Chapter 7

Properties of Bulk Matter

Topic 1: Mechanical Properties of Solids

Revision Notes

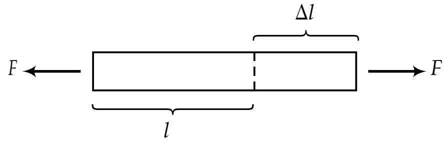
- **Elastic behaviour :**

Elasticity is the ability of an object/material to return to its normal shape after the removal of deforming force.

Stress-strain

- **Strain :**

Strain is the amount of deformation which an object faces in stretching in comparison to their original size and shape.



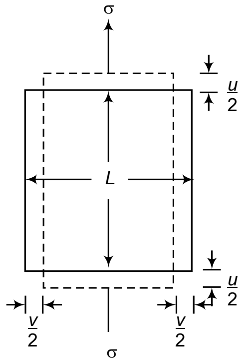
Strain is the change in dimensions of a material as a result of an applied stress.

The formula for strain is $\varepsilon = \Delta l/l$ where symbols have usual meanings

Strain has no dimensions and units because of complete ratio.

- **Tensile Strain**

It is a function of stress which is applied.



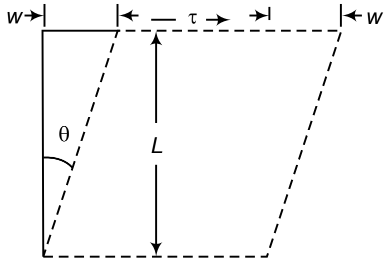
A tensile stress (s) will produce a tensile strain (ε).

The nominal tensile strain is $\varepsilon_n = u / L$, while nominal lateral strain is $\varepsilon_n = -v / L$

The Poisson's ratio will be (σ) = – lateral strain / tensile strain

- **Shear Strain**

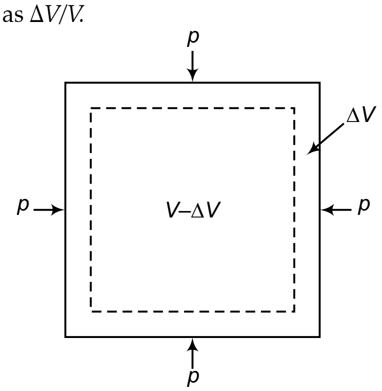
It is measured as a displacement of surface which is in direct contact with applied shear stress from its original position as $\tau = W/L = \tan\theta$.



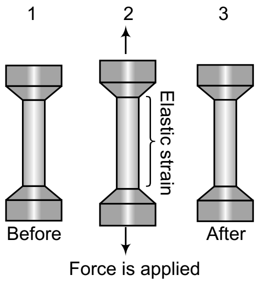
- **Volume Strain :**

It is the strain that is measured as a change in volume δV with respect to original volume V.

The strain is amount of elongation in three dimensions expressed as $\Delta V/V$.



⏩ Elastic Strain :



When a material is stressed, there results a strain.

If stress is low, strain will be elastic strain which is caused by stretching of bonds in the material.

If the force on the material is released, the strain is removed and the material reverts to its initial dimensions.

⏩ Plastic Strain

If a higher stress is applied to the material, there results elastic strain along with small amount of inelastic or plastic strain.

The plastic strain is caused by rearrangement of atoms in the material which is not reversible.

When stress is removed, plastic deformation remains in the material.

⏩ Stress

Stress is the internal force per unit area having similar units as pressure.

It is a complex quantity as compared to pressure as it varies with direction and surface of contacts.

⏩ Tensile Stress :

A block which is kept on the floor and when a force tends to act on it, the floor will exert an equal and opposite force back on the block which makes the block to stop.

The force when acts on sections through the block parallel to top surface, allows the block to be in state of stress.

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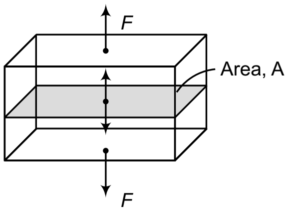
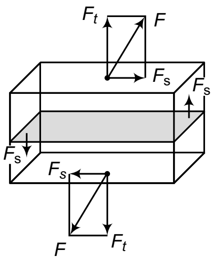
Tensile stress & strain, compressive stress & shear stress



The intensity of stress s, is given by force which is divided by area of block surface as $s = F/A$

The stress is known as tensile stress as force is acting outwards at right angles to the block surface.

⏩ Shear Stress :



When a force is applied on the block at right angle, it gets separated in two components; perpendicular to surface (F_t) and parallel to surface (F_s).

The component which is perpendicular to the surface creates a tensile stress and results in magnitude of F_t/A.

The component of stress which is acting parallel to surface is shear stress τ, and it's magnitude is given by $\tau = F_s/A$.

⏩ Stress-strain Curve

In order to measure the mechanical properties of a material, we need to have the relationship between the stress and strain.

As external forces are applied to objects made of elastic materials, they tend to produce changes in shape and size of object.

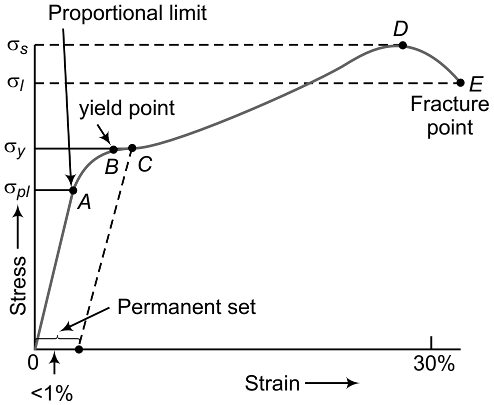
The relationship between stress and strain for a particular material is described by stress-strain curve where the result is shown by the amount of deformation at certain intervals of tensile/compressive loading.

Stress-strain curve is the graph where stress values of the material is plotted on y axis and corresponding strain values are plotted on x axis.

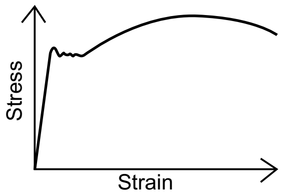
Stress-strain curve also sometimes is known as stress-strain diagram.

Stress-strain curve has different regions and points. These regions and points are:

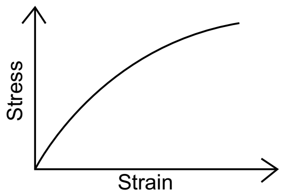
- Proportional limit (OA)
- Elastic limit (A)
- Yield point (B)
- Ultimate stress point (D)
- Fracture or breaking point (E).



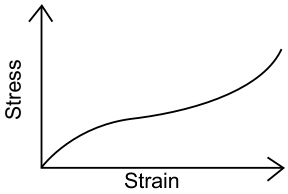
Stress-strain curve for different material is different which may vary as per temperature and loading conditions of the material.



Mild Steel



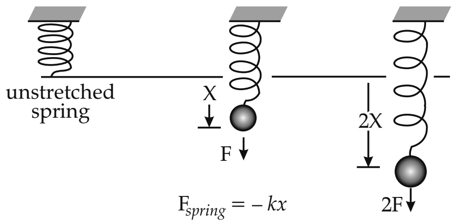
Iron



Rubber

⏩ Hooke's Law

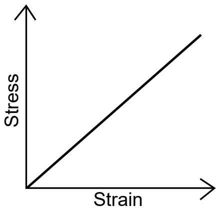
According to this law, stress is directly proportional to the strain within the elastic limit, i.e., stress ∝ strain.



In this, force F needed to extend or compress a spring by distance x is proportional to that distance which is $F = -kx$.
Hooke's Law is applicable in case of elastic deformation of body.

⏩ Young's Modulus

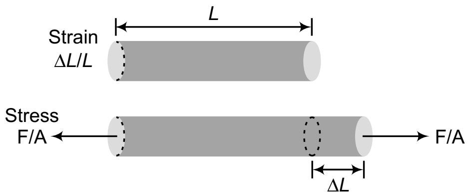
It is a fundamental property of every material which can't be changed and is dependent on temperature and pressure.



In this, a number shows how easy it is to deform a material.
If a material is stretched, stress is directly proportional to strain upto limit of elasticity.
The gradient of the graph gives the value of Young's Modulus for particular material.
It is written as Young Modulus = tensile stress / tensile strain

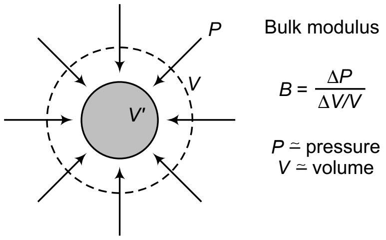
$$Y = \frac{[F/A]}{[\Delta L/L]} = \frac{FL}{A\Delta L}$$

Young's modulus can be used to calculate the elongation or compression of an object as long as the stress is less than the yield strength of the material.



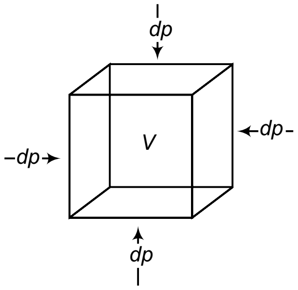
⏩ Bulk Modulus

It is a modulus associated with a volume strain, when a volume is compressed or expanded.



The formula for bulk modulus is
Bulk modulus = – (pressure applied / fractional change in volume)

It is related to elastic modulus.
The reciprocal of bulk modulus is compressibility of the substance.
The bulk modulus of solid influences the speed of sound and other mechanical waves in the material.
It is a factor which indicates amount of energy that is stored in solid material in Earth's crust.
In this, elastic energy gets released violently in earthquake, so bulk modulus for Earth's crust materials is important in study of earthquakes.



The bulk modulus is one of the factor in the speed of seismic waves from earthquakes.
As Bulk Modulus of Elasticity or Volume Modulus is the property of the material which characterizes the compressibility of fluid by judging, how easily the unit volume of fluid gets changed due to change in pressure.
Bulk Modulus can be calculated as

$$K = -\frac{dp}{(dV/V_0)} = \frac{-(p_1 - p_0)}{\{(V_1 - V_0)/V_0\}}$$

⏩ Shear Modulus of Rigidity

It is also known as Modulus of rigidity that states the rate of change of shear stress with respect to shear strain for pure shear in the proportional limit.
It is denoted by η and is expressed in pascals, [also in Gigapascals (GPa)].
Modulus of rigidity value of a material can be obtained by torsion test.

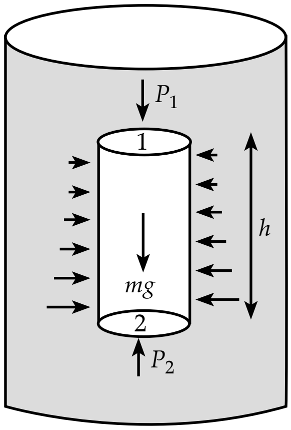
Shear Modulus $\eta = \dfrac{Y}{2(1+\sigma)}$ [For isotropic materials]

The general formula of Shear Modulus is $\tau = \gamma \times G$, where τ = Shear stress in given member (N/m ^{2} or lbf/ft^2), γ = Shear strain, η = Shear Modulus or Modulus of Rigidity
Shear modulus is coefficient of elasticity for shearing force which is the ratio of shear stress to the displacement per unit sample length.
Shear modulus of rigidity is concerned with deformation of solid when it experiences a force parallel to its surfaces while its opposite face experiences an opposing force.
The shear modulus of metals decreases with increasing temperature.

Topic 2: Mechanical Properties of Fluids

Revision Notes

⏩ Variation of Pressure with depth:



Here $P_2 - P_1 = \rho gh$; where ρ is the density and g is the acceleration due to gravity.
This pressure difference depends on the vertical distance h between the points 1 and 2.
If we shift the point 1 to the top of the liquid surface which is open to the atmosphere, P_1 becomes the atmospheric pressure P_a. Taking P_2 as P then, the above equation becomes

$$P - P_a = \rho gh$$
$$P = P_a + \rho gh$$

The excess pressure $P - P_a$, at depth h is called a gauge pressure at that point.

⏩ Factors Affecting Fluid Pressure

The following factors affect the fluid pressure.
Depth of fluid: Pressure is directly proportional to the depth of the fluid. As the depth increases, the intensity of pressure also increases.

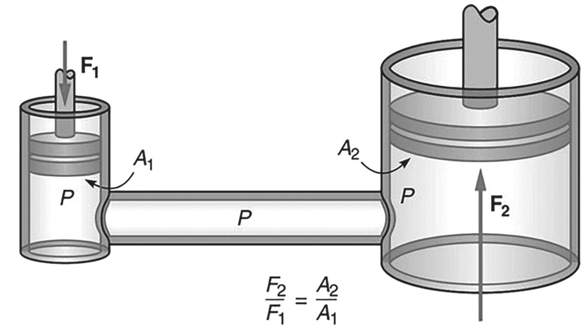
Density of fluid: The denser the fluid, more is the fluid pressure. For example, air exerts less pressure as compared to water.

⏩ Effect of Gravity on Fluid Pressure

Gravity induces heightened pressure in static fluids at deeper levels, attributable to hydrostatic pressure. Moreover, in the realm of moving fluids, gravity influences flow rates, pressure dispersion, and siphoning mechanisms through the interplay of potential and kinetic energies. Fluid density remains a pivotal factor in these fluid dynamics.

⏩ Pascal's Law

If pressure changes by some value at a place in an incompressible confined liquid, then pressure changes by the same value at every point inside the liquid.

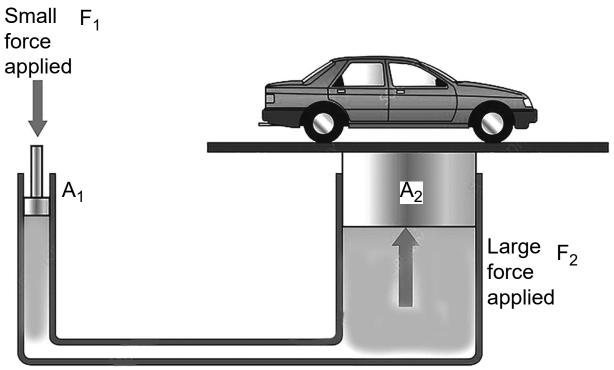


$$F = PA$$

Where, F is the applied force, while P is the transmitted pressure and A represents the cross-sectional area.

⏩ Applications of Pascal's Law:

⏩ Hydraulic Lift:



$$\frac{F}{A_1} = \frac{W}{A_2} \text{ or, } W = F\frac{A_2}{A_1}$$

This is the maximum load that can be raised by exerting force F on A.

⏩ Hydraulic Braking System:

When a moving vehicle undergoes sudden braking, the risk of skidding increases as the wheels fail to slow uniformly. To mitigate this, braking systems are engineered to ensure simultaneous and uniform deceleration of each wheel, thereby minimizing skid potential. Hydraulic brakes, operating in accordance with Pascal's law, achieve this synchronized braking action. These hydraulic braking systems are employed in automobiles, motorcycles, and trucks alike.

Hydraulic Jack:

Operating on the principles of Pascal's Law within a closed container system, hydraulic jacks serve the purpose of lifting heavy objects. Widely utilized in the automotive industry, these jacks play a crucial role in elevating vehicles for repair and maintenance tasks.

⏩ Viscosity

Viscosity is the quantity which shows fluid resistance to flow where the fluids resist the relative motion of immersed objects by motion of layers with different velocities.

Viscosity of a fluid is a measure of its resistance to gradual deformation by shear, stress or tensile stress.

Quantities that described viscosity are dynamic viscosity, kinematics/absolute viscosity

Viscosity (η) or Dynamic viscosity is ratio of shearing stress $\left(\frac{F}{A}\right)$ to velocity gradient $\left(\frac{\Delta v_x}{\Delta z} \text{ or } \frac{dv_x}{dz}\right)$ in a fluid as $\eta = \left|\frac{(F/A)}{(\Delta v_x/\Delta z)}\right| = \left|\frac{(F/A)}{(dv_x/dz)}\right|$

The Newton's second law of motion ($F = ma$), shows $\frac{F}{A} = \frac{\eta \Delta v_x}{\Delta z}$ or $F = \frac{m\Delta v}{\Delta 6}$

SI unit of viscosity is pascal second [Pa s].

As pascal second is not commonly used unit today, so the common unit of viscosity is dyne second/ square centimeter [dyne s/cm^2] which is given the name poise P.

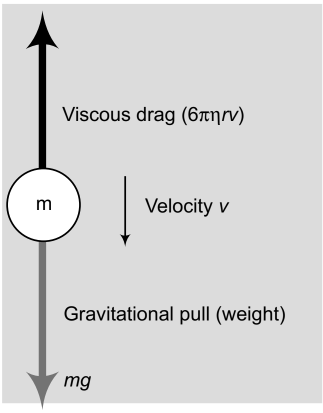
⏩ Stokes' Law

In a viscous liquid and a sphere having a ball bearing of radius 1 millimeter, the liquid flows smoothly around the sphere as it falls with particular flow pattern.

The velocity in such fluid flow pattern varies around the sphere, where the total viscous force on sphere with velocity gradient around the area of spherical surface. As per Stokes, drag force 'F' depends on size of the sphere having radius 'r' moving through fluid of viscosity 'η' at speed 'v' as $F = 6\pi\eta rv$

The coefficient of viscosity 'η' has dimensional formula $[ML^{-1}T^{-1}]$.

When the density of material of sphere is 'r' and liquid is 'σ', then effective gravitational force is $4/3\pi r^3 (r - \sigma)$, so viscosity (η) = $2gr^2 (r - \sigma)/9v$.



Stokes' law shows that the frictional drag force (F) is directly proportional to weight of sphere where terminal velocity (v) is proportional to radius squared making velocity 'v' to be more for large sphere as compared to small sphere.

⏩ Terminal Velocity

The maximum constant velocity acquired by a body while falling through a viscous medium is called its terminal velocity. It is usually denoted by v_T.

When the body acquires terminal velocity,

The upward viscous force + The upward buoyant force = Weight of the ball

⇒ F = Weight of the ball – The upward buoyant force

⇒ The upward viscous force = Apparent weight of the ball in the liquid.

i.e., $6\pi\eta a v_T$ = (mass of ball-mass of liquid displaced by ball) × g

$$6\pi\eta a v_T = \frac{4}{3}\pi a^3 (\rho - \sigma) g$$

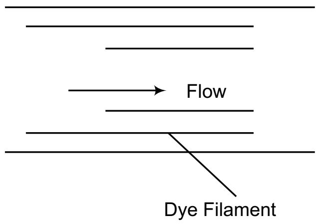
[ρ = density of the falling body, σ = density of fluid]

$$v_T = \frac{2}{9}\frac{a^2}{\eta}(\rho - \sigma) g$$

⏩ Streamline and Turbulent Flow

A liquid flowing in a pipe having disturbed pattern of fluid flow as a result of increase in velocity flow.

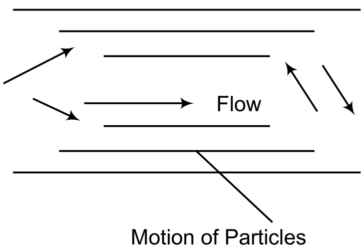
When the flow is slow, the pattern is smooth, but when the flow is rapid, then there are disturbances in the fluid flow pattern in terms of velocity, directions and angle of flow.



The injection of dye in the fluid, shows that at low velocities, dye filament remains unchanged and shows parallel lines in stream of flow.

The type of flow pattern is known as Laminar flow or viscous flow or streamlined flow.

If velocity of flow increases gradually, dye filament gets broken and spread across the cross section of pipe and the type of flow arrangement is known as turbulent flow where fluid particles will not move in parallel lines but will tend to move across the normal fluid flow direction.



If a fluid particle in a stream gets disturbed, then due to inertia, it tends to move in new direction where viscous forces from surrounding fluid will tend to move in normal direction of flow.

If shear force is large enough to overcome any deviation, there appears viscous or laminar flow. When shear forces are weaker and will not handle the inertia of particles, there result a turbulent flow.

The ratio of inertia to viscous forces shows flow is laminar or turbulent is decided on basis of flow condition.

⏩ Critical Velocity

Critical velocity is the maximum velocity of a fluid, above which, the streamline flow get changed to turbulent flow.

At maximum fluid velocity, the flow of fluid will remain as streamline flow while above the maximum fluid velocity; the flow of fluid becomes turbulent.

⏩ Critical velocity (v_C) = (R_e × η) / (ρr)

Dimensional Formula of Reynolds number (R_e) = $[M^0L^0T^0]$

Dimensional Formula of coefficient of viscosity (η) = $[M^1L^{-1}T^{-1}]$

Dimensional Formula of Density of fluid (ρ) = $[M^1L^{-3}T^0]$

Dimensional Formula of radius (r) = $[M^0L^1T^0]$

Dimensional Formula of Critical velocity is v_C = $[M^0L^1T^{-1}$

SI unit of Critical velocity v_C is m/s.

Critical velocity is further divided as lower critical velocity and upper critical velocity

Lower Critical Velocity

It is the velocity at which the laminar flow stops.

In this, the flow enters from laminar to transition period which exists between laminar and turbulent flow.

If a laminar flow changes into turbulent, it does not change abruptly, but there results a transition period between such flows.

Upper Critical Velocity

It is the velocity at which the turbulent flow starts.

In this, the flow enters from transition period to turbulent flow.

⏩ Bernoulli's Theorem and its Applications

Bernoulli's theorem states that for an ideal liquid, that flows in continuous stream, the total energy of a particle remains the same, while the particle moves from one point to another.

The theorem is based upon law of conservation of energy where sum of all the energies in a steady, streamlined, incompressible flow of fluid always remains constant,

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

or, $$\frac{P}{\rho g} + \frac{1}{2}\frac{v^2}{g} + h = \text{constant}$$

Here, $\frac{P}{\rho g} \rightarrow$ Pressure head, $\frac{1}{2}\frac{v^2}{g} \rightarrow$ Velocity head and

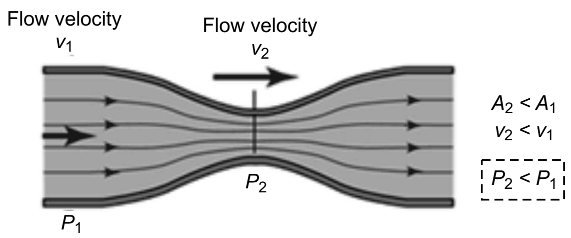
$h \rightarrow$ Gravitational head

In a steady flow of constant density fluid in converging duct, without losses due to friction, the flow satisfies all restrictions governing the use of Bernoulli's equation.

For an upstream and downstream of contraction, it is assumed that the velocity is constant over inlet and outlet areas and is parallel.

When streamlines are parallel, pressure remains constant across the flow except for hydrostatic head differences.

On ignoring the gravity, the pressure over inlet and outlet areas are constant.



Along streamline on centerline, Bernoulli equation and one-dimensional continuity equation result as

$$P_1 - P_2 = \frac{1}{2}\rho (v_2^2 - v_1^2)$$

Equation of continue, $A_1 v_1 = A_2 v_2 =$ constant

If the fluid passes over a solid body, the streamlines get closer and flow velocity increases while pressure decreases.

⏩ Bernoulli Equation as Conservation of Energy Principle

Bernoulli Equation is a statement of conservation of energy principle for flowing fluids.

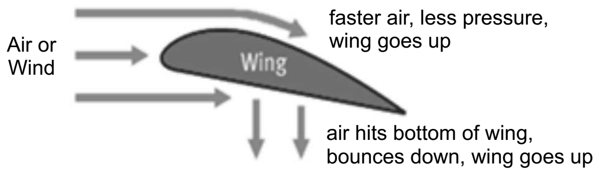
It is the sum of kinetic and potential energies of masses at one place which is equal to sum at other place with work done on mass among the two points, as

$KE_1 + PE_1 = W + KE_2 + PE_2$

$1/2\, mv_1^2 + mgh_1 = \int F\, dx + 1/2\, mv_2^2 + mgh_2$

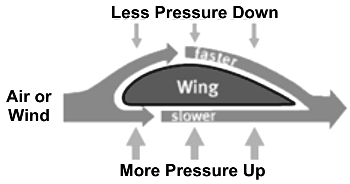
Applications of Bernoulli Principle

⏩ Aerofoil



Flight of an aeroplane is based on Bernoulli's principle as the effect of flow of air around its wings.

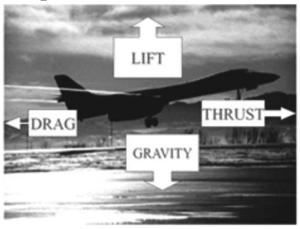
The shape of the aerofoil has rounded front edge and pointed trailing edge with top surface as curved and flat bottom surface.



When wing in shape of aerofoil moves through the air or wind, the flow of wind/air over the top surface travels faster in order to cover long distance thereby creates low pressure region.

The flow of air below the wing is slow which provides higher pressure region.

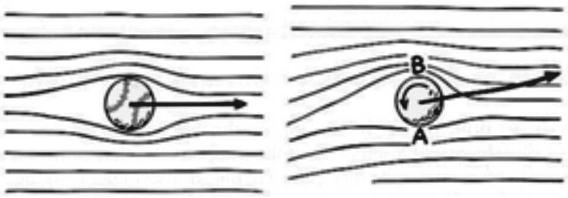
The difference between top surface pressure and bottom surface pressure creates a net upward force, which finally lifts and helps the plane to take off.



⏩ Spinning of Ball

While playing baseball, football and volleyball a player is able to make the ball to move in a curved path by spinning it.

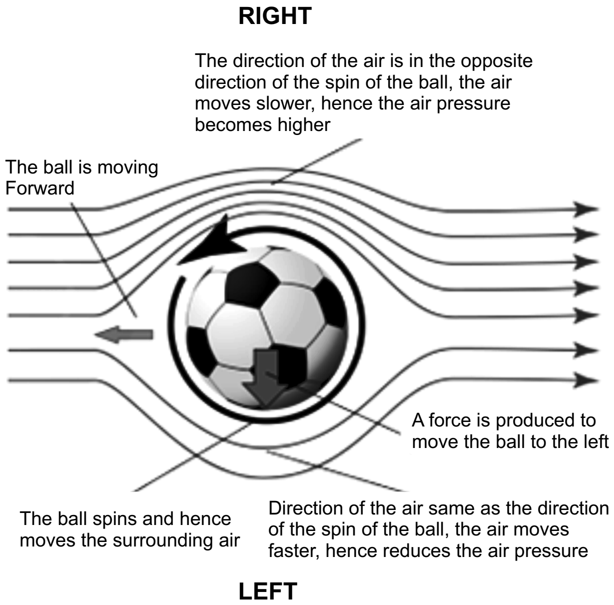
The effect of spinning of ball is explained by Bernoulli's Principle where results a symmetric airflow in a ball which is not spinning.



No Spin Spin

Football, baseball or volleyball can be thrown or hit with a spin making the ball to go in a curve as one side of the ball experiences a reduced pressure.

On sides of the ball, boundary layers move in similar direction as free stream air which carries around the ball before separating in turbulent flow.



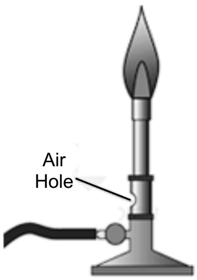
On side where boundary layer is opposed by free stream flow, there results a separation which shows net deflection of air stream in single direction behind the ball making Newton's 3rd law of reaction force on the ball in opposite direction giving an effective force in similar direction.

⏩ Bunsen Burner

When a bunsen burner is connected to a gas supply, the gas flows at high velocity through a narrow passage in the burner which creates a region of low pressure.

In this, outside air, which is at atmospheric pressure is drawn to mix with gas.

The mixture of gas and air allows the gas to burn completely so as to produce a clean hot fire.



Bunsen Burner

⏩ Carburetor

⏩ Carburetor is a device whose function is to provide air-fuel mixture to automobile engine in required proportion.

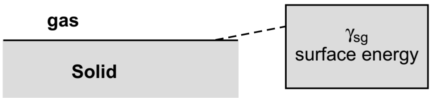
⏩ It mixes the correct amount of gasoline with air in order to allow the engine to run properly.

⏩ It works on the Bernoulli's Principle which shows that the velocity of an ideal gas increases thereby dropping the pressure.

Surface Energy and Surface Tension

⏩ Surface Energy

⏩ Surface energy is the energy difference which exists between bulk of material and surface of material.



It is surface energy per unit surface area similar to surface tension measured.

The unit of surface energy is J/m^2.

If surface energy is provided by an external source, the liquid is said to be bubbling.

It is an interfacial tension of solid-gas interface which is shown by γ_{sg}, where '*s*' is for solid and '*g*' is for gas.

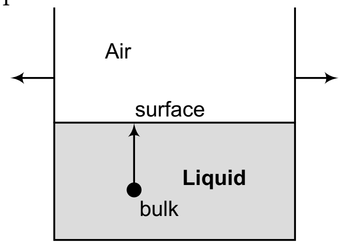
If a solid has high surface energy, a strong interaction with the surface is possible as high surface energy is good for adhesion, while solids having low surface energy as plastics are difficult to coat and needs special treatment for more surface energy.

In a thin film membrane where force F pulls on the membrane and stretches liquid film at per unit length L of surface, then in liquid film, membrane is pulled by a distance Δx with work done $F\Delta x$ and the increase in surface area $2L\Delta x$, then surface energy E is $E = F\Delta x / 2L\Delta x = F / 2L = \gamma$

⏩ Surface Tension

Surface tension is a property of liquids which is managed by intermolecular interactions which exist from cohesive forces among the molecules in a liquid.

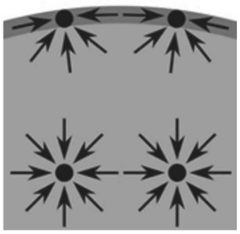
It is the resistance of a fluid to deform or break which directly defines by intermolecular forces which are present on liquid surface.



When substrate has high surface energy, it tends to attract with adhesive forces having low surface tension and resistance to deform or rupture, thereby producing good wetting of adhesive on substrate.

In homogeneous liquid, all molecules in central parts of liquid have same amount of force which pull it to all sides and surrounding molecules pull the central molecule uniformly on all directions.

The surface molecules have forces which act on it toward the liquid and air-liquid adhesive forces are not as strong as liquid-liquid cohesive forces, so surface molecules get attracted towards the center of the liquid forming a packed layer of molecules.



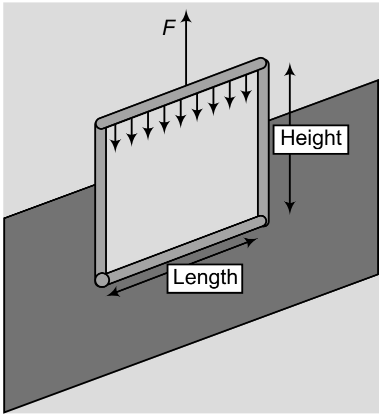
The surface tension results as force which is parallel to surface that is perpendicular to unit length line drawn on the surface.

The unit of surface tension is N/m or J/m^2.

⏩ Measuring Surface Tension

Surface tension is measured using wire frame method where a rectangular wire frame is suspended in a liquid and is pulled upwards with force F to balance the downward force of surface tension T.

In this, the applied upward force F is acting up which balances the surface tension force $F_{down} = 2 \times T \times l$ from the two surfaces that clings to the top of frame, *i.e.*, $F_{down} = 2 \times T \times l$ or $T = F / 2 \times l$

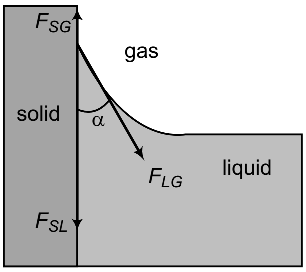


⏩ Angle of Contact

If a liquid surface coincides with solid surface, the angle between the two surfaces is known as angle of contact (α).

If the angle α is less than 90°, then liquid will spread which will wet the surface and when angle of contact is more than 90° , the liquid will form the droplets.

For a clean glass-water boundary, the angle of contact is typically close to zero. On a waxed surface, however, the angle of contact may increase, potentially exceeding 90°. This increase in the angle of contact on a waxed surface enhances the capillary action or the ability of water to 'stick' to the surface. The greater the angle of contact, the stronger the cohesive forces between the water molecules and the solid surface, leading to a stronger 'pull' or adhesion of water on the waxed surface.



The forces, F_{SG} = upward force among solid and gas, F_{SL} = downward force among solid and liquid, F_{LG} = inclined force among liquid and gas are resolved vertically as force among solid and gas F_{SG} is much smaller than other two forces, then $F_{LG} \cos \alpha = F_{SL} - F_{SG}$ or $\cos \alpha = F_{SL} - F_{SG} / F_{LG} = F_{SL} / F_{LG}$

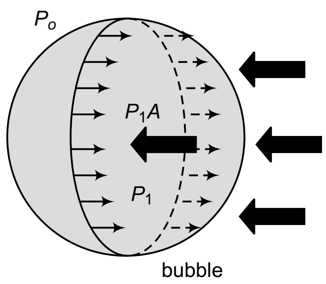
If forces F_{SL} and F_{LG} are in similar direction, then $\cos \alpha$ is positive, α is less than 90°, meniscus is positive and liquid will wet the surface.

If forces F_{SL} and F_{LG} are in opposite directions, then $\cos \alpha$ is negative, α is greater than 90° meniscus will be negative and liquid will not wet the surface.

⏩ Contact angles for some interfaces

most organic liquids – glass	0° - 10°
mercury – copper	0°
pure water – glass	0°
water – glass	20°
kerosene – glass	26°
water – silver	90°
water – paraffin	106°
mercury – glass	148°

⏩ Excess of Pressure across curved surface



In liquid, curved surface is formed due to difference in pressure which occurs between the atmosphere and liquid which is expressed in terms of area and surface tension.

It is a fact that air needs to be blown into drop of soap solution so as to make a bubble which shows that pressure in the bubble is more than outside.

The extra pressure will create a force which balances the inward pull of soap film of bubble as a result of surface tension.

If a soap bubble of radius r with external pressure P_e and internal pressure P_i, then excess pressure P in bubble will be $P_i - P_e$

The force acting from right to left as a result of internal excess pressure is PA, where A is area of section through the centre of bubble.

If soap bubble is in equilibrium, forces will get balanced by force due to surface tension which acts from left to right which is $2 \times 2\pi rT = PA = P\pi r^2$ giving excess pressure in soap bubble $P = 4T/r$

It is noted that air bubble in liquid has only one liquid-air surface where excess pressure in the bubble results as $P = 2T/r$

⏩ Application of surface tension; ideas to drops, bubbles and capillary rise

Scan the QR code

Surface tension

Surface tension is an elastic tendency of fluid surface that uses least surface area.

At liquid–air interfaces, surface tension occurs from more attraction of liquid molecules due to cohesion as compared to molecules in air due to adhesion.

The results is that total effect is inward force at surface which causes liquid to behave like as its surface were covered with stretched elastic membrane.

⏩ Drops/Droplets

It is seen that presence of molecules exists at the surface, which if small, have low potential energy where intermolecular attractive forces act to minimize surface area of a liquid.

If the surface area is minimised, the wall tension will pull inwards from all sides that will lead to spherical shape.

The shape which has smallest ratio of surface area to volume is a sphere. So, very small quantities of liquids will form spherical drop. As the size of the drops increase, due to the accumulation of water, their weight causes them to deform into a teardrop shape.

Surface tension is responsible for shape of liquid droplets. As easily deformable water droplets tend to adopt a spherical shape due to the cohesive forces of the surface layer. Therefore, the combined effects of surface tension and adhesion determine the shape of a water droplet on a twig.

⏩ Bubbles

The surface tension of water gives required wall tension for formation of bubbles with water.

Minimizing wall tension pulls soap bubbles into spherical shapes. Despite soap films having lower surface tension than pure water, they maintain strong cohesion in thin bubbles. Pressure differences inside and outside a bubble depend on surface tension and radius, visualized as two hemispheres held together by surface tension, without internal pressure pushing them apart.

⏩ Capillary Action

Capillary action takes place due to adhesion and surface tension.

The adhesion of water to the walls of a vessel results in an upward force on the liquid at the edges, which is reflected in the meniscus, causing it to curve in an upward direction.

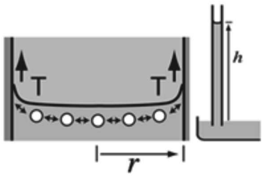
The surface tension will act to hold the surface tightly, so instead of edge to move in upward direction, the whole liquid surface gets dragged upwards.

Capillary action occurs when the adhesion to the walls is stronger as compared to cohesive forces that exist among the liquid molecules.

In this, the height to which capillary action takes the water in a uniform circular tube is limited by surface tension.

The force acting around the circumference will act in upward direction

$F_{upward} = T \times 2\pi \times r$



The height 'h' to which capillary action lifts the water, depend on the weight of water that surface tension lifts $T \times 2\pi \times r = \rho \times g$ $(h \times \pi \times r^2)$

The height to which the liquid can be lifted is given as $h = 2T / \rho \times g \times r$

⏩ Properties of Solid and Liquid

Pressure in a fluid that increases with fluid's depth and weight.

$$P_{\text{fluid}} = P + \rho g h$$

Pressure applied anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid.

$$\frac{F_2}{F_1} = \frac{A_2}{A_1}$$

For spherical liquid drop, $P = \dfrac{2T}{R}$

For a spherical soap bubble, $P = \dfrac{4T}{R}$

Conduction involves the transmission of heat from a hot body to a cold body via free electrons.

Heat transfer in fluids caused by the movement of molecules is known as convection.

Radiation is a method of heat transfer directly without the use of a medium.

Topic 3: Thermal Properties of Matter

Revision Notes

Heat

Heat is a form of energy having its units as joule.

Apart from unit joule, other units of heat are calories and BTU (British Thermal Unit).

Temperature

It is the average kinetic energy of all molecules taken together which is basically the average energy of the particles in an object.

It shows how hot or cold an object is, in degrees. (Degree of hotness or coldness)

It is measured in Kelvin, Celsius and Fahrenheit scales.

It is one of the principal quantities in study of thermodynamics.

Kinds of Temperature Scale

There are many kinds of temperature scales which can be classified based on empirically and theoretically. Basic relation is given as

$$\frac{C-0}{100}=\frac{F-32}{180}=\frac{K-273.15}{100}=\frac{R-0}{80}$$

Thermal Expansion

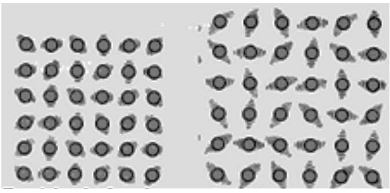
It is the tendency of matter by virtue of which, it changes in shape, area and volume in response to change in temperature.

It occurs when an object expands and becomes larger due to a change in object's temperature.

Higher temperature results in faster movement of molecules on heating thereby increasing the size of objects.

Thermal Expansion of Solids, Liquids and Gases

The three states of matter (solid, liquid and gas) expand when heated.



The atoms themselves do not expand, but the volume they take up does.

If a solid is heated, its molecules gain kinetic energy and atoms vibrate faster about their fixed points.

As vibration become larger, molecules are pushed further apart and the solid expands slightly in all directions.

The relative increase in the size of solids when heated is small.

If a liquid is heated, its molecules gain kinetic energy and vibrate more vigorously.

When vibration increases, the molecules are pushed further apart and liquid expands slightly in all directions.

As the bonds between molecules in liquid are weak, so they expand more as compared to solids.

If temperature increases, it results in expansion of the liquid which means it rises up in the glass.

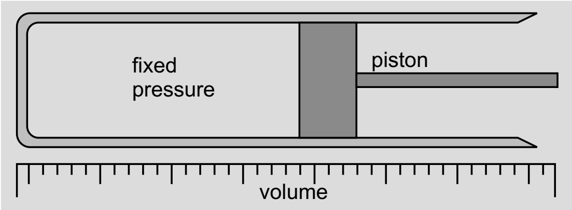
The liquid level drops due to the expansion of its container which initially absorbed all the heat.

After a while, the heat reaches the liquid it compensates for the expansion of the container and rises much more than the original level.

The expansion of gases is much more larger than that of solids or liquids under the same rise in temperature.

Molecules in the gases are more apart and are weakly bonded with each other.

If the gases are heated, heat causes the molecules to move faster, thereby increasing the volume of gas more as compared to volume of solid or liquid.



If temperature of a gas is increased, the molecules move faster and the collisions become more violent thus they spread away from each other causing the volume to increase.

In gas, molecules keep on moving and travels fast thereby hitting each other and at the sides of the container.

On increasing the temperature, the molecules will move faster which results in more violent collisions making the pressure to increase.

Thermal Expansions in Solids

(i) Linear thermal expansion

Coefficient of linear expansion $\alpha=\frac{L_f-L_i}{L_i\times(t_f-t_i)}$

(ii) Superficial thermal expansion

Coefficient of superficial expansion $\beta=\frac{A_f-A_i}{A_i\times(t_f-t_i)}$

(iii) Cubical thermal expansion

Coefficient of cubical expansion $\gamma=\frac{V_f-V_i}{V_i\times(t_f-t_i)}$

Specific Heat Capacity of Substances

Substance	Cal g^{-1} K^{-1}
H_2O (*l*)	4.184
Ice @ 0°C	2.010
Steam @ 100°C	2.010
Vegetable oil	2.000
Air	1.020
Aluminium	0.900
Concrete	0.880
Glass	0.840
Brass	0.380
Sand	0.290
Silver	0.240
Mercury	0.14
Gold	0.129

Here all alphabets are in their usual meanings.

⏩ Relation between a, b and c

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3} \text{ or } \alpha : \beta : \gamma = 1 : 2 : 3$$

⏩ Specific Heat Capacity

Specific heat capacity is the amount of heat energy required to raise the temperature of unit degree of a substance per unit of mass or specific heat capacity (C) is amount of heat in joules required to raise temperature of 1 kg of substance by 1 K.

Specific heat capacity of a material is a physical property.

It's SI unit is J/kg·K.

It is reported in units of calories per gram per degree Celsius.

Molar heat capacity in J/mol·K and volumetric heat capacity in J/m^3·K.

As water needs more time to boil as compared to alcohol, so water requires more heat as compared to alcohol in order to raise the same temperature.

Water has high specific heat capacity.

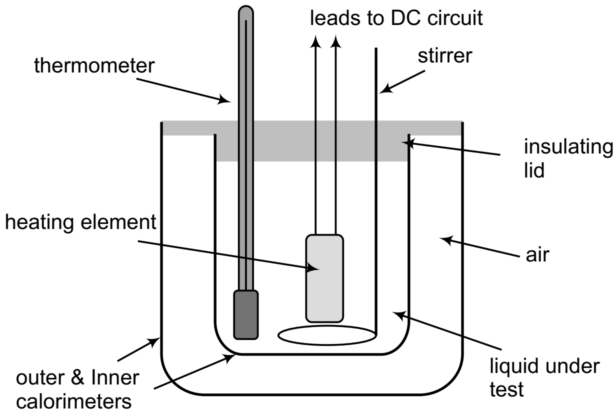
Equation for specific heat capacity :

$$(C) = \frac{\text{Heat Energy}}{(\text{mass of substance} \times \text{change in temperature})}$$

$$(C) = \frac{\Delta Q}{m \times \Delta\theta}$$

⏩ Specific Heat Capacity of a Liquid

The heat energy supplied by element is given to liquid that generates temperature rise of $\Delta\theta$ where heat current (I) and voltage (V) gets monitored for time (t).



The energy supplied by heater = VIt

Energy absorbed by liquid and container = $m_L C_L \Delta\theta + m_C C_C \Delta\theta$

Principle of calorimetry states

Heat given by hot object = Heat taken by cold object

$VIt = m_L C_L \Delta\theta + m_C C_C \Delta\theta$

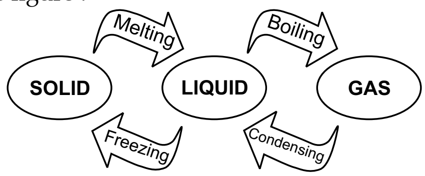
⏩ Calorimetry

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 made is called a calorimeter.

⏩ Change of State

There are three states of matter: solids, liquids and gases. From the figure :

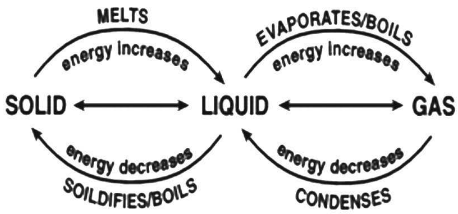


- **Melting :** Change of state from solid to liquid.
- **Vaporization :** Change of state from liquid to gas.
- **Condensation :** Change of state from gas to liquid.
- **Freezing :** Change of state from liquid to solid.
- **Sublimation :** Change of state directly from solid to gas.
- **Deposition :** Change of state directly from gas to solid.

Solids, liquids and gases are made of particles and they differ on the basis of amount of energy present in these particles.

Change of state will occur, when the particle energy is given to the molecules or is taken away by the molecules.

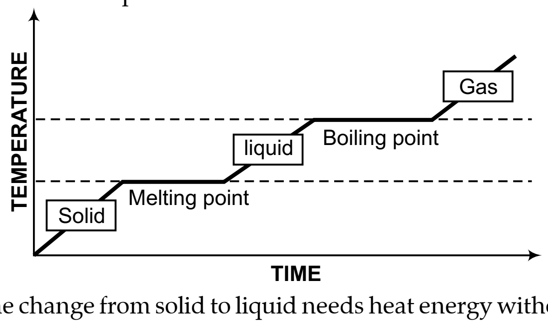
On heating a solid, some of the energy is given to it which causes the particles to move apart resulting in change of state from solid to liquid or melting.



If the energy is taken from a gas, it causes the gas to change its state to liquid or resulting in condense.

The cooling of liquid results in freezing.

For changing solid into gas, a large amount of energy is given to solid particles.



The change from solid to liquid needs heat energy without any rise in temperature as all of the energy is used in changing the particles from solid to liquid.

If the particles changes it state from liquid to gas, the heat is given to liquid for warming up.

If more heat is supplied, it will not cause the temperature to rise as all the heat is applied to change the state from liquid to gas.

⏩ Latent Heat (L)

Latent heat is the amount of heat which is taken in / or given out during change of state of material, *e.g.* solid to liquid or liquid to gas.

It is written as $Q = mL$

If a material changes its state from solid to liquid, it is known as latent heat of fusion, while if a material changes its state from liquid to gas, it is known as latent heat of vaporization.

The phase changes involving latent heat energy are :

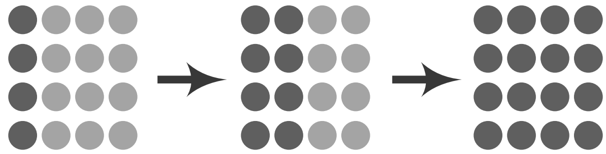
Phase change	Action	Symbol
solid to liquid	melting	L_F
liquid to solid	freezing	L_F
liquid to vapour	vaporization	L_V
vapour to liquid	condensation	L_V
solid to vapour	sublimation	L_S
vapour to solid	desublimation	L_S

⏩ Heat Transfer

Conduction, Convection and Radiation

⏩ Conduction

Conduction is the method of heat transfer through molecular disturbance in a material without any motion of particular material. In this process, molecules in hotter part of object start vibrating fast as compared to molecules, which are at cooler parts.

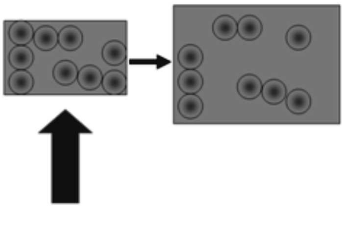


The fast moving molecules are able to transfer the part of energy to slow moving molecules by transferring heat through the object. In this, steady state is achieved when heat enters the object at one side which gets balanced by that, which is emitted from other side. During the process, the object's heat remains constant.

Consider a metal rod where one end of it has higher temperature. Here the energy gets transferred down the rod towards the colder end as high speed particles collide with the slower ones, result in the net transfer of energy to slower ones.

In case of heat transfer among two plane surfaces, the rate of conduction of heat transfer is

$$\frac{Q}{t} = \frac{kA(T_{hot} - T_{cold})}{d}$$



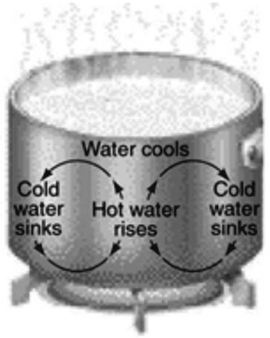
⏩ Convection

Convection is the method of transferring heat using mass motion of fluid like air or water when heated fluid is made to move away from source of heat with energy in it.

Convection above the hot surface takes place as hot air expands and becomes less dense and further rises. So hot water is less dense as compared to cold water and rises which results in convection currents that transport energy.

Convection lead to circulation in a liquid, as in case of heating of bowl of water over a flame. The heated water expands and becomes more buoyant and cooler water will become dense near the surface, forming the circulation patterns.

Convection plays an important from the center of the Sun movements of hot magma be earth.

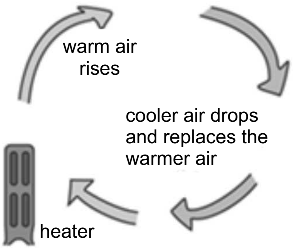


Convection is the movement of heat which can be done through the currents, since heated molecules tend to move from hot places to cold places.

Higher temperature fluid molecules expand the space in which they are.

The heated space is less dense as compared to the cooler space.

While heating, less dense fluid rises to replace the denser colder, fluid, that further sink in warmer areas.

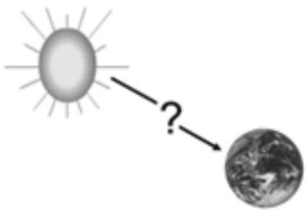


The continuous of warming and cooling liquid or gas lead to convection current.

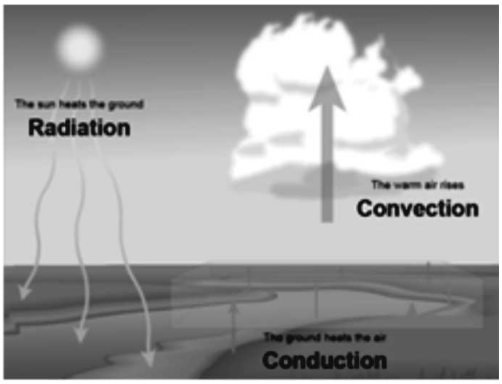
By warming one side of a container of fluid, the convection currents are able to transfer heat to other sides.

⏩ Radiation

Radiation is the method in which the heat energy gets transferred through space by electromagnetic waves. Most of the electromagnetic radiations which appear on earth result from sun and are not visible, but only a small portion appears in shape of visible light.



Thermal radiation is emitted as a result of random movements of atoms and molecules in matter. As atoms and molecules are made of charged particles like protons and electrons, their movements result in emission of electromagnetic radiation that carries energy away from the surface of body.



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Topic 1: Previous Year's Questions

1. **Assertion A:** Steel and brass are more elastic than copper and aluminum.
Reason R: That's why they are preferred in heavy-duty machines and in structural designs.
(a) If both assertion and reason are true, and reason is the correct explanation of assertion.
(b) If both assertion and reason are true, but reason is not the correct explanations of assertion.
(c) If assertion is true, but reason is false.
(d) If both assertion and reason is false

2. **Assertion A:** The compressibility of solids is less than that of gases and liquids.
Reason R: There is tight coupling between the neighboring atoms in solids.
(a) If both assertion and reason are true, and reason is the correct explanation of assertion.
(b) If both assertion and reason are true, but reason is not the correct explanations of assertion.
(c) If assertion is true, but reason is false.
(d) If both assertion and reason is false

3. **Let a wire be suspended from the ceiling (rigid support) and stretched by a weight W attached at its free end. The longitudinal stress at any point of cross-sectional area A of the wire is**
(a) $\frac{W}{A}$ (b) $\frac{W}{2A}$
(c) Zero (d) $\frac{2W}{A}$ **[NEET 2023]**

4. **Assertion (A):** The stretching of a spring is determined by the shear modulus of the material of the spring.
Reason (R): A coil spring of copper has more tensile strength than a steel spring of same dimensions.
(a) Both (A) and (R) are true and (R) is the correct explanation of (A)
(b) Both (A) and (R) are true and (R) is not the correct explanation of (A)
(c) (A) is true but (R) is false
(d) (A) is false but (R) is true **[NEET 2022]**

5. **A wire of length L, area of cross section A is hanging from a fixed support. The length of the wire changes to L_1 when mass M is suspended from its free end. The expression for Young's modulus is:**
(a) $\frac{Mg(L_1-L)}{AL}$ (b) $\frac{MgL}{AL_1}$
(c) $\frac{MgL}{A(L_1-L)}$ (d) $\frac{MgL_1}{AL}$
[NEET 2020 Phase I]

6. **Two wires are made of the same material and have the same volume. The first wire has cross-sectional area A and the second wire has cross-sectional area $3A$. If the length of the first wire is increased by Δl on applying a force F, how much force is needed to stretch the second wire by the same amount?**
(a) $9F$ (b) $6F$
(c) $4F$ (d) F **[NEET 2018]**

7. **The bulk modulus of a spherical object is 'B'. If it is subjected to uniform pressure 'p', the fractional decrease in radius is :**
(a) $B/3p$ (b) $3p/B$
(c) $p/3B$ (d) p/B **[NEET 2017]**

8. **The Young's modulus of steel is twice that of brass. Two wires of the same length and same area of cross section, one of steel and another of brass, are suspended from the same roof. If we want the lower ends of the wires to be at the same level, then the weights added to the steel and brass wires must be in the ratio of:**
(a) 4 : 1 (b) 1 : 1
(c) 1 : 2 (d) 2 : 1 **[AIPMT 2015]**

9. **The approximate depth of an ocean is 2700 m. The compressibility of water is 45.4×10^{-11} Pa and density of water is 10^3 kg/m^3. What fractional compression of water will be obtained at the bottom of the ocean?**
(a) 0.8×10^{-2} (b) 1.0×10^{-2}
(c) 1.2×10^{-2} (d) 1.4×10^{-2} **[AIPMT 2015]**

10. **Copper of fixed volume V is drawn into wire of length l. When this wire is subjected to a constant force F, the extension produced in the wire is Δl. Which of the following graphs is a straight line?**
(a) Δl versus $1/l$ (b) Δl versus l^2
(c) Δl versus $1/l^2$ (d) Δl versus l
[AIPMT 2014]

11. **The following four wires are made of same material. Which of these will have the largest extension when the same tension is applied?**
(a) Length = 50 cm, diameter = 0.5 mm
(b) Length= 100 cm, diameter= 1 mm
(c) Length = 200 cm, diameter = 2 mm
(d) Length= 300 cm, diameter= 3 mm
[AIPMT 2013, CPMT 1983]

12. **When a weight of 10 kg is suspended from a copper wire of length 3 m and diameter 0.4 mm, its length increases by 2.4 cm. If the diameter of the wire is doubled, then the extension in its length will be :**
(a) 7.6 cm (b) 4.8 cm
(c) 1.2 cm (d) 0.6 cm **[AIPMT2010]**

13. **A force of 6×10^6 Nm^{-2} is required for breaking a material. The density ρ of the material is 3×10^3 kg m^{-3}. If the wire is to break under its own weight, the length of the wire made of that material should be (Taking g = 10 ms^{-2}) :**
(a) 20 m (b) 200 m
(c) 100 m (d) 2000 m **[AIPMT 2010]**

14. **The Young's modulus of brass and steel are respectively 1.0×10^{11} Nm^{-2} and 2.0×10^{11} Nm^{-2}. A brass wire and a steel wire of the same length are extended by 1 mm each under the same force. If radii of brass and steel wires are R_B and R_S respectively, then :**
(a) $R_S=\sqrt{2}R_B$ (b) $R_S=R_B/\sqrt{2}$
(c) $R_S=4R_B$ (d) $R_S=R_B/2$
[AIPMT 2010]

15. **A rubber cord catapult has cross-sectional area 25 mm^2 and initial length of rubber cord is 10 cm. It is stretched to 5 cm and then released to project a missile of mass 5 gm. Taking $Y_{rubber}=5\times10^8$ N/m^2 velocity of projected missile is :**

(a) 20 m/s (b) 100 m/s
(c) 250 m/s (d) 200 m/s **[CPMT 2002]**

16. A wire is stretched by 0.01 m by a certain force *F*. Another wire of same material whose diameter and length are double to the original wire is stretched by the same force. Then its elongation will be :
(a) 0.005 m (b) 0.01 m
(c) 0.02 m (d) 0.002 m **[CPMT 2001]**

17. The units of Young's modulus of elasticity are :
(a) N/m (b) N-m
(c) N/m^2 (d) $N\text{-}m^2$ **[CPMT 2000]**

18. Two similar wires under the same load yield elongation of 0.1 mm and 0.05 mm respectively. If the area of cross-section of the first wire is 4 mm^2, then the area of cross-section of the second wire is :
(a) 6 mm^2 (b) 8 mm^2
(c) 10 mm^2 (d) 12 mm^2 **[CPMT 2000]**

19. If a spring is extended to length *l*, then according to Hook's law :
(a) $F = kl$ (b) $F = k/l$
(c) $F = k2/l$ (d) $F = k^2/l$ **[CPMT 1997]**

20. When a certain weight is suspended from a long uniform wire, its length increases by one cm. If the same weight is suspended from another wire of the same material and length but having a diameter half of the first one then the increase in length will be :
(a) 0.5 cm (b) 2 cm
(c) 4 cm (d) 8 cm **[CPMT 1984, 90]**

Answer Key

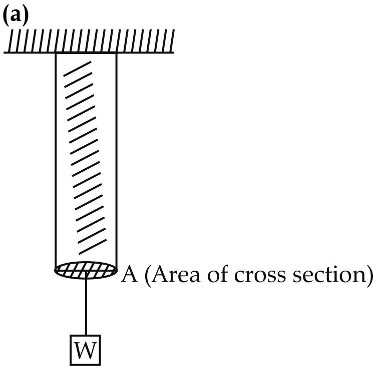
1.	(d)	**2.**	(a)	**3.**	(a)	**4.**	(c)	**5.**	(c)	**6.**	(a)
7.	(c)	**8.**	(d)	**9.**	(c)	**10.**	(b)	**11.**	(a)	**12.**	(d)
13.	(b)	**14.**	(b)	**15.**	(c)	**16.**	(a)	**17.**	(c)	**18.**	(b)
19.	(a)	**20.**	(c)								

Answers with Explanation

1. (d) Steel is more elastic than copper, brass and aluminum. Because of this reason steel is preferred in heavy duty, machines and in structural designs.

2. (a) The molecules in liquids are bound with their neighbors but not as strong as in solids. Molecules in gases are very poorly coupled to their neighbors.

3. (a)



Stress is, restoring force per unit area. As there in no mass of Rod. Restoring force is equal to the applied force in magnitude.

So, stress = $\dfrac{W}{A}$

4. (c) In stretching a spring, its shape changes and hence the shear modulus. So, assertion (A) is correct.
Reason is incorrect as $Y_{steel} > Y_{Copper}$.

5. (c) Stress = $\dfrac{Mg}{A}$

Strain= $\dfrac{\Delta L}{L} = \dfrac{L_1 - L}{L}$

Young's modulus= $\dfrac{\text{Stress}}{\text{Strain}} = \dfrac{MgL}{A(L_1 - L)}$

6. (a) Let the wire 1 is of length = l and wire 2 of length = $l/3$
Now, area of wire 1 = A while area of wire 2 = $3A$
When the length of wire 1 is increased by Δx if force F is applied, so $Y = \dfrac{(F/A)}{[\Delta x/l]}$

Now, for wire 2 : $Y = \dfrac{(F'/A)}{[\Delta x/l/3]}$

For wire 2 amount of force needed will be analysed using above expressions :

$\dfrac{F/A)}{l/\Delta x} = \dfrac{F'}{3A} \times \dfrac{l}{3\Delta x}$

Hence, the force $F' = 9F$

7. (c) $V = \dfrac{4}{3} \times r^3$ Here, r is the radius of object

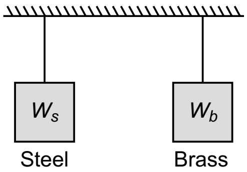
Now, for fractional change

$$\frac{\Delta V}{V} = 3\frac{\Delta r}{r}$$

Again, $B = p\Big/\left(\dfrac{\Delta V}{V}\right) = p\Big/\left(3\dfrac{\Delta r}{r}\right)$

So, $\dfrac{\Delta r}{r} = \dfrac{p}{3B}$

8. (d) Consider L and A as length and area of cross section of each wire with weights attached as shown.



From Young's modulus, elongation in steel wire will be:

$Y = \dfrac{[W/A]}{[\Delta L/L]}$ or $\Delta L_s = \dfrac{W_s L}{Y_s A}$

Now, from Young's modulus, elongation in brass wire will be :

$\Delta L_b = \dfrac{W_b L}{Y_b A}$

As the elongation of both wires are same, so

$\dfrac{W_s L}{Y_s A} = \dfrac{W_b L}{Y_b A}$

Now, ratio of weights added to steel and brass wires will be $W_s/W_b = \dfrac{Y_s}{Y_b} = \dfrac{2Y_b}{Y_b} = 2:1$

9. (c) We have d = 2700 m, $\rho = 10^3$ kg/m^3, compressibility = 45.4×10^{-11} /pascal

Now, the pressure at bottom of ocean is
P = ρgd
$= 10^3 \times 10 \times 2700$
$= 27 \times 10^6$ Pa
Hence, fractional compression
$= 45.4 \times 10^{-11} \times 27 \times 10^6$
$= 1.2 \times 10^{-2}$

10. (b) From Young Modulus $Y = \dfrac{Fl}{A\Delta l} = \dfrac{Fl}{(V/l)}\Delta l$

Now, $\Delta l = \dfrac{Fl^2}{VY}$

Also, $\Delta l \propto l^2$

11. (a) To find the largest extension in the wires, we use Young's Modulus

$Y = \dfrac{Fl}{A\Delta l}$ or $\Delta l = \dfrac{Fl}{AY} \propto \dfrac{l}{A}$

Among the following wires, wire of least length and least diameter will have the largest extension.

12. (d) Volume $= \pi r^2 l$
So, for constant volume

$$l \propto \frac{l}{r^2}$$

So, $\dfrac{l_1}{l_2} = \left(\dfrac{r_2}{r_1}\right)^2$

or, $l_2 = l_1\left(\dfrac{r_2}{r_1}\right)^2$

$= 2.4/4$
$l_2 = 0.6$ cm

13. (b) Weight of wire $mg = F$
As F = volume × density × $g = AL\rho g$
Now,
Stress = Force/Area
$= mg/A = V\rho g/A$
$= LA\rho g/A$
Hence, Stress $= \rho Lg$
It is given that :
Stress $= 6 \times 10^6$ Nm^{-2}
Density of wire $\rho = 3 \times 10^3$ kgm^{-3}
Acceleration $g = 10$ ms^{-2}
Hence, the length of wire of that material will be :
L = Stress/ρg
$= 6 \times 10^6/3 \times 10^3 \times 10$
$= 2 \times 10^2$
$= 200$ m

14. (b) Now, Young's modulus is given as
$Y = Fl/A\Delta l$
So, YA = constant
Now, $Y_1 r_1^2 = Y_2 r_2^2$
$1.0 \times R_B^2 = 2 \times R_s^2$
Hence, $R_S = R_B/\sqrt{2}$

15. (c) It is noted that potential energy stored in rubber cord catapult will be converted to kinetic energy

$$\frac{1}{2}mv^2 = \frac{1}{2} \times YAl^2/L$$

Now, $v = \sqrt{YAl^2/mL}$

$$= \sqrt{\frac{5 \times 10^8 \times 25 \times 10^{-6} \times (5 \times 10^{-2})^2}{5 \times 10^{-3} \times 10 \times 10^{-2}}}$$

On solving, we have velocity of projected missile as 250 m/s.

16. (a) Now stretched length $l = FL/\pi r^2 \times Y$
So, $l \propto L/r^2$
Now, $l_2/l_1 = L_2/L_1 \times (r_1/r_2)^2$
$= 2 \times (1/2)^2 = 1/2$
So, $l_2 = l_1/2 = 0.01/2 = 0.005$ m

17. (c) Young's modulus is the ratio of stress to strain, so Young's modulus has units of pressure. Its SI unit is therefore pascal Pa or N/m^2.

18. (b) Now, length $l = FL/AY$
So, $l \propto 1/A$ where F, L and Y are constants
Further, $A_2/A_1 = l_1/l_2$
$\Rightarrow A_2 = A_1(0.1/0.05) = 2A_1$
$= 2 \times 4 = 8$ mm^2

19. (a) As per Hooke's law, force (F) needed to extend or compress a spring by distance l scales linearly with respect to that distance. Further, $F = kl$, where
k = constant factor characteristic of spring
l = small compared to total possible deformation of spring

20. (c) Now $l = FL/AY$
$\Rightarrow l \propto 1/r^2$
Further,
$l_2/l_1 = (r_1/r_2)^2$
$= (2)^2 = 4$
$\Rightarrow l_2 = 4l_1 = 4$ cm

Topic 2: Previous Year's Questions

1. **Assertion A:** Bernoulli's equation holds for non-steady or turbulent flows.
Reason R: In these situations, velocity and pressure are constant with time.
(a) If both assertion and reason are true, and reason is the correct explanation of assertion.
(b) If both assertion and reason are true, but reason is not the correct explanations of assertion.
(c) If assertion is true, but reason is false.
(d) If both assertion and reason is false

2. **Assertion A:** If an object is submerged in fluid at rest, the fluid exerts a force on its surface.
Reason R: The force exerted by the fluid at rest has to be parallel to the surface in contact with it.
(a) If both assertion and reason are true, and reason is the correct explanation of assertion.
(b) If both assertion and reason are true, but reason is not the correct explanations of assertion.
(c) If assertion is true, but reason is false.
(d) If both assertion and reason is false.

3. **The amount of energy required to form a soap bubble of radius 2 cm from a soap solution is nearly (surface tension of soap solution = 0.03 Nm^{-1})**
(a) 5.06×10^{-4}J **(b)** 3.01×10^{-4}J
(c) 50.1×10^{-4}J **(d)** 30.16×10^{-4}J **[NEET 2023]**

4. **The venturi-meter works on**
(a) Bernoulli's principle
(b) The principle of parallel axes
(c) The principle of perpendicular axes
(d) Huygen's principle **[NEET 2023]**

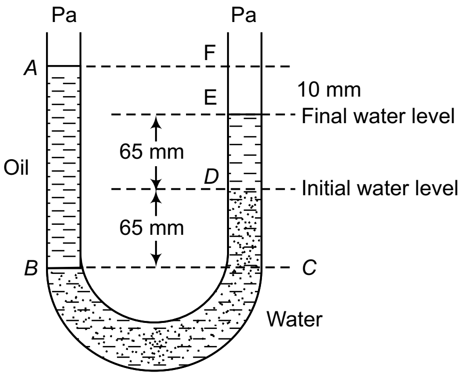
5. **Two copper vessels A and B have the same base area but of different shapes. A takes twice the volume of water as that B requires to fill upto a particular common height. Then the correct statement among the following is:**
(a) Pressure on the base area of vessels A and B is same.
(b) Pressure on the base area of vessels A and B is not same.
(c) Both vessels A and B weigh the same.
(d) Vessel B weighs twice that of A. **[NEET 2022]**

6. **The terminal velocity of a copper ball of radius 5 mm falling through a tank of oil at room temperature is 10 cm s^{-1}. If the viscosity of oil at room temperature is 0.9 kg m^{-1} s^{-1}, the viscous drag force is:**
(a) 8.48×10^{-3} N (b) 8.48×10^{-5} N
(c) 4.23×10^{-3} N (d) 4.23×10^{-6} N
[NEET 2022]

7. **A soap bubble, having radius of 1 mm, is blown from a detergent solution having a surface tension of 2.5×10^{-2} N/m. The pressure inside the bubble equals at a point Z_0 below the free surface of water in a container. Taking g = 10 m/s^2, density of water = 10^3 kg/m^3, the value of Z_0 is:**
(a) 10 cm (b) 1 cm
(c) 0.5 cm (d) 100 cm **[NEET 2019]**

8. **A small sphere of radius r falls from rest in a viscous liquid. As a result, heat is produced due to viscous force. The rate of production of heat when the sphere attains its terminal velocity, is proportional to**
(a) r^5 (b) r^2
(c) r^3 (d) r^4 **[NEET 2018]**

9.



A U tube with both ends open to the atmosphere, is partially filled with water and oil, which is immiscible with water, is poured into one side until it stands at a distance of 10 mm above the water level on the other side. Meanwhile the water rises by 65 mm from its original level (see diagram). The density of the oil is :
(a) 650 kgm^{-3} (b) 425 kgm^{-3}
(c) 800 kgm^{-3} (d) 928 kgm^{-3} **[NEET 2017]**

10. **Two non-mixing liquids of densities ρ and $n\rho$ ($n > 1$) are put in a container. The height of each liquid is h. A solid cylinder of length L and density d is put in this container. The cylinder floats with its axis vertical and length pL ($p < 1$) in the denser liquid. The density d is equal to :**
(a) $\{1 + (n + 1)p\}\rho$ (b) $\{2 + (n + 1)p\}\rho$
(c) $\{2 + (n - 1)p\}\rho$ (d) $\{1 + (n - 1)p\}\rho$
[AIPMT 2016]

11. **A rectangular film of liquid is extended from (4 cm × 2 cm) to (5 cm × 4 cm). If the work done is 3×10^{-4} J, the value of the surface tension of the liquid is:**
(a) 8.0 Nm^{-1} (b) 0.250 Nm^{-1}
(c) 0.125 Nm^{-1} (d) 0.2 Nm^{-1} **[AIPMT 2016]**

12. **Three liquids of densities ρ_1, ρ_2 and ρ_3 (with $\rho_1 > \rho_2 > \rho_3$), having the same value of surface tension T, rise to the same height in three identical capillaries. The angles of contact θ_1, θ_2 and θ_3 obey:**
(a) $\pi/2 > \theta_1 > \theta_2 > \theta_3 \geq 0$ (b) $0 \leq \theta_1 < \theta_2 < \theta_3 < \pi/2$
(c) $\pi/2 < \theta_1 < \theta_2 < \theta_3 < \pi/2$ (d) $\pi > \theta_1 > \theta_2 > \theta_3 > \pi/2$
[AIPMT 2016]

13. **Water rises to height 'h' in capillary tube. If the length of capillary tube above the surface of water is made less than 'h', then :**
(a) water does not rise at all.
(b) water rises upto the tip of capillary tube and then starts overflowing like a fountain.
(c) water rises upto the top of capillary tube and stays there without overflowing.
(d) water rises upto a point a little below the top and stays there. **[AIPMT 2015]**

14. **A wind with speed 40 m/s blows parallel to the roof of a house. The area of the roof is 250 m^2. Assuming that the pressure inside the house is atmospheric pressure, the force exerted by the wind on the roof and the direction of the force will be : (ρ_{air} = 1.2 kg/m^3)**
(a) 2.4 x 10^5 N, upwards
(b) 2.4 x 10^5 N, downwards
(c) 4.8 x 10^5 N, downwards
(d) 4.8 x 10^5 N, upwards **[AIPMT 2015]**

15. **A certain number of spherical drops of a liquid of radius 'r' coalesce to form a single drop of radius 'R' and volume 'V'. If 'T' is the surface tension of the liquid, then :**
(a) energy = $4VT$ $(1/r - 1/R)$ is released
(b) energy = $3VT$ $(1/r + 1/R)$ is absorbed
(c) energy = $3VT$ $(1/r - 1/R)$ is released
(d) energy is neither released nor absorbed
[AIPMT 2014]

16. **The wet-ability of a surface by a liquid depends primarily on :**
(a) density
(b) angle of contact between surface and liquid
(c) viscosity
(d) surface tension **[AIPMT 2013]**

17. **There is a hole in the bottom of tank having water. If total pressure at bottom is 3 atm (1 atm = 10^5 N/m^2) then the velocity of water flowing from hole is:**
(a) $\sqrt{400}$ m/s (b) $\sqrt{600}$ m/s
(c) $\sqrt{60}$ m/s (d) None of these
[CPMT 2002]

Answer Key

1.	(d)	2.	(c)	3.	(b)	4.	(a)	5.	(a)	6.	(a)
7.	(b)	8.	(a)	9.	(d)	10.	(d)	11.	(c)	12.	(b)
13.	(c)	14.	(a)	15.	(c)	16.	(b)	17.	(a)		

Answers with Explanation

1. **(d)** Bernoulli's equations does not hold for non-steady or turbulent flow of liquid, it is because velocity and pressure are constantly fluctuating with time.

2. **(c)** when an object is placed in fluid at rest, the fluid always exerts a force normal to the object's surface.

3. **(b)** Surface tension = $\frac{\text{Work done}}{\Delta \text{ Area}}$

A soap bubble has 2 free surface.

So, area, $A = 2\times4r\pi r^2 = 8\pi r^2$

$\Rightarrow$ Work done = surface tension $\times\ 8\pi r^2$

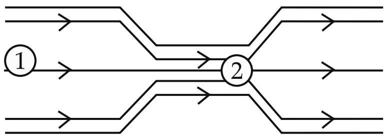
$= (0.03) \times 8 \times \pi \times (2 \times 10^{-2})^2$

$= 3.01 \times 10^{-4}$J.

4. **(a)** Bernoulli's principle is based on conservation of energy, that is the total work done by pressure, gravity and change in KE is constant for an ideal fluid flowing in a closed tube.

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

Venturie–meter works on this principle.



$$P_1+\frac{1}{2}\rho v_1^{\,2}+\rho gh=P_2+\frac{1}{2}\rho v_2^{\,2}+\rho gh$$

Perpendicular and parallel axes theorem helps to find moment inertia at different axes of rotation

Huygens theory explain the wave nature of light.

5. **(a)** Pressure, $P = h\rho g$ ...(1)

In above equation, ρ represents density of water, g represents acceleration due to gravity and h is the height of the vessel.

As both vessels have same height and containing water, then densities are also same. Hence, the pressure on the base area of vessels A and B is same.

6. **(a)** By Stobal's law,

keF $= 6\pi\eta rv$

(where, the symbols have their usual meanings)

$F = 6 \times 3.14 \times 0.9 \times 5 \times 10^{-3} \times 10 \times 10^{-2}$

$F = 84.78 \times 10^{-4}$

$= 8.478 \times 10^{-3}$ N $= 8.48 \times 10^{-3}$ N

7. **(b)** For the soap, Excess pressure $= \frac{4T}{R}$,

Gauge pressure $= \rho g Z_0$

Apply the given condition,

$$P_0 + \frac{4T}{R} = P_0 + \rho g Z_0$$

or, $Z_0 = \frac{4T}{R \times \rho g}$

or, $Z_0 = \frac{4 \times 2.5 \times 10^{-2}}{10^{-3} \times 1000 \times 10}$ m

or, $Z_0 = 1$ cm

8. **(a)** We see that heat produced is the power which is given as $6\pi\eta r V_T^{\,2}$

As terminal velocity $V_T \propto r^2$, so rate of production of heat $P \propto r^5$

9. **(d)** From the figure, it is observed that:

Pressure at B = Pressure at C

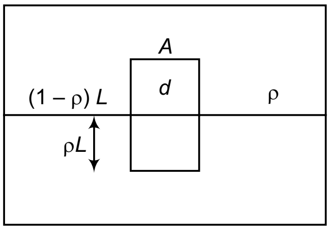
So, $\rho_0 g \times 140 \times 10^{-3} = \rho_w g \times 130 \times 10^{-3}$

Hence,

$\rho_o = (130/140) \times 10^3$

$= 928$ kg/m^3

10. **(d)**



According to Archimedes principle,

Weight of the cylinder = (upthrust)$_1$ + (upthrust)$_2$

i.e., $ALdg = (1 - p)\ LA\rho g + (pLA)\ n\rho g$

$\Rightarrow$ $d = (1 - p)\ \rho + pn\rho$

$= \rho - p\rho + np\rho$

$= \rho + (n + 1)p\rho$

$= \rho[1+(n - 1)\ p]$

11. **(c)** As there are two film surfaces, so increase in surface area

$= (20\text{ cm}^2 - 8\text{ cm}^2) \times 2$

$= 12 \times 2$ cm

$= 24$ cm^2

Now work done $= T.\Delta S$

$3 \times 10^{-4} = T \times 24 \times 10^{-4}$

or, $T = \frac{3}{24} = 0.125$ N/m

12. **(b)** Since,

$h = 2 \times T \cos\theta / r\rho g$

As $r \propto \cos\theta$ since T, h and r being constants, so

$\rho\uparrow \Rightarrow \theta\downarrow$

$\theta_1<\theta_2<\theta_3$ [as $\rho_1 > \rho_2 > \rho_3$]

It shows $0 \le \theta_1 < \theta_2 < \theta_3 < \pi/2$

13. **(c)** It is given that water rises to a height 'h' in a capillary tube. so, the length of the capillary tube above the surface water is made less than 'h' then the height of water > length of capillary tube, so in such case, water will not overflow, but create constant flow using energy without any energy input. The similar force that pulls water along inside of capillary tube will hold it there when it reaches the end. Such force doesn't just pull upward, it pulls the water along the glass. At a certain height, the weight of the water column balances this pull. In that case the pull is upward since there is water below not above.

14. (a) Using Bernoulli's theorem and assuming density constant,

$$P_1 + 1/2\rho v_1^2 = P_2 + 1/2\rho v_2^2$$

where:

P_2 = pressure outside house
P_1 = pressure inside house
v_1 = speed of air inside house
v_2 = speed of air outside house

Pressure difference,

$$P_1 - P_2 = 1/2\rho\,[v_2^2 - v_1^2]$$

Now, $P_1 - P_2 = 1/2 \times 1.2\,[40^2 - 0^2]$

$$P_1 - P_2 = 960 \text{ N/m}^2$$

Since Pressure P = Force/Area, so force acting on roof will be :

$$F = P \times A$$
$$F = 960 \times 250$$
$$F = 960 \times 1000/4$$
$$F = 24 \times 10^4 \text{ or } 2.4 \times 10^5 \text{ N}$$

which is acting upward.

15. (c) As volume is same, so

$$n(4/3\pi r^3) = 4/3\pi R^3$$
$$n = R^3/r^3$$
$$U = T\Delta A$$
$$= T[4\pi R^2 - n4\pi r^2]$$
$$= 4\pi T[R^2 - nr^2]$$
$$= 4\pi T[R^2 - R^3/r^3 \times r^2]$$
$$= 4\pi R^3 T\,[1/R - 1/r]$$
$$= 3(4/3\pi R^3) \times T(1/R - 1/r)$$
$$U = 3VT(1/R - 1/r) \text{ as } R > r$$
$U = 3VT(1/r - 1/R)$ so energy is released.

16. (b) Wetting is the ability of a liquid to maintain contact with a solid surface, resulting from intermolecular interactions when the two are brought together.

17. (a) Pressure at the bottom of tank $P = h\rho g$

$$= 3 \times 10^5 \text{ Nm}^{-2}$$

Pressure due to liquid column :

$$P_l = 3 \times 10^5 - 1 \times 10^5 = 2 \times 10^5$$

As the velocity of water $v = \sqrt{2gh}$

$$v = \sqrt{2gh}$$
$$= \sqrt{2\frac{P_l}{\rho}} \text{ (as } P_l = \rho g h)$$
$$= \sqrt{\frac{2 \times 2 \times 10^5}{10^3}}$$
$$= \sqrt{400} \text{ m/s}$$

Topic 3: Previous Year's Questions

1. **Assertion A:** In change of state from solid to liquid the temperature decreases until the entire amount of the solid substance melts.
   Reason R: The phenomenon of refreezing is called melting
   (a) If both assertion and reason are true, and reason is the correct explanation of assertion.
   (b) If both assertion and reason are true, but reason is not the correct explanations of assertion.
   (c) If assertion is true, but reason is false.
   (d) If both assertion and reason is false

2. **Assertion A:** Coefficient of absorption of radiation of an ideal black body is 1.
   Reason R: An ideal black body emits radiation of all wavelengths.
   (a) If both assertion and reason are true, and reason is the correct explanation of assertion.
   (b) If both assertion and reason are true, but reason is not the correct explanations of assertion.
   (c) If assertion is true, but reason is false.
   (d) If both assertion and reason is false.

3. **Two rods one made of copper and other made of steel of the same length and same cross sectional area are joined together. The thermal conductivity of copper and steel are 385 J s^{-1} K^{-1} m^{-1} and 50 J s^{-1} m^{-1} respectively. The free ends of copper and steel are held at 100°C and 0°C respectively. The temperature at the junction is, nearly:**
   (a) 12°C **(b)** 50°C
   (c) 73°C **(d)** 88.5°C **[AIPMT 2022]**

4. **Coefficient of linear expansion of brass and steel rods are α_1 and α_2. Lengths of brass and steel rods are l_1 and l_2 respectively. If $(l_2 - l_1)$ is maintained same at all temperatures, which one of the following relations holds good?**
   (a) $\alpha_1 l_2 = \alpha_1 l_1$ **(b)** $\alpha_1 l_2 = \alpha_2 l_1$
   (c) $\alpha_2 l_2 = \alpha_1 l_1$ **(d)** $\alpha_1 l_1 = \alpha_2 l_2$
   [AIPMT 2016]

5. **Two identical bodies are made of a material for which the heat capacity increases with temperature. One of these is at 100°C, while the other one is at 0°C. If the two bodies are brought into contact, then, assuming no heat loss, the final common temperature is**
   (a) less than 50°C but greater than 0°C
   (b) 0°C
   (c) 50°C
   (d) more than 50°C **[AIPMT 2016]**

6. **A Centigrade and a Fahrenheit thermometers are dipped in boiling water. The water temperature is lowered until the Fahrenheit thermometer registers a temperature of 140°C. The fall of temperature as registered by the centigrade thermometer is:**
   (a) 80°C **(b)** 40°C
   (c) 50°C **(d)** 90°C **[AIPMT 2011]**

7. **A hot body at temperature T loses heat to the surrounding temperature T_S by radiation. If the difference in temperature is small then the rate of loss of heat by the hot body is proportional to :**
   (a) $T - T_S$ **(b)** $(T - T_S)^2$
   (c) $(T - T_S)^{1/2}$ **(d)** $(T - T_S)^4$ **[AIPMT 2010]**

8. **On a new scale of temperature (which is linear), a called the W scale, the freezing and boiling point of water are 39°W and 239°W respectively. What will be the temperature on the new scale, corresponding to a temperature of 39°C on the Celsius scale ?**
   (a) 78°W **(b)** 117°W
   (c) 200°W **(d)** 139°W **[AIPMT 2008]**

9. **A planet having average surface temperature T_0 at an average distance d from the sun. Assuming that**

the planet receives radiant energy from the sun only and it loses radiant energy only from the surface and neglecting all other atmospheric effects we conclude:

(a) $T_0 \propto d^2$ **(b)** $T_0 \propto d^{-2}$

(c) $T_0 \propto d^{1/2}$ **(d)** $T_0 \propto d^{-1/2}$

[AIPMT 2007]

10. Expansion during heating :

(a) Occurs only in solids

(b) Increases the weight of a material

(c) Decreases the density of a material

(d) Occurs at the same rate for all liquids and solids

[CBSE PMT 1994]

11. If the length of a cylinder on heating increases by 2%, the area of its base will increase by :

(a) 0.5% **(b)** 2%

(c) 1% **(d)** 4% **[CPMT 1993]**

Answer Key

1.	(d)	**2.**	(b)	**3.**	(d)	**4.**	(c)	**5.**	(d)	**6.**	(b)
7.	(a)	**8.**	(b)	**9.**	(d)	**10.**	(c)	**11.**	(d)		

Answers with Explanation

1. (d) Both the solid and liquid states of the substances coexist in thermal equilibrium during the change of state from solid to liquid and temperature is constant. The phenomenon of refreezing is called regelation.

2. (b) We know that for ideal black body reflectance (r) = 0 transmittance (t) = 0 absorptance (a) = 1. It is clear that when heated the black body will radiate all energy. Which is absorbed by it.

3. (d) As per question, we have;

100°C | Cu | Steel | 0°C

θ = ?

As $K = \dfrac{Qd}{A\,\Delta t}$,

where, K = thermal conductivity

Q = amount of heat transferred

d = distance between two planes

A = area of surface, and

ΔT = difference in Temp.

$$\frac{\Delta Q}{\Delta t} = \frac{385 \times A \times (100°C - \theta)}{l}$$

$$= \frac{50 \times A \times (\theta - 0°C)}{l}$$

$\Rightarrow 385\,(100°C - \theta) = 50(\theta - 0°C)$

$\Rightarrow \quad \theta = 88.5°C$

4. (c) If α_1 is coefficient of linear expression of brass and l_1 be its length, while α_2 is coefficient of linear expression of steel with l_2 be its length, then

$l'_2 - l'_1 = l_2 - l_1$

$l_2(1 + \alpha_2\Delta t) - l_1(1 + \alpha_1\Delta t) = l_2 - l_1$

Hence, $l_2\alpha_2 = l_1\alpha_1$

5. (d) If the final common temperature is T_c, C_c and C_h average heat capacities of cold and hot bodies then as per principle of calorimetry,

heat lost = heat gained

$C_h\,(100°C - T_c) = C_c \times T_c$

Now $T_c = C_h/(C_h + C_c) \times 100°C$

$= 100/[1 + (C_c/C_h)]$, where $C_c/C_h < 1$

It is seen that $1 + C_c/C_h < 2$

Hence, $T_c > (100/2)°C$ or $T_c > 50°C$

6. (b) Applying the formula:

F – 32°/180 = C/100

Now,140 – 32/180 = C/100

So C = 60°

Now the temperature of boiling water = 100°C

So fall in temperature = 100° – 60° = 40°C

7. (a) $dT/dt = A\varepsilon\sigma/mc \times [T^4 - T_s^4]$

As temperature difference between the body and its surrounding is not too large, then

$T - T_s = \Delta T$

Also, $T^4 - T_s^4$ results as $4T_s^3\Delta T$

So, $dT/dt = A\varepsilon\sigma/mc \times 4T_s^3\Delta T$

$dT/dt \propto \Delta T$

8. (b) W is the temperature on new scale corresponding to 39°C on °C scale.

So, $(C - 0)/(100 - 0) = (W - 39)/(239 - 39)$

$C/100 = (W - 39)/200$

$W = (C/100) \times 200 + 39$

$= (39/100) \times 200 + 39$

$= 78 + 39 = 117$

So, temperature on new scale is 117°W corres- ponding to 39°C.

9. (d) Now energy received/second from planet:

$P/4\pi d^2 \times (\pi \times R^2)$

Here : P = power radiated by Sun

R = radius of planet

$P/4\pi d^2 \times (\pi \times R^2) = \sigma(4\pi R^2) \times T_0^4$

or, $T_0^4 \propto d^{-2}$

or, $T \propto d^{-1/2}$

10. (c) It is seen that solids, liquids and gases all expand on heating. So in such case, density which is equal to mass/volume, will decrease.

11. (d) We see that $A \propto L^2$

Also, $\Delta A/A = 2 \times \Delta L/L$

$\Delta A/A = 2 \times 2 = 4\%$

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