**Chapter – 9/10 Combined Mechanical Properties of Solids & Fluids**

**Elasticity**

**Rigid body:** When the external forces do not produce any deformation in the body, the body is called a rigid body. Diamond is the nearest approach to a rigid body.

**Elasticity:**

(i) Elasticity of a material is its property by virtue of which it resists strain when deforming forces are applied on it and recovers from strain when deforming forces are removed.

(ii) When the body regains its original shape and size completely after the removal of deforming forces, then the body is said to be perfectly elastic, e.g., Quartz fibre.

(iii) If the body does not have any tendency to recover its original shape and size, the body is said to be perfectly plastic, e.g., wet clay.

(iv) Truly speaking, the behaviour of bodies lie between these two extreme limits.

**Stress:**

(i) When external forces are exerted on a body, the body gets distorted, i.e., different portions of the body move relative to each other. Due to these displacements atomic forces (restoring forces) are set up inside the body to restore the original form. **The restoring force per unit area set up inside the body is called stress**. This is measured by the magnitude of deforming force per unit area of the body when the equilibrium is established. If F is the force applied to an area of cross-section A, then stress = (F/A)

(ii) When the stress is applied normal to a surface. This is called as **normal stress**. It produces a change in length of a wire or a change in volume of a body. The normal stress to a wire or body may be compressive or tensile according as it produces a decrease or increase in the length of a wire or volume of the body.

(iii) When the stress is applied tangential to a surface, it is called **tangential or shearing stress**.

(iv) Dimensional formula of stress is [M L-l T-2 ] and CGS and MKS units are dyne/cm2 and newton/m2 respectively.

(v) Stress is a tensor quantity.

*(vi)Though both stress and pressure are defined as force per unit area but even then they differ from each other due to following reasons*:

(a) Pressure is always normal to the area while stress can be either normal or tangential.

(b) Pressure on a body is always compressive while stress can be either compressive or tensile.

(c) Pressure is a scalar while stress E is a tensor.

4. **Strain**:

(i) The deforming forces acting on a body cause a relative displacement of its various parts and the body is then said to be strained. Either a change in length or a change in volume or change in shape occurs. The relative change produced in the body due to the influence of external forces is called **strain**.

(ii) Strain has no dimension as it is a pure number.

(iii) (a) The change in length per unit length is called as **linear strain**.

(b) The change in volume per unit volume is called as **volume strain**.

(c) If there is a change in shape, the strain is called **shearing strain or shear**. It is measured by the angle through which a line originally perpendicular to the fixed surface is turned.

**Hooke's law and moduli of elasticity**:

According to Hooke's law, within elastic limit, stress applied to a body is directly proportional to corresponding strain, i.€.,

Stress α Strain or Stress/ Strain = constant = E

The constant of proportionality E is known as modulus of elasticity. Following three moduli of elasticity are possible:

(a) **Young's modulus Y :** Within limits of proportionality the ratio of linear stress either compressive or tensile to the longitudinal strain is called as Young's modulus of the material of the body.

Y= linear stress/ longitudinal strain

If a rod or wire of length L and C.S. area A under the action of a stretching force F applied normally to its face suffers an increase ∆L in length, then in equilibrium,

(b) **Bulk modulus B**: When a solid or fluid (liquid or gas) is subjected to change in pressure its volume changes, but the shape remains unchanged. The force per unit area, applied normally and uniformly to the surface of the body, i.e., pressure gives the stress and the change in volume per unit volume strain. *Within the limits of proportionality, the ratio of uniform and normal stress on the surface of a body to the volume strain is called Bulk modulus of the material of the body i.e.,*

(i) The reciprocal of bulk modulus is called **compressibility**, i. e

(ii) *All the states of matter possess volume elasticity" Bulk modulus of gases is very low while that of liquids and solids is very high*.

(c) Modulus of rigidity (η): Within limits of proportionality the ratio of tangential stress to the shearing strain is called modulus of rigidity of the material of the body and is denoted by η, i.e.,

η = shearing stress/shearing strain

Consider a cube of material fixed at the lower face and acted upon by a tangential force F at its upper surface having area A. The shearing stress then, will be **Shearing stress = F/A**

This shearing force causes the consecutive horizontal layers of the cube to be slightly displaced or sheared relative to one another; each line such as AB or CD in the cube rotates through an angle ϕ by this shear. The shearing strain is defined as the angle ϕ in radians through which a line normal to a fixed surface has turned. For small values of angle

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Shearing is exhibited by solids only as these have definite shape

**6. Poisson's ratio:** (a) When longitudinal force is applied on a wire its length increases but its radius decreases. Thus, two strains are produced by a single force :

(i) Longitudinal strain = ∆L/L (ii) Lateral strain = ∆R/R

(b) Poisson discovered that within limits of proportionality, the ratio of the lateral strain to the longitudinal strain is constant for a given material. This constant is called as Poisson's ratio and is represented by σ.

σ = lateral strain/longitudinal strain = - ∆R/R /∆L/L

(i) σ has no units and dimensions

(ii) Theoretically, σ lies between -l and +½

(iii) Practically, no substance has been found for which σ is negative, i.e., **practically σ lies between zero**

**and +½.**

**7. Some important points concerning the moduli of elasticity (Y, B and η):**

(a) The value of moduli of elasticity is independent of the magnitude of the stress and strain.

It depends only on the nature of the material of the body.

(b)The modulus of elasticity has same dimensional formula and unit as that of stress since strain is dimensionless, i.e., the dimensional formula for Y, B and η is [ML-l T-2] while units dyne/cm2 or, newton/m 2.

**(c)Greater the value of modulus of elasticity, more elastic is the material.**

But as Y α 1/∆L , B α (1/∆V) and η α (1/ϕ) for a constant stress, **so smaller change of shape or size for L given stress corresponds to greater elasticity**.

For a rigid body ∆L , ∆V and ϕ =0 so Y,B or η will be ∞, i.e., **elasticity of a rigid body is infinite**.

(d) The moduli of elasticity Y and η exist only for solids (Y = 3η, in case of solids usually) as liquids and gases cannot be deformed along one dimension only and also cannot sustain shear strain. However, B exists for all states of matter, solid, liquid or gas.

(e) Gases being most compressible are least elastic while solids are most, i.e., *the bulk modulus of gases is very low while that for liquids and solids is very high, i.e.,*

Esolid >Eliquid > Egas

(f) Gases have two bulk moduli, namely, **isothermal elasticity** E**θ** and **adiabatic elasticity** E**ϕ**.lt can be easily proved that at a given pressure P,

E**θ** =P and E**ϕ**= γP



(g)With rise in temperature, the distance between atoms increases and so the elastic restoring force will decrease. This in turn decreases the elasticity, i.e., **with rise in temperature, Y, B and η decrease.**

(h) **Relations among elastic constants**: Moduli of elasticity are three, viz., Y, B and η while elastic constants are four, viz., Y, B, η and σ. **Poisson's ratio σ** is not modulus of elasticity as it is the ratio of two strains and not of stress to strain.

Elastic constants are found to depend on each other through the following relations:

(i) Y =3B(l -2σ) (ii) Y = 2η(1 + σ) (iii) Y =9Bη/(3B +η) (iv) σ = (3B - 2η) / (6B + 2η)

8. **Some more important points regarding elasticity:**



(a) If the length of a wire is doubled, the longitudinal strain will be :

So, Young's modulus is numerically equal to the stress which will double the length of a wire

(b) As for a loaded wire ∆L = FL/πr2Y , So, if same stretching force is applied to different wires of same material,

∆L α L/r2 i.e., greater the ratio L/r2 greater will be the elongation.

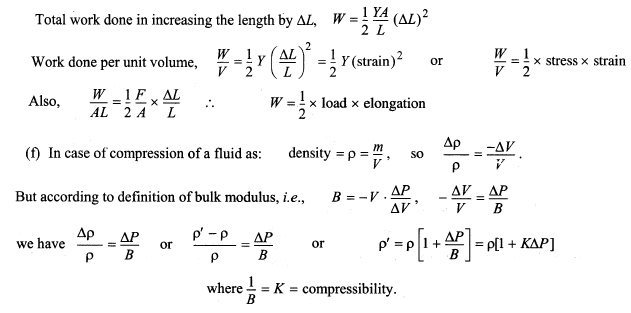
(c) Elongation in a wire by its own weight: If a wire of length L and cross-section A is stretched by a force F, then by definition of Y,

∆L α FL/AY

In case of elongation by its own weight, F (=Mg) will act at centre of gravity of the wire, so that length of wire which is stretched is (L/2),

(d) **Thermal stress**: If a rod is fixed between two supports, due to change in temperature its length will change and so it will exert a normal stress (compressive if temperature increases, and tensile if temperature decreases) on the supports. This stress is called thermal stress. Thermal stress = Yα dθ

(e) **Work done in stretching a wire:** In stretching a wire, work is done against internal restoring forces. This work is stored in the body as **elastic potential energy or strain energy**.



(g) In case of bending of a beam of length L, breadth b and thickness d, by a load Mg at the middle, depression δ is given by:

δ = MgL3 /4bd3Y or = MgL3/3YI (I =Moment of Inertia)

(h)In case of twisting of a cylinder (or wire) of length L and radius r, elastic **restoring couple per unit twist** is given by

C = πηr4/2L

(i) In case of a rod of length L and radius r fixed at one end, angle of shear ϕ is related to angle of twist θ by

the relation:

Lϕ =rθ

(j) **Elastic after-effect**: When a wire is loaded continuously, then a state is reached when the wire does not return to its original state immediately after the removal of force. *This temporary absence of elastic property in the wire is called elastic after-effect.*

(k) **Effect of hammering and rolling on elasticity**: Operations like hammering, rolling, etc., which help in breaking up the crystal grains into smaller units, result in an increase of elastic property of substances.

(L) **Effect of annealing on elasticity**: Operations like annealing which tend to produce a uniform pattern of orientation of the constituent crystals, by orienting them in one particular direction and thus forming of large crystal grain, result in decrease of elastic properties of materials.

(m) **Effect of change of temperature on elasticity**: A rise of temperature generally decreases the elastic properties of materials :

(i) In case of invar steel the elasticity remains practically unaffected by changes of temperature.

(ii) Lead becomes elastic first like steel when cooled in liquid air.

(iii) A carbon filament which is highly elastic at ordinary temperatures becomes plastic when heated by passing current through it.

(n) **Effect of impurities on elasticity**: Impurities affect the elastic properties of the metal to which they are added by enhancing or impairing them according as they are themselves more elastic or plastic than the metal concerned.

(o)**Breaking stress depends only on the material of wire.** It is independent of length and area of cross-section of the wire

-- When the rod is of non-uniform area of cross section then A = √(A1A2)

**Surface Tension**

1. **Surface tension**:

(i) The property of the surface of a liquid by virtue of which it tends to contract and occupy the minimum possible surface area (as it is in a state of tension) is called surface tension.

(ii) The surface tension of a liquid is defined as the force per unit length in the plane of the liquid surface, acting at right angles on either side of an imaginary line drawn in that surface.

(iii) Surface tension of a liquid may also be defined as the work done per unit area in increasing the surface area of a liquid under isothermal conditions, i.e., T = W/∆A

(iv) Surface tension of a liquid is a **scalar** physical quantity as it possesses an unique direction.

(v) The unit of surface tension in MKS system is either newton/metre or joule/metre2 while in CGS system either dyne/cm or erg/cm2 .

(vi) With a rise in temperature, surface tension of a liquid decreases till it becomes zero at the boiling point or the critical temperature whichever is lower. There is also an exception to it. **Surface tension of molten cadmium and copper increases with increase in temperature.**

(vii) If a material exists in solid phase, liquid phase and gaseous phase, then Tsolid > T Liquid > T gas and Tgas =0

(viii) **With the presence of impurity** in a liquid, surface tension of the liquid decreases if the impurity is sparingly soluble in the liquid (e.g., soap, phenol, camphor, sodium in water) and surface tension of liquid increases when the impurity is highly soluble in the liquid (e.g., common salt or sugar added to water).

**2. Intermolecular forces: Cohesive and adhesive forces**

(i) The force of attraction between the molecules of the same substance is called as **cohesive force** while the force of attraction between the molecules of different substances is called **adhesive force.**

(ii) These forces are totally different from the gravitational forces and **do not obey the inverse square law**.

(iii) When the distance between the molecules is greater than 10-9 metre, the force of attraction becomes negligibly small. When the distance between the molecules decreases, the force of attraction increases very rapidly.

(iv) The molecular range is the maximum distance (= l0-19 m) upto which molecules attract each other.

**3. Some more important points concerning surface tension:**

(i) Free surface of a liquid always remains in a state of tension and tends to have minimum possible surface area due to property of surface tension. If the area of liquid surface is increased, work will be done. This work is stored as potential energy in the surface. The amount of this energy per unit area of the surface under isothermal condition is called **free surface energy density**.

(ii) As work done by external force in increasing the total surface area of film by dA is W = TdA, hence free surface energy density = (W/dA) = T.

(iii) (a) Work done in forming a drop or bubble inside a liquid, W=T. 4πr2.

(b) Work done in forming a bubble in air, W =T . (2. 4πr2) =8πr2T.

(c) Work done in increasing the surface of a soap bubble of radius r1 into a bubble of radius r2 is: W =8π( r22 – r12 )T

(d) Work done in spraying a liquid drop of radius R into N equal droplets

W=T. 4πr2[N⅓ – 1]

(iv) When a wire bent in the form of a ring is dipped into soap solution and taken out, a film is formed due to surface tension.

(v) The liquid surface always acquires minimum surface area due to surface tension. So, small drops of liquid or rain drops always assume spherical shape.

(vi) Surface tension of liquid metals is very very high. For mercury it is 0.487 N/m at room temperature.

(vii) The larvae eggs float on water due to surface tension.

(viii) If a ring of negligible thickness and radius r floats on Liquid surface,

then the force of surface tension is:

F = T .2. (2πr) because the length of the ring in contact with the liquid surface is 2. (2πr).

**4. Excess pressure:**

(i) The pressure on the concave side of the liquid surface is always grater than the pressure on the convex side. The difference of pressure is called as excess pressure.

(ii) (a) In case of liquid drop in air or an air bubble in a liquid the excess pressure, ∆P = 2T/ R.

(b) In case of a spherical film like a soap bubble in air, the excess pressure, ∆P=4T/R where R is the radius of the spherical surface.

(iii) When two bubbles of different sizes are in communication with each other, air passes from smaller one to larger one and larger one grows at the expense of smaller one. This happens due to pressure inside the smaller bubble being higher than that inside the larger bubble.

(iv) If two soap bubbles of different radii r1 and r2 (r1 > r2) coalesce to form a single double bubble having a common surface, then the radius of curvature of the interface is given by:

r = (r1r2 )/( r1 - r2 )

The interface will be concave towards smaller bubble and convex towards larger bubble.

(v) If two spherical soap bubbles of radii r1 and r2 coalesce in vacuum to form a bigger bubble of radius R, then there is no change in temperature and surface energy. This implies that surface area remains unchanged, i.e.,

4πr12 + 4πr22 = 4πR2 or R = √ ( r12 +r22)



(vi) If a small drop of water is squeezed between two parallel glass plates so that a very thin layer of large area is formed then the pressure inside the water layer is less than the pressure on the plates by (2T/d) (where d is the distance between the plates).

(vii) When a bigger drop splits into smaller drops, energy is required to break it but when smaller drops coalesce to form a bigger drop energy is released

(viii) The excess pressure in case of a drop or bubble in a liquid is **2T/R** and is directed from inside to outside, i. e., from concave to convex side. This result is also valid for meniscus of liquids, i.e., **in case of concave meniscus**

PA – PB = 2T/R i.e. PB = PO -2T/R

i.e., **pressure below the meniscus is lower than above it by 2T/R where R is the radius of meniscus.**

Similarly, **in case of convex meniscus**, PB – PA = 2T/R i.e. PB = PA + 2T/R = PO + 2T/R

**i.e., pressure below the meniscus is more than above it by (2T/R).**

5. **Angle of contact:**

(i) When the free surface of a liquid comes in contact with a solid, it becomes curved near the place of contact. The angle between the tangent to the liquid surface and the tangent to the solid surface at the point of contact (inside the liquid) is known as angle of contact.

(ii) The angle of contact is different for different pairs of solids and liquids. For mercury and glass, the angle of contact is 1350. For ordinary water and glass, the angle of contact is nearly 80.

(iii) Angle of contact increases on increasing the temperature.

(iv) Angle of contact decreases on adding soluble impurity in a liquid.

(v) Angle of contact does not depend on the inclination of the tube.

(vi) A water proofing agent increases the angle of contact from an acute angle to an obtuse angle.

(vii) (a) **If angle of contact is less than 900, then the liquid wets the surface, the liquid spreads on the surface, there is a capillary rise and the liquid meniscus is concave up.**

**(b) If the angle of contact is greater than 900, then the liquid does not wet the surface, the liquid does not spread on the surface, there is a capillary dip and the liquid meniscus is convex up.**

6**. Capillarity:**

(i) The phenomenon of rise or depression of liquids in a capillary tube is known as capillarity.

(ii) The rise or fall of liquid in a capillary (=h) is given by:

h= 2Tcosθ/rρg

where r is the radius of capillary tube; g, the acceleration due to gravity; ρ, the density of liquid and θ, the angle of contact.

(iii) In case of pure water and clean glass, angle of contact θ = 00; then capillary rise is: h= 2T/rρg

(iv) For a given liquid, capillary rise (h) is inversely proportional to the radius of capillary tube, i.e. h α 1/r

or h1r1 =h2r2

(v) Phenomenon of capillarity depends on the nature of liquid and solid both, i.e.,T ,θ and ρ.

(a) If **θ > 900, i.e., meniscus is convex** ,h will be negative, i.e., the liquid will descend in the capillary tube as actually found in case of mercury in a glass capillary.

(b) If **θ = 900**, i.e., **meniscus is plane**, h = 0, so no phenomenon of capillarity.

(c) If **θ < 900**, i.e., **meniscus is concave towards air**, h will be +ve, i.e., the liquid will rise in the capillary.

(vi) In equilibrium the height h is independent of the shape of capillary if the radius of meniscus remains same. This is why the vertical height h of a liquid column in capillaries of different shapes and sizes will be same if the radius of meniscus remains the same and also the vertical height of the liquid in a capillary does not change when it is inclined to the vertical.

(vii) In case of capillary of **insufficient length** i.e., **L<h**, the liquid will neither overflow from the upper end like a fountain nor will trickle along the vertical sides of the tube. The liquid after reaching the upper end will increase the radius of the meniscus without changing its nature such that : **hr = Lr'**.

(vii) **Applications of capillarity**:

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

(b) When a candle burns the molten wax rises up through the wick and there it burns.

(c) Action of towel in soaking up moisture from the body is due to capillary action of cotton in the towel.

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

**Fluid Mechanics -1 ( Pressure and Archimedes Principle)**

l. Density:

(i) In a fluid (which includes both liquid and gas),density ρ at a point is defined as:

(ii) Density is a SCALAR, as it has no directional properties in case of homogeneous isotropic substance.

(iii) It has dimensions [ML-3 ] and SI unit kg/m3 while CGS unit g/cc.

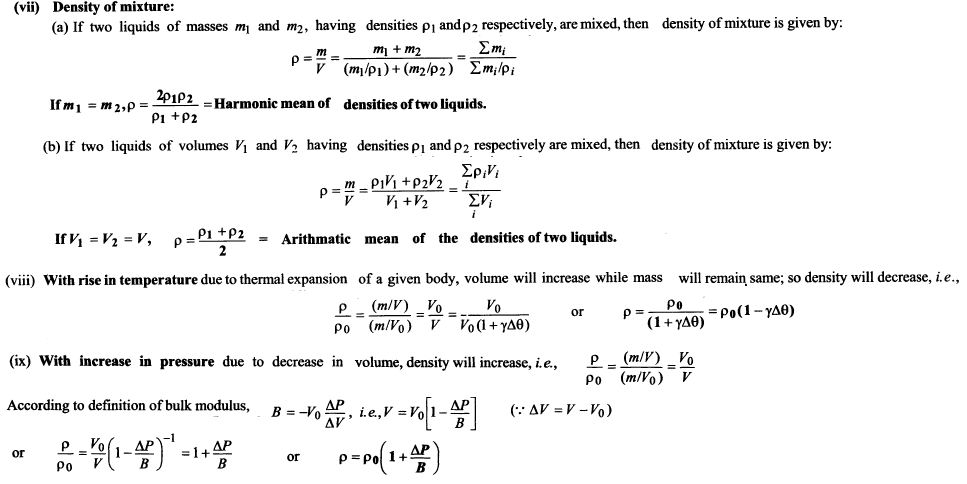
(iv) Density of a substance = mass/volume occupied by the substance

For a solid body, density of body = density of substance

but for a hollow body, density of body < density of substance

When two or more immiscible liquids of different densities are poured in a vessel, the liquid of the highest density will lie at the bottom while that of the lowest density at the top and interfaces will be plane.

(vi) **Relative density or specific gravity** is defined as: RD: (density of body/density of water)



**2. Pressure:**

(i) When a vessel having a hole is filled with a fluid, the fluid starts flowing out of the hole. But if the hole is covered with a plate of exactly same size as that of hole, the plate can remain in its position only if we exert some external force on the plate. This shows that fluid exerts some force on the plate to push it outwards. If ∆S is the area of the plate and ∆F is the normal force exerted by the fluid, the pressure at the hole is given by



(ii) If we consider a point P at a depth h below the surface of a liquid of density ρ. Then hydrostatic pressure P is given by P =Po + ρgh

Fig. 10.1 where Po represents the **atmospheric pressure**. The pressure difference between hydrostatic pressure and atmospheric pressure is called **gauge-pressure** and will be P - Po = ρgh

(iii) Though pressure is produced by a force that has directional properties and is a vector, but **pressure itself is a *scalar* as its direction (which is always normal to the area under consideration) is unique and not to be specified.**

(iv) It has dimensions [ML-1T-2] and SI unit N/m2 which is also called Pascal (Pa). Other practical units of pressure are atmosphere, bar or torr (or mm of Hg). They are related with each other as follows :

**1 atmosphere (atm) = 1.01 x 105 N/m2 = 1.01 x 105 Pa = 1.01 bar = 760 mm of Hg =760 torr**

(v) Pressure acts equally in all possible directions. If a pressure measuring device is at a given point in a fluid, whatever may be its orientation, the pressure remains the same.

(vi)Pressure always acts normal to the boundaries of the fluid because flowing ability of the fluids makes them unable to sustain a tangential force.

(vii) Pressure depends on the depth of the point below the surface (h), nature of liquid (ρ) and acceleration due to gravity (g) while it is independent of amount of liquid, shape of container or cross-sectional area considered. So, if a given liquid is filled in vessels of different shapes to same height, the pressure in each vessel's base will be the same, though the volume or weight of the Liquid in different vessels will be different.

(viii) Pressure will be same at all points in a Liquid lying at the same level. This is why the height of liquid is same in vessels of different shapes containing different amounts of the same liquid at rest when they are in communication with each other.

(ix) In case of a fluid P = Po + hρg so if Po is changed by ∆Po, then increase in pressure at a given point ∆P = ∆Po (as hρg is constant for a given point), i.e., **if an external pressure is applied to an enclosed fluid, it is transmitted undiminished to every position of the fluid and to the walls of container. This is called Pascal's law.**

(x) In case of a given mass of an ideal gas at constant temperature, P α1/V or PV = constant. This is called **Boyle's law.**

(xi) **Barometer** is used to measure atmospheric pressure while **manometer** measures pressure difference, i.e., gauge pressure.

**3. Archimedes' Principle and Buoyant Force:**

(i) According to Archimedes' principle, when a body is immersed partly or wholly in a fluid, it is buoyed up with a force equal to the weight of the fluid displaced by the body.

(ii) When a body is partly or wholly dipped into a fluid, the fluid exerts force on the body due to hydrostatic pressure. At any small portion of the surface of the body, the force exerted by the fluid is perpendicular to the surface and is equal to the pressure at that point multiplied by the Area. The resultant of all these constant forces is called upthrust or **Buoyant force.**

(iii) The magnitude of buoyant force is equal to weight of fluid displaced by the body. It acts vertically upwards (opposite to the weight of the body) through the centre of gravity of displaced fluid (called **centre of buoyancy**). This result is also valid for partly submerged bodies or a body in more than one fluid

(iv) Upthrust or Buoyant force is independent of all the factors of the body such as its mass ,size, density ,etc., except the volume of the body inside the fluid,

i.e. , **Thrust α Volume of body inside liquid**

This is the reason that two bodies of different masses, shapes and sizes may experience same thrust when their volumes inside a fluid are equal.

(v) Upthrust or Buoyant force depends on the nature of fluid, i.e., **Thrust α density of fluid (σ)**. This is why upthrust on a fully submerged body is more in sea water than in fresh water ('.' σsea > σfresh water ).

(vi) Upthrust or Buoyant force depends on acceleration due to gravity, i.e., ., **Thrust α g** So, if a lift is accelerated down with a < g, then **Thrust α Vin (g-a) σ** and in the state of free fall as a = g, **Thrust =0.**

(vii) Due to upthrust the weight of body will decrease, i.e.,

decrease in weight of the body= up thrust= weight of fluid displaced by the body

(viii) When a (sinking) solid is suspended from an independent support in a liquid the weight of liquid will increase by an amount equal to decrease in weight of the solid (i.e. up thrust). As for every action there is an equal and opposite reaction.

*(ix) If the solid (sinking or floating) of* ***weight a*** *is placed or suspended in a liquid of* ***weight b*** *by a support attached to the pan of weighing machine, then reading of balance will always be*

*(a – thrust ) + (b +thrust) = a+b*

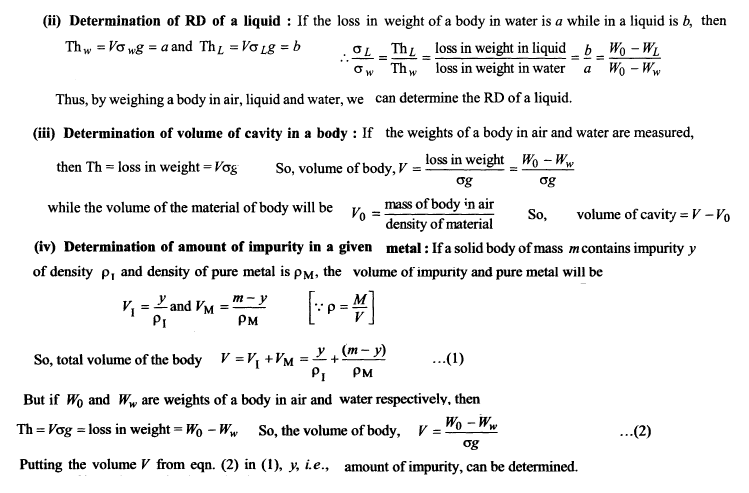
**Some important applications of Archimedes' Principe:**

(i) Determination of RD (relative density) of a body: According to definition of RD

**RD** = density of body /density of water = weight of body /weight of equal volume of water

= weight of body /upthrust due of water = weight of body /Loss in weight in water

= weight of body / (weight of body in air - weight of body in water) = **W0 /(WO – WW)**

Thus, by weighing a body first in air and then in water, we can determine the relative density of the body

**5. Floatation: Translatory equilibrium:**

(i) When a body of density ρB (which may be different from the density of material of body) and volume V is immersed in a liquid of density σ, following two forces act on the body:

(a) **The weight of body, W** **= mg =VρBg**, acting vertically downwards through centre of gravity of the body.

(b) **The upthrust**, **Thrust = Vσg**, acting vertically upwards through the centre of gravity of the displaced liquid, i. e., centre of buoyancy.

(ii) Depending upon relative magnitudes of above two forces, following three cases are possible:

**(a) The density of body is greater than that of liquid (i.e., ρB > σ).** In this situation as weight will be more than upthrust the body will sink.

**(b) The density of body is equal to the density of liquid (i.e. ρB = σ).** In this situation W = Th, so the body will float fully submerged in neutral equilibrium anywhere in the liquid.

**(c) The density of body is lesser than that of liquid (i.e. ρB < σ ).** In this situation W < Th, so the body will move upwards and in equilibrium will float **partially immersed** in the liquid such that

**W = Vinσg** or V **ρB** = **Vinσ**

**(iii) Important points:**

(a) A body will float in a liquid only and only if **ρB ≤ σ**.

(b) When a body is floating, weight of body is equal to upthrust, i.e., V **ρB** = **Vinσ** .

(c) In case of floating as W = Th, the apparent weight of the floating body will be zero i.e., Wapp= W-Th = o

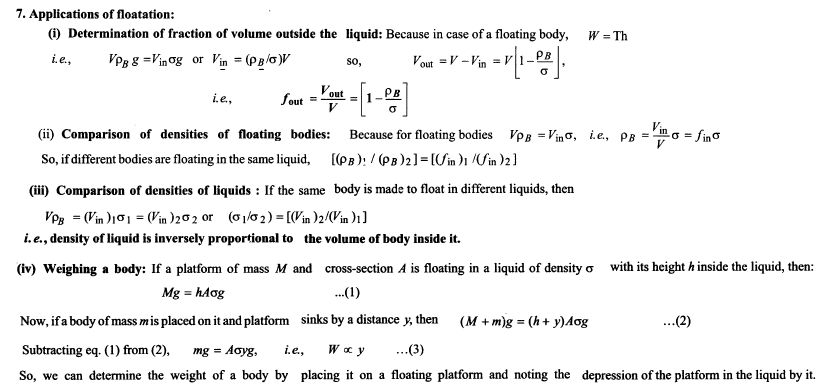
(d) In case of floating as W = Th implies V **ρB** = **Vinσ** the equilibrium of floating body is unaffected by variation in g though both thrust and weight depend on g.

**6. Floatation: Rotatory equilibrium**

(i) When a floating body is slightly tilted from equilibrium position, the centre of buoyancy B shifts to new position B'. The vertical line passing through the new centre of buoyancy and initial vertical line meet at a point M called **meta-centre**

(ii) If the meta-centre M is above the centre of gravity the couple due to weight of body (acting at centre of gravity of body in downward direction) and upthrust force (acting at new centre of buoyancy in upward direction) tends to bring the body back to its original position. **Hence, for rotational equilibrium of floating body the meta-centre must always be higher than the centre of gravity of the body.**

(iii) If meta-centre goes below centre of gravity, the couple formed due to weight and upthrust tends to topple the floating body.



**Fluid Mechanics -2 (Flow of Liquids, Bernoulli's Theorem and Viscosity)**

l. **Hydrodynamics:** The science of fluids in motion is called as hydrodynamics.

2. **Principle of continuity:**

(i) According to this principle, in case of steady flow of incompressible and non-viscous fluid through a tube of non-uniform cross-section, the product of the area of cross-section and the velocity of flow remains same at every point in the tube, i.e. Av= constant

(ii) Above equation is known as **equation of continuity** and **represents the conservation of mass** in case of moving fluids

(iii) If the liquids are assumed non-viscous, the velocity of flow is independent of the nature of liquid.

(iv) The velocity of flow will increase if cross-section decreases and vice-versa. This is why (a) deep water appears to be still, and; (b) falling stream of water becomes narrower.

**3.Bernoulli's theorem:**

(i) According to this theorem, in case of steady flow of incompressible and non-viscous fluid through a tube of non-uniform cross-section, the sum of the pressure, the potential energy per unit volume and the kinetic energy per unit volume is same at every point in the tube, i.e., **P + ρgh + (½)ρv2** = constant

(ii) Above equation is called Bernoulli's equation and represents **conservation of mechanical energy** in case of moving fluids.

(iii) **Drop of pressure when fluid moves from broader to narrower horizontal pipe**: According to continuity equation: Av = constant So, where the area is small, velocity will be large and vice-versa.

But by Bernoulli's equation for a horizontal pipe (i.e., h = constant) **P + (½)ρv2** = constant

i.e., **where the velocity is large, pressure will be small. Hence, when fluid flows from broader to narrower pipe, its velocity increases and so the pressure decreases**.

(iv) **Blowing off of roofs by wind storms**: During a tornado when a high speed wind blows over a roof of straw or tin, it creates a low pressure in accordance with Bernoulli's theorem. However, pressure below the roof is still atmospheric. So, due to this difference of pressure, the roof is lifted up and is then blown off by the wind.

(v) **Attraction between two closely parallel moving boats or buses**: When two boats or buses move side by side in the same direction, the water (or air) in the region between them moves faster than that on the remote sides. Consequently in accordance with Bernoulli's principle, the pressure between them is reduced and hence due to pressure difference they are pulled towards each other creating the so called attraction.

(vi) **Magnus effect**: When a spinning ball is thrown, it deviates from its usual path in flight. This effect is called magnus effect. This effect also occurs in accordance with Bernoulli's theorem

**4. Applications of Bernoulli's principle:**

(i) The action of aspirator, carburettor, paint-gun, scent spray or insect-sprayer is based on Bernoulli's principle. In all these, by means of motion of a piston in a cylinder high speed air is passed over a tube dipped in liquid to be sprayed.

High speed air creates low pressure over the tube due to which liquid rises in it and is then blown off in very small droplets with expelled air.

(ii) Working of aeroplane is also based on Bernoulli's principle.

(iii) Velocity of efflux:

(a) If a liquid is filled in a vessel upto height **H** and a hole is made at a depth **h** & below the free surface of the liquid, then velocity of liquid coming out from the hole is given by ***v* = √(2gh)**

which is the same speed that an object would acquire in falling from rest through a distance h. The velocity given by above equation is called velocity of efflux.

(b) The speed of liquid coming out of orifice is independent of the nature and quantity of liquid in the container or the area of the orifice.

(c) Greater is the distance of the hole from the free surface of liquid, greater will be the velocity of efflux (i.e., ***v* α √(h).**This is the reason that liquid flows out with maximum velocity from the orifice which is at maximum distance from the free surface of the liquid.

(d) As the vertical velocity of liquid at the orifice is zero and it is at a height H-h from the base.The time taken by the liquid to reach the base level t = **√(2(H-h)/g).**

(e) **Range of liquid flowing out from the orifice is R = vt = √(2gh) x √(2(H-h)/g) = 2√(h(H-h))**

This range will be maximum (=H) when h=H/2

(f) Range will be same if the orifice is at a depth h or (H - h) below the free surface or **range is same for liquid coming out of holes at same distance below the top and above the bottom.**

(g) If the hole is at the bottom of the tank, time t taken by the tank to be emptied **t = (A/Ao) √(2H/g)**

where Ao is the area of the orifice and A that of container.

**5. Viscosity and Newton's law of viscous force:**

(i) The property of a fluid due to which it opposes the relative motion between its different layers is called viscosity and the force between the layers opposing the relative motion viscous force. A briskly stirred fluid comes to rest after a short while because of viscosity.

(ii) Newton found that viscous force F acting on any layer of a fluid is directly proportional to its area A and to the velocity gradient at the layer, i.e.,

**F α A dv/dy or F = -ηAdv/dy**

where η is a constant called coefficient of viscosity.

-The negative sign signifies that viscous force on a layer acts in a direction opposite to relative velocity of layer.

(iii) Viscosity of layer depends only on the nature of fluid and is independent of area considered or velocity gradient.

(iv) Its dimensions are [ML-1T-1] and SI unit is Poiseuille (Pl) white CGS units dyne-sec/cm2 called Poise (P) with I PI = 10 Poise.

(V) Viscosity of liquids is much greater (say about 100 times more) than that of gases.

(vi) **In case of liquids viscosity increases with density while for gases it decreases with increase in density.**

(vii) **With rise in temperature the viscosity of liquids decreases while that of gases increases.**

(viii) **With increase in pressure, the viscosity of liquids (except water) increases while that of gases is practically independent of pressure.**

(ix) In case of steady flow of a liquid of viscosity η in a capillary tube of length L and radius r under a pressure difference P across it , the velocity of flow at a distance y from the axis is given by

***v* = (P/4ηL) (r2 –y2)** i.e., the profile of advancing liquid in a capillary is a parabola

Velocity of flow is maximum along the axis = **= (P r2/4ηL)**  and minimum (: zero)along the walls

(x) In case of steady flow of a liquid of viscosity η in a capillary tube of length L and radius r under a pressure difference P across it, the volume of liquid flowing per second is given by:

dQ/dt = **(πP r4/8ηL)**

**6. Stokes' law and terminal velocity:**

(i) When a body moves through a fluid, the fluid in contact with the body is dragged with it. This establishes relative motion in fluid layers near the body, due to which viscous force starts acting. The fluid exerts viscous force on the body to oppose its motion. The magnitude of the viscous force depends on the shape and size of the body, its speed and the viscosity of the fluid. Stokes established that if a sphere of radius r moves with velocity *v* through a fluid of viscosity η , the viscous force opposing the motion of the sphere is

**F = 6πηr*v*  [ Stoke’s Law]**

(ii)The terminal velocity of a sphere of radius r falling in a fluid of density σ and coefficient of viscosity η is given by:

where ρ is the density of the body

We note the following important points from above expression

(a) vT α r2 i.e. terminal velocity depends on the radius of the sphere, so if radius is made n times, terminal velocity will become n2 times

(b) vT depends on the density of the solid. Greater the density, greater will be the terminal velocity.

(c) vT depends on the nature of fluid. Greater the density and viscosity of the fluid, lesser will be the terminal velocity.

(d) vT α g, i.e., terminal velocity also depends on acceleration due to gravity 'g'. So, it will change with change of planet or in accelerated systems.

**7. Critical velocity and Reynold's number:**

(i) The maximum velocity up to which fluid motion remains steady is called critical velocity.

(ii) Reynold thru experiments established that in case of motion of fluids in thin tubes, critical velocity depends on the density(ρ), viscosity (η) of the fluid and radius r of the tube.

i.e. ***v*c α η/ρr or *v*c = NR [η/ρr ]**

where, **NR** is a dimensionless constant called Reynold's number.

(iii) *R*e is a dimensionless number and therefore, it remains same in any system of units.

-It is found that flow is streamline or laminar for *R*e less than 1000.

-The flow is turbulent for *R*e > 2000.

-The flow becomes unsteady for *R*e between 1000 and 2000.

(iv) From equation for critical velocity, it is also clear that if η = 0, vc =0, i.e**., zero critical velocity implies the motion is turbulent** (as critical velocity represents the maximum velocity upto which fluid motion is steady and that maximum velocity is zero here). **Viscosity thus appears to be a property of fluid which is responsible for orderliness and steady flow.**

**Home Assignment- Mechanical properties of Solids**

(Some constants Ysteel = 2.0 × 1011 N m-2 ; Bulk modulus of water = 2.2 × 109 N m–2; Bulk modulus of rubber is 9.8×108 N m–2; and the density of sea water is 103 kg m–3)

1. Define Elasticity and Plasticity ?
2. What is the reason for the elastic behaviour shown by solids ?
3. What do you mean by stress and strain ?
4. Define and write formula’s for different types of strains ?
5. Define Hooke’s law alongwith expression ?
6. Describe in detail alongwith graph the stress-strain curve ?
7. Define elastomers ?
8. What do you mean by elastic moduli ?
9. Define and derive expression for different type of elastic moduli?
10. Define elastic after effect and elastic fatigue ?
11. What do you mean by Poisson’s ratio ?
12. Write relation between Y,B,G and σ ?
13. Write an expression for effect of compression on the density of liquid ?
14. Which is more elastic rubber or steel explain?
15. Why springs are made up of steel and not of copper?

**NCERT Solved**

1. A structural steel rod has a radius of 10 mm and a length of 1.0 m. A 100 kN force stretches it along its length. Calculate (a) stress, (b) elongation, and (c) strain on the rod.
2. A copper wire of length 2.2 m and a steel wire of length 1.6 m, both of diameter 3.0 mm, are connected end to end. When stretched by a load, the net elongation is found to be 0.70 mm. Obtain the load applied.
3. The average depth of Indian Ocean is about 3000 m. Calculate the fractional compression, Δ*V/V***,** of water at the bottom of the ocean, given that the bulk modulus of water is 2.2 × 109 N m–2. (Take *g* = 10 m s–2)

**NCERT Unsolved**

1. Read the following two statements below carefully and state, with reasons, if it is true or false.
   1. The Young’s modulus of rubber is greater than that of steel;
   2. The stretching of a coil is determined by its shear modulus.
2. A rigid bar of mass 15 kg is supported symmetrically by three wires each 2.0 m long. Those at each end are of copper and the middle one is of iron. Determine the ratios of their diameters if each is to have the same tension.
3. A 14.5 kg mass, fastened to the end of a steel wire of unstretched length 1.0 m, is whirled in a vertical circle with an angular velocity of 2 rev/s at the bottom of the circle. The cross-sectional area of the wire is 0.065 cm2. Calculate the elongation of the wire when the mass is at the lowest point of its path.
4. What is the density of water at a depth where pressure is 80.0 atm, given that its density at the surface is 1.03 × 103 kg m–3?
5. Determine the volume contraction of a solid copper cube, 10 cm on an edge, when subjected to a hydraulic pressure of 7.0 × 106 Pa.
6. How much should the pressure on a litre of water be changed to compress it by 0.10%?

**Exemplar**

1. The Young’s modulus for steel is much more than that for rubber. For the same longitudinal strain, which one will have greater tensile stress?
2. Is stress a vector quantity?
3. Identical springs of steel and copper are equally stretched. On which, more work will have to be done?
4. What is the Young’s modulus for a perfect rigid body?
5. What is the Bulk modulus for a perfect rigid body?
6. A wire of length *L* and radius *r* is clamped rigidly at one end. When the other end of the wire is pulled by a force *f,* its length increases by *l.* Another wire of the same material of length 2*L* and radius 2*r,*is pulled by a force 2*f.* Find the increase in length of this wire.
7. Two identical solid balls, one of ivory and the other of wet-clay, are dropped from the same height on the floor. Which one will rise to a greater height after striking the floor and why?
8. A steel rod of length 2*l,* cross sectional area *A* and mass *M* is set rotating in a horizontal plane about an axis passing through the centre. If *Y* is the Young’s modulus for steel, find the extension in the length of the rod. (Assume the rod is uniform.)

**Home Assignment- Mechanical properties of Fluids**

1. Define 1 pascal ?
2. Write and explain the expression for variation of pressure with depth ?
3. Define Pascal’s law of transmission ?
4. Why does the walls of the dams are very wide at the bottom ?
5. What is the difference between absolute and guage pressure ?
6. Other than the obvious problem that occurs with freezing, why don’t we use water in a barometer in the place of mercury?
7. What is Archimedes’s principle?
8. A glass of water contains a single floating ice cube. When the ice melts, does the water level go up, go down, or remain the same?
9. When a person in a rowboat in a small pond throws an anchor overboard, does the water level of the pond go up, go down, or remain the same?
10. What are the different assumptions made in the ideal flow ? Explain in detail ?
11. What do you mean by a streamline?
12. What do you mean by a tube of flow?
13. Write and derive equation of continuity ?
14. What do you mean by volume flux ? Explain equation of continuity in terms of volume flux ?
15. Derive Bernoulli’s equation ?
16. Explain the working of Venturi tube and derive an expression for velocity thru narrow end ?
17. Define and derive Torricelli’s law ?
18. What do you mean by magnus effect ?
19. What do you mean by laminar flow ?
20. Draw velocity distribution diagram for laminar flow thru a circular pipe?
21. What do you mean by Viscosity? Write an expression for coefficient of viscosity η?
22. Define and derive stoke’s law?
23. Define and derive expression for terminal velocity?
24. What do you mean by Reynolds Number? What is it’s significance ?
25. Define surface tension and surface energy ?
26. Derive an expression for surface tension of a film?
27. What is angle of contact and what is it’s value for different liquids, explain in detail?
28. Derive an expression for pressure inside a drop and a soap bubble?
29. Derive an expression for capillary rise in water?
30. Define relative density?
31. What do you mean by hydrostatic paradox ?
32. Write different units for atmospheric pressure ?
33. Derive an expression for excess pressure inside an air bubble in a liquid ?
34. What do you mean by ‘Ascent Formula’ , write an expression for it ?
35. What will happen when a liquid will rise in a tube of insufficient length? Explain in detail ?
36. Derive an expression for radius of new bubble formed when two bubbles coalesce ?
37. Write an expression with diagram for radius of interface when two soap bubbles of different radii are in contact?

**NCERT**

1. What is the pressure on a swimmer 10 m below the surface of a lake?
2. The density of the atmosphere at sea level is 1.29 kg/m3.Assume that it does not change with altitude. Then how high would the atmosphere extend?
3. Explain why
   1. The blood pressure in humans is greater at the feet than at the brain
   2. Atmospheric pressure at a height of about 6 km decreases to nearly half of its value at the sea level, though the height of the atmosphere is more than 100 km
   3. Hydrostatic pressure is a scalar quantity even though pressure is force divided by area.
4. Explain why
   1. The angle of contact of mercury with glass is obtuse, while that of water with glass is acute.
   2. Water on a clean glass surface tends to spread out while mercury on the same surface tends to form drops. (Put differently, water wets glass while mercury does not.)
   3. Surface tension of a liquid is independent of the area of the surface
   4. Water with detergent dissolved in it should have small angles of contact.
   5. A drop of liquid under no external forces is always spherical in shape
5. Explain why
   1. To keep a piece of paper horizontal, you should blow over, not under, it
   2. When we try to close a water tap with our fingers, fast jets of water gush through the openings between our fingers
   3. The size of the needle of a syringe controls flow rate better than the thumb pressure exerted by a doctor while administering an injection
   4. A fluid flowing out of a small hole in a vessel results in a backward thrust on the vessel
6. Can Bernoulli’s equation be used to describe the flow of water through a rapid in a river? Explain.
7. Does it matter if one uses gauge instead of absolute pressures in applying Bernoulli’s equation ? Explain.

**Exemplar**

1. An ideal fluid flows through a pipe of circular cross-section made of two sections with diameters 2.5 cm and 3.75 cm. The ratio of the velocities in the two pipes is ......
2. Are viscosity and surface tension vector quantities?
3. The free surface of oil in a tanker, at rest, is horizontal. If the tanker starts accelerating the free surface will be titled by an angle θ. If the acceleration is *a* m/s2, what will be the slope of the free surface?
4. Two mercury droplets of radii 0.1 cm. and 0.2 cm. collapse into one single drop. What amount of energy is released? The surface tension of mercury *T*= 435.5 × 10–3 N/m.
5. If a drop of liquid breaks into smaller droplets, it results in lowering of temperature of the droplets. Let a drop of radius *R*, break into *N* small droplets each of radius *r*. Estimate the drop in temperature.

**Objective Questions**

**Section -1 Elasticity**

1. A wire can be broken by applying a load of 20 kg-wt. The force required to break the wire of twice the diameter is (a) 20 kg-wt (b) 5 kg-wt (c) 80 kg-wt (d) 160 kg-wt

2. A cable that can support a load W is cut into two equal parts. The maximum load that can be supported by either part is: (a) W/4 (b) W/2 (c) W (d) 2W

3. The breaking stress for a wire of unit cross-section is called as :

(a) yield point (b) tensile strength (c) elastic fatigue (d) Young's modulus

4. Wires A and B are made from the same material. A has twice the diameter and three times the length of B. If the elastic limits are not reached, when each is stretched by the same tension, the ratio of energy stored in A to that in B is: (a) 2:3 (b) 3:4 (c) 3:2 (d) 6:1 (e)12:1

5. A uniform steel wire of density 7800 kg/m3 is 2.5 m long and weighs 15.6 x l0-3 kg. It extends by 1.25 mm when loaded by 8 kg. Calculate the value of Young's modulus for steel

(a) l96 x l0ll N/cm2 (b) l.96 x l0ll N/m2 (c) l9.6 x l0ll N/m2 (d) 0.l96 x l0ll N/m2

6. A beam of metal supported at the two ends is loaded at the centre. The depression at the centre is proportional to: (a) Y2 (b) Y (c) 1/Y (d) 1/Y2

7. The Young's modulus of a perfectly rigid body is

(a) zero (b) unity (c) infinity (d) may have any finite non-zero value

8. The Bulk modulus of a perfectly rigid body is equal to:

(a) zero (b) unity (c) infinity (d) may have any finite non-zero value

9. The shear modulus of a liquid is:

(a) zero (b) unity (c) infinity (d) may have any finite non-zero value

10. A wire of cross-section 4 mm2 is stretched by 0.1 mm by a certain weight. How far (length) will the wire of same material and length but of area 8 mm2 stretch under the action of same force?

(a) 0.05 mm (b) 0.10 mm (c) 0.15 mm (d) 0.20 mm (e) 0.25 mm

11. The breaking stress of a material is 106 N/m2. If the density of the material is 3 x 103 kg/m3, what should be the length of the material so that it breaks by its own weight?

(a) 0.33 m (b) 3.33 m (c) 33.3 m (d) None of these

12. A long spring is stretched by 2cm and the potential energy is U. If the spring is stretched by l0cm, its potential energy will be: (a) U/25 (b) U/5 (c) 5U (d) 25U

13. A slightly conical wire of length L and end radii r1 and r2 is stretched by two forces F,F applied parallel to length in opposite directions and normal to end faces. If Y denotes the " Young's modulus, then extension produced is:(a) FL/πr12Y (b) FL/πr1Y (c) FL/πr1r2Y (d) FL Y /πr1r2

14. If Y and B represent Young's modulus and bulk modulus for a material, then in practice:

(a) Y<3B (b) Y = 3B (c) Y>3B (d) B = 3Y

15. If Y and η represent Young's modulus and rigidity for a material, then in practice:

(a) Y>2η (b) Y = 2η (c) Y<2η (d) η = 2Y

16. A uniform pressure P is exerted on all sides of a solid cube. It is heated through ∆t0 in order to bring its volume back to the value it had before the application of pressure. Then: (γ is the cubical coefficient of expansion.) (a) ∆t =P/Bγ (b) ∆t =B/Pγ (c) ∆t =PBγ (d) ∆t =Bγ/P

17. If B is the bulk modulus of a metal and a pressure P is applied uniformly on all sides of the metal with density D, then the fractional increase in density is given by:

(a) B/P (b) P/B (c) PD/B (d) BD/P

18. The bulk modulus of rubber is 9.l x 108 N /m2. To what depth (approximately) a rubber ball be taken in a lake so that its volume is decreased by 0.1%. (a) 25 m (b) 100 m (c) 200 m (d) 500 m

19. The length of a metal wire is L1, when the tension in it is T1 and is L2 when the tension is T2. The unstretched length of the wire is:

(a) √(L1 L2) (b) (L1 + L2)/2 (c) (L1T2 - L2T1)/(T2-T1) (d) (L1T2 + L2T1)/(T2+T1)

20. When a metal wire elongates by hanging a load on it, then fractional change in volume ∆V/V is proportional to : (a) (∆L/L) (b) ) (∆L/L)2  (c) ) (∆L/L)3 (d) ) √(∆L/L)



21. The graph shown was obtained from experimental measurements of the time period of oscillation T for different masses M placed in the scale pan on the lower end of the spring balance fig 8.4.The most likely reason for the line not passing through the origin is that the: (a) spring does not obey Hooke's law (b) amplitude of oscillation was too large

(c) clock used needed regulating (d) mass of the pan was not neglected

22. The Young's modulus of brass and steel are respectively l x l010 N/m2 and 2 x 1010 N/m2. A brass wire and a steel wire of the same length are extended by I mm under the same force; the radii of brass and steel wires are Rb and Rs respectively. Then

(a) Rs = Rb√2 (b) Rs = Rb/√2 (c) Rs = 4Rb (d) Rs = Rb/4

23. A steel wire is suspended vertically from a rigid support when loaded with a weight in air, it extends by La and when the weight is immersed completely in water, the extension is reduced to Lw. Then the relative density of the material of the weight is:

(a) La/Lw (b) La/La -Lw (c) Lw/ La -Lw (d) Lw/La

24. The normal density of gold is ρ and its bulk modulus is K. The increase in density of a lump of gold when a pressure P is applied uniformly on all sides is: (a) ρP/K (b) ρK/P (c)P/ρK (d) K/ρP



25. The potential energy U between two atoms in a diatomic molecule as a function of the distance *x* between atoms has been shown in the adjoining figure 8.5. The atoms are:

(a) attracted when *x* lies between A and B and are repelled when *x* lies between B and C

(b) attracted when *x* lies between B and C are repelled when *x* lies between A and B

(c) attracted when they reach B (d) repelled when they reach B

26. The length of an elastic string is *a* metre when the tension is 4 newton and *b* metre when the tension is 5 newton. The length in metres when the tension is 9 newton is

(a) 4a -5b (b) 5b -4a (c)9b -9a (d) a+b

27. A steel ring of radius ***r*** and cross-sectional area **A** is fitted on to a wooden disc of radius R(R > r) If Young's modulus be Y, then the force with which the steel ring is expanded is:

(a) AYR/r (b) AY(R-r)/r (c)Y(R –r)/Ar (d) Yr/AR

28. A thick rope of rubber of density l.5 x 103 kg/m3 and Young's modulus 5x l06 N/m2, 8m in length is hung from the ceiling of a room. The increase in its length due to its own weight is: (g = l0m/s2)

(a) 9.6 x 10-2m (b) 19.2 x 10-7m (c) 9.6 x 10-7m (d) 9.6 m

29. Two cylinders A and B of the same material have same length, their radii being in the ratio of 1:2 respectively. The two are joined end to end as shown in the adjoining figure 8.7. The upper end of A is rigidly fixed. The lower end of B is twisted through an angle θ, the angle of twist of the cylinder A is:(a) 15θ/16 (b) 16θ/15 (c) 16θ/17 (d) 17θ/16

30. A copper wire and a steel wire of the same diameter and length are joined end to end and a force is applied which stretches their combined length by 1 cm. Then the two wires will have:

(a) the same stress and strain (b) the same stress but different strains

(c) the same strain but different stresses (d) different stresses and strains

31. A thin walled circular tube of mean radius 8 cm and thickness 0.04 cm is melted up and recast into a solid rod of the same length. The ratio of their torsional rigidities in the two cases is:

**Surface Tension**

32. If C is the radius of the sphere of influence of a liquid, then the thickness of the surface film is equal to:

(a) C (b) 2C (c) C/2 (d) zero

33. If FA and FC denote cohesive and adhesive force on a liquid molecule near the surface of a solid, then the surface of liquid is concave, when:(a) FA<FC/√2 (b) FA=FC/√2 (c) FA>FC/√2 (d) FA>FC

34. If FA and FC denote cohesive and adhesive force on a liquid molecule near the surface of a solid, then the angle of contact of a liquid surface with a solid surface is 900 when:

:(a) FA<FC/√2 (b) FA=FC/√2 (c) FA>FC/√2 (d) FA>FC

35. When charge is given to a soap bubble, it shows:

(a) a decrease in size (b) no change in size (c) an increase in size

(d) sometimes an increase and sometimes a decrease in size

36. Two soap bubbles, each with radius r coalesce in vacuum under isothermal conditions to form a bigger bubble of radius R. Then R is equal to:

37. A soap bubble of radius r1 is placed on another soap bubble of radius r2(r1<r2). The radius R of the soapy film separating the two bubbles is :

38. A cylindrical vessel with a circular hole of radius 0.2 mm in its bottom, is filled with water. If surface tension of water is equal to 70 dyne per cm, density of water is 1 gm/cm3 and g is equal to 980 cm/sec2, then the maximum height to which the vessel can be filled without water flowing out of the hole is nearly:

(a) zero (b) 14.28 cm (c) 7.14 cm (d) 0.714 cm

39. The lower end of a capillary tube of radius r is placed vertically in water. Then, with the rise of water in the capillary, heat evolved is( where d is the density) :

(a) +π2r2h2dg/J (b) +πr2h2dg/2J (c) - πr2h2dg/2J (d) - πr2h2dg/J

40. Two glass plates are separated by water. If surface tension of water is 75 dynes per cm and area of each plate wetted by water is 8 cm2 and the distance between the plates is 0.12 mm, then the force applied to separate the two plates in dynes is: (a) 102 (b) 104 (c) 105 (d) 106

41. Liquid rises to a height of 2 cm in a capillary tube. The angle of contact between the solid and the liquid is zero. The tube is depressed more now so that the top of the capillary is only 1 cm above the liquid. Then, the apparent angle of contact between the solid and the liquid is :

(a) 00 (b) 300 (c) 600 (d) 900

42. An air bubble of radius r in water is at a depth h below the water surface at some instant. If P is atmospheric pressure, d and T are density and surface tension of water respectively, the pressure inside the bubble will be: (a) P +hdg – (4T/r) (b) P +hdg + (2T/r) (c) P +hdg – (2T/r) (d) P +hdg + (4T/r)

43.In a surface tension experiment with a capillary tube water rises upto 0.1 m. If the same experiment is repeated in an artificial satellite, which is revolving around the earth; water will rise in the capillary tube upto a height of (a) 0.1 m (b) 0.2 m (c) 0.98 m (d) full length of tube

44. Water rises in a capillary tube to a certain height such that the upward force due to surface tension is balanced by 75 x 10-4 N force due to the weight of the liquid. If the surface tension of water is 6x l0-2 N/m, the inner circumference of the capillary tube must be:

(a) l.25 x l0-2m (b) 0.5 x l0-2m (c) 6.5 x l0-2m (d) 12.5 x l0-2m

45. A U-tube is such that the diameter of one limb is 0.4 mm and that of other is d mm. If the surface tension of water contained in the tube is 0.07 N/m and the difference in the levels of liquid in the limbs is 3.6 cm, then the value of d is:

(a) l.6 x l0-3 m (b) 0.4 x l0-3 m (c) 8 x l0-3 m (d) 4 x l0-3 m

46. A drop of liquid pressed between two glass plates spreads into a circle of diameter 10 cm. Thickness of the liquid film is 0.5 mm and coefficient of surface tension is 70 x 10-3 N/m. The force required to pull them apart : (a) 4.4 N (b) 1.1 N (c) 2.2 N (d) 3.6 N

47. A spherical soap bubble of radius 1 cm is formed inside another of radius 3 cm. The radius of a single soap bubble which maintains the same pressure difference as inside the smaller and outside the larger soap bubble is: (a) 0.75 cm (b) 0.75 m (c) 7.5 cm (d) 7.5 m

48. When a capillary tube is dipped in a liquid the capillary rise is h1, when the inner surface is coated with wax, the capillary rise is h2,then: (a) h1 = h2 (b) h1 < h2 (c) h1 > h2 (d) none

49. A needle is 7.5 cm long. Assuming that needle is not wetted by water, how heavy can it be and still floated on water? (T =70 dyne/cm) (a) 1.07 gm-wt (b) 1.07N (c) 1.07 dyne (d) 1 kg-wt

50. The material of wire has specific gravity 8. If it is not wetted by water, what is the maximum diameter of the wire that will float on the surface of water? (T = 70dyne/cm)

(a) 0.75 mm (b) 1.5 mm (c) 1.5 cm (d) None of these

51. A ring is cut from a platinum tube 8.5 cm internal and 8.7 cm external diameter. It is supported horizontally from a pan of a balance so that it comes in contact with the water in a glass vessel. What is the surface tension of water if an extra 3.97 gm-weight is required to pull it away from water?(g =980 cm/s2)

(a) 72.13 dyne/cm (b) 72.13 N/m (c) 7.213 dyne/m (d) None of these

52. What is the potential energy of the soap film formed on a frame of area 4 x l0-3 m2 ? If the area of the film is reduced to half, what is the change in its potential energy?(Surface tension =40 x 10-3 N/m);

(a) 32 x 10-5 J (b) 16 x 10-5 J (c) 8 x 10-5 J (d) 16 x 10-3 J

53. With rise of temperature the surface tension of a liquid:

(a) decreases (b) increases (c) remains constant (d) none of these

54. Water rises to a height of 10 cm in a capillary tube and mercury falls to a depth of 3.42 cm in the same capillary tube. If the density of mercury is 13.6 gm/cm3 and angle of contact is 1350, the ratio of surface tension for water and mercury is: (Angle of contact for water and glass is 80)

(a) 1 :0.5 (b) 1 :3 (c) 1 :6.5 (d) 1.5: I

55. Liquid reaches an equilibrium as shown in fig 9.6,in a capillary tube of internal radius r. If the surface tension of the liquid is T, the angle of contact θ and density of liquid ρ, then the pressure difference between P and Q is :

(a) 2Tcosθ /r (b) T/rcosθ (c) 2T/rcosθ (d) 4Tcosθ /r

56. Two unequal soap bubbles are formed one on each side of a tube closed in the middle by a tap. What happens when the tap is opened to put the two bubbles in communication?

(a) No air passes in any direction as the pressures are the same on two sides of the tap

(b) Larger bubble shrinks and smaller bubble increases in size till they become equal in size

(c) Smaller bubble gradually collapses and the bigger one increases in size

(d) None of the above

57. A soap bubble in vacuum has a radius of 3 cm and another soap bubble in vacuum has a radius of 4 cm. If the two bubbles coalesce under isothermal conditions then the radius of the new bubble is:

(a) 2.3 cm (b) 4.5 cm (c) 5 cm (d) 7 cm

58. 1000 drops of water all of same size join together to form a single drop and the energy released raises the temperature of the drop. Given that T is the surface tension of water, r the radius of each small drop, ρ the density of liquid, J the mechanical equivalent of heat. What is the rise in temperature?

(a) T/Jr (b) 10T/Jr (c) 100T/Jr (d) none of these

59. Liquid drops are falling slowly one by one from a vertical glass tube. Establish a relation between the weight W of a drop, the surface tension T and the radius r of the tube (θ =00)

(a) W =πr2T (b) W =2πrT (c) W = 2πr2T (d) W = 4πr3T/3

60. If a capillary tube is dipped into liquid and the levels of the liquid inside and outside are same, then the angle of contact is: (a) 00 (b) 900 (c) 450 (d) 300

**Fluid Mechanics -1 ( Pressure and Archimedes Principle)**

61. In case of a hollow body, if ρh and ρs, represent the densities of hollow body and solid body having same mass respectively, then:

(a) ρh = ρs (b) ρh < ρs (c) ρh > ρs (d) none of these

62. A dam for water reservoir is built thicker at the bottom than at the top because:

(a) pressure of water is very large at the bottom due to its large depth

(b) water is likely to have more density at the bottom due to its large depth

(c) quantity of water at the bottom is large (d) none of the above

63. The height to which a cylindrical vessel be filled with a homogeneous fluid, to make the average force with which the fluid presses the side of the vessel equal to the force exerted by the liquid on the bottom of the vessel, is equal to :(a) half of the radius of the vessel (b) radius of the vessel

(c) one-fourth of the radius of the vessel (d) three-fourth of the radius of the vessel

64. As a bubble comes from the bottom of a lake to the top, its radius:

(a) increases (b) decreases (c) does not change (d) becomes zero

65. An inverted bell lying at the bottom of a lake 47.6 m deep has 50 cm3 of air trapped in it. The bell is brought to the surface of the lake. The volume of the trapped air will be: (atmospheric pressure : 70 cm of Hg and density of Hg = 13.6 gm/cc ) : (a) 350 cm3 (b) 300 cm3 (c) 250 cm3 (d) 22 cm3

66. A boy is carrying a bucket of water in one hand and a jug of plastic in the other. After transferring the plastic jug to the bucket (in which it floats) the boy will carry:

(a) same load as before (b) more load as before (c) less load as before

(d) either less or more load, depending on the density of plastic

67. A body floats with one-third of its volume outside water and3/4 of its volume outside another liquid. The density of another liquid in gm/cc is : (a) 9/4 (b) 4/9 (c) 8/3 (d) 3/8

68. A bird resting on the floor of an airtight box which is being carried by a boy, starts flying. The boy will feel that the box is now: (a) heavier (b) lighter (c) same in weight

(d) lighter in the beginning and heavier later

69.A parrot sitting on the floor of a wire cage which is being carried by a boy, starts flying. The boy will feel that the box is now: (a) heavier (b) lighter (c) same in weight

(d) lighter in the beginning and heavier later

70.Two solid pieces, one of gold and the other of silver when immersed completely in water have equal weights. When weighed in air: (a) the gold piece will weigh more (b) the silver piece will weigh more

(c) they will have the same weight (d) both of them weigh less than they weighed in water

71. A raft of wood (density 600 kg/m3) of mass 120 kg floats in water. How much weight can be put on the raft to make it just sink? (a) 120 kg (b) 200 kg (c) 40 kg (d) 80 kg

72. An iceberg is floating partly immersed in sea water, the density of sea water is 1.03 g/cm3 and that of ice is 0.92 gm/cm3.The fraction of the total volume of the iceberg above sea level is

(a) 8.1% (b) 11% (c) 34% (d) 0.8%

73. A steel ball is floating in a trough of mercury. If we fill the empty part of the trough with water, what will happen to the steel ball? (a) It will continue in its position (b) It will move up

(c) It will move down (d) It will execute vertical oscillations

74. A piece of ice is floating in a jar containing water. When the ice melts, then the level of water

(a) rises (b) falls (c) remains unchanged (d) rises or falls depending upon the mass of ice

75. A body floats in a liquid contained in a beaker. The whole system starts falling freely under gravity. The upthurst on the body due to the fluid is : (a) zero (b) equal to the weight of the liquid displaced

(c) equal to the weight of the body in air (d) equal to the weight of the immersed body

76. If there were a smaller gravitational effect, which of the following forces do you think would alter in some respect : (a) Viscous forces (b) Archimedes' uplift (c) Electrostatic forces (d) Nuclear forces

77. A body is just floating in a liquid (their densities are equal).If the body is slightly pressed down and released it will: (a) start oscillating (b) sink to the bottom

(c) come back to the same position immediately (d) come back to the same position slowly

78. Find the density of a block of wood that floats in water with 0.1 of its volume above water :

(a) 0.9 gm/cc (b) 0.9 (c) 0.1gm/cc (d) 0.1

79. A balloon of volume 1500 m3 and weighing 1650 kg with all its equipment is filled with helium (density 0.2kg/m3). If the density of air is 1.3 kg/m3, the pull on the rope tied to the balloon will be:

(a) zero (b) 300 kg (c) 16.5 kg (d) 1950kg

80. A cork ball is floating on the surface of water in a beaker. The beaker is covered with a bell jar and the air is evacuated. What will happen to the ball? (a) Sink a little (b) Rise a little

(c) Remain unchanged (d) Sink completely

81. In making an alloy, a substance of specific gravity s1, and mass m1 is mixed with another substance of specific gravity s2 and mass m2 ; then the specific gravity of the alloy is



82. Two substances of densities ρ1 and ρ2 are mixed in equal volume and the relative density of mixture is 4. When they are mixed in equal masses, the relative density of the mixture is 3.The values of ρ1 and ρ2 are

(a) ρ1 = 6 and ρ2 = 2 (b) ρ1 = 3 and ρ2 = 5 (c) ρ1 = 12 and ρ2 = 4 (d) none of these

83. A wooden cube just floats inside water, when a 200 g mass is placed on it. When the mass is removed the cube is 2 cm above the water level. The size of the cube is:

(a) 5 cm (b) l0 cm (c) 15 cm (d) 20 cm

84. A body of volume 100 cc floats immersed completely in water contained in a jar. The mass of water and jar before immersion of the body was 700 g. After immersion mass of water and jar will be:

(a) 500 g (b) 700 g (c) 100 g (d) 800 g

85. A block of aluminium of mass l kg and volume 3.6 x 10-4 m3 is suspended from a string and then completely immersed in a container of water. The decrease in tension in the string after immersion is:

(a) 9.8 N (b) 6.2 N (c) 3.6 N (d) 1.0 N

86. A wooden ball of density *D* is immersed in water of density *d* to a depth *h* below the surface of water and then released. Upto what height will the ball jump out of water?

(a) dh/D (b) (d/D -1)h (c) h (d) zero

87. An open vessel containing water is given a constant acceleration *a* in the horizontal direction. Then, the free surface of water gets sloped with the horizontal at an angle θ given by:



88. A cubical block of wood of specific gravity 0.5 and a chunk of concrete of specific gravity 2.5 are fastened together. The ratio of the mass of wood to the mass of concrete which makes the combination to float with its entire volume submerged under water is: (a) 1/5 (b) l/3 (c) 3/5 (d) 2/5

**Fluid Mechanics -2 (Flow of Liquids, Bernoulli's Theorem and Viscosity)**

89. Viscosity of gases is:

(a) about hundred times less than those of liquids (b) about twenty times less than those of liquids

(c)about five hundred times less than those of liquids (d)about ten hundred times less than those of liquids

90. The light machine oil used for lubrication is about:

(a) one hundred times more viscous than water (b) ten times more viscous than water

(c) one thousand times more viscous than water (d) ten times less viscous than water

91. Which of the following has the greatest viscosity?

(a) Hydrogen (b) Air (c)Water (d)Ammonia

92. The profile of advancing liquid in a tube is a:

(a)straight line (b)circle (c)parabola (d)hyperbola

93. If the velocity of the fluid is the same at a given point at all times, then the flow is

(a) turbulent (b) rapid (c) viscous (d) stream-lined

94. The aerofoils are so designed that the speed of air:

(a) on top side is more than on lower side (b) on top side is less than on lower side

(c) is same on both sides (d) is turbulent

95. If a small sphere is let fall vertically in a large quantity of still liquid of density smaller than that of the material of the sphere: (a) at first its velocity increases, but soon approaches a constant value

(b) it falls with a constant velocity all along from the very beginning

(c) at first it falls with a constant velocity which after some time goes on decreasing

(d) nothing can be said about its motion

96. A ball of mass m and radius r is released in viscous liquid. The value of its terminal velocity is proportional to: (a) 1/r only (b) m/r (c) √(m/r) (d) m only

97. The terminal velocity *v* of a small steel ball of radius r falling under gravity through a column of viscous liquid of coefficient of viscosity η depends on mass of the ball m, acceleration due to gravity g, coefficient of viscosity η and radius r. Which of the following relations is dimensionally correct?

(a) *v* α mgr/η (b) *v* α mgrη (c) *v* α mg/rη (d) *v* α mgη/r

98. The rate of outflow of liquid through an orifice does not depend upon:

(a) radius of the orifice (b) height of liquid column

(c) acceleration due to gravity (d) density of the liquid

99. In the figure 11.1 given below the flow of liquid through a horizontal pipe. Three tubes A, B and C are connected to the pipe. The radii of the tubes A, B and C at the junction are respectively 2 cm, I cm and 2 cm. It can be said that the: (a) height of the liquid in the tube A is maximum

(b) height of the liquid in the tubes A and B is the same

(c) height of the liquid in all the three tubes is the same

(d) height of the liquid in the tubes A and C is the same

100. A tank is filled with water upto a height H figure 11.2. Water is allowed to come out of a hole P in one of the walls at a depth D below the surface of water. Express the horizontal distance x in terms of H and D:

(a) *x =[D(H-D)]1/2* (b) *x =[ D(H-D)/2 ]1/2*

(c) *x =2 [D(H-D)]1/2* (d) *x = 4 [D(H-D)]1/2*



101.As shown in the adjoining figure 11.3, water squirts horizontally out of two small holes in the side of the cylinder and the two streams strike the ground at the same point. If the hole Q is at a height h above the ground and the level of water stands at height H above the ground, then the height of P above ground level is(a) *2h*  (b) *H/h* (c) *H-h* (d) *H/2*

102. A vessel of area of cross-section A has liquid to a height H. There is a hole at the bottom of vessel having area of cross-section *a*. The time taken to decrease the level from Hl to H2 will be (see review for hint) :



103. A gale blows over a house. The force due to gale on the roof is:

(a) in the downward direction (b) in the upward direction

(c) in the horizontal direction (d) zero

104. A rectangular vessel when full of water takes l0 minutes to be emptied through an orifice in its bottom. How much time will it take to be emptied when half filled with water?

(a) 9 minute (b) 7 minute (c) 5 minute (d) 3 minute

105. A cylinder containing water stands on a table of height H. A small hole is punched in the side of cylinder at its base. The stream of water strikes the ground at a horizontal distance R from the table. Then, the depth of water in the cylinder is: (a) H (b) R (c) √(RH) (d) R2/4H

106. If *A* denotes the area of free surface of a liquid and & *h* the depth of an orifice of area of cross-section *a*, below the liquid surface, then, the velocity *v* of flow through the orifice is given by:



107. More viscous oil is used in summer than in winter in motors due to:

(a) rise in temperature in summer; the viscosity of oil decreases

(b) rise in temperature in summer; viscosity of oil increases

(c) S.T. of oil decreases (d) S.T. of oil increases

108. Water contained in a tank flows through an orifice of diameter 2 cm, under a constant pressure difference of 10 cm of water column. The rate of flow of water through the orifice in cc/sec is:

(a) 44 (b) 4.4 (c) 440 (d) 4400

109. A spherical solid ball of volume V is made of a material of density ρ1. It is falling through a liquid of density ρ2 (ρ2<ρ1 ) Assume that the liquid applies a viscous force on the ball that is proportional to the square of its speed *v*, i. e., Fviscous = - k v2 (k> 0). The terminal speed of the ball is :



110. A volume V of a viscous liquid flows per unit time due to a pressure head ∆P along a pipe of diameter *d* and length *l*. Instead of this pipe, a set of four pipes each of diameter *d/2* and length *2l* is connected to the same pressure head ∆P. Now the volume of liquid flowing per unit time is:

(a) V/16 (b) V/8 (c) V/4 (d) V

111. A small sphere of mass M is dropped from a great height. After it has fallen 100 metres, it has attained its terminal velocity and continues to fall at that speed. The work done by air friction against the sphere during the first 100 metres of fall is:

(a) greater than the work done by air friction in the second 100 metres

(b) less than the work done by air friction in the second 100 metres

(c) equal to 100 mg (d) greater than 100 mg

112. We have three beakers A, B and C containing glycerine, water and kerosene respectively. They are stirred vigorously and placed on a table. The liquid which comes to rest at the earliest is:

(a) glycerine (b) water (c) kerosene (d) all of them at the same time

113. In areas far removed from the tanks, the water does not rise to desired heights. This is because the pressure falls due to: (a) gravity (b) density (c) surface tension (d) viscosity

114. In a laminar flow the velocity of the liquid in contact with the walls of the tube is:

(a) zero (b)maximum (c) in between zero & maximum (d) equal to critical velocity

115. In a turbulent flow, the velocity of the liquid molecules in contact with the walls of the tube is:

(a) zero (b)maximum (c) equal to critical velocity (d) in between zero & maximum

116. The value of coefficient of viscosity, in comparison to coefficient of friction, is:

(a) very large (b) very small (c) nearly same (d) eight to ten times more

117. The vertical sections of a wing of a fan are shown in fig 1.Maximum up thrust is in:



118. A steadily flowing liquid enters a wide tube and continues to flow steadily. What will be nature of flow in the widened part of the tube?(a) Crowded (b) Widened

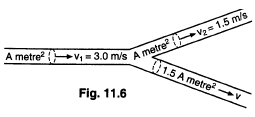
(c) Will remain same as before (d) May be crowded or widened

119. A liquid is flowing through a tube of varying diameter. The rate (R) of flow of liquid in any portion and the diameter (*d*) of the tube in that portion are related as:

(a) R α d (b) R α 1/d (c) R α 1/d2 (d) none of these

120. A hole is made at the bottom of a tank filled with water (density = 103 kg/m3 ). If the total pressure at the bottom of the tank is three atmosphere (l atmosphere = 105 N/m2), then the velocity of efflux is:

(a) √400 m/s (b) √200 m/s (c) √600 m/s (d) √500 m/s



121. An incompressible liquid flows through a horizontal tube as shown in the figure 11.6. Then, the velocity v of the fluid is:

(a) 3 m/s (b) 1.5 m/s

(c) 1 m/s (d) 2.25 m/s

122. Stream-line flow is more likely for liquids with:

(a) low density and low viscosity (b) high viscosity and high density

(c) high viscosity and low density (d) low viscosity and high density

123. A solid sphere falls with a terminal velocity of l0 cm/sec in the earth's gravitational field. If it is allowed to fall in a region outside the gravitational field of the earth, the terminal velocity will be:

(a) equal to 10 cm/sec (b) more than l0 cm/sec (c) less than l0 cm/sec (d) zero

124. A small drop of water falls from rest through a large height h in air; the final velocity is:

(a) proportional to √h (b) proportional to h

(c) inversely proportional to h (d) almost independent of h

125. A spherical body falling through a viscous liquid of infinite extent ultimately attains a constant value, when: (a) upthrust + weight = viscous drag (b) weight + viscous drag = upthrust

(c) viscous drag + upthrust = weight (d) viscous drag + upthrust > weight

126. A spherical body is dropped in a viscous liquid of infinite extent. What happens to the net force acting on it? (a) It goes on increasing (b) It goes on decreasing, till it becomes zero

 (c) First increases then decreases (d) None of the above

127. Figure 11.4 shows a capillary tube C dipped in a liquid that wets it. The liquid rises to a point A. If we blow air through the horizontal tube H , what will be happen to the liquid column in the capillary tube?

(a) Level will rise above A (b) Level will fall below A

(c) Level will remain at A (d) It is difficult to predict

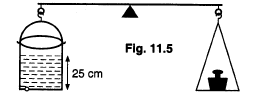
128. The pans of a physical balance are in equilibrium. Air is blown under the right hand pan; then the right hand pan will: (a) move up (b) move down (c) move erratically (d) remain at the same level

129. A cylindrical tank has a hole of l cm2 in its bottom. If the water is allowed to flow into the tank from a tube above it at the rate of 70 cm3/s. Then the maximum height upto which water can rise in the tank is:

(a) 2.5 cm (b) 5 cm (c) 10cm (d) 0.25 cm

130.A cylinder containing water upto a height of 25cm has a hole of cross-section 0.25 cm2 in its bottom fig 11.5. It is counterpoised in a balance. What is the initial change in the balancing weight when water begins to flow out? (a) Increase of 12.5 gm-wt (b) Increase of 6.25 gm-wt

(c) Decrease of 12.5 gm-wt (d) Decrease of 6.25 gm-wt



**Answers Objective (Mechanical Properties of Solids & Fluids)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1. C | 1. C | 1. B | 1. B | 1. B | 1. C |
| 1. C | 1. C | 1. A | 1. A | 1. C | 1. D |
| 1. C | 1. A | 1. A | 1. A | 1. B | 1. B |
| 1. C | 1. A | 1. D | 1. B | 1. B | 1. A |
| 1. B | 1. B | 1. B | 1. A | 1. C | 1. B |
| 1. C | 1. A | 1. C | 1. B | 1. C | 1. C |
| 1. D | 1. C | 1. B | 1. C | 1. C | 1. B |
| 1. D | 1. D | 1. C | 1. C | 1. A | 1. C |
| 1. A | 1. B | 1. A | 1. B | 1. A | 1. C |
| 1. A | 1. C | 1. C | 1. D | 1. B | 1. B |
| 1. B | 1. A | 1. B | 1. A | 1. B | 1. A |
| 1. C | 1. C | 1. B | 1. B | 1. D | 1. B |
| 1. B | 1. C | 1. A | 1. B | 1. B | 1. A |
| 1. A | 1. A | 1. C | 1. A | 1. B | 1. D |
| 1. C | 1. B | 1. A | 1. C | 1. A | 1. A |
| 1. C | 1. C | 1. D | 1. A | 1. A | 1. B |
| 1. C | 1. D | 1. D | 1. C | 1. C | 1. A |
| 1. B | 1. B | 1. D | 1. D | 1. A | 1. C |
| 1. A | 1. B | 1. B | 1. A | 1. D | 1. A |
| 1. D | 1. B | 1. A | 1. B | 1. D | 1. A |
| 1. C | 1. C | 1. D | 1. D | 1. C | 1. B |
| 1. A | 1. B | 1. A | 1. C |  |  |

**Explanations (Mechanical Properties of Solids & Fluids)**

