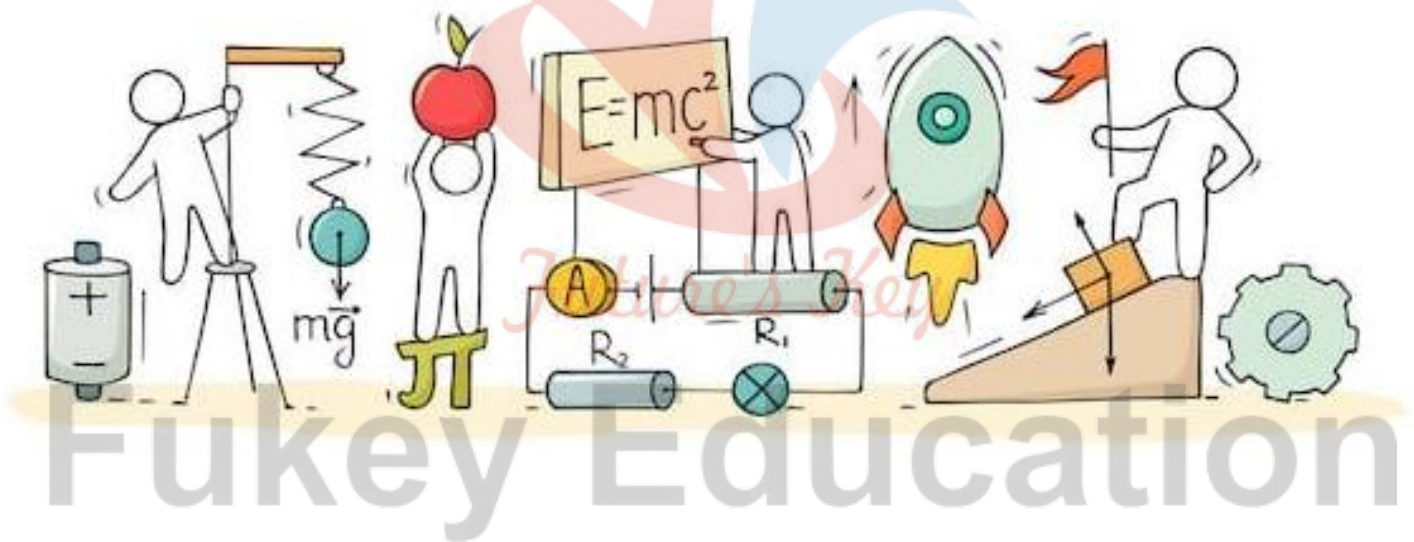# PHYSICS

Chapter 9: Mechanical Properties of Fluids

Mechanical Properties of Fluids

Fluids

Fluids can be defined as any substance which is capable of flowing.

They don't have any shape of their own.

For example: water which does not have its own shape but it takes the shape of the container in which it is poured.

But when we pour water in a tumbler it takes the shape of the tumbler

Both liquids and gases can be categorised as fluids as they are capable of flowing.

Volume of solids, liquids and gas depends on the stress or pressure acting on it.

In this chapter we will study if we apply force on the fluid how does it affects the internal properties of fluids.

Fluids offer very little resistance to shear stress.

We will also study some characteristic properties of fluids.

Pressure

Pressure is defined as force per unit area.

$$Pressure = \frac{Force}{Area}$$

For Example:

Consider a very sharp needle which has a small surface area and consider a pencil whose back is very blunt and has more surface area than the needle. If we poke needle in our palm it will hurt as needle gets pierced inside our skin. Whereas if we poke the blunt side of the pencil into our hand it won't pain so much.

This is because area of contact between the palm and the needle is very small therefore the pressure is large. Whereas the area of contact between the pencil and the palm is more therefore the pressure is less.

Two factors which determine the magnitude of the pressure are:-

Force – greater the force greater is the pressure and vice-versa.

Coverage area – greater the area less is the pressure and vice-versa.

Example:

Consider a stuntman lying on the bed of nails which means there are large numbers of nails on any rectangular slab. All the nails are identical and equal in height.

We can see that the man is not feeling any pain and he is lying comfortably on the bed. This is because there isa large number of nails and all the nails are closely spaced with each other.

All the small, pointed nails make large surface area therefore the weight of the body is compensated by the entire area of all the nails.

The surface area increases therefore pressure is reduced.

But even if one nail is greater than the others then it will hurt. Because then the surface area will be less as a result pressure will be more.
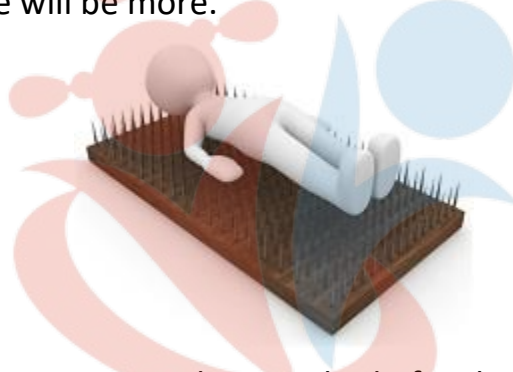
Stuntman lying on bed of nails.

Pressure in Fluids:

Normal force exerted by fluid per unit area.

This means force is acting perpendicular to the surface of contact.

Consider a body submerged in the water, force is exerted by the water perpendicular to the surface of the body.

If there is no force applied perpendicularly but in the parallel direction then there will be motion along the horizontal direction.

Since fluid is at rest and body is submerged in the fluid. Therefore there cannot be motion along the horizontal direction.

Therefore we always say the force is applied perpendicularly.

Pressure is a scalar quantity. Because the force here is not a vector quantity but it is the component of force normal to the area.
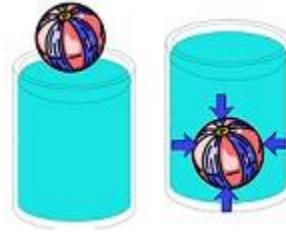
Dimensional Formula $[ML^{-1}T^{-2}]$

I Unit: N/m^2 or Pascal (Pa).

Atmosphere unit (atm) is defined as pressure exerted by the atmosphere at sea level. It is a

common unit of pressure.

1atm = 1.013×10^5 Pa

Pascal's Law

Pascal's law states that if the pressure is applied to uniform fluids that are confined, the fluids will then transmit the same pressure in all directions at the same rate.

Pascal's law holds good only for uniform fluids.

For example:

Consider a vessel filled with water which is uniform throughout as there is only one type of fluid which is water.

Consider a vessel which has oil and water then it is not uniform. As it have two different fluids.

Mixture of Oil & Water

Fluid should be confined meaning fluid is present within region in space. It is not allowed to spread.

For example, 1:

A balloon filled with water and when we press it hard against the wall.

We will see the shape of the balloon changes. This is because if we apply force on balloon, pressure is exerted on the water.

Water is uniform fluid, and it is confined with in this balloon and is not allowed to spread.

On applying pressure, it is transmitted in all other directions.

Variation of pressure with depth

Consider a cylindrical object inside a fluid; consider 2 different positions for this object.

Fluid is at rest therefore the force along the horizontal direction is 0.

Forces along the vertical direction:

Consider two positions 1 and 2.

Force at position 1 is perpendicular to cross sectional area A, $F_1 = P_1$

Similarly, $F_2 = P_2$

Total force $F_{net} = -F_1 + F_2$ as F_1 is along negative y axis therefore it is –ive. And F_2 is along +ive y -axis.

$F_{net} = (P_2 - P_1)A$

This net force will be balanced by the weight of the cylinder(m).

Therefore, under equilibrium condition

F_{net} = mg = weight of the cylinder = weight of the fluid displaced.

= ρ Vg where ρ = density = volume of the fluid

= ρhAg where V = hA (h = height and A = area)

Therefore $(P_2 - P_1) A = \rho$hAg

$P_2 - P_1 = \rho$hg, Therefore the difference in the pressure is dependent on height of the cylinder.

Consider the top of the cylinder exposed to air therefore $P_1 = P_a$ (where $P_a = P_1$ is equal to atmospheric pressure.)

Then $P_2 = P_a + \rho$hg

The pressure P, at depth below the surface of a liquid open to the atmosphere is greater than atmospheric pressure by an amount ρhg.

The pressure is independent of the cross sectional or base area or the shape of the container.
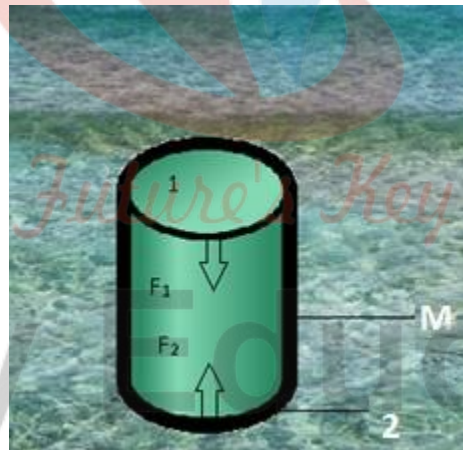
Cylinder is inside the fluid.

Hydrostatic Paradox

Hydrostatic Paradox means: - hydro = water, static = at rest

Paradox means that something taking place surprisingly.

Consider 3 vessels of very different shapes (like thin rectangular shape, triangular and some filter shape) and we have a source from which water enters into these 3 vessels.

Water enters through the horizontal base which is the base of these 3 vessels we observe that the level of water in all the 3 vessels is same irrespective of their different shapes.

This is because pressure at some point at the base of these 3 vessels is same.

The water will rise in all these 3 vessels till the pressure at the top is same as the pressure at the bottom.

As pressure is dependent only on height therefore in all the 3 vessels the height reached by the water is same irrespective of difference in their shapes.

This experiment is known as Hydrostatic Paradox.
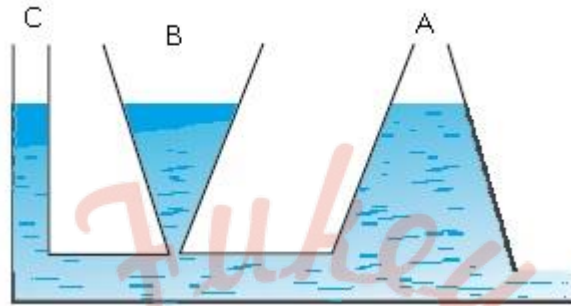
The three vessels A, B and C contain different amounts of liquids, all up to the same height
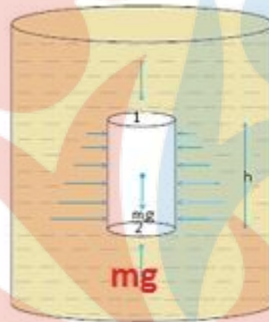
Fluid is under gravity. The effect of gravity is illustrated through pressure on a vertical cylindrical column

Atmospheric Pressure

Pressure exerted by the weight of the atmosphere.

Atmosphere is a mixture of different gases. All these gas molecules together constitute some weight. By virtue of this weight there is some pressure exerted by the atmosphere on all the objects.

This pressure is known as atmospheric pressure.

Value of atmospheric pressure at sea level is $1.01*10^5$

$1atm = 1.01*10^5 Pa$

Gauge Pressure

Pressure difference between the system and the atmosphere.

From relation $P = Pa + \rho gh$ where P = pressure at any point, Pa = atmospheric pressure.

We can say that Pressure at any point is always greater than the atmospheric pressure by the amount ρgh.

P – Pa = ρgh where

P = pressure of the system, Pa = atmospheric pressure,

(P - Pa) = pressure difference between the system and atmosphere.

hρg = Gauge pressure.

How to measure Gauge pressure

Gauge pressure is measured by Open Tube Manometer.

Open Tube Manometer is a U-shaped tube which is partially filled with mercury (Hg).

One end is open and other end is connected to some device where pressure is to be determined. This means it is like a system.

The height to which the mercury column will rise depends on the atmospheric pressure. Similarly depending on the pressure of the system the height of mercury in another tube rises.

The pressure difference between these two heights is the difference between the atmospheric pressure and system.
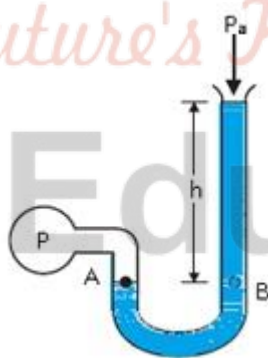
This difference in pressure is the gauge pressure.

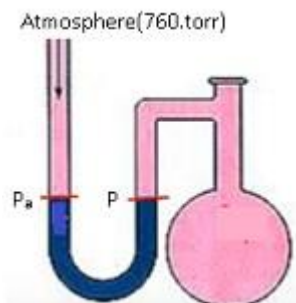Consider if the level of mercury column is same in both the U-tubes.

P_{atm} = P, therefore the difference between the atmospheric pressure and the pressure of the system is 0.

Gauge Pressure is 0.

P_{atm} = 760torr.

Open tube manometer

Closed end manometer

Absolute Pressure

Absolute pressure is defined as the pressure above the zero value of pressure.

It is the actual pressure which a substance has.

It is measured against the vacuum.

Absolute pressure is measured relative to absolute zero pressure.

It is sum of atmospheric pressure and gauge pressure.

$P = P_a + h\rho g$ where P = pressure at any point, P_a = atmospheric pressure and $h\rho g$ = gauge pressure.

Therefore $P = P_a +$ Gauge Pressure. Where P = absolute pressure.

It is measured with the help of barometer.

Pascal's law for transmission of fluid pressure

Pascal's law for transmission of fluid pressure states that the pressure exerted anywhere in a confined incompressible fluid is transmitted undiminished and equally in all directions throughout the fluid.

The above law means that if we consider a fluid which is restricted within a specific region in space and if the volume of the fluid doesn't change with the pressure, then the amount of pressure exerted will be same as the amount of pressure transmitted.

Consider a circular vessel which have 4 openings and along these 4 openings 4 pistons are attached.

When piston A is moved downwards pressure is exerted on the liquid in the downward direction, this pressure gets transmitted equally along all the directions. As a result, all the other 3 pistons move equal distance outwards.
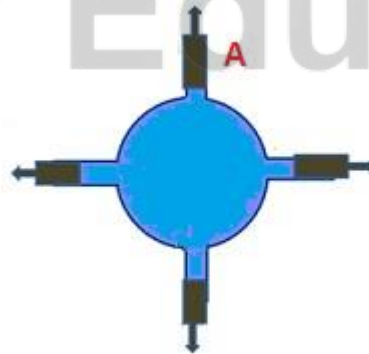
A circular vessel fitted with movable piston at all the four ends and when piston A is moved downward a pressure is exerted downward. Equal amount of pressure is exerted along all the directions as a result they will move equal distances outward.

Applications: Pascal's law for transmission of fluid pressure

Hydraulic lift:

Hydraulic lift is a lift which makes use of a fluid.

For example: Hydraulic lifts that are used in car service stations to lift the cars.

Principle:

Inside a hydraulic lift there are 2 platforms, one has a smaller area and the other one has a larger area.

It is a tube-like structure which is filled with uniform fluid.

There are 2 pistons (P_1 and P_2) which are attached at both the ends of the tube.

Cross-sectional area of piston P_1 is A_1 and of piston P_2 is A_2.

If we apply force F_1 on P_1, pressure gets exerted and according to Pascal's law the pressure gets transmitted in all the directions and same pressure gets exerted on the other end. As a result the Piston P_2 moves upwards.

Advantage of using hydraulic lift is that by applying small force on the small area we are able to generate a larger force.

Mathematically: $F_2 = PA_2$
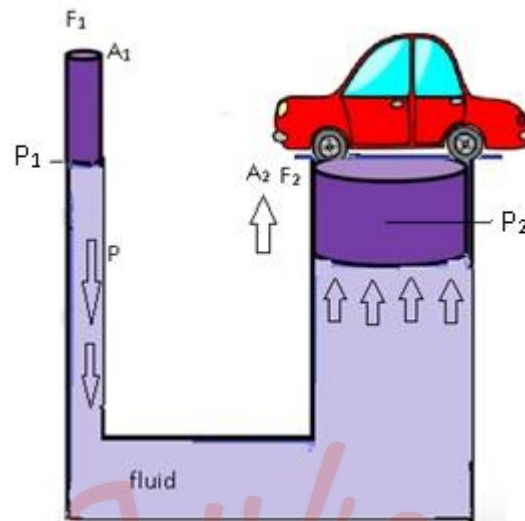
where F_2 = Resultant Force, A_2 = area of cross-section

$F_2 = \left(\frac{F_1}{A_1}\right) A_2$ where $P = \frac{F_1}{A_1}$ (Pressure P is due to force F_1 on the area A_1)

$F_2 = \left(\frac{A_2}{A_1}\right) F_1$. This shows that the applied force has increased by $\frac{A_2}{A_1}$

Because of Pascal's law the input gets magnified.

The above figure shows the internal structure of the hydraulic lift.

Hydraulic Brakes

Hydraulic brakes work on the principle of Pascal's law.

According to this law whenever pressure is applied on a fluid it travels uniformly in all the directions.

Therefore, when we apply force on a small piston, pressure gets created which is transmitted through the fluid to a larger piston. As a result of this larger force, uniform braking is applied on all four wheels.

As braking force is generated due to hydraulic pressure, they are known as hydraulic brakes.

Liquids are used instead of gas as liquids are incompressible.

Construction

The fluid in the hydraulic brake is known as brake fluid.

It consists of a master cylinder, four-wheel cylinders and pipes carrying brake fluid from master cylinder to wheel cylinders.

Master cylinder consists of a piston which is connected to pedal through connecting rod.

The wheel cylinders consist of two pistons between which fluid is filled.

Each wheel brake consists of a cylinder brake drum. This drum is mounted on the inner side of wheel. The drum revolves with the wheel.

Two brake shoes which are mounted inside the drum remain stationary.

Working

When we press the brake pedal, piston in the master cylinder forces the brake fluid through a linkage.

As a result, pressure increases and gets transmitted to all the pipes and to all the wheel cylinders according to Pascal's law.

Because of this pressure, both the pistons move out and transmit the braking force on all the wheels.

Advantages:

Equal braking effort to all the four wheels.

Less rate of wear due to absence of joints.

By just changing the size of one piston and cylinder, force can be increased or decreased.

Disadvantages:

Leakage of brake fluid spoils the brake shoes.

Even the slightest presence of air pockets can spoil the whole system.
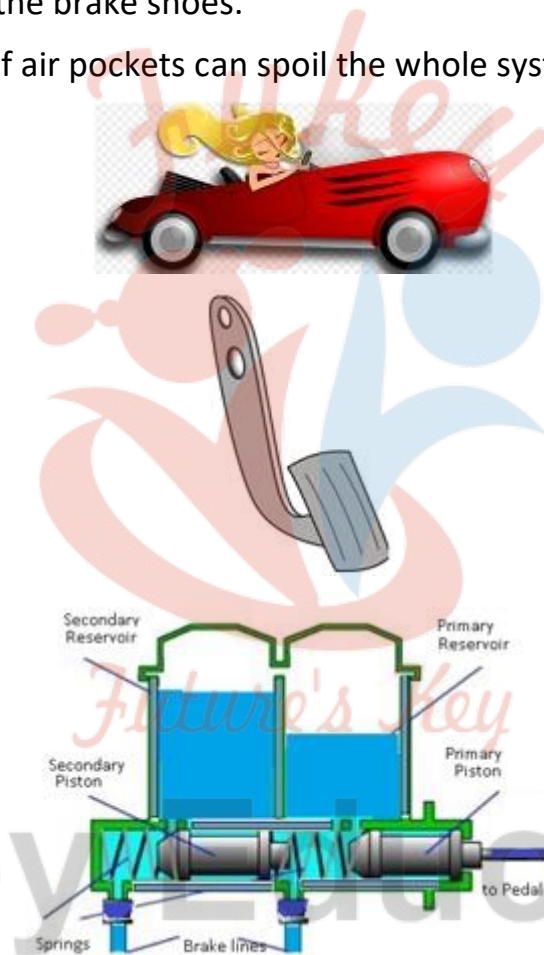
Inside of the cylinder

Types of Fluid flow: Steady Flow
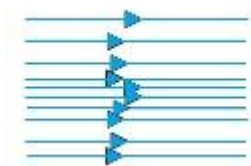
Some streamlines for fluid flow

The flow of a fluid is said to be steady, if at any point, the velocity of each passing fluid particle

remains constant within that interval of time.

Streamline is the path followed by the fluid particle.

It means that at any particular instant the velocities of all the particles at any point are same. But the velocity of all the particles won't be same across all the points in the space.

Steady flow is termed as 'Streamline flow' and 'Laminar flow'.

Consider a case when all the particles of fluid passing point A have the same velocity. This means that the first particle will have velocity V_1 and second will have velocity V_1 and so on. All the particles will have the same velocity V_1 at point A.

At point B, all particles will have velocity V_2.

Similarly at point C the velocity of all the particles is V_3.

We can see that the velocity is changing from point to point but at one particular point it is same.

No two streamlines can intersect.

If two streamlines intersect each other, the particles won't know which path to follow and what velocity to attain. That is why no two streamlines intersect.
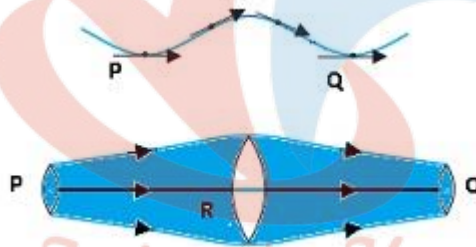
The meaning of streamlines:

(a) A typical trajectory of a fluid particle.

(b) A region of streamline flow.
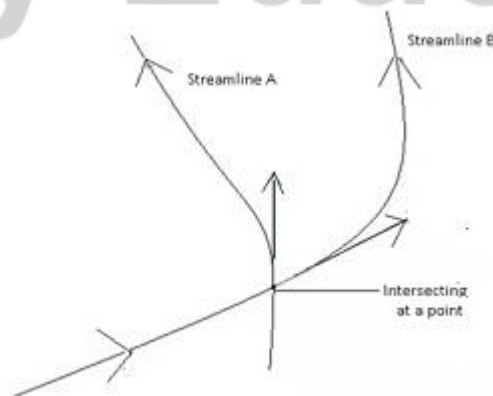
Equation of Continuity

According to the equation of continuity Av = constant. Where A = cross-sectional area and v = velocity with which the fluid flows.

It means that if any liquid is flowing in streamline flow in a pipe of non-uniform cross-section area, then rate of flow of liquid across any cross-section remains constant.

Consider a fluid flowing through a tube of varying thickness.

Let the cross-sectional area at one end (I) = A_1 and cross-sectional area of other end (II) = A_2.

The velocity and density of the fluid at one end (I) = v_1, ρ_1 respectively, velocity and density of fluid at other end (II) = v_2, ρ_2

Volume covered by the fluid in a small interval of time Δt, across left cross-sectional is Area (I) = $A_1 \times v_1 \times \Delta t$

Volume covered by the fluid in a small interval of time Δt across right cross-sectional Area (II) = $A_2 \times v_2 \times \Delta t$

Fluid inside is incompressible (volume of fluid does not change by applying pressure) that is density remains same $\rho_1 = \rho_2$. (Equation 1)

Along(I) mass = $\rho_1 A_1 v_1 \Delta t$ and along second point (II) mass = $\rho_2 A_2 v_2 \Delta t$

By using equation (1). We can conclude that $A_1 v_1 = A_2 v_2$. This is the equation of continuity.

From Equation of continuity, we can say that Av = constant.

This equation is also termed as "Conservation of mass of incompressible fluids".
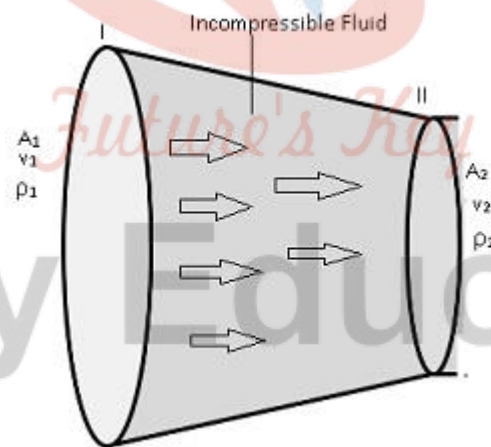
Conclusion:

Volume flux/Flow rate remains constant throughout the pipe. This means rate of flow of fluid of liquid is more if cross-sectional area is more, then the velocity will be less, and vice-versa.

But the Av will remain constant.

So, the volume which is covered by the fluid at any cross-sectional area is constant throughout the pipe even if pipe has different cross-sectional areas.

The fluid is accelerated while passing from the wider cross-sectional area towards the narrower

area. This means if area is more the velocity is less and vice-versa.

Turbulent Flow:

A fluid flow is said to be turbulent if the velocity of the particles vary at any point erratically.

This means fluid particles are moving here and there, they are not moving in organized manner. They all will have different velocities.

Eddies are generated by this flow. Eddies are same as ripples.

All the particles are moving here and there randomly.

Bernoulli's Principle

For a streamline fluid flow, the sum of the pressure (P), the kinetic energy per unit volume $\left(\frac{\rho v^2}{2}\right)$ and the potential energy per unit volume (ρgh) remain constant.

Mathematically: $P + \frac{\rho v^2}{2} + \rho g h$ = constant

where P = pressure,

$$\frac{E.}{Volume} = \frac{\frac{1}{2}mv^2}{V} = \frac{\frac{1}{2}v^2}{\left(\frac{m}{V}\right)} = \frac{1}{2}\rho v^2$$

$$\frac{E.}{Volume} = \frac{mgh}{V} = \left(\frac{m}{V}\right)gh = \rho g h$$

Derive: Bernoulli's equation

Assumptions:

Fluid flow through a pipe of varying width.

Pipe is located at changing heights.

Fluid is incompressible.

Flow is laminar.

No energy is lost due to friction: applicable only to non-viscous fluids.

Mathematically:

Consider the fluid initially lying between B and D. In an infinitesimal time interval Δt, this fluid would have moved.

Suppose v_1 = speed at B and v_2 = speed at D, initial distance moved by fluid from to C = $v_1\Delta t$.

In the same interval Δt fluid distance moved by D to E = $v_2\Delta t$.

P_1 = Pressure at A_1, P_2 = Pressure at A_2.

Work done on the fluid at left end (BC) $W_1 = P_1 A_1 (v_1\Delta t)$.

Work done by the fluid at the other end (DE) $W_2 = P_2 A_2 (v_2\Delta t)$

Net work done on the fluid is $W_1 - W_2 = (P_1 A_1 v_1\Delta t - P_2 A_2 v_2\Delta t)$

By the Equation of continuity Av = constant.

- $P_1 A_1 v_1\Delta t - P_2 A_2 v_2\Delta t$ where $A_1 v_1\Delta t = P_1\Delta V$ and $A_2 v_2\Delta t = P_2\Delta V$.

Therefore Work done = $(P_1 - P_2)\Delta V$ equation (a)

- Part of this work goes in changing Kinetic energy, $\Delta K = (\tfrac{1}{2})m (v_2^2 - v_1^2)$ and part in gravitational potential energy, $\Delta U = mg (h_2 - h_1)$.

The total change in energy $\Delta E = \Delta K + \Delta U = (\tfrac{1}{2}) m (v_2^2 - v_1^2) + mg (h_2 - h_1)$. (i)

Density of the fluid $\rho = m/V$ or $m = \rho V$

Therefore in small interval of time Δt, small change in mass Δm

- $\Delta m = \rho\Delta V$ (ii)

Putting the value from equation (ii) to (i)

$\Delta E = 1/2\ \rho\Delta V (v_2^2 - v_1^2) + \rho g\Delta V (h_2 - h_1)$ equation (b)

By using work-energy theorem: $W = \Delta E$

From (a) and (b)

$(P_1 - P_2)\Delta V = (1/2)\ \rho\Delta V (v_2^2 - v_1^2) + \rho g\Delta V (h_2 - h_1)$

$P_1 - P_2 = 1/2\rho v_2^2 - 1/2\rho v_1^2 + \rho g h_2 - \rho g h_1$ (By cancelling ΔV from both the sides).

After rearranging we get, **$P_1 + (1/2)\ \rho\ v_1^2 + \rho g\ h_1 = (1/2)\ \rho\ v_2^2 + \rho g\ h_2$**

$P + (1/2)\ \rho v^2 + \rho g\ h$ = constant.

This is the Bernoulli's equation.
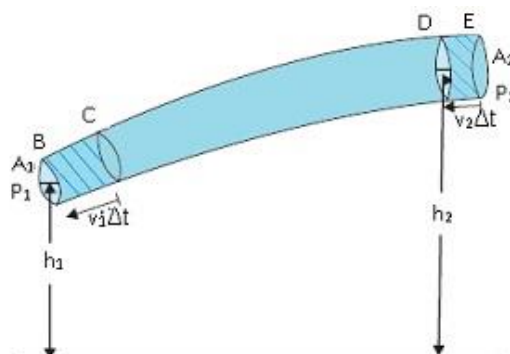
The flow of an ideal fluid in a pipe of varying cross section. The fluid in a section of length $v_1\Delta t$ moves to the section of length $v_2\Delta t$ in time Δt.

Bernoulli's equation: Special Cases

When a fluid is at rest. This means $v_1=v_2=0$.

From Bernoulli's equation $P_1 + (1/2) \rho v_1^2 + \rho g\, h_1 = (1/2) \rho v_2^2 + \rho g\, h_2$
By putting $v_1=v_2=0$ in the above equation changes to

$P_1-P_2= \rho g(h_2-h_1)$. This equation is same as when the fluids are at rest.

When the pipe is horizontal. $h_1=h_2$. This means there is no Potential energy by the virtue of height.

Therefore from Bernoulli's equation $(P_1 + (1/2) \rho v_1^2 + \rho g\, h_1 = (1/2) \rho v_2^2 + \rho g\, h_2)$
By simplifying, $P+(1/2) \rho v^2 = $ constant.

Torricelli's law

Torricelli law states that the speed of flow of fluid from an orifice is equal to the speed that it would attain if falling freely for a distance equal to the height of the free surface of the liquid above the orifice.

Consider any vessel which has an orifice (slit) filled with some fluid.

The fluid will start flowing through the slit and according to Torricelli law the speed with which the fluid will flow is equal to the speed with which a freely falling body attains such that the height from which the body falls is equal to the height of the slit from the free surface of the fluid.

Let the distance between the free surface and the slit = h

Velocity with which the fluid flows is equal to the velocity with which a freely falling body attains if it is falling from a height h.

Derivation of the Law:

- Let A_1= area of the slit (it is very small), v_1= Velocity with which fluid is flowing out.
  - A_2=Area of the free surface of the fluid, v_2=velocity of the fluid at the free surface.
- From Equation of Continuity, Av=constant. Therefore $A_1v_1 = A_2v_2$.
  - From the figure, $A_2>>>A_1$, This implies $v_2<<v_1$ (This means fluid is at rest on the free surface), Therefore $v_2\sim 0$.
- Using Bernoulli's equation,
  - $P+ (1/2) \rho v^2+\rho gh = $ constant.

- Applying Bernoulli's equation at the slit:
  - $P_a + (1/2) \rho v_1^2 + \rho g y_1$ (Equation 1) where P_a=atmospheric pressure,y_1=height of the slit from the base.
- Applying Bernoulli's equation at the surface:
- $P + \rho g y_2$(Equation 2) where as $v_2=0$ therefore $(1/2) \rho v_1^2=0$, y_2=height of the free surface from the base.
- By equating(1) and (2),
- $P_a + (1/2) \rho v_1^2 + \rho g y_1 = P + \rho g y_2$
- $(1/2) \rho v_1^2 = (P-P_a) + \rho g(y_2-y_1)$
- $=(P-P_a) \rho g h$ (where $h=(y_2-y_1)$)
- $v_1^2 = 2/\rho [(P-P_a) + \rho g h]$
- Therefore **$v1=\sqrt{2/\rho} [(P-P_a) + \rho g h]$**.This is the velocity by which the fluid will come out of the small slit.
- **v_1 is known as Speed of Efflux. This means the speed of the fluid outflow.**
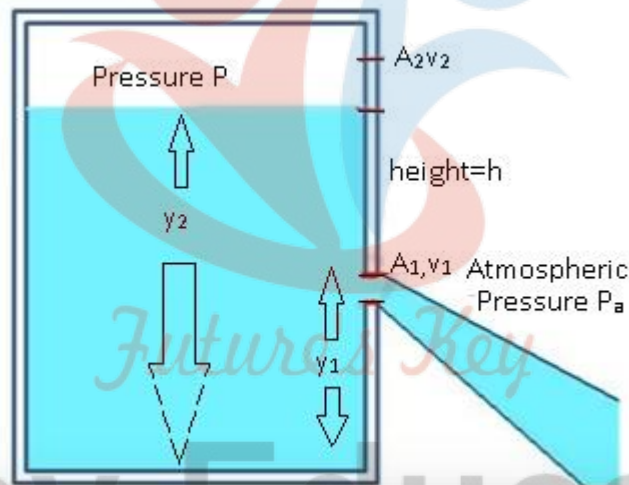
Torricelli's law. The speed of efflux, v1,from the side of the container is given bythe application of Bernoulli's equation.

Case1: The vessel is not closed it is open to atmosphere that means P = Pa.

Therefore $v_1 = \sqrt{2gh}$.This is the speed of a freely falling body.

This is accordance to Torricelli's law which states that the speed by which the fluid is flowing out of a small slit of a container is same as the velocity of a freely falling body.

Case2: Tank is not open to atmosphere but P>>Pa.

Therefore 2gh is ignored as it is very very large, hence $v_1 = \sqrt{2P/\rho}$.

The velocity with which the fluid will come out of the container is determined by the Pressure at the free surface of the fluid alone.

Venturimeter

Venturimeter is a device to measure the flow of incompressible liquid.

It consists of a tube with a broad diameter having a larger cross-sectional area but there is a small constriction in the middle.

It is attached to U-tube manometer. One end of the manometer is connected to the constriction and the other end is connected to the broader end of the Venturimeter.

The U-tube is filled with fluid whose density is ρ.

A_1 = cross-sectional area at the broader end, v_1 = velocity of the fluid.

A_2 =cross-sectional area at constriction, v_2 = velocity of the fluid.

By the equation of continuity, wherever the area is more velocity is less and vice-versa. As A_1 is more this implies v_1 is less and vice-versa.

Pressure is inversely $\propto$ to Therefore at A_1 pressureP_1 is less as compared to pressure P_2 at A_2.
   o This implies $P_1 < P_2$ as $v_1 > v_2$.

As there is difference in the pressure the fluid moves,this movement of the fluid is marked by the level of the fluid increase at one end of the U-tube.
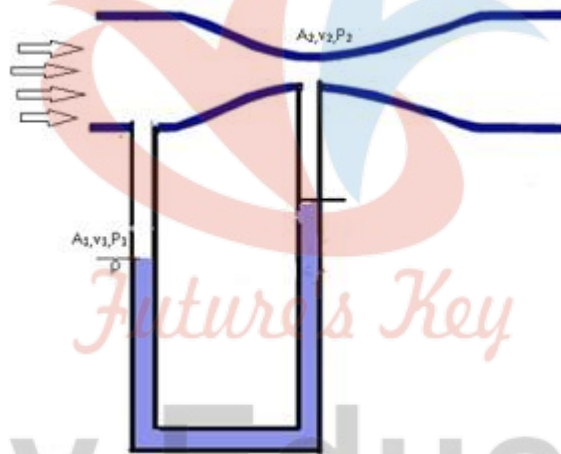
A schematic diagram of Venturimeter

Venturimeter: determining the fluid speed

- By Equation of Continuity: $-A_1 v_1 = A_2 v_2$.
- This implies $v_2 = (A_1/A_2) v_1$ (Equation(1))
- By Bernoulli's equation:- $P_1 + (1/2)\, \rho\, v_1^2 + \rho g\, h = (1/2)\, \rho\, v_2^2 + \rho g\, h$
   o As height is same we can ignore the term ρg
   o This implies $P_1 - P_2 = (1/2)\, \rho (v_2^2 - v_1^2)$
   o $= 1/2 \rho (A_1^2/A_2^2 v_1^2 - v_1^2)$(Using equation(1)
   o $= 1/2 \rho v_1^2 (A_1^2/A_2^2 - 1)$
   o $= 1/2 \rho v_1^2 (A_1^2/A_2^2 - 1)$

- As there is pressure difference the level of the fluid in the U-tube changes.
- $(P_1 - P_2) = h\rho_m g$ where ρ_m (density of the fluid inside the manometer).
- $\frac{1}{2}\rho v_1^2 (A_1^2/A_2^2 - 1) = h\rho_m g$
- $v_1 = 2h\rho_m g/\rho[A_1^2/A_2^2 - 1]^{-1/2}$

Practical Application of Venturimeter:

Spray Gun or perfume bottle- They are based on the principle of Venturimeter.

- Consider a bottle filled with fluid and having a pipe which goes straight till constriction. There is a narrow end of pipe which has a greater cross sectional area.
- The cross sectional area of constriction which is at middle is less.
- There is pressure difference when we spray as a result some air goes in, velocity of the air changes depending on the cross sectional area.
- Also because of difference in cross sectional area there is pressure difference, the level of the fluid rises, and it comes out.
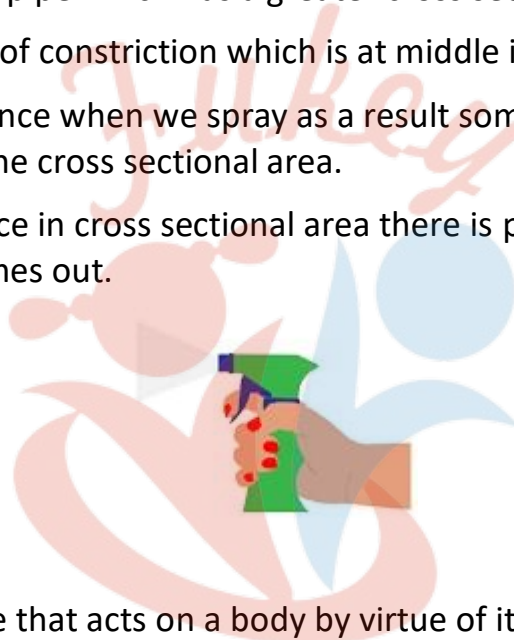
Dynamic Lift

Dynamic lift is the normal force that acts on a body by virtue of its motion through a fluid.

Consider an object which is moving through the fluid, and due to the motion of the object through the fluid there is a normal force which acts on the body.

This force is known as dynamic lift.

Dynamic lift is most popularly observed in aeroplanes.

Whenever an aeroplane is flying in the air, due to its motion through the fluid here fluid is air in the atmosphere. Due to its motion through this fluid, there is a normal force which acts on the body in the vertically upward direction.

This force is known as Dynamic lift.

Examples:

Airplane wings

Spinning ball in air

Dynamic lift on airplane wings:

Consider an aeroplane whose body is streamline. Below the wings of the aeroplane there is air which exerts an upward force on the wings. As a result aeroplane experiences dynamic lift.

Magnus Effect

Dynamic lift by virtue of spinning is known as Magnus effect.

Magnus effect is a special name given to dynamic lift by virtue of spinning.

Example: Spinning of a ball.

Case1: When the ball is not spinning.

The ball moves in the air it does not spin, the velocity of the ball above and below the ball is same.

As a result, there is no pressure difference. (ΔP= 0).

Therefore, there is no dynamic lift.

Case2: When the ball is moving in the air as well as spinning.

When the ball spins it drags the air above it therefore the velocity above the ball is more as compared to the velocity below the ball.

As a result there is a pressure difference; the pressure is more below the ball.

Because of pressure difference there is an upward force which is the dynamic lift.

Viscosity

Viscosity is the property of a fluid that resists the force tending to cause the fluid to flow.

It is analogous to friction in solids.

Example:

Consider 2 glasses one filled with water and the other filled with honey.

Water will flow down the glass very rapidly whereas honey won't. This is because honey is more viscous than water.

Therefore in order to make honey flow we need to apply greater amount of force. Because honey has the property to resist the motion.

Viscosity comes into play when there is relative motion between the layers of the fluid. The different layers are not moving at the same pace.

Coefficient of Viscosity

Coefficient of viscosity is the measure of degree to which a fluid resists flow under an applied force.

This means how much resistance does a fluid have to its motion.

Ratio of shearing stress to the strain rate.

It is denoted by 'η'.

Mathematically

Δt=time, displacement = Δx

Therefore,

shearing stress = $\frac{\Delta x}{l}$ where l = length

Strain rate = $\frac{\Delta x}{l\Delta t}$

$$\eta = \frac{shearing\ stress}{strain\ rate}$$

$$\frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta x}{l\Delta t}\right)} = \frac{Fl}{vA}\ where\ \frac{\Delta x}{t} = v$$

Therefore $\eta = \frac{Fl}{vA}$

I. Unit: Poiseiulle $\frac{\frac{Pl}{Pa}}{Nsm^{-2}}$

Dimensional Formula: $[ML^{-1}T^{-1}]$
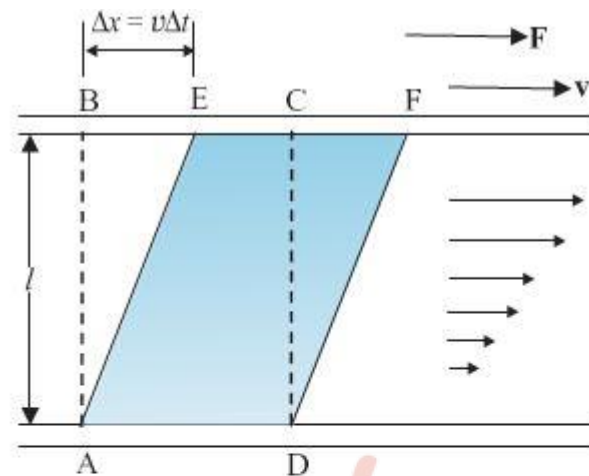
(a)
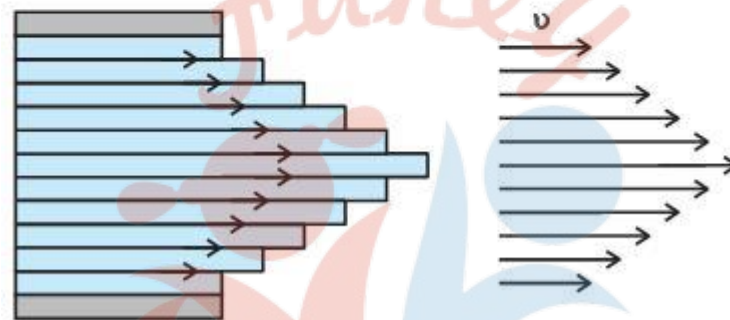
(b)

(a) A layer of liquid sandwiched between two parallel glass plates in which the lower plate is fixed and the upper one is moving to the right with velocity v

Velocity distribution for viscous flow in a pipe.
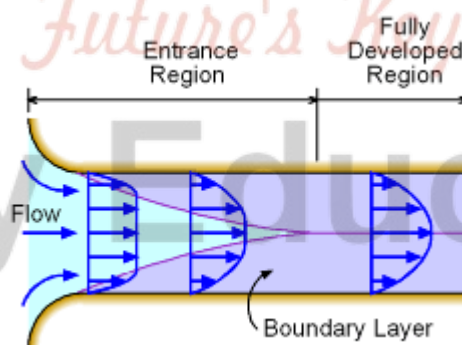
Stokes Law

The force that retards a sphere moving through a viscous fluid is directly ∝to the velocity and the radius of the sphere, and the viscosity of the fluid.

Mathematically: F =6πηrv where

Let retarding force F∝v where v =velocity of the sphere

F ∝ r where r=radius of the sphere

F∝η where η=coefficient of viscosity

6π=constant

Stokes law is applicable only to laminar flow of liquids. It is not applicable to turbulent law.

Example: Falling raindrops

Consider a single rain drop, when raindrop is falling it is passing through air.

The air has some viscosity; there will be some force which will try to stop the motion of the rain drop.

Initially the rain drop accelerates but after some time it falls with constant velocity.

As the velocity increases the retarding force also increases.

There will be viscous force F_v and bind force F_b acting in the upward direction. There will also be Gravitational force acting downwards.

After some time $F_g = F_r (F_v + F_b)$

Net Force is 0. If force is 0 as a result acceleration also becomes 0.
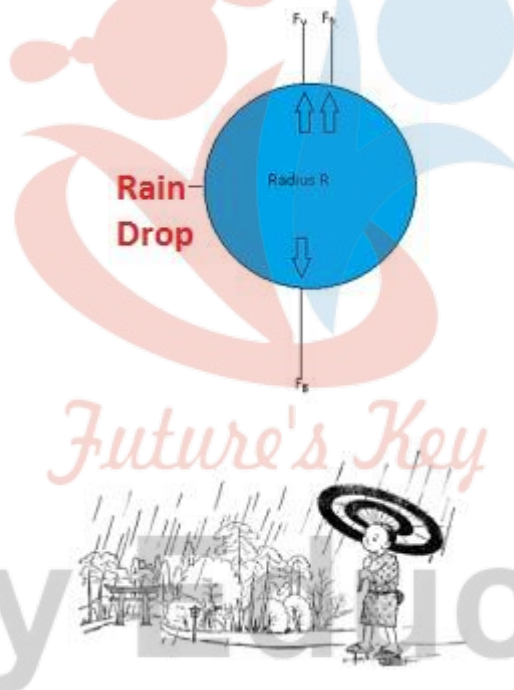
Terminal Velocity

Terminal velocity is the maximum velocity of a body moving through a viscous fluid.

It is attained when force of resistance of the medium is equal and opposite to the force of gravity.

As the velocity is increasing the retarding force will also increase and a stage will come when the force of gravity becomes equal to resistance force.

After that point velocity won't increase and this velocity is known as terminal velocity.

It is denoted by 'vt'. Where$_t$ = terminal.

Mathematically:

Terminal velocity is attained when Force of resistance = force due to gravitational attraction

$6\pi\eta rv = mg$

$6\pi\eta rv$ = densityxVg (Because density=m/V), density=$\rho - \sigma$ where ρ and σ are the densities of the sphere and the viscous medium resp.

$6\pi\eta rv = (\rho - \sigma) \times 4/3\pi r^3 g$ where Volume of the sphere(V) =$4/3\pi r^3$

By simplifying

$= (\rho - \sigma)g \times 4/3r^2 \times 1/(6\eta)$

$v_t = 2r^2(\rho - \sigma)g/9\eta$ .This is the terminal velocity. Where(v=v_t)

Gravitational Force= mg
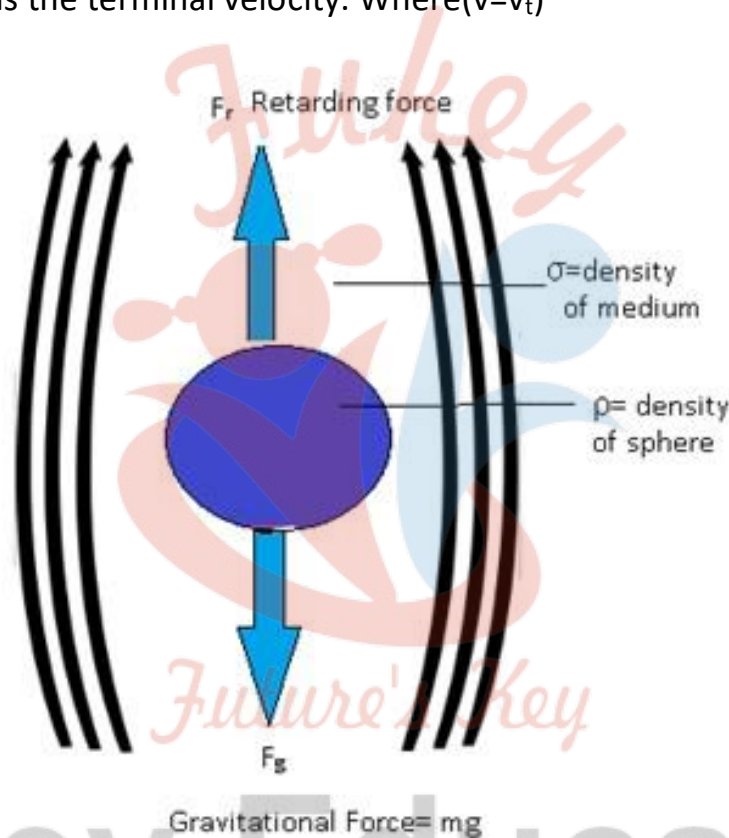
Reynolds Number

Reynolds number is a dimensionless number, whose value gives an idea whether the flow would be turbulent or laminar.

Types of flow are classified as 2 types: laminar flow and turbulent flow.

Reynolds number helps us to determine whether the flow is laminar or turbulent.

It is denoted by Re. where 'e' shows Reynolds.

Expression: Re=$\rho vd/\eta$;

where ρ = density of the fluid,

v=velocity of the fluid,

d=diameter of the pipe through which the fluid flows

η=viscosity of the fluid.

Liquid Surfaces

Certain properties of free surfaces:

Whenever liquids are poured in any container they take the shape of that container in which they are poured and they acquire a free surface.

Consider a case if we pour water inside the glass it takes the shape of the glass with a free surface at the top.

Top surface of the glass is a free surface. Water is not in contact with anything else, it is in contact with the air only.

This is known as free surfaces.

Liquids have free surfaces. As liquids don't have fixed shape they have only fixed volume.

Free surfaces have additional energy as compared to inner surfaces of the liquid.

Surface Energy

Surface energy is the excess energy exhibited by the liquid molecules on the surface compared to those inside the liquid.

This means liquid molecules at the surface have greater energy as compared to molecules inside it.

Suppose there is a tumbler and when we pour water in the tumbler,it takes the shape of the tumbler.

It acquires free surface.

Case 1: When molecules are inside the liquid:

Suppose there is a molecule inside the water, there will be several other molecules that will attract that molecule in all the directions.

As a result this attraction will bind all the molecules together.

This results in negative potential energy of the molecule as it binds the molecule.

To separate this molecule huge amount of energy is required to overcome potential energy.

Some external energy is required to move this molecule and it should be greater than the potential energy.

Therefore in order to separate this molecule a huge amount of energy is required.

Therefore a large amount of energy is required by the molecules which are inside the liquid.

Case2: When the molecules are at the surface:

When the molecule is at the surface, half of it will be inside and half of it is exposed to the atmosphere.

For the lower half of the molecule it will be attracted by the other molecules inside the liquid.

But the upper half is free. The negative potential energy is only because of lower half.

But the magnitude is half as compared to the potential energy of the molecule which is fully inside the liquid.

So the molecule has some excess energy, because of this additional energy which the molecules have at the surface different phenomenon happen like surface energy, surface tension.

Liquids always tend to have least surface are when left to itself.

As more surface area will require more energy as a result liquids tend to have least surface area.

Case 1: Molecule is fully inside the liquid

Case 2: Molecule is at the free surface
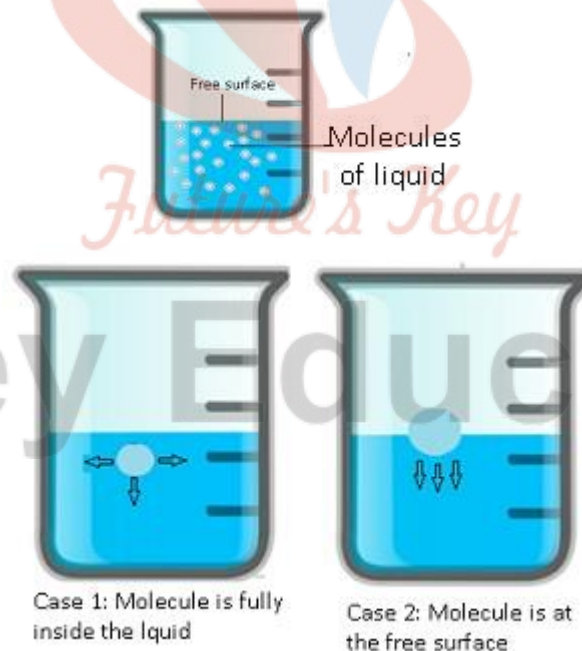
Surface energy for two fluids in contact

Whenever there are two fluids, in contact, surface energy depends on materials of the surfaces in contact.

Surface energy decreases if the molecules of the two fluids attract.

Surface energy increases if molecules of the two fluids repel.

Surface Tension

Surface tension is the property of the liquid surface which arises due to the fact that surface molecules have extra energy.

Surface energy is the extra energy which the molecules at the surface have.

Surface tension is the property of the liquid surface because the molecules have extra energy.

Surface energy is defined as surface energy per unit area of the liquid surface.

Denoted by 'S'.

Mathematically:

Consider a case in which liquid is enclosed in a movable bar.

Slide the bar slightly and it moves some distance ('d').

There will be increase in the area, (dl) where l=length of the bar.

Liquids have two surfaces one on the bar and other above the bar. Therefore area=2(dl)

Work done for this change = F x displacement.

Surface tension(S)=Surface Energy/area

Or Surface Energy=S x area

=Sx2dl

Therefore S x 2dl =F x d

S = F/2d

Surface tension is the surface energy per unit area of the liquid surface.

It can be also defined as Force per unit length on the liquid surface.

Important: -At any interface (it is a line which separates two different medium) the surface tension always acts in equal and opposite direction and it is always perpendicular to the line at the interface.
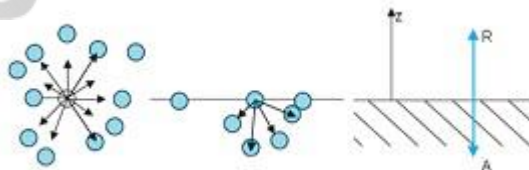
Schematic picture of molecules in a liquid, at the surface and balance of forces

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

Surface tension and Surface energy: practical applications

Consider a molecule which is present completely inside the liquid and if it is strongly attracted by the neighbouring molecules then the surface energy is less.

Consider a molecule which is present partially inside the liquid the force of attraction by the neighbouring molecules is lesser as a result surface energy is more.

Consider a molecule whose very little part is inside the water so very small force of attraction by the neighbouring molecules as a result more surface energy.

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

This means S_{sf}(solid fluid) < S_{fa}(fluid air) + S_{sa}(Solid air)
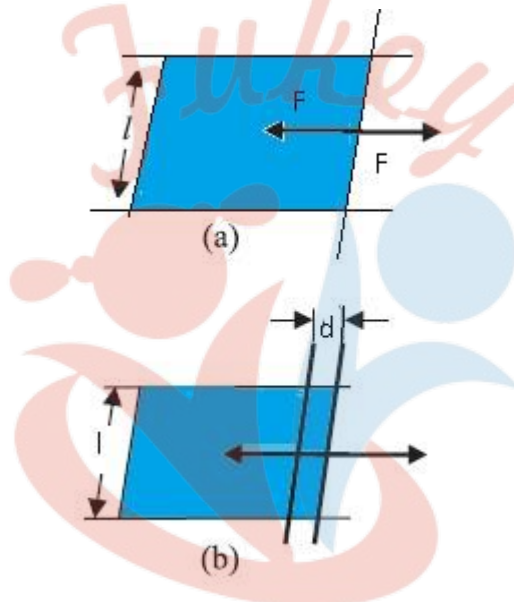
Stretching a film (a) A film in equilibrium;(b) The film stretched an extra distance.

How detergents work

Washing alone with the water can remove some of the dirt but it does not remove the grease stains. This is because water does not wet greasy dirt.

We need detergent which mixes water with dirt to remove it from the clothes.

Detergent molecules look like hairpin shape. When we add detergents to the water one end stick to water and the other end sticks to the dirt.

As a result dirt is getting attracted to the detergent molecules and they get detached from the clothes and they are suspended in the water.

Detergent molecules get attracted to water and when water is removed the dirt also gets removed from the clothes.
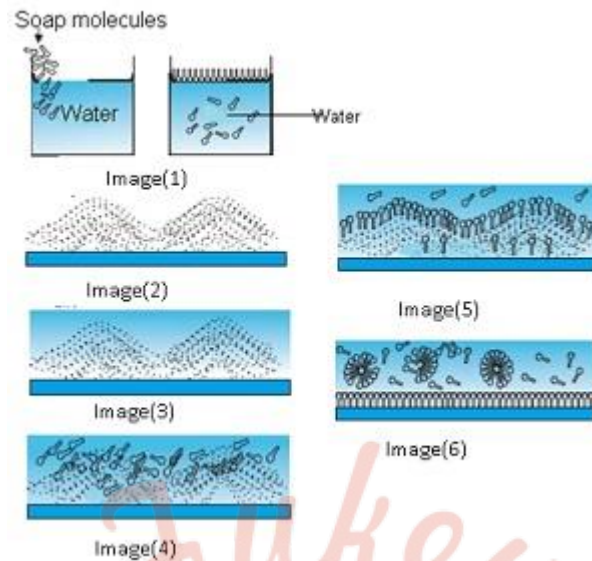
Detergent action in terms of what detergent molecules do.

In image (1) Soap molecules with head attracted to water

In image (2) greasy dirt

In image (3) water is added but dirt does not get removed

In image (4) when detergent is added, other end of the molecules get attracted to the boundary where water meets dirt.

In image (5) Dirt gets surrounded by inert end and dirt from the clothes can be removed by moving water.

In image (6) dirt is held suspended, surrounded by soap molecule,

Angle of Contact

Angle of contact is the angle at which a liquid interface meets a solid surface.

It is denoted by θ.

It is different at interfaces of different pairs of liquids and solids.

For example: - Droplet of water on louts leaf. The droplet of water(Liquid) is in contact with the solid surface which is leaf.

This liquid surface makes some angle with the solid surface. This angle is known as angle of contact.

Water form a spherical shape on lotus leaf

Water spilt on the table.

Significance of Angle of Contact

Angle of contact determines whether a liquid will spread on the surface of a solid or it will form droplets on it.

If the Angle of contact is obtuse: then droplet will be formed.

If the Angle of contact is acute: then the water will spread.

Case1: When droplet is formed

Consider we have a solid surface, droplet of water which is liquid and air.

The solid liquid interface denoted by S_{sl}, solid air interface denoted by S_{sa} and liquid air interface denoted by S_{la}.

The angle which S_{sl} makes with S_{la}. It is greater than the 90⁰.

Therefore droplet is formed.
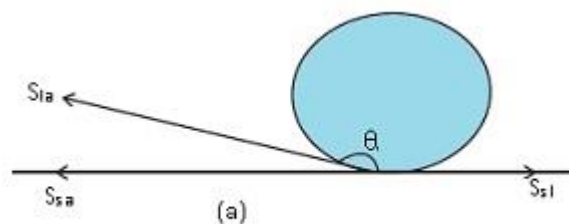
Case 2: When water just spreads

The angle which liquid forms with solid surface is less than 90^0.

(b)
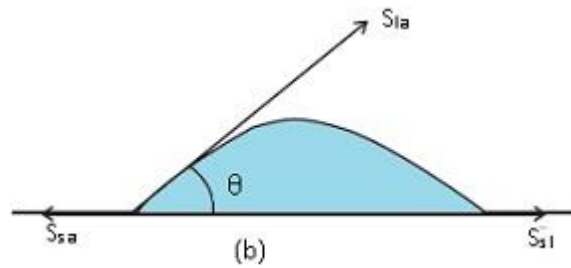
Drops and Bubbles

Why water and bubbles are drops

- Whenever liquid is left to itself it tends to acquire the least possible surface area so that it has least surface energy so it has most stability.

- Therefore for more stability they acquire the shape of sphere, as sphere has least possible area.

Spherical Shape

Distinction between Drop, Cavity and Bubble

Drop: Drop is a spherical structure filled with water.

There is only one interface in the drop.

The interface separates water and air.

Example: Water droplet.

Water droplets

Cavity: -Cavity is a spherical shape filled with air.

In the surroundings there is water and in middle there is cavity filled with air.

There is only one interface which separates air and water.

Example: - bubble inside the aquarium.

Bubble: - In a bubble there are two interfaces. One is air water and another is water and air.

Inside a bubble there is air and there is air outside.

But it consists of thin film of water.

Capillary Rise

In Latin the word capilla means hair.

Due to the pressure difference across a curved liquid-air interface the water rises up in a narrow tube in spite of gravity.

Consider a vertical capillary tube of circular cross section (radius a) inserted into an open vessel of water.

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

$$(P_i - P_o) = (2S/r) = 2S/(a \sec \theta) = (2S/a) \cos \theta \quad (i)$$

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

Consider the two points A and B. They must be at the same pressure,

$$P_0 + h \rho g = P_i = P_A \text{ (ii)}$$

where ρ is the density of water, and h is called the capillary

$$h \rho g = (P_i - P_0) = (2S \cos \theta)/a \text{ (By using equations (i) and (ii))}$$

Therefore the capillary rise is due to surface tension. It is larger, for a smaller radius.

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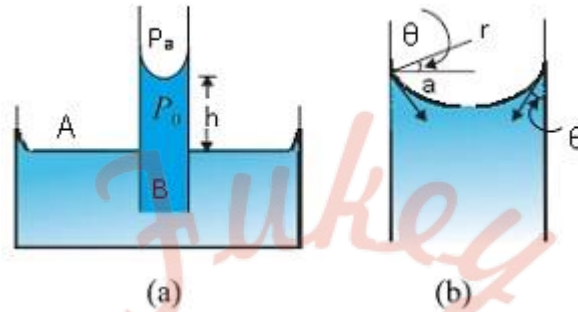
Capillary rise, (a) Schematic picture of a narrow tube immersed water. (b) Enlarged picture near interface.

Top Formulae
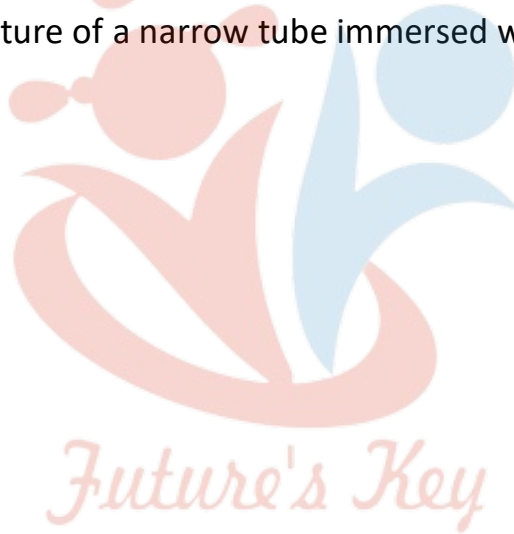
Pressure of a fluid having density ρ at height h	$P = h\rho g$
Gauge pressure	= total pressure − atmospheric pressure
Pascal's law: (*in hydraulic lift*)	$\dfrac{F_1}{a_1} = \dfrac{F_2}{2}$
Surface tension and surface energy are related as	$S = F/2\ell$
Work done	= surface tension × increase in area
Excess of pressure inside the liquid drop	$p = P - P_o = \dfrac{2S}{r}$
Excess of pressure inside the soap bubble	$p = P - P_o = \dfrac{4S}{r}$
Total pressure in the air bubble at a depth h below the surface of liquid of density ρ	$P = P_o + h\rho g + \dfrac{2S}{r}$
In case of capillary action	Ascent / descent formula, $h = \dfrac{2S\cos\theta}{r\rho g}$, where θ is the angle of contact.
Newton's viscous dragging force	$F = \eta A \dfrac{dv}{dx}$, where η is coefficient of viscosity, A is the area of layer of liquid and $\dfrac{dv}{dx}$ is the velocity gradient.
Stoke's law	$F = 6\pi\eta rv$
Terminal velocity	$v = \dfrac{2r^2(\rho - \sigma)g}{9\eta}$, where ρ and σ are the densities of the spherical body and medium, respectively; r is the radius of the spherical body.
Reynold's number	$R_N = \dfrac{\rho D v}{\eta}$, where D is the diameter of the tube and v is the velocity of liquid flow through the tube.

Bernoulli's theorem	Pressure energy per unit mass + potential energy per unit mass + kinetic energy per unit mass = constant $$\frac{P}{\rho} + gh + \frac{1}{2}v^2 = constant$$
Venturi meter, volume of liquid flowing per second	$$V = a_1 a_2 \sqrt{\frac{2\rho_m gh}{\rho(a_1{}^2 - a^2)}},$$ where a_1 and a_2 are the areas of cross-section of bigger and smaller tube; h is the difference of pressure head at the two tubes of a Venturi meter.
Velocity of efflux: Torricelli's law	$v = \sqrt{2gh}$

Class : 11th Physics
Chapter- 10 : Mechanical Properties of Fluids

Venturimeter
Device used to measure the rate of flow of liquid. Volume of liquid flowing per second.

$$Q = a_1 a_2 \sqrt{\frac{2h \rho_m g}{\rho \left(a_1^2 - a_2^2\right)}}$$

Toricell's Low
Velocity of efflux of liquid through an orifice
$$V = \sqrt{2gh}$$

Applications
o Lift of an aircraft wing.
o Sprayer or atomizer
o Blowing off the roofs during windstorm.

Stroke's law $F = 6 \eta vr$

For an incompressible non-viscous streamline, irrotational flow of fluid,

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

Opposing force between different layers of fluid in relative motion

Viscous drag $F = -\eta A \frac{dv}{dx}$
η = coefficient of viscosity

Streamline : In liquid flow when the Velocity is less than critical velocity, each particle of the liquid passing through a point travels along the same path and same velocity as the preceding particles.
Turbulent : When velocity of liquid flow is greater than critical velocity and particles follow zig-zag path.

Bernoulli's principal

Viscosity

Flow of fluids

Mechanical Properties of Fluids

Formulae

Laws of Fluids

- Surface tension $S = \frac{F}{l}$
- Surface Energy $= \frac{\text{work done in increasing area}}{\text{increase in surface area}} = \frac{W}{\Delta A}$
- Capillary rise or fall, $h = \frac{2S \cos\theta}{r \rho g}$
- Excess Pressure inside a drop (liquid)
$$P_{excess} = \frac{2S}{R}$$
- Excess Pressure inside a bubble (soap)
$$P_{excess} = \frac{4S}{R}$$

That can flow like liquids and gases

Equation of continuity
$m = a_1 v_1 \rho_1 = a_2 v_2 \rho_2$
for an incompressible liquid,
$\rho_1 = \rho_2$ then $a_1 v_1 = a_2 v_2$
or $av = \text{constant}$

Pascal's law : The pressure exerted at any point on an enclosed liquid is transmitted equally in all direction.

$$\text{Pressure}(P) = \frac{\text{thrust}(F)}{\text{area}(A)} = \lim_{\Delta A \to 0} \frac{\Delta E}{\Delta A} = \frac{dF}{dA}$$
Pressure exerted by a liquid column of height h, $(p) = h\rho g$

Atmospheric Pressure(Pa)
Pressure (atm) exerted by the atmosphere. At sea level, 1 atm = pressure exerted by 0.76m of Hg = $h\rho g = 0.76 \times 13.6 \times 10 \times 9.8 = 1.013 \times 10$ Nm2 = 101.3kPa

Absolute Pressure(P)
Total or actual pressure at a point. Absolute pressure = atmospheric pressure + gauge pressure

Gauge Pressure(Pg)
Difference between the absolute pressure at a point and the atmospheric pressure.
Pg = absolute pressure (P) – atmospheric pressure (Pa)

Important Questions

Multiple Choice questions-

1. Plants get water through the roots because of

(a) Capillarity

(b) Viscosity

(c) Gravity

(d) Elasticity

2. Water rises up to a height h_1 in a capillary tube of radius r. the mass of the water lifted in the capillary tube is M. if the radius of the capillary tube is doubled, the mass of water that will rise in the capillary tube will be

(a) M

(b) 2M

(c) M/2

(d) 4M

3. A number of small drops of mercury coalesce adiabatically to form a single drop. The temperature of drop

(a) Increases

(b) Is infinite

(c) Remains unchanged

(d) May decrease or increase depending upon size

4. When a soap bubble is charged

(a) It contracts

(b) It expands

(c) It does not undergo any change in size

(d) None of these

5. A liquid is kept in a glass vessel. If the liquid solid adhesive force between the liquid and the vessel is very weak as compared to the cohesive force in the liquid, then the shape of the liquid surface near the solid should be

(a) Concave

(b) Convex

(c) Horizontal

(d) Almost vertical

6. A capillary tube is placed vertically in a liquid. If the cohesive force is less than the adhesive force, then

(a) The meniscus will be convex upwards

(b) The liquid will wet the solid

(c) The angle of contact will be obtuse

(d) The liquid will drip in the capillary tube

7. When there are no external forces, the shape of a liquid drop is determined by

(a) Surface tension of the liquid

(b) Density of liquid

(c) Viscosity of liquid

(d) Temperature of air only

8. Water can rise up to a height of 12 cm in a capillary tube. If the tube is lowered to keep only 9 cm above the water level then the water at the upper end of the capillary will

(a) Overflow

(b) From a convex surface

(c) From a flat surface

(d) From a concave surface

9. Rain drops are spherical in shape because of

(a) Surface tension

(b) Capillary

(c) Downward motion

(d) Acceleration due to gravity

10. When the angle of contact between a solid and a liquid is 90°, then

(a) Cohesive force > Adhesive force

(b) Cohesive force < Adhesive force

(c) Cohesive force = Adhesive force

(d) Cohesive force >> Adhesive force

Very Short:

1. State the law of floatation?

2. The blood pressure of humans is greater at the feet than at the brain?

3. Define surface tension?

4. Define surface tension?

5. Oil is sprinkled on sea waves to calm them. Why?

6. Oil is sprinkled on sea waves to calm them. Why?

7. The diameter of ball A is half that of ball B. What will be their ratio of their terminal velocities in water?

8. Define viscosity?

9. Give two areas where Bernoulli's theorem is applied?

10. What is conserved in Bernoulli's theorem?

Short Questions:

1. A glass bulb is balanced by an iron weight in an extremely sensitive beam balance covered by a bell jar. What shall happen when the bell jar is evacuated?

2. It is easier to swim in seawater than in river water. Why?

3. Does Archimedes' Principle hold in a vessel in free fall or in a satellite moving in a circular orbit?

4. A block of wood floats in a pan of water in an elevator. When the elevator starts from rest and accelerates downward, does the 1 block floats higher above the water surface? What happens when the elevator accelerates upward?

5. The thrust on a human being due to atmospheric pressure is about 15 tons. How human being can withstand such an enormous thrust while it is impossible for him to carry a load of even one ton?

6. Why are sleepers used below the rails? Explain.

7. The passengers are advised to remove the ink from their f pens while going up in an airplane. Explain why?

8. Why a sinking ship often turns over as it becomes immersed in water?

9. Explain why a balloon filled with helium does not rise in the air indefinitely but halts after a certain height?

10. A light ball can remain suspended in a vertical jet of water flow?

11. In the case of an emergency, a vacuum brake is used to stop the train. How does this brake work?

12. Why dust generally settles down in a closed room?

13. How will the rise of a liquid be affected if the top of the capillary tube is closed?

14. What are buoyancy and the center of buoyancy?

15. Under what conditions:

(a) Centre of buoyancy coincides with the center of gravity?

(b) The center of buoyancy does not coincide with the center of gravity?

Long Questions:

1. A copper cube of mass 0.50 kg is weighed in water ($\rho = 10^3$ kg m^{-3}). The mass comes out to be 0.40 kg. Is the cube hollow or solid? Given density of copper = 8.96×10^3 kg m^{-3}.

2. A piece of pure gold ($\rho = 9.3$ g cm^{-3}) is suspected to be hollow. It weighs 38.250 g in air and 33.865 in water. Calculate the volume of the hollow portion in gold, if any.

3. A glass plate of length 20 cm, breadth 4 cm, and thickness 0.4 cm weights 40 g in air. If it is held vertically with the long side horizontal and the plate half breadth immersed in water, what will be its apparent weight, the surface tension of water = 70 dyne cm^{-1}.

4. What is the work done in blowing a soap bubble of diameter 0.07 m?

5. If 3.6960×10^3 J of work is done to blow it further, find the new radius. Surface tension of soap solution is 0.04 Nm1.

Assertion Reason Questions:

1. *Directions:*

   (a) If both assertion and reason are true and the reason is the correct explanation of the assertion.
   (b) If both assertion and reason are true but reason is not the correct explanation of the assertion.
   (c) If assertion is true but reason is false.
   (d) If the assertion and reason both are false.

Assertion: It is easier to spray water in which some soap is dissolved.
Reason: Soap is easier to spread.

2. *Directions:*

   (a) If both assertion and reason are true and the reason is the correct explanation of the assertion.
   (b) If both assertion and reason are true but reason is not the correct explanation of the assertion.
   (c) If assertion is true but reason is false.
   (d) If the assertion and reason both are false.

Assertion: The angle of contact of a liquid decrease with increase in temperature.
Reason: With increase in temperature, the surface tension of liquid increase.

✓ **Answer Key:**

Multiple Choice Answers-

1. Answer: (a) Capillarity

2. Answer: (b) 2M

3. Answer: (d) May decrease or increase depending upon size

4. Answer: (b) It expands

5. Answer: (b) Convex

6. Answer: (b) The liquid will wet the solid

7. Answer: (a) Surface tension of the liquid

8. Answer: (c) From a flat surface

9. Answer: (a) Surface tension

10. Answer: (c) Cohesive force = Adhesive force

Very Short Answers:

1. Answer: Law of floatation states that a body will float in a liquid, if weight of the liquid displaced by the immersed part of the body is at least equal to or greater than the weight of the body.

2. Answer: The height of the blood column in the human body is more at the feet than at the brain as since pressure is directly dependent on height of the column, so pressure is more at feet than at the brain.

3. Answer: It is measured as the force acting on a unit length of a line imagined to be drawn tangentially anywhere on the free surface of the liquid at rest.

4. Answer: Archimedes's Principle will not hold in a vessel in free – fall as in this case, acceleration due to gravity is zero and hence buoyant force will not exist.

5. Answer: Since the surface tension of sea-water without oil is greater than the oily water, therefore the water without oil pulls the oily water against the direction of breeze, and sea waves calm down.

6. Answer: Since the cohesive forces between the oil molecules are less than the adhesive force between the oil molecules and the drop of oil spreads out and reverse holds for drop of water.

7. Answer: The terminal velocity is directly proportional to the square of radius of the ball, therefore the ratio of terminal velocities will be 1:4.

8. Answer: Viscosity is the property of a fluid by virtue of which an internal frictional force comes into play when the fluid is in motion and opposes the relative motion of its different layers.

9. Answer: Bernoulli's theorem is applied in atomizer and in lift of an aero plane wing.

10. Answer: According to Bernoulli's theorem, for an incompressible non – Viscous liquid (fluid) undergoing steady flow the total energy of liquid at all points is constant.

Short Questions Answers:

1. Answer: The upthrust on the bulb is larger than the upthrust on the iron weight. When the bell jar has evacuated the upthrust on both the bulb and the iron weight become zero. Clearly, the bulb is affected more than the iron weight. Thus the pan containing the bulb shall go down.

2. Answer: Due to the presence of salt, the density of seawater is more than that of river water. Hence seawater offers more upthrust as compared to river water. Therefore a lesser portion of our body is submerged in, seawater as compared to river water. Hence it is easier to swim in sea-water than in river water.

3. Answer: A vessel in free fall or in a satellite moving in a circular orbit is in the state of weightlessness. It means the value of 'g' is zero. Thus the weight of the vessel and upthrust will be zero. Hence Archimedes' Principle does not hold good.

4. Answer: When the elevator accelerates downward, the weight of the block of wood decreases. Hence it will float higher above the water's surface.

5. Answer: There is a large number of pores and openings on the skin of a body. Through these openings, air goes within the system and there is free communication between the inside and the outside. The presence of; the air inside the body counterbalances the pressure outside.

6. Answer: When sleepers are placed below the rails, the area of the cross- p section is increased. We know that $P = \frac{F}{A}$, so when the train runs on the rails, the pressure exerted on the ground due to the weight of the train is small because of a large area of cross-section of the sleeper. Hence the ground will not yield under the weight of the train.

7. Answer: With the increase in height, the atmospheric pressure decreases. The ink in the pen is filled at the atmospheric pressure on the surface of the earth. So as the plane rises up, the pressure decreases \ and the ink will flow out of the pen from higher pressure to the low 'pressure region. This will spoil the clothes of passengers.

8. Answer: When the ship is floating, the metacenter of the ship is above the center of gravity. While sinking the ship takes in water and as a result, the center of gravity is raised above the metacenter. The ship turns over due to the couple formed by the weight and the buoyant force.

9. Answer: The balloon initially rises in the air because the weight of the displaced air i.e> upthrust is greater than the weight of the helium and the balloon. Since the density of air decreases with height, therefore, the balloon halts at a particular height where the density of air is such that the weight of air displaced is just equal to the weight of helium gas and the balloon. Hence the net force acting on the balloon is zero and the balloon stops rising.

10. Answer: The region where the ball and the vertical jet of water are in contact is a region of low pressure because of higher velocity. The pressure on the other side of the ball is larger. Due, to the pressure difference, the ball remains suspended.

11. Answer: Steam at high pressure is made to enter the cylinder of the vacuum brake. Due to high velocity, pressure decreases in accordance with Bernoulli's principle. Due to this decrease in pressure, the piston gets lifted. Hence the brake gets lifted.

12. Answer: Dust particles may be regarded as tiny spheres. They acquire terminal velocity after having fallen through some distance in the air. Since the terminal velocity varies directly as the square of the radius therefore the terminal velocity of dust particles is very small. So they settle down gradually.

13. Answer: The air trapped between the meniscus of the liquid and the closed end of the tube will be compressed. The compressed air shall oppose the rise of liquid in the tube.

14. Answer: 1. The upward thrust acting on the body immersed in a liquid is called buoyancy or buoyant force.

    2. The center of buoyancy is the center of gravity of the displaced liquid by the body when immersed in a liquid.

15. Answer: (a) For a solid body of uniform density, the center of gravity coincides with the center of buoyancy.

    (b) For a solid body having different densities over different parts, its center of gravity does not coincide with the center of buoyancy.

Long Questions Answers:

1. Answer: Let V be the volume of the cube, then according to Archimedes' principle,

   Loss of weight in water = weight of water displaced …. (i)

   Here, mass in air, ma = 0.5 kg

   mass in water, mw = 0.4 kg …. (ii)

   ρ of water = 10^3 kg m³.

   ∴ From (i) and (ii), we get

$$(0.5 - 0.4) g = V \times 10^3 \times g$$

or

$$V = \frac{0.1}{10^3} = 10^{-4} m^{-3}$$

Now density of cube $= \frac{m_a}{V} = \frac{0.5}{10^{-4}} kg\, m^{-3}$

$$= 5 \times 10^3\, kg\, m^{-3}$$

which is less than the density of copper (8.96×10^3 kg m^{-3}). So the cube must be hollow.

2. Answer: Density of pure gold, $\rho = 9.3$ g cm^3,

   mass of gold piece, M = 3 8.250 g

   $\therefore$ volume of the gold piece, $V = \frac{M}{P} = \frac{38.250}{9.3}$

   = 4.113 cm^3

   Also mass of gold piece in water

   m' = 33.865 g

   $\therefore$ apparent loss in mass of the gold piece in water = (M − m')

   = (38.250 − 33.865)g

   = 4.3.85 g

   ρ_{water} = 1 g Cm^{-3}

   $\therefore$ volume of displaced water $= \frac{m}{\rho} = \frac{4.385}{1} cm^{-3}$

   = 4.385 cm^{-3}

   $\therefore$ volume of the hollow portion in the gold piece

   = 4.385 − 4.113

   = 0.272 cm^{-3}.

3. Answer: Here, l = 20 m, b = 4 cm , t = 0.4 cm, T = 70 dyne cm-1

   Following three forces are acting on the plate:

   1. Weight of the plate, W = 40 grand actings vertically downward.

   2. Force due to surface tension acting vertically downward.

   If F be the force due to surface tension, then

$$F = T \times \text{length in contact with water}$$
$$= 70 \, [2 \, (\text{length} + \text{thickness})]$$
$$= 70 \, [2(20 + 0.4)]$$
$$= 70 \times (40.8) = 2856 \text{ dynes}$$
$$= \frac{2856}{980} \text{ gf} = 2.9143 \text{ gf.}$$

(iii) Upthrust, $U = V\rho g$

Now volume of water displaced $= l \times \dfrac{b}{2} \times t$

$$= 20 \times \frac{4}{2} \times 0.4$$
$$= 16 \text{ cm}^3$$
$$\rho = 1 \text{ gm cm}^{-3}$$
$$g = 980 \text{ cm s}^{-2}$$
$$U = 16 \times 1 \times 980 \text{ dynes}$$
$$= \frac{16 \times 980}{980} \text{ gf} = 16 \text{ gf}$$
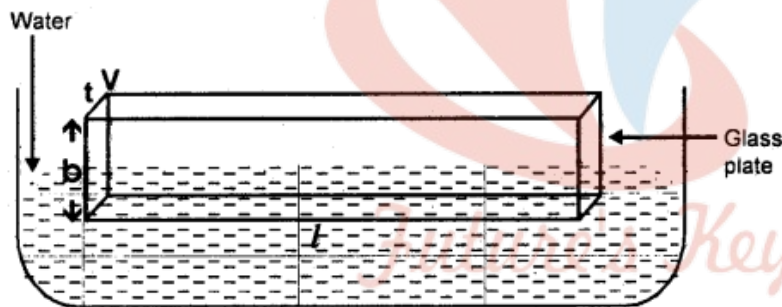
∴ Net weight = W + F − U

= 40 + 2.9143 − 16

= 26.9143 gf

4. Answer: Here, initial radius of soap bubble, $r_1 = 0$

   Final radius of soap bubble, $r_2 = 0.035$ m (∵ $D_2 = 0.07$m)

   Increase in surface area of soap bubble

$$= 2\left(4\pi r_2^2 - 4\pi r_1^2\right)$$
$$= 2 \times 4\pi \, [(0.035)^2 - 0]$$
$$= 8\pi \times 0.1225 \times 10^{-2}$$
$$= 0.0308 \text{ m}^2$$

   surface tension of soap solution = T = 0.04 Nm^{-1}

   ∴ work done to blow soap bubble = increase in area × T

= 0.0308 × 0.04

= 1.232 × 10⁻³

5. Answer: Let r be the new radius =?

$$\therefore \quad 3.6960 \times 10^{-3} = 2\left[4\pi\left(r^2 - r_2^2\right)\right] \times T$$

$$= 2 \times 4\pi\left[r^2 - (0.035)^2\right] \times 0.04$$

$$\text{or} \qquad r^2 = 1225 \times 10^{-6} + \frac{3.69 \times 10^{-3}}{8\pi \times 0.04}$$

$$= 1.225 \times 10^{-3} + 3.67 \times 10^{-3}$$

$$= 4.875 \times 10^{-3}\ m$$

$$\therefore \qquad r = 0.07\ m.$$

Assertion Rason Answer:

1. (c) If assertion is true but reason is false.

   Explanation:

   When a liquid is sprayed, the surface area of the liquid increases. Therefore, work has to be done in spraying the liquid, which is directly proportional to the surface tension.
   Because on adding soap, surface tension of water decreases, the spraying of water becomes easy.

2. (c) If assertion is true but reason is false.

   Explanation:

   With increase in temperature surface tension of the liquid decreases and angle of contact also decreases.

Case Study Questions-

1. **Surface Tension**
   The property due to which the free surface of liquid tends to have the minimum surface area and behaves like a stretched membrane is called surface tension. It is a force per unit length acting in the plane of interface between the liquid and the bounding surface i.e., S = F/L, where F = force acting on either side of an imaginary line on the surface and L = length of the imaginary line. Surface tension decreases with rise in temperature. Highly soluble impurities increase surface tension and sparingly soluble impurities decrease surface tension.

   i. **The excess pressure inside a soap bubble is three times than excess pressure inside a second soap bubble, then the ratio of their surface area is**

      a. 9 : 1

      b. 1 : 3

      c. 1 : 9

d. 3 : 1

ii. **Which of the following statements is not true about surface tension?**

  a. A small liquid drop takes spherical shape due to surface tension.

  b. Surface tension is a vector quantity.

  c. Surface tension of liquid is a molecular phenomenon.

  d. Surface tension of liquid depends on length but not on the area.

iii. **Which of the following statement is not true about angle of contact?**

  a. The value of angle of contact for pure water and glass is zero.

  b. Angle of contact increases with increase in temperature of liquid.

  c. If the angle of contact of a liquid and a solid surface is less than 90°, then the liquid spreads on the surface of solid.

  d. Angle of contact depend upon the inclination of the solid surface to the liquid surface.

iv. **Which of the following statements is correct?**

  a. Viscosity is a vector quantity.

  b. Surface tension is a vector quantity.

  c. Reynolds number is a dimensionless quantity.

  d. Angle of contact is a vector quantity

v. **A liquid does not wet the solid surface if the angle of contact is**

  a. 0°

  b. equal to 45°

  c. equal to 90°

  d. greater than 90°

2. A system is said to be isolated if no exchange or transfer of heat occurs between the system and its surroundings. When different parts of an isolated system are at different temperature a quantity of heat transfers from the part at higher temperature to the part at lower temperature. The heat lost by the part at higher temperature is equal to the heat gained by the part at lower temperature. Calorimetry means measurement of heat. When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is allowed to escape to the surroundings. A device in which heat measurement can be done is called a calorimeter. It consists of a metallic vessel and stirrer of the same material, like copper or aluminium. The vessel is kept inside a wooden jacket, which contains heat insulating material. Matter normally exists in three states: solid, liquid and gas. A transition from one of these states to another is called a change of state. Two common changes of states are solid to liquid and liquid to gas (and, vice versa).

These changes can occur when the exchange of heat takes place between the substance and its surroundings. The change of state from solid to liquid is called melting and from liquid to solid is called fusion. It is observed that the temperature remains constant until the entire amount of the solid substance melts. That is, both the solid and the liquid states of the substance coexist in thermal equilibrium during the change of states from solid to liquid. The temperature at which the solid and the liquid states of the substance is in thermal equilibrium with each other is called its melting point. The change of state from liquid to vapour (or gas) is called vaporisation. It is observed that the temperature remains constant until the entire amount of the liquid is converted into vapour. That is, both the liquid and vapour states of the substance coexist in thermal equilibrium, during the change of state from liquid to vapour. The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point. The change from solid state to vapour state without passing through the liquid state is called sublimation, and the substance is said to sublime. Dry ice (solid CO_2) sublimes, so also iodine. During sublimation both the solid and vapour states of a substance coexist in thermal equilibrium.

i. **Device used for measurement of heat is**

    a. Calorimeter

    b. Thermometer

    c. Both a and b

    d. No one of these

ii. **The change of state from solid to liquid is called**

    a. Melting

    b. Vaporization

    c. Sublimation

    d. None of these

iii. **Define melting point and boiling point**

iv. **What is sublimation?**

v. **Define fusion process**

Case Study Answer-

1. Answer

i. (c) 1 : 9

ii. (b) Surface tension is a vector quantity.

iii. (d) Angle of contact depend upon the inclination of the solid surface to the liquid surface.

iv. (c) Reynolds number is a dimensionless quantity.

v. (d) greater than 90°

2. Answer

i. (a) Calorimeter

ii. (a) Melting

iii. The change of state from solid to liquid is called melting process and temperature at which conversion of solid into liquid happens is called as melting point.
The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point.

iv. The change from solid state directly into vapour state without passing through the liquid state is called sublimation, and the substance is said to sublime.

The change of state from liquid state to solid state is called as fusion process