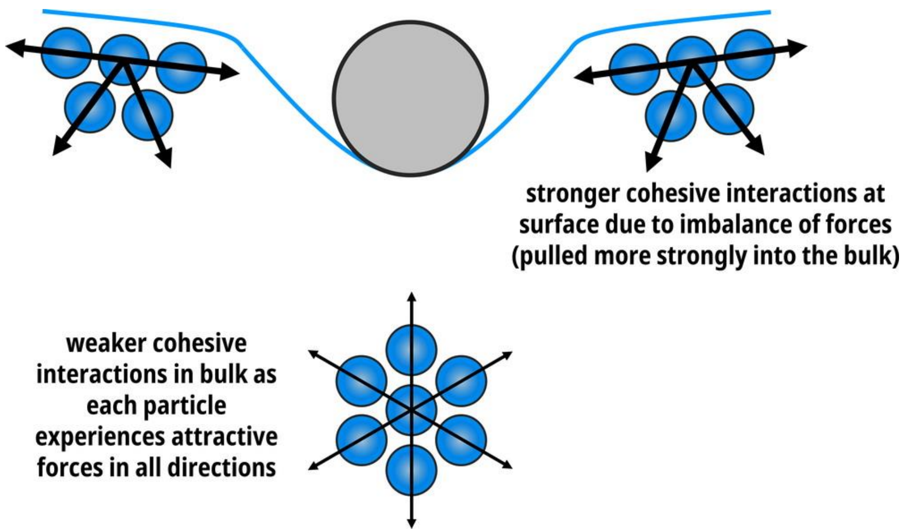


water in contact with air varies from 0.0736 N/m [or 0.0075 kg (f)/m] at 19°C to 0.0589 N/m [or 0.006 kg (f)/m] at 100°C

Surface Tension

Surface tension is the tendency of fluid surfaces to shrink into the minimum surface area possible.

Surface acts as stretched surface.



Surface Tension

$T = F/L$

- *F* is the force per unit length
- *L* is the length in which force act
- *T* is the surface tension of the liquid

Surface tension is typically measured in dynes/cm, the force in dynes is required to break a film of length 1 cm.

1 dyn/cm = 0.001N/m = 1 mN/m

The **surface tension** of water at 20 °C is 72.75 mN/m.

Surface Tension

Effect of temperature

On increasing temperature, cohesion decreases so does surface tension

Soap, detergent decreases the surface tension

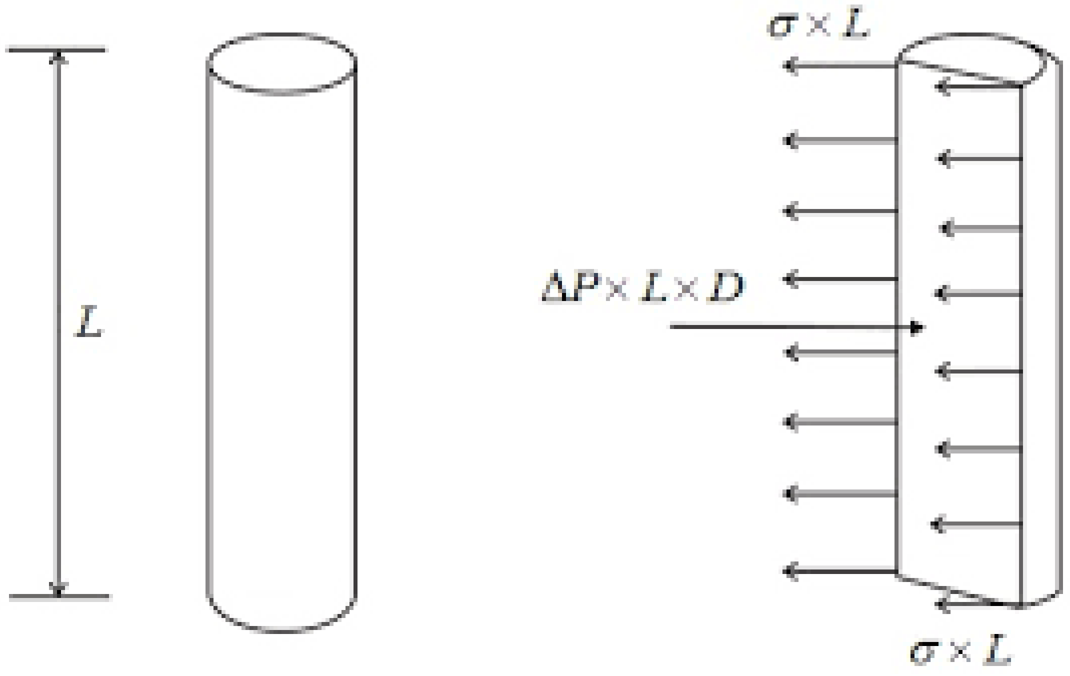
Salts like NaCl increases surface tension

Surface Tension

Excess Pressure
Inside Soap bubble

$$\Delta P = \frac{T}{R}$$

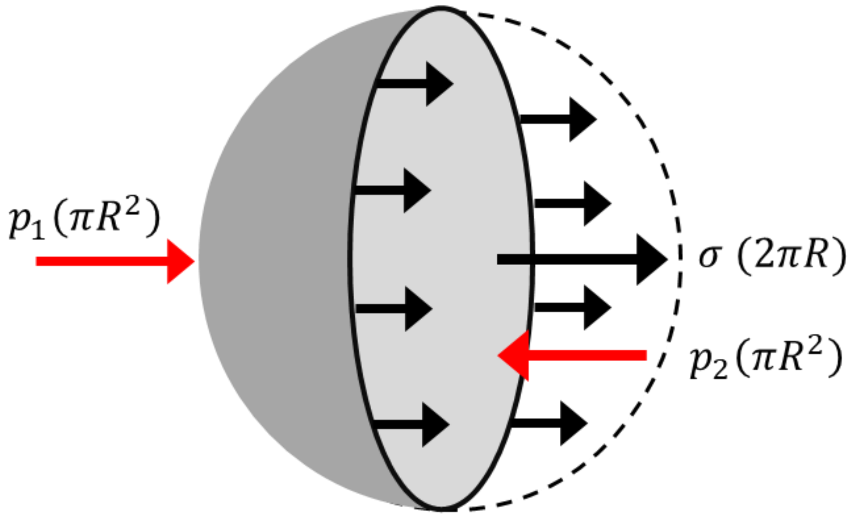
$$\mathrm{P_{inside}} = \mathrm{P_{outside}} + \Delta P$$



Surface Tension

Excess Pressure
Inside Drops and air bubble

$$\Delta P = \frac{2T}{R}$$



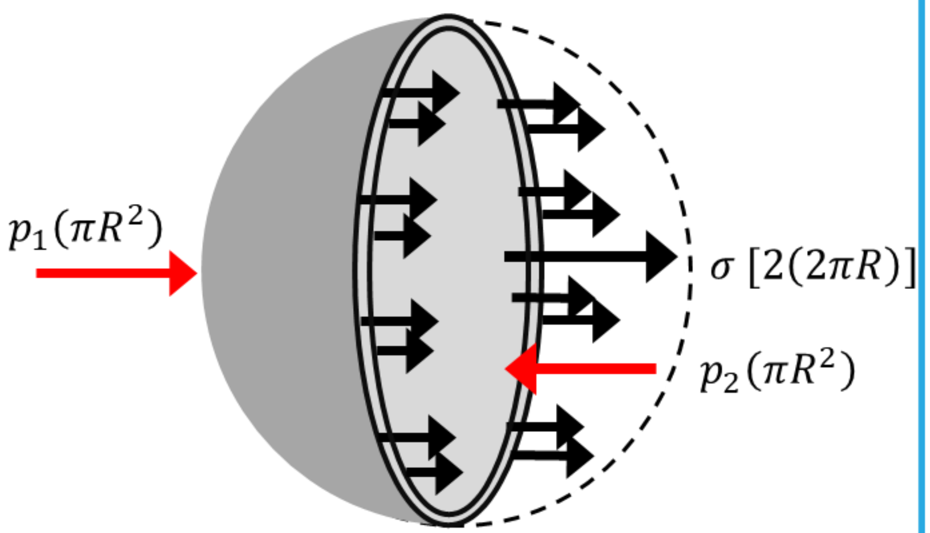
The cross section of an air bubble of radius R.

Surface Tension

Excess Pressure
Inside Soap bubble

$$\Delta P = \frac{4T}{R}$$

$$\mathrm{P_{inside}} = \mathrm{P_{outside}} + \Delta P$$



The cross section of an soap bubble of radius R.

Surface Tension

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If excess pressure is balanced by a column of oil (with specific gravity 0.8) 4 cm high, where R = 2.0 cm, find the surface tension of the soap bubble.

$$T = 0.1568 \ \ N/m$$

Surface Tension

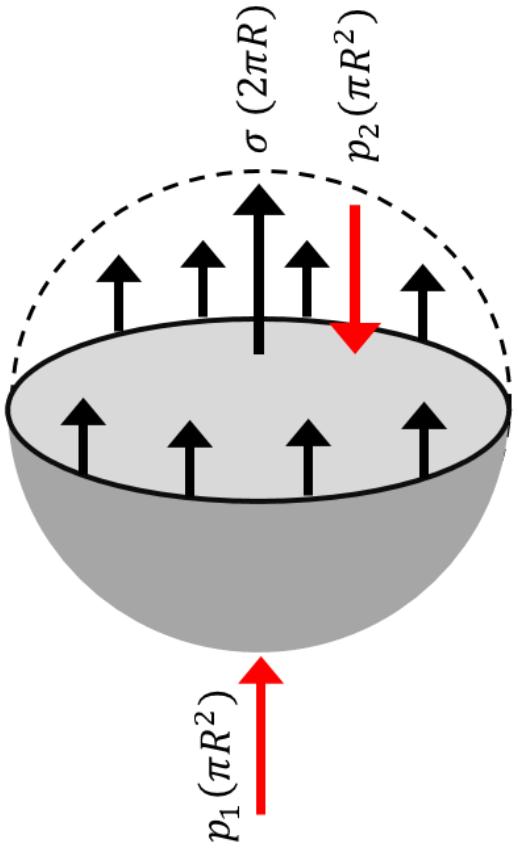
Let 2 .4×10^−4 *J* of work is done to increase the area of a film of soap bubble from 50 cm² to 100 cm². Calculate the value of surface tension of soap solution.

$$T = 0.024 \ N/m$$

Surface Tension

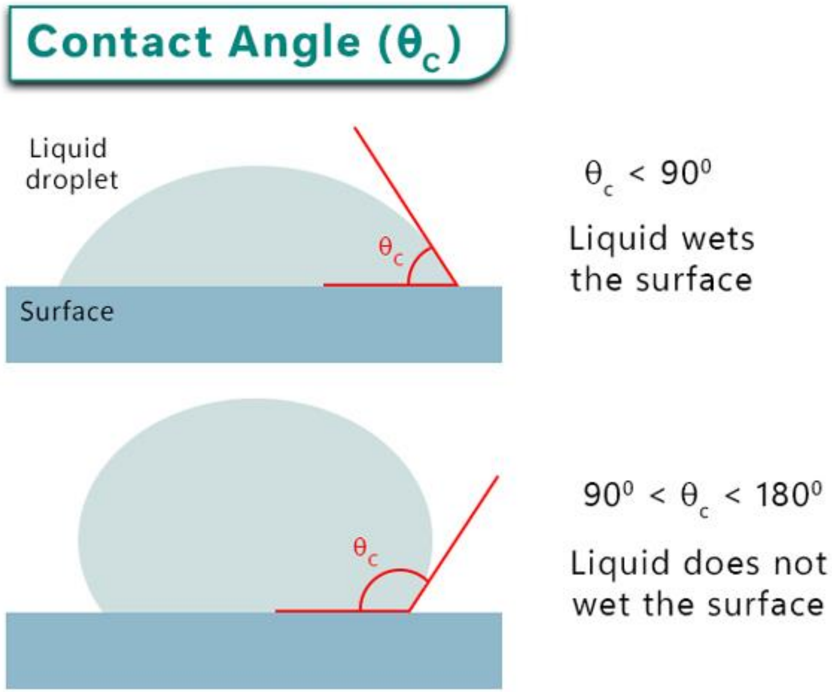
Excess Pressure
Concave and convex surface

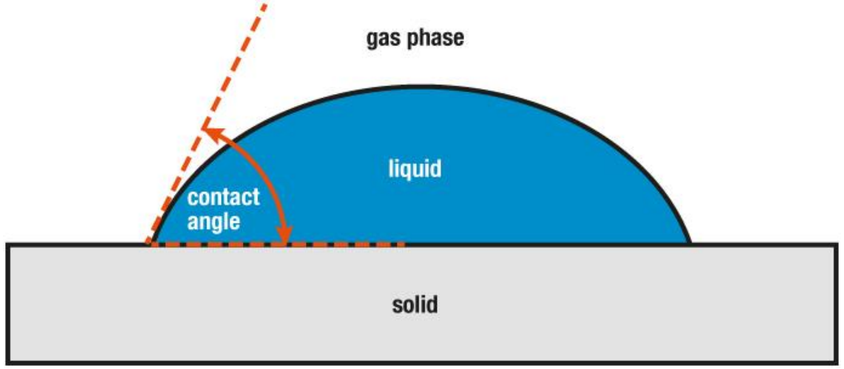
$$\Delta P = \frac{2T}{R}$$



Contact angle

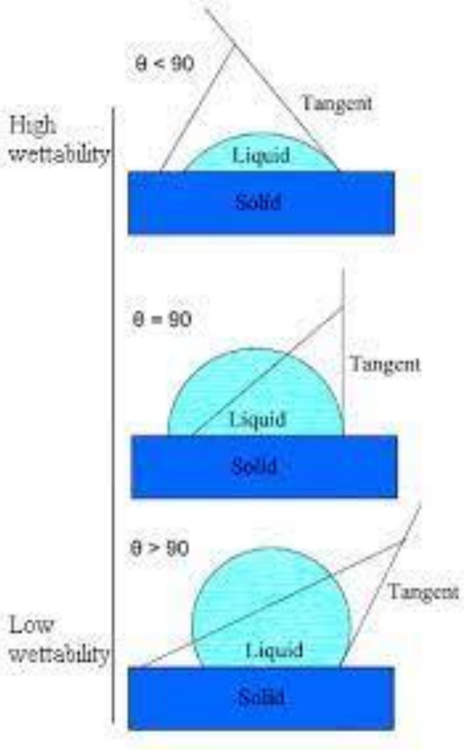
It is defined as the angle subtended between the tangents drawn at the liquid surface and the solid surface inside the liquid at the point of contact



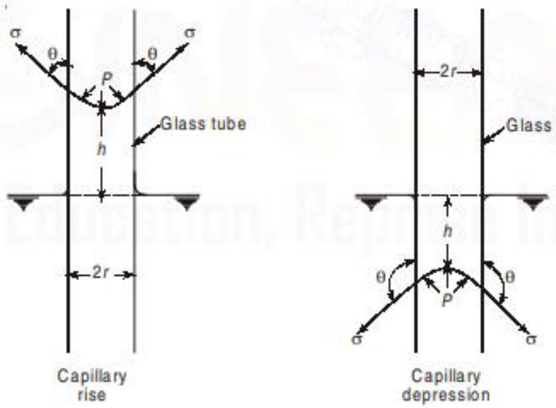


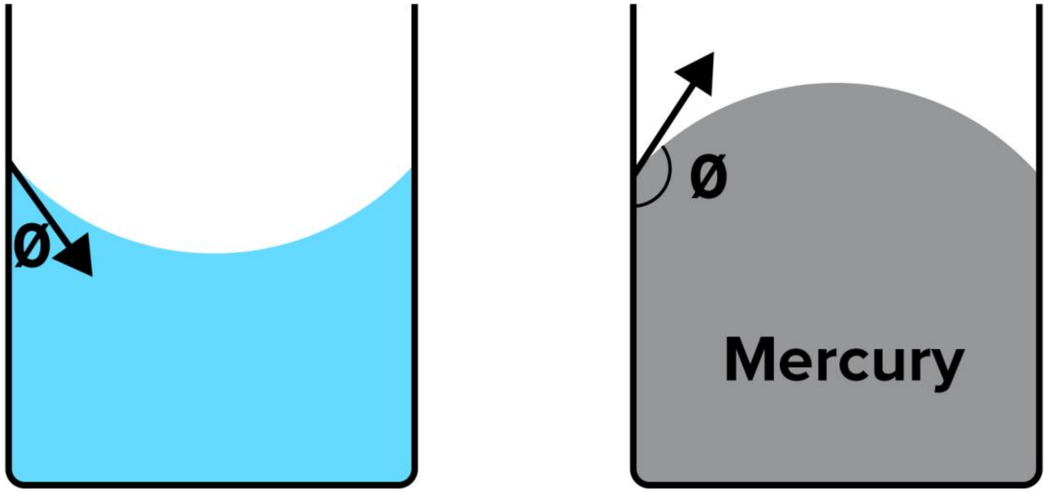
Contact angle

Wetting Behavior	Angle of Contact	Characteristics
Wetting	0°	The liquid spreads over the solid surface, forming a relatively flat contact area. It indicates good adhesion and surface wetting. Adhesive >> Cohesive
Non-Wetting	Greater than 90°	The liquid forms a droplet on the solid surface, not spreading effectively. It shows poor adhesion and surface repelling. Cohesive > Adhesive
Partial Wetting	Between 0° and 90°	The liquid wets the solid surface to some extent but not completely. It exhibits a combination of wetting and non-wetting characteristics. Adhesive > Cohesive



Contact angle

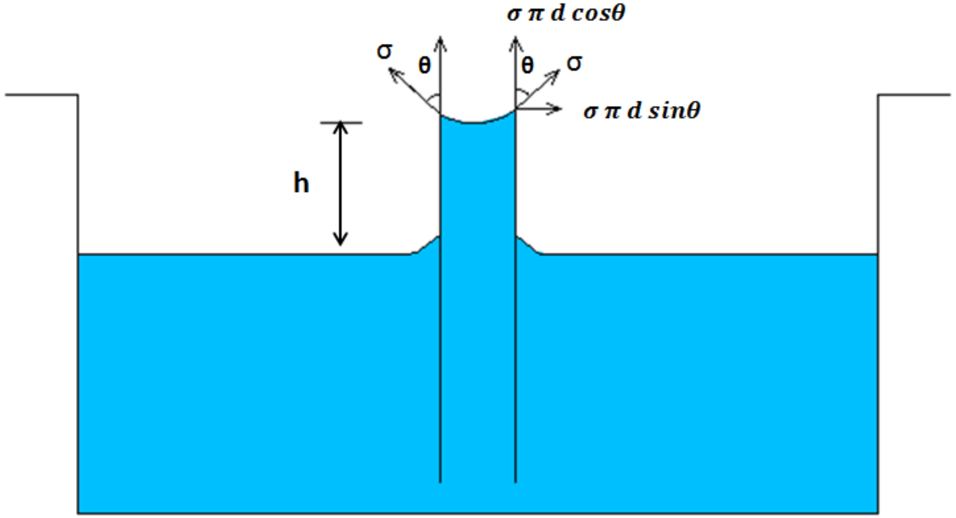


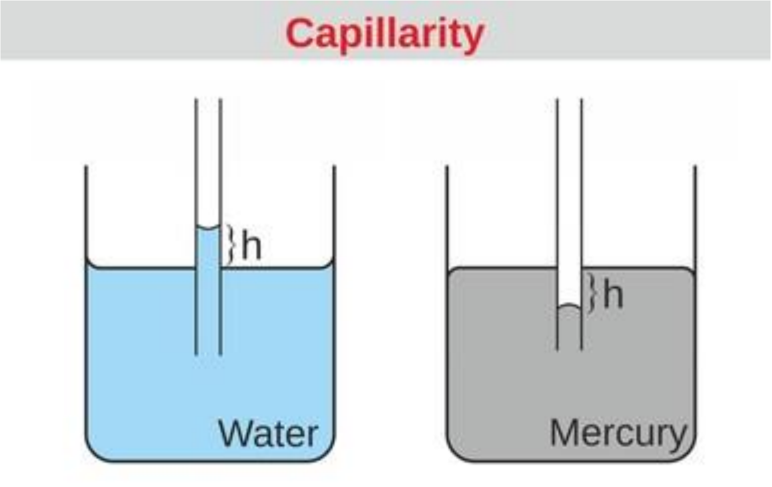


(A) Acute angle

(B) Obtuse angle

Capillarity





$$h = \frac{2T\ cos\theta}{\rho g r}$$

$$h = \frac{2T}{\rho g R}$$

r is radius of capillary tube

Capillarity

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$$h = \frac{2T\ cos\theta}{\rho g r}$$

- If contact angle $\theta < 90^0$, $cos\theta$ will be positive that implies h>0. So it means these liquids rise in the capillary tube and wets the surface. It will have concave meniscus.
- If contact angle $\theta < 90^0$, $cos\theta$ will be negative that implies h<0. It means these liquids fall in the capillary tube so it does not wet the surface. It will have concave meniscus.
- If contact angle $\theta = 90^0$, $cos\theta$ will be zero that implies h=0. It means these liquids do not rise or fall in the capillary tube. It will have a flat meniscus.

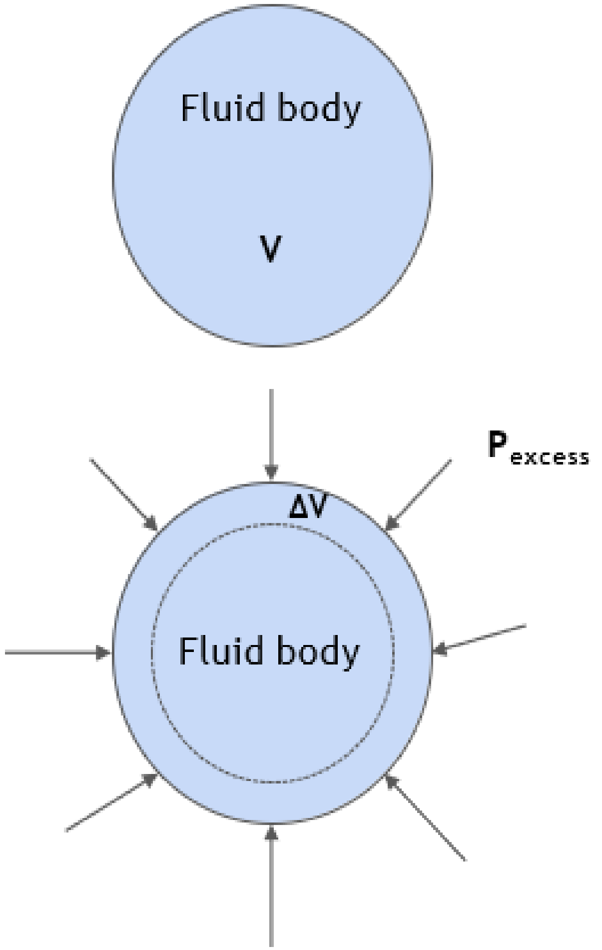
Bulk Modulus

Water - 2.06 × 109 N/m2 [or 2.1 × 108 kg (f)/m2] and
Air - 1.03 × 105 N/m2 [or 1.05 × 104 kg (f)/m2]
the bulk modulus of water roughly doubles as the pressure is raised from 1 atmosphere to 3500 atmospheres.

$$B = \frac{\text{Volume Stress}}{\text{Volume Strain}}$$

$$B = \frac{\Delta P}{|\Delta v/v|} = -\frac{P_{excess}}{\Delta v/v}$$

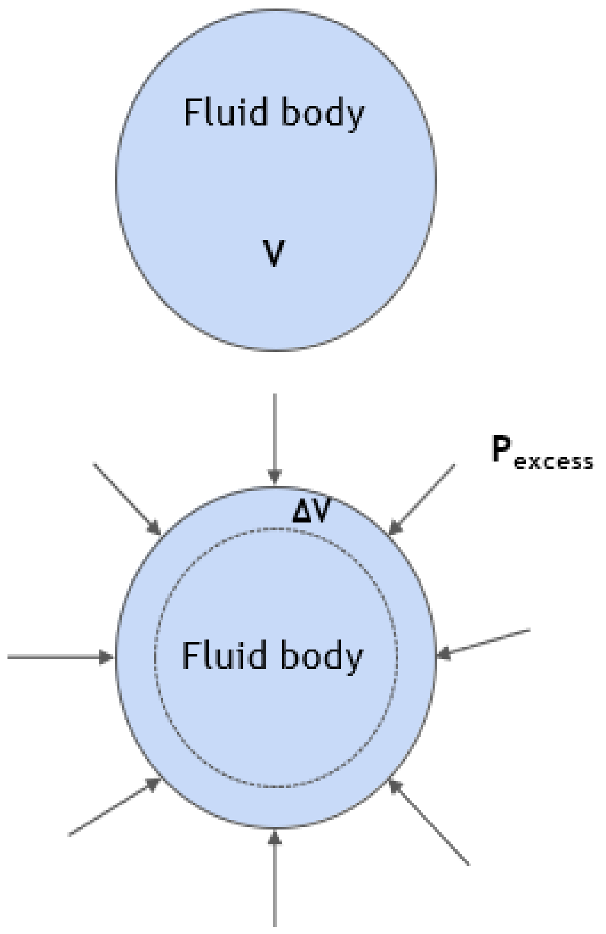
Modulus Δv is -ve for decrease in volume



Compressibility

$$C = \frac{1}{B} = \frac{Volume\ Strain}{Volume\ Stress}$$

Ideal fluid is incompressible
So, compressibility = 0, Bulk modulus = ∞



Vapour pressure

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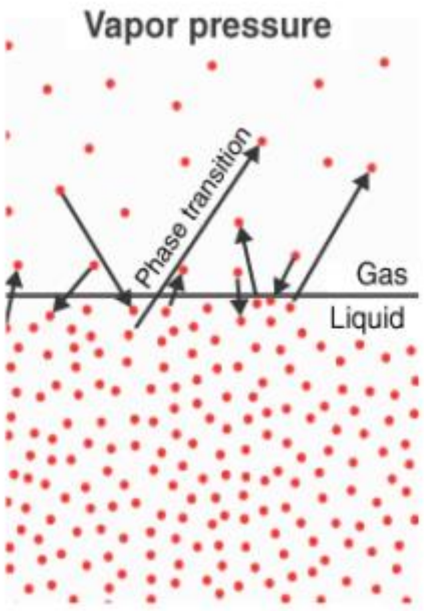
Vapour pressure can be defined as pressure formed by the vapor of the liquid over the surface of the liquid.



Vapour pressure

Vapour pressure can be defined as pressure formed by the vapor of the liquid over the surface of the liquid.

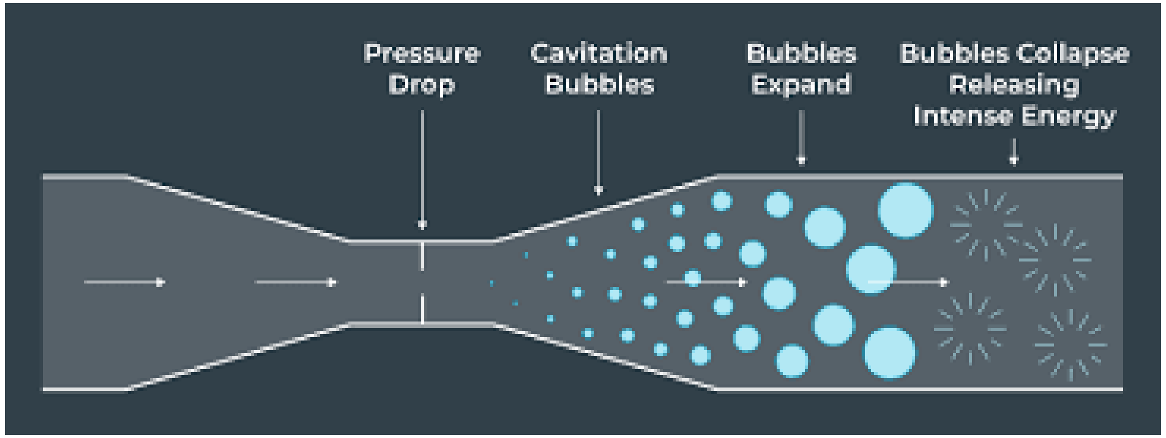
Liquid’s evaporation rate is identified by the equilibrium vapor pressure.

Vapour pressure increases with the temperature.

The boiling point of the liquid is the point when the pressure exerted by surrounding equals to the pressure exerted by vapor.

Cavitation

Cavitation, formation of vapour bubbles within a liquid at low-pressure regions that occur in places where the liquid has been accelerated to high velocities



Cavitation

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The static pressure of a liquid reduces to below the liquid's vapour pressure.

It leads to the formation of small vapor-filled cavities in the liquid.

When subjected to higher pressure, these cavities, called "bubbles" or "voids", collapse and can generate shock waves that may damage machinery.

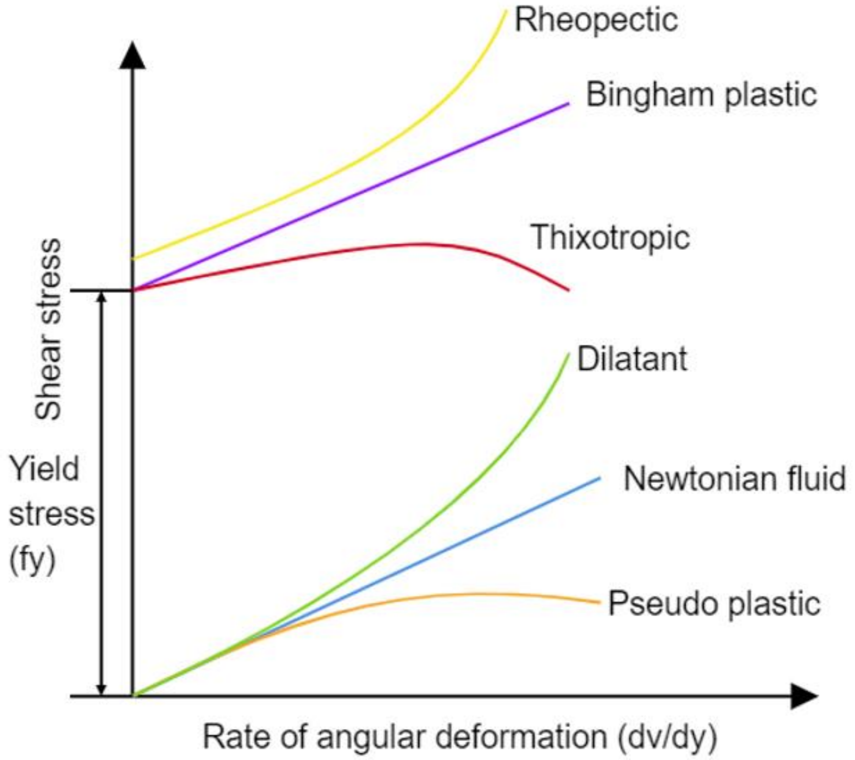
Types of fluid

Time dependent

- Rheopectic
- Thixotropic

Time independent

- Bingham plastic (ideal plastic)
- Dilatant
- Pseudo plastic
- Newtonian



Rheopectic and Dilatant fluids have a shear thickening behaviour

Types of fluid

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- Dilatant: The viscosity of these fluids increases when shear stress is applied. Quicksand, cornflour with water, and putty are examples of dilatant fluids.
- Pseudoplastic: The viscosity of these fluids decreases when shear stress is applied. These fluids are the opposite of dilatant fluids. Ketchup is an example of pseudoplastic.
- Rheopectic: The viscosity of these fluids increases when shear stress is applied along with time. They are similar to dilatant fluids, however, these fluids are time-dependent. Cream and gypsum paste are examples of rheopectic fluids.
- Thixotropic: The viscosity of these fluids decreases when shear stress is applied along with time. Cosmetics and paint are examples of thixotropic fluids.