MAR GREGORIOS COLLEGE
OF ARTS & SCIENCE

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DEPARTMENT OF ELECTRONICS & COMMUNICATION SCIENCE

SUBJECT NAME: BASIC PHYSICS-I

SUBJET CODE: TBG3A

SEMESTER: III

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BASIC PHYSICS – I

UNIT – 1

ROTATION : Moment of inertia – Radius of gyration – Moment of inertia of a circular ring, circular disc, solidsphere – Kinetic energy of a rolling object – Acceleration of a body rolling down an inclined plane – Uniformcircular motion – Centripetal force – Banking of curved tracks.

UNIT – 2

ELASTICITY: stress – strain diagram – factors affecting elasticity -Young's modulus – Bending moment –Bending of beams – Young's modulus by non-uniform bending – Rigidity Modulus - Torsion in a wire – TorsionalPendulum – Definition of Poisson's ratio.

UNIT – 3

VISCOSITY: Streamline and turbulent flow – Comparison of viscosities by burette method – – Stoke's law –Terminal velocity – Viscosity of a highly viscous liquid – Lubrication. SURFACE TENSION: Molecular theory of surface tension – Excess of pressure inside a soap bubble – surfacetension by drop weight method - interfacial surface tension.

UNIT – 4

HEAT AND THERMODYNAMICS – Thermal conductivity – Lee's Disc methods – Radial flow of heat –Thermal insulation in buildings – Laws of thermodynamics – Carnot's cycle as heat engine and refrigerator –Carnot's theorem – Concept of entropy

UNIT – 5

ACOUSTICS – Acoustics of buildings – Absorption coefficient – Intensity – Loudness – Reverberation time –Sabine's formula – Noise pollution – Noise control in a machine – Ultrasonics – production – Piezoelectric methods– Applications of ultrasonics in Engineering and Medicine.

UNIT – 1

ROTATION

Moment of Inertia

Moment of inertia is defined as the quantity expressed by the body resisting angular acceleration which is the sum of the product of the mass of every particle with its square of a distance from the axis of rotation. Or in more simple terms, it can be described as a quantity that decides the amount of torque needed for a specific angular acceleration in a rotational axis. Moment of Inertia is also known as the angular mass or rotational inertia. The SI unit of moment of inertia is kg m^2.

Moment of inertia is usually specified with respect to a chosen axis of rotation. It mainly depends on the distribution of mass around an axis of rotation. MOI varies depending on the axis that is chosen.

Moment of Inertia Formula

In General form Moment of Inertia is expressed as $I = m \times r^2$

where,

m = Sum of the product of the mass.

r = Distance from the axis of the rotation.

and, Integral form: $I = \int dI = \int_0^M r^2\, dm$

⇒ The dimensional formula of the moment of inertia is given by, $M^1 L^2 T^0$.

The role of the moment of inertia is the same as the role of mass in linear motion. It is the measurement of the resistance of a body to a change in its rotational motion. It is constant for a particular rigid frame and a specific axis of rotation.

Moment of inertia, $I = \sum m_i r_i^2$. . . . . . . (1)

Kinetic Energy, $K = \frac{1}{2} I \omega^2$ . . . . (2)

Factors on which Moment of Inertia Depends

The moment of inertia depends on the following factors,

- The density of the material
- Shape and size of the body
- Axis of rotation (distribution of mass relative to the axis)

We can further categorize rotating body systems as follows:

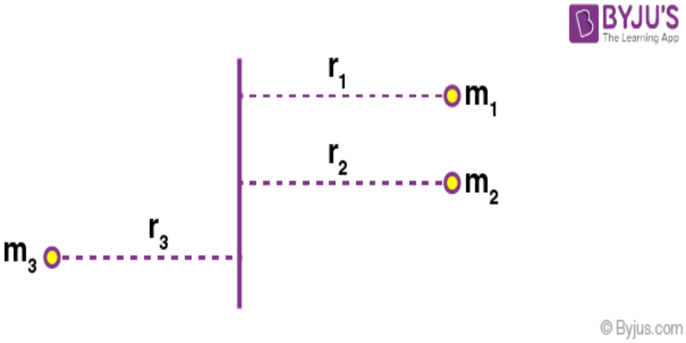
1. Discrete (System of particles)
2. Continuous (Rigid body)

Moment of Inertia of a System of Particles

The moment of inertia of a system of particles is given by,

$I = \sum m_i r_i^2$ [from equation (1)]

where r_i is the perpendicular distance from the axis to the ith particle which has mass m_i.



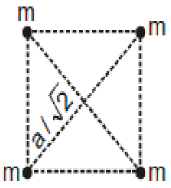
Example:

Ex. ***Four particles each of mass m are kept at the four corners of a square of edge a. Find the moment of inertia of the system about a line perpendicular to the plane of the square and passing through the centre of the square.***

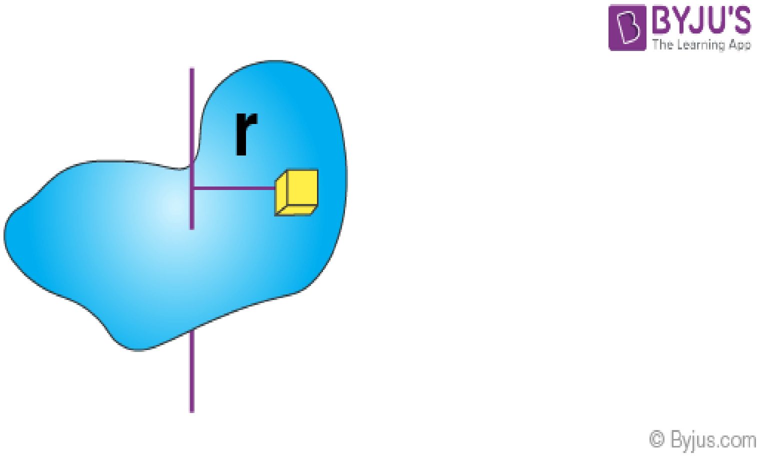
Sol.

The perpendicular distance of every particle from the given line is $a/\sqrt{2}$. The moment of inertia of one particle is, therefore, $m(a/\sqrt{2})^2 = \frac{1}{2}ma^2$. The moment of inertia of the system is,

therefore, $4 \times \frac{1}{2}ma^2 = 2\,ma^2$.



Moment of Inertia of Rigid Bodies



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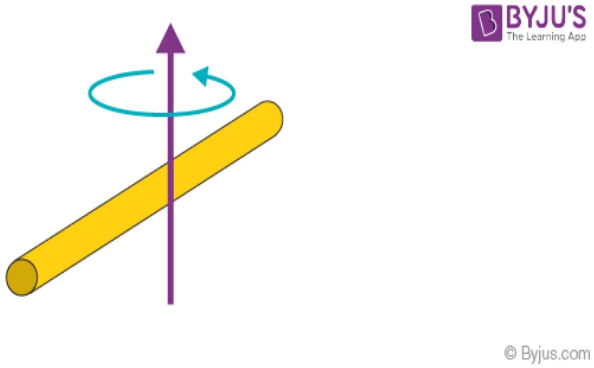
The moment of inertia of continuous mass distribution is found by using the integration technique. If the system is divided into an infinitesimal element of mass ‘dm’ and if ‘x’ is the distance from the mass element to the axis of rotation, the moment of inertia is:

$I = \int r^2\, dm$ . . . . . . (3)

Moment of Inertia of a Uniform Rod about a Perpendicular Bisector



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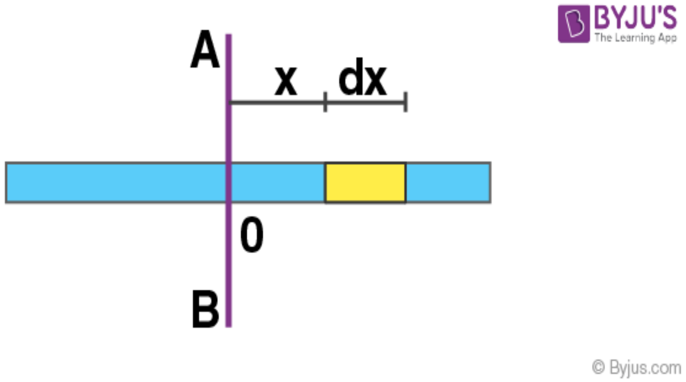

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Consider a uniform rod of mass M and length L and the moment of inertia should be calculated about the bisector AB. Origin is at 0.

The mass element ‘dm’ considered is between x and x + dx from the origin.

As the rod is uniform, mass per unit length (linear mass density) remains constant.

∴ $M/L = dm/dx$

$dm = (M/L)dx$

Moment of inertia of dm ,

$dI = dm\, x^2$

$dI = (M/L)\, x^2.dx$

$I = \int_{-L/2}^{+L/2} dI = M/L \times \int_{-L/2}^{+L/2} x^2\, dx$

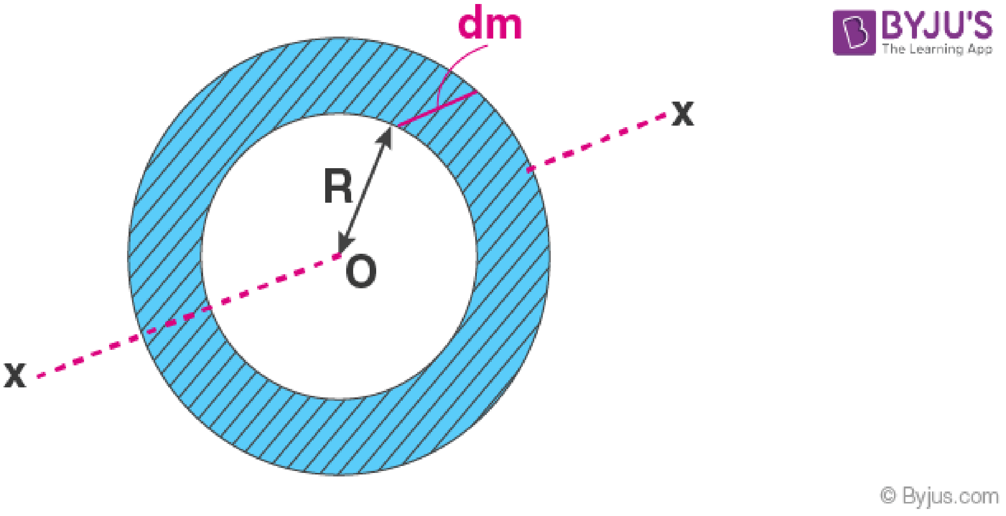
Here, x = -L/2 is the left end of the rod and ‘x’ changes from –L/2 to +L/2, the element covers the entire rod.

$I = M/L \times [x^3/3]_{-L/2}^{+L/2}$

$I = ML^2/12.$

Therefore, the moment of inertia of a uniform rod about a perpendicular bisector (I) = $ML^2/12$.

Moment of Inertia of a Circular Ring about its Axis



Consider the line perpendicular to the plane of the ring through its centre. The radius of the ring is taken as R and its mass as M. All the elements are at the same distance from the axis of rotation, R.

Linear mass density is constant.

∴ $M/2\pi = dm/d\theta$

$dm = M/2\pi \times d\theta$

$I = \int R^2\, dm = R^2 \int_0^{2\pi} [M/2\pi]\, d\theta$

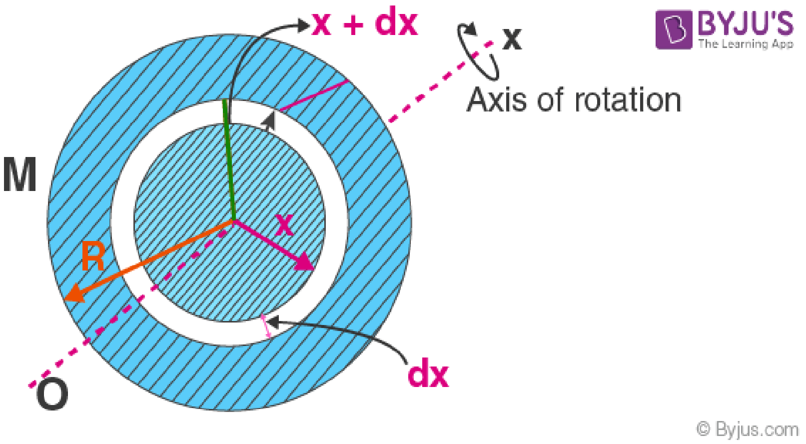
Limits: $\theta = 0$ to 2π includes the whole mass of the ring

$\therefore I = R^2\, [M/2\pi] \times [\theta]^{2\pi}_0$

Therefore, the moment of inertia of a circular ring about its axis (I) = MR^2.

⇒ Note that in one-dimensional bodies, if it's uniform, their linear mass density (M/L) remains constant. Similarly, for 2D and 3D, M/A (surface density) and M/V (volume density) remain constant respectively.

Moment of Inertia of a Uniform Circular Disc about its Axis



Let the mass of the plate be M and the radius be R. The centre is at O and the axis is perpendicular to the plane of the plate. The mass element considered is a thin ring between x and x+dx with thickness dx and mass dm.

As the plane is uniform, the surface mass density is constant.

$M/A = dm/da$

$M/\pi R^2 = dm/[2\pi.x.dx]$

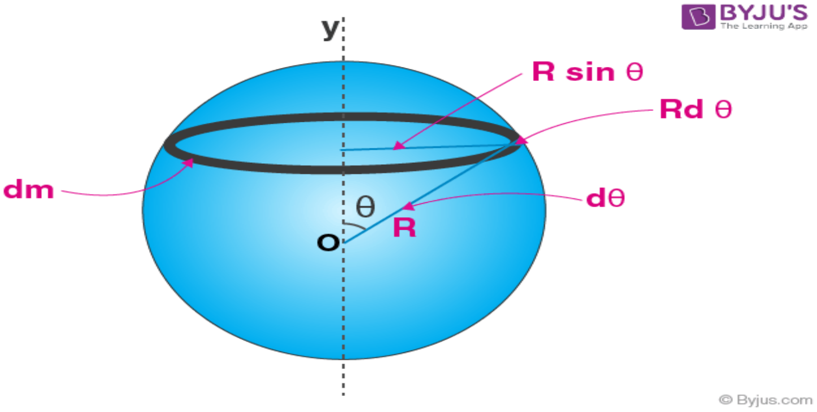
$I = \int x^2\, dm = 2M/R^2 \times \int_0^R x^3\ .\ dx$

Limits: As we take the area of all mass elements from x=0 to x=R, we cover the whole plate.

$I = (2M/R^2)[x^4/4]^R_0 = (2M/R^2) \times R^4/4 = MR^2/2$

Therefore, the moment of inertia of a uniform circular plate about its axis (I) = $MR^2/2$.

Moment of Inertia of thin Spherical Shell or Uniform Hollow Sphere



Let M and R be the mass and the radius of the sphere, O at its centre and OY be the given axis. The mass is spread over the surface of the sphere and the inside is hollow.

Let us consider radii of the sphere at an angle θ and at an angle θ+dθ with the axis OY and the element (thin ring) of mass dm with radius Rsinθ is taken as we rotate these radii about OY. The width of this ring is Rdθ and its periphery is 2πRsinθ.

As the hollow sphere is uniform, the surface mass density (M/A) is constant.

$M/A = dm/da$

$(M/4\pi R^2) = dm/[2\pi \times R\sin\theta \,.\, Rd\theta]$

$dm = [M/4\pi R^2] \times 2\pi R^2 \,.\, \sin\theta \, d\theta = [M/2] \times \sin\theta \, d\theta$

$I = \int x^2 \, dm = {}_0\!\int^{\pi} (R \sin \theta)^2 \times [M/2] \sin\theta \, d\theta$

Limits: As θ increases from 0 to π, the elemental rings cover the whole spherical surface.

$I = [MR^2/2] \times {}_0\!\int^{\pi} \sin^3 \theta \, d\theta = MR^2/2 \times {}_0\!\int^{\pi} [\sin^2 \theta \,.\, \sin \theta] \times d\theta$

$= [MR^2/2] \, {}_0\!\int^{\pi} (1 - \cos^2 \theta) \sin \theta \times d\theta$

Now, on integrating the above equation by the substitution method we get,

Take $u = \cos \theta \, d\theta$

Then, $du = - \sin \theta \, d\theta$

Changing limits, when $\theta = 0$, $u = 1$

When, $\theta = \pi$, $u = -1$

$I = [MR^2/2] \times {}_1\!\int^{-1} (1 - u^2) \, (-du)$

$= [MR^2/2] \times {}_1\int^{-1} (u^2 - 1)\,(du)$

$= [MR^2/2] \times [u^3/3 - u]_1^{-1}$

$= [MR^2/2]\,[-2/3 + 2] = [MR^2/2\,] \times [4/3] = 2MR^2/3$

Therefore, the moment of inertia of thin spherical shell and uniform hollow sphere (I) = $2MR^2/3$.

Moment of Inertia of a uniform solid sphere

Let us consider a sphere of radius R and mass M. A thin spherical shell of radius x, mass dm and thickness dx is taken as a mass element. Volume density (M/V) remains constant as the solid sphere is uniform.

$M/V = dm/dV$

$M/[4/3 \times \pi R^3] = dm/[4\pi x^2.dx]$

$dm = [M/(4/3 \times \pi R^3)\,] \times 4\pi x^2\,dx = [3M/R^3]\,x^2\,dx$

$I = \int dI = (2/3) \times \int dm\,.\,x^2$

$= (2/3) \times \int [3M/R^3\,dx]\,x^4$

$=(\,2M/R^3) \times {}_0\int^R x^4\,dx$

Limits: As x increases from 0 to R, the elemental shell covers the whole spherical surface.

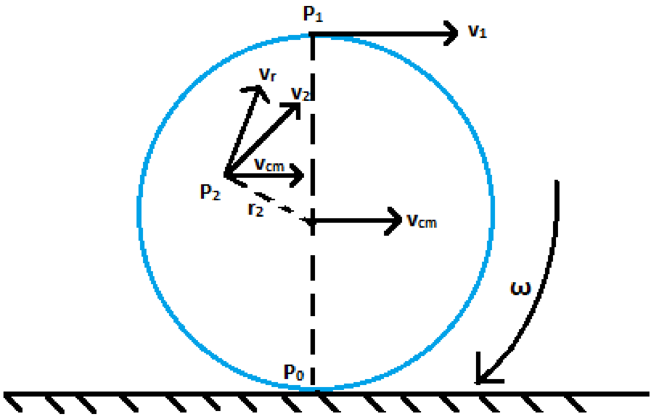
$I = (2M/R^3)[x^5/5]^R{}_0$

$= (2M/R^3) \times R^5/5$

Therefore, the moment of inertia of a uniform solid sphere (I) = $2MR^2/5$.

Kinetic energy of a rolling object

The rolling motion is a combination of translational motion and rotational motion. For a body, the motion of the centre of mass is the translational motion of the body. During the rolling motion of a body, the surfaces in contact get deformed a little temporarily. Due to this deformation, a finite area of both bodies comes in contact with each other. The overall effect of this phenomenon is that the component of the contact force parallel to the surface opposes motion resulting in friction.



Let v_{cm} is the velocity of the centre of mass of a disc-shaped body. Since for a rolling disc, the centre of mass would lie at the geometric centre C, the velocity of body or velocity of C is v_{cm} which is parallel to the rolling surface. The rotational motion of the body occurs about its axis of symmetry, therefore, the velocity at any point P_0, P_1 or P_2 of the body comprises two parts, translational velocity v_{cm} and due to rotational motion, it has linear velocity v_r, where $v_r = r\omega$. ω is the angular velocity of the rolling disc. v_r is perpendicular to radius vector at any point lying on the disc with respect to the geometric centre C. Consider the point P_0 on the disc. v_r is directed opposite to v_{cm} and at this point $v_r = R\ \omega$, where R is the radius of the disc. Therefore, for the disc, the condition for rolling without slipping is given by $v_{cm} = R\ \omega$.

The kinetic energy of such a rolling body is given by the sum of kinetic energies of translational motion and rotation.

$$K = \frac{1}{2}mv_{cm}^2 + \frac{1}{2}I\omega^2$$

Where,

m is the mass of the body

v_{cm} is the rotational motion

I is the Moment of Inertia

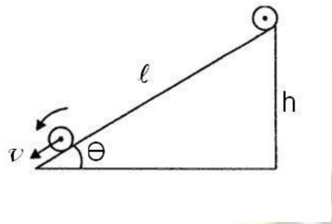
ω is the angular velocity of the rolling body

Acceleration of a body rolling down an inclined plane

Consider a body of mass (M) and radius (R) rolling down (without slipping) a smooth inclined plane making an angle of inclination (Θ). When a body rolls down its Potential Energy (resting at the top of inclined plane) is converted into the Kinetic energy of translation as well as rotation. As we know that body is rolling down a smooth inclined plane this means there will be no loss of energy due to friction. So the loss in Potential Energy is same as gain in kinetic energy.

Loss in potential Energy = Gain in kinetic energy

$Mgh = ½ (M v^2) + ½ (I \omega^2)$



From the above fig we know that $h = \ell \sin \Theta$, substituting this in the above equation we get,
$Mg \ell \sin \Theta = ½ (M v^2) + ½ (I \omega^2)$
$Mg \ell \sin \Theta = ½ (M v^2) + ½ (M K^2 .(v^2 / R^2))$
Where K = radius of gyration, $\omega = v/R$ and $I = M K^2$

$Mv^2 / 2 (1 + (K^2 / R^2)) = Mg \ell \sin \Theta$
$v^2 = 2 g \ell \sin \Theta / (1 + (K^2 / R^2))$ but $v^2 = 2a\ell$
So Formula for acceleration of a body rolling down a smooth inclined plane,

$a = g \sin \Theta / (1 + (K^2 / R^2))$

Centripetal Force

Any force or combination of forces can cause a centripetal or radial acceleration. Just a few examples are the tension in the rope on a tether ball, the force of Earth's gravity on the Moon, friction between roller skates and a rink floor, a banked roadway's force on a car, and forces on the tube of a spinning centrifuge. Any net force causing uniform circular motion is called a centripetal force. The direction of a centripetal force is toward the center of curvature, the same as the direction of centripetal acceleration. According to Newton's second law of motion, net force is mass times acceleration: net $F = ma$. For uniform circular motion, the acceleration is the centripetal acceleration—$a = a_c$. Thus, the magnitude of centripetal force F_c is $F_c = ma_c$.

By using the expressions for centripetal acceleration a_c

$a_c = v^2r$;

$a_c = r\omega^2$

we get two expressions for the centripetal force F_c in terms of mass, velocity, angular velocity, and radius of curvature:

$F_c = mv^2r$;

$Fc = mr\omega^2$

Banking of curved roads and tracks and Condition for skidding

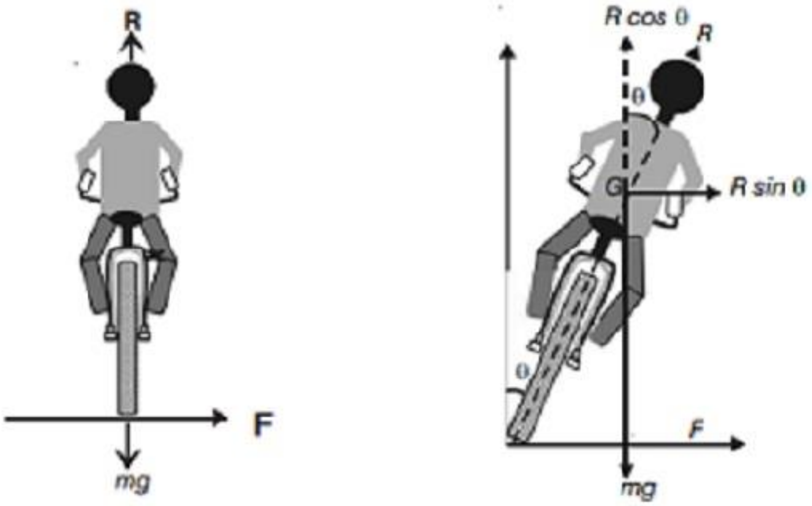


Fig Bending of a cyclist in a curved road

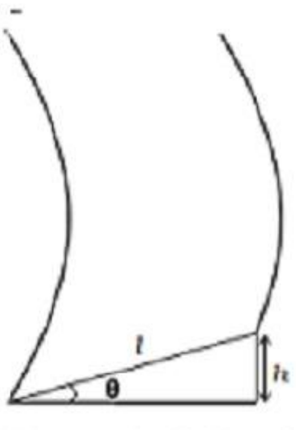


Fig . Banked road

When a car goes round a level curve, the force of friction between the tyres and the road provides the necessary centripetal force. If the frictional force, which acts as centripetal force and keeps the body moving along the circular road is not enough to provide the necessary centripetal force, the car will skid.

Banking of curved roads and tracks

When a car goes round a level curve, the force of friction between the tyres and the road provides the necessary centripetal force. If the frictional force, which acts as centripetal force and keeps the body moving along the circular road is not enough to provide the necessary centripetal force, the car will skid. In order to avoid skidding, while going round a curved path the outer edge of the road is raised above the level of the inner edge. This is known as banking of curved roads or tracks.

Bending of a cyclist round a curve

A cyclist has to bend slightly towards the centre of the circular track in order to take a safe turn without slipping.

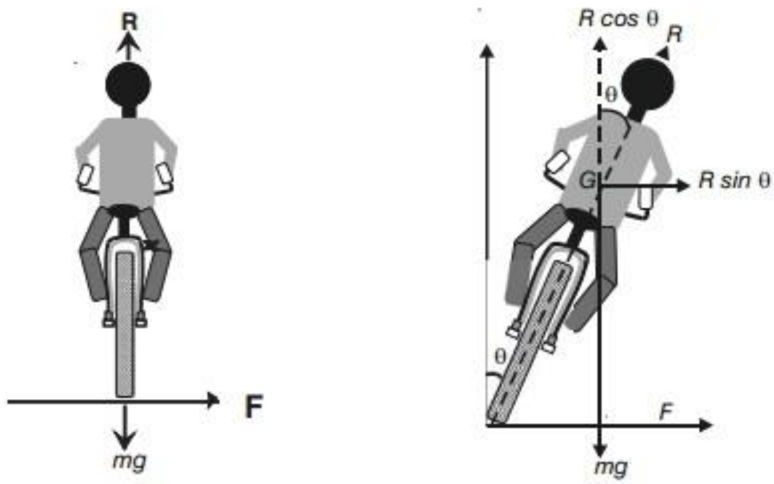


Fig Bending of a cyclist in a curved road

Fig. shows a cyclist taking a turn towards his right on a circular path of radius r. Let m be the mass of the cyclist along with the bicycle and v, the velocity. When the cyclist negotiates the curve, he bends inwards from the vertical, by an angle θ. Let R be the reaction of the ground on the cyclist. The reaction R may be resolved into two components: (i) the component R sin θ, acting towards the centre of the curve providing necessary centripetal force for circular motion and (ii) the component R cos θ, balancing the weight of the cyclist along with the bicycle.

(i.e) $$R \sin \theta = \frac{mv^2}{r} \qquad \ldots(1)$$

and $$R \cos \theta = mg \qquad \ldots(2)$$

Dividing equation (1) by (2), $$\frac{R \sin \theta}{R \cos \theta} = \frac{\frac{mv^2}{r}}{mg}$$

$$\tan \theta = \frac{v^2}{rg} \qquad \ldots(3)$$

(i.e) R sin θ = mv^2/r ...(1)

and R cos θ = mg ...(2)

Dividing equation (1) by (2),

Rsin θ/R cos θ = (mv^2/r) / mg

tan θ = v^2/rg ...(3)

Thus for less bending of cyclist (i.e for θ to be small), the velocity v should be smaller and radius r should be larger.

For a banked road (Fig.), let h be the elevation of the outer edge of the road above the inner edge and l be the width of the road then,

sin θ = h/l ...(4)

For small values of θ, sin θ = tan θ

Therefore from equations (3) and (4)

tan θ = h/l = v^2/rg

Obviously, a road or track can be banked correctly only for a particular speed of the vehicle. Therefore, the driver must drive with a particular speed at the circular turn. If the speed is higher than the desired value, the vehicle tends to slip outward at the turn but then the frictional force acts inwards and provides the additional centripetal force. Similarly, if the speed of the vehicle is lower than the desired speed it tends to slip inward at the turn but now the frictional force acts outwards and reduces the centripetal force.

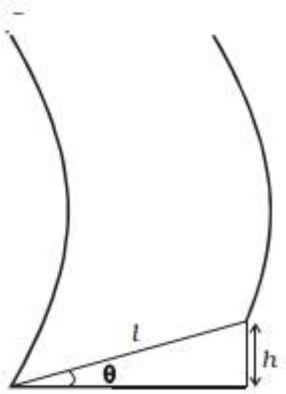


Fig . Banked road

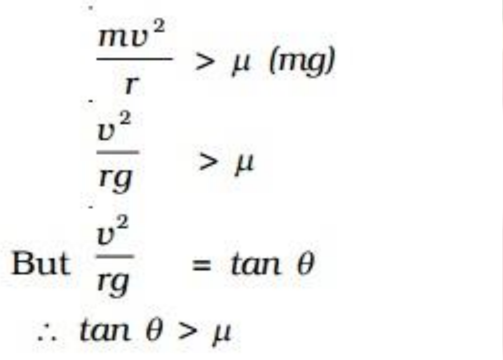
Condition for skidding

When the centripetal force is greater than the frictional force, skidding occurs. If ? is the coefficient of friction between the road and tyre, then the limiting friction (frictional force) is f = ?R where normal reaction R = mg

$\therefore f = m\,(mg)$

Thus for skidding,

Centripetal force > Frictional force



$$\frac{mv^2}{r} > \mu\ (mg)$$

$$\frac{v^2}{rg} > \mu$$

$$\text{But } \frac{v^2}{rg} = \tan\theta$$

$$\therefore \tan\theta > \mu$$

$mv^2/r > m\,(mg)$

$v^2/rg > m$

But $v^2/rg = \tan\theta$

$\therefore \tan\theta > m$

(i.e) when the tangent of the angle of banking is greater than the coefficient of friction, skidding occurs.

UNIT – 2 – ELASTICITY

Stress

In mechanics, stress is defined as a force applied per unit area. It is given by the formula

$\sigma = F/A$

where,

σ is the stress applied

F is the force applied

A is the area of force application

The unit of stress is N/m^2

Stress applied to a material can be of two types. They are:

- **Tensile Stress**: It is the force applied per unit area which results in the increase in length (or area) of a body. Objects under tensile stress become thinner and longer.
- **Compressive Stress**: It is the force applied per unit area which results in the decrease in length (or area) of a body. The object under compressive stress becomes thicker and shorter.

Strain

According to the strain definition, it is defined as the amount of deformation experienced by the body in the direction of force applied, divided by initial dimensions of the body. The relation for deformation in terms of length of a solid is given below.

$\epsilon=\delta l/L$

where,

ϵ is the strain due to stress applied

δl is the change in length

L is the original length of the material.

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

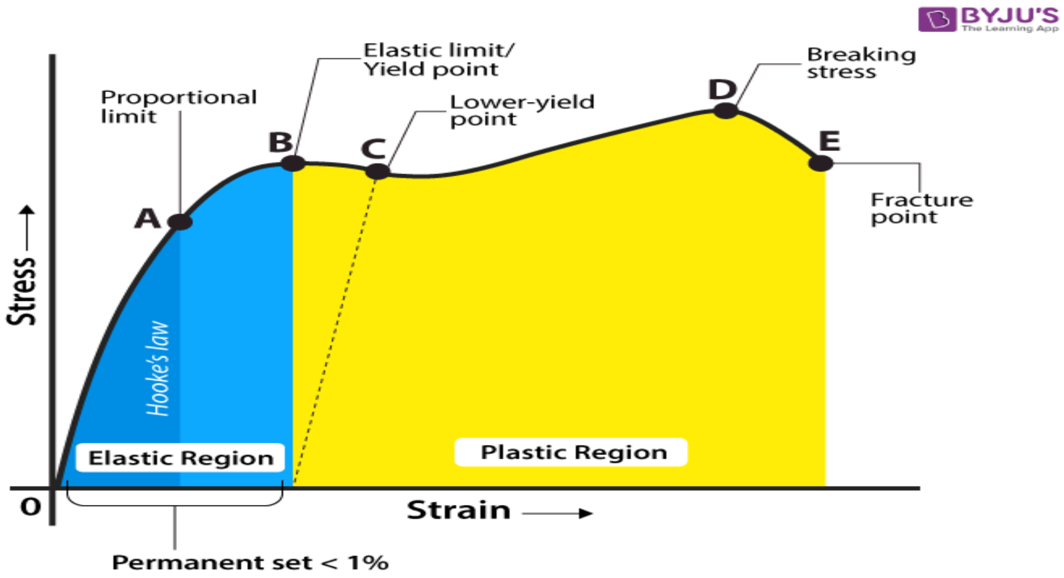
Depending on stress application, strain experienced in a body can be of two types. They are:

- **Tensile Strain**: It is the change in length (or area) of a body due to the application of tensile stress.
- **Compressive Strain**: It is the change in length (or area) of a body due to the application of compressive strain

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

Stress-Strain Curve

The stress-strain relationship for materials is given by the material’s stress-strain curve. Under different loads, the stress and corresponding strain values are plotted. An example of a stress-strain curve is given below.



Stress-Strain Curve

The stress-strain graph has different points or regions as follows:

- Proportional limit
- Elastic limit
- Yield point
- Ultimate stress point
- Fracture or breaking point

(i) Proportional Limit

It is the region in the stress-strain curve that obeys Hooke's Law. In this limit, the ratio of stress with strain gives us proportionality constant known as young's modulus. The point OA in the graph is called the proportional limit.

(ii) Elastic Limit

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

(iii) Yield Point

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

(iv) Ultimate Stress Point

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

(v) Fracture or Breaking Point

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

Hooke’s Law

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

Hooke’s Law states that the strain of the material is proportional to the applied stress within the elastic limit of that material.
Mathematically, Hooke’s law is commonly expressed as:

$$\mathbf{F = -k.x}$$

Where,

- F is the force
- x is the extension length
- k is the constant of proportionality known as spring constant in N/m

FACTORS AFFECTING ELASTICITY

The material will have change in their elastic property because of the following factors.

a) Effect of stress: For large number of cycles of stresses, it loses its elastic property even within the elastic limit. Therefore, the working stress on the material should be kept lower than the ultimate tensile strength and the safety factor.

b) Effect of Annealing: Annealing is made to a material it results in the formation of large crystal grains, which ultimately reduces the elastic property of the material.

c) Effect of temperature: Normally the elasticity increases with the decrease in temperature and vice-versa.

Ex. 1. The elastic property of lead increases when the temperature is decreased.

2. The carbon filament becomes plastic at higher temp.

d) Effect of impurities: The addition of impurities produces variation in the elastic property of the materials. The increase and decrease of elasticity depend upon the type of impurity added to it.

Ex. 1. When potassium is added to gold, the elastic property of gold increases.

2. When carbon is added to molten iron, the elastic property of iron decreases provided the carbon content should be more than 1% in iron.

e) Effect of nature of crystals: The elasticity also depends upon the types of the crystals, whether it is a single crystal or poly crystals. For a single crystal the elasticity is more and for a poly crystal the elasticity is less.

There are 3 types of Modulus of elasticity

- 1) Young's modulus of Elasticity (Y)
- 2) Rigidity modulus of Elasticity (G)
- 3) Bulk modulus of Elasticity (K)
- 1) Young's modulus of Elasticity (Y) : It is defined as the ratio of longitudinal stress to longitudinal strain.

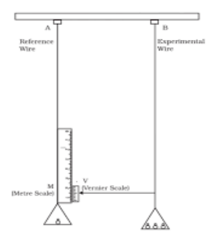
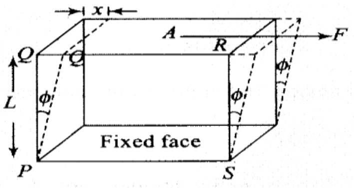


Fig. 2 *An arrangement for the determination of Young's modulus of the material of a wire.*

- Y = longitudinal stress/longitudinal strain
- $Y = \dfrac{F/A}{l/L}$ (N/m^2)
- 2) Rigidity modulus of Elasticity (G) : It is defined as the ratio of tangential stress to tangential strain.
- G = Tangential stress/tangential strain

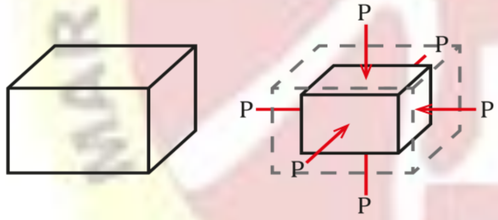
- $G = \frac{F/A}{\Phi}$ (N/m^2)



i.e. $\eta = \frac{\text{Shearing stress}}{\text{Shearing strain}}$

Rigidity modulus of Elasticity may also be denoted by η

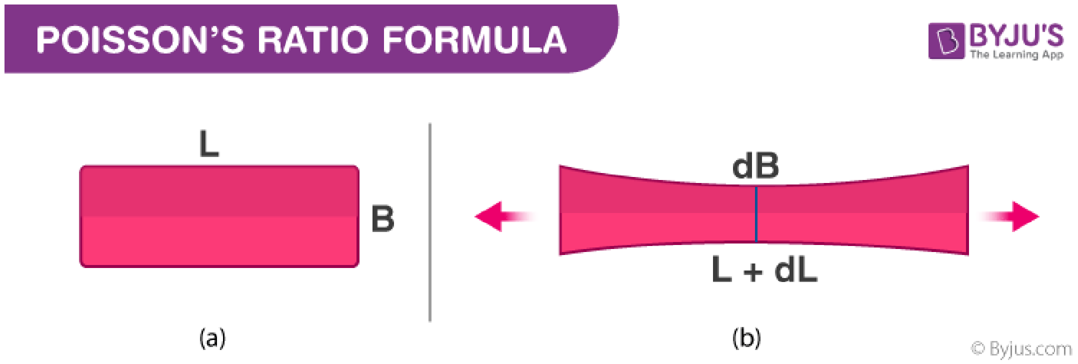
- 3) Bulk modulus of Elasticity (K): It is defined as the ratio of volumetric stress to volumetric strain.
- K = Volumetric stress/Volumetric strain
- $K = = \frac{F/A}{v/V}$ (N/m^2)



- Poisson's Ratio : It is defined as the ratio of lateral strain to longitudinal strain

ν = Lateral strain/Longitudinal strain (no unit)

$\nu = - \frac{r/R}{l/L}$ (no unit)



If the original length and breadth of the rubber are taken as L and B respectively, then when pulled longitudinally, it tends to get compressed laterally. In simple words, length has increased by an amount dL and the breadth has increased by an amount dB.

In this case,

$\varepsilon t=-dB/B \ \varepsilon l=-dL/L$

The formula for Poisson's ratio is,

$\text{Poisson}'\text{sratio}=\text{Transversestarin}/\text{Longitudinalstrain} \Rightarrow \nu=-\varepsilon t/\varepsilon l$

where,

εt is the Lateral or Transverse Strain

εl is the Longitudinal or Axial Strain

ν is the Poisson's Ratio

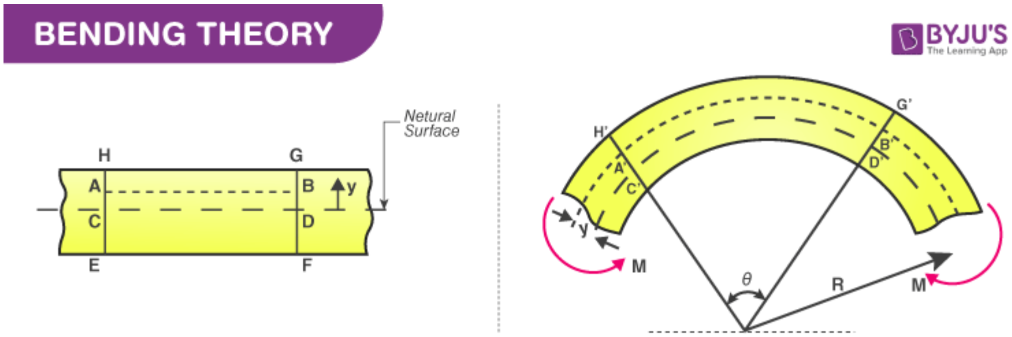
The strain on its own is defined as the change in dimension (length, breadth, area…) divided by the original dimension.

Bending equation derivation

Following are the assumptions made before the derivation of the bending equation:

- The beam used is straight with a constant cross-section.
- The beam used is of homogeneous material with a symmetrical longitudinal plane.
- The plane of symmetry has all the resultant of applied loads.
- The primary cause of failure is buckling.
- E remains same for tension and compression.
- Cross-section remains the same before and after bending.

Consider an unstressed beam, which is subjected to a constant bending moment such that the beam bends up to radius R. The top fibres are subjected to tension whereas the bottom fibres are subjected to compression. The locus of points with zero stress is known as neutral axis.



With the help of the above figure, the following are the steps involved in the derivation of the bending equation:

Strain in fibre AB is the ratio of change in length to original length.

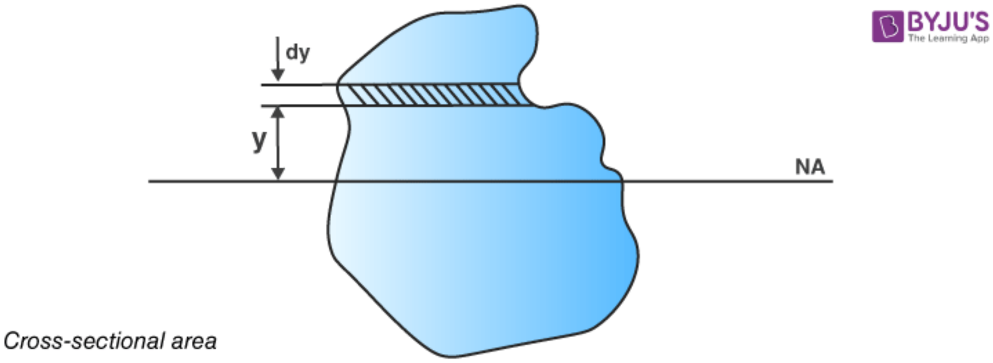
Strain in fibre $AB = A'B' - AB/AB$ $\therefore strain = A'B' - C'D'/C'D'$ (as AB = CD and CD = C’D’)
CD and C’D’ are on the neutral axis and stress is assumed to be zero, therefore strain is also zero on the neutral axis.

$=(R+y)\Theta - R\Theta/R\Theta = R\Theta + y\Theta - R\Theta/R\Theta = y/R$

$\sigma/E = y/R$ where E is Young’s Modulus of Elasticity

Or

$\sigma/y = E/R$



$\sigma = E/R \times y$ (eq.1)

$F = \sigma\delta A = E/Ry\delta A$ (force acting on the strip with area dA)

$Fy=E/Ry^2\delta A$ (momentum about neutral axis)

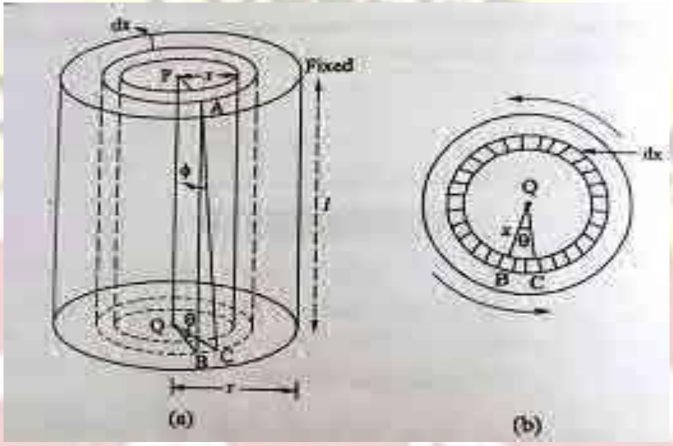
$M=\sum E/Ry^2$ (total momentum for entire cross-sectional area)

$\delta A=E/R\sum y^2\delta A$;$\sum y^2\delta A$ is known as second moment of area and is represented as I.

$\therefore M=E/R\times I$

TwistingCoupleOnaWire

Consider a cylindrical wire of length l and radius r fixed at one end. . It is twistedthroughanangleθbyapplyingcoupletoitslowerend.Now,thewireissaidtobeundertorsion.



Duetoelasticpropertyofthewire,aninternalrestoringcoupleissetupinsidethewire.Itisequal and opposite to the external twisting couple (applied). The cylinder is imagined to consistofalargenumberof thinhollowcoaxialcylinders.

Consideronesuchcylinderofradius xandthicknessdx (fig.1.11b)

ABis a line parallel to PQ on the surface of this cylinder. As the cylinder is twisted, the lineABisshiftedtoACthroughanangleBAC=Φ

ShearingstrainorAngleofshear=ΦAng

le of twist at the free end =

θFromthefigure

$BC=x\theta=l$

$$=\frac{x\theta}{l}$$

—

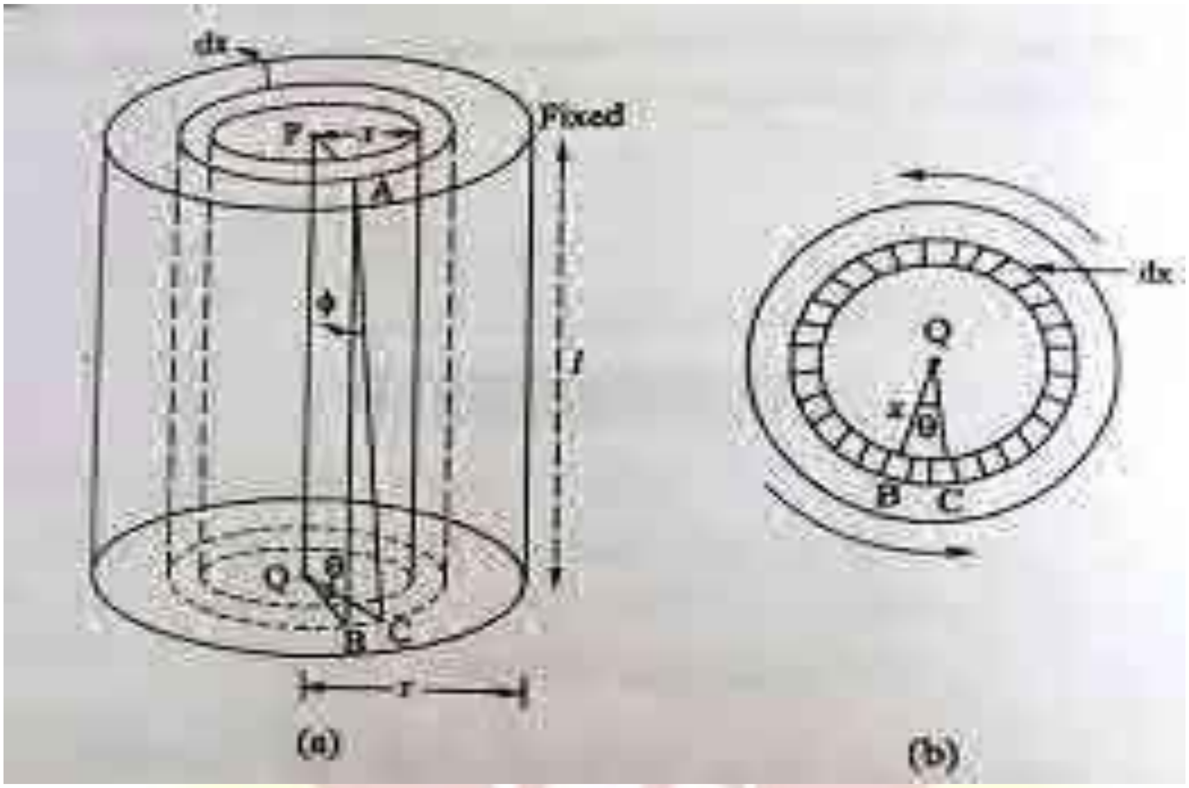
$$\text{Rigiditymodulusn}=\frac{\mathit{Sh}\text{earingstress}}{\mathit{Sh}\text{earingstrain}}$$

∴Shearingstress=n×Shearingstrain= n

nxθ

$= \frac{\quad}{l}$

Shearingstress= $\frac{\text{Shearing force}}{\text{Areaoverwhich theforceacts}}$



Areaoverwhichtheforceacts=$n(x+dx)^2-nx^2$

$=n(x^2+2xdx+dx^2)-nx^2$

$=nx^2+2nxdx+ndx^2-nx^2$

(dx^2termisneglectedsinceitisverysnall)

$=2nxdx$

Hence,SheraingforceF= $\frac{nx\theta}{l}$ ____

$=\frac{2\pi n\theta}{l}x^2dx$ _____

∴Momentofthisforceabouttheaxis PQ of thecylinder.

=Force×perpendiculardistance

$$=\frac{2\pi n\theta}{l}x^2dx\times x$$

$$=\frac{2\pi n\theta}{l}x^3dx$$

Themomentoftheforceactingontheentirecylinderofradiusrisobtainedbyintegratingtheexpression(3)betweenthelimitsx=0andx= r.

Twistingcoupleperunittwist$C=\frac{\pi nr^4}{2l}$

TORSIONPENDULUM –THEORY

Acircularmetallicdiscsuspendedusingatinwirethatexecutes torsionaloscillationis calledtorsionalpendulum.

Itexecutestorsionaloscillationwhereasasimplependulumexecuteslinearoscillations.

Description

Atorsionalpendulumconsistsofametalwiresuspendedverticallywiththeupperendfixed.Thelowerendofthe wireisconnectedtothecentreofaheavycirculardisc.

Whenthediscis rotatedbyapplyingatwist,thewireistwistedthroughanangleθ.Then,therestoringcouplesetupinthewire

$$=C\theta \qquad \text{— —— ———(1)}$$

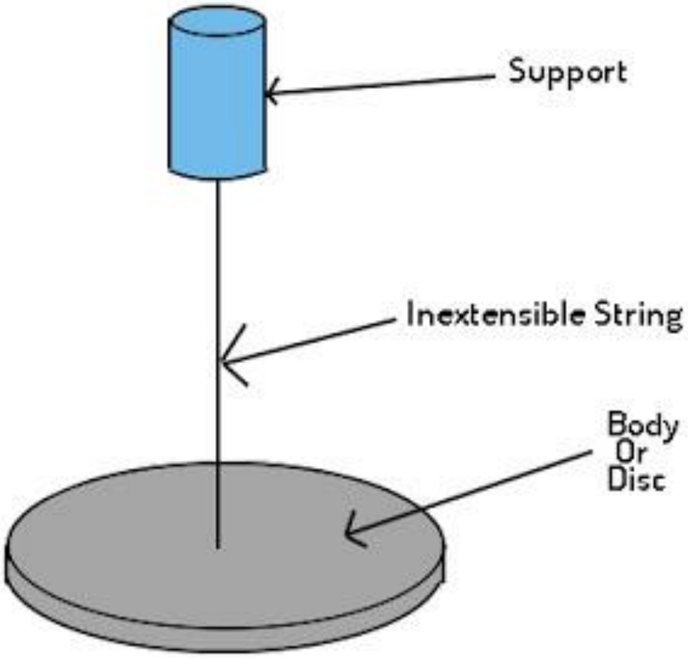
WhereC– coupleperunittwist.

If the disc is released, it oscillates with angular velocity $d\theta/dt$in the horizontal plane about theaxisofthewire.Theseoscillationsareknownastorsionaloscillations.

If$d^2\theta/dt^2$istheangularaccelerationproducedinthediscandIitsmoment ofinertiaofthediscabouttheaxisof thewirethen,

$$\text{Appliedcouple}=I\frac{d^2\theta}{dt^2} \qquad \text{—— ———(2)}$$

Inequilibrium,appliedcouple= restoringcouple



Torsional Pendulum

$$I\frac{d^2\theta}{dt^2} = C\theta$$

$$\frac{d^2\theta}{dt^2} = -\frac{C}{I}\theta \qquad ------(3)$$

Thisequationrepresentssimpleharmonicmotionwhich showsthatangularacceleration

$\left(\frac{d\theta}{dt^2}\right)^2$isproportionaltoangulardisplacementθandisalwaysdirectedtowardsthemeanposition.

Hence,themotion ofthediscbeingsimpleharmonicmotion,thetimeperiodoftheoscillationisgivenby

$$=2\pi\sqrt{\frac{\theta}{\frac{C}{I}\times\theta}}$$

$$T=2\pi\sqrt{\frac{I}{C}} \qquad -----(4)$$

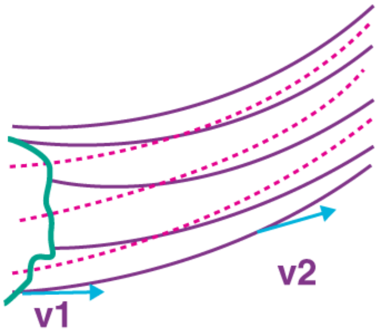
UNIT – 3 VISCOSITY

Streamline Flow

Streamline flow in fluids is defined as the flow in which the fluids flow in parallel layers such that there is no disruption or intermixing of the layers and at a given point, the velocity of each fluid particle passing by remains constant with time. Here, at low fluid velocities, there are no turbulent velocity fluctuations and the fluid tends to flow without lateral mixing. Here, the motion of particles of the fluid follows a particular order with respect to the particles moving in a straight line parallel to the wall of the pipe such that the adjacent layers slide past each other like playingcards.

Streamlines

Streamlines are defined as the path taken by particles of fluid under steady flow conditions. If we represent the flow lines as curves, then the tangent at any point on the curve gives the direction of the fluid velocity at that point.



As can be seen in the image above, the curves describe how the fluid particles move with respect to time. The curve provides a map for the flow of this given fluid, and for a steady flow. This map is stationary with time i.e., every particle passing a point behaves exactly like the previous particle that has just passed that point.The streamlines in a laminar flow follow the equation of continuity, i.e., Av = constant, where, A is the cross-sectional area of the fluid flow, and v is the velocity of the fluid at that point. Av is defined as the volume flux or the flow rate of the fluid, which remains constant for steady flow. When the area of the cross-section is greater, the velocity of the liquid is lesser and vice versa.

Turbulent flow, type of fluid (gas or liquid) flow in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction. The flow of wind and rivers is generally turbulent in this sense, even if the currents are gentle. The air or water swirls and eddies while its overall bulk moves along a specific direction.Most kinds of fluid flow are turbulent, except for laminar flow at the leading edge of solids moving relative to fluids or extremely close to solid surfaces, such as the inside wall of a pipe, or in cases of fluids of high viscosity (relatively great sluggishness) flowing slowly through small channels. Common examples of turbulent flow are blood flow in arteries, oil transport in pipelines, lava flow, atmosphere and ocean currents, the flow through pumps and turbines, and the flow in boat wakes and around aircraft-wing tips.

Definition for Viscosity

Viscosity is defined as the measure of the resistance of a fluid to gradual deformation by shear or tensile stress. In other words, viscosity describes a fluid’s resistance to flow. Simply put, we can say that honey is thicker than water; in turn, honey is more viscous than water.

The Coefficient of Viscosity Formula

The force of friction between two layers of fluid having the area in square centimetre and separated by distance will have a velocity is given by:

$f \ \infty \ AdV/dx$

Or

$f = \eta AdV/dx$

Here,

η is coefficient of viscosity

dV/dx is velocity gradient

If dx is 1cm, A is 1cm2 and dv is 1cm/s

Then, $f = \eta$

The coefficient of viscosity is defined as the force of friction that is required to maintain a difference of velocity of **1cm/s** between parallel layers of fluid. The unit is usually expressed in poise or centipoise. As we all know that viscosity is nothing but the measure of a substance’s resistance to the motion under an applied force The resulting unit is measured in centipoise which is the equivalent of 1 mPa (MilliPascal second). The major industries where Viscosity measurements are used are in the food industry to improve the overall cost-effectiveness and maximizing production efficiency. Besides, the food industry Viscosity is also primarily used in other industries such as Adhesives, Petroleum, Concrete, and Cosmetics industry.

Determination of coefficient of viscosity of water by Poiseuille's flow method

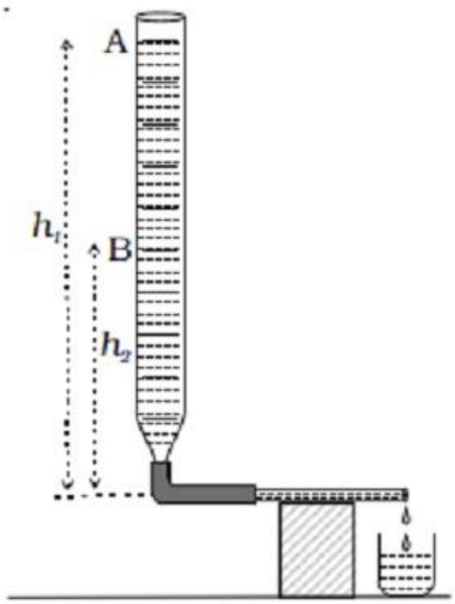


Fig. Determination of coefficient of viscosity by Poiseuille's flow

Poiseuille's equation

Poiseuille investigated the steady flow of a liquid through a capillary tube. He derived an expression for the volume of the liquid flowing per second through the tube.

Consider a liquid of co-efficient of viscosity η flowing, steadily through a horizontal capillary tube of length l and radius r. If P is the pressure difference across the ends of the tube, then the volume V of the liquid flowing per second through the tube depends on η, r and the pressure gradient p/l.

(i.e) $V \alpha \eta^x r^y (P/l)^z$

$V = k\,\eta^{x}\,r^{y}\,(P/l)^{z}$

where k is a constant of proportionality. Rewriting equation (1) in terms of dimensions,

$[L^{3}T^{-1}] = [ML^{-1}\,T^{-1}]^{x}\,[L]^{y}[ML^{-1}T^{-2} / L]^{z}$

Equating the powers of L, M and T on both sides we get $x = -1$, $y = 4$ and $z = 1$

Substituting in equation (1),

$V = kPr^{4}/ \eta l$

Experimentally k was found to be equal to $\pi/ 8$

$V = \pi Pr^{4} / 8\,\eta l$

This is known as Poiseuille's equation.

Determination of coefficient of viscosity of water by Poiseuille's flow method

A capillary tube of very fine bore is connected by means of a rubber tube to a burette kept vertically. The capillary tube is kept horizontal as shown in Fig.. The burette is filled with water and the pinch - stopper is removed. The time taken for water level to fall from A to B is noted. If V is the volume between the two levels A and B, then volume of liquid flowing per second is V/t. If l and r are the length and radius of the capillary tube respectively, then

$V/t = \pi Pr^{4} / 8\,\eta$

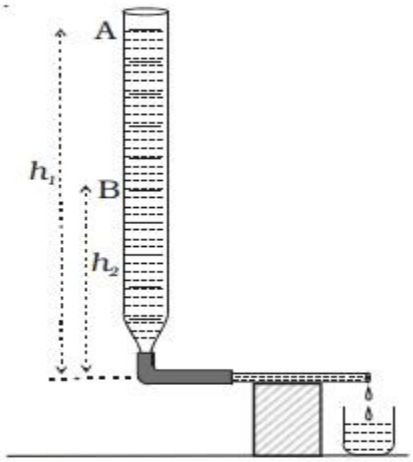


Fig. Determination of coefficient of viscosity by Poiseuille's flow]

If ρ is the density of the liquid then the initial pressure difference between the ends of the tube is $P_1 = h_1\rho g$ and the final pressure difference $P_2 = h_2\rho g$. Therefore the average pressure difference during the flow of water is P where

$$P = (P_1 + P_2)/2$$

$$=[(h1+h2)/2]hg$$

Substituting in equation (1), we get

$$V/t = \pi h\rho g r^4 / 8l\eta$$

or

$$\eta = \pi h\rho g r^4 t / 8lV$$

Viscosity - Practical applications

The importance of viscosity can be understood from the following examples.

(i) The knowledge of coefficient of viscosity of organic liquids is used to determine their molecular weights.

(ii) The knowledge of coefficient of viscosity and its variation with temperature helps us to choose a suitable lubricant for specific machines. In light machinery thin oils (example, lubricant oil used in clocks) with low viscosity is used. In heavy machinery, highly viscous oils (example, grease) are used.

Stoke's law (for highly viscous liquids)

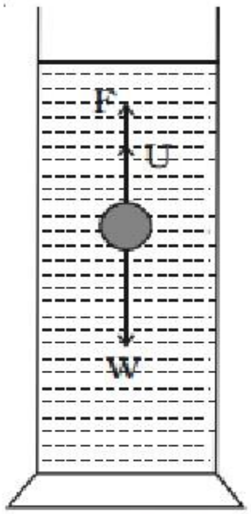


Fig. Sphere falling in a viscous liquid

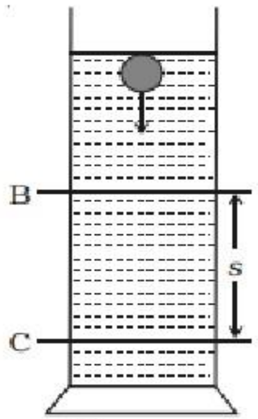


Fig. Experimental determination of viscosity of highly viscous liquid

When a body falls through a highly viscous liquid, it drags the layer of the liquid immediately in contact with it. This results in a relative motion between the different layers of the liquid.

Stoke's law (for highly viscous liquids)

When a body falls through a highly viscous liquid, it drags the layer of the liquid immediately in contact with it. This results in a relative motion between the different layers of the liquid. As a result of this, the falling body experiences a viscous force *F*. Stoke performed many experiments on the motion of small spherical bodies in different fluids and concluded that the viscous force *F* acting on the spherical body depends on

(i) Coefficient of viscosity η of the liquid
(ii) Radius a of the sphere and
(iii) Velocity v of the spherical body. Dimensionally it can be proved that

$F = k \eta a v$

Experimentally Stoke found that

$k = 6\pi$

$F = 6\pi\ \eta a v$

This is Stoke's law.

Expression for terminal velocity

Consider a metallic sphere of radius 'a' and density ρ to fall under gravity in a liquid of density σ. The viscous force F acting on the metallic sphere increases as its velocity increases. A stage is reached when the weight W of the sphere becomes equal to the sum of the upward viscous force F and the upward thrust U due to buoyancy (Fig.). Now, there isno net force acting on the sphere and it moves down with a constant velocity v called terminal velocity.

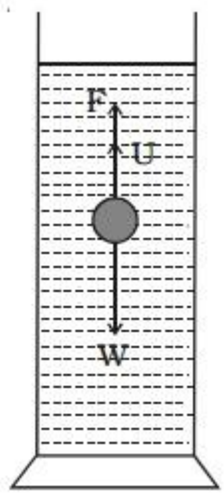


Fig. Sphere falling in a viscous liquid

$W - F - U = O$ ...(1)

Terminal velocity of a body is defined as the constant velocity acquired by a body while falling through a viscous liquid.

From (1), $W = F + U$ �.. ...(2)

According to Stoke's law, the viscous force F is given by $F = 6\pi\eta a v$.

The buoyant force U = Weight of liquid displaced by the sphere

$= 4/3\ \pi a^3 \sigma g$

The weight of the sphere $W = 4/3\ \pi a^3 \rho g$

Substituting in equation (2)

$4/3\ \pi a\ \rho g = 6\pi\ \eta a v + 4/3\ \pi a^3\ \sigma\ g$

$\therefore\ v = 2\ a^2(\rho - \sigma)g\ \ /\ 9\eta$

Experimental determination of viscosity of highly viscous liquids

The coefficient of highly viscous liquid like castoroil can be determined by Stoke's method. The experimental liquid is taken in a tall, wide jar. Two marking B and C are marked as shown in Fig.. A steel ball is gently dropped in the jar.

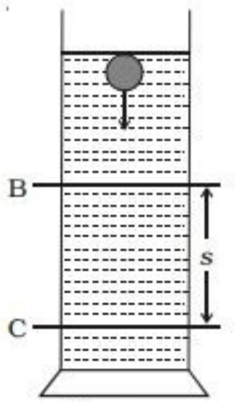


Fig. Experimental determination of viscosity of highly viscous liquid

The marking B is made well below the free surface of the liquid so that by the time ball reaches B, it would have acquired terminal velocity v.

When the ball crosses B, a stopwatch is switched on and the time taken t to reach C is noted. If the distance BC is s, then terminal velocity v =s / t.

The expression for terminal velocity is

$v = 2\ a^2(\rho - \sigma)g\ \ /\ 9\eta$

$\eta = 2/9\ .\ 2\ a^2(\rho - \sigma)g\ .\ t/s$

Knowing a, ρ and σ, the value of η of the liquid is determined.

Application of Stoke's law

Falling of rain drops: When the water drops are small in size, their terminal velocities are small. Therefore they remain suspended in air in the form of clouds. But as the drops combine and grow in size, their terminal velocities increases because $v \propto a^2$. Hence they start falling as rain.

Molecular theory of surface tension

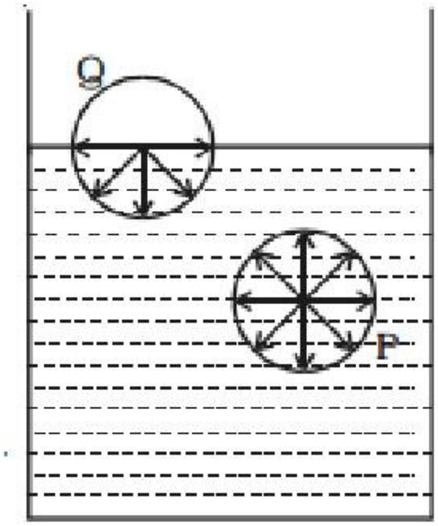


Fig. Surface tension based on molecular theory

Consider two molecules P and Q as shown in the above figure. Taking them as centres and molecular range as radius, a sphere of influence is drawn around them.The molecule P is attracted in all directions equally by neighbouring molecules. Therefore net force acting on P is zero. The molecule Q is on the free surface of the liquid. It experiences a net downward force because the number of molecules in the lower half of the sphere is more and the upper half is completely outside the surface of the liquid. Therefore all the molecules lying on the surface of a liquid experience only a net downward force.If a molecule from the interior is to be brought to the surface of the liquid, work must be done against this downward force. This work done on the molecule is stored as potential energy. For equilibrium, a system must possess minimum potential energy. So, the free surface will have minimum potential energy. The free surface of a liquid tends to assume minimum surface area by contracting and remains in a state of tension like a stretched elastic membrane.

Surface tension of a liquid

Surface tension is the property of the free surface of a liquid at rest to behave like a stretched membrane in order to acquire minimum surface area.Imagine a line AB in the free surface of a liquid at rest (Fig.). The force of surface tension is measured as the force acting per unit length on either side of this imaginary line AB. The force is perpendicular to the line and tangential to the liquid surface. If F is the force acting on the length l of the line AB, then surface tension is given by T=F/l.

Surface tension is defined as the force per unit length acting perpendicular on an imaginary line drawn on the liquid surface, tending to pull the surface apart along the line. Its unit is N m-1 and dimensionalformula is MT^{-2}.

Excess of pressure inside a liquid drop, a soap bubble, and an air bubble

When the free surface of the liquid is curved, there is a difference in pressure between the inner and outer side of the surface.The free surface of a liquid becomes curved when it has contact with a solid. Depending upon the nature of liquid-air or liquid-gas interface, the magnitude of interfacial surface tension varies. In other words, as a consequence of surface tension, the above such interfaces have energy and for a given volume, the surface will have a minimum energy with least area. Due to this reason, the liquid drop becomes spherical (for a smaller radius).

When the free surface of the liquid is curved, there is a difference in pressure between the inner and outer the side of the surface .

i) When the liquid surface is plane, the forces due to surface tension (T, T) act tangentially to the liquid surface in opposite directions. Hence, the resultant force on the molecule is zero. Therefore, in the case of a plane liquid surface, the pressure on the liquid side is equal to the pressure on the vapour side.

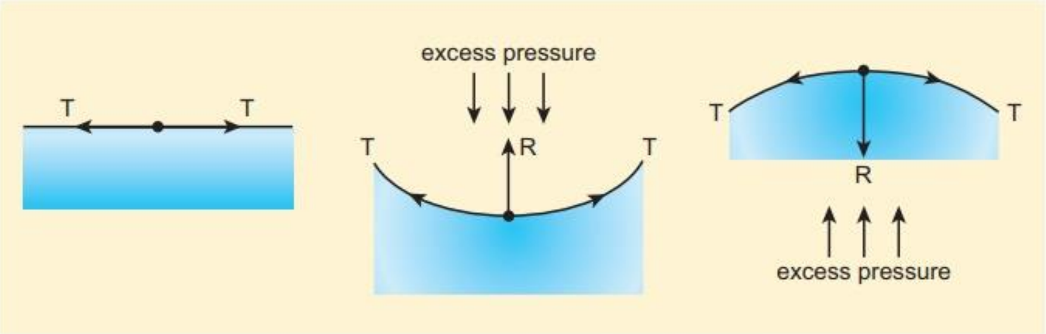


Figure7.27 Excess of pressure across a liquid surface

ii) When the liquid surface is curved, every molecule on the liquid surface experiences forces (F_T, F_T) due to surface tension along the tangent to the surface. Resolving these forces into rectangular components, we find that horizontal components cancel out each other while vertical components get added up. Therefore, the resultant force normal to the surface acts on the curved surface of the liquid. Similarly, for a convex surface, the resultant force is directed inwards towards the centre of curvature, whereas the resultant force is directed outwards from the centre of curvature for a concave surface. Thus, for a curved liquid surface in equilibrium, the pressure on its concave side is greater than the pressure on its convex side.

Excess of pressure inside a bubble and a liquid drop:

The small bubbles and liquid drops are spherical because of the forces of surface tension. The fact that a bubble or a liquid drop does not collapse due to the combined effect indicates that the pressure inside a bubble or a drop is greater than that outside it.

1) Excess of pressure inside air bubble in a liquid.

Consider an air bubble of radius R inside a liquid having surface tension T as shown in Figure . Let P_1 and P_2 be the pressures outside and inside the air bubble, respectively. Now, the excess pressure inside the air bubble is $\Delta P = P_1 - P_2$.

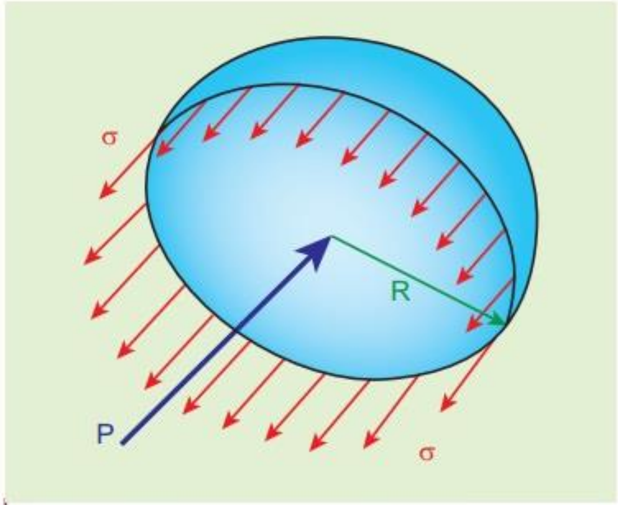


Figure 7.28. (a) Air bubble

In order to find the excess pressure inside the air bubble, let us consider the forces acting on the air bubble. For the hemispherical portion of the bubble, considering the forces acting on it, we get,

i) The force due to surface tension acting towards right around the rim of length $2\pi R$ is $F_T = 2\pi RT$

ii) The force due to outside pressure P_1 is to the right acting across a cross sectional area of πR^2 is $F_{P1} = P_1\pi R^2$

iii) The force due to pressure P_2 inside the bubble, acting to the left is $F_{P2} = P_2\pi R^2$.

As the air bubble is in equilibrium under the action of these forces, $F_{P2} = F_T + F_{P1}$

$P_2\pi R^2 = 2\pi RT + P_1\pi R^2$

$(P_2 - P_1)\pi R^2 = 2\pi RT$

2) **Excess pressure inside a soap bubble**

Consider a soap bubble of radius R and the surface tension of the soap bubble be T as shown in Figure 7.28 (b). A soap bubble has two liquid surfaces in contact with air, one inside the bubble and other outside the bubble. Therefore, the force on the soap bubble due to surface tension is $2\times2\pi RT$. The various forces acting on the soap bubble are,

i) Force due to surface tension $F_T=4\pi RT$ towards right

ii) Force due to outside pressure, $F_{P1}= P_1\pi R^2$ towards right

iii) Force due to inside pressure, $F_{P2}= P_2\pi R^2$ towards left

As the bubble is in equilibrium, $F_{P2}= F_T + F_{P1}$

$P_2\pi R^2 = 4\pi RT + P_1\pi R^2$

$(P_2 - P_1)\pi R^2 = 4\pi RT$

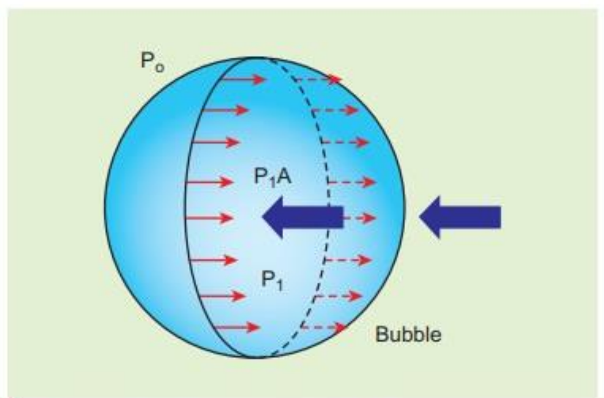


Figure7.28 (b) Soap bubble

3) Excess pressure inside the liquid drop

Consider a liquid drop of radius R and the surface tension of the liquid is T as shown in Figure .

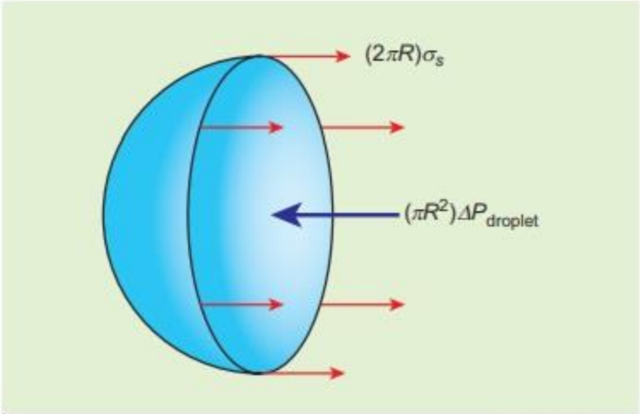


Figure7.28 (c) Liquid drop

The various forces acting on the liquid drop are,

i) Force due to surface tension $F_T=2\pi RT$ towards right

ii) Force due to outside pressure, $F_{P1}= P_1\pi R^2$ towards right

iii) Force due to inside pressure, $F_{P2}= P_2\pi R^2$ towards left

As the drop is in equilibrium,

$F_{P2}= F_T + F_{P1}$

$P_2\pi R^2 = 2\pi RT + P_1\pi R^2$

$= > (P_2 - P_1)\pi R^2 = 2\pi RT$

EXAMPLE

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

Solution

The excess of pressure inside the soap bubble is

$$\Delta P = P_2 - P_1 = \frac{4T}{R}$$

But $\Delta P = P_2 - P_1 = \rho g h \Rightarrow \rho g h = \frac{4T}{R}$

$\Rightarrow$ Surface tension,

$$T = \frac{\rho g h R}{4} = \frac{(800)(9.8)(4\times10^{-3})(2\times10^{-2})}{4} =$$

$$T = 15.68\times10^{-2}\,N\,m^{-1}$$

UNIT – 4- HEAT AND THERMODYNAMICS

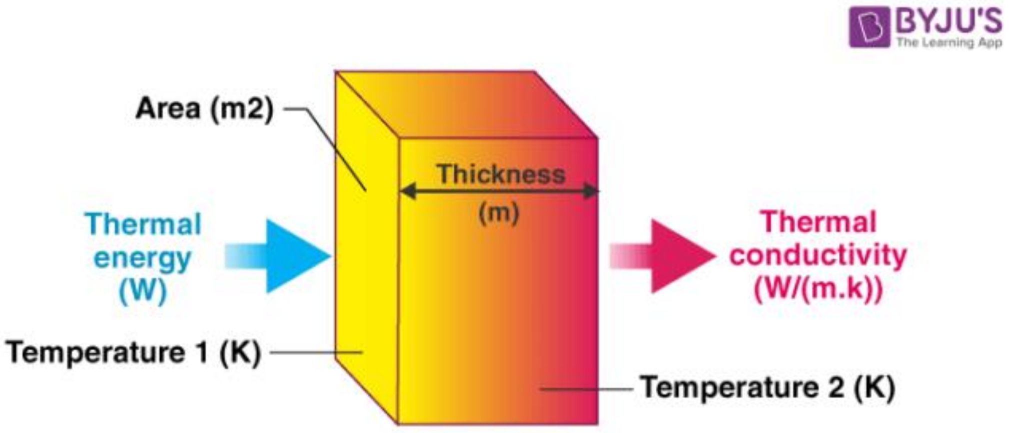
Thermal Conductivity

Thermal conductivity refers to the ability of a given material to conduct/transfer heat. It is generally denoted by the symbol ‘k’ but can also be denoted by ‘λ’ and ‘κ’. The reciprocal of this quantity is known as thermal resistivity. Materials with high thermal conductivity are used in heat sinks whereas materials with low values of λ are used as thermal insulators.

Fourier’s law of thermal conduction (also known as the law of heat conduction) states that the rate at which heat is transferred through a material is proportional to the negative of the temperature gradient and is also proportional to the area through which the heat flows. The differential form of this law can be expressed through the following equation:

$q = -k.\nabla T$

Where ∇T refers to the temperature gradient, q denotes the thermal flux or heat flux, and k refers to the thermal conductivity of the material in question.



An illustration describing the thermal conductivity of a material in terms of the flow of heat through it is provided above. In this example, Temperature$_1$ is greater than Temperature$_2$. Therefore, the thermal conductivity can be obtained via the following equation:

Heat Flux = -k * (Temperature$_2$ – Temperature$_1$)/Thickness

Every substance has its own capacity to conduct heat. The thermal conductivity of a material is described by the following formula:

K = (QL)/(AΔT)

Where,

- K is the thermal conductivity in W/m.K
- Q is the amount of heat transferred through the material in Joules/second or Watts
- L is the distance between the two isothermal planes
- A is the area of the surface in square meters
- ΔT is the difference in temperature in Kelvin

Measurement

There exist several methods of measuring the thermal conductivities of materials. These methods are broadly classified into two types of techniques – transient and steady-state techniques.

SI Unit

- Thermal conductivity is expressed in terms of the following dimensions: Temperature, Length, Mass, and Time.
- The SI unit of this quantity is watts per meter-Kelvin or $Wm^{-1}K^{-1}$.
- It is generally expressed in terms of power/(length * temperature).
- These units describe the rate of conduction of heat through a material of unit thickness and for each Kelvin of temperature difference.

Steady-State Techniques

- These methods involve measurements where the temperature of the material in question does not change over a period of time.
- An advantage of these techniques is that the analysis is relatively straightforward since the temperature is constant.
- An important disadvantage of steady-state techniques is that they generally require a very well-engineered setup to perform the experiments.
- Examples of these techniques are the Searle's bar method for measuring the thermal conductivity of a good conductor and Lee's disc method.

Transient Techniques

- In these methods, the measurements are taken during the heating-up process.
- An important advantage of these methods is that the measurements can be taken relatively fast.
- One of the disadvantages of transient techniques is the difficulty in mathematically analysing the data from the measurements.
- Some examples of these techniques include the transient plane source method, the transient line source method, and the laser flash method.

Thus, there exist various methods of measuring the thermal conductivity of materials, each with their own advantages and disadvantages. It is important to note that it is easier to experimentally study the thermal properties of solids when compared to fluids.

Effect of Temperature on Thermal Conductivity

Temperature affects the thermal conductivities of metals and non-metals differently.

Metals

- The heat conductivity of metals is attributed to the presence of free electrons. It is somewhat proportional to the product of the absolute temperature and the electrical conductivity, as per the Wiedemann-Franz law.
- With an increase in temperature, the electrical conductivity of a pure metal decreases.
- This implies that the thermal conductivity of the pure metal shows little variance with an increase in temperature. However, a sharp decrease is observed when temperatures approach 0K.
- Alloys of metals do not show significant changes in electrical conductivity when the temperature is increased, implying that their heat conductivities increase with the increase in temperature.
- The peak value of heat conductivity in many pure metals can be found at temperatures ranging from 2K to 10K.

Non-Metals

- The thermal conductivities of non-metals are primarily attributed to lattice vibrations.
- The mean free path of the phonons does not reduce significantly when the temperatures are high, implying that the thermal conductivity of non-metals does not show significant change at higher temperatures.
- When the temperature is decreased to a point below the Debye temperature, the heat conductivity of a non-metal decreases along with its heat capacity.

Other Factors that Affect Thermal Conductivity

Temperature is not the only factor which causes a variance in thermal conductivity of a material. Some other important factors that influence the heat conductivity of substances are tabulated below.

Factor	**Effect on Thermal Conductivity**
The chemical phase of the material	When the phase of a material changes, an abrupt change in its heat conductivity may arise. For example, the thermal conductivity of ice changes from 2.18 $Wm^{-1}K^{-1}$ to 0.56 $Wm^{-1}K^{-1}$ when it melts into a liquid phase
Thermal Anisotropy	The differences in the coupling of phonons along a specific crystal axis causes some substances to exhibit different values of thermal conductivity along different crystal axes. The presence of thermal anisotropy implies that the direction in which the heat flows may not be the same as the temperature gradients direction.
The electrical conductivity of the material	The Wiedemann-Franz law that provides a relation between electrical conductivity and thermal conductivity is only applicable to metals. The heat conductivity of non-metals is relatively unaffected by their electrical conductivities.
Influence of magnetic fields	The change in the thermal conductivity of a conductor when it is placed in a magnetic field is described by the Maggi-Righi-Leduc effect. The development of an orthogonal temperature gradient is observed when magnetic fields are applied.
Isotopic purity of the crystal	The effect of isotopic purity on heat conductivity can be observed in the following example: the thermal conductivity of type IIa diamond (98.9% concentration of carbon-12 isotope) is 10000 $Wm^{-1}K^{-1}$ whereas that of 99.9% enriched diamond is 41,000 $Wm^{-1}K^{-1}$

Lee’s Disc method

Lee’s Disc method is used to measure the thermal conductivity of a poorly conducting material, such as glass, wood, or polymer. There is little information about the origin of the method, although it was first reported around the year 1898 by English scientist Lee. This was one of the earliest methods used to measure thermal conductivity that gave reliable results, and is a steady state method. Steady state methods are ones where the experimental setup must reach equilibrium before any calculations can be made. In comparison, transient methods are ones where equilibrium is not required before calculations are made, as calculations are made from temperature versus time curves plotted during heating.

Experimental setup for Lee’s Disc method is quite simple and involves the use of two metal discs (usually brass), a steam chamber, the sample to be measured and two thermometers to measure the temperature gradient. The sample is placed in between the two metal discs (the thermometers are inserted into the metal discs) and the steam chamber is placed on top of the top metal disc. The whole setup is suspended in air so any other conduction effects are removed, although convection is a key factor in calculations. See Figure 1 for experimental setup.

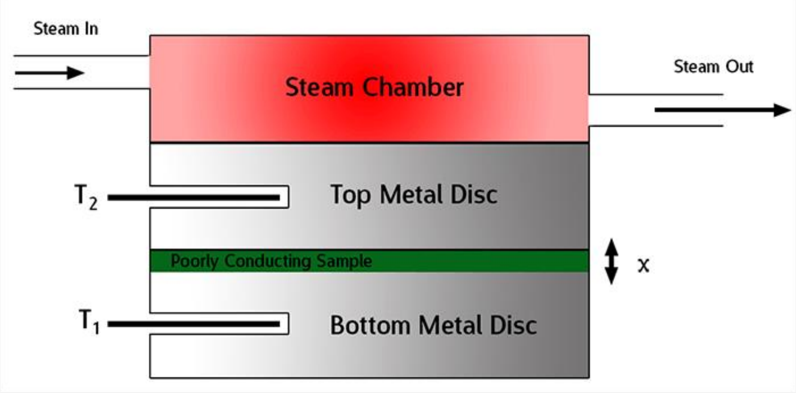


Figure 1. Experimental setup for Lee’s Disc steady-state thermal conductivity measurement.

In the experiment, water is heated to produce steam, which is then pushed through a steam chamber which is directly above one of the metal discs with a thermometer in it. This steam causes the metal disc to heat up and transfer heat to the poor conductor that is being tested. The poor conductor in turn transfers heat to the bottom metal disc, which loses heat to convection. After a certain time, each of the two metal discs will have reached a steady temperature. The two temperatures are different and are used to calculate the thermal conductivity. At equilibrium, the amount of heat transferred from the poor conductor to the bottom disc is equal to the heat lost by that disc due to convection.Once the setup has reached thermal equilibrium and the temperature of each disc is recorded, the steam chamber is removed along with the top metal disc and poor conductor. The steam chamber is then used to heat the bottom metal disc directly until it is around 10 degrees above its equilibrium temperature. An insulating material (not necessarily the poorly conducting material being tested) is then placed on top of the bottom metal disc, and the disc is allowed to cool to room temperature, while the temperature is being recorded with respect to time. This cooling curve will allow the cooling rates at various temperatures to be determined, thus the cooling rate at the equilibrium temperature can be determined and this value will allow the calculation of thermal conductivity of the poor conductor.

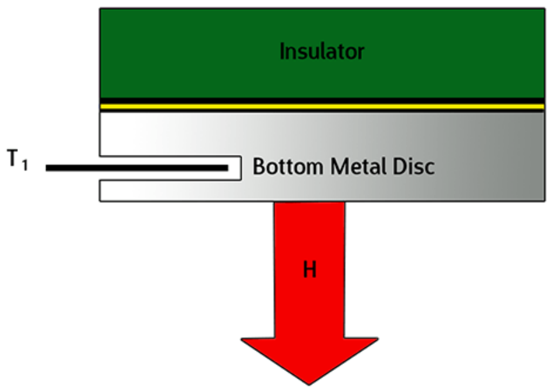


Figure 2. Once the setup has reached equilibrium, the bottom disc is allowed to cool to room temperature (by loss of heat to convection) in order to plot a temperature versus time curve.

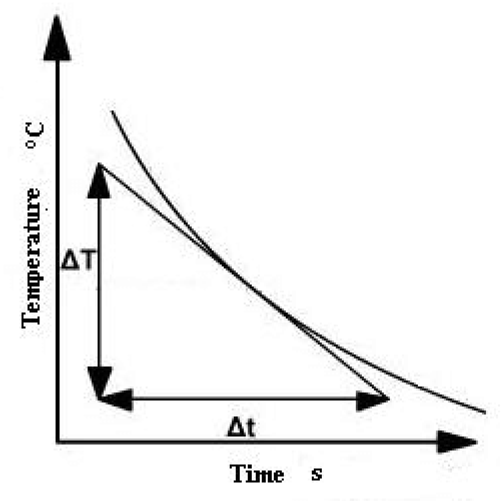


Figure 3. Cooling curve for the bottom metal disc. From this curve, the cooling rate can be determined at a specific temperature (equilibrium temperature of the bottom metal disc) and then used to calculate thermal conductivity.

Radial low of heat

In this method, heat flows from the inner side towards the other side along the radius of the cylindrical shell.

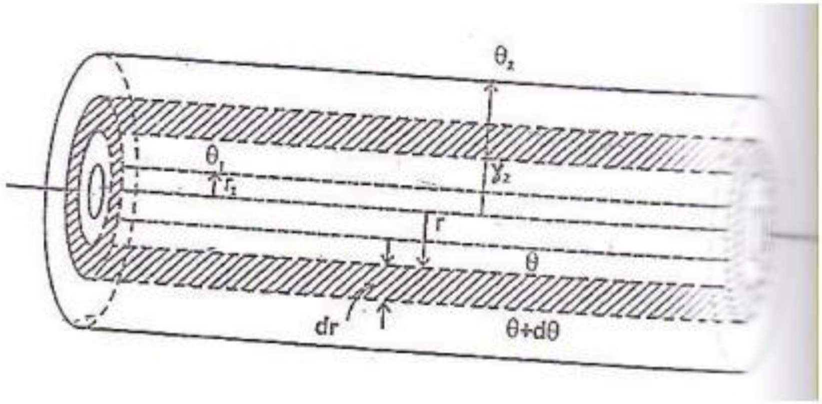
This method is interesting because there is no loss of heat as in the other methods.

Cylindrical Shell method

Consider a cylindrical tube of length l, inner radius r1 and outer radius r2 as shown in the figure. The tube carries steam or some hot liquid.

Heat is conducted radially across the wall of the tube. After the steady state is reached, the temperature of the inner surface θ_1 and on the outer surface θ_2. This thick pipe is imagined to consist of a large number of thin coaxial cylinders of increasing radius. Any such thin imaginary cylinder of the material of thickness 'dr' at a distance r from the axis of the pipe is taken.

Amount of heat flowing per second through this elementary cylinder



$$Q = -KA\frac{d\theta}{dr} \qquad \longrightarrow \qquad 1$$

Now, surface area of the imaginary cylinder

$$A = 2\pi r \times l$$

$$\therefore Q = -2\pi r l K\frac{d\theta}{dr} \qquad \longrightarrow \qquad 2$$

After steady state is reached, the amount of heat flowing(Q) through all imaginary cylinders is same.

Rearranging, the equation 2, we get

$$\frac{dr}{r}=\left(\frac{-2\pi lK}{Q}\right)d\theta$$

Integrating both sides between their proper limits we have,

$$\int_{r_1}^{r_2}\frac{dr}{r}=\frac{-2\pi lK}{Q}\int_{\theta_1}^{\theta}d\theta$$

$$\left[\log_e r\right]_{r_1}^{r_2} = \frac{-2\pi lK}{Q}\left[\theta\right]_{\theta_1}^{\theta_2}$$

$$\frac{-2\pi lK}{Q}\left[\theta_2-\theta_1\right]$$

$$\left[\log_e r_2-\log_e r_1\right]_{r_1}^{r_2} = \frac{2\pi lK}{Q}\left[\theta_1-\theta_2\right]$$

$$\log_e\left(\frac{r_2}{r_1}\right)=\frac{2\pi lK}{Q}\left(\theta_1-\theta_2\right)$$

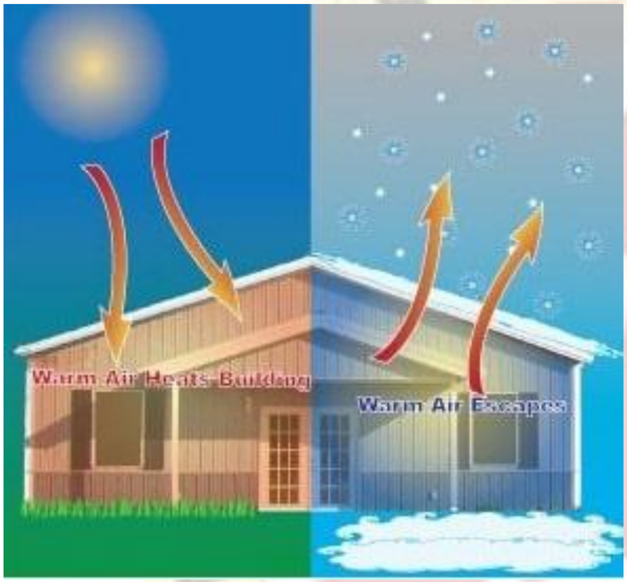
$$Q=\frac{K2\pi l\left(\theta_1-\theta_2\right)}{\log_e\frac{r_2}{r_1}}$$

$$Q=\frac{K2\pi l\left(\theta_1-\theta_2\right)}{\log_e\frac{r_2}{r_1}}$$

$$K=\frac{Q\log_e\frac{r_2}{r_1}}{2\pi l\left(\theta_1-\theta_2\right)}$$

Thermal Insulation of Buildings

In general, people living in hot regions wants to make their inside atmosphere very cool similarly people living in cold regions, wants warmer atmosphere inside. But, we know that the heat transfer takes place from hotter to colder areas. As a result, heat loss happens. To overcome this loss in buildings thermal insulation is provided to maintain required temperature inside the building. The aim of thermal insulation is to minimize the heat transfer between outside and inside of building.



Materials and Methods of Thermal Insulation of Buildings

There are many forms of thermal insulation materials are available in the market as follows:

1. Slab or block insulation
2. Blanket insulation
3. Loose fill insulation
4. Bat insulating materials
5. Insulating boards
6. Reflective sheet materials
7. Lightweight materials

1. Slab or Block Insulation

The blocks are made of mineral wool, cork board, cellular glass, and cellular rubber or saw dust etc. These are fixed to the walls and roofs to prevent heat loss and maintains required temperature. These boards are available in 60cmx120cm

(or more area) with 2.5cm thickness.

2. Blanket Insulation

Blanket insulation materials are available in blanket shape or like paper rolls which are directly spread over the wall or ceilings. They are flexible and having a thickness about 12 to 80mm. these blankets are made of animal hair or cotton or
wood fibers etc.

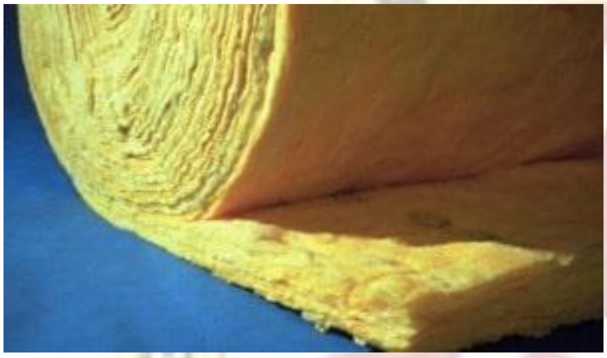
..

3. Loose Fill Insulation

Stud space is provided in wall where windows and doors are to be provided. In that studding space of wall loose fill of some insulating materials is provided. The materials are rock wool, wood fiber wool, cellulose etc.

4. Bat Insulating Materials

These are also available as blanket rolls but bat insulating rolls are having more thickness than blanket type materials. These are also spreader over the walls or ceilings.



5. Insulating Boards

Insulating boards are made from pulp of wood, cane or other materials. These pulp is pressed hard with some stress at suitable temperature to make it as a solid boards. They are available in many sizes in the market. And these are generally provided for interior lining of walls as well as for partition walls.

6. Reflective Sheet Materials

Reflective sheet materials like aluminum sheets, gypsum boards, steel sheet Materials will have more reflectivity and low emissivity. So, these materials are having high heat resistance. The heat gets reduced when solar energy strike and gets reflected. These are fixed outside of the structure to stop the heat entrance into the building.

7. Lightweight Materials

By using light weight aggregates while preparing concrete mixture will also results good results in heat loss preventions. Concrete will have more heat resistance if it is made of light weight aggregates like blast furnace slag, vermiculite, burnt clay aggregates etc.

Other General Methods of Building Thermal Insulation

Without using any thermal insulating materials as said above we can achieve the thermal insulation from the following methods.

- By providing roof shading
- By proper height of ceiling
- Orientation of building

8. By Providing Roof Shading

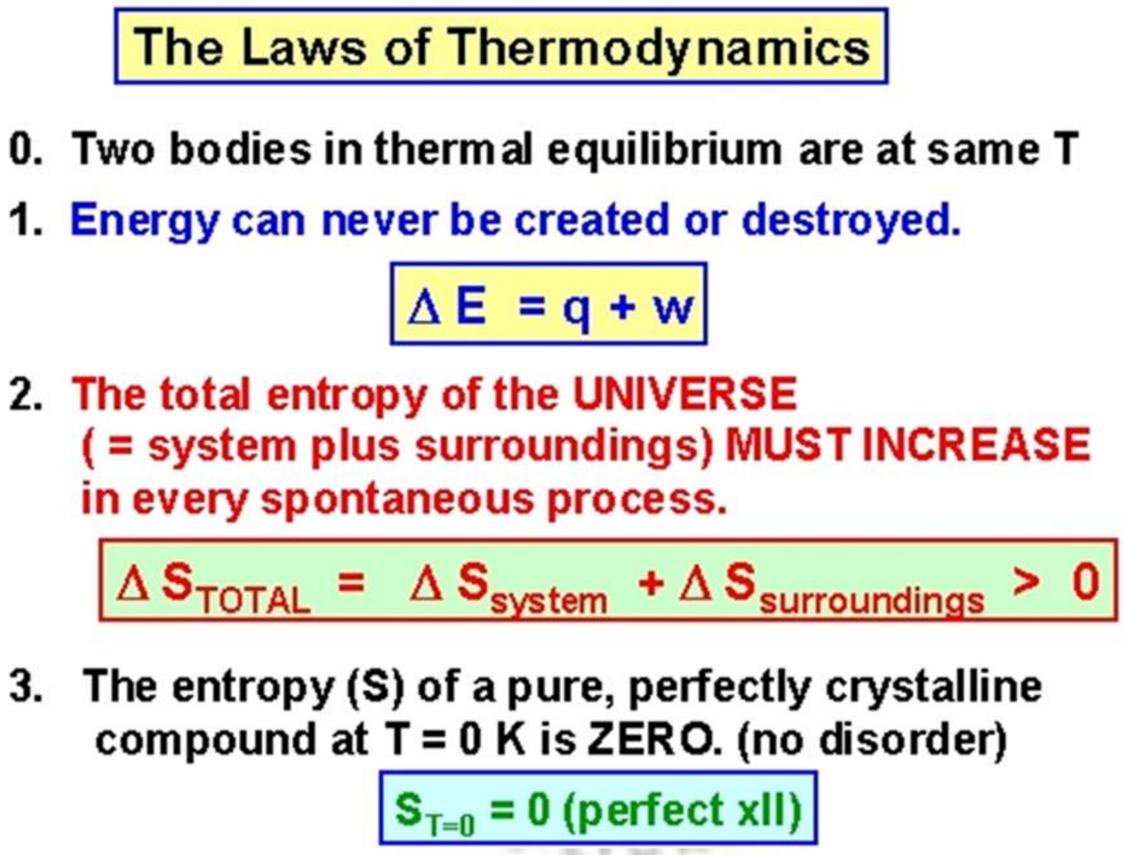
By providing roof shading for the building at the place where sun directly strikes the building during peak hours, we can reduce the heat by shading of roof. Accurate angle should be provided for shading to prevent from sun light.

9. By Proper Height of Ceiling

The heat gets absorbed by the ceiling and emitted downwards that is into the building. But, the point should be noted is, the vertical gradient of radiation intensity is not significant beyond 1 to 1.3 m. it means it can travel up to 1 to 1.3 m downward from the ceiling. So, provision of ceiling at 1 to 1.3m height from the height of occupant will reduce some heat loss.

10. Orientation of Building

The building orientation with respect to sun is an important thing. So, the building should be constructed in an orientation in such a way that it shouldn't subject to more heat losses.



The Laws of Thermodynamics

0. Two bodies in thermal equilibrium are at same T
1. Energy can never be created or destroyed.

$$\Delta E = q + w$$

2. The total entropy of the UNIVERSE (= system plus surroundings) MUST INCREASE in every spontaneous process.

$$\Delta S_{TOTAL} = \Delta S_{system} + \Delta S_{surroundings} > 0$$

3. The entropy (S) of a pure, perfectly crystalline compound at T = 0 K is ZERO. (no disorder)

$S_{T=0} = 0$ (perfect xll)

Zeroth Law of Thermodynamics: The Zeroth Law of Thermodynamics states that if two systems are in thermodynamic equilibrium with a third system, the two original systems are in thermal equilibrium with each other. Basically, if system A is in thermal equilibrium with system C and system B is also in thermal equilibrium with system C, system A and system B are in thermal equilibrium with each other.

First Law of Thermodynamic::The first law of thermodynamics states that energy can be converted from one form to another, but cannot be created or destroyed. The most important and critical aspect of life revolves around the idea of energy. During the course of a single day, a person finds him or herself using energy in all sorts to live their lives. Whether driving a car or eating lunch, the consumption of some sort of energy is unavoidable. While it may seem that energy is being created for our purposes and destroyed during it, there is in fact no change in the amount of energy in the world at one time. Taking this a step farther, one may state the entirety of the energy in the universe is at a constant with energy just being converted into different forms.

System and Surroundings

To obtain a better understanding of the workings of energy within the universe, it is helpful to classify it into two distinct parts. The first being the energy of a specific system, Esys, and the second being whatever energy was not included in the system which we label as the energy of the surroundings, E_{surr}. Since these two parts are equal to the total energy of the universe, Euniv, it can be concluded that

Euniv=Esys+Esurr ……..(1)

Now, since we stated previously that the total amount of energy within the universe does not change, one can set a change in energy of the system and surroundings to equal

ΔEsys+ΔEsurr=0…..(2)

A simple rearrangement of Equation 22 leads to the following conclusion

ΔEsys=−ΔEsurr……(3)

Equation 3 represents a very important premise of energy conservation. The premise is that any change in energy of a system will result in an equal but opposite change in the surroundings. This essentially summarizes the First Law of Thermodynamics which states that energy cannot be created nor destroyed.

Types of Energy

Now that the conservation of energy has been defined, one can now study the different energies of a system. Within a system, there are three main types of energy. These three types are kinetic (the energy of motion), potential (energy stored within a system as a result of placement or configuration), and internal (energy associated with electronic and intramolecular forces). Thus, the following equation can be given

$E_{total}=KE+PE+U$…….(4)

where KE is the kinetic energy, PE is the potential energy, U is the internal energy, and E_{total} is the total energy of the system. While all forms of energy are very important, the internal energy, U, is what will receive the remainder of the focus.

Internal Energy, U

As stated previously, U is the energy associated with electronic and intramolecular forces. Yet, despite the abundance of forces and interactions that may be occurring within a system, it is near impossible to calculate its internal energy. Instead, the change in the U of a system, ΔU, must be measured instead. The change in ΔU of a system is affected by two distinct variables. These two variables are designated at heat, q, and work, w. Heat refers to the total amount of energy transferred to or from a system as a result of thermal contact. Work refers to the total amount of energy transferred to or from a system as a result of changes in the external parameters (volume, pressure). Applying this, the following equation can be given

$\Delta U=q+w$……(5)

If the change of ΔU is infinitesimal, then Equation 5 can be altered to

$dU=dq+dw$…..(6)

Within this equation it should be noted that U is a state function and therefore independent of pathways while q and w are not.

Having defined heat and work, it becomes necessary to define whether a process is exhibiting positive or negative values of q and w. Table describes the sign conventions of both work and heat.

Process	Sign
Work done by the system on the surroundings	-
Work done on the system by the surroundings	+
Heat absorbed by the system from the surroundings (endothermic)	+
Heat absorbed by the surroundings from the system (exothermic)	-

Second Law of Thermodynamics : The Second Law of Thermodynamics states that the state of entropy of the entire universe, as an isolated system, will always increase over time. The second law also states that the changes in the entropy in the universe can never be negative.

Introduction

Why is it that when you leave an ice cube at room temperature, it begins to melt? Why do we get older and never younger? And, why is it whenever rooms are cleaned, they become messy again in the future? Certain things happen in one direction and not the other, this is called the "arrow of time" and it encompasses every area of science. The thermodynamic arrow of time (entropy) is the measurement of disorder within a system. Denoted as $\Delta S\Delta S$, the change of entropy suggests that time itself is asymmetric with respect to order of an isolated system, meaning: a system will become more disordered, as time increases.

Major players in developing the Second Law

- Nicolas Léonard Sadi Carnot was a French physicist, who is considered to be the "father of thermodynamics," for he is responsible for the origins of the Second Law of Thermodynamics, as well as various other concepts. The current form of the second law uses entropy rather than caloric, which is what Sadi Carnot used to describe the law. Caloric relates to heat and Sadi Carnot came to realize that some caloric is always lost in the motion cycle. Thus, the thermodynamic reversibility concept was proven wrong, proving that irreversibility is the result of every system involving work.

- Rudolf Clausius was a German physicist, and he developed the Clausius statement, which says "Heat generally **cannot flow spontaneously** from a material at a lower temperature to a material at a higher temperature."
- William Thompson, also known as Lord Kelvin, formulated the Kelvin statement, which states "It is **impossible** to convert heat completely in a cyclic process." This means that there is no way for one to convert all the energy of a system into work, without losing energy.
- Constantin Carathéodory, a Greek mathematician, created his own statement of the second low arguing that "In the neighborhood of any initial state, there are states which **cannot** be approached arbitrarily close through adiabatic changes of state."

If a given state can be accomplished in more ways, then it is more probable than the state that can only be accomplished in a fewer/one way.

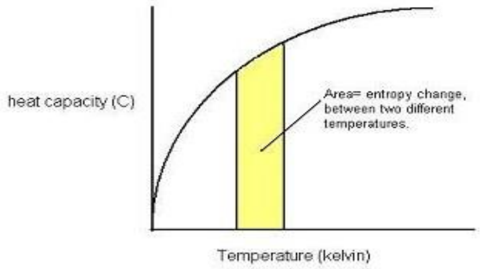
Assume a box filled with jigsaw pieces were jumbled in its box, the probability that a jigsaw piece will land randomly, away from where it fits perfectly, is very high. Almost every jigsaw piece will land somewhere away from its ideal position. The probability of a jigsaw piece landing correctly in its position, is very low, as it can only happened one way. Thus, the misplaced jigsaw pieces have a much higher multiplicity than the correctly placed jigsaw piece, and we can correctly assume the misplaced jigsaw pieces represent a higher entropy.

To understand why entropy increases and decreases, it is important to recognize that two changes in entropy have to considered at all times. The entropy change of the surroundings and the entropy change of the system itself. Given the entropy change of the universe is equivalent to the sums of the changes in entropy of the system and surroundings:

$\Delta Suniv = \Delta Ssys + \Delta Ssurr = qsys/T+qsurr/T$

Third Law of Thermodynamics:The 3rd law of thermodynamics will essentially allow us to quantify the absolute amplitude of entropies. It says that when we are considering a totally perfect (100% pure) crystalline structure, at absolute zero (0 Kelvin), it will have no entropy (S). Note that if the structure in question were not totally crystalline, then although it would only have an extremely small disorder (entropy) in space, we could not precisely say it had no entropy. One more thing, we all know that at zero Kelvin, there will still be some atomic motion present, but to continue making sense of this world, we have to assume that at absolute Kelvin there is no entropy whatsoever.

From physics we know that the change in entropy ΔS equals to the area under the graph of heat capacity (C) versus some temperature range. We can now extend this reasoning when trying to make sense of absolute entropies as well.



Entropy at an absolute temperature

First off, since absolute entropy depends on pressure we must define a standard pressure. It is conventional to choose the standard pressure of just 1 bar. Also, from now on when you see "S" we mean the absolute molar entropy at one bar of pressure. We know that $\Delta S=ST=final-ST=0$; however, by the 3rd law this equation becomes $\Delta S=ST=final\Delta S=ST=final$.

Now note that we can calculate the absolute entropy simply by extrapolating (from the above graph) the heat capacities all the way down to zero Kelvin. Actually, it is not exactly zero, but as close as we can possible get. For several reasons, it is so hard to measure the heat capacities at such low temperatures ($T=0$) that we must reserve to a different approach, much simpler.

Carnot's Heat Engine

- According to second law of thermodynamics, no heat engine can have 100% efficiency
- Carnot's heat engine is an idealized heat engine that has maximum possible efficiency consistent with the second law.

- Cycle through which working substance passed in Carnot's engine is known as Carnot's Cycle.
- Carnot's engine works between two temperatures

  T1 - temperature of hot reservoir

  T2 - temperature of cold reservoir
- In a Complete Carnot's Cycle system is taken from temperature T_1 to T_2 and then back fromtemperature T_2 to T_1.
- We have taken ideal gas as the working substance of carnot engine.
- Fig below is an indicator digram for Carnot Cycle of an ideal gas

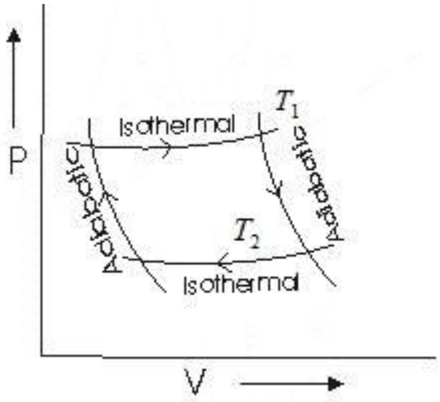


Figure 7

(i) In step b→cb→c isothermal expansion of gas taken place and thermodynamic variables of gas changes from (P_1, V_1,T_1) to (P_2,V_2,T_1)

- If Q_1 is the amount of heat absorbed by working substance from the source and W_1 the work done by the gas then Work done in an isothermal expansion Q1=W1=nRT1ln(V2/V1) ---(1)as process is isothermal.

(ii) Step c→dc→d is an adiabatic expansion of gas from (P_2, V_2, T_1) to (P_3,V_3,T_2). Work done by gas in adiabatic expansion is given as W2=nR(T1−T2)γ−1 ---(2)

(iii)Step d→ad→a is isothermal compression of gas from (P_3,V_3,T_2) to (P_4,V_4,T_2). Heat Q_2 would be released by the gas to the at temperature T_2

- Work done on the gas by the environment is
  $W3=Q2=nRT2ln(V3/V4)$ --(3)
  (iv)Step $a\rightarrow ba\rightarrow b$ is adiabatic compression of gas from (P_4, V_4, T_2) to (P_1, V_1, T_1)
- Work done on the gas is
  $W4=nR(T1-T2)(\gamma-1)W4=nR(T1-T2)(\gamma-1)$ --(4)
- Now total work done in one complete cycle is
  $W=W1+W2-W3-W4$
  $=nRT1ln(V2/V1)-nRT2ln(V3/V4)$ --(5)as $W2=W4$

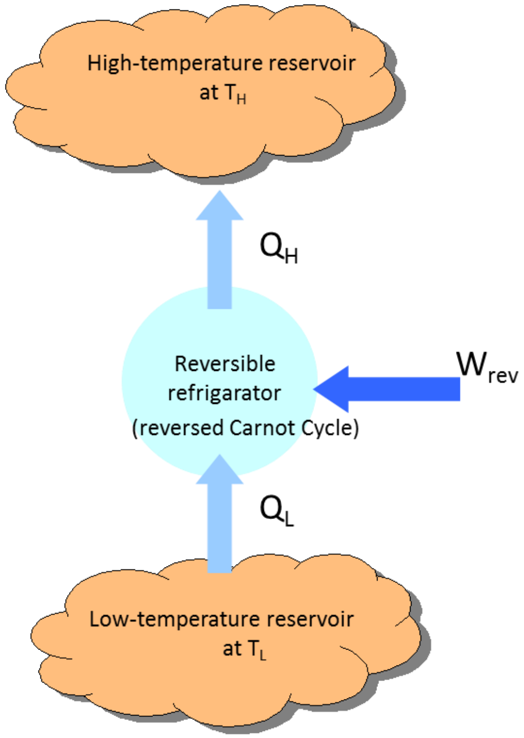
Efficiency of carnot engine

$\eta=W/Q1=1-(Q2/Q1)$
$=1-(T2/T1)ln(V3/V4)ln(V2/V1)$ --(6)
Since points b and c lie on same isothermal
$\Rightarrow P1V1=P2V2$--(7)
Also points c and d lie on same adiabatic
$\Rightarrow P2(V2)\gamma=P3(V3)\gamma$----(8)
Also points d and a lie on same isothermal and points a and b on same adiabatic thus,
$P3V3=P4V4$ ---(9)
$P4(V4)\gamma=P1(V1)\gamma$ ----- (9)
Multiplying all the above four eqns we get
$V3V4=V2V1$ ---(10)
Putting this in equation (5) we get
$\eta=1-(T2/T1)$ ---(11)
From above eqn we can draw following conclusions that efficiency of Carnot engine is
(i) independent of the nature of working substance
(ii) depend on temperature of source and sink

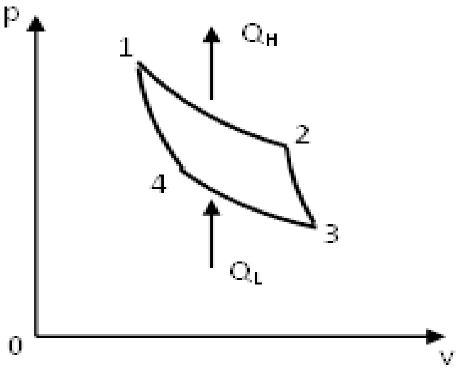
Reversed Carnot Cycle (Refrigerator)

Unlike the Carnot heat engine, the Carnot refrigeration cycle undergoes a process with opposite direction. We see from the model, heat Q_L is absorbed from the low-temperature reservoir

(T_L=constant) and heat Q_H is rejected to a high-temperature reservoir (T_H=constant). In this case a work input in the amount of W_{rev} is required to achieve this process. And we know from the 1st law of thermodynamics, the required work can be determined in $W_{rev} = -Q_H - Q_L$. Here $Q_H < 0$ and $Q_L > 0$.



The reversed Carnot cycle also consists of two isentropic and two isothermal processes. The process undergoes in direction 3-2-1-4-3



Process 3-2: Reversible Adiabatic Compression

This process is isentropic. The engine is perfect insulated so that no heat is lost and absorbed. Gas is compressed slowly until the temperature rises from T_L to T_H.

Process 2-1: Reversible Isothermal Compression (T_H=constant)

During this process, heat is rejected. Gas is compressed reversibly at the constant temperature T_H.

Process 1-4: Reversible Adiabatic Expansion

This process is isentropic. The engine is perfect insulated so that no heat is lost and absorbed. Gas expands slowly until the temperature drops from T_H to T_L.

Process 4-3: Reversible Isothermal Expansion (T_L=constant)

During this process, heat is absorbed. Gas is compressed reversibly at the constant temperature T_H.

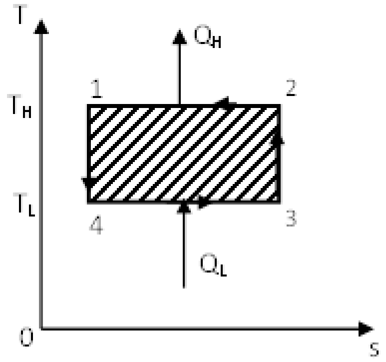
The coefficient of performance (COP) of any refrigerator or heat pump, reversible or irreversible, can be calculated with the general expression:

- For a Carnot refrigerator:

$$COP_R = \frac{Q_L}{W_{rev}} = \frac{Q_L}{-Q_H - Q_L}$$

- For a Carnot heat pump:

$$COP_{HP} = \frac{-Q_H}{W_{rev}} = \frac{-Q_H}{-Q_H - Q_L}$$



From the T-s-diagram, we obtain

$Q_{ab}=Q_H = T_H \cdot \Delta S_{2\rightarrow 1}$

$Q_{zu}=Q_L = T_L \cdot \Delta S_{4\rightarrow 3}$

$\Delta S_{2\rightarrow 1}= - \Delta S_{4\rightarrow 3}$

Therefore

- For a Carnot refrigerator:

$$COP_R = \frac{Q_L}{-Q_H - Q_L} = \frac{T_L \cdot \Delta S_{4\rightarrow 3}}{-T_H \cdot \Delta S_{2\rightarrow 1} - T_L \cdot \Delta S_{4\rightarrow 3}} = \frac{T_L}{T_H - T_L} = \frac{1}{\frac{T_H}{T_L} - 1}$$

- For a Carnot heat pump:

$$COP_{HP} = \frac{-Q_H}{-Q_H - Q_L} = \frac{-T_H \cdot \Delta S_{2\rightarrow 1}}{-T_H \cdot \Delta S_{2\rightarrow 1} - T_L \cdot \Delta S_{4\rightarrow 3}} = \frac{T_H}{T_H - T_L} = \frac{1}{1 - \frac{T_L}{T_H}}$$

According to coefficient of performance (COP), we can also draw the following conclusions:

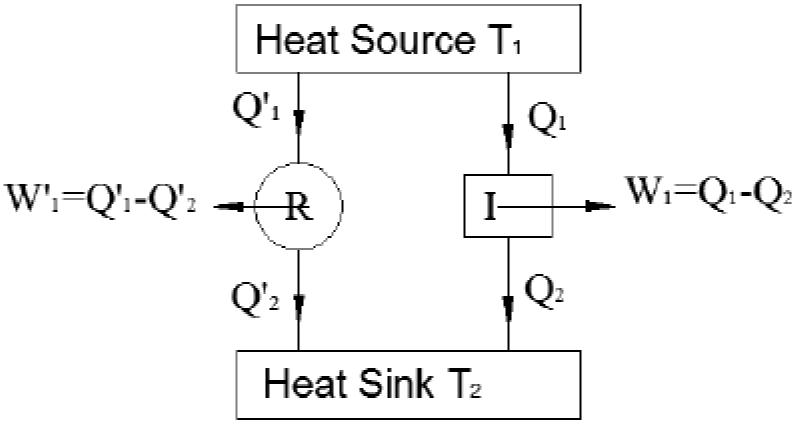
1. The coefficient of performance (COP) of a reversed Carnot cycle only depends on the highest and lowest temperature.
2. Normally $T_H>T_L$, so that means $COP_R>1$ and $COP_{HP}>1$
3. Both coefficients of performance (COP) have a relationship: $COP_{HP} = COP_R +1$
4. If T_L decreases, both COP_R and COP_{HP} decrease.

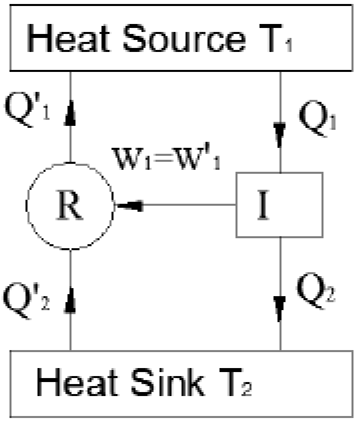
As mentioned above, the reversed Carnot cycle is a reversible process. Hence, if a real refrigerator has the coefficient of performance of COP, then:

- $COP_R < COP_{R,rev}$: irreversible refrigerator
- $COP_R = COP_{R,rev}$: reversible refrigerator
- $COP_R > COP_{R,rev}$: unrealistic refrigerator

Carnot Theorem:

The Carnot theorem states: No heat engine operating on a cycle between two heat reservoirs at different fixed temperatures can be more efficient than a reversible engine. Two reversible heat engines operating between two heat reservoirs at different fixed temperatures will have the same efficiency.





Proof of Statement (1):

Consider two heat reservoir at fixed temperatures T1 and T2 (T1 > T2). A reversible engine R and irreversible engine (I) are operating between the same two thermal reservoir as shown in Fig.

The engine I takes in heat Q1, rejects heat Q2 and does the work W1

$W1 = Q1 - Q2$

While the reversible engine takes in heat Q1’ rejects heat Q2’ and does the work W1’

$W1' = Q1' - Q2'$

Both the engines are so adjusted that they produce equal amount of work i.e. $W1 = W1'$ $Q1 - Q2 = Q1' - Q2'$……………..(i)

Assume that efficiency of irreversible engine in greater than the efficiency of reversible engine.

$\eta I > \eta R$

$W1/ Q1 > W1'/ Q1'$

$Q1' > Q1$ …………….

(ii) since $W1 = W1'$

from eqns (i) and (ii)

$Q2' > Q2$

It follows from equation (ii) and (iii) that more efficient reversible engine will abstract less amount of heat from source and rejects less amount of heat to the sink compared to less efficient reversible engine provided both produce equal amount of work.

The reversible engine can now be operated as a heat pump since the engine is reversible, it is possible and the work developed by the irreversible engine is used to drive the pump as shown in fig.

The magnitude of heat and work transfer for the reversible heat engine will remain the same but their directions will be reversed when it works as a heat pump.

Combining engine I and heat pump R into one system, We observe that the sole effect of the combined system is the transfer of heat energy $Q2' - Q2$ equal to $Q1' - Q1$ from low temperature heat reservoir to high temperature reservoir without any external effect violates the Clausius statement of second law of thermodynamics.

Therefore basic assumption $\eta I > \eta R$ is wrong.

Therefore **the efficiency of an irreversible engine cannot be greater than that of the reversible engine if both operate between the fixed temperature heat reservoirs.**

$\eta R \geq \eta I$

Proof of statement (2):

Let both the engines I and R be reversible engines. Assuming that either of the reversible engine with higher efficiency to operated upon as an engine and the other less efficient reversible engine as heat pump.

We can show that in either case the second law of thermodynamics is violated. Hence either of the reversible can be more efficient than the other.

We conclude that, "**All reversible engines will have the same efficiency when operating between two fixed temperature heat reservoirs."**

Entropy:

Generally, entropy is defined as a measure of randomness or disorder of a system. This concept was introduced by a German physicist named Rudolf Clausius in the year 1850.

Apart from the general definition, there are several definitions that one can find for this concept. The two definitions of entropy that we will look here are the thermodynamic definition and the statistical definition.

From a thermodynamics viewpoint of entropy, we do not consider the microscopic details of a system. Instead, entropy is used to describe the behaviour of a system in terms of thermodynamic properties such as temperature, pressure, entropy, and heat capacity. This thermodynamic description took into consideration the state of equilibrium of the systems.

Meanwhile, the statistical definition which was developed at a later stage focused on the thermodynamic properties which were defined in terms of the statistics of the molecular motions of a system. Entropy is a measure of the molecular disorder.

Properties of Entropy

- It is a thermodynamic function.
- It is a state function. It depends on the state of the system and not the path that is followed.
- It is represented by S but in the standard state, it is represented by S°.
- It's SI unit is J/Kmol.
- It's CGS unit is cal/Kmol.
- Entropy is an extensive property which means that it scales with the size or extent of a system.

Note: The greater disorder will be seen in an isolated system, hence entropy also increases. When chemical reactions take place if reactants break into more number of products, entropy also gets increased. A system at higher temperatures has greater randomness than a system at a lower temperature. From these examples, it is clear that entropy increases with a decrease in regularity.

Entropy order: gas > liquid > solids

Entropy Change and Calculations

During entropy change, a process is defined as the amount of heat emitted or absorbed isothermally and reversibly divided by the absolute temperature. Entropy formula is given as;

$\Delta S = q_{rev,iso}/T$

If we add the same quantity of heat at a higher temperature and lower temperature, randomness will be maximum at a lower temperature. Hence, it suggests that temperature is inversely proportional to the entropy.

Total entropy change, $\Delta S_{total} = \Delta S_{surroundings} + \Delta S_{system}$

Total entropy change is equal to the sum of entropy change of system and surroundings.

If the system loses an amount of heat q at a temperature T1, which is received by surroundings at a temperature T2.

So, ΔS_{total} can be calculated

$\Delta S_{system} = -q/T_1$

$\Delta S_{surrounding} = q/T_2$

$\Delta S_{total} = -q/T1 + q/T2$

- If ΔS_{total} is positive, the process is spontaneous.
- If ΔS_{total} is negative, the process is non-spontaneous.
- If ΔS_{total} is zero, the process is at equilibrium.

Points To Remember

- A spontaneous process is thermodynamically irreversible.
- The irreversible process will attain equilibrium after some time.

Entropy change during the isothermal reversible expansion of an ideal gas

$\Delta S = q_{rev,iso}/T$

According to the first law of thermodynamics,

$\Delta U = q + w$

For the isothermal expansion of an ideal gas, $\Delta U = 0$

$q_{rev} = -w_{rev} = nRT\ln(V_2/V_1)$

Therefore,

$\Delta S = nR\ln(V_2/V_1)$

Entropy Change During Reversible Adiabatic Expansion

For an adiabatic process heat exchange will be zero(q=0), therefore reversible adiabatic expansion is taking place at a constant entropy (isentropic),

$q = 0$, Therefore,$\Delta S = 0$

Even though the reversible adiabatic expansion is isentropic, irreversible adiabatic expansion is not isentropic, ΔS not equal to Zero.

UNIT – 5- ACOUSTICS

- Acoustics is an interdisciplinary science that studies different mechanical waves passing through solid, liquid, and gases.
- Basically, acoustics is the science of sound that describes the generation, transmission, and effects of sounds; it also, including biological and psychological effects sound
- Likewise, acoustics studies vibration, sound, ultrasound, infrasound.
- The term "acoustic" is a Greek word i.e. ‘akoustikos,’ which means "of or for hearing, ready to hear."
- These days, acoustics technology is very much applicable in many industries specially to reduce the noise level.

Acousticians

- The person who is an expert in the field of acoustics is known as acoustician.
- There are a variety of acoustics fields of study. For example, the production sound, control of sound, transmission of sound, reception of sound, or effects of sound on human beings as well as on animals.

Types of Acousticians

- Following are the major types of acousticiansn −
- **Bioacoustician** − The expert of this field researches and studies birds of a given geographic region to determine that the man-made noise changes their behavior.
- **Biomedical Acoustician** − The expert of this field researches and develop medical equipment to treat kidney stone.

- **Underwater Acoustician** − The expert of this field research and design sophisticated sonar hardware that explores the ocean floor.
- **Audiologist** − The expert of this field diagnose hearing impairments.
- **Architectural Acoustician** − The expert of this field designs an opera house to manage the high pitch sound (inside the house).

Fields of Acoustics

Following are the major fields of acoustics.

- **General Acoustics** − This field of acoustic studies about the sounds and waves.
- **Animal Bioacousticians** − This field of acoustic studies how animals create, use, and hear sounds.
- **Architectural Acoustics** − This field of acoustic studies about the building designs to have the pleasing sound quality and safe sound levels.
- **Medical Acoustics** − This field of acoustic researches and studies the use acoustics to diagnose and treat various types of illnesses.
- **Archaeoacoustics** − This field of acoustic studies sound systems of archaeological sites and artefacts.
- **Psychoacoustics** − This field of acoustic studies – how human beings respond to a particular sound.

Characteristics of musical sound

(i) Pitch of Sound: Pitch of a sound depends on the frequency of the sound. High pitch means higher frequency and low pitch means lower frequency.

(ii) Intensity of sound : Intensity of sound at any point is the amount of sound energy incident on unit area held normal to the direction of propagation of sound in one second. i.e., It is the sound power on unit area. Intensity of sound is proportional to the square of the amplitude of sound wave. Its basic unit is W/m^2.

(iii) Timbre or quality: Timbre is an important property which helps the ear to distinguish musical sound which have the same pitch and loudness. Timbre is mainly characterised by the harmonic content of sound and its dynamic properties.

(iv) Loudness and its units : Loudness of sound is the degree of sensation of sound. It depends on the intensity of sound and the∗ sensitivity of ear or microphone. Loudness of sound is proportional to logarithm of intensity of sound.

Absorption of sound: All materials absorb certain amount of sound energy. The degree of absorption depends on many factors. An open window is a perfect absorber of sound because the sound incident on it will not be reflected back. One Sabine is the amount of sound energy absorbed by one square meter of an open window.)αAbsorption Coefficient ( ) is defined as the ratio of the amount of sound energy absorbedαThe absorption coefficient of sound (by the surface to the amount of sound energy incident on the surface. Since, open window is a perfect absorber, the absorption coefficient of all substances are measured in = 1αterms of open window unit (OWU). For open window, =α Amount of sound energy absorbed by a surface Amount of sound energy incident on the surface Absorption coefficient is expressed as open window unit OWU

Reverberation: Sound produced by a source in a hall suffers multiple reflections from various objects in the hall, like wall, floor, ceiling etc. Hence the listeners hear a series of sound in addition to the original sound. So sound persists for a time even after the source has stopped. The phenomenon of persistence of sound in a hall due to multiple reflections from the ceiling, floor, walls, and other materials, even after the source of sound has cut off is called reverberation.

Reverberation time (T): It is defined as the time required by the sound energy to reduce its intensity to 10^{-6} times of its original intensity (or reduce its intensity by 60dB of its original intensity) from the moment the source of sound is stopped.

Significance of reverberation time : Reverberation time is an important factor deciding the acoustic quality of a building. If reverberation time is so small, sound vanishes very rapidly. This produces dead silence in the hall. If reverberation time is too large, there will be multiple reflections and the sound waves will overlaps one over other producing loss of clarity. Hence reverberation time should have an optimum value for good acoustics of a hall. Reverberation time can be adjusted according to the purpose of the hall by arranging necessary sound absorbing materials in the hall.

Sabine's Formula Prof. Wallace C. Sabine (1868 - 1919) of Harvard University investigated architectural acoustics scientifically, particularly with reference to reverberation time. He deduced experimentally, that the reverberation time is:

- directly proportional to the volume of the hall
- inversely proportional to the effective absorbing surface area of the walls and the materials inside the hall

$T\alpha V\Sigma aA$

Where, V is the volume of the hall, a is the absorption coefficient of an area A. If the volume is measured in cubic feet and area in square feet, then the experimentally obtained value of the constant of proportionality, according to Sabine is 0.05. Then,

$T=0.05V\Sigma aA$

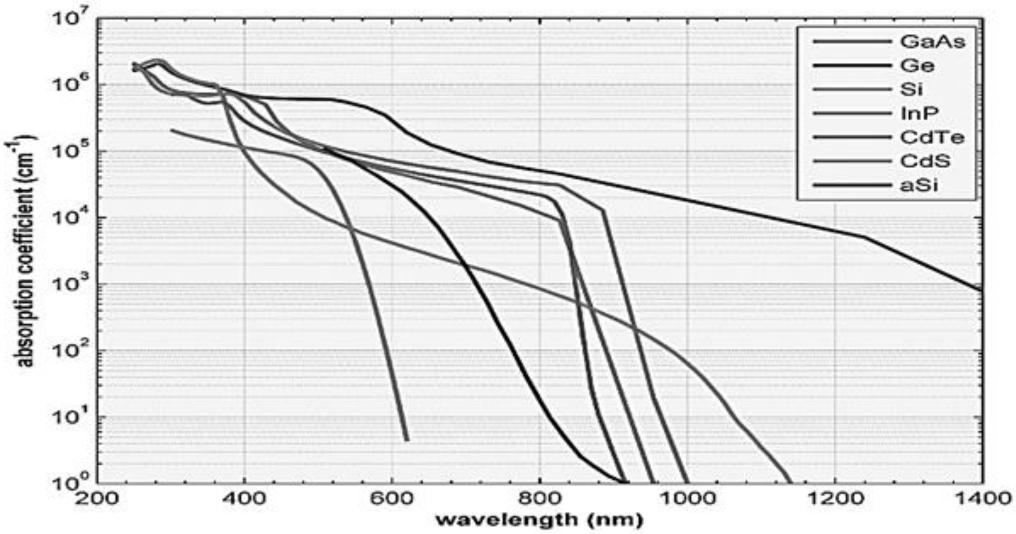
If there are different absorbing surfaces of area A1,A2,A3,A4A1,A2,A3,A4 etc., having absorption coefficients a1,a2,a3,a4a1,a2,a3,a4 etc., then,
$T=0.05Va1A1+a2A2+a3A3+a4A4+..$

If the area is measured in square meters and the volume in cubic meters, then Sabine's formula can be written as:

$T=0.16V\Sigma aA$

Increasing the effective area of complete absorption like, changing the wall materials or adding more furniture may decrease an excessive reverberation time for a hall. But this also decreases the intensity of a steady tone. Also, too much absorption will make the reverberation time too short and cause the room to sound acoustically 'dead'. Hence, the optimum reverberation time is a compromise between clarity of sound and its intensity.

The absorption coefficient determines how far into a material light of a particular wavelength can penetrate before it is absorbed. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will appear transparent to that wavelength. The absorption coefficient depends on the material and also on the wavelength of light which is being absorbed. Semiconductor materials have a sharp edge in their absorption coefficient, since light which has energy below the band gap does not have sufficient energy to excite an electron into the conduction band from the valence band. Consequently this light is not absorbed. The absorption coefficient for several semiconductor materials is shown below.



The above graph shows that even for those photons which have an energy above the band gap, the absorption coefficient is not constant, but still depends strongly on wavelength. The probability of absorbing a photon depends on the likelihood of having a photon and an electron interact in such a way as to move from one energy band to another. For photons which have an energy very close to that of the band gap, the absorption is relatively low since only those electrons directly at the valence band edge can interact with the photon to cause absorption. As the photon energy increases, not just the electrons already having energy close to that of the band gap can interact with the photon. Therefore, a larger number of electrons can interact with the photon and result in the photon being absorbed.

The absorption coefficient, α, is related to the extinction coefficient, k, by the following formula:

$\alpha=4\pi k\lambda$

Where λ is the wavelength. If λ is in nm, multiply by 107107 to get the absorption coefficient in the units of cm−1cm−1.

Factors Affecting Acoustics Of Buildings And Their Remedies:

(1)Reverberation time: It is an important factor deciding the acoustic quality of a building. If reverberation time is so small, sound vanishes very rapidly. This produces dead silence in the hall.∗ If reverberation time is too large, there will be multiple reflections and the sound waves will overlap∗ one over other producing loss of clarity. Hence reverberation time should have an optimum value for good acoustics of a hall. Reverberation∗ time can be adjusted according to the purpose of the hall by arranging necessary sound absorbing materials in the hall.

Remedies: Reverberation time can be controlled by∗ (i) by selecting suitable building materials. (ii) by providing proper windows and ventilators. (iii) by covering walls and ceilings with sound absorbing materials. (iv) by covering floor with carpets. (v) by using thick curtains. (vi) by furnishing with upholstered seats.

Echoes: Echo is due to reflection of sound at different objects. Echo is produced when the time interval between the direct and reflected sound waves is about 1∗ 5 th of a second. Long halls produce echo and almost all rooms produce reverberation.

Remedies: Echoes can be controlled by∗ (i) by covering distant walls and ceilings with sound absorbing materials. (ii) by providing thick curtains with folding.

Focussing surfaces : If there are any focussing surfaces such as concave surface, spherical, cylindrical or parabolic surfaces∗ on the walls, floor and ceiling of the hall, the sound energy will be focussed to only certain region. This causes less sound in some other region.

Remedies: For uniform distribution of sound energy throughout the hall,∗ (i) There should not be any curved surfaces in the hall. If any such surfaces are present, they must be covered with sound absorbing materials. (ii) Ceiling must be of less height. (iii) A parabolic surface must be arranged with the speaker at its focus. This send out a uniform sound energy in the entire hall.

Sufficient Loudness :For satisfactory hearing, sufficient loudness throughout the hall is necessary.

Remedies: For sufficient loudness,∗ (i) by placing loud speakers at proper positions in the hall. (ii) Ceiling is kept low, so that the sound gets reflected from the ceiling and reaches the audience. (iii) by keeping large polished boards behind the speaker.

Resonance Effect :Cavities, holes, air pockets etc in the walls and ceiling of the hall will contain air columns. These air∗ columns are set into vibrations due to resonance and as a result sound is produced. In some cases, section of wooden portions, window panes etc will vibrate and produce sound waves.∗ This will also produce resonance. Sometimes, these created sounds will interfere with original sound. These resonance and interference produces distortion and losses the clarity of the original sound.∗

Remedies: To avoid these,∗ (i) cavities, air pockets, holes etc in the halls should be avoided or covered with sound absorbing materials. (ii) fixing the window panes properly. (iii) damping the resonant vibrations by suitable methods.

Echelon effect: Regular spacing of reflecting surfaces, or steps with equal width may produce additional musical notes∗ due to regular repetition of echoes. This is called echelon effect. This makes original sound confusing.

Remedies: This can be reduced by∗ (i) making steps and pillars of unequal width. (ii) covering equally spaced steps with sound absorbing materials.

Noise: Unwanted sound in a hall is called noise. Noises are divided into three∗ Air born noise: Noise from outside the hall through windows, door, ventilators etc are called air born noise. Eg: Vehicle moving outside produce noises. This can be eliminated by avoiding openings and holes, using double door and double windows on separate frame with an insulator between them etc. Structure born noise: This is caused by the vibration of the structure due to different activities going on nearer to building like drilling, working of heavy machines etc. This can be eliminated by breaking the continuity of the hall with proper sound insulators(using double walls with air in between them) etc. Inside noise: The noise produced inside the hall is called inside noise and this is produced by the machines like fan, engines etc. This noise can be eliminated by furnishing the floor with carpets and mats etc.

Ultrasound : Sound waves with frequencies higher than the upper audible limit of human hearing are called ultrasound. The limit varies from person to person but is approximately 20,000 Hertz. The physical properties of ultrasound are similar to the normal audible sound.

This type of scientific concept is used in many different fields such as navigation, medicine, imaging, cleaning, mixing, communication, testing etc. Even in nature, bats and porpoises use this particular technique for the location of prey and obstacles. In the following section, we shall learn about its applications.

Applications:

Cleaning:

In objects with parts that are difficult to reach, for example, spiral tubes and electronic components, the process of ultrasonic cleaning is used. Here, the object is dipped in a solution of suitable cleaning material and ultrasonic waves are passed into it. As a result of this, high-frequency waves are generated that cause the dirt and grease to detach from the surface.

Ultrasonic cleaning

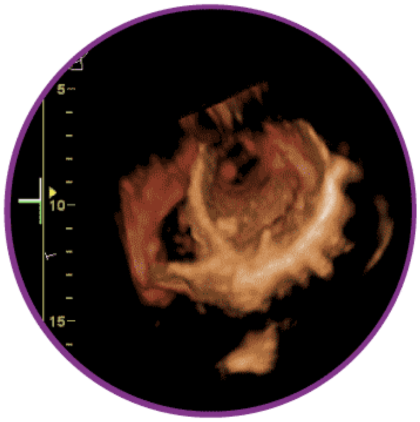
Detection of cracks:

Ultrasound is used to detect cracks in the metallic components that are used in the construction of high rise structures such as buildings and bridges. They generate and display an ultrasonic waveform that is interpreted by a trained operator, often with the aid of analysis software, to locate and categorize flaws in test pieces. High-frequency sound waves reflect from flaws in predictable ways, producing distinctive echo patterns that can be displayed and recorded by portable instruments. A trained operator identifies specific echo patterns corresponding to the echo response from good parts and from representative flaws. The echo pattern from a test piece may then be compared to the patterns from these calibration standards to determine its condition.

Detection of cracks

Echocardiography:

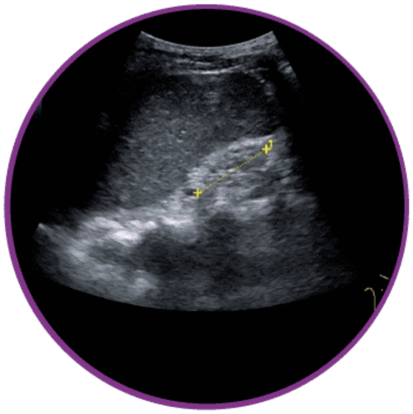
In the process of electrocardiography, the ultrasonic waves are used to form an image of the heart using reflection and detection of these waves from various parts.



Echocardiography

Ultrasonography:

Medical ultrasound is a diagnostic imaging technique based on it. It is used for the imaging of internal body structures such as muscles, joints and internal organs. Ultrasonic images are known as sonograms. In this process, pulses of ultrasound are sent to the tissue using a probe. The sound echoes off the tissue, where different tissues reflect sound varying in degrees. These echoes are recorded and displayed an image.



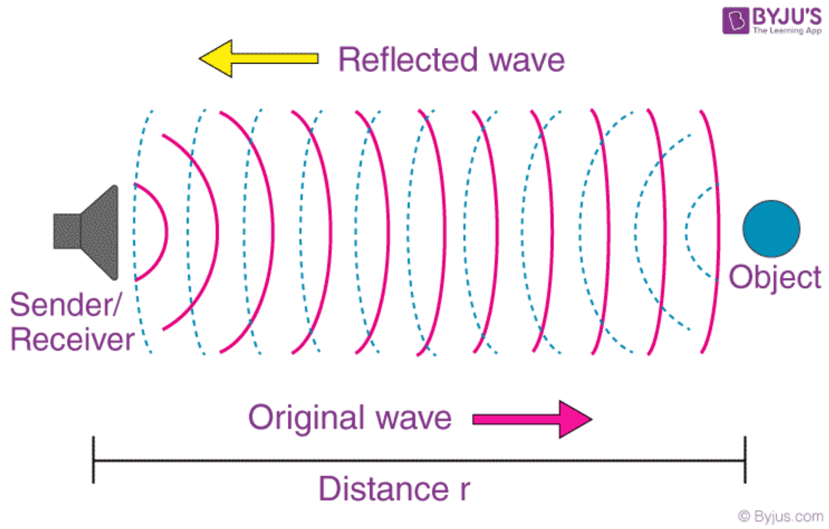
Ultrasonography

Lithotripsy:

Ultrasonic waves are used to break stones in the kidney. High energy sound waves are passed through the body without injuring it and break the stone into small pieces. These small pieces move through the urinary tract and out of the body more easily than a large stone.

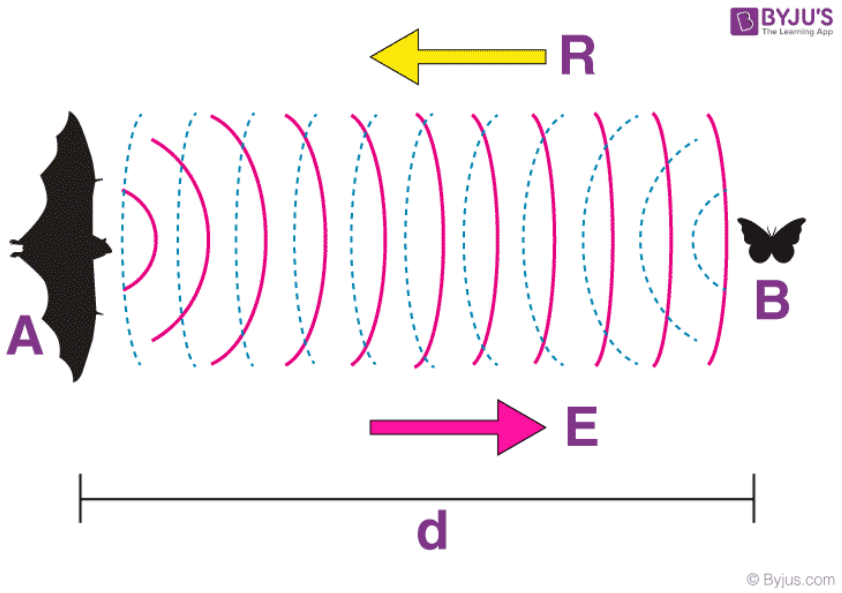
SONAR:

SONAR, Sound Navigation, and Ranging is a technique in which sound waves are used to navigate, detect and communicate under the surface of the water.



Echolocation:

Echolocation is the process where sound waves and echoes are used to determine objects in space. Echolocation is used by bats to navigate and find their food in the dark. Bats send out sound waves from their mouth and nose, which then hit the objects in their vicinity producing echoes, which are then received by the bats. The nature of the echo helps them determine the size, the shape and the distance of the object.



Production of Ultra sonic waves – Piezo Electric Effect

Principle:

This is based on the **Inverse piezoelectric effect.** When a quartz crystal is subjected to an alternating potential difference along the electric axis, the crystal is set into elastic vibrations along its mechanical axis. If the frequency of electric oscillations coincides with the natural frequency of the crytal, the vibrations will be of large amplitude. If the frequency of the electric field is in the ultrasonic frequency range, the crystal produces ultrasonic waves.

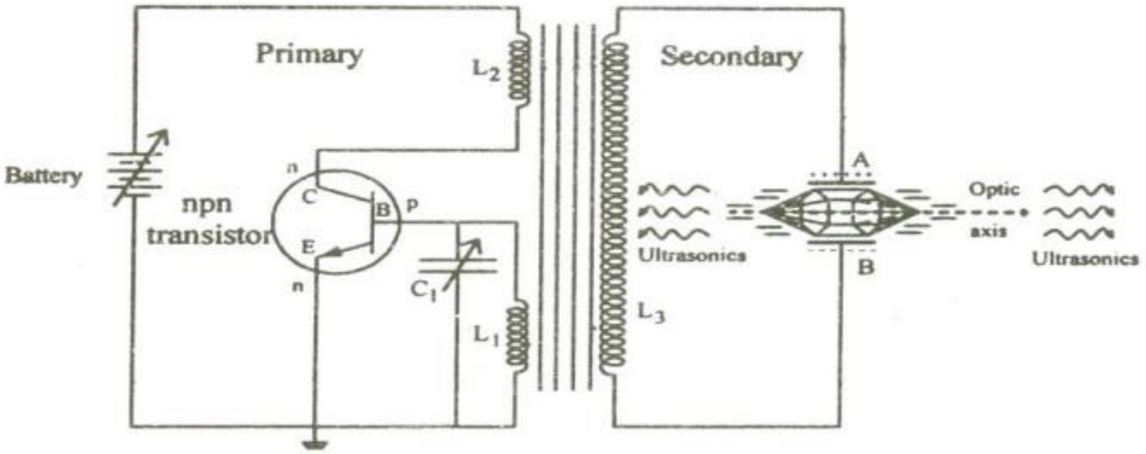


Figure Piezo-Electric Oscillators

Construction:

The circuit diagram is shown in the figure 1.5 It is base turned oscillator circuit. A slice of Quartz crystal is placed between the metal plates A and B so as to form a parallel plate capacitor with the crystal as the dielectric. This is coupled to the electronic oscillator through the primary coil L_3 of the transformer.Coils L_2 and L_1 of oscillator circuit are taken for the primary of the transformer. The collector coil L_2 is inductively coupled to base coil L_1. The coil L_1 and variable capacitor C form the tank circuit of the oscillator.

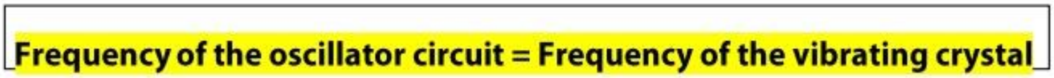
Working:

When the battery is switched on, the oscillator produces high frequency oscillations. An oscillatory e.m.f is induced in the coil L3 due to transformer action. So the crystal is now under high frequency alternating voltage.

The capacitance of C1 is varied so that the frequency of oscillations produced is in resonance with the natural frequency of the crystal. Now the crystal vibrates with larger amplitude due to resonance. Thus high power ultrasonic waves are produced.

Condition for Resonance:

Frequency of the oscillator circuit = Frequency of the vibrating crystal



Frequency of the oscillator circuit = Frequency of the vibrating crystal

$$F = \frac{I}{2\pi\sqrt{L_1C_1}} = \frac{P}{2l}\sqrt{\frac{E}{\rho}}$$

Where ‘l’ is the length o the rod

‘E’ is the Young’s modulus o the rod

‘ρ’ is the density of the material of the rod.

‘P’ = 1,2,3 …. Etc for fundamental, first overtone, second overtone etc respectively

Advantages:

1. Ultrasonic frequencies as high as 500MHz can be generated.
2. The output power is very high. It is not affected by temperature humidity.
3. It is more efficient than the Magnetostriction oscillator.
4. The breadth of the resonance curve is very small. So we can get a stable and constant frequency of ultrasonic waves.

Disadvantages:

1. The cost of the quartz crystal is very high.
2. Cutting and shaping the crystal is quite complex.

Ways to Reduce Noise in Factories | Noise Pollution

There are seven ways of reducing noise in factories. The ways are:

1. Noise Reduction at Source
2. Vibration Isolation
3. Noise Reduction and Layout
4. Enclosures to Reduce Noise
5. Sound-Absorbing Materials
6. Partial Enclosures and Screens
7. Ear Protection.

1. Noise Reduction at Source:

(i) Process and Machine Tools Selection:

One of the basic principles of noise control is that noise should be reduced as near the source as possible. The greatest number of people are protected from the noise by this means, and moreover, the noise control treatment is less expensive.The noise that is likely to be produced should be considered at the very beginning of the planning of a factory, even before the orders are placed for machines and tools. The process used for production determines, to a very large extent, the noise problem in a factory. When a factory is planned, the planners should keep in mind that many of the very noisy processes have alternatives that produce far less noise.

Some of the common examples of this are:

(a) Welding instead of riveting;

(b) Pressing instead of forging; and

(c) Grinding instead of chipping.

Noise can hardly be a major consideration in the choice of an industrial process; but it must be taken into account as one of the economic factors. The reason is that, once a process has been selected and introduced in a factory, no amount of noise reduction treatment inside the factory is likely to reduce the noise level of one of the noisy processes to that of its quieter alternative.To a lesser extent, the machine tools and other equipment used in the factory will also influence the noise level in the factory. It may so happen that one make of a machine tool may have particularly noisy gears, compared with another of similar performance.Since very few machine tool manufacturers give noise levels for their products at present (in India and other developing countries, at least) factory engineers should compare the noise produced by different makes of machine tools in operation. One should also keep in mind that excessive noise from a tool, for its type, size and power level, generally indicates low mechanical efficiency.

Reducing the Potential Noise Energy:

It is well known that the amount of noise radiated from a surface depends on the amplitude of the vibration and on the area of the radiating surface. Among these two factors, the amplitude is determined by the resistance of the surface to oscillatory motion, and the power available to drive it.

It follows from the above discussion that there are two basic methods of reducing the noise at source, viz.,

(a) By reducing the amount of energy communicated to the vibrating surface; and

(b) By reducing the efficiency of the surface as a radiator of noise.

Unless the way in which the power is applied is changed, however, reducing the energy is only likely to be effective if the operation generating the noise is not an essential part of the process.

The sources of noise in a factory can be grouped under:

(a) Impact;

(b) Reciprocation;

(c) Friction; and

(d) Air turbulence.

We discuss now the precautions that should be taken to keep the noise energy of a source at a minimum, for each of these groups of noise sources. Where impact is essential to the process (as in hammering and riveting, for example), the possibilities of reducing noise at the source are usually limited to using no more power than is absolutely necessary, and preventing unnecessary impacts.If the impact can be spread over a short period (and thus converted into more of a squeezing or shearing operation), an appreciable noise reduction is obtained. Riveting, punching, and pressing are processes where this is sometimes possible. On the other hand, impact that is not essential to the process can often be quietened.

For example, noise caused by the handling and dropping of materials on hard surfaces can be reduced by the following methods:

(a) By covering surfaces with resilient materials;

(b) By using resilient materials for containers; and

(c) By fitting rubber tyres on trolleys.

- Machine rattle can be minimised by proper maintenance. Often a rattle can be eliminated merely by securing a lose panel. If reciprocating or vibrating movement is part of the work process, the amplitude of such a vibration should be kept to a minimum.

- In cases where the rate of reciprocation is not important, decreasing this rate will reduce the noise, provided that lose parts are not excited to vibrate at a higher frequency. Vibration from rotating machinery can usually be reduced by dynamic balancing. If practicable, a reduction of speed will also prove to be effective.

- Frictional noise generated by the cutting action of tools and saws can be reduced by keeping them sharp. Changes in the shape of cutting tools may also be beneficial.

- Other noises caused by friction in machines, conveyors, and roller trolleys can be minimised by proper lubrication. Often the noise excites a high-frequency resonance. Such a resonance can be prevented by substituting a highly damped, material for the resonating component.

- Air-turbulence noise from air and steam exhausts can be simply and effectively reduced at the source, with a silencer that lowers the escape velocity of the exhaust. In the case of small pneumatic tools, for example, this can be achieved by incorporating in the tools an exhaust collecting sleeve.

- Another method, suitable for larger portable tools, is to conduct the exhaust air away, through a second line, to a remote silencer. When a jet of air is used for cleaning off, or for lifting parts from dies, the air pressure should be kept at the minimum required for the operation.

- Noise caused by turbulence at outlets, valves, and bends in pipes and ducts can be reduced by careful streamlining as well as by lowering the velocity of air or gas passing through them.

Reducing the Radiation of Noise:

For a given amplitude of vibration of a source, the intensity of noise produced by it will be roughly proportional to the area of the radiating surface, if the dimensions of the surface are large compared with the wavelength of the sound generated.

This means that if the surface area is halved, the intensity of the noise will be reduced by 3 dB; and at lower frequencies (i.e., larger wavelengths), the reduction will be much greater. To radiate sound effectively at 100 Hz, for example, a source must be of the order of a square metre in area; but at 1,000 Hz intense sound can be radiated from a source of only a few cm^2.

The directional properties of a source are also determined by the size of the radiating surfaces. If the dimensions of the radiating surface are much greater than the wavelength of the sound generated, the sound will be emitted primarily in one direction. Thus, even quite small sources will be directional at high frequencies (i.e., small wavelengths).

Supporting structures for vibrating machines and other equipment will radiate less noise if they are frames than if they are cabinets or sheeted enclosures. An enclosed machine may be noisier in fact (unless proper precautions are taken to isolate its housing) than if it were not enclosed.

The reason for this is the larger surface area in the case of an enclosed machine. The noise radiated by machinery guards can be minimized by making them of perforated sheet or of wire mesh.

Resonance and Damping:

As a general rule, the noise radiated from metal plates and other metal parts is made more intense by resonance in such parts. The well-known phenomenon of resonance occurs in this case when the natural frequency of the metal plate, which depends on its stiffness, is equal to the frequency of the source driving it.

The amplitude of vibration is then limited only by the damping in the material. For example, a steel sheet (which has very little damping) will vibrate freely at resonance; but a lead sheet (with high damping) will not.

Resonance can be prevented in machine parts by:

(a) Stiffening;

(b) Increasing the damping; or

(c) A combination of both.

- Stiffening, which is generally easier, is satisfactory when the frequency range of the driving source is narrow and constant. Where the panel concerned is a permanent part of the equipment, it can be stiffened by corrugations or by adding ribs. If the work-piece is resonating, clamping of it to a suffer structure will reduce the noise.

- On the other hand, increasing the damping will be more effective if the exciting force covers a wide range of frequency. A permanent increase in damping (in resonating parts of equipment, for example) will be achieved if the surface concerned is coated with a chemical compound of the kind used for under-sealing cars.

- To be effective, however, the coating should be at least equal in weight to the panel. A temporary increase in damping, to reduce the noise from the riveting of steel plates for example, can be obtained with sand bags, or even by ensuring that the plate is continuously supported over its whole area.

2. Vibration Isolation:

Basic Principles:

- A source of sound usually does not itself have a large enough area to radiate much noise. However, the vibration is conducted along a mechanically rigid path to a surface that can act as an effective radiator.

- The vibration can be transmitted, in this way, for long distances with very little reduction. If the rigid connecting path is interrupted by a resilient material of the correct characteristics, however, the vibration transmitted (and the noise radiated) will be greatly reduced.

- The reduction of vibration obtained in this way depends on the ratio of the driving frequency of the source to the natural frequency of the resiliently supported system. The natural frequency depends on the stiffness of the system.

- The higher the ratio between the two frequencies, the greater the noise reduction; but it is difficult to achieve a very large reduction in practice. Table 1 gives approximate values of the transmissibility (i.e., the ratio of the amplitude of vibration transmitted to the amplitude of the driving vibration), and the equivalent noise reduction, for various ratios of these frequencies.

However, the values given in Table 1 are theoretical values. In practice, it has been found that a ratio of not less than about 3:1 between the driving frequency and the natural frequency is satisfactory for most purposes. Such a ratio will reduce the vibration transmitted by 87% (equivalent to a noise reduction of about 18 dB).

The discussion given above applied to steady-state vibration (for example, the vibration from an electric motor); but the vibration can also be impulsive (for example, the vibration from a punch press). The isolation of impact vibration (or shock) is based on a different principle.

In this case, the vibration energy is not absorbed in the amount. It is stored for a short time and released at a slower rate. This requires a reasonably stiff mount.

Resilient Materials:

The resilient material used for vibration isolation may be in the form of a pad, or of a proprietary mounting.

The materials commonly used for this purpose are:

a. Felt, cork, and glass wool;

b. Natural or synthetic rubber; and

c. Steel springs.

- Felt, cork, and glass wool are often used for resilient mats or pads under machine bases. The total area of such a mat is important; and so is its thickness. The load per unit area must be high enough to give deflection adequate for the isolation required.

- Similarly, the thickness of the material should be such that, at this deflection, it is not loaded beyond its elastic limit. In many cases, a large area of material has been used with negligible effect because the mounting has been too stiff.

- Natural or synthetic rubber is used occasionally as a mat, but more frequently as part of a proprietary mount. It must be used either in shear or in compression, and is generally bonded to metal in order to provide connections.

- Coil springs of steel are very useful in giving large deflections for isolating low frequencies, but high frequencies may be transmitted along with the coils unless there is another resilient material in series with the spring.

Isolation Methods:

In addition to resilient materials, pneumatic suspension has also been suggested as a method of vibration isolation, although it would be more expensive than other forms of suspension.

- In this method, the stiffness of the mounting system could varied to suit the characteristics of the source, and automatic leveling devices would make it possible to use very "soft" suspension without impairing the stability of the machine. The advantages of this method may make its extra cost justifiable in special cases.

- The normal position for vibration isolation is between a machine and the floor; but it can be applied as well between any energy source and radiating surface. Isolating machines from the floor will reduce the radiation of low-frequency noise, and also prevent its transmission to remote parts of the factory.

- This type of isolation will also prevent vibration from being transmitted to delicate machinery. In multi-storey factories (where the floors are more liable to vibrate, and to radiate noise both upwards and downwards), such isolation is an essential part of noise reduction.

- Most machine tools are not likely to generate low-frequency vibration, and the resilient mount may then be placed between the machine casting and the floor. Where there is low-frequency vibration, however, the deflection necessary for adequate isolation may cause too great a movement of the machine.

- When this is the case, the resilient mounts may be placed under an independent concrete base to which the machine is bolted. This arrangement increases the mass and reduces the amount of movement. A similar arrangement is necessary if a machine needs to be bolted down to achieve sufficient rigidity.

- Besides reducing noise, vibration isolation between the machine and the floor has other important advantages. For example, the reduction in vibration transmitted to the floor will enable the live-load allowance for vibration to be reduced, and the reduction of shock loading within the machine may increase its useful life.

- Some of the proprietary mounts have built-in leveling devices, and since vibration mounting stops the machine from “walking”, holding down bolts are not required. This gives greatly increased flexibility to the plant layout.

Other Considerations:

For reducing the noise in a factory, equally important is the isolation of a vibrating source within a machine from other parts that can radiate the noise. Noise may, for example, be radiated by the sheet metal enclosing the moving parts. In such cases, the cover should be isolated from the source by resilient fixings.

- The frequencies involved here are generally higher than with floor isolation, so that the deflection required in these fixings need not be so large. In other cases, the source of noise may be isolated as a separate part within the machine, with the power transmitted through belts or shafts incorporating resilient couplings.
- The factory engineer should ensure that vibration is not transmitted to objects fixed to machines. Sheet metal ducts and chutes, for example, should be attached to machines only through flexible canvas couplings.
- In factories, the vibration isolation of service equipment is often neglected. However, the noise from service equipment can often be as intense as that from the production machinery. A very common example of this is an axial-flow fan rigidly mounted in the sheeted side of a factory. Other potential sources of vibration and noise are unit heaters, dust extraction equipment, conveyors, cranes, and transformers.
- An otherwise satisfactory vibration-isolating installation can often be made useless by rigid pipe and conduit connections, which “short-circuit” the isolators. All such connections should, therefore, be flexible and loose. Even a flexible connection will transmit vibration if it is taut.

- Where flexible connections are impracticable, the introduction of bends into a pipe will reduce its efficiency as a conductor of vibration. Alternatively, the pipe itself should be supported on vibration mounts for a considerable distance from the source.

3. Noise Reduction and Layout:

Site Layout:

- If the factory under consideration is located in a built-up area, or in an area that is likely to be developed in the future, consideration should be given to the position of noise sources on the site.

- Management should take care to place the noisiest part of the factory as far away as possible from the neighbouring buildings, since the noise level decreases by 6 dB as the distance from the source is doubled. For example, if a noise source is placed at the centre of a 400 x 400 m^2 site, the noise level at the boundary of the site will be at least 18 dB lower (at all frequencies) than the noise source were 25 m from the boundary.
- Buildings and high walls between the noise source and the listeners will act as screens. This is particularly true for the high-frequency noise, which is more directional. For such a screen to be effective, however, its height above the level of noise source must at least equal half its distance from the source.

- Moreover, the directional characteristics of high- frequency noise should also be taken into account. Factory engineers should see to it that open windows, doors, and other openings that allow high-frequency noise to escape from the factory, should not face neighbouring buildings.

- Frequently, the designer of factory building faces the problem of deciding what part of a factory is likely to be noisy. The manufacturers of equipment’s should be consulted in case of any doubt regarding this. Potential noise sources that are often placed on the perimeter of factories include loading bays, dust or air extraction plant, compressor houses, boiler houses, and transformers.

Factory Layout:

Small factories (in the case of small-scale industrial units, for example) generally consist of only two main groups of accommodation viz.,

(a) A production unit; and

(b) Office space.

- Large factories, on the other hand, may have separate enclosed areas tor different parts of the production process, and thus may offer more scope for noise control. Wherever possible, the office space should be a completely separate building, and it should not share a common wall with the production area.

- The office should, in any case, be situated away from the noisiest part of the factory. Where it is not possible to avoid a common wall between the office space and the production area, the wall should be heavy, with as few connecting doors as possible and no permanent openings.

- If the production area is divided into separate compartments (in the case of larger factories), it may be possible to grade these compartments in the order of noise produced, and to separate the very noisy areas from the relatively quieter ones. In multi-storey factories, the division of production area will help to reduce the airborne noise if the very noisy machines can be kept together, preferably on the ground floor.

- In factories where there is no such internal subdivision, not much noise reduction can be achieved by the layout of the machines alone. In very large undivided areas with relatively low ceilings, the noise level decreases continuously as the distance from the source increases. The actual reduction in this case depends on the amount of sound absorption in the space between the noise source and the listener.

- Even in small areas, the noise level decreases for a short distance from the source. It follows, therefore, that if the factory contains only a few sources of loud noise which can be grouped together and positioned away from the densely populated areas, some benefit in noise reduction can be obtained.

4. Enclosures to Reduce Noise:

(i) Introductory Remarks:

Once the noise has been generated and radiated, the most effective way of controlling it is to contain it within the enclosure. A reduction in noise level of about 50 dB can be readily achieved by an ordinary building enclosure.

- The region enclosed may be that of the whole factory (to reduce the noise reaching residential areas in the neighbourhood), or only a small area of it (a single machine, for example).

- The smaller the region, the greater the number of people who benefit from noise reduction. On the other hand, the noise level within the enclosure itself will be higher than it would have been if uncontained, unless some extra noise absorption treatment is applied.

- When airborne sound reaches an impervious partition, this (i.e., the partition) must be set in vibration before the sound can be radiated by the other side of it. Consequently, the resultant noise reduction will depend on the resistance of the partition to vibration (i.e., on its weight per unit area) and also on the frequency of the noise concerned (since it requires more energy to move the partition at a faster rate).

The sound reduction factor of a partition increases by about 5 dB for each doubling of the weight, or of the frequency of sound.

Double-Leaf Enclosure:

For a given weight of material, a higher sound reduction can sometimes be obtained by using a double-leaf enclosure. A double- leaf enclosure, in its simplest form, is a cavity wall with no rigid ties across the cavity. A more elaborate form of this is the completely isolated “box within a box” that may be required for a quiet listening test or other similar uses.

- A double wall will give twice the reduction of a single leaf. This, however, would only be so if the cavity between the walls were impracticably wide, and there were no indirect transmission through floor or ceiling.

- For walls with cavities up to 5 cm. wide, the noise reduction obtained at low frequencies is no better (and may even be worse) than for a solid wall of the same total weight. But the sound reduction factor of a double wall increases more rapidly with frequency than that of a solid wall, giving relatively greater reductions at high frequencies.

- The double wall may give a higher average noise reduction than a single wall, though it is more effective only at high frequencies. To increase the effectiveness of the double-leaf enclosure at low frequencies, the cavity must be made 15 to 30 cm wide.

Enclosure Efficiency:

In addition to weight of the wall and frequency of the noise concerned, the efficiency of an enclosure depends also on its completeness and uniformity. A direct air leak (through a hole or through porous material) will transmit the air pressure fluctuations, propagating the noise without reduction.

- Holes amounting to as little as 0.01% of the total area of the enclosing construction will transmit more than half the sound energy, thus lowering the total sound reduction by 3 db.

- For this reason, porous sound-absorbing materials are in fact poor sound barriers. The best partitions, for the purpose of noise reduction, are generally of “wet” construction, since they can be more easily made airtight.

- Prefabricated partitions, and those constructed of sheet materials, require special precautions to ensure that all the joints are properly sealed. Any parts of the enclosure construction that, although airtight, transmit sound more easily than the rest will have much the same effect.

- Where the “weaker” part of the construction makes up half its total surface area, the total sound reduction factor cannot be more than 3 dB above the lower value (corresponding to the “weaker” part of the enclosure). Thus, in a building of heavy construction (such as a multi-storey factory), most of the noise escapes through the windows, which act as the “weak” parts of the enclosure.

- The noise transmission paths round a partition must also be considered. There may, for example, be a direct air path over the top of a partition (as through a porous sound-absorbing ceiling). Besides ceiling, other direct air paths may be from one open window to another (by-passing the partition), or along a duct through the enclosure.

- Similarly, the sound transmission through flanking floors may be critical if the noise reduction required is more than about 45 db. A flanking wall may transmit the sound from one side of the partition to the other by vibration caused by the airborne sound on the noisy side. This is the main reason why the cavity needs to be continuous all round a double-leaf enclosure for noise reductions above 50-55 db.

- Access openings will generally be weak points in an enclosure. Doors should be provided with (and, if possible, give) the same degree of sound reduction as the rest of the enclosure. This is particularly needed if the doors form a large part of the total wall area. If a high degree of noise reduction is required, double doors with a large airspace between them will be necessary.

- Doors must be equipped with gaskets or some other means of providing an airtight seal when closed. Door-closers may be an advantage if the doors are used frequently. Permanent openings may be required for ventilation or for conveyors.

- The noise transmitted through these openings can be reduced by adding a duct to the opening and lining the inside with a sound-absorbing material. To obtain an appreciable amount of noise reduction, the duct should incorporate several right- angle bends; otherwise, it needs to be very long.

Noise Source Covers:

- Another form of enclosure is a cover for a noise source or a machine. An example of this is a casing for noisy gears (where the noise is radiated from the face of the gears). To contain the noise, the cover should be heavy and aright. The cover should, moreover, be coated with a layer of damping compound of equal weight to reduce the effects of resonance.

- The junction of the cover and the machine should be sealed with a gasket Soft enough to stop vibration being transmitted to the cover. The fastenings also should be isolated, or they will "short-circuit" the gasket. In addition, some sound-absorbing material will be necessary inside the cover to prevent the build- up of sound energy.

5. Sound-Absorbing Materials:

Reverberant Sound:

- When a source of noise is enclosed in a room, the direct sound will decrease as the distance from the source increases (as is the case in open air). This reduction in the intensity of sound will continue up to the boundaries of the enclosure.

- At the boundary surfaces, some of the sound will be reflected back, and back again indefinitely. In this way, the sound level continues to build up, if the source is continuous, to a total level appreciably higher than that of the original direct sound. The total intensity of sound at any point, therefore, will consist of a direct component and a reflected (or reverberant) component.

- The build-up of reverberant sound within an enclosure can be controlled by the use of sound absorbing materials. Such materials reduce the amount of reflected sound by absorbing it. Sound-absorbing materials, however, do not reduce the direct component of the sound level, which is predominant near the source.

- The reason is that the sound must reach the absorbing material before it can have any effect on the former. But as the distance between the source and the listener increases, the total sound level decreases to a point where the reflected component alone determines the noise level.

Fig. 1 shows the typical decrease in sound pressure level with increasing distance from the source for an untreated factory with normal hard inside surfaces, and for a similar factory of same size with a lining of sound-absorbing material at the ceiling.

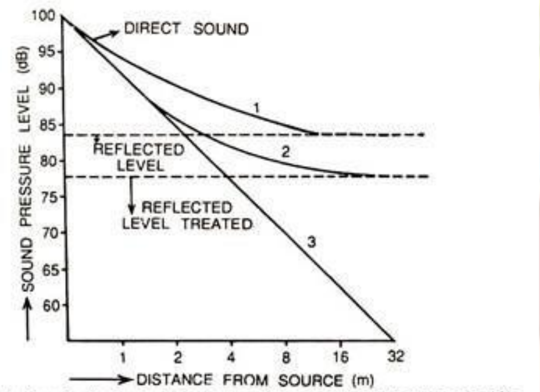


Fig. 1. Reduction of noise level with increasing distance in a treated and untreated factory (1. Untreated factory, 2. Treated factory, 3. Reduction due to distance in open air)

Noise Reduction:

- The reduction in noise level obtained by sound-absorbing treatment increases with the size of the enclosure, and with the area and sound-absorbing efficiency (i.e., sound absorption coefficient) of the absorbing material, as well as with the distance from the source. For any one constant noise source, the reflect sound level will always be lower in a large enclosure than in a small one.

- The reason is that the acoustic energy is spread over a larger volume in the case of a large enclosure. Sound-absorbing material should be used inside an enclosure designed to reduce noise. If this is not done, the noise level inside the enclosure will be higher than before (due to reflected sound), and this will reduce the efficiency of the enclosure besides making the noise worse for its occupants.

- In very large spaces where the smallest horizontal dimension is more than ten times the height, the total (i.e., direct plus reflected) sound level tends to decrease continuously as the distance from the source increases.

- The reason is that in the case of such large spaces, the direct sound that reaches the wails is insignificant compared with that reflected between the floor and ceiling, with some sound being absorbed at each reflection, as it moves out from the source.

- In this case, the reduction in sound level will obviously increase with the absorption coefficient of the reflecting surfaces. If the absorption coefficient of the ceiling or floor is close to unity, the reduction of sound level with distance will be almost equal to that in open air.

Noise Levels:

- In a factory where most of the machines produce roughly equal amounts of noise, the average distance from the source (and, consequently, the average noise level) will be determined by the spacing of the machines.

- The typical noise reduction achieved by lining the roof of a factory with a sound absorbing material is shown in Fig. 2 as a function of average machine spacing. With densely packed machinery in a factory, the reduction in a factory, the reduction in sound level due to the absorption is very small.

- Consequently, sound absorption treatment does not attain its maximum effectiveness until machine spacing’s of more than 10 m are used. Although the reduction in measured sound level with close spacing of machinery is small, the subjective quality of the noise environment is improved by the acoustic treatment.

- The reduction in the reflected noise level from distant machines makes the direct noise stand out, so that its source is more readily apparent. The noise in a factory with close machine spacing and sound absorbent treatment is, in fact, less confusing.

- This will be an advantage if the machine operators have to be able to locate “information” sounds from their own machines. In addition, the increased directional characteristics of the noise environment will also improve speech communication a little.

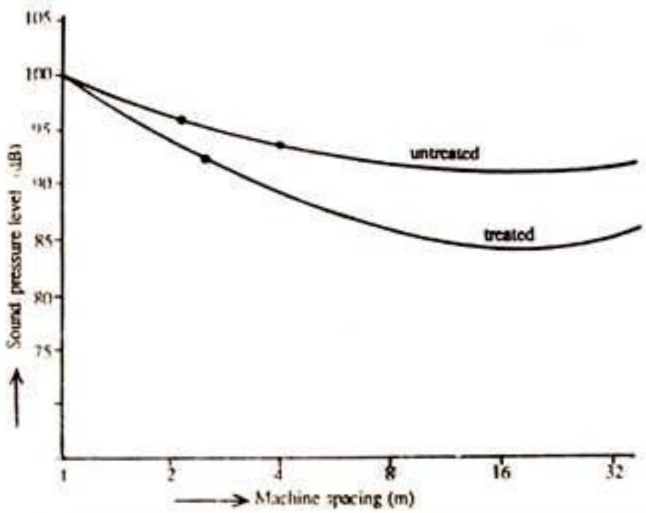


Fig. 2. Reduction in noise level with increasing machine spacing in a treated and untreated factory

We consider now the case of an impulsive noise source. In this case, the decay of the noise level (once the source has stopped) is directly proportional to the amount of sound absorption in the space concerned. If the noise emission from an impulsive source is not too frequent, an appreciable reduction in the average noise level can be obtained by sound-absorbing treatment.

The typical decay of the noise level for an impulsive emission of sound every second is shown in Fig. 3 for the treated and untreated factories. Since the average noise near the source is also lower, there is some relief for the machine operator in the treated factory, though the reduction in the peak noise levels is negligible.

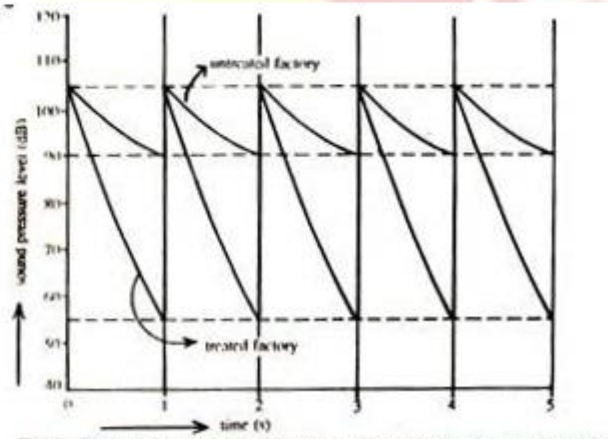


Fig. 3. Decay of impulsive noise in a treated and untreated factory

(iv) Sound-Absorbing Materials:

- It is a well-known fact that all building materials absorb sound to some extent. On the other hand, porous materials, and thin sheet materials mounted in panels over an airspace, are much more efficient as sound absorbers than heavy, hard-surfaced materials. Moreover, sound absorption characteristics of materials vary with the frequency of sound.

- For example, porous materials absorb high-frequency sound more efficiently; but their low-frequency absorption can be improved by increasing the thickness of the material, or by mounting them over an airspace. The peak absorption of a panel occurs when the panel vibrates in resonance, and this condition generally occurs at a low frequency.

- The absorption coefficients of some common sound-absorbing materials are given in Table 2. The absorption of a heavy, hard-surfaced building material (concrete) is also included in this table for comparison. It will be noticed from Table that most of the porous sound- absorbing materials are also effective heat-insulating materials.

- A specific degree of thermal insulation for the roof structure is required for certain factory buildings, and the material used for this purpose may also reduce the noise in the building at no extra cost, provided it is correctly installed.

Sound-Absorption Treatment:

- Obviously, the absorbing material must be exposed to the direct noise. It should not be shielded appreciably by projecting parts of the building or by other materials. Even a coat of paint, for example, will considerably reduce the sound-absorption efficiency of some porous materials.

- The greatest benefit from the sound-absorbing treatment is realised when it is placed near the source, so as to intercept as much as possible of the direct sound before it has travelled far. If there are only a few noisy machines in the factory, placing the absorbing materials on screens or nearby surfaces will be the most effective solution.

- If, on the other hand, the sources of noise are distributed throughout the factory, the ceiling is the most useful area to treat. The sound absorption is likely to be a little higher if the absorbing material is installed vertically in the roof space, as a series of baffles, than if it is applied as a roof lining.

- But the latter type of application will certainly be necessary, if it is to provide thermal insulation as well. In an overall treatment, the walls should not be covered at the expense of ceiling unless the space is high and narrow, though local absorption on the walls will reduce the noise from nearby machines.

- In existing factories, there may be no clear surface that can be lined with sound absorbing material; or its installation may greatly interfere with production. In such cases, the material can be hung from the roof members in sheets, or in hollow fabricated shapes (which give increased absorption for the same quantity of material).

6. Partial Enclosures and Screens:

- When combined with sound-absorbing treatment, the shielding of a noise source by a partial enclosure is a very useful method of noise reduction in factories where complete enclosure cannot be achieved (because of large openings required for continuous access, or other reasons).

- A small partial enclosure around a single machine is one of the few forms of noise control that protects the operator from the noise of his own machine. The machine is then operated through the opening of such a small, partial enclosure.

- Tunnels, open-sided boxes, hoods, and combinations of screens are a few examples of partial enclosures. As a general rule, partial enclosures are specially designed for each situation; but they may also be made up of standard panels when such enclosures are not required for long periods.

- As most of the noise that escapes is radiated from the opening of a partial enclosure, the noise reduction obtained depends on the degree of enclosure. Their shielding effect is mainly limited to the more directional high frequencies. With fairly complete enclosure (such as that provided by a tunnel), a reduction of about 20 dB above 500 Hz may be achieved.

- Partial enclosures may also be used to create a quiet area; for example, a cover may be provided over a conveyor to form a tunnel, so that a listening test may be made on the product without removing it from the conveyor.

- The enclosing structure should have a sound reduction factor equal to the noise reduction expected. Since this is limited to about 20 dB, almost any sheet material having the strength to stand up to industrial use will be adequate. The enclosure must be lined on all surfaces with an effective sound absorbing material to prevent the noise being reflected around the inside and escaping out of the opening.

- Wherever it is possible, the opening should face a wall covered with sound-absorbing material, or should be baffled with a screen of the same construction as the enclosure. If the top of the enclosure is open the noise reduction will be increased by placing the sound-absorbing material on the ceiling overhead.

7. Ear Protection:

In some particularly noisy industries, the methods of noise reduction described in the preceding sections may not be adequate to reduce the noise to safe levels.

- Even in factories where the noise has been reduced to acceptable levels for the majority of workers, some operators of noisy machines may still be exposed to noise levels that are much higher. In such cases, the noise in the ear must be reduced to the safe level by individual ear protection if hearing damage is to be prevented.

- The two most common forms of commercially available ear protectors are earplugs and earmuffs. Earplugs are inexpensive, small, and inconspicuous when worn. Some workers find them uncomfortable at first, but soon become used to them, and can wear them for long periods.

- Earplugs are available in various sizes, and must be correctly fitted to the ear to give a good seal. In some cases, a different size may be required for each ear.

- Dry cotton wool is often used as a makeshift earplug; but, being porous, it does not provide an adequate seal, and the reduction of noise is slight. Waxes cotton wool, on the other hand, will give more reduction; but it still does not compare with a well- designed earplug.

- Earmuffs fit over the ears. They are much heavier and more expensive than earplugs; but they give greater noise reduction. The earmuffs having a liquid-filled, ring-shaped cushion to form a seal between the head and the muff are very comfortable to wear even for long periods. The typical noise reduction obtained in the ear from well-designed earplugs and earmuffs is shown in Fig. 4.

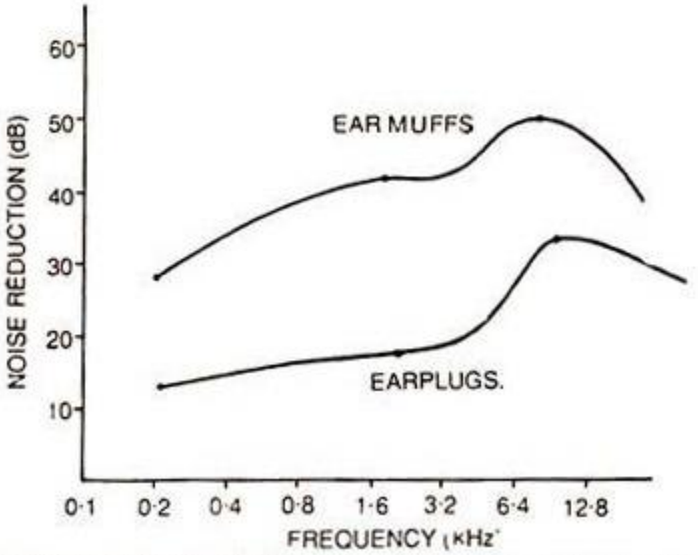


Fig. 4. Noise reduction obtained in the ear from earplugs and earmuffs

- In the case of extremely high levels of noise, it may be necessary to use a combination of earplugs and earmuffs. The total noise reduction, however, is not equal to the sum of their individual noise reductions.

- The reason is that there is an upper limit to the amount of noise reduction that can be obtained locally at the ear. Beyond this, the noise is conducted directly by the bone structure of the head to the inner ear (by-passing the hearing protection).

- We note here that the hearing of speech and warning signals in a noisy factory is not affected by ear protection, since both the speech level and the noise level are reduced in the same ratio. In fact, the speech communication may even be improved because the sound levels are reduced to a range in which the ear is more sensitive.

- Ear protection, however, is not likely to be popular with factory workers unless they understand why it is necessary. An educational programme, therefore, on the nature of industrial hearing damage and the role of ear protectors is desirable when the hearing protection programme is introduced. Subsequently, there should be proper supervision to ensure that the ear protectors are worn regularly.

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