U23PHT13- PHYSICS FOR ENGINEERS AND TECHNOLOGISTS

R-2023

RAJIVGANDHI S

ASSISTANT PROFESSOR

DEPARTMENT OF PHYSICS

DHANALAKSHMI SRINIVASAN ENGINEERING COLLEGE (A)

PERAMBALUR – 621 212

UNIT I ELASTICITY

1.1 INTRODUCTION

Elasticity is the branch of physics deals with the elastic property of the materials, when an external force is applied to a body, there will be some change in its length, shape and volume. When the external force is removed, if the body regains its, original shape and size, then the body is said to be a perfectly elastic body. If the body doesn't regain its original shape (or) size, after the removal of the applied force, then it is said to be a perfectly plastic body. In nature no body is perfectly elastic' (or) perfectly plastic. Therefore elasticity is the property of the body by virtue of which it tend store gain its original shape (or) size after the removal of deforming forces applied externally to it.

1.2 DEFORMING FORCE

Consider body which is not free to move and is acted upon by external force. Due to the action of external forces the body changes its shape or size. Now the body is said to be deformed. Thus the applied external force which causes deformation is called deforming force.

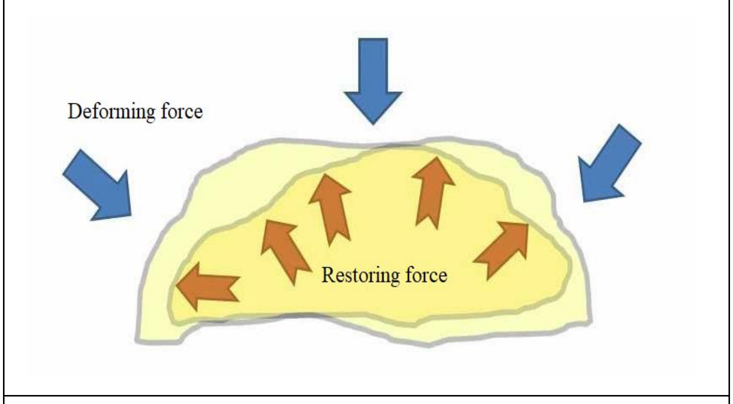


Fig 1.1 Deforming force and restoring force

1.3 RESTORING FORCE

When deforming force is applied to a body then molecules of body tend to displace from their position. As a result of this, are action force is developed with in the body which tries to bring the molecules back to its equilibrium position. This reaction force which is developed in the body is called internal force or restoring force**.**

1.4 ELASTICITY

When a body is acted upon by a suitable force, it undergoes a change inform then this change inform is called Deformation. The change could be either in shape or size or even both. If the body recovers its original state on the removal of deforming force, then it is called as an Elastic material.

Ex:. Quartz, Rubber

"Elasticity is the property of the material of a body by virtue of which it regains its original shape and size after the deforming forces is removed".

1.5 PLASTICITY

If the body does not show any tendency of returning back to its original or initial state and stays in the changed form after the withdrawal of external force, then it is said to be in Plastic state.

Ex: Clay, plastics

"Plasticity is the property of the material of a body by virtue of which it fails to regain its original shape and size after the deforming forces is removed".

1.5 STRESS

Stress is defined as the restoring force per unit area which brings back the body to its original state from the deformed state. The restoring force is equal to the force applied.

Stress = Force applied/ area

= F/A

Unit: Stress = N / m^2.

1.5.1 TYPES STRESS

Based on the direction of force applied, the stress is classified as follows.

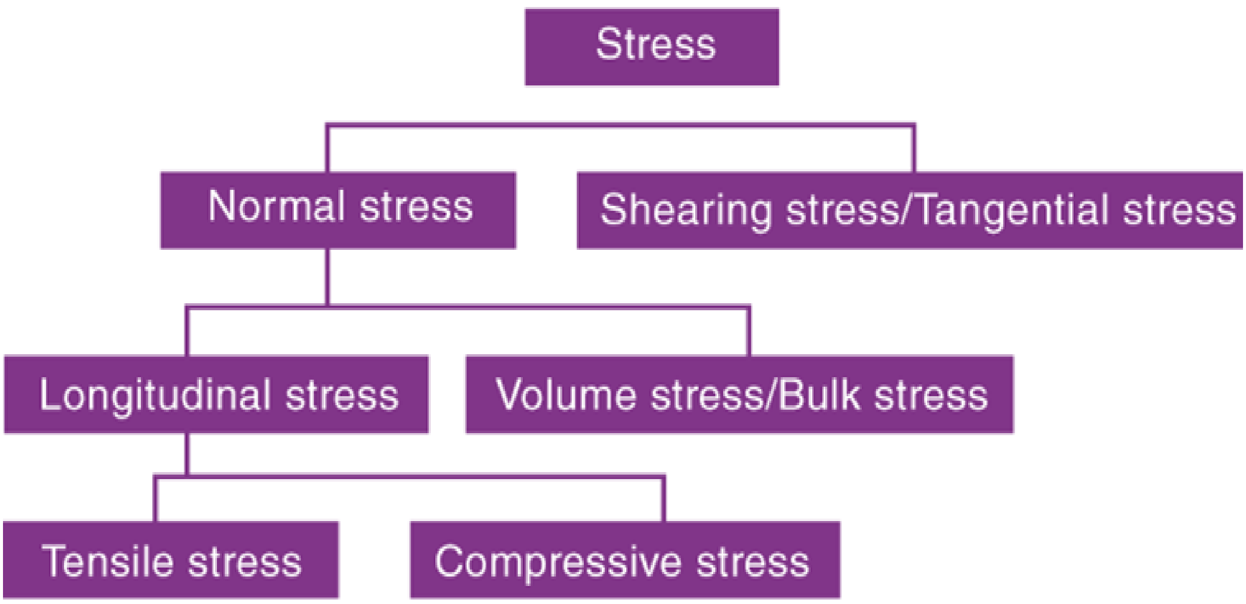


Fig 1.2. Classification of stress

NORMAL STRESS:

Stress is said to be Normal stress when the direction of the deforming force is perpendicular to the cross-sectional area of the body. The length of the wire or the volume of the body changes stress will be at normal.

Two type of normal stresses are

- Longitudinal stress
- Bulk stress

LONGITUDINAL STRESS:

A body gets deformation either compression or expansion due to force applied along its parallel direction is called as longitudinal force.

The Longitudinal Stress either stretch the object or compress the object along its length. Thus, it can be further classified into two types based on the direction of deforming force-

- Tensile stress
- Compressive stress

TENSILE STRESS:

If the deforming force or applied force results in the increase in the object’s length then the resulting stress is termed as tensile stress.

COMPRESSIVE STRESS:

If the deforming force or applied force results in the decrease in the object’s length then the resulting stress is termed as compressive stress.

VOLUME OR BULK STRESS:

When the deforming force or applied force acts from all dimension resulting in the change of volume of the object then such stress in called volumetric stress or Bulk stress.

SHEARING STRESS OR TANGENTIAL STRESS:

When the direction of the deforming force or external force is parallel to the cross-sectional area, the stress experienced by the object is called shearing stress or tangential stress. This results in the change in the shape of the body.

1.6 STRAIN:

Strain is defined as the change in dimension (fractional deformation) produced by the external force on the body.

In other way it can also be defined as the ratio of the change in dimension to the original dimension. The dimension may be length (1D) or area (2D) or volume (3D).

Strain =Change in dimension / Original dimension

Unit: no unit

1.6.1 TYPES OF STRAIN

LONGITUDINAL (OR) TENSILE STRAIN

It is defined as the ratio between the change in length to the original length, without any change in its shape, after the removal of the external forces.

Longitudinal strain = change in length / original length

= l / L

SHEARING STRAIN

It is defined as the angular deformation produced on the body due to the application of external tangential forces on it.

Shearing strain = change in area / original area

$= \phi$

Where ϕ be angle of shear

VOLUMETRIC STRAIN

It is defined as the ratio between the change in volume to the original volume, without any change in its shape.

Bulk or volume strain = change in volume / original volume

= v / V

1.7 HOOKE'S LAW

Robert Hooke proposed a relation between stress and strain and is named as Hooke's law by his name.

Statement: According to this law, "Stress is directly proportional to the strain produced, within the elastic limit".

Stress α Strain

(or) Stress = E X Strain

E = Stress / Strain Nm^{-2}

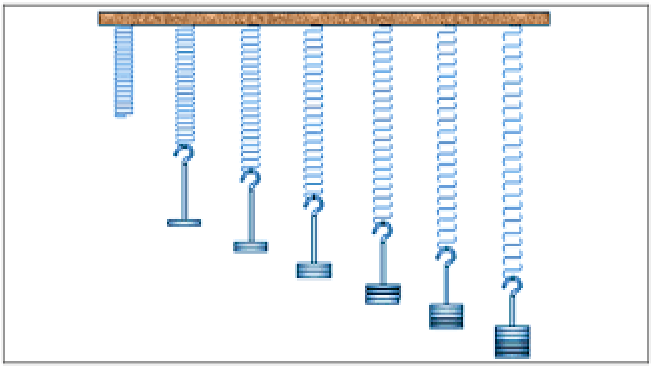


Fig 1.3. Hooke's law

Where E is called as modulus of Elasticity. The value of E depends upon the nature of the material.

MODULUS OF ELASTICITY (E):

The ratio of stress to strain is a constant. This constant is called as modulus of elasticity or coefficient of elasticity.

Unit : N/m^2

1.7.1 TYPES OF MODULI OF ELASTICITY:

Based on the stress, strain, Elastic modulus can be classified into 3 types namely,

(i) Young's modulus (Y or E)

(ii) Rigidity modulus (n) and

(iii) Bulk modulus (K)

YOUNG'S MODULUS (Y or E):

It is defined as the ratio between the longitudinal stress to the longitudinal strain, with in the elastic limit.

$$\text{Young's modulus(Y)} = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} \; N/m^2$$

Explanation:

Let us consider a wire of length 'L' with an area of cross – section 'A'. Let one end of the wire is fixed and the other end is loaded (or) stretched.

Let 'l' be the change in length due to the action of force, then,

Longitudinal stress = $\frac{F}{A}$,

Longitudinal strain = $\frac{l}{L}$

$Y = \frac{FL}{Al}$ N/m^2

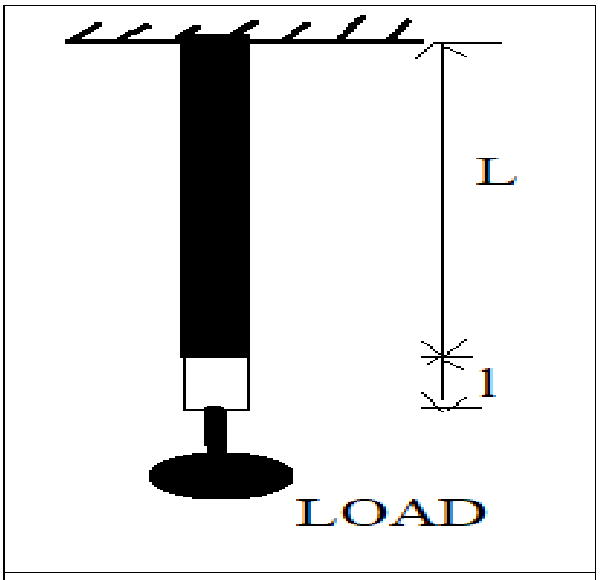


Fig 1.4. Young's Modulus

RIGIDITY MODULUS (n):

It is defined as the ratio between the tangential stress to the shearing strain, within in the elastic limit.

$$\text{Rigidity modulus (n)} = \frac{\text{Tangential stress}}{\text{Shearing strain}} \; N/m^2$$

Explanation:

Let us consider a solid square ABCD, whose lower face AB is fixed. A tangential force 'F' is applied over the upper face CD. The result is that the square sets deformed into ABC'D'. During deformation, shearing angle 'ϕ' is produced.

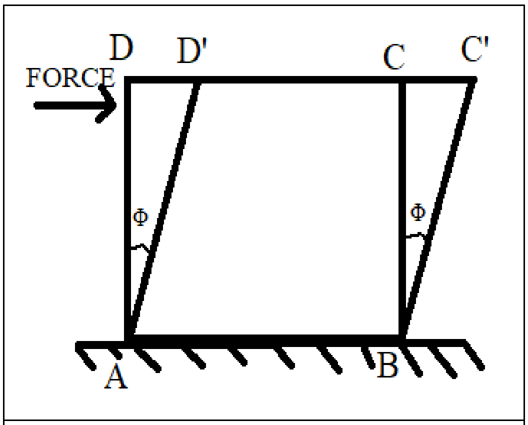


Fig 1.6. Rigidity Modulus

Tangential stress = $\frac{F}{A}$

The shearing strain (ϕ) can be defined as the ratio of the relative displacement between the two layers in the direction of the stress, to the distance measured perpendicular to the layers.

We know, Rigidity modulus (n) = $\frac{Tangential stress}{Shearing strain}$

$$n = \frac{F}{A\phi} \text{ N/m}^2$$

BULK OR VOLUME MODULUS (K):

It is defined as the ratio between the bulk stress to the bulk strain, within in the elastic limit.

Bulk modulus $= \frac{Bulk\ stress}{bulk\ strain}$ N/m^2

Explanation:

Let 'V' be the volume of the cube before force is applied. Due to the application of external force, the volume of the cube changed to 'v'.

Bulk stress = $\frac{F}{A}$

Bulk strain = change in volume / original volume

= v / V

Bulk modulus, K = FV / Av

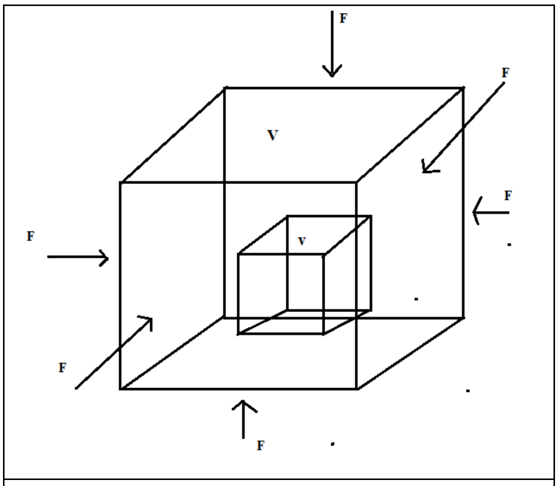


Fig 1.7. Bulk Modulus

1.8 POISSON RATIO

In case of any deformation taking place along the length of a body like a wire, due to a deforming force, there is always some change in the thickness of the body. This change which occurs in a direction perpendicular to the direction along which the deforming force is acting is called lateral strain.

Within elastic limits of a body, the ratio of lateral strain to the longitudinal strain is a constant and is called Poisson's ratio. It is represented by the symbol σ.

Let 'α' be the longitudinal strain and 'β' be the lateral strain.

Poisson ratio, $\sigma = \frac{\beta}{\alpha}$

The σ value changes from 0 to 0.5. There are no units for Poisson's ratio. It is a dimensionless quantity.

Explanation:

If a deforming force acting on a wire of length 'L' produces a change in length 'l' accompanied by a change in diameter of 'd' in it which has an original diameter of 'D'.

Then,

Lateral strain $\beta = \frac{d}{D}$ and

Longitudinal strain $\alpha = \frac{l}{L}$

Subs α, β values, we get

$\therefore \sigma = \frac{Dl}{dL}$

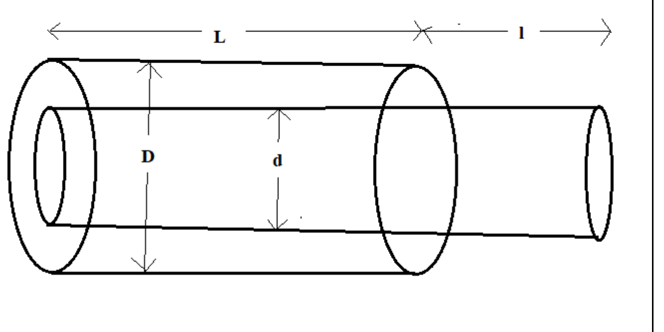


Fig 1.9 Poisson ratio

1.9 THREE MODULII OF ELASTICITY

When a body undergoes an elastic deformation, it is studied under any of the three elastic moduli depending upon the type of deformation. However, these moduli are related to each other. Now, their relation can be understood by knowing how one type of deformation could be equated to combination of other types of deformation.

We know the relation between K, α and β

$$K = \frac{1}{3(\alpha - 2\beta)} \text{ --------------------------------- (1)}$$

We know the relation between n, α and β

$$n = \frac{1}{2(\alpha + \beta)} \text{ ----------------------------------- (2)}$$

Rearranging the above equations we get,

$$\alpha - 2\beta = \frac{1}{3K} \text{ ----------------------------------(3)}$$

$\alpha + \beta = \frac{1}{2n}$ ------------------------------------(4)

Now subtracting eqn 1 from eqn 2

$\alpha + \beta - \alpha + 2\beta = \frac{1}{2n} - \frac{1}{3K}$

$3\beta = \frac{1}{2n} - \frac{1}{3K}$

$3\beta = \frac{3K - 2n}{6nK}$

$\beta = \frac{3K - 2n}{18nK}$ -----------------------------------(5)

Multiplying the eqn 4 by 2

$2\alpha + 2\beta = \frac{1}{n}$ ------------------------------------(6)

Adding eqn 3 and 6 we get

$2\alpha + 2\beta + \alpha - 2\beta = \frac{1}{n} + \frac{1}{3K}$

$3\alpha = \frac{1}{n} + \frac{1}{3K} = \frac{3K + n}{3Kn}$

$\alpha = \frac{3K + n}{9Kn}$ --(7)

We know relation between Y and α is

$\alpha = \frac{1}{Y}$ --(8)

Equating eqn 7 & 8,

$\frac{1}{Y} = \frac{3K + n}{9Kn}$

$\frac{9}{Y} = \frac{3K + n}{Kn}$

Or, $\frac{9}{Y} = \frac{3}{n} + \frac{1}{K}$ -------------------------------(9)

Equation (9) represents the relation between Y, n and K.

1.10. STRESS AND STRAIN DIAGRAM

Consider a long wire of length "l" is fixed at one end and load is added at other end. Due to load added, some extension is produced. Addition of loads is increased at free end until the wire is cut in to two pieces. Load (stress) and extension (strain) are noted and tabulated.

We plot a graph between stress along Y axis and strain along X axis, we get a curve as shown in figure and is called as stress-strain diagram.

From the above figure, we found that

- ❖ The body obeys Hooke's Law up to the OA called as elastic range.
- ❖ As soon as the maximum elastic limit (i.e.) A is crossed, the strain increases than the stress.
- ❖ At this stage the body neither elasticity and nor plasticity which is represented by the curve AB.

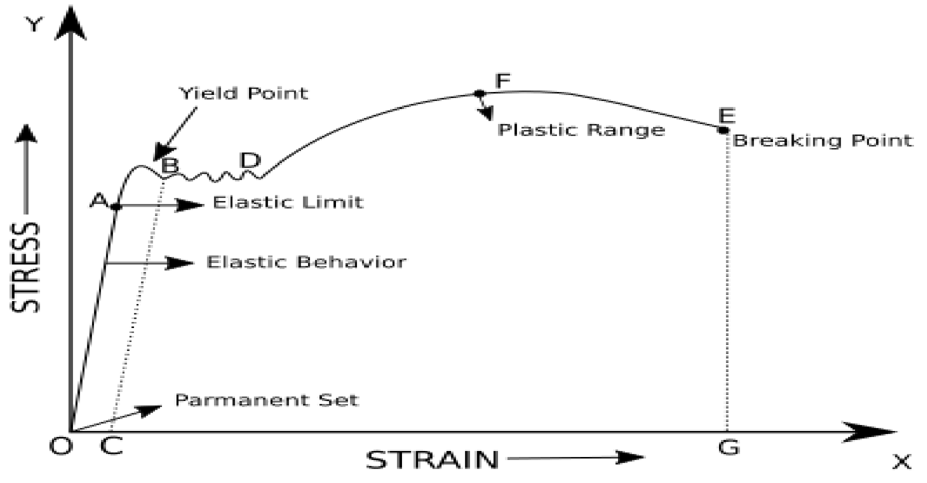


Fig 1.9. Stress - strain diagram

- ❖ At this point, if force is removed from the body, the body does not come back to their original shape. Because some strain is persisted in that body. The point C is called permanent set.
- ❖ Now, even if a small external force is applied, the body will take a new path BD.
- ❖ Further increasing of stress, the body behaves as plastic called as plastic range.
- ❖ After this, the body will not come to its original state and it breaks down at a point called as a breaking stress, indicated by EF.

- The point F is called as ultimate tensile stress i.e the maximum load (or force) to which the body is subjected divided by its original cross sectional area is called the ultimate strength
- Beyond the E the body breaks into two pieces

1.11 FACTORS AFFECTING ELASTICITY:

It is founded that some bodies lose their elastic property even within the elastic limit due to elastic fatigue (ie) if a body us continuously subjected to stress (or) strain, it gets fatigued (weak).

Apart from elastic fatigue some materials will have change in their elastic property because of the following factors.

(i) Effect of stress
(ii) Effect of annealing
(iii) Change in Temperature
(iv) Hammering and rolling process
(v) Presence of impurities
(vi) Due to the nature of crystals.

Effect of stress:

We know that, when a material is continuously subjected to stresses, it loses its elastic property. Therefore the working stress on the material should be kept lower than the ultimate tensile strengthening and the safety factor.

Effect of Annealing:

Annealing is a process by which the material is heated to a very high temperature and then it is slowly cooled. This process is adopted to increase the softness and ductility in the materials.

Effect of Temperature:

The elastic property of the materials changes with the temperature. Generally, the elasticity increases with the decrease in temperature.

Eg. (a) The elastic property of Lead increases when the temperature is decreased.

(b) The carbon filament becomes plastic at high temperature.

Hammering and rolling process:

During rolling and hammering process, size of the crystals are decreased. Due to small grain size, elastic property of the material is increases.

Effect of impurities:

The addition of impurities produces variation in the elastic property of the materials. The increase and decrease of elasticity depends on the type of impurity added to it.

Eg. (a) When potassium is added to gold, the elastic property of gold increases.

(b) When carbon is added to molten iron, the elastic property of iron decreases.

Effect of nature of crystals:

The elasticity also depends on the types of the crystals, whether it is a single crystal (or) poly crystals. For a single crystals the elasticity is more and for a Poly – Crystals the elasticity is less.

1.12 BEAM:

A beam is defined as a rod (or) bar of uniform cross – section whose length is very much greater than its other dimensions such as breath and thickness. It is commonly used in the construction of bridges to support roofs of the buildings etc.

In order to studying the bending of beams, the following assumptions hey to be made.

(i) Length of the beam should be large compared to other dimensions.

(ii) The load applied to the beam is very large compared to the weight of the beams.

(iii) Shearing stresses are negligible.

(iv) Curvature of the beam is very small.

1.12.1 BENDING OF BEAMS

A beam consists of more number of small layers namely top later, bottom layer and middle layer (neutral axis). A single layer is called as filament. Assume that, a set of equal loads are added at both ends of the beam. Due to loads added, the beam gets bending. Now, the above neutral axes are expanded and below neutral axis are compressed. But there is no change in neutral axis.

Each layer constitutes couple. Summation of couple produced along each layer is called total couple moment or internal couple moment.

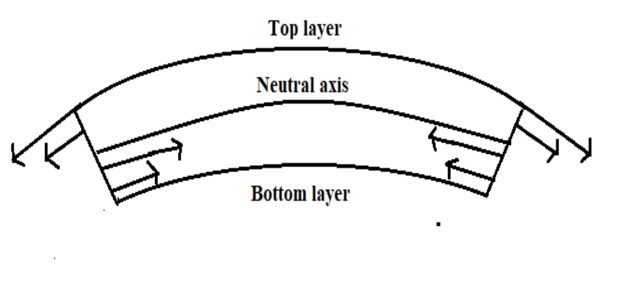


Fig 1.10. Bending of beams

COUPLE:

The product of magnitude of force (F) and distance between two forces (d) is called couple.

Mathematically, Couple = F X d

1.13 INTERNAL BENDING MOMENT – DERIVATION

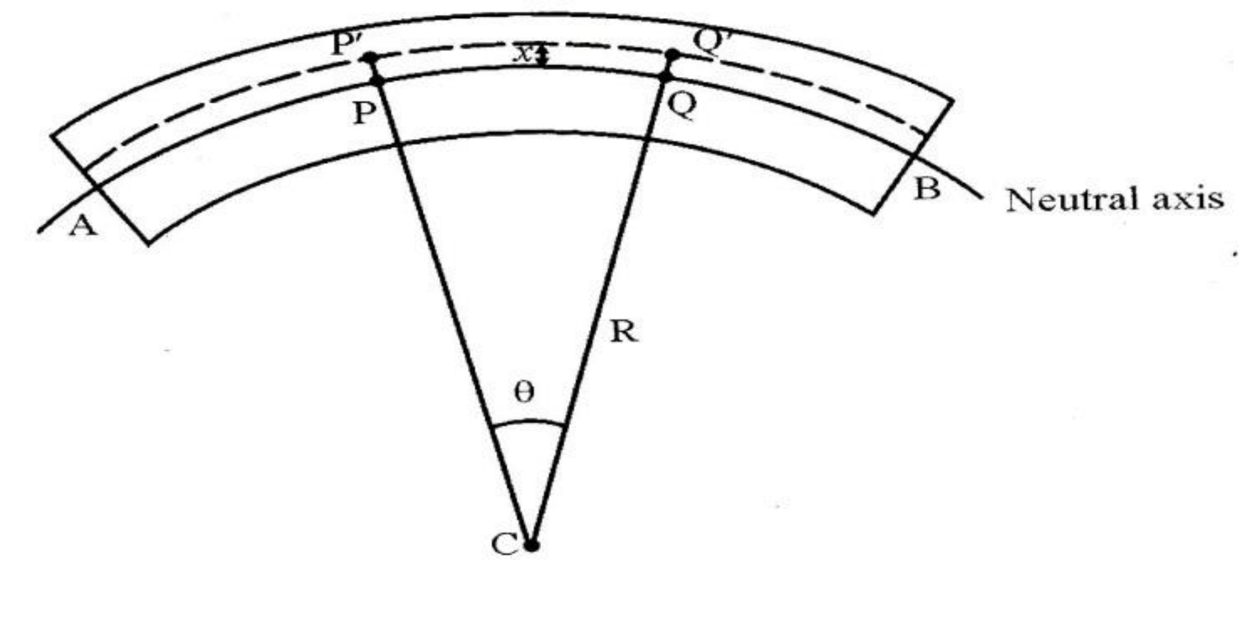


Fig 1.11 Internal bending moment

- Let us consider a beam, due to applied forces, the beam bends into a circular arc.
- Let AB be the neutral axis, P&Q are the points considered on the neutral axis and P' &Q' are the points considered above neutral axis with the distance of 'x'
- Due to load applied the above AB are elongated (expanded) and the below AB are compressed (shrinked).
- The filament AB remains unchanged.
- Let C, R & θ are be the center of curvature of arc, radius of curvature and the angle subtended by it at its center of curvature respectively.

Original length, PQ = R θ --(1)

Extended length, $P^{'}Q^{'}$ = (R+x) θ ------------------------------------(2)

From (1) & (2), we can calculate

Increase in its length, = $P^{'}Q'$ – PQ

(or) = (R+x) θ - R θ

∴ Increase in its length = x θ--------------------------------------(3)

We know, linear strain = $\frac{increase\ in\ length}{original\ length}$

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

Linear strain, = $\frac{x}{R}$ ------------------------------------(4)

We know,

Young's modulus, Y = $\frac{Linear\ stress}{Linear\ strain}$

(or) Stress = Y x linear strain ------------------(5)

Subs. eqn (4) in (5), Stress = $\frac{Yx}{R}$ --------------------------------(6)

If δA is the area of cross – section of the filament P'Q'.

Then, the tensile force on the area δA = Stress x Area.

(ie) Tensile force, = $\frac{Yx}{R}\delta A$ ----------------------------(7)

W.K, moment of force = Force x Perpendicular distance.

$$PQ = \frac{Yx}{R}\delta A \times x$$

$$PQ = \frac{Y}{R}\delta A x^2 \text{ -------------------------(8)}$$

The moment of the force acting on both the upper and lower halves of the neutral axis can be got by summing all the moments of tensile and compressive forces.

The moment of all the forces about the neutral axis = $\frac{Y}{R}\sum \delta A x^2$

Here, $I_g = \sum x^2 \delta A = AK^2$ is called the geometrical moment of inertia.

Where, A – total area of the beam

K – radius of gyration.

$\therefore$ Total moment of all the forces (or) Internal bending moment = $\frac{YI_g}{R}$ ---------(9)

Special cases:

i) Rectangular cross – section:

If 'b' is the breadth and 'd' is the thickness of the beam, then

Area, A = bd and

$$K^2 = \frac{d^2}{12}$$

$$I_g = AK^2 = \frac{bd^3}{12}$$

Substituting the value of I_g in eqn (9),

Bending moment of a rectangular cross – section = $\frac{Ybd^3}{12R}$ ------------------(10)

ii) Circular Cross – section:

For a circular cross section if 'r' is the radius, then Area, A = πr^2

And $K^2 = \frac{r^2}{4}$

$$I_g = AK^2 = \frac{\pi r^2 \times r^2}{4}, \; I_g = \frac{\pi r^4}{4}$$

Substituting the value of I_g in eqn (9)

The bending moment of a circular cross – section = $\frac{Y\pi r^4}{4R}$ ------------------- (11)

1.14 CANTILEVER

Definition:

A beam fixed horizontally at one end and other end is free or loaded. This arrangement is called as cantilever.

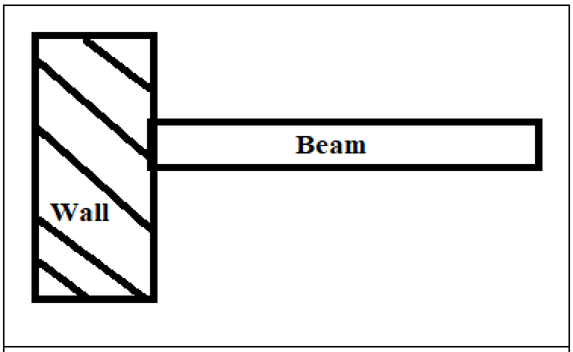


Fig 1.12 Cantilever

Theory:

At equilibrium condition, internal bending moment is equal to external bending moment.

i.e.

Internal bending moment = External bending moment.

Depression of a cantilever beam (y) - Derivation:

- Let l be the length of the cantilever beam OA.
- It is fixed at one end at O and another end A is free.
- Now load W is applied at free end A.
- Due to load applied, it produces depression(T, S and A')
- Let 'dy' be the small depression produced by load.
- Let C, R &dθ are be the center of curvature of arc, radius of curvature and the angle subtended by it at its center of curvature respectively.

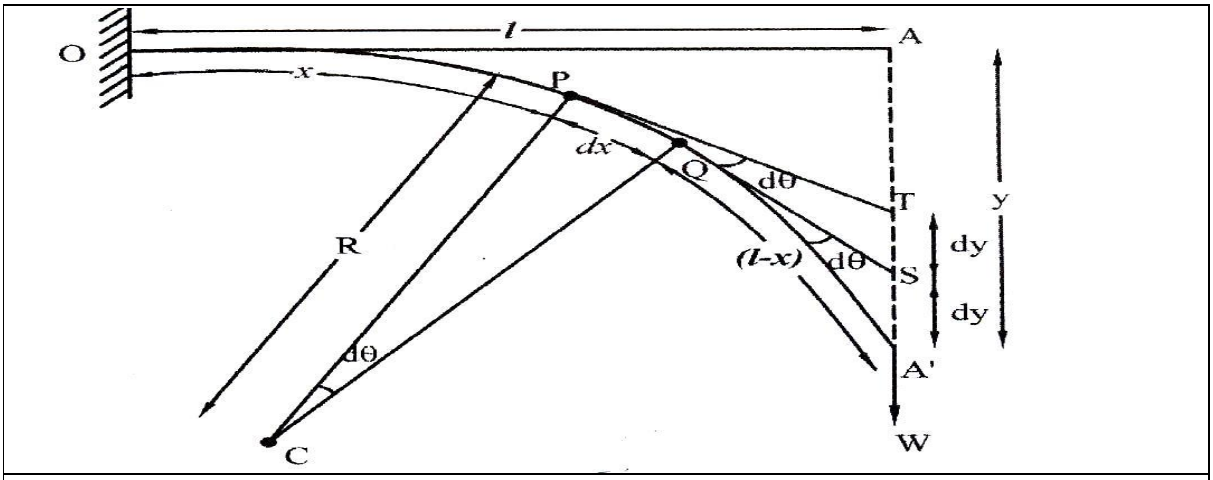


Fig 1.13 depression of a cantilever

- P & Q are the points noted along beam with length 'dx' and 'x' be the length of OP
- Let l-x be the length of A'Q.

Due to the load applied, an external couple is created between the load W at A' and the force of reaction at Q '. Here, the arm of the couple is (l - x).

The external bending moment = W (l – x)--------------------------------(1)

The internal bending moment $= \frac{YI_g}{R}$ ------------------------------------- (2)

Based on theory, under equilibrium condition,

External bending moment = Internal bending moment

∴ eqn (1) = eqn (2),

$$W(l - x) = \frac{YI_g}{R}$$

$$R = \frac{YI_g}{W(l-x)} \text{ ---------------------------------------(3)}$$

Two tangents are drawn at points P and Q, which meet the vertical line AA' at T and S respectively.

∴ We can write the arc length PQ = R dθ =dx

$$d\theta = \frac{dx}{R} \text{ ---(4)}$$

Subs. eqn (3) in (4),

$$d\theta = \left[\frac{dx}{\frac{YI_g}{W(l-x)}}\right] = \frac{W(l-x)dx}{YI_g} \text{ ---------------------(5)}$$

The small length, $dy = (l - x)d\theta$ --------------------(6)

Subs. eqns (5) in (6),

$$dy = \frac{W(l-x)(l-x)dx}{YI_g}$$

$$= \frac{W(l-x)^2 dx}{YI_g} \text{ --------------------------(7)}$$

Eqn 7 represents the small depression produced by load (W).

∴ Total depression of the cantilever can be obtained by integrating (7) within the limits 0 to l

$$\therefore \quad \int dy = \int_0^l \frac{W(l-x)^2 dx}{YI_g}$$

$$\int dy = \frac{W}{YI_g}\int_0^l (l-x)^2\,dx$$

$$\int dy = \frac{W}{YI_g}\int_0^l \left[l^2 + x^2 - 2lx\right]dx$$ $((a-b)^2 = a^2+b^2-2ab)$

Integrating we get

$$y = \frac{W}{YI_g}\left[l^2x + \frac{x^3}{3} - \frac{2lx^2}{2}\right]_0^l$$

Applying and simplify the above equation

$$y = \frac{Wl^3}{3YI_g} \text{ --(8)}$$

Equation 8 represents depression of a cantilever.

Special cases:

Rectangular cross-section:

If 'b' is the breadth and 'd' is the thickness of the beam, then we know

$$I_g = \frac{bd^3}{12}$$

$$\therefore y = \frac{4Wl^3}{bd^3Y} \text{ --------------------------------(9)}$$

Circular cross-section:

If 'r' is the radius of circular cross-section, then

$$I_g = \frac{\pi r^4}{4}$$

$$\therefore y = \frac{4Wl^3}{3\pi r^4Y} \text{ ---------------------------------(10)}$$

Experimental determination of young's modulus by cantilever Depression:

Description:

It consists of a beam fixed at one end and the other end load is suspended. A pin is fixed at the load end with the help of wax. A microscope is used to measure the variation of height of the pin.

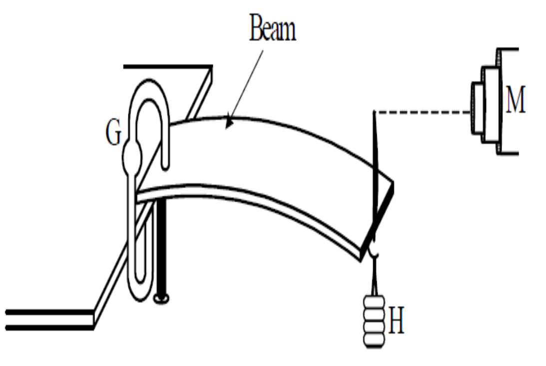


Fig 1.14 Cantilever experiment

Procedure:

- Before loading, the microscope is adjusted and the tip of the pin is made to coincide with the horizontal cross wire.

S.No.	Load M	Microscope Reading			Depression y (m)
		Loading $X10^{-2}$ m	Unloading $X10^{-2}$ m	Mean $X10^{-2}$ m	
1	W				
2	W+50				
3	W+100				
4	W+150				
				Mean, y =	

- Then the weights m, 2m, 3m etc are increased in steps.
- For various positions of the pins, the readings are noted.
- The experiment is repeated by decreasing the loads.
- The mean depression 'y' for a load M is found using table.
- The breadth of the beam can be calculated by using vernier and thickness of a beam can be measured using screw gauge.
- Length of the beam taken is measured initially using meter scale.
- By substituting the known values in the following equation, we can find the Y value

$$\therefore Y = \frac{4Mgl^3}{3bd^3y} \text{ N/m}^2 \qquad (W=Mg)$$

1.15 UNIFORM BENDING

Definition:

The beam is loaded uniformly on its both ends; the bend forms an arc of a circle. The elevation in the beam is produced .This bending is called uniform bending.

Theory:

At equilibrium condition, internal bending moment is equal to external bending moment. i.e.

Internal bending moment = External bending moment.

Elevation of a beam-derivation:

- Let us consider a beam of negligible mass, supported symmetrically on the two knife edges A and B.
- Let the length between A and B be 'l '
- Let equal weight 'W' be added to the C and D end.
- Let the distance CA = BD = a

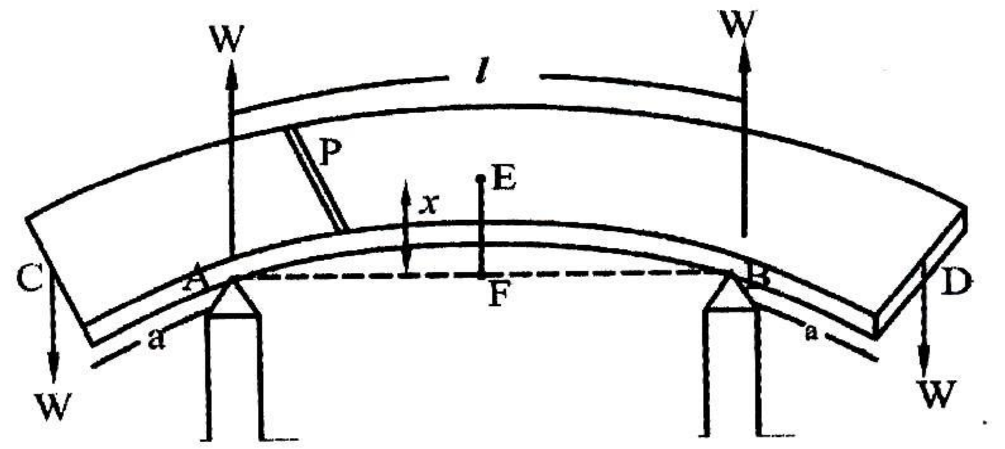


Fig 1.15 Uniform bending method

- Due to load applied, the beam bends from F to E into an arc of a circle and produces as elevation 'x' from position F to E.
- Let 'W' be the reaction produced of the points A and B which acts vertically upwards.

External bending moment between C & A is =W X a---------------------------------(1)

Internal bending moment = $\frac{YI_g}{R}$ ---(2)

According to theory,

Eqn 1 = eqn 2

$$Wa = \frac{YI_g}{R} \text{ --(3)}$$

Here W, Y, I_g, a and R are constants. So it is called as uniform bending method. When loads are applied it makes a circle as shown in fig.

From figure

$\Delta AFO,$

$OA^2 = AF^2 + FO^2$

$$R^2 = \left(\frac{l}{2}\right)^2 + (R-x)^2$$

$$R^2 = \left(\frac{l^2}{4}\right) + (R^2 + x^2 - 2Rx)$$

The elevation produced is very small. So, higher term of x is negligible.

$$R^2 - R^2 + 2Rx = \frac{l^2}{4}$$

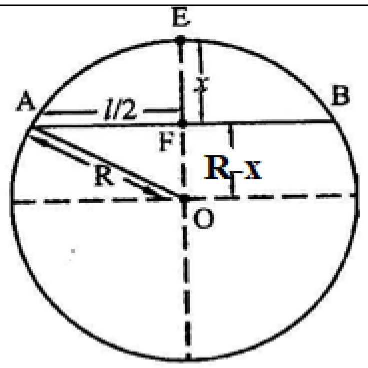


Fig 1.16 Uniform bending method

Rearranging

$$2Rx = \frac{l^2}{4}$$

Or $R = \frac{l^2}{2X4x} = \frac{l^2}{8x}$ --(4)

Subs eqn 4 in 3, we get

$$Wa = \frac{YI_g}{(l^2/8x)} = \frac{8xYI_g}{(l^2)}$$

Rearranging

Elevation, $x = \frac{Wal^2}{8YI_g}$ --(5)

Equation 5 represents elevation of a beam.

Special case:

For rectangular beam, $I_g = \frac{bd^3}{12}$

Equation 5 becomes

$$x = \frac{Wal^2}{\frac{8Ybd^3}{12}} = \frac{3Wal^2}{2bd^3Y}$$

Elevation of rectangular beam, $x = \frac{3Wal^2}{2bd^3Y}$ ---------------------------------------(6)

Experimental determination of young's modulus by uniform bending:

- ✓ It consists of a beam, symmetrically supported on the two knife edge A and B.
- ✓ The two weight hangers are suspended on both side of the beam at the position C and D.
- ✓ The distance bet AC & BD are adjusted to be equal. A pin is fixed vertically at the centre of the beam.
- ✓ Travelling microscope is placed in front of the beam for finding readings.

Procedure:

- Taking the weight hanger as the dead load (w), the microscope is adjusted and the tip of the pin is made to coincide with the vertical cross wire. The reading is noted.
- Now, increasing the load by W, W+50, W+100,….etc and corresponding reading are noted.

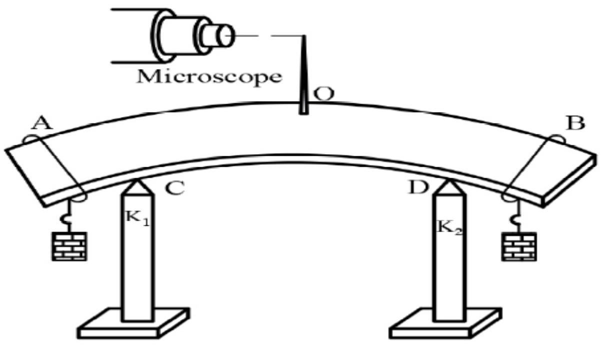


Fig 1.17 Uniform bending method-experiment

S.No.	Load M	Microscope Reading			Elevation x (m)
		Loading $X10^{-2}$ m	Unloading $X10^{-2}$ m	Mean $X10^{-2}$ m	
1	W				
2	W+50				
3	W+100				
4	W+150				
				Mean, x =	

- The same procedure is repeated during unloading.
- Mean x value calculated using table.
- By substituting all know values in below given equation, we can find the value of Young's modulus of materials using the formula,

$$Y = \frac{3Mgal^2}{2bd^3x}$$

1.16 NON - UNIFORM BENDING

Definition

If the beam is loaded at its mid-point, the depression is produced in the beam. It does not form an arc of a circle. This type of bending is known as **non-uniform bending.**

Theory:

At equilibrium condition, internal bending moment is equal to external bending moment. i.e.

Internal bending moment = External bending moment.

Depression of a beam – derivation

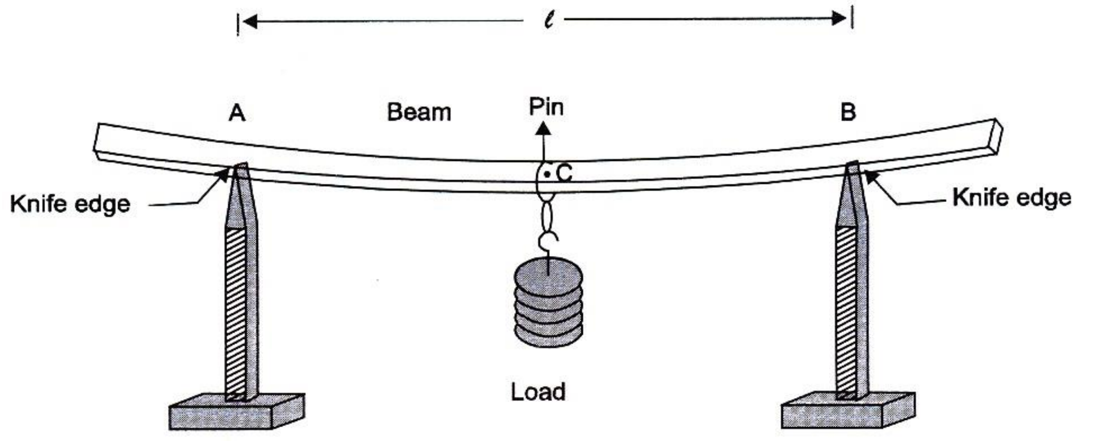


Fig 1.18 Non- Uniform bending method

- Consider a beam.
- It is supported on two knife edges *A & B*.
- l – Distance between two knife edges.
- W – Weight suspended at the centre C.
- When the load is applied, the beam bends.
- The maximum displacement is at the point ‘D’.
- This beam is considered as two cantilevers.
- Their free ends carry a load *W/2* each of length *l/2*.

Depression of a cantilever, $y = \dfrac{W l^3}{3 Y I_g}$

Sub. $l = \dfrac{l}{2}$ & $W = \dfrac{W}{2}$

Depression of D below A, $y = \dfrac{\left(\frac{W}{2}\right)\left(\frac{l}{2}\right)^3}{3 Y I_g}$

$$y = \frac{\left(\frac{W}{2}\right)\left(\frac{l^3}{8}\right)}{3 Y I_g}$$

$$y = \frac{W l^3}{48 Y I_g}$$

Sub. $I_g = \dfrac{bd^3}{12}$ & $W = Mg$

$$y = \frac{Mg\, l^3}{48 Y \frac{bd^3}{12}}$$

$$y = \frac{12\, Mg\, l^3}{48 Y\, bd^3}$$

Depression, $y = \dfrac{Mg\, l^3}{4 Y\, bd^3}$

The above equation represents depression of a beam, when loads are added at middle of the beam.

NON-UNIFORM BENDING – EXPERIMENTAL ARRANGEMENT

- ✓ Consider a rectangular beam.
- ✓ It is supported on two knife edges *A & B.*
- ✓ Two weight hangers are suspended at the center.
- ✓ A pin is fixed at the center of the beam.
- ✓ A travelling microscope is placed in front of the whole set up.

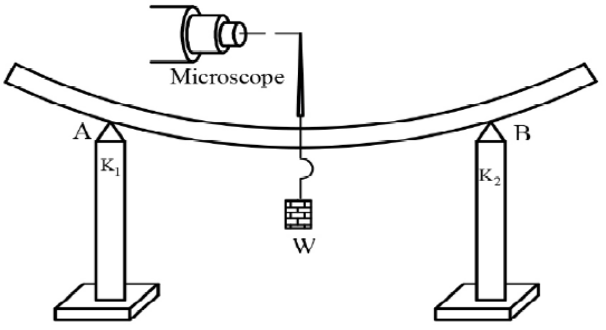


Fig 1.19 Non- Uniform bending method- experiment

- ✓ The tip of the pin is adjusted with the horizontal cross wire by the microscope.
- ✓ The weights are added at the center *C* and the readings are noted during loading.
- ✓ The same procedure is repeated for unloading and the readings are tabulated.

Load	**Microscope readings**			**Depression ‘*y*’**
	Loading	**Unloading**	**Mean**	
W				
W+50				
W+100				
W+150				
			Mean ‘*y*’	

- ✓ The mean depression ‘*y*’ is found.
- ✓ The values of *a, l, b* and *d* are measured.
- ✓ The Young’s modulus can be determined by the following formula

$$Y = \frac{Mgl^3}{4bd^3y} \quad N/m^2$$

1.17 I – SHAPE GIRDERS

Definition:

The girders with upper and lower section broadened and the middle section tapered, so that it can withstand heavy loads over its called as I shape girders. Since the girders look like letter I as shown in figure, they are named as I shape girder.

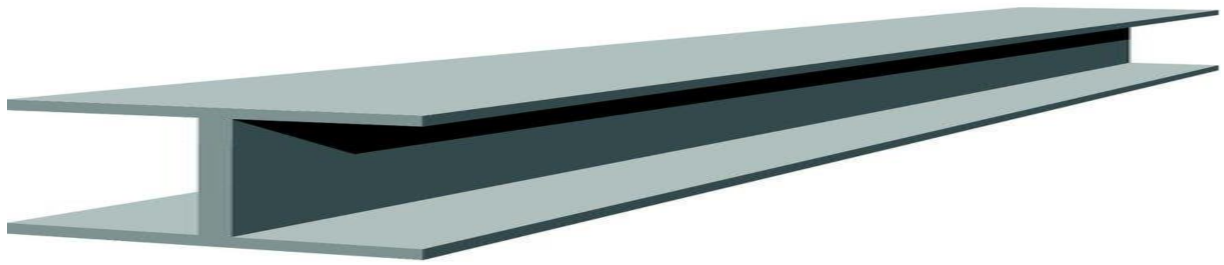


Fig 1.20 I shaped girder

Explanation:

In general any girder supported at its two ends as on the opposite walls of a room, bends under its own weight and a small depression is produced at the middle portion. This may also be caused when loads are applied to the beams. Due to depression produced, the upper parts of the girder above the neutral axis contracts, while, the lower parts below the neutral axis expands. i.e the stresses have a maximum value at the top and bottom. The stresses progressively decrease as it approaches towards the neutral axis. Therefore the upper and lower surfaces of the girder must be stronger than the intervening part. Thus the girders are made of I shape girders. We know the depression produced in the case of a rectangular section.

$$y = \frac{W l^3}{4 b d^3 Y} \quad N/m^2$$

Therefore for stability, the upper part and the lower part is made broader than the centre part and hence forming an I shape called as I shape girders. The depression can also be reduced by properly choosing the materials of high young modulus.

APPLICATIONS

- They are used in the construction of bridges over the rivers.
- They are very much useful in the production of iron rails which are employed in railway tracks.
- They are used as supporting beams for the ceilings in the construction of buildings.
- They are used in the construction of iron beams to support the bridges for the heavy vehicles and also in the construction of dams.

ADVANTAGES

- More stability
- More stronger
- High durability

1.18 TWISTING COUPLE IN A CYLINDRICAL WIRE

Consider a cylindrical wire of length 'l', radius 'r' and coefficient of rigidity modulus 'n'. Its upper end is fixed and force is applied at lower end as shown in figure.

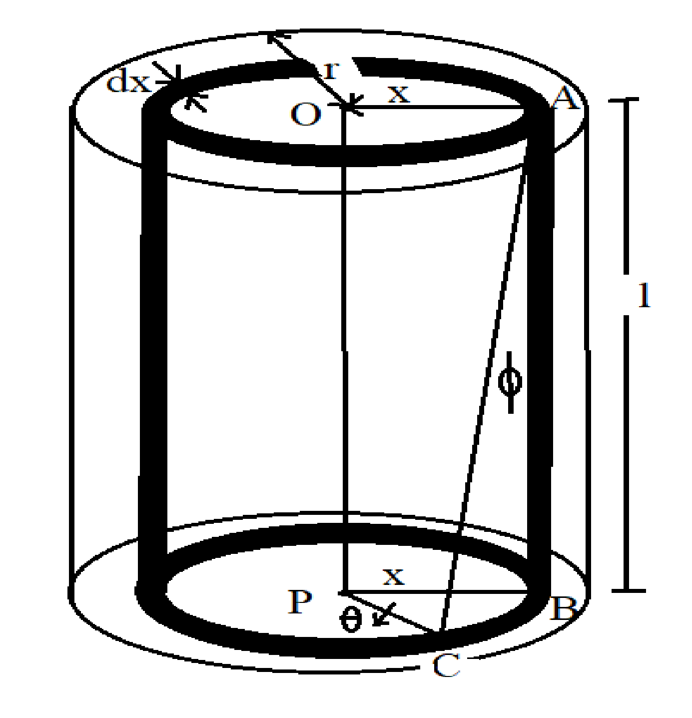


Fig 1.21 Twisting couple / unit twist

- Consider a cylinder is consists a large number of co-axial hollow cylinders. Now, consider a one hollow cylinder of radius x and radial thickness dx as shown in figure.
- As shown in, Let AB be the line parallel to the axis OP.
- When wire is twisted, B shifts to C, then line AB become AC.
- The angles $\phi \,\&\, \theta$ are produced along vertical and horizontal plane respectively.
- Let ϕ is the twisting angle. The θ be the displacement is greatest at the rim and decreases as the center is approached where it becomes zero.

The angle of shear, $\angle BAC = \phi$

From fig

BC= $l\phi$ ----------------(1) (Vertical direction)

BC= $x\theta$ ----------------(2) (Horizontal direction)

Equating eqns 1 & 2

$$l\phi = x\theta$$

$$\phi = \frac{x\theta}{l} \quad \text{------------------------(3)}$$

We know rigidity modulus, n = $\frac{shearing\ stress}{shearing\ strain}$

$$n = \frac{F}{A\phi}$$

Rearranging, $F = nA\phi$ -----------------(4)

Subs. Eqn 3 in 4, we get

$$F = \frac{nAx\theta}{l} \quad \text{--------------------(5)}$$

Area of the hollow cylinder of thickness dx, A = $\pi(x+dx)^2 - \pi x^2$

$$= \pi(x^2 + dx^2 + 2xdx) - \pi x^2$$

$$= \pi x^2 + \pi dx^2 + 2\pi xdx - \pi x^2$$

Higher terms of "dx" are negligible

$$A = 2\pi xdx \text{ -----------------(6)}$$

Subs. Eqn 6 in 5

$$F = \frac{nx\theta}{l}(2\pi xdx)$$

$$F = \frac{2\pi nx^2\theta dx}{l}$$

Moment of force (F_m) is defined as the product of force applied and its distance (F_m=F X x)

Moment of force, $$F_m = \frac{2\pi nx^2\theta dx}{l}x$$

$$F_m = \frac{2\pi nx^3\theta dx}{l} \text{ -----------(7)}$$

Twisting couple (τ) can be calculated by integrating eqn 7 within the limit 0 to r,

$$\tau = \int_0^r \frac{2\pi nx^3\theta dx}{l}$$

$$\tau = \left[\frac{2\pi nx^4\theta}{4l}\right]_0^r$$

$$\tau = \left[\frac{\pi nr^4\theta}{2l}\right] \text{-------------(8)}$$

Twisting couple per unit twist (C) is written by,

$$C = \frac{\tau}{\theta} \text{ --------------------(9)}$$

Subs. Eqn. 8 in 9, we get,

$$C = \left[\frac{\pi nr^4}{2l}\right] \text{----------(10)}$$

Equation 10 represents twisting couple per unit twist.

Special case: A hallow cylinder contains radius r_1 and r_2, then

$$\tau = \int_{r_1}^{r_2} \frac{2\pi nx^3\theta dx}{l} = \left[\frac{2\pi nx^4\theta dx}{4l}\right]_{r1}^{r2} = \frac{\pi n\theta dx}{2l}(r_2^4 - r_1^4)$$

$$C = \left[\frac{\pi n(r_2^4 - r_1^4)}{2l}\right]$$

1.19 TORSIONAL PENDULUM

It consists of long metal wire and metal disc. One end of the wire is fixed and another end is attached with metal disc as shown in fig.

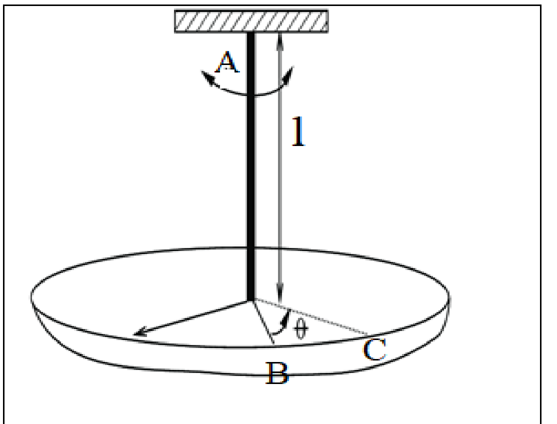


Fig 1.22 Torsional pendulum

Principle

When a disc is rotated through a horizontal plane, the disc produces simple harmonic oscillation due to the restoring couple produced in the wire.

Description:

- A torsional pendulum consists of a metal wire.
- It is suspended vertically with an upper end fixed.
- The lower end is connected to a circular disc.
- l – Length of the wire
- r – Radius of the wire
- R- Radius of the disc
- C – Couple per unit twist

Working:

- The circular disc is rotated in horizontal plane, B is shifted to C.
- The wire is twisted through an angle θ.
- The wire undergoes shearing strain and a restoring couple.

Restoring couple = twisting couple per unit twist X angular displacement

$= C.\theta$ ---(1)

- When the disc is released, it produces torsional oscillation.
- The couple acting on the disc produces angular acceleration.

Applied couple $= I\dfrac{d^2\theta}{dt^2}$ --(2)

Where $\dfrac{d^2\theta}{dt^2}$ = angular acceleration

To find time period (T):

At equilibrium condition,

Applied couple = restoring couple

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

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

From eqn 3, angular acceleration is directly proportional to angular displacement produced. This oscillation is called as simple harmonic oscillation.

We know, time period, $T=2\pi\sqrt{\frac{angular\ displacement}{angular\ acceleration}}$

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

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

To find moment of inertia of the disc (I_o): (Experiment)

To determine the moment of inertia of the disc, the time period of oscillation is calculated in three different methods.

1. Period of oscillation without any mass
2. Period of oscillation with mass at a distance 'd_1'
3. Period of oscillation with mass at a distance 'd_2'

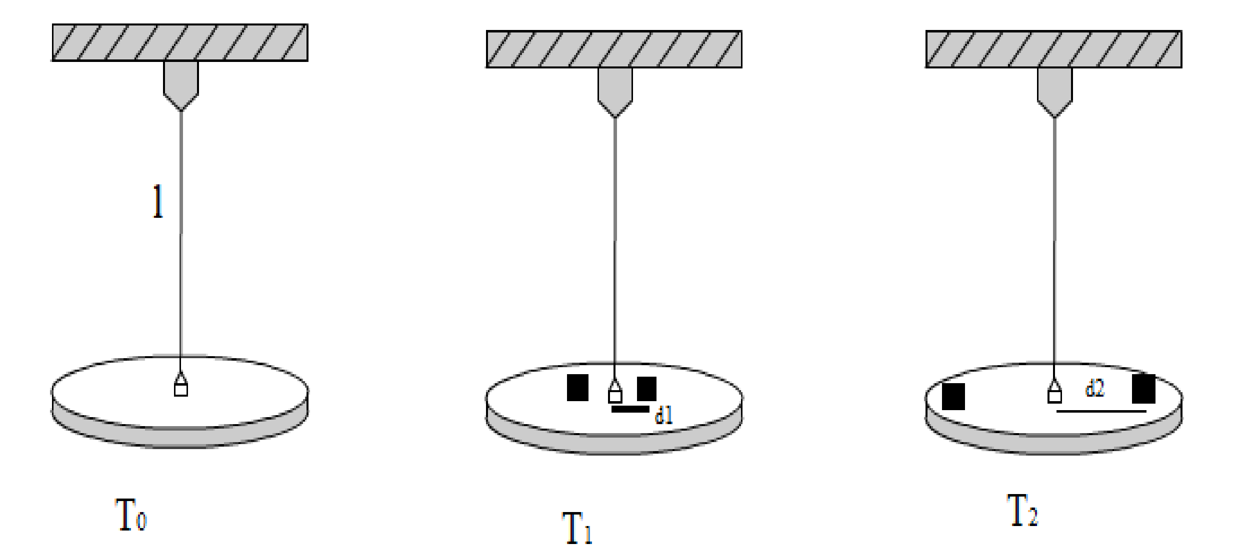


Fig 1.23 To find time period T_0, T_1 & T_2

1. **Period of oscillation without any mass**

The disc is allowed to make to and fro motion at without mass position. Now time period is noted as T_0.

Period of oscillation without any mass

$$T_0 = 2\pi\sqrt{\frac{I_0}{C}}$$

Squaring on both sides

$$T_0^2 = 4\pi^2 \frac{I_0}{C} \quad \text{-------------------------------------(5)}$$

2. Period of oscillation with mass at a distance '*d_1*'

The disc is allowed to make to and fro motion at with two masses on disc at a distance of d_1. Now time period is noted as T_1.

$$T_1 = 2\pi\sqrt{\frac{I_1}{C}}$$

Squaring on both sides

$$T_1^2 = 4\pi^2 \frac{I_1}{C} \quad \text{-------------------------------------(6)}$$

Where, I_1 – moment of inertia of the disc with mass at a distance d_1.

From Parallel axis theorem,

The moment of inertia, $I_1 = I + 2I_m + 2md_1^2$ ---------------(7)

Where, I_m – Moment of inertia of each mass passing through its centre

m – Mass of the weight

subs. Eqn 7 in 6, we get,

$$T_1^2 = 4\pi^2 \left(\frac{(I + 2I_m + 2md_1^2)}{C} \right) \quad \text{--------------------(8)}$$

3. Period of oscillation with mass at a distance '*d_2*'

The disc is allowed to make to and fro motion at with two masses on disc at a distance of d_2. Now time period is noted as T_2.

$$T_2 = 2\pi\sqrt{\frac{I_2}{C}}$$

Squaring on both sides

$$T_2^2 = 4\pi^2 \frac{I_2}{C} \quad \text{-------------------------------------(9)}$$

Where, I_2 – moment of inertia of the disc with mass at a distance d_2.

From Parallel axis theorem,

The moment of inertia, $I_2 = I + 2I_m + 2md_2^2$ ----------------------(10)

Where, I_m – Moment of inertia of each mass passing through its center

m – Mass of the weight

subs. Eqn. 10 in 9, we get,

$$T_2^{\,2} = 4\pi^2\left(\frac{(I + 2I_m + 2md_2^{\,2})}{C}\right) \text{------------------------(11)}$$

From eqn. 5, 8 & 11

$$\frac{T_0^{\,2}}{T_2^{\,2} - T_1^{\,2}} = \left[\frac{4\pi^2\left(\frac{I_0}{C}\right)}{4\pi^2\left(\frac{I + 2I_m + 2md_2^2}{C}\right) - 4\pi^2\left(\frac{I + 2I_m + 2md_1^2}{C}\right)}\right]$$

Simplify the above equation we get,

$$\frac{T_0^{\,2}}{T_2^{\,2} - T_1^{\,2}} = \left[\frac{\frac{I_0}{C}}{2m\left(\frac{d_2^2 - d_1^2}{C}\right)}\right] = \left[\frac{I_0}{2m(d_2^2 - d_1^2)}\right]$$

Rearranging

$$I_0 = \frac{2m(d_2^2 - d_1^2)T_0^{\,2}}{T_2^{\,2} - T_1^{\,2}} \text{---(12)}$$

Equation 12 represents moment of inertia of the disc.

To find rigidity modulus of a wire (n):

We know, Torque per unit twist $C = \frac{\pi n r^4}{2l}$ ------------------- (13)

Subs eqn 13 in 5,

$$T_0^{\,2} = 4\pi^2\left(\frac{2I_0 l}{\pi n r^4}\right)$$

$$T_0^{\,2} = \frac{8\pi I_0 l}{n r^4}$$

Rigidity modulus, $n = \frac{8\pi I_0 l}{T_0^{\,2} r^4} \quad N/m^2$ --------------(14)

Equation 14 represents rigidity modulus of wire.

UNIT II ULTRASONICS AND ITS APPLICATIONS

2.1 INTRODUCTION

Sound is transmitted from one place to another by means of waves. The character of any wave can be described by identifying two related properties: its wavelength (lambda, λ) or its frequency (f). The unit used to measure the frequency of any wave is hertz. One hertz is defined as the passage of a single wave per second.

Ultrasonics, then, deals with sound waves that pass a given point at least 20,000 times per second. Since ultrasonic waves vibrate very rapidly, additional units also are used to indicate their frequency. The kilohertz (kHz), for example, can be used to measure sound waves vibrating at the rate of 1,000 times per second, and the unit megahertz (MHz) stands for a million vibrations per second. Some ultrasonic devices have been constructed that produce waves with frequencies of more than a billion hertz.

It has many applications in science, industry, medical, defence and etc.

2.2 CLASSIFICATION OF SOUND

Mechanical disturbance from a state of equilibrium that propagates through an elastic material medium is called as sound. There are many different types of sound including, audible, inaudible, unpleasant, pleasant, soft, loud, noise and music. But based on the frequency, sound waves are classified in to three categories. They are

- Infrasonics
- Audible range
- Ultrasonics

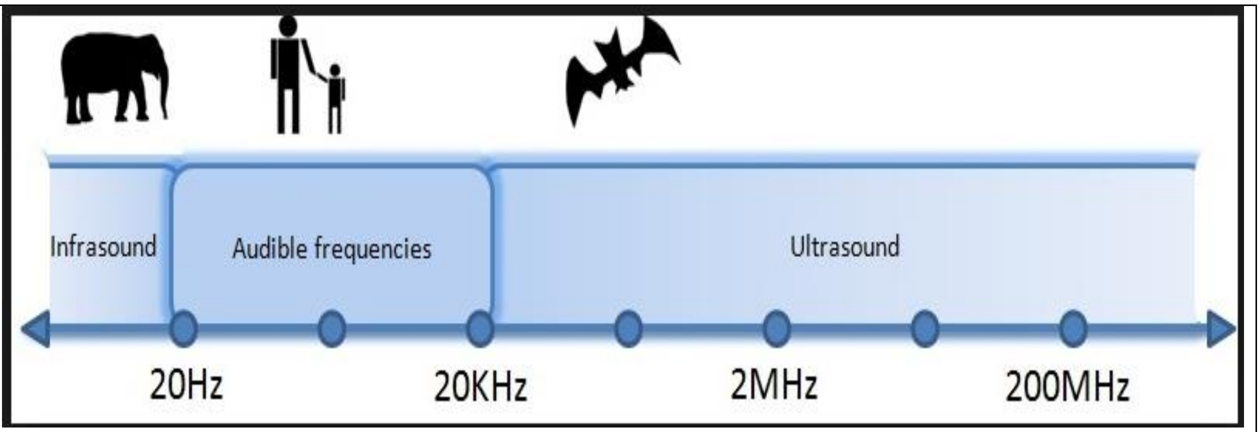


Fig 2.1 Classification of sound

2.2.1 INFRASONICS

The sound wave having frequency less than 20 Hz are called as infrasonics or infra sound.

For example, some animals, such as whales, elephants and giraffes communicate using infrasound over long distances. Avalanches, volcanoes, earthquakes, ocean waves, waterfalls and meteors generate infrasonic waves.

Properties:

- Frequency range is less than 20 Hz
- Infrasonic sounds are very low frequency sound.
- These are produced by those objects which vibrate very slowly.
  For example, a vibrating simple pendulum produces infrasonic sound.
- It cannot be heard by human.
- They cannot travel through vacuum.
- They undergo reflection, refraction and absorption.
- Whales and elephants produce infrasonic waves.

2.2.2 AUDIBLE FREQUENCY SOUND

The sound wave having frequency between 20 Hz to 20,000 Hz are called as audible frequency sound.

Examples of vibrating sources that produce sound in the audible range of frequencies are drums, guitar strings, tuning fork, human vocal cords and diaphragms of loudspeakers.

Properties:

- The frequency range lies between 20 Hz to 20 KHz
- Audible sounds are moderate frequency sound.
- These are produced by those objects which vibrate normally.
- It can be heard by human ear.
- They cannot travel through vacuum.
- They undergo reflection, refraction and absorption.
- Human sense these waves and it is used to share information.

2.2.3 ULTRASONICS

The sound wave having frequency more than 20 KHz or 20000 Hz are called as ultrasonics or ultra sound.

For example, some animals like dogs and bats are used for its communication.

Both infrasonics and ultrasonics are inaudible to human ear.

Properties:

- Ultrasonic waves vibrate at a frequency greater than the audible range for humans (20 kilohertz).
- They have smaller wavelengths. As a result, their penetrating power is high.
- They cannot travel through vacuum.
- Ultrasonic waves travel at the speed of sound in the medium. They have maximum velocity in a denser medium.
- In a homogeneous medium, they travel at a constant velocity.
- In low viscosity liquids, ultrasonic waves produce vibrations.
- They undergo reflection, refraction and absorption.
- They have high energy content. They can be transmitted over a large distance without much loss of energy.
- They produce intense heat when they are passed through objects.
- Like sound waves, ultrasonic waves are longitudinal waves that produce alternate compressions and rarefactions.

2.4 PRODUCTION OF ULTRASONICS

There are three methods for producing ultrasonics. They are:

- Mechanical generator or Galton's Whistle
- Magnetostriction generator
- Piezo-electric generator

2.4.1 MAGNETOSTRICTION GENERATOR

Principle:

Basic principle of magnetostriction generator is magnetostrictive effect.

"When a ferromagnetic rod is subjected to alternative magnetic field, then continuous contraction and expansion is produced. This effect is called as magnetostrictive effect."

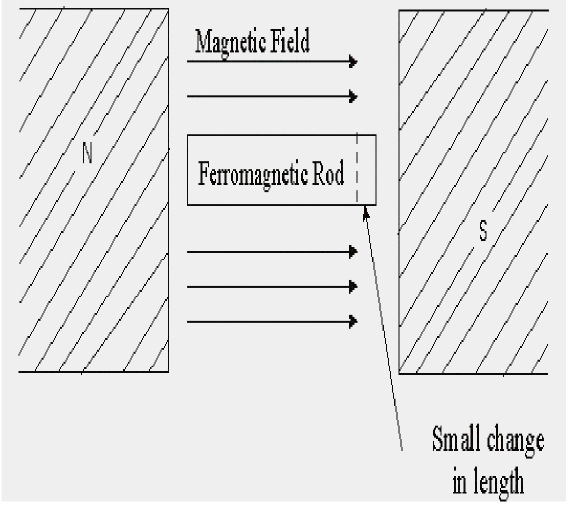


Fig 2.2 Magnetostriction effect

During this contraction and expansion the rod starts vibrating. When the frequency of vibrating rod is equal to frequency of oscillatory circuit, then ultrasonic wave are produced from ferromagnetic rod.

Construction:

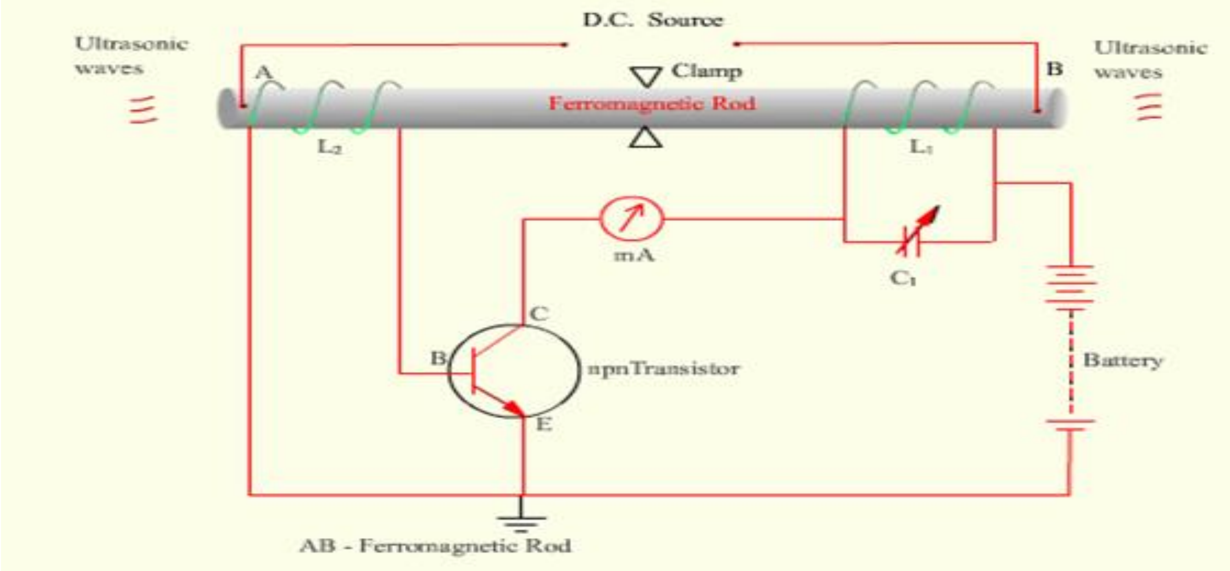


Fig 2.3 Magnetostriction generator

- AB is a rod of ferromagnetic materials like iron or nickel. The rod is clamped in the middle.
- The alternating magnetic field is generated by electronic oscillator.
- The coil L_1 wound on the right hand portion of the rod along with a variable capacitor C_1.
- This forms the resonant circuit of the collector tuned oscillator. The frequency of oscillator is controlled by the variable capacitor.
- The coil L_2 wound on the left hand portion of the rod is connected to the base circuit. The coil L_2 acts as feed –back loop.

Working:

- When High Tension (H.T) battery is switched on, the collector circuit oscillates with a frequency,

$$f = \frac{1}{2\pi\sqrt{L_1C_1}}$$

- This alternating current flowing through the coil L_1 produces an alternating magnetic field along the length of the rod. The result is that the rod starts vibrating due to magnetostrictive effect.
- The frequency of vibration of the rod is given by

$$f = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

- where l = length of the rod, Y = Young's modulus of the rod material and ρ =density of rod material
- The capacitor C_1 is adjusted so that the frequency of the oscillatory circuit is equal to natural frequency of the rod and thus resonance takes place.
- Now the rod vibrates longitudinally with maximum amplitude and generates ultrasonic waves of high frequency from its ends.

Condition for resonance:

Frequency of the oscillatory circuit = Frequency of the vibrating rod

$$\frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

Merits:

- Magnetostrictive materials are easily available and inexpensive.
- Oscillatory circuit is simple to construct.
- Large output power can be generated.

Limitations:

- It can produce frequencies upto 3 MHz only.
- It is not possible to get a constant single frequency, because rod depends on temperature and the degree of magnetization.
- As the frequency is inversely proportional to the length of the vibrating rod, to increase the frequency, the length of the rod should be decreased which is practically impossible.

2.4.2 PIEZO ELECTRIC GENERATOR

Piezo-electric crystals

The crystals which produce piezo-electric effect are called piezo-electric crystals.

Examples: quartz, tourmaline, Rochelle salts etc.

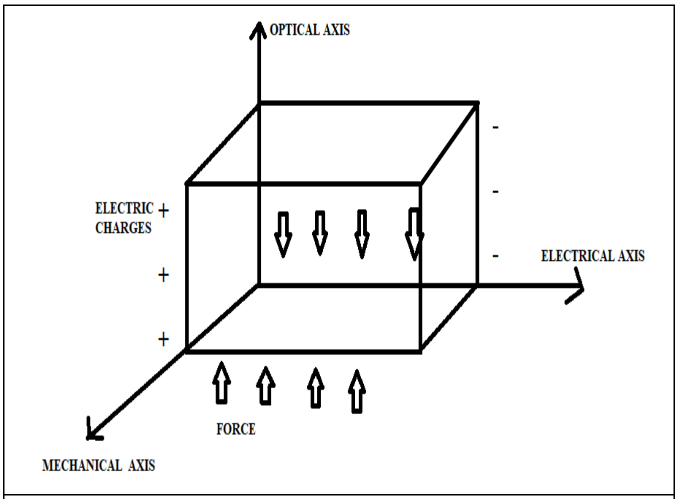


Fig 2.4 Piezo electric effect

Piezo-electric effect:

When mechanical force is applied along mechanical axis perpendicular to both electrical and optical axis, then equal and opposite charges are produced along electrical axis. This phenomenon is known as Piezo-electric effect.

Inverse or converse Piezo electric effect:

When an alternating e.m.f or voltage is applied along electrical axis perpendicular to both mechanical and optical axis, then mechanical vibrations are produced along mechanical axis. This effect is known as inverse piezoelectric effect.

Principle:

Inverse or converse Piezo-electric effect is a principle behind piezo electric generator.

Construction:

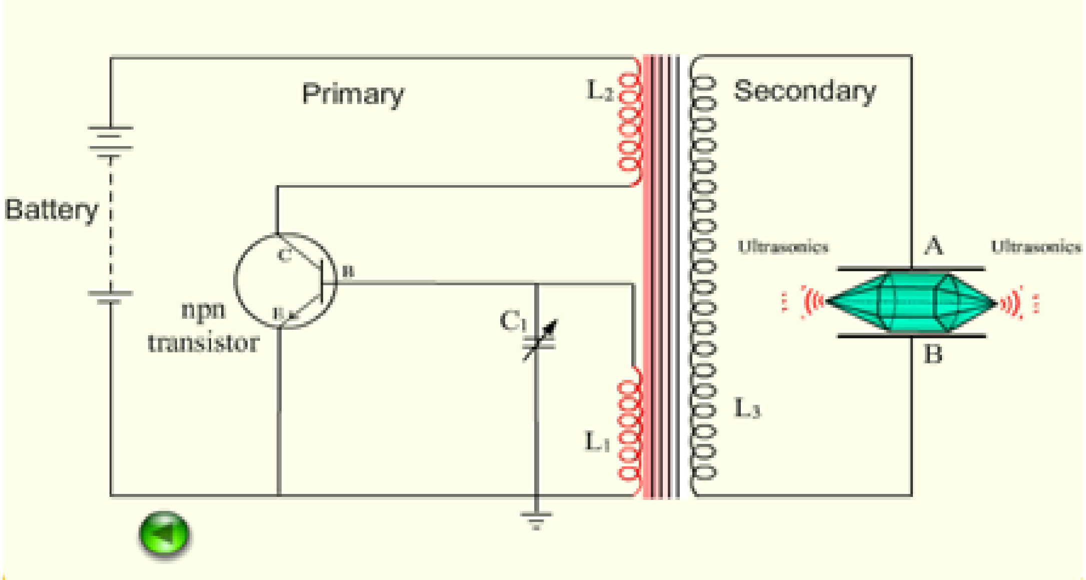


Fig 2.5 Piezo electric generator

- The circuit diagram is shown in the figure 3.5 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_1 form the tank circuit of the oscillator.

Working:

- When H.T. battery is switched on, the oscillator produces high frequency alternating voltages with a frequency.

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

- Due to the transformer action, an oscillatory e.m.f. is induced in the coil L_3. This high frequency alternating voltages are fed on the plates A and B.
- Inverse piezo-electric effect takes place and the crystal contracts and expands alternatively. The crystal is set into mechanical vibrations.
- The frequency of the vibration is given by

$$f = \frac{P}{2l}\sqrt{\frac{Y}{\rho}}$$

- Where, P = 1,2,3,4 … etc. for fundamental, first over tone, second over tone etc.,

  Y = Young's modulus of the crystal and

  ρ = density of the crystal.
- The variable condenser C_1 is adjusted such that the frequency of the applied AC voltage is equal to the natural frequency of the quartz crystal, and thus resonance takes place.
- The vibrating crystal produces longitudinal ultrasonic waves of large amplitude.

Condition for resonance:

Frequency of the oscillatory circuit = Frequency of the vibrating rod

$$\frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{P}{2l}\sqrt{\frac{Y}{\rho}}$$

Advantages:

- Ultrasonic frequencies as high as 5 x 10^8Hz or 500 MHz can be obtained with this arrangement.
- The output of this oscillator is very high.
- It is not affected by temperature and humidity.

Disadvantages:

- The cost of piezo electric quartz is very high
- The cutting and shaping of quartz crystal are very complex.

2.5 DEDUCTION OF ULTRASONICS

We know,ultrasonics is not heard by human ear. But we have to sense the sound waves. Ultrasonic waves propagated through a medium can be detected in a number of ways.

2.5.1 Kundt's tube method:

Ultrasonic waves can be detected with the help of Kundt's tube. At the nodes, lycopodium powder collects in the form of heaps. The average distance between two adjacent heaps is equal to half the wavelength. This method cannot be used if the wavelength of ultrasonic waves is very small i.e., less than few mm. In the case of a liquid medium, instead of lycopodium powder, powdered coke is used to detect the position of nodes.

2.5.2 Sensitive flame method:

A narrow sensitive flame is moved along the medium. At the positions of antinodes, the flame is steady. At the positions of nodes, the flame flickers because there is a change in pressure. In this way, positions of nodes and antinodes can be found out in the medium. The average distance between the two adjacent nodes is equal to half the wavelength. If the value of the frequency of ultrasonic wave is known, the velocity of ultrasonic wave propagated through the medium can be calculated.

2.5.3 Thermal detectors:

This is the most commonly used method of detection of ultrasonic waves. In this method, a fine platinum wire is used. This wire is moved through the medium. At the position of nodes, due to alternate compressions ad rarefactions, adiabatic changes in temperature takes place. The resistance of the platinum wire changes with respect to time. This can be detected with the help of Callendar and Garrifith's bridge arrangement. At the position of the antinodes, the temperature remains constant. This will be indicated by the undisturbed balanced position of the bridge.

2.5.4 Quartz crystal method:

This method is based on the principle of Piezo-electric effect. When one pair of the opposite faces of a quartz crystal is exposed to the ultrasonic waves, the other pairs of opposite faces developed opposite charges. These charges are amplified and detected using an electronic circuit.

2.6 ACOUSTICAL GRATING METHOD

Principle:

"When ultrasonic waves travel through a transparent liquid, due to alternate compression and rarefaction, longitudinal stationary waves are produced. If monochromatic light is passed through the liquid perpendicular to these waves, the sound wave behaves as diffraction grating. Such a grating is known as Acoustic Grating. Here the lines of compression and rarefaction act as grating element for transparent light waves."

Construction:

- It is consists of a glass tank, filled with the liquid.
- A piezo-electric crystal (Quartz) is fixed at the bottom of the glass tank and is connected with piezo-electric oscillatory circuit as shown in the figure.
- A sodium lamp is used as a monochromatic source and a telescope arrangement is used to view the diffraction pattern.
- A collimator consisting of two lenses L_1 and L_2 is used to focus the light effectively in the glass tank.

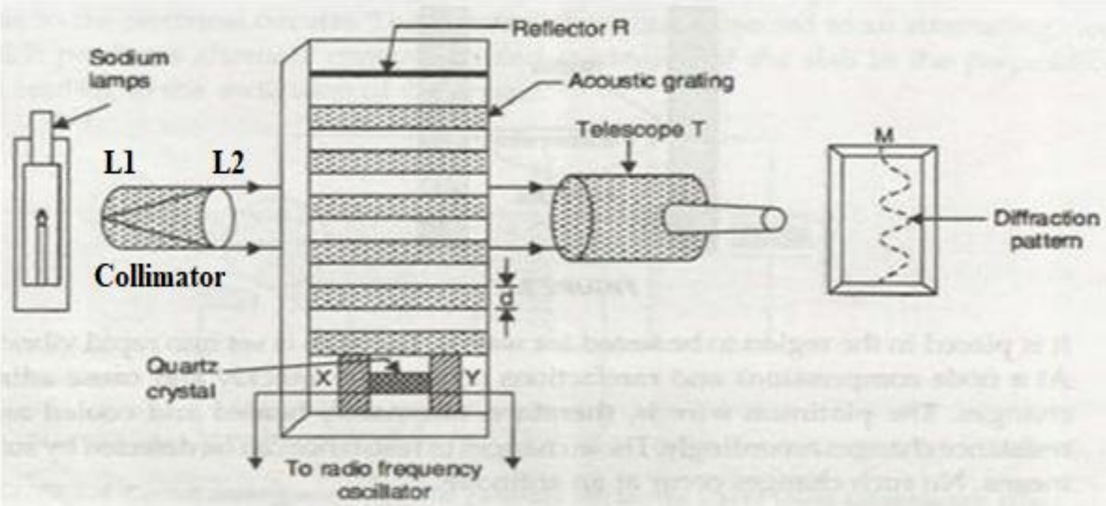


Fig 2.6 Experimental set up of acoustic grating

Working:

(i) When the piezo-electric crystal is kept at rest:

- Initially the piezo-electric crystal is kept at rest and the monochromatic at light is switched ON.
- When the light is focused in the glass tank filled with the liquid, a single image, a vertical peak is observed in telescope.
- i.e., there is no diffraction.

(ii) When the piezo-electric crystal is set into vibrations:

- Now the crystal is put into vibrations using piezo-electric oscillatory circuit.
- At Resonance, Ultrasonic waves are produced and are passed through the liquid.
- These Ultrasonic waves are reflected by the walls of the glass tank and form a stationery wave pattern with nodes and antinodes in the liquid.
- At nodes the density of the liquid becomes more and at antinodes the density of the liquid becomes less.
- Thus, the liquid behaves as a directing element called acoustical grating element.

- Now when the monochromatic light is passed the light gets directed and a diffraction pattern consisting of central maxima and principle maxima on either side is viewed through the telescope as shown in figure.

Calculation of Ultrasonic Velocity

The velocity of ultrasonic waves can be determined using the diffraction condition

i.e., $2d \sin\theta = n\lambda$ ---------- (1)

Where

'd' is the distance between successive nodes (or) antinodes.

θ is the angle of diffraction.

n is the order of spectrum.

λ is the wavelength of the monochromatic source of light.

If λ_u is the wavelength of ultrasonic, then

$\lambda_u = 2d$ ------------(2)

Equation (1) becomes

$\lambda_u \sin\theta = n\lambda$

$$\lambda_u = \frac{n\lambda}{\sin\theta} \quad \text{------------(3)}$$

We know, ultrasonic velocity = (frequency of ultrasonic) x (wavelength of ultrasonic)

Velocity of ultrasonic (V) = $\nu_u \lambda_u$-------- ---------(4)

Substituting equation (3) in (4), we get

$$V = \frac{\nu_u n\lambda}{\sin\theta} \quad \text{---------------(5)}$$

Thus the velocity (or) wavelength of the ultrasonic can be determined using acoustical grating.

2.7 INDUSTRIAL APPLICATIONS OF ULTRASONICS

1) Ultrasonic drilling and cutting:

Ultrasonic are used for making holes in very hard materials such as glass, diamond etc.

2) Ultrasonic welding and soldering:

Some materials cannot weld at high temperatures. In such case the welding can be done at room temperature using ultrasonic and it is called as **cold welding.** It is also used for soldering aluminum foil condensers, aluminum wires etc., without any flux.

3) Ultrasonic cleaning and drying:

Ultrasonic can also be employed in cleaning motors, aero planes, electronic assemblies etc. further; it can also dry using acoustic drier.

4) Coagulation:

They are used in coagulation (changing from liquid phase to a semi solid phase) and crystallization, hence can be used in the manufacturing of paints, polisher etc.

5) Sound signaling:

The ultrasonic signal can be used for the identification and landing the ships. In military field, the method of sound signaling can used to identify our warships.

6) Depth sounding:

Echo sounding is the principle used to find the depth of the sea. A beam of ultrasonic is directed towards the bottom of the sea and the reflected signal is received as shown in fig.

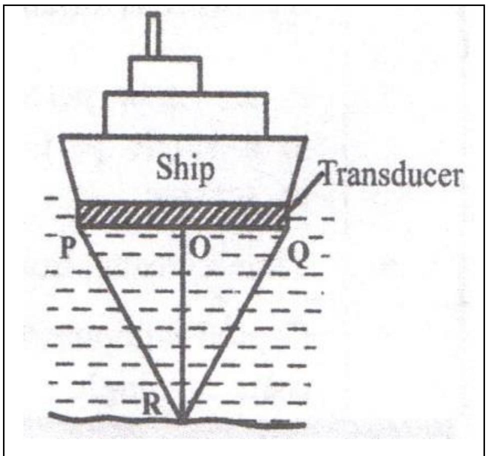


Fig 2.7 Sonar

The time interval between the transmitted and received signal is noted and let it be‘t’. If ‘V’ is the velocity of the ultrasonic, then

$$V = \frac{distance travelled}{time taken}$$

From fig, we can write

$$V = \frac{PR+RO}{t} = \frac{2RO(approx)}{t}$$

RO = Depth of sea = $\frac{vt}{2}$

The depth of the sea can be directly calibrated using the instrument called as Fathometer (or) Echo meter.

2.8 APPLICATIONS OF ULTRASONIC WAVES IN ENGINEERING

2.8.1 Non Destructive Testing (NDT) - Detection of flaws in metals (Pulse Echo System through transmission and reflection modes)

NDT (Non-Destructive Testing) refers to an array of inspection techniques that allow inspectors to collect data about a material without damaging it.

Principle

Ultrasonic waves are used to detect the presence of flaws or defects in the form of cracks, blowholes, porosity etc., in the internal structure of a material.

By sending out ultrasonic beam and by measuring the time interval of the reflected beam, flaws in the metal block can be determined.

Block diagram

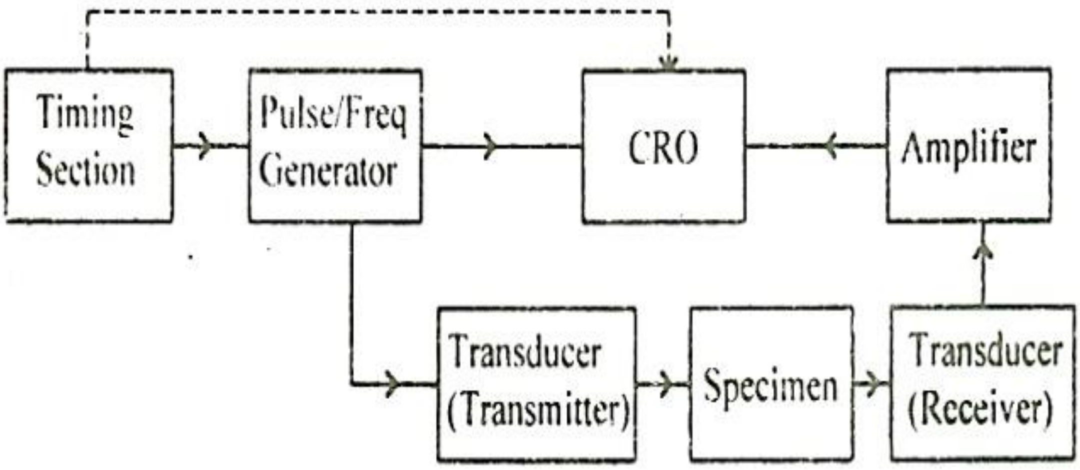


Fig 2.8 Ultrasonic flaw detector - Block diagram

Construction:

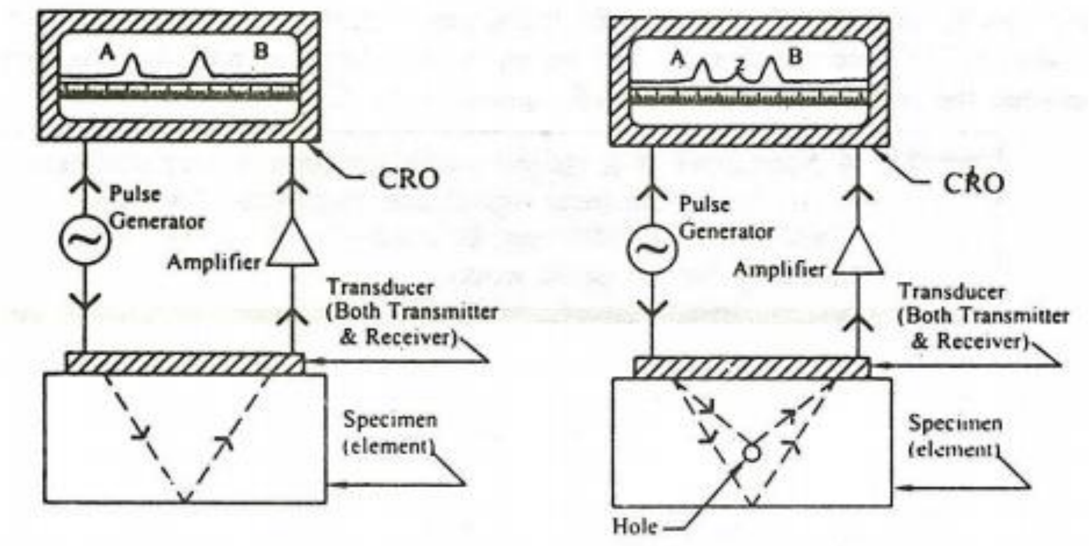


Fig 2.9 Ultrasonic flaw detector - Experiment

It consists of an ultrasonic frequency generator (pulse generator), cathode ray oscilloscope (CRO), transmitting transducer, receiving transducer and an amplifier.

- Frequency generator is used to produce high frequency sound waves
- Transducer is act as both transmitter and receiver. It is used to convert non electrical signal into electric signal and vice versa. It is made up of piezo electric cystals.
- Amplifier is used to amplify the low frequency sound waves received by receiver end.
- Timing circuit is used to calculate the time difference between transmitted sound wave and received sound wave.

- CRO is used to display the output of the specimen.

Working

- The frequency generator produces high frequency sound waves and the same is send to RF pulser.
- RF pulser concerts sound wave in to electrical pulses.
- These electrical pulses are fed to transmitter end of the transducer. Now, electrical signals are converted to ultrasonic wave based on inverse piezo electric effect.
- These waves are reflected by any flaws. Because, whenever there is change in medium, sound waves are reflected.
- The reflected waves are received by receiver end of the transducer.
- The reflected beam (echoes) is recorded by using cathode ray oscilloscope.
- The time interval between initial and flaw echoes depends on the range of flaw.
- By examining echoes on CRO, flaws can be detected and their sizes can be estimated.

Advantages of NDT

- Very minute flaws can be detected
- Location, nature and size of a defect can be accurately determined.
- It is of low cost and it has high speed inspection.
- Even large size specimens can be inspected in a short duration.

Disadvantages of NDT

- No permanent record of the flaw can be obtained. It can be observed only on the screen.
- This requires skilled and well trained technicians.
- It is difficult to find the defects of the specimen which has complex shapes.

2.9 ULTRASONIC SCANNING METHODS – A, B AND C SCAN DISPLAYS

In the ultrasonic scanning methods based on the position of the transducer, there are several modes of displaying the reflected information on the CRO. The most commonly used methods are,

- A-Scan (or) Amplitude Scan.
- B-Scan (or) Brightness Scan.
- C-Scan (or) Time Motion Scan.

2.9.1 A –Scan:

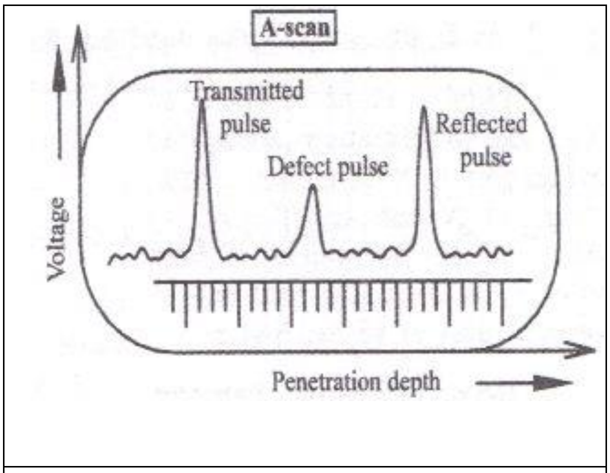


Fig 2.10 A-Scan

1. A-scan is also called amplitude scan.
2. It gives only one dimensional image of the object.
3. In this method, the transducer is fixed at one position and a number of echoes are received which appear as vertical pulses in CRO.
4. These peaks help to find the position and depth of the penetration.
5. Thus, by passing the ultrasonic of known velocity and by noting the time delay, we can
6. find the distance at which the defect (or) flaws and present by using given formula

Distance = Velocity x Time

In ultrasonic flaw detector, A-scan method is used to detect the position and size of the flaws.

2.9.2 B – Scan:

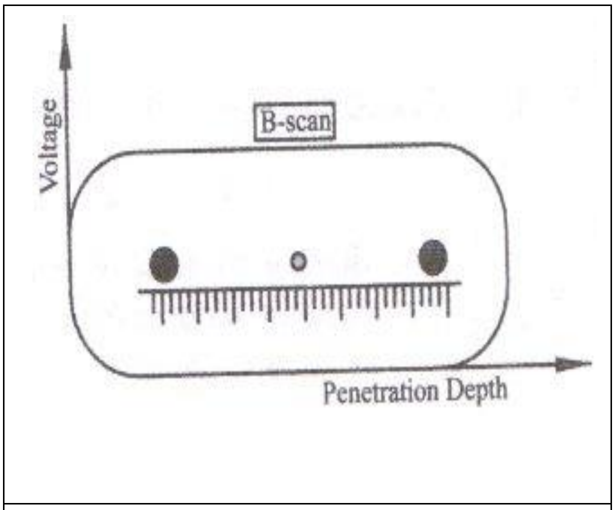


Fig 2.11 B-Scan

1. B-scan is also called Brightness scan.
2. It gives a two-dimensional image of the object.
3. In this case, transducer is moved on the object surface along X and Y direction.
4. The position and orientation of the object are recorded in CRO.
5. The echoes are displayed as dot on the screen as shown in fig.
6. The brightness and size of the dot depends on the intensity and strength of reflected echo pulses respectively.
7. The distance between the two dots gives the penetration depth.

B-scan used to detect pregnancy, multiple fetuses, the age of fetus, the position of the placenta, etc.

2.9.3 C –Scan:

1. It is also called Time Motion scan (or) T.M scan.
2. It gives a three dimensional image of the object.
3. This is a combination of A-scan and B-scan methods.
4. The transducer is fixed like A-scan; dots appear like B-scan.
5. It is used to record the image of moving objects.

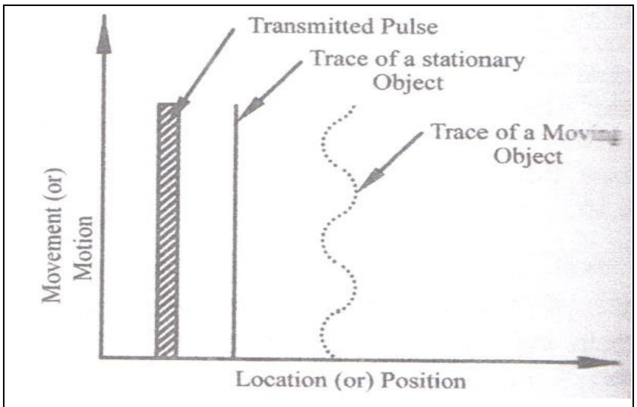


Fig 2.12 C-Scan

6. In this scan, the x-axis indicates the dots at relevant location of position of the defect; the y-axis indicates the movement of the object.
7. A straight line is displayed for the object in rest, when the object is moving; the trace of moving object is recorded as dots.

This type of display is very much useful for obtaining the pulsation structure.

2.10 SONOGRAM OR ULTRASONOGRAPHY

Acoustic event of heart are divided into

- Heart sound
- Murmurs

Heart sound: These are due to the opening and closing of heart valves. These have low frequency and higher amplitudes.

Murmurs: Noisy characters which are of longer duration. This is due to turbulent flow of blood in the heart. They have high frequency and smaller amplitudes.

We know about ECG (Electro Cardio Graphy) in which the activity of heart such as, rhythmic disturbance of the myocardial activity can be found with electrical techniques. But valvular defects cannot be identified by using ECG. Hence PCG can be used for detecting these defects.

- Phono-Cardiograph records the sound produced by the pumping action of the heart.
- If provides information on heart rate, rhythmicity, blood pumping, valve action etx.,

2.10.1 FETAL HEART MOVEMENT

Principle

Doppler Effect is the principle used in the sonogram i.e., there is an apparent change in frequency between the incident sound waves on the fetus and the reflected sound waves from the fetus.

Description

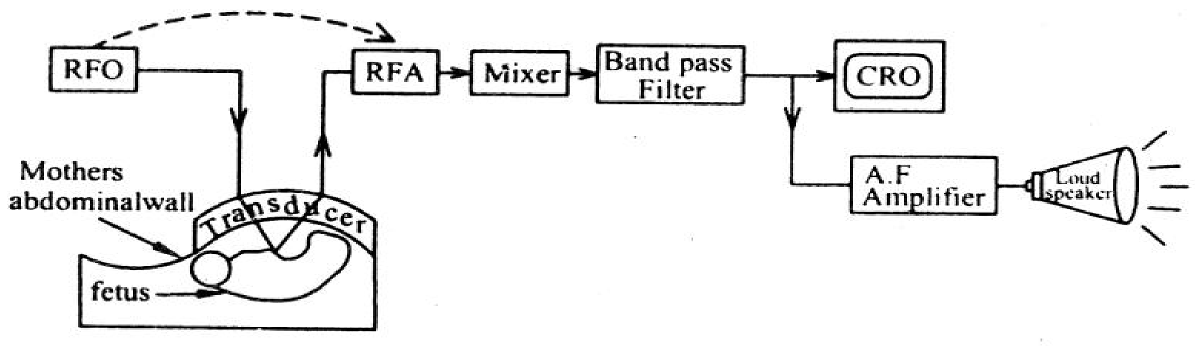


Fig 2.12 Sonogram

- It consists of a Radio Frequency Oscillator (RFO), for producing 2MHz of frequency.
- A single transducer is used as both transmitter and receiver. It converts non electrical signal in to electrical signal and vice versa.
- RFA (Radio Frequency Amplifier) to amplify the received signals.
- Mixer is used to mix the transmitted signals and the received signals.
- Band pass filter is used to filter the unwanted frequency of sound.
- The loud speaker helps to hear the sound.
- The CRO used to view the output of the sound waves.

Working

- The transducer is fixed over the mother's abdominal wall, with the help of a gel (or) oil.
- RFO is switched ON to drive the pulses and hence the transducer produces ultrasonic waves of 2 MHz (if more than 2MHz, i.e., very high frequency waves are passed then it will affect the fetus). These ultrasonic waves are made to incident on the fetus.
- The reflected ultrasonic waves from the fetus are received by the transducer and are amplified by RFA.

- Both the incident and received signals are mixed by the mixer and is filtered to distinguish the various types of sound and finally the Doppler shift (or) change in frequency is measured.
- The movement of heart can be viewed visually by CRO (or) can be heard by the loud speaker, after necessary amplification by Audio frequency (AF) amplifier.

Diagnosis

- When the heart of the fetus is moving towards the transducer i.e., towards the source of sound, the shift in frequency is higher.
- When the heart of the fetus is moving away from the transducer, i.e., away from the source, the frequency shift is lower.

Thus from the Doppler shift in frequency the movement of the fetal heart can be found.

Further in the output the sound of mother’s blood flow will also be present. But it can be easily distinguished with respect to the higher pulse rate of the fetus (or) from the following diagnosis.

S.No	Type of Sound	Frequency	Rhythm of sound	Diagnosis Result
1	Thuummp, Thuummp….	Low	Slow	Mother’s body movements
2	Thump, Thump…	Low	Fast	Fetal heart movement
3	Wooch, Wooch…..	Mid	Slow	Mother’s Arteries
4	Swish, Swish,…..	High	Fast	Umbilical cord sound

Thus, with the help of the type of the sound heard and the Doppler shift in frequency the movement of heart can be easily diagnosed.

UNIT III MODERN PHYSICS

3.1 INTRODUCTION

Modern physics (Quantum physics), deals with the behavior of matter and light on the atomic and subatomic scale. It attempts to describe and account for the properties of molecules and atoms and their constituents like electrons, protons, neutrons, and other more esoteric particles such as quarks and gluons. These properties include the interactions of the particles with one another and with electromagnetic radiation (i.e., light, X-rays, and gamma rays).

The behavior of matter and radiation on the atomic scale often seems peculiar, and the consequences of quantum theory are accordingly difficult to understand and to believe. Its concepts frequently conflict with common-sense notions derived from observations of the everyday world. There is no reason, however, why the behavior of the atomic world should conform to that of the familiar, large-scale world.

At a fundamental level, both radiation and matter have characteristics of particles and waves. The gradual recognition by scientists that radiation has particle-like properties and that matter has wavelike properties provided the impetus for the development of quantum mechanics. Influenced by Newton, most physicists of the 18th century believed that light consisted of particles, which they called corpuscles.

From about 1800, evidence began to accumulate for a wave theory of light. At about this time Thomas Young showed that, if monochromatic light passes through a pair of slits, the two emerging beams interfere, so that a fringe pattern of alternately bright and dark bands appears on a screen. The bands are readily explained by a wave theory of light.

According to the theory, a bright band is produced when the crests (and troughs) of the waves from the two slits arrive together at the screen; a dark band is produced when the crest of one wave arrives at the same time as the trough of the other, and the effects of the two light beams cancel.

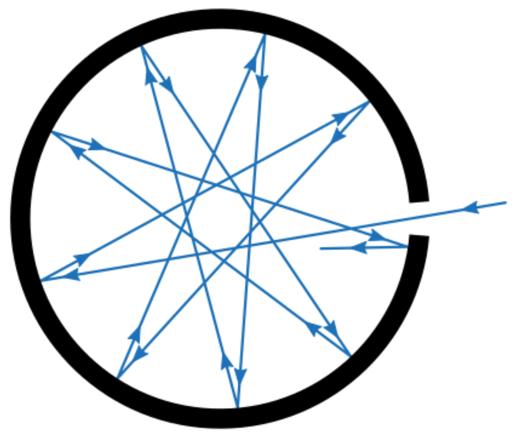
Beginning in 1815, a series of experiments by Augustin-Jean Fresnel of France and others showed that, when a parallel beam of light passes through a single slit, the emerging beam is no longer parallel but starts to diverge; this phenomenon is known as diffraction. Given the wavelength of the light and the geometry of the apparatus (i.e., the separation and widths of the slits and the distance from the slits to the screen), one can use the wave theory to calculate the expected pattern in each case; the theory agrees precisely with the experimental data.

3.2 BLACK BODY RADIATION

Black body

A perfect black body is one which absorbs and emits in all the radiations (corresponding to all wavelengths) that fall on it.

Let us consider a hollow sphere coated with lamp black on its inner surface. A fine hole is made for radiations to enter into the sphere as shown in the figure.



3.1 Black body

Now when the radiations are made to pass through the hole it undergoes multiple reflections and are completely absorbed. Thus the black body acts as a perfect absorber.

Now when the black body is placed in a temperature bath of fixed temperature, the heat radiations will come out only through the hole in the sphere and not through the walls of the sphere.

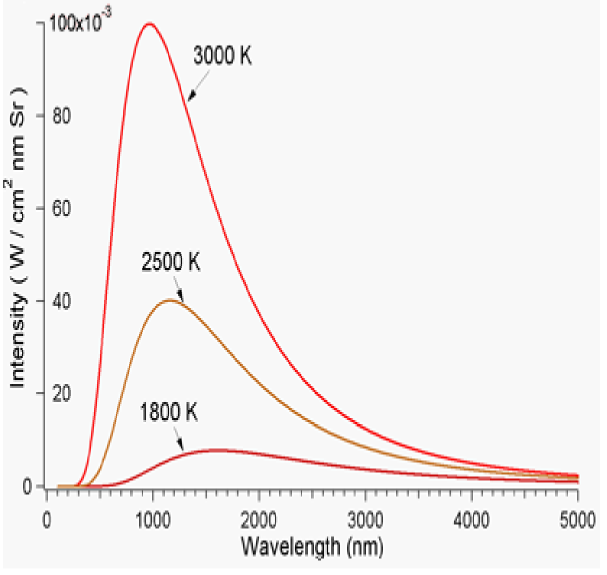
Therefore, we can conclude that the radiations are emitted from the inner surface of the sphere and not from the outer surface of the sphere. Thus a perfect black body is a perfect absorber and also a perfect radiator of all wavelengths.

Black body radiation

The radiation emitted by a perfect black body is called Black body radiation.

Energy spectrum

When a perfect black body is allowed to emit radiations at different temperatures, then the distribution of the energy for different wavelengths at various temperatures is obtained as shown in the figure.



3.2 Energy spectrum

From figure the following results are formulated.

- The energy distribution is not uniform for a given temperature.
- The intensity of radiation (E) increases with respect to the increase in wavelength at particular wavelength in

becomes maximum (λ_m) and after this it starts decreasing with respect to the increase in wavelength.

- When the temperature is increased, the maximum wavelength (λ_m) decreases.
- For all the wavelengths an increase in its temperature causes increase in energy.
- The total energy emitted at any particular temperature can be calculated from the area under that particular curve.

3.3 CLASSICAL LAWS FOR BLACK BODY RADIATION

3.3.1 Stefan- Boltzmann law

According to this law the radiant energy (E) of the body is directly proportional to the fourth power of the temperature (T) of the body.

$$E \propto T^4$$

$$E = \sigma T^4$$

Where, σ is called as Stefan's constant. It is given by $\sigma = \frac{2\pi^5 K^4}{15h^3C^2} = 5.67x10^{-8} Wm^{-2}K^{-4}$

3.3.2 Wien's displacement law

This law states that the product of then wavelength maximum energy and the absolute temperature (T) is a constant.

$$\lambda_m T = \text{constant}$$

$$\lambda_m T = \text{b}$$

Where b is called as Wien's constant. It's value is 2.897×10^{-3} m K.

This law shows that, as the temperature increases, the wavelength corresponding to maximum energy decreases.

Wien also showed that the maximum energy (E_m) is directly proportional to the fifth power of the absolute temperature.

$$E_m \propto T^5$$

$$E_m = const.T^5$$

By deducing this law he obtained a law called Wien's law of distribution of energy (E_λ), given by

$$E_\lambda = C_1 \lambda^{-5} \exp\left[\frac{-C_2}{\lambda T}\right]$$

Where, $C_1 = 8\pi hc$ and $C_2 = \frac{hc}{K}$

C_1& C_2 are called as constants.

This law is very good agreement for shorter wavelengths and not for longer wavelengths.

3.3.3 Rayleigh Jean's law

The energy distribution is directly proportional to the absolute temperature and is inversely proportional to the fourth power of the wavelength. It is governed by the equation,

$$E_\lambda \propto \frac{T}{\lambda^4}$$

$$E_\lambda = \frac{8\pi KT}{\lambda^4}$$

Where, K is Boltzmann Constant.

This law holds well only for longer wavelength regions and not for shorter wavelengths.

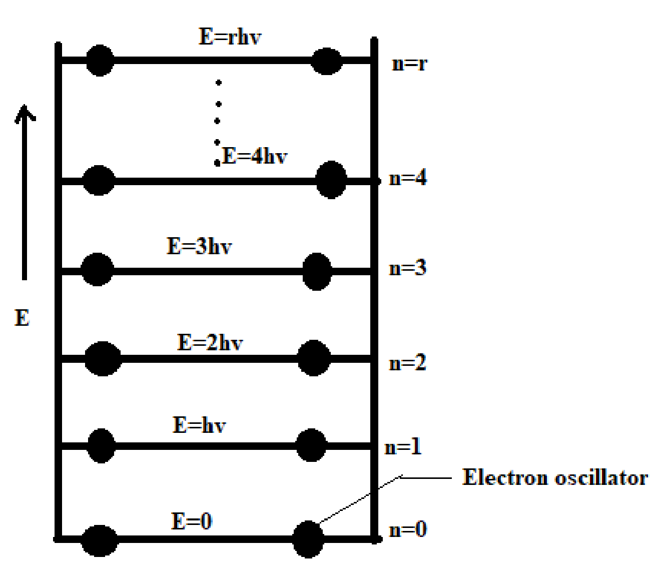
It is found that, both Wien's and Raleigh Jeans law don't agree with the experimental results. Therefore we can conclude that the classical theory was not able to explain the emission of black body radiation. Thus Max Planck used Quantum theory to explain Black body radiation.

3.4 PLANCK'S LAW FOR BLACK BODY RADIATION

Planck suggested that the correct results could be obtained if the energy of oscillating electrons is taken as discrete rather than continuous. He suggested quantum theory of radiation. Planck suggested in deriving the formula, which agrees extremely well with experimental results. He derived the radiation law by using the following assumptions.

3.4.1 Planck's hypothesis or assumptions

- A black body chamber is filled up not only with radiation, but also with simple harmonic oscillators or harmonic oscillators or resonators of molecular dimensions.
- They can vibrate with all possible frequencies.
- The frequency of radiation emitted by an oscillator is the same as the frequency of its vibration.
- An oscillator cannot emit energy in a continuous manner. It can emit energy in the multiples of a small unit called Quantum (Photon).



3.3 Blackbody radiator

- If an oscillator is vibrating with a frequency γ, it can radiate in quanta's of magnitude hυ. The oscillator can have only discrete energy given by,

$$E = nh\nu$$

Where, n=0, 1, 2, 3………r

The emission of radiation corresponds to a decrease and absorption to an increase in the energy and amplitude of an oscillator.

3.4.2 Statement

The energy density of heat radiation emitted from an enclosure at temperature T in the wavelength range from λ to λ + dλ is given by

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5\left[\exp\left(\frac{h\nu}{KT}\right)-1\right]}d\lambda$$

Here h = Planck's constant

C= speed of the light

K= Boltzmann constant

T = temperature of the enclosure

3.4.3 Derivation

Let E_T be the total energy of the blackbody radiator and N be the total number of oscillators. Then the average energy of the radiator is given by

$$\overline{E} = \frac{E_T}{N} \text{ --(1)}$$

Let N_0, N_1, N_2, N_3…… are the number of oscillators in different energy levels. The total number of oscillators can be calculated by adding number of oscillators in each energy level.

$$N = N_0 + N_1 + N_2 + N_3 \ldots\ldots\ldots \text{ --------------------------(2)}$$

According to Maxwell- Boltzmann distribution law, the number of particles can be calculated by using the relation,

$$N_r = N_0 e^{-rE/KT} \text{ -----------------------------------(3)}$$

Where, r=0, 1, 2, 3……

For, r=0, $N_0 = N_0 e^{-0E/KT} = N_0$

r=1, $N_1 = N_0 e^{-E/KT}$

r=2, $N_2 = N_0 e^{-2E/KT}$

r=3, $N_3 = N_0 e^{-3E/KT}$

----------------(4)

Subs. Eqns 4 in eqn 3

$$N = N_0 + N_0 e^{-E/KT} + N_0 e^{-2E/KT} + N_0 e^{-3E/KT} + ...$$

$$N = N_0\left[1 + e^{-E/KT} + e^{-2E/KT} + e^{-3E/KT} + ...\right] \text{---------(5)}$$

Put, $x = e^{-E/KT}$

Eqn 5 becomes

$$N = N_0\left(1 + x + x^2 + x^3 + ...\right) \text{------------------------------(6)}$$

Using binomial theorem,

$$\left(1 + x + x^2 + x^3 + ...\right) = \frac{1}{1-x} \text{------------------------------(7)}$$

Subs. Eqn 7 in 6, we get,

$$N = \frac{N_0}{1-x} \text{--(8)}$$

Let 0, E, 2E, 3E…………are the energies of oscillator N_0, N_1, N_2, N_3……..respectively. Total energy can be calculated by multiplying oscillator and its energy.

$$E_T = N_0(0) + N_1 E + N_2(2E) + N_3(3E) + ... \text{-----------(9)}$$

Subs. Eqn 4 in 9

$$E_T = 0 + N_0 e^{-E/KT} E + 2N_0 e^{-2E/KT} E + 3N_0 e^{-3E/KT} E + ...$$

$$E_T = N_0 E e^{-E/KT}\left(1 + 2e^{-E/KT} + 3e^{-2E/KT} + ...\right)$$

Or

$$E_T = N_0 E x\left(1 + 2x + 3x^2 + ...\right) \text{---------------------------(10)}$$

Using binomial theorem,

$$\left(1 + 2x + 3x^2 + ...\right) = \frac{1}{(1-x)^2} \text{----------------------------(11)}$$

$$E_T = \frac{N_0 E x}{(1-x)^2} \text{--(12)}$$

Subs eqn 8 & 12 in eqn 1, we get,

$$\overline{E} = \frac{\left[\frac{N_0 Ex}{(1-x)^2}\right]}{\left[\frac{N_0}{1-x}\right]} \Rightarrow \frac{Ex}{1-x} \Rightarrow \left[\frac{E}{\frac{1-x}{x}}\right] \Rightarrow \left[\frac{E}{\frac{1}{x}-1}\right] \text{------------(13)}$$

Subs. x value in eqn 13, we get

$$\left[\frac{E}{\frac{1}{e^{\frac{-E}{KT}}}-1}\right] \Rightarrow \left[\frac{E}{e^{\frac{E}{KT}}-1}\right] \text{--(14)}$$

We know, $E = h\nu$

Eqn 14 becomes,

$$\overline{E} = \left[\frac{h\nu}{e^{\frac{h\nu}{KT}}-1}\right] \text{--(15)}$$

Equation 15 represents average energy of the oscillator.

Number of oscillator with in the frequency range ν and $\nu + d\nu$ is given by

$$N = \frac{8\pi\nu^2}{c^3} d\nu \text{ --(16)}$$

The product of average energy of oscillator and number of oscillator is called as energy density ($E_\lambda d\lambda$)

Energy density ($E_\nu d\nu$) = Average energy of an oscillator X number of oscillator

$$E_\nu d\nu = \overline{E} X N$$

$$= \left(\frac{8\pi\nu^2}{c^3}\right)\left(\frac{h\nu}{e^{\frac{h\nu}{KT}}-1}\right) d\nu$$

$$E_\nu d\nu = \left(\frac{8\pi\nu^2}{c^3}\right)\left(\frac{h\nu}{e^{\frac{h\nu}{KT}}-1}\right) d\nu$$

$$E_\nu = \left(\frac{8\pi h\nu^3}{c^3}\right)\left(\frac{1}{e^{\frac{h\nu}{KT}}-1}\right) \text{-----------------------------------(17)}$$

Equation 17 is called as Planck's radiation law in terms of frequency.

3.4.4 Planck's law in terms of wavelength

We know that, $\nu = \frac{c}{\lambda}$

Differentiating with respect to λ

$$dv = \frac{-c}{\lambda^2} d\lambda$$

– symbol is omitted by taking modulus

$$= \frac{c}{\lambda^2} d\lambda$$

Sub. the values of *v* & *dv* in (8)

$$E_\lambda d\lambda = \left(\frac{8\pi \frac{c^2}{\lambda^2}}{c^3} \right) \left(\frac{c}{\lambda^2} d\lambda \right) \left(\frac{h \frac{c}{\lambda}}{e^{\frac{hc}{\lambda KT}} - 1} \right)$$

$$E_\lambda = \left(\frac{8\pi hc}{\lambda^5} \right) \left(\frac{1}{e^{\frac{hc}{\lambda KT}} - 1} \right)$$ ------------------------(18)

Equation 18 is called as Planck's radiation law in terms of wavelength.

3.4.5 Deductions

(a) Wien's law from Planck's law

This law is very good agreement for shorter wavelength. If wavelength λ is small, frequency υ is higher.

Hence, $\frac{h\nu}{KT} >> 1$ and $e^{\frac{h\nu}{KT}} >> 1$

Then 1 is neglected in denominator.

$$E_\lambda = \left(\frac{8\pi hc}{\lambda^5} \right) \left(\frac{1}{e^{\frac{hc}{\lambda KT}}} \right)$$

$$= (8\pi hc)\lambda^{-5}\left(\exp\left(\frac{hc}{\lambda KT} \right) \right)$$

$$E_\lambda = C_1 \lambda^{-5} \exp\left[\frac{-C_2}{\lambda T} \right]$$

--(19)

Where, $C_1 = 8\pi hc$ and $C_2 = \frac{hc}{K}$

(b) Rayleigh-Jean's law from Planck's law

This law holds well only for longer wavelength regions and not for shorter wavelengths. If wavelength λ is high, frequency υ is low.

Hence, $\frac{h\nu}{KT} << 1$ and

$$e^{\frac{h\nu}{KT}} = 1 + \frac{h\nu}{KT}$$ (Using exponential series)

$$E_\lambda = \left(\frac{8\pi hc}{\lambda^5}\right)\left(\frac{1}{1+\frac{h\nu}{KT}-1}\right)$$

$$E_\lambda = \left(\frac{8\pi hc}{\lambda^5}\right)\left(\frac{1}{\frac{hc}{\lambda KT}}\right) \quad (\nu = \frac{c}{\lambda})$$

$$E_\lambda = \left(\frac{8\pi KT}{\lambda^4}\right)$$ ---(20)

From equations 19 & 20 Planck's radiation law is holds good for all wavelength.

3.5 PHOTON AND ITS PROPERTIES

Definition

A photon is the smallest discrete amount or quantum of electromagnetic radiation. It is the basic unit of all light.

Photons are always in motion and, in a vacuum, travel at a constant speed to all observers of 2.998 x 108 m/s. This is commonly referred to as the speed of light, denoted by the letter c.

As per Einstein's light quantum theory, photons have energy equal to their oscillation frequency times Planck's constant. Einstein proved that light is a flow of photons, the energy of these photons is the height of their oscillation frequency, and the intensity of the light corresponds to the number of photons. Essentially, he explained how a stream of photons can act both as a wave and particle.

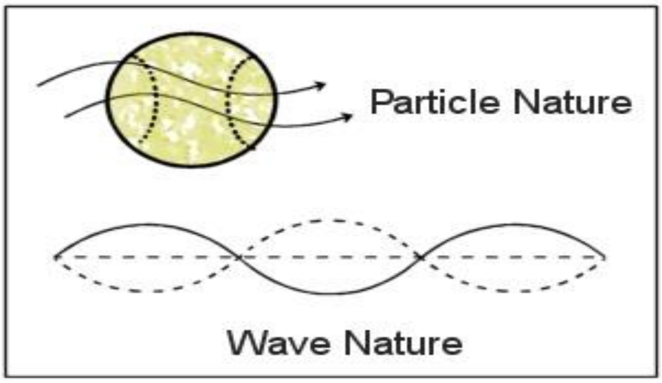
Properties

- The energy of a photon is given as $E=h\nu$, here, ν is the frequency and h is the Planck's constant.
- We know that speed of light is given by c = 3 x 10^8 m/s. Therefore, the speed of the photon is also equal to c = 3 x 10^8 m/s.
- The rest mass of the photon is zero.
- Photons are stable particles.
- They do not have any electric charge.
- Photons are not affected by the magnetic field and electric field.
- Irrespective of the intensity of the radiation, every photon of frequency ν has the momentum, $p=h\nu/c$ and energy $E=h\nu$

- The dynamic mass of the photon is $m = E/c^2$, where E is the energy of the photon.
- Photons can interact with other particles like electrons, which can be seen in Compton effect.
- Photons can be created or destroyed when the radiation is emitted or absorbed.
- During photon-electron collision, the momentum and total energy are conserved.
- Photons do not decay on their own.
- The energy possessed by the photon can be transferred to other particles when it interacts with other particles.
- Photons only exist as moving particles.
- Photons are particles with a spin 1. Its spin direction is parallel to the direction of travel.

3.6 DUAL NATURE OF PARTICLE OR WAVE-PARTICLE DUALITY OR MATTER WAVES

The true nature of light is difficult to assess. Experiments showed that light exhibited wavelike properties of diffraction and interference. On the other hand, photoelectric effect indicates that light has the aspects of a particle photon, with both energy and momentum. Thus light exhibits a wave-particle duality.



3.8 Wave particle duality

The wave-particle duality was extended to particles as matter waves by Louis de Broglie. His theoretical study on the nature of particles and waves led to the invention of a new mechanics of particles called quantum mechanics.

3.6.1 MATTER WAVES

The radiant energy has dual aspects of particle and wave; hence a natural question arises, if radiation has a dual nature, why not the matter. In 1924, a French Physicist Louis de Broglie put forward the bold hypothesis that moving particles should possess wave like properties under suitable conditions. He reasoned this idea, from the fact, that nature is symmetrical and hence the basic physical entities matter and energy should have symmetrical characters. If radiation shows dual aspects, so should matter.

3.6.2 LOUIS DE BROGLIE HYPOTHESIS

1. Nature loves symmetry
2. There is a closed parallelism between mechanics and optics

Explanation:

In classical mechanics, Maupertuis's principle states that "the path followed by a physical system is the one of least length". This statement is called as principle of least action.

Example: when a ball throw in space, it choose straight path.

In optics, Fermat's principle states that "light travels between two points along the path that requires the least time, as compared to other nearby paths." This statement is called as principle of least action in optics.

Example: when a torch light is switched ON, the light ray choose straight path.

3. Integer rule used

Explanation:

In classical mechanics, According to Bohr's atomic model, the angular momentum of electron orbiting around the nucleus is quantized. He further added that electrons move only in those orbits where angular momentum of an electron is an integral multiple of $h/2\pi$.

$\omega = nh/2\pi$ (n=0, 1,2, 3………..)

In optics, the integral multiple of half wavelength is equal to length of the wire used.

$L = n\lambda/2$ (n=0, 1,2, 3………..)

3.6.3 DE BROGLIE'S WAVELENGTH OF MATTER WAVES-DERIVATION

From the theory of light, considering a photon as a particle the total energy of the photon is given by

$$E=mc^2 \text{--}(1)$$

Where m is the mass of the particle and c is the velocity of light

Considering the photon as a wave, the total energy is given by

$$E = h\nu \text{--}(2)$$

Where h is the Planck's constant, ν is the frequency of the radiation.

From equations (1) and (2)

$$E = h\nu = mc^2 = mc.c \text{ ----------------------------------}(3)$$

We know Momentum, p = Mass × velocity,

$$p = mc,$$

hv = pc

$$\frac{h}{p} = \frac{c}{v} = \lambda \text{ --(4)}$$

De-Broglie suggested that the equation 4 can be applied both for photons and material particles. If m is the mass of the particle and v is the velocity the particle, then

Momentum p = mv

De-Broglie wavelwngth, $\lambda = \frac{h}{mv}$ --(5)

This is expression for wavelength of matter waves.

a. De-Broglie wavelength in terms of energy

We know, kinetic energy, $E = \frac{1}{2} mv^2$,

$2E = mv^2$

Multiply by m on both sides,

$2mE = m^2v^2$

Taking root on both sides, $mv = \sqrt{2mE}$ ----------------------------(6)

Subs. eqn. 6 in 5 we get,

$$\lambda = \frac{h}{\sqrt{2mE}} \text{ ----------------------------(7)}$$

b. De-Broglie wavelength in terms of voltage

If an electron of charge e is accelerated by a potential difference of V volts, then the electron gains a velocity v and hence,

Work done on the electron = eV---(8)

Kinetic energy of electron = $\frac{1}{2} mv^2$---------------------------------------(9)

Equating eqns 8 & 9

$\frac{1}{2} mv^2 = eV$,

$mv^2 = 2eV$,

Multiply by m on both sides

$m^2v^2 = 2meV$

Taking root on both sides, $mv = \sqrt{2meV}$ --------------------------------(10)

Subs. eqn 10 in eqn 5 we get,

$$\lambda = \frac{h}{\sqrt{2meV}} \text{ ---------------------------------------(11)}$$

c. De-Broglie wavelength in terms of temperature

According to Maxwell Boltzmann statistics, an electron is considered as gas.

Kinetic energy of electron gas = $\frac{3}{2}$ KT---------------------------------(12)

Kinetic energy of electron, $= \frac{1}{2}$ mv^2-----------------------------------(13)

Equating eqns 12 & 13

$$\frac{1}{2} mv^2 = \frac{3}{2} KT ,$$

$$mv^2 = 3KT,$$

Multiply by m on both sides

$$m^2v^2 = 3mKT$$

Taking root on both sides, $mv = \sqrt{3mKT}$ --------------------------------(14)

Subs. eqn 14 in eqn 5 we get,

$$\lambda = \frac{h}{\sqrt{3mKT}} \quad \text{----------------------------------(15)}$$

3.6.4 PROPERTIES OF MATTER WAVES

- If the mass of the particle is smaller, then the wavelength associated that particle is higher.
- If the velocity of the particle is smaller, then the wavelength associated that particle is higher.
- If v=0, then λ=∞ , the wave become indetermine and v=∞, then λ=0. This indicates that the matter waves are generated by moition of the particles.
- These waves does not depends on charge of the particles. So these are not a electromagnetic waves.

3.7 SCHRODINGER'S WAVE EQUATIONS

Schrodinger wave equation is a mathematical expression describing the energy and position of the electron in space and time, taking into account the matter wave nature of the electron inside an atom. These equations were presented by Ervin Schrodinger in 1925.

It is based on three considerations. They are;

- Classical plane wave equation,
- Broglie's Hypothesis of matter-wave, and
- Conservation of Energy.

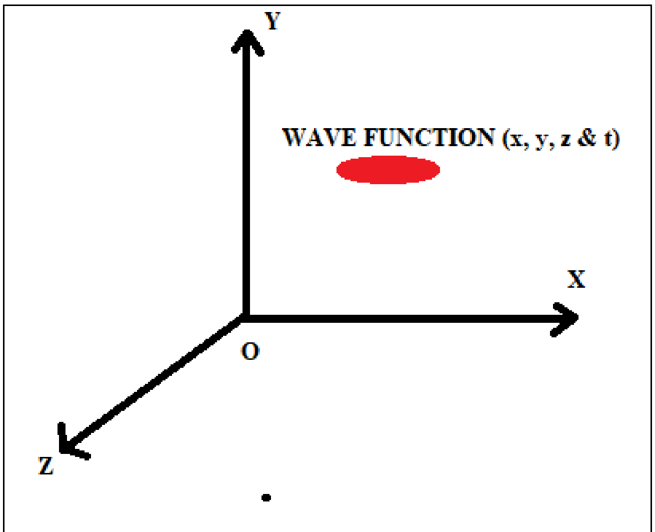
Schrodinger equation gives us a detailed account of the form of the wave functions or probability waves that control the motion of some smaller particles. The equation also describes how these waves are influenced by external factors. Moreover, the equation makes use of the energy conservation concept that offers details about the behaviour of an electron that is attached to the nucleus.

There are two equations, which are

- Schrodinger time-independent Schrödinger equation and
- Schrodinger time-dependent Schrödinger equation

3.7.1 Schrodinger's Time Independent Wave Equation

It is a second order differential wave equation. Let us consider a particle of mass (m) moving with velocity (v) at time (t) along x, y and z directions in space. Let O be the origin.



3.9 Wave function

According to classical wave equation,

$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}=\frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} \text{ ------(1)}$$

We use wave function ψ instead of displacement 'u'.

$$\frac{\partial^2 \psi}{\partial x^2}+\frac{\partial^2 \psi}{\partial y^2}+\frac{\partial^2 \psi}{\partial z^2}=\frac{1}{c^2}\frac{\partial^2 \psi}{\partial t^2}$$

$$\nabla^2\psi=\frac{1}{c^2}\frac{\partial^2 \psi}{\partial t^2} \text{ -----------------------------------(2)}$$

Where,

∇ be the Laplacian operator $\left(\nabla^2=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)$

'c' be speed of light

'ψ' be the wave function (i.e. It is variable quantity which describes the wave nature of the particles)

Solution of the above equation is given by.

$$\psi=\psi_0 e^{-i\omega t} \text{ ------------------------------(3)}$$

Where,

'ψ_0' be the amplitude of the wave, 'ω' be the angular frequency

Differentiating twice the eqn 3 with respect to 't'

$$\frac{\partial^2\psi}{\partial t^2} = -i\omega . -i\omega . \psi_0 e^{-i\omega t}$$

$$\frac{\partial^2\psi}{\partial t^2} = i^2\omega^2\psi \qquad [i^2 = -1]$$

$$\frac{\partial^2\psi}{\partial t^2} = -\omega^2\psi \text{ ----------------------------(4)}$$

Subs. Eqn 4 in eqn 2

$$\nabla^2\psi = \frac{-\omega^2}{c^2}\psi \text{ ---(5)}$$

We know angular frequency, $\omega = 2\pi\nu$

Squaring we get, $\omega^2 = 4\pi^2\nu^2$ ---------------------(6)

Subs eqn 6 in 5 we get

$$\nabla^2\psi = -4\pi^2\frac{\nu^2}{c^2}\psi \left[c = \nu\lambda : \lambda = \frac{c}{\nu}\right]$$

$$\nabla^2\psi = -\frac{4\pi^2}{\lambda^2}\psi$$

$$\nabla^2\psi + \frac{4\pi^2}{\lambda^2}\psi = 0 \text{ --(7)}$$

According to De-Broglie wave length of matter waves given by

$$\lambda = \frac{h}{mv}$$

Squaring above equation, we get

$$\lambda^2 = \frac{h^2}{m^2v^2} \text{ --(8)}$$

Subs eqn 8 in 7

$$\nabla^2\psi + \left[\frac{4\pi^2}{\left(\frac{h^2}{m^2v^2}\right)}\right]\psi = 0$$

$$\nabla^2\psi + \frac{4\pi^2 m^2 v^2}{h^2}\psi = 0 \text{ ----------------------(9)}$$

According to law of conservation of energy, total energy of the particle can be calculated by summing potential energy and kinetic energy.

Total energy= potential energy + kinetic energy

$$E = V + \frac{1}{2}mv^2$$

Rearranging we get

$$E = V + \frac{1}{2}mv^2$$

Multiplying by 'm' on both sides in above equation

$$2m(E - V) = m^2v^2 \text{ --------(10)}$$

Subs. eqn 10 in 9 we get

$$\nabla^2\psi + \frac{4\pi^2(2m(E-V))\psi}{h^2} = 0$$

$$\nabla^2\psi + \frac{8\pi^2 m(E-V)\psi}{h^2} = 0 \text{ --------------------(11)}$$

But, Reduced Planck's constant, $\hbar = \frac{h}{2\pi}$

Squaring the above equation

$$\hbar^2 = \frac{h^2}{4\pi^2} \text{ or } h^2 = 4\pi^2\hbar^2$$

Equation 11becomes,

$$\nabla^2\psi + \frac{2m(E-V)\psi}{\hbar^2} = 0 \text{ -----------------------(12)}$$

Equations 11 and 12 are called as Schrodinger's time independent wave equation.

3.7.2 Schrodinger's Time Dependent Wave Equation

Schrodinger's Time Dependent Wave Equation can be derived from Schrodinger's time independent wave equation by eliminating energy E value.

The solution of second order differential wave equation is given by

$$\psi = \psi_0 e^{-i\omega t} \text{ ------------------------------(1)}$$

Differentiating the eqn 1 with respect to 't'

$$\frac{\partial \psi}{\partial t} = -i\omega.\psi_0 e^{-i\omega t}$$

$$\frac{\partial \psi}{\partial t} = -i\omega.\psi \text{ ---------------------------(2)}$$

We know

Angular frequency, $\omega=2\pi\nu$-----------------------------------(3)

Subs eqn 3 in 2, we get

$$\frac{\partial \psi}{\partial t} = -i(2\pi\nu)\psi \text{ ------------------(4)}$$

We know, photons of energy, $E=h\nu$

Or $\nu = \frac{E}{h}$---(5)

Subs. Eqn 5 in 4

$$\frac{\partial \psi}{\partial t} = -i(\frac{2\pi E}{h})\psi \text{ ------------------------(6)}$$

We know, $\hbar^2 = \frac{h^2}{4\pi^2}$ or $h^2 = 4\pi^2\hbar^2$

Eqn 6 becomes,

$$\frac{\partial \psi}{\partial t} = -i\left(\frac{2\pi E}{2\pi\hbar}\right)\psi$$

$$\frac{\partial \psi}{\partial t} = -i\left(\frac{E}{\hbar}\right)\psi \text{ --------------------------------------(7)}$$

Multiplying by 'i' on both sides

$$i\frac{\partial \psi}{\partial t} = -iXi\left(\frac{E}{\hbar}\right)\psi$$

$$i\hbar\frac{\partial\psi}{\partial t} = E\psi \text{ ------------------------------(8)}$$

We know Schrodinger’s time independent wave equation for matter waves is given by,

$$\nabla^2\psi + \frac{2mE\psi}{\hbar^2} - \frac{2mV\psi}{\hbar^2} = 0$$

$$\nabla^2\psi + \frac{2mE\psi}{\hbar^2} = \frac{2mV\psi}{\hbar^2} \text{ ------------(9)}$$

Subs eqn 8 in eqn 9

$$\nabla^2\psi + \frac{2m}{\hbar^2}\left(i\hbar\frac{\partial\psi}{\partial t}\right) = \frac{2mV\psi}{\hbar^2} \text{ ----------(10)}$$

Multiplying by $\frac{2m}{\hbar^2}$ on both sides

$$\frac{2m}{\hbar^2}(\nabla^2\psi) + \frac{2m}{\hbar^2}.\frac{2m}{\hbar^2}\left(i\hbar\frac{\partial\psi}{\partial t}\right) = \frac{2m}{\hbar^2}.\frac{2mV\psi}{\hbar^2}$$

$$\frac{2m}{\hbar^2}(\nabla^2\psi) + \left(i\hbar\frac{\partial\psi}{\partial t}\right) = V\psi$$

Rearranging, $i\hbar\frac{\partial\psi}{\partial t} = -\frac{2m}{\hbar^2}(\nabla^2\psi) + V\psi$

$$E\psi = H\psi$$

E is known as energy operator and

$$E = i\hbar\frac{\partial}{\partial t}$$

H is know as Hamiltonian operator

$$H = -\frac{2m}{\hbar^2}(\nabla^2 + V)$$

Equation 11 is called as Schrodinger’s time dependent wave equation.

3.7.3 PHYSICAL SIGNIFICANCE OF WAVE FUNCTION (Ψ)

- The variable quantity that characterizes d-Broglie wave is called wave function .
- The wave function represents the variations in the matter waves and it connects the particle nature and its associated wave nature statistically.

- The wave function associated with a moving particle at a particular instant of time and at a particular point in space is related to the probability of finding the particle at that instant and at that point.
- The probability 0 corresponds to the certainty of not finding the particle and probability 1 corresponds to the certainty of finding the particle.

If particle is present, $\iiint \psi^* \psi d\tau = 1$

If particle is absent, $\iiint \psi^* \psi d\tau = 0$

- The wave function is a complex quantity that cannot be measured.
- The probability of finding a particle at particular region must be real and positive, but the wave function ψ is in general a complex quantity.

3.7.3 Application of Schrodinger's wave equation: Particle in a one dimensional rigid box or potential box

Let us consider particle (electron) of mass 'm' moving along the x-axis, enclosed in a one dimensional potential box as shown in the figure.

Since the walls are of infinite potential the particle does not penetrate out from the box.

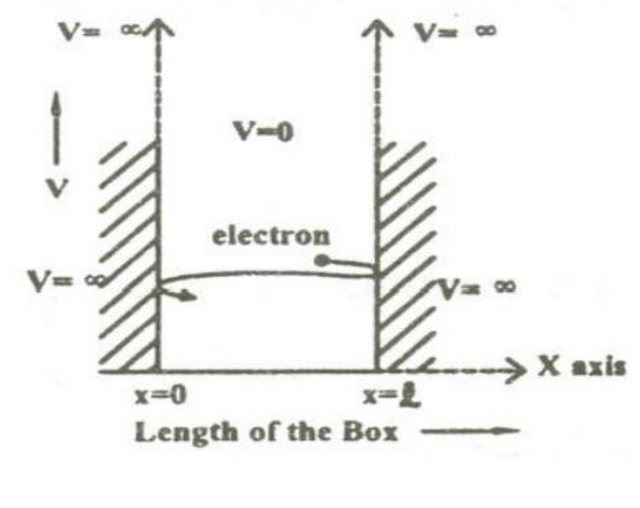
Also, the particle is confined between the length 'l' of the box and has elastic collisions with the walls. Therefore, the potential energy of the electron inside the box is constant and can be taken as zero for simplicity.

We can say that the Outside the box and on the wall of the box, the potential energy V of the electron is .

Inside the box the potential energy (V) of the electron is zero.

In other words we can write the boundary condition as

$$V = 0 \; for \; 0 < x < l$$
$$V = \infty \; for \; 0 \geq x \geq l$$



3.10 Particle in 1 D box

To find the wave function of the particle within the box of length 'l', let us consider the Schrodinger time independent wave equation for one dimensional.

$$\frac{\partial^2\psi}{\partial x^2}+\frac{8\pi^2 m(E-V)\psi}{h^2}=0$$ ----------------------------------(1)

But inside the box potential energy V=0

Equation 1 becomes

$$\frac{\partial^2\psi}{\partial x^2}+\frac{8\pi^2 mE\psi}{h^2}=0$$

$$\frac{\partial^2\psi}{\partial x^2}+k^2\psi=0$$ ---(2)

Where,

$$k^2=\frac{8\pi^2 mE}{h^2}$$ --(3)

Equation 2 is second order differential equation. Solution of equation 2 is given by

$\psi(x)=A\sin kx+B\cos kx$---------------------------------------(4)

Where A and b are called Arbitrary constants, which can be found by applying the boundary conditions.

$$V=0\ for\ 0<x<l$$

Boundary condition 1: at x=0, $\psi(x)=0$

Subs these boundary condition in eqn 4,

$0=A\sin k(0)+B\cos k(0)$

B=0---(5)

Boundary condition 2: at x=l, $\psi(x)=0$

Subs these boundary condition in eqn 4,

$0=A\sin k(l)+B\cos k(l)$ (B=0)

$0=A\sin k(l)$

$A\neq 0$ but ,Sinkl = 0, --------------------------------(6)

We know,

$\sin\pi=\sin 2\pi=\sin 3\pi=.............\sin n\pi=0$ ------------- (7)

Comparing equations 6 and 7

$n\pi=kl$

Or, $k = \frac{n\pi}{l}$ --(8)

Subs.eqns 5, 8 in 4

$$\psi(x) = A\sin\left(\frac{n\pi x}{l}\right) \text{ --(9)}$$

Equation 9 is called as Eigen function.

Energy of electron:

Squaring eqn 8

$$k^2 = \frac{n^2\pi^2}{l^2} \text{ ---(10)}$$

Equating equations 3 &10

$$\frac{8\pi^2 mE}{h^2} = \frac{n^2\pi^2}{l^2}$$

$$E = \frac{n^2 h^2 \pi^2}{8\pi^2 m l^2}$$

$$E = \frac{n^2 h^2}{8ml^2} \text{ --(11)}$$

Equation 11 is called as Eigen energy value.

3.7.4 Normalization of wave function:

It is the process by which the probability (P) of finding the particle (electron) inside the box can be done.

We know that the total probability (P) is equal to 1 means then there is a particle inside the box.

Probability, $P = \int_0^l \psi * \psi dx = 1$

$$P = \int_0^l \psi^2 dx = 1 \text{ -----------------------------------(12)}$$

Subs eqn 9 in 12

$$P = \int_0^l \left[A\sin\left(\frac{n\pi x}{l}\right)\right]^2 dx = 1$$

$$\int_0^l \left[A^2 \sin^2\left(\frac{n\pi x}{l}\right)\right] dx = 1$$

$$A^2 \int_0^l \left[\sin^2\left(\frac{n\pi x}{l} \right) \right] dx = 1$$ ---------------(13)

We know, $\sin^2 x = \frac{1-\cos 2x}{2}$

Equation 13 can be written as

$$A^2 \int_0^l \left[\left(\frac{1-\cos 2\left(\frac{n\pi x}{l} \right)}{2} \right) \right] dx = 1$$

$$A^2 \int_0^l \left[\left(\frac{1}{2} - \frac{\cos 2\left(\frac{n\pi x}{l} \right)}{2} \right) \right] dx = 1$$

Integrating, we get

$$A^2 \left[\frac{x}{2} - \frac{1}{2} \cdot \frac{\sin(2n\pi x/l)}{2n\pi x/l} \right]_0^l = 1$$

But sin nπ=0, so

$$A^2 \left[\frac{x}{2} \right]_0^l = 1$$

$$A^2 \left[\frac{l}{2} \right] = 1$$

Or, $A = \sqrt{\frac{2}{l}}$ --(14)

Subs eqn 14 in eqn 9

$$\psi(x) = \sqrt{\frac{2}{l}} \sin\left(\frac{n\pi x}{l} \right)$$ --(15)

3.7.5 Energy levels of an electron:

For various values of 'n' we get various energy values of the electron. The lowest energy value or ground state energy value can be got by substituting different 'n' in equation (11)

$$E_n = \frac{n^2h^2}{8ml^2} \text{ ---------------------------------(11)}$$

For n=1, $E_1 = \frac{1^2h^2}{8ml^2} = \frac{h^2}{8ml^2}$

For n=2, $E_2 = \frac{2^2h^2}{8ml^2} = \frac{4h^2}{8ml^2} = 4E_1$ --------(16)

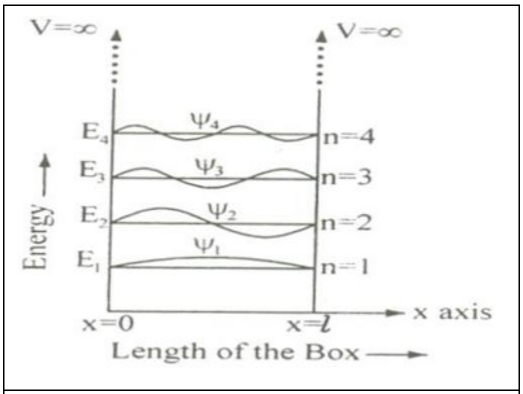
For n=3, $E_3 = \frac{3^2h^2}{8ml^2} = \frac{9h^2}{8ml^2} = 9E_1$

In general we can write the Eigen energy value,

$$E_n = n^2E_1 \text{ ---------------------------(17)}$$

It is found that from the energy levels E_1, E_2, E_3……… etc the energy levels of an electron are discrete.

This is the great success which is achieved in Quantum Mechanics than classical mechanics, in which the energy levels are found to be continuous.



3.11 Energy levels of an electron

The various energy Eigen values and their corresponding Eigen functions of an electron enclosed in a one dimensional box is as shown in the figure. Thus we have discrete energy values.

For three dimensional potential box, Eigen function and Eigen energy value can be written as,

$$\psi_{(n_x,n_y,n_z)} = A^3 \sin\frac{n_x\pi x}{l}.\sin\frac{n_y\pi y}{l}.\sin\frac{n_z\pi z}{l}$$

$$E_{(n_x,n_y,n_z)} = \frac{h^2}{8ml^2}(n_x^2 + n_y^2 + n_z^2)$$

Where,

n_x, n_y, n_z are called as quantum numbers.

3.8 DEGENERATE AND NON DEGENERATE STATES

Degeneracy:

For several combinations of quantum numbers we have same energy Eigen value but different Eigen functions. Such states and energy levels are called Degenerate state.

The three combinations of quantum numbers (112), (121) and (211) which gives same Eigen value but different Eigen functions are 3 fold degenerate state.

Example: Eigen function can be calculated as,

$$\left.\begin{aligned}\psi_{(112)} &= A^3 \sin\frac{\pi x}{l}.\sin\frac{\pi y}{l}.\sin\frac{2\pi z}{l}\\ \psi_{(121)} &= A^3 \sin\frac{\pi x}{l}.\sin\frac{2\pi y}{l}.\sin\frac{\pi z}{l}\\ \psi_{(211)} &= A^3 \sin\frac{2\pi x}{l}.\sin\frac{\pi y}{l}.\sin\frac{\pi z}{l}\end{aligned}\right\} \quad \text{-----------------------}(1)$$

All the Eigen functions are differing from one another.

Eigen energy can be calculated as,

$$\left.\begin{aligned}E_{(112)} &= \frac{h^2}{8ml^2}(1^2+1^2+2^2) = \frac{6h^2}{8ml^2}\\ E_{(121)} &= \frac{h^2}{8ml^2}(1^2+2^2+1^2) = \frac{6h^2}{8ml^2}\\ E_{(211)} &= \frac{h^2}{8ml^2}(2^2+1^2+1^2) = \frac{6h^2}{8ml^2}\end{aligned}\right\} \quad \text{-----------------------}(2)$$

All the Eigen functions are same.

Non-degeneracy:

For several combinations of quantum numbers we have same energy Eigen value and same Eigen functions. Such states and energy levels are called Non degenerate state.

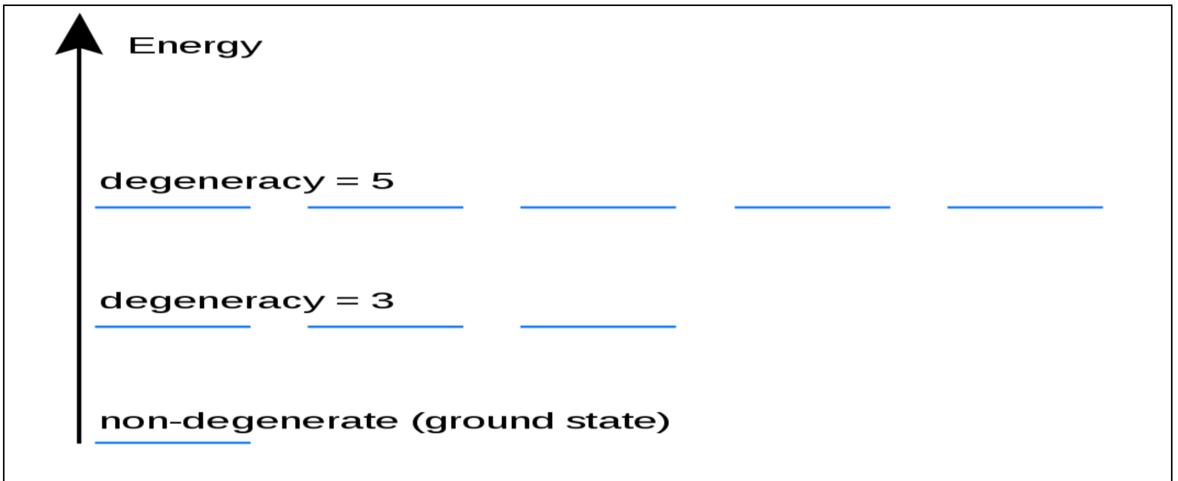
For different combinations of (111), (111), (111) we have,

$$\left.\begin{aligned}\psi_{(111)} &= A^3 \sin\frac{\pi x}{l}.\sin\frac{\pi y}{l}.\sin\frac{\pi z}{l}\\ \psi_{(111)} &= A^3 \sin\frac{\pi x}{l}.\sin\frac{\pi y}{l}.\sin\frac{\pi z}{l}\end{aligned}\right\} \quad \text{-----------------------}(3)$$

$$\psi_{(111)} = A^3 \sin\frac{\pi x}{l} . \sin\frac{\pi y}{l} . \sin\frac{\pi z}{l}$$

$$\left.\begin{aligned} E_{(111)} &= \frac{h^2}{8ml^2}(1^2 + 1^2 + 1^2) = \frac{3h^2}{8ml^2} \\ E_{(111)} &= \frac{h^2}{8ml^2}(1^2 + 1^2 + 1^2) = \frac{3h^2}{8ml^2} \\ E_{(111)} &= \frac{h^2}{8ml^2}(1^2 + 1^2 + 1^2) = \frac{3h^2}{8ml^2} \end{aligned}\right\} \text{---------------(4)}$$

Here different combinations of quantum numbers, all the Eigen function and Eigen energy values are same.



3.12 Degeneracy and Non degeneracy

3.9 PHOTO ELECTRIC EFFECT

3.9.1 Definition

Photoelectric emission is the phenomena by which a good number of substances, chiefly metals, emit electrons under the influence of radiation such as γ rays, X-rays, ultraviolet and even visible light.

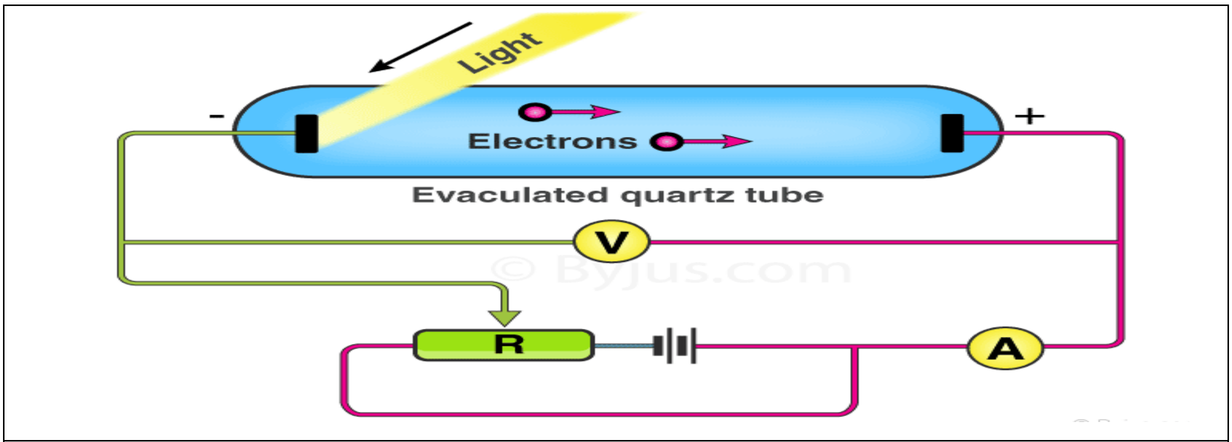
This effect was discovered by Heinrich Hertz in 1887 while working with resonance electrical circuits. A year later, Hallwachs, Elster and Geitel investigated the phenomenon with a simple experimental arrangement.

3.9.2 HALLWACH'S EXPERIMENT

Principle

Ejection of electron from the surface of metal, when light radiation hit the surface of material.

Construction



3.7 Photo electric effect – Experimental set up

- Hallwach's experimental set-up to study the photo electric effect is shown in Fig .
- It consists of an evacuated quartz bulb with two zinc plates cathode C and anode A.
- The plates are connected to a battery and a sensitive galvanometer. In the absence of any radiation incident on the plates, there is no flow of current and hence there is no deflection in the galvanometer.

Working

- When an electromagnetic radiation like ultraviolet radiation is allowed to fall on the plate C which is connected to the negative terminal of the battery, a current begins to flow, indicated by the deflection in the galvanometer (G).
- But, when ultraviolet radiation is made to fall on A, there is no deflection in the galvanometer.
- These observations reveal that the particles emitted by the plate C due to the photoelectric effect are negatively charged.
- These particles were found to be electrons. The observed current known as the photoelectric current is due to the flow of electrons.

After the study of photoelectric effect by Hallwach's, scientists J.J.Thomson, Lenard, Richardson, Compton did a series of experiments to study the relationship between photoelectric current, intensity of incident radiation, velocity and the kinetic energy of the photo electrons, and their dependence on the wave length of incident radiation used.

3.9.3 LAWS OF PHOTOELECTRIC EMISSION

The experimental observations on photoelectric effect may be summarized as follows, which are known as the fundamental laws of photoelectric emission.

1. For a given photo sensitive material, there is a minimum frequency called the threshold frequency, below which emission of photoelectrons stops completely, however great the intensity may be.
2. For a given photosensitive material, the photo electric current is directly proportional to the intensity of the incident radiation, provided the frequency is greater than the threshold frequency.
3. The photoelectric emission is an instantaneous process. i.e. there is no time lag between the incidence of radiation and the emission of photo electrons.
4. The maximum kinetic energy of the photo electrons is directly proportional to the frequency of incident radiation, but is independent of its intensity.

3.9.4 EINSTEIN'S PHOTOELECTRIC EQUATION

In 1905, the miracle year of Physics, Albert Einstein proposed an equation to explain this effect. Einstein argued that light was a wave that interacts with matter in the form of a packet of energy or a quantum of energy. This quantum of radiation was a photon and the equation was called Einstein’s photoelectric equation.

According to Einstein, the emission of photo electron is the result of the interaction between a single photon of the incident radiation and an electron in the metal. When a photon of energy hν is incident on a metal surface, its energy is used up in two ways:

1. A part of the energy of the photon is used in extracting the electron from the surface of metal, since the electrons in the metal are bound to the nucleus. This energy spent in releasing the photo electron is known as photoelectric work function of the metal. The work function (W) of a photo metal is defined as the minimum amount of energy required to liberate an electron from the metal surface.
2. The remaining energy of the photon is used to impart kinetic energy to the liberated electron.

If m is the mass of an electron and v, its velocity then, energy of the incident photon is equal to addition of work function and kinetic energy of the electron.

i.e.

$$h\nu = W + \frac{1}{2}mv^2 \text{ ---------------------------------------(1)}$$

If the electron does not lose energy by internal collisions, as it escapes from the metal, the entire energy (hν-W) will be exhibited as the kinetic energy of the electron. Thus, entire energy (hν-W) represents the maximum kinetic energy of the ejected photo electron. If v_{max} is the maximum velocity with which the photoelectron can be ejected, then

$$h\nu = W + \frac{1}{2} m v_{max}^2 \text{ -------------------------------------(2)}$$

This equation is known as Einstein's photoelectric equation.

When the frequency (ν) of the incident radiation is equal to the threshold frequency (ν_o) of the metal surface, kinetic energy of the electron is zero. Then equation (2) becomes,

$$h\nu_o = W \text{ ---(3)}$$

Substituting the value of W in equation (2) we get,

$$h\nu = h\nu_o + \frac{1}{2} m v_{max}^2$$

or

$$h\nu - h\nu_o = \frac{1}{2} m v_{max}^2$$

$$h(\nu - \nu_0) = \frac{1}{2} m v_{max}^2 \text{ ------------------------------------(4)}$$

This is another form of Einstein's photoelectric equation.

3.10. APPLICATIONS

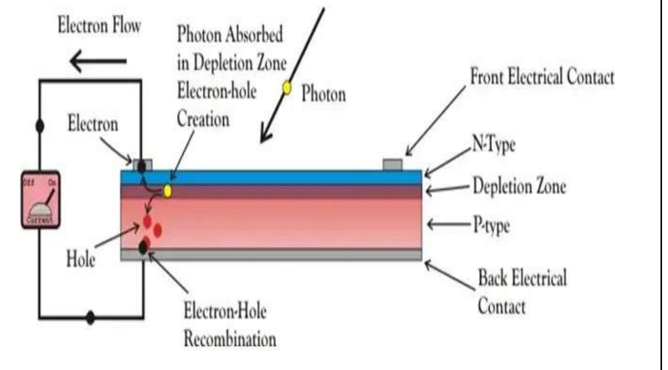
3.10.1 Solar Cell

A solar cell (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.

Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

Construction of Solar Cell

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.



3.8 Solar cell

These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell from any mechanical shock.

Working Principle of Solar Cell

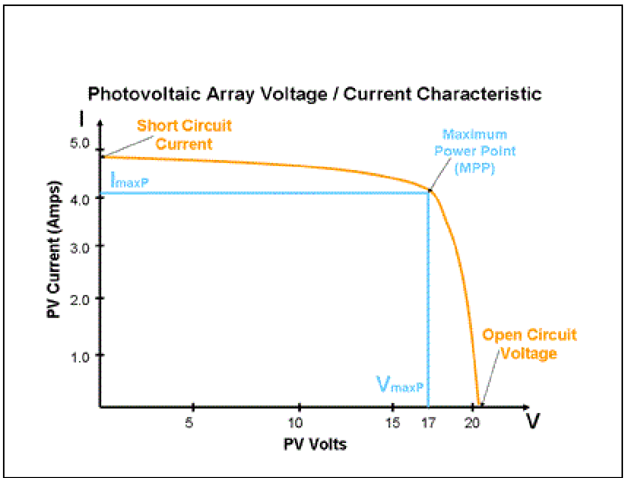
When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction.

Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

V-I Characteristics of a Photovoltaic Cell

The V-I Characteristics of a Photovoltaic Cell is shown in fig 3.9



3.9 V-I characteristics of Solar cell

Materials Used in Solar Cell

The materials which are used for this purpose must have band gap close to 1.5ev. Commonly used materials are-

1. Silicon.
2. GaAs.
3. CdTe.
4. CuInSe2

Criteria for Materials to be Used in Solar Cell

1. Must have band gap from 1ev to 1.8ev.
2. It must have high optical absorption.
3. It must have high electrical conductivity.
4. The raw material must be available in abundance and the cost of the material must be low.

Advantages of Solar Cell

1. No pollution associated with it.
2. It must last for a long time.
3. No maintenance cost.

Disadvantages of Solar Cell

1. It has high cost of installation.

2. It has low efficiency.
3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

Uses of Solar Generation Systems

1. It may be used to charge batteries.
2. Used in light meters.
3. It is used to power calculators and wrist watches.
4. It can be used in spacecraft to provide electrical energy.

3.10.2 Solar water heater

The solar water heater is one of the popular solar system devices that utilize solar energy. The solar water heater is a cheap yet cost-effective way to supply hot water for your home, and it also uses solar radiation or sunshine as fuel to heat water. We are blessed with unlimited solar power at no cost.

Though the solar water heater or solar water heating system is the cheapest method of heating water, we don't require to pay for the heat of the sun. It can be used for homes, hospitals, nursing homes, community centers, hotels, dairy plants, ashrams, hostels, swimming pools, canteens, and industries.

Construction

The solar water heaters are manufactured in different designs, but, they have common components:

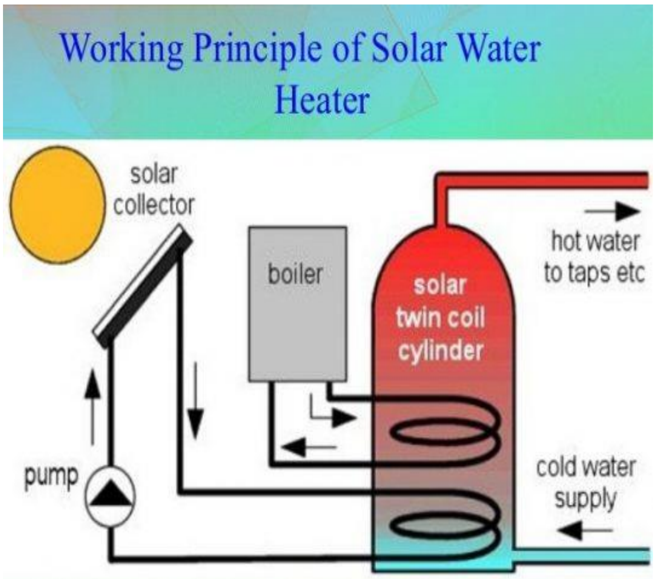
- Solar Collector (helps in collecting solar energy)
- Insulated Storage Tank (its purpose is to store hot water)
- Supporting Stand
- Connecting Pipes and Instrumentation, etc.

Solar Water Heater Working Principle

First of all the Sun rays fall on the Solar Collector, which is consists a black absorbing surface (absorber) that absorbs solar radiation, and transfers the heat energy to water flowing through it.

After this, heated water is collected in a tank, insulated to prevent heat loss. Then the circulation of water from the tank through the collector and back to the tank continues automatically.

An Insulated Storage Tank of a Solar Water Heater is useful to collect solar energy by collector panels to store hot water.



3.10 Solar Water Heater

<u>Salient Features of Solar Water Heating System:</u>

- Fuel Saving- A 100 liters capacity SWH can save 1500 units of electricity annually.
- Beneficial for Environment- A Solar Water Heater of 100 liters capacity can prevent the emission of 1.5 tons of carbon dioxide per year.
- Total Life- 15 to 20 years of life span (durability) approximately.

- Costing- Rs.15000- 20,000 for a 100 liters capacity system and Rs.110-150 per installed liter for higher capacity solar water heating systems.
- Payback period- 3-4 years' time duration for payback when electricity is replaced 4-5 years/when furnace oil is replaced 5-6 years/when coal is replaced.
- Solar Water Heater has the longest warranty period as compared to other solar energy devices.
- Solar Water Heater is one of the most reliable and durable devices.

3.11 LIGHT DEPENDENCE RESISTOR (LDR)

A photoresistor or light dependent resistor is an electronic component that is sensitive to light. When light falls upon it, then the resistance changes. Values of the resistance of the LDR may change over many orders of magnitude the value of the resistance falling as the level of light increases.

It is not uncommon for the values of resistance of an LDR or photoresistor to be several megohms in darkness and then to fall to a few hundred ohms in bright light.

With such a wide variation in resistance, LDRs are easy to use and there are many LDR circuits available. The sensitivity of light dependent resistors or photoresistors also varies with the wavelength of the incident light.

LDRs are made from semiconductor materials to enable them to have their light sensitive properties. Many materials can be used, but one popular material for these photoresistors is cadmium sulphide, CdS, although the use of these cells is now restricted in Europe because of environmental issues with the use of cadmium.

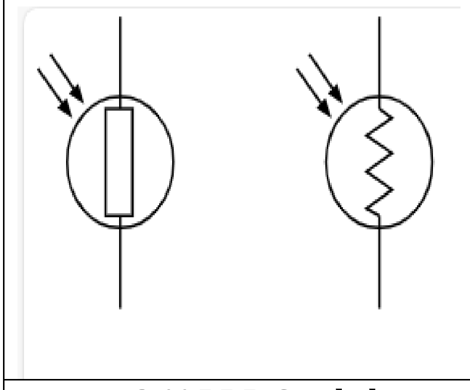
Similarly other cadmium based semiconductor materials like cadmium CdSe are also restricted. Other materials that can be used include lead sulphide, PbS and indium antimonide, InSb.

Although a semiconductor material is used for these photoresistors, they are purely passive devices because they do not possess a PN junction, and this separates them from other photodetectors like photodiodes and phototransistors.

LDR / photoresistor symbol

The LDR symbol used in electronic circuits is based around the resistor circuit symbol, but shows the light, in the form of arrows shining on it. In this way it follows the same convention used for photodiode and phototransistor circuit symbols where arrows are used to show the light falling on these components.

The light dependent resistor / photoresistor circuit symbols are shown for both the newer style resistor symbol, i.e. a rectangular box and the older zig-zag line resistor circuit symbols.

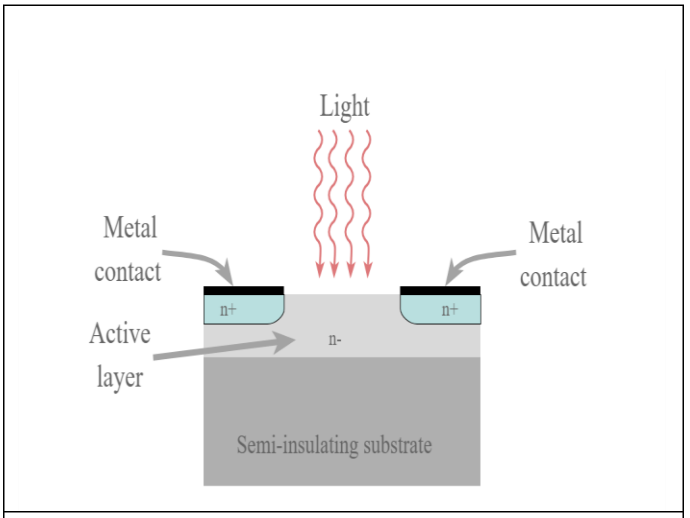


3.11 LDR Symbol

Often the light dependent resistor symbol may be shown without the circle around it. This is often done on the electronic circuit schematic to save space and reduce the number of lines and circles ont he diagram to redice complication.

Photoresistor / LDR structure

Structurally the photoresistor is a light sensitive resistor that has a horizontal body that is exposed to light. The active semiconductor region is normally deposited onto a semi-insulating substrate and the active region is normally lightly doped.



3.12 LDR Structure

In many discrete photoresistor devices, an interdigital pattern is used to increase the area of the photoresistor that is exposed to light. The pattern is cut in the metallisation on the surface of the active area and this lets the light through. The two metallise areas act as the two contacts for the resistor. This area has to be made relatively large because the resistance of the contact to the active area needs to be minimised.

Photoresistor structure showing inter digital pattern to maximize exposed area. This type of structure is widely used for many small photo resistors or light dependent resistors that are seen. The inter digital pattern is quite recognisable.

The materials used for photo resistors are semiconductors and include materials such as CdSe, CdS, CdTe, InSb, InP, PbS, PbSe, Ge, Is, GaAs. Each material gives different properties in terms of the wavelength of sensitivity, etc.

In view of the environmental concerns of using Cadmium, this material is not used for any product in Europe, and global use of this type of semiconductor has reduced significantly.

Photoresistor applications

- Photoresistors are found in many different applications and can be seen in many different electronic circuit designs. They have a very simple structure and they are low cost and rugged devices.
- They are widely used in many different items of electronic equipment and circuit designs including photographic light meters, fire or smoke alarms as well as burglar alarms, and they also find uses as lighting controls for street lamps.
- Extrinsic photoresistors provide sensitivity for longer wavelengths and as a result they are popular in various electronic circuit designs as infra-red photodetectors. Photoresistors can also be used to detect nuclear radiation.

UNIT IV LASERS

4.1 INTRODUCTION ABOUT LASER

Light is a kind of energy released by an atom. Light is made up of very small particles called photons.

Light shows properties of both waves and particles so it can behave simultaneously as a particle or a wave. Einstein believed that light is a particle or photon and the flow of photons is a wave. Light is obtained from various sources like candles, lamps and sun-rays.

Candles and lamps are called as the man made light sources and sun-rays is called natural light source.

The first reliable artificial light source (incandescent light bulb) was invented in 1879 by Thomas Edison. In incandescent light bulb, electric current flows through a filament inside the bulb.

When sufficient electric current is passed through the filament, it gets heated up and emits visible light. Thus, visible light is emitted from the incandescent light bulb.

The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Laser is a device that amplifies or increases the intensity of light and produces highly directional light.

Laser not only amplifies or increases the intensity of light but also generates the light. Laser emits light through a process called stimulated emission of radiation which amplifies or increases the intensity of light. Some lasers generate visible light but others generate ultraviolet or infrared rays which are invisible.

In conventional light sources, excited electrons emit light at different times and in different directions so there is no phase relation between the emitted photons.

On the other hand, the photons emitted by the electrons of laser are in same phase and move in the same direction.

Einstein gave the theoretical basis for the development of laser in 1917, when he predicted the possibility of stimulated emission. In 1954, C.H. Townes and his co-workers put Einstein's prediction for practical realization.

They developed a microwave amplifier based on stimulated emission of radiation. It was called as MASER (Microwave Amplification by Stimulated Emission of Radiation. Maser operates on principles similar to laser but generates microwaves rather than light radiation.

In 1958, C.H. Townes and A. Schawlow extended the principle of masers to light. In 1960, T.H. Maiman built the first laser device.

4.2 PROPERTIES OR CHARACTERISTICS OF LASER

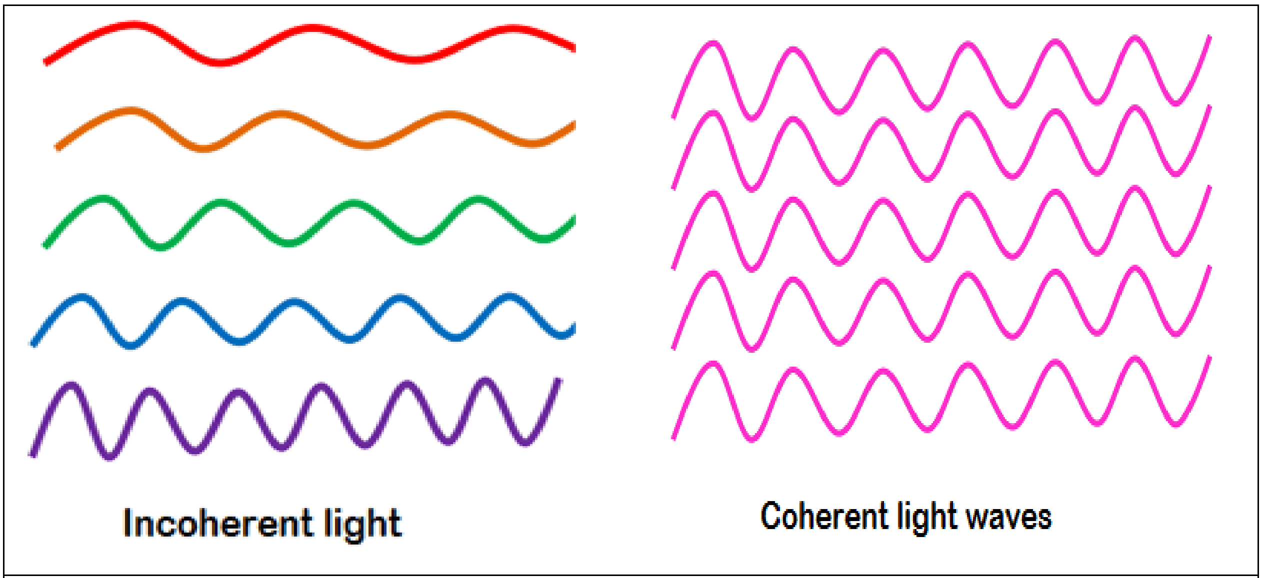
Laser light has four unique characteristics that differentiate it from ordinary light: these are

- Coherence
- Directionality
- Monochromatic
- High intensity

Coherence

We know that visible light is emitted when excited electrons (electrons in higher energy level) jumped into the lower energy level (ground state). The process of electrons moving from higher energy level to lower energy level or lower energy level to higher energy level is called electron transition.

In ordinary light sources (lamp, sodium lamp and torch light), the electron transition occurs naturally. In other words, electron transition in ordinary light sources is random in time. The photons emitted from ordinary light sources have different energies, frequencies, wavelengths, or colors. Hence, the light waves of ordinary light sources have many wavelengths. Therefore, photons emitted by an ordinary light source are out of phase.



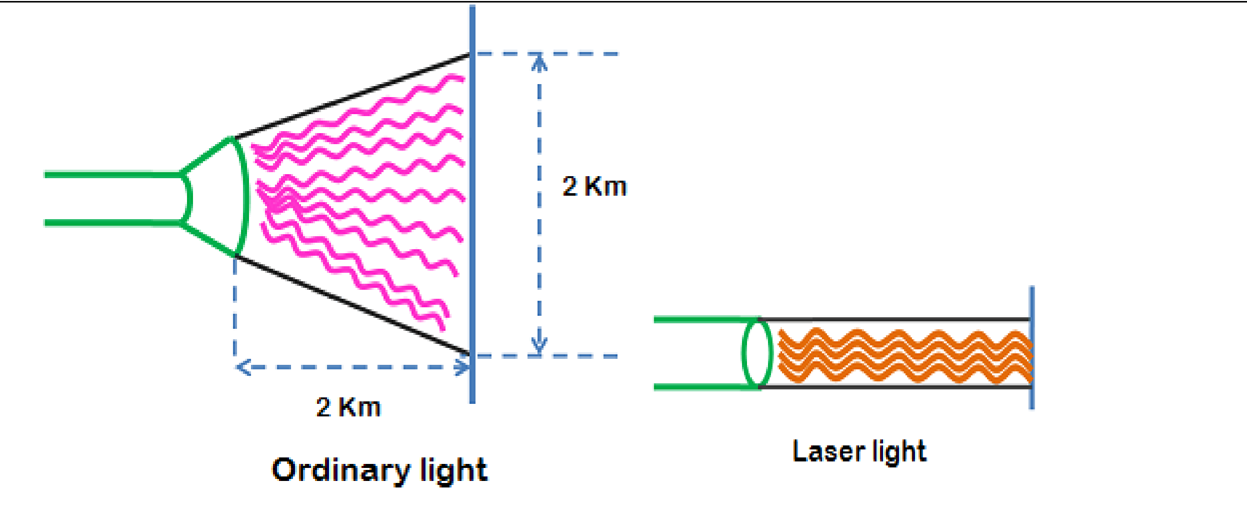
4.1 Coherence

In laser, the electron transition occurs artificially. In other words, in laser, electron transition occurs in specific time. All the photons emitted in laser have the same energy, frequency, or wavelength. Hence, the light waves of laser light have single wavelength or color. Therefore, the wavelengths of the laser light are in phase in space and time. In laser, a technique called stimulated emission is used to produce light.

Thus, light generated by laser is highly coherent. Because of this coherence, a large amount of power can be concentrated in a narrow space.

Directionality

In conventional light sources (lamp, sodium lamp and torchlight), photons will travel in random direction. Therefore, these light sources emit light in all directions.



4.2 Directionality

On the other hand, in laser, all photons will travel in same direction. Therefore, laser emits light only in one direction. This is called directionality of laser light. The width of a laser beam is extremely narrow. Hence, a laser beam can travel to long distances without spreading.

If an ordinary light travels a distance of 2 km, it spreads to about 2 km in diameter. On the other hand, if a laser light travels a distance of 2 km, it spreads to a diameter less than 2 cm.

Monochromatic

Monochromatic light means a light containing a single color or wavelength. The photons emitted from ordinary light sources have different energies, frequencies, wavelengths, or colors. Hence, the light waves of ordinary light sources have many wavelengths or colors. Therefore, ordinary light is a mixture of waves having different frequencies or wavelengths.

On the other hand, in laser, all the emitted photons have the same energy, frequency, or wavelength. Hence, the light waves of laser have single wavelength or color. Therefore, laser light covers a very narrow range of frequencies or wavelengths.

High Intensity

In laser, the light spreads in small region of space and in a small wavelength range. Hence, laser light has greater intensity when compared to the ordinary light.

Thus, these four properties of laser beam enable us to cut a huge block of steel by melting. They are also used for recording and reproducing large information on a compact disc (CD).

4.3 DIFFERENCES BETWEEN ORDINARY LIGHT AND LASER BEAM

S.No	Ordinary light	Laser beam
1	The radiations are polychromatic.	The radiations are monochromatic.
2	It is not a coherent beam.	It is a coherent beam.
3	Intensity of light is lesser.	Intensity of light is higher.
4	Ordinary light is not directional.	Laser light is more directional.
5	The angular spread is more.	The angular spread is less.
6	Ex. Sunlight, mercury vapour lamp etc.	Ex. He-Ne laser, CO_2 laser etc.

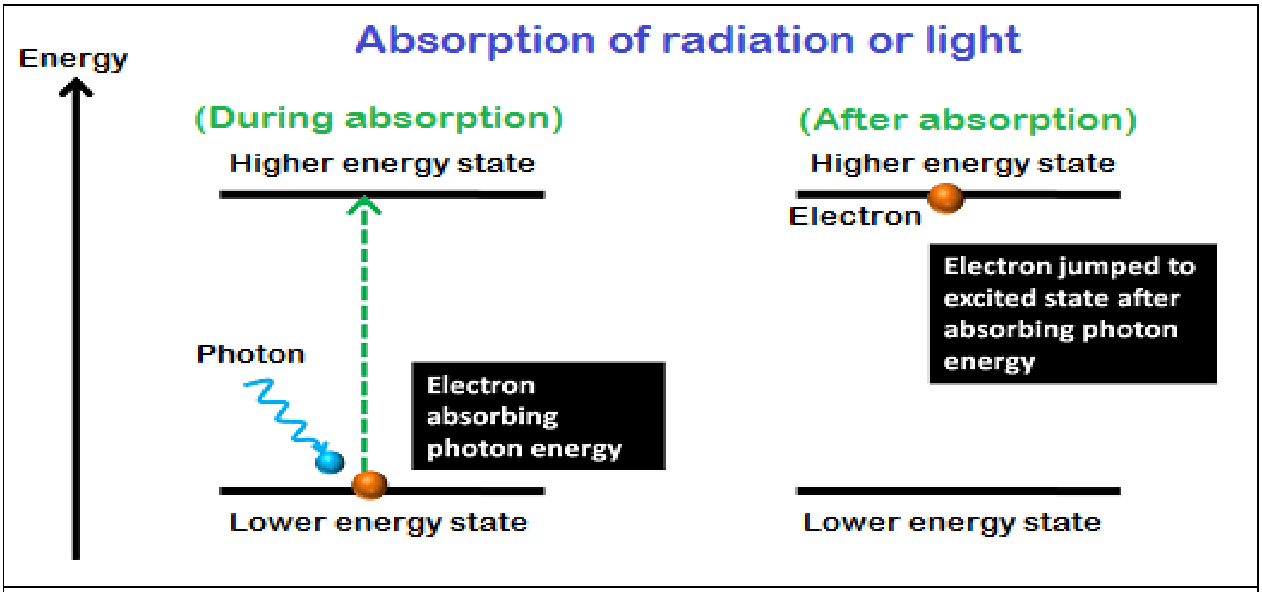
4.4 PROCESS OF LASER AND EINSTEIN'S A AND B COEFFICIENTS

In lasers, photons are interacted in three ways with the atoms:

- Stimulated absorption
- Spontaneous emission
- Stimulated emission

Stimulated absorption

Let us consider two energy levels (E_1 and E_2) of electrons. E_1 is the ground state or lower energy state of electrons and E_2 is the excited state or higher energy state of electrons. The electrons in the ground state are called lower energy electrons or ground state electrons whereas the electrons in the excited state are called higher energy electrons or excited electrons.



4.3. Stimulated absorption

In general, the electrons in the lower energy state can't jump into the higher energy state. They need sufficient energy in order jump into the higher energy state.

When photons or light energy equal to the energy difference of the two energy levels ($E_2 - E_1 = h\nu$) is incident on the atom, the ground state electrons gains sufficient energy and jumps from ground state (E_1) to the excited state (E_2).

The absorption of radiation or light occurs only if the energy of incident photon exactly matches the energy difference of the two energy levels ($E_2 - E_1$).

Definition:

An atom in the ground state (E_1) can absorbs the energy of photon ($h\nu$), then it jump to excited state (E_2). This process is called as stimulated absorption.

Mathematically,

Rate of absorption, $R_{ab} = B_{12} N_1 Q$ ------------------------------(1)

Where,

B_{12} be the constant of probability of transition from E_1 to E_2

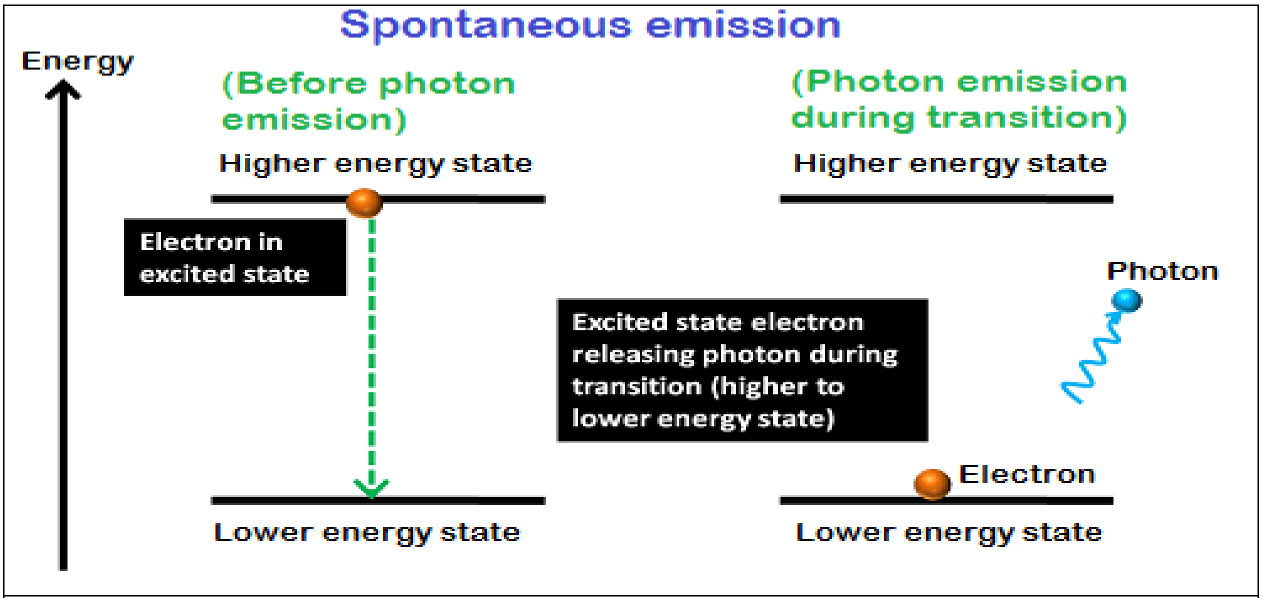
N_1 be the No. of atoms in ground state

Q be the energy distribution

Spontaneous emission

Spontaneous emission is the process by which electrons in the excited state return to the ground state by emitting photons.

The electrons in the excited state can stay only for a short period. The time up to which an excited electron can stay at higher energy state (E_2) is known as the lifetime of excited electrons. The lifetime of electrons in excited state is 10^{-8} second.



4.4 Spontaneous emission

Thus, after the short lifetime of the excited electrons, they return to the lower energy state or ground state by releasing energy in the form of photons.

In spontaneous emission, the electrons move naturally or spontaneously from one state (higher energy state) to another state (lower energy state) so the emission of photons also occurs naturally. Therefore, we have no control over when an excited electron is going to lose energy in the form of light. The photons emitted in spontaneous emission process constitute ordinary incoherent light.

Definition:

An atom in the excited state (E_2) can return to the ground state (E_1) spontaneously by emitting one photon of energy 'hν' without inducement of photon. This process is called as spontaneous emission.

Mathematically,

Rate of spontaneous emission, $R_{sp} = A_{21}N_2$ ------------------------------(2)

Where,

A_{21} be the constant of probability of transition from E_2 to E_1

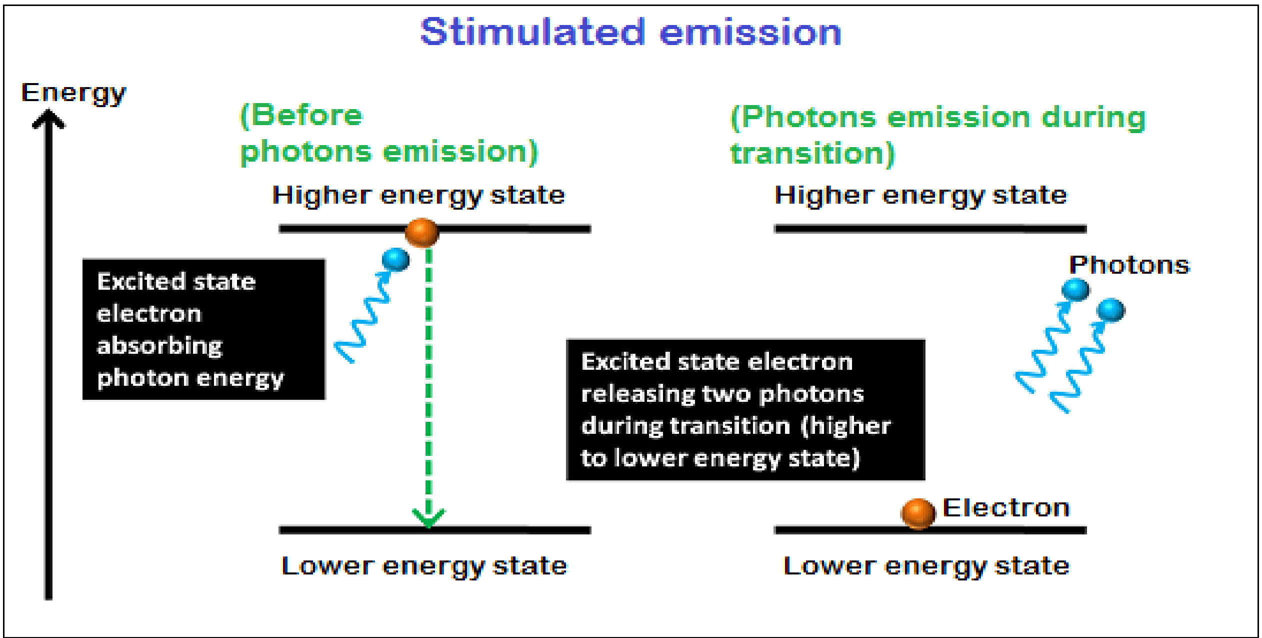
N_2 be the No. of atoms in excited state

Stimulated emission

Stimulated emission is the process by which incident photon interacts with the excited electron and forces it to return to the ground state.

In stimulated emission, the light energy is supplied directly to the excited electron instead of supplying light energy to the ground state electrons.

Unlike the spontaneous emission, the stimulated emission is not a natural process it is an artificial process.



4.5 Stimulated emission

In spontaneous emission, the electrons in the excited state will remain there until its lifetime is over. After completing their lifetime, they return to the ground state by releasing energy in the form of light.

However, in stimulated emission, the electrons in the excited state need not wait for completion of their lifetime. An alternative technique is used to forcefully return the excited electron to ground state before completion of their lifetime. This technique is known as the stimulated emission.

When incident photon interacts with the excited electron, it forces the excited electron to return to the ground state. This excited electron release energy in the form of light while falling to the ground state.

In stimulated emission, two photons are emitted (one additional photon is emitted), one is due to the incident photon and another one is due to the energy release of excited electron. Thus, two photons are emitted.

The stimulated emission process is very fast compared to the spontaneous emission process.

All the emitted photons in stimulated emission have the same energy, same frequency and are in phase. Therefore, all photons in the stimulated emission travel in the same direction.

The number of photons emitted in the stimulated emission depends on the number of electrons in the higher energy level or excited state and the incident light intensity.

Definition:

An atom in the excited state (E_2) can return to the ground state (E_1) by emitting two photon of energy 'hv' with inducement of photon. This process is called as stimulated emission.

Mathematically,

Rate of stimulated emission, $R_{st} = B_{21} N_2 Q$ ------------------------------(3)

Where,

B_{21} be the constant of probability of transition from E_2 to E_1

N_2 be the No. of atoms in excited state

Q be the energy distribution

At equilibrium condition,

Rate of absorption = Rate of emission

Rate of absorption = Rate of spontaneous emission+ Rate of stimulated emission

$$B_{12} N_1 Q = A_{21} N_2 + B_{21} N_2 Q$$

Rearranging

$$B_{12} N_1 Q - B_{21} N_2 Q = A_{21} N_2$$

$$Q(B_{12} N_1 - B_{21} N_2) = A_{21} N_2$$

Dividing by N_2 on both sides

$$Q(B_{12}\left(\frac{N_1}{N_2}\right) - B_{21}) = A_{21}$$

$$Q = \frac{A_{21}}{(B_{12}\left(\frac{N_1}{N_2}\right) - B_{21})} \text{ ---(4)}$$

According to Maxwell-Boltzmann distribution law, number of atoms can be calculated using the relation

$$N_r = N_0 e^{-\frac{E_r}{KT}} \text{ ---(5)}$$

Where, r=0, 1, 2, 3…………………..

N_0 be the number of atoms in ground state

K be the Boltzmann constant

T be the absolute temperature

For r = 1, $N_1 = N_0 e^{-\frac{E_1}{KT}}$

For r = 2, $N_2 = N_0 e^{-\frac{E_2}{KT}}$ --(6)

Subs eqn 6 in 4 we get

$$Q = \frac{A_{21}}{(B_{12}\left(\frac{\exp\left(\frac{-E_1}{KT}\right)}{\exp\left(\frac{-E_2}{KT}\right)}\right) - B_{21})}$$

$$Q = \frac{A_{21}}{(B_{12}\exp\left(\frac{E_2 - E_1}{KT}\right) - B_{21})} \text{ ---------------------------------------(7)}$$

Dividing by B_{21} in RHS of eqn 7

$$Q = \frac{\left(\frac{A_{21}}{B_{21}}\right)}{\left(\frac{B_{12}}{B_{21}}\exp\left(\frac{E_2 - E_1}{KT}\right) - 1\right)}$$ ---(8)

$B_{12}=B_{21}$

Eqn 8 becomes

$$Q = \frac{\left(\frac{A_{21}}{B_{21}}\right)}{\left(\exp\left(\frac{E_2 - E_1}{KT}\right) - 1\right)}$$

But, $E_2-E_1=h\nu$

$$Q = \frac{\left(\frac{A_{21}}{B_{21}}\right)}{\left(\exp\left(\frac{h\nu}{KT}\right) - 1\right)}$$ --(9)

According to Planck's radiation law, the energy distribution can be expressed as,

$$Q = \left(\frac{8\pi h\nu^3}{c^3}\right)\left(\frac{1}{\exp(\frac{h\nu}{KT}) - 1}\right)$$

---------------------------------(10)

Comparing eqn 9 & 10

$$\frac{A_{21}}{B_{21}} = \left(\frac{8\pi h\nu^3}{c^3}\right)$$

$A_{21}=A$ and $B_{12}=B_{21}=B$

The constants A and B are called as Einstein's A and B coefficients.

4.5 RATIO OF MAGNITUDES OF STIMULATED AND SPONTANEOUS EMISSION RATES

From equation (2) and (3) we have

$$\frac{R_{21}(St)}{R_{21}(Sp)} = \frac{B_{21}\rho N_2}{A_{21}N_2}$$

$$\frac{R_{21}(St)}{R_{21}(Sp)} = \frac{B_{21}}{A_{21}}\rho$$

Rearranging eqn (6), we can write

$$\frac{B_{21}}{A_{21}}\rho = \frac{1}{(B_{12}/B_{21})e^{h\upsilon/K_BT} - 1}$$

Since $B_{12} = B_{21}$ we have

$$\frac{1}{e^{h\upsilon/K_BT} - 1} = \frac{B_{21}}{A_{21}}\rho$$

Comparing eqn (9) &(10) we get

$$\frac{R_{21}(St)}{R_{21}(Sp)} = \frac{1}{e^{h\upsilon/K_BT} - 1} = \frac{B_{21}}{A_{21}}\rho$$

In a simpler way the ratio can be written as

$$R = \frac{B_{21}}{A_{21}}\rho$$

The spontaneous emission produces incoherent light. In ordinary conventional light source, the spontaneous emission is dominant. In laser action, stimulate emission should be predominant over spontaneous emission and absorption. To achieve this, an artificial condition known as population inversion is required.

4.6 DIFFERENCES BETWEEN SPONTANEOUS AND STIMULATED EMISSION OF RADIATION

S.no	Spontaneous emission	Stimulated emission
1	An atom in the excited state is returns to ground state by emitting a single photon without any external inducement.	An atom in the excited state is forced to go to ground state, resulting in two photons of same frequency and energy.
2	The emitted photons move at random direction.	The emitted photons move in a single direction.
3	The radiation of light is less intense, polychromatic and incoherent.	The radiation of light is highly intense, monochromatic and coherent.
4	Angular spread is more.	Angular spread is less.
5	The photons are not in phase.	The photons are in phase.

4.7 POPULATION INVERSION

The state of achieving more number of atoms in higher energy state is greater than that in lower energy state is called population inversion.

Consider two energy level systems E_1 and E_2. Normally the number of atoms (population) presents in the ground state N_1 is higher than the number of atoms in the excited state N_2.

i.e., $N_2 < N_1$.

The process of making the number of atoms in higher energy state is greater than that in lower energy state is called population inversion (or) Inverted population.

i.e., $N_2 > N_1$

Active medium:

The medium in which the population inversion takes place is called as active medium.

Active centre:

The material in which the atoms are raised to excited state to achieve population inversion is called as active centre.

4.8 PUMPING METHODS

The process of raising the atoms from ground state to excited state by artificial means is called pumping process.

Some of the commonly used pumping methods are:

1) Optical pumping
2) Electric discharge method
3) Inelastic collision between atoms
4) Direct pumping
5) Chemical process

Optical pumping:

The atoms in the ground state absorb the energy (E=hv) from the incident photon and raised to the excited state is called optical pumping.

Source: flash lamps

EX: solid state lasers like Ruby laser and Nd-YAG.

Electric discharge method:

In this method, the electrons are produced in an electric discharge tube and accelerated to very high velocities by strong electric field and they collide with gas atoms and these atoms are raised to excited state.

Source: electric discharge tube

EX: gas lasers like Ar gas laser, He-Ne laser, CO_2 laser etc.

Inelastic collision between atoms:

In this method a combination of two gases say A and B having nearly the same higher energy level are used.

During electric discharge 'A' atoms get excited due to collision with electrons.

$$e^- + A \longrightarrow A^*$$

The excited A* atoms now collide with 'B' atoms so that 'B' goes to excited state B*

$$A^* + B \longrightarrow B^* + A$$

Source: electric discharge tube

EX: di gas lasers like He-Ne laser, CO_2laser

Direct pumping:

When the electrical energy is applied in some semiconductors (like GaAs), the energy is directly converted into light energy.

Source: battery

EX: semiconductor laser.

Chemical method:

Due to some chemical reaction, the atom may be raised to excited state.

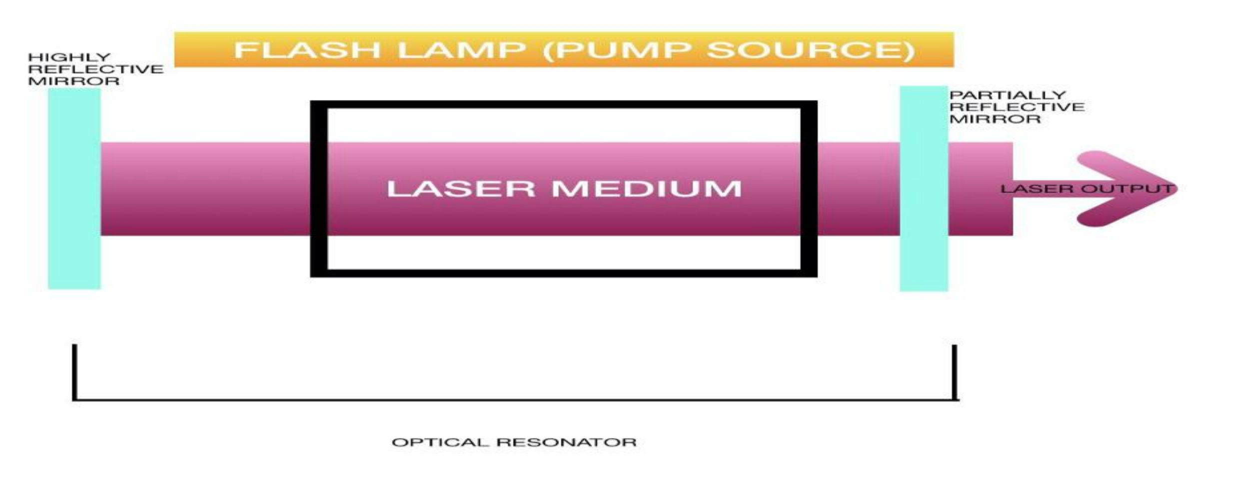
Source: chemical reaction takes place between chemicals

EX: chemical, Dye laser.

4.9 OPTICAL RESONATOR

Optical resonator is a device made of set of reflecting surfaces. One of its surfaces is fully reflecting mirror and the other is partially reflecting mirror. Active material (laser medium) is placed between two reflecting surfaces.

The photons generated between various energy levels of active medium starts moving between these surfaces. These photons moving parallel to axis of the active medium is only leads laser action.



5.6 Optical resonator

4.10 TYPES OF LASERS

Lasers are classified into five major categories based on the type of active medium.

1) **Solid state laser**

It is classified into two types

a) 3 level laser (e.g) Ruby laser

b) 4 level laser (e.g) Nd-YAG laser

2) **Gas lasers**

Examples: CO_2 laser, He-Ne laser.

3) **Semiconductor laser**

Examples: GaAs (Gallium Arsenide laser)

4) **Liquid lasers**

Examples: Europium benzoyl acetonate dissolved in alcohol.

5) **Dye laser and chemical lasers**

Examples: Rhodamine 6G laser, Hydrogen fluride laser and Coumarin dye laser.

4.10.1 MOLECULAR GAS LASER OR CO_2 LASER

- In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous.
- In CO2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.
- It was the first molecular gas laser developed by Indian born American scientist Prof.C.K.N.Pillai.
- It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser.

Energy States of CO_2 Molecule

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations. They are

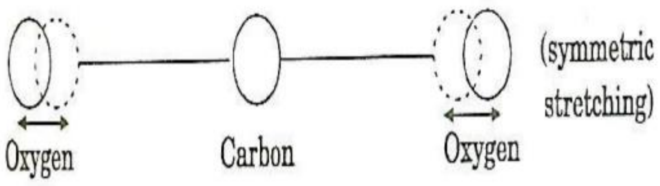
a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

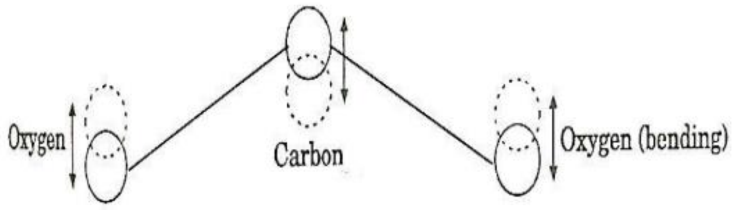
Symmetric stretching mode.

In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.

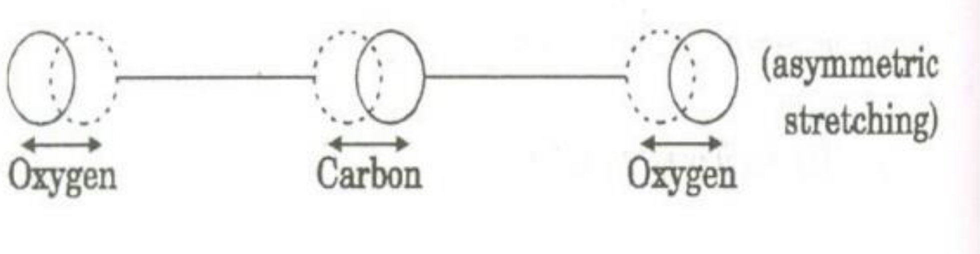


Bending mode

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.



Asymmetric stretching mode.

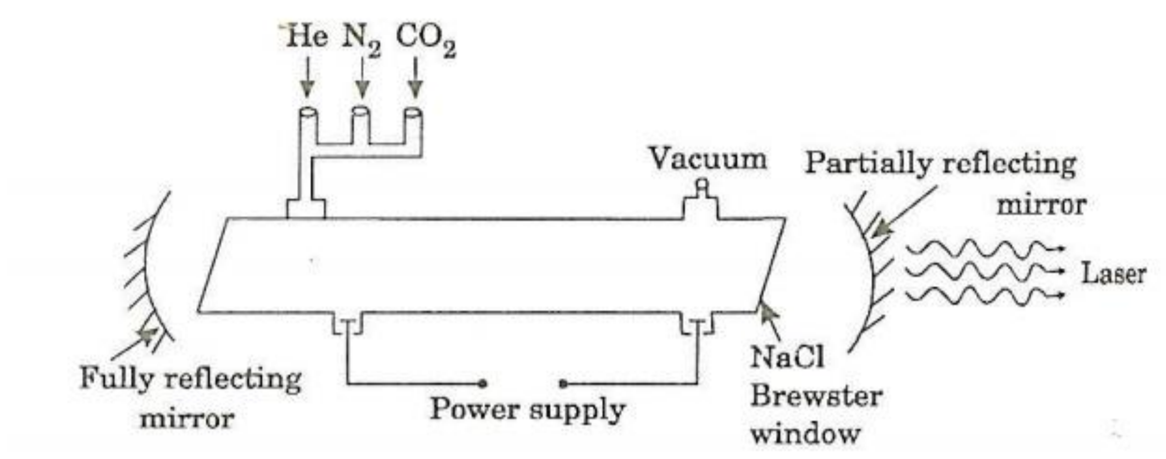


In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.

Principle:

The active medium is a gas mixture of CO2, N2 and He. The laser transition takes place between the vibrational states of CO2molecules.

Construction:

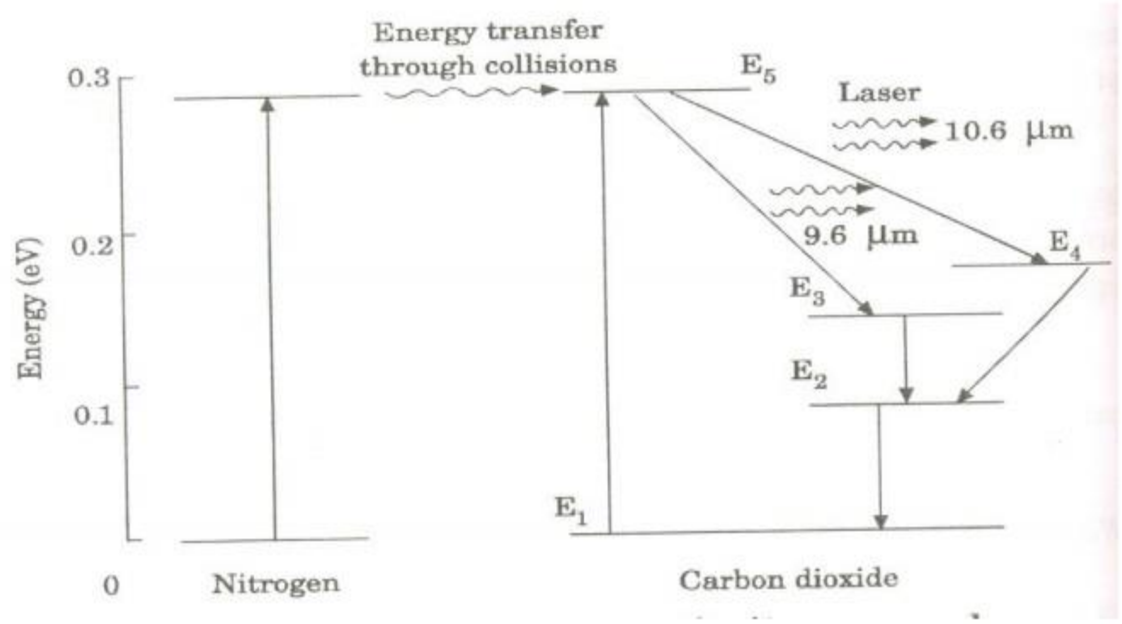


4.7 CO_2 LASER

- It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO_2(active medium), helium and nitrogen with suitable partial pressures.

- The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.
- Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Working:



4.8 Energy level diagram- CO_2 LASER

Figure shows energy levels of nitrogen and carbon dioxide molecules.

- When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

  $N_2 + e^* = N_2^* + e$
  - N_2 = Nitrogen molecule in ground state e* = electron with kinetic energy
  - N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

- Now N_2 molecules in the excited state collide with CO_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels.
  - This process is represented by the equation

  $N_2^* + CO_2 = CO_2^* + N_2$

  N_2^* = Nitrogen molecule in excited state.
  CO_2 = Carbon dioxide atoms in ground state
  CO_2^* = Carbon dioxide atoms in excited state
  N_2 = Nitrogen molecule in ground state.

- Since the excited level of nitrogen is very close to the E_5 level of CO_2 atom, population in E_5 level increases.

- As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

  Transition E_5 to E_4 :
  This will produce a laser beam of wavelength 10.6μm
  Transition E_5 to E_3:

- This transition will produce a laser beam of wavelength 9.6μm. Normally 10.6μm transition is more intense than 9.6μm transition. The power output from this laser is 10kW.

Advantages of CO_2 Laser:

1. The construction of CO2 laser is simple
2. The output of this laser is continuous.
3. It has high efficiency
4. It has very high output power.
5. The output power can be increased by extending the length of the gas tube.

Disadvantages of CO_2Laser:

1. The contamination of oxygen by carbon monoxide will have some effect on laser action
2. The operating temperature plays an important role in determining the output power of laser.
3. The corrosion may occur at the reflecting plates.
4. Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

Applications of CO_2Laser:

1. High power CO2 laser finds applications in material processing, welding, drilling, cutting soldering etc.
2. The low atmospheric attenuation (10.6μm makes CO2 laser suitable for open air communication.
3. It is used for remote sensing
4. It is used for treatment of liver and lung diseases.
5. It is mostly used in neuro surgery and general surgery.
6. It is used to perform microsurgery and bloodless operations.

4.10.2 SEMICONDUCTOR LASERS

Definition:

It is specifically fabricated p-n junction diode. This diode emits laser light when it is forward biased.

A laser diode, injection laser diode, or diode laser is a semiconductor device similar to a light-emitting diode in which a diode pumped directly with electrical current can create lasing conditions at the diode's junction. Laser diodes can directly convert electrical energy into light.

Types of semiconductor laser:

There are two types of semiconductor diode lasers

i. Homo junction laser
ii. Hetero- Junction laser.

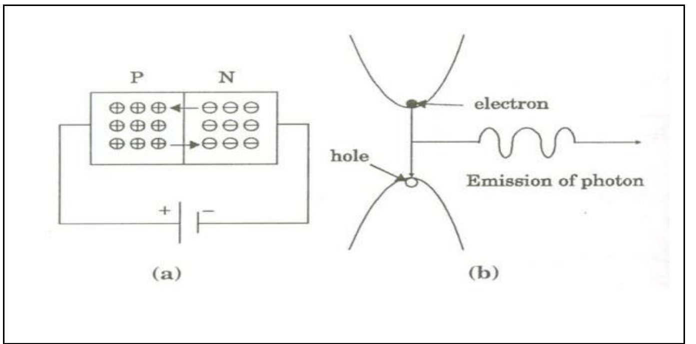
HOMO JUNCTION LASER

If a p-n junction is formed in a single crystalline material, then it is called as homo-junction laser.

Example: single crystal of gallium Arsenide (Ga-As)

Principle:

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombined with each other.



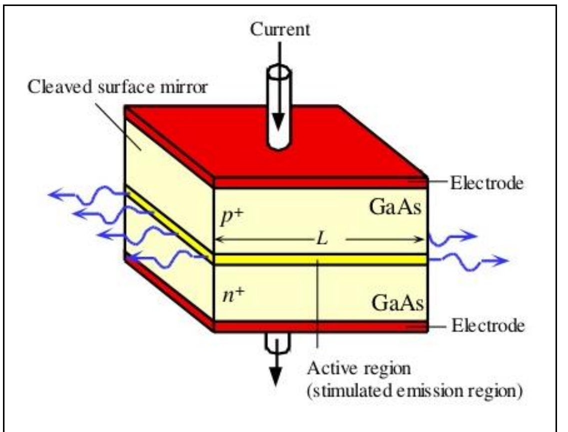
4.9 Principle of semiconductor laser

During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.

Construction:

- The active medium is a p-n-junction diode made from a single crystalline material i.e., GaAs, in which p-region is doped with germanium and n-region with Tellurium.
- The junction of the 'p' and 'n' are well polished and are parallel to each other as shown in fig.
- The refractive index of GaAs is high; it acts as optical resonator so that the external mirrors are not needed.

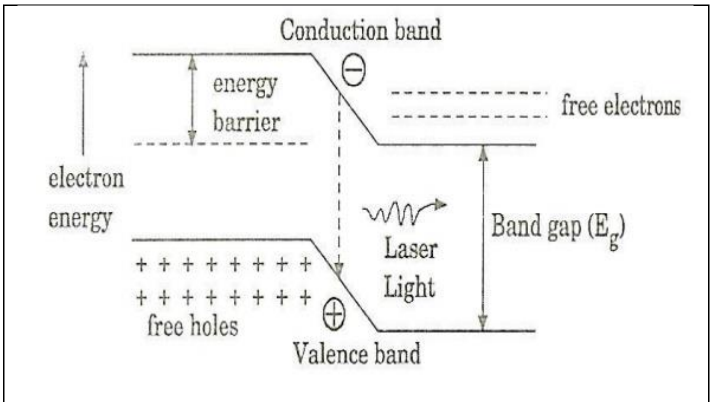


4.10 Homo junction semiconductor laser

- The upper and lower electrodes are connected to positive and negative terminals of the battery.

Working:

- The p-n junction is forward biased with large applied voltage. The electrons and holes are injected into junction region.
- At the junction contains large amount of electrons within the conduction band and large amount of holes in the valance



4.11 Energy level diagram

band.

- After achieving population inversion, the electrons and holes recombine each other and produce radiation in the form of light (photon).
- These emitted photons can trigger a chain of stimulated recombination resulting the photons are in phase.
- These photons moving at the plane of the junction travels back and forth by reflection between the two sides parallel opposite to each other to get intense beam of LASER.
- Calculation of wavelength

Band gap of GaAs =1.44 eV

$$\lambda = hc/E_g = \frac{6.625\times10^{-34} \times 3\times10^{8}}{1.44\times1.6\times10^{-19}} = 8626Å$$

The wavelength is near IR region.

- The wavelength of the emitted radiation depends on i) the band gap and ii) the concentration of donar and acceptor atoms in GaAs.

Advantages:

- It is easy to manufacture the diode.
- The cost is low.

Disadvantages:

- It produces low power output.
- The output wave is pulsed and will be continuous only for some time.
- The beam has large divergence.
- They have high threshold current density.

Applictions:

- It is widely used in fiber optic communication
- It is used to heal the wounds by infrared radiation
- It is also used as a pain killer
- It is used in laser printers and CD writing and reading.

HETERO JUNCTION LASER

If p-n junction is formed with different semiconducting materials, then it is known as Hetero- Junction laser. It is also called modern laser diode.

Example: Hetero- Junction laser can be formed between Ga-As and Ga-Al-As.

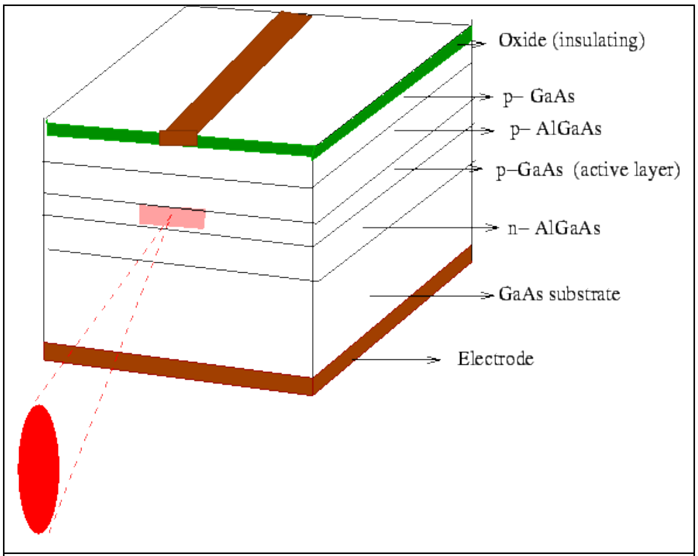
Principle:

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombined with each other.

During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.

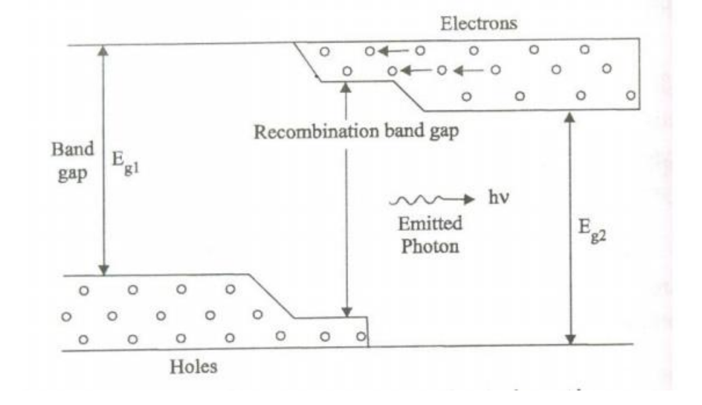
Construction:



4.12 Hetero junction laser

- It consists of five layers as shown in fig (1). A layer of 'P' type semiconductor (layer-3) made of GaAs will acts as an active region and layer has narrow band gap.
- This layer is placed between two layer (layer-2 and 4) having wider band gap.
- The 'p' type layer-1 is used for making necessary biasing with lower 'n' type layer-5.
- The junction between the 3rd and 4th layer is well polished and hence it acts as an optical resonator.

Working:



4.13 Energy level diagram

- The working of a heterojunction laser is same as the working of a homojunction laser.
- The diode is forward biased; the charge carriers are produced in the layer 2 and 4.
- These charge carriers are injected into the active region (layer-3) till the population inversion achieved.
- The charge carrier recombines and produced spontaneously emitted photon, start stimulate the injected charge carriers to emit photons.
- As a result more number of stimulated emissions arises and produced large number of photons.
- These photons are reflected back and forth and hence the intense coherent beam of LASER emerges out from the layer-3 and 4.

- The wavelength of the LASER

$$\lambda = hc/E_g$$

$$= \frac{6.625x10^{-34} x\ 3x10^{8}}{1.55x1.6x10^{-19}} = 8014\text{Å}$$

This wavelength is lies in IR region.

Advantages

- Output power is very high.
- It has high coherence and directionality.
- It produced continuous wave output.
- It has longer life time.

Disadvantages

- Cost of the diode is high.
- It has 5 layers, growing different layers is more complex.

Applications:

- This type of laser is mostly used in optical applications
- It is widely used in computers, especially on CD-ROMs

5.11 APPLICATIONS OF LASER:

Medical application:

- Performing Micro-surgery and bloodless operations.
- It is used to destroy tumors.
- Using laser, Cancer treatment can also be done.
- It is used to cut the bones precisely.

Engineering application:

- Communication between planets is possible with LASER.
- Computer print-out is done with LASER printers.
- They are used for welding and cutting.

Industrial applications

- The laser beam is used to drill extremely fine holes in diamonds, hard sheets etc.,
- They are also used for cutting thick sheets of hard metals and welding.
- The laser beam is used to vaporize the unwanted material during the manufacture of electronic circuit on semiconductor chips.
- They can be used to test the quality of the materials.

4.11 LIDAR – Light Detecting and Ranging

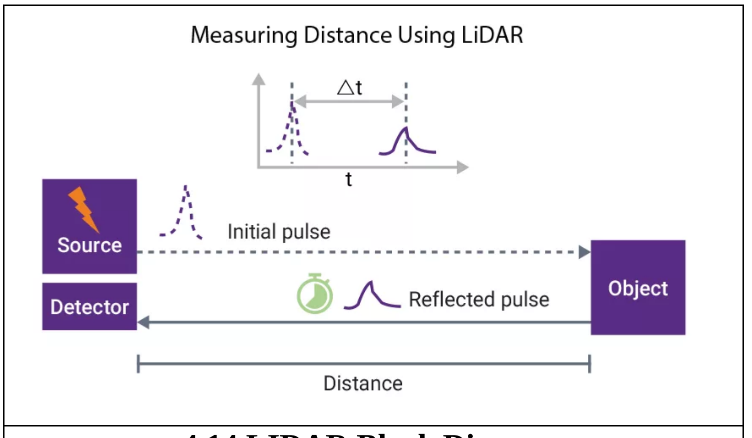
LiDAR is an acronym for Light Detection and Ranging. In LiDAR, laser light is sent from a source (transmitter) and reflected from objects in the scene. The reflected light is detected by the system receiver and the time of flight (TOF) is used to develop a distance map of the objects in the scene.

LiDAR is an optical technology often cited as a key method for distance sensing for autonomous vehicles. Many manufacturers are working to develop cost-effective, compact LiDAR systems. Virtually all producers pursuing autonomous driving consider LiDAR a key enabling technology, and some LiDAR systems are already available for Advanced Driver Assistance Systems (ADAS).

Working:

Essentially, LiDAR is a ranging device, which measures the distance to a target. The distance is measured by sending a short laser pulse and recording the time lapse between outgoing light pulse and the detection of the reflected (back-scattered) light pulse.

A LiDAR system may use a scan mirror, multiple laser beams, or other means to "scan" the object space. With the ability to provide accurate measurement of distances, LiDAR can be used to solve many different problems.



4.14 LIDAR Block Diagram

In remote sensing, LiDAR systems are used to measure scatter, absorption, or re-emission from particles or molecules in the atmosphere. For these purposes, the systems may have specific requirements on the wavelength of the laser beams. The concentration of a specific molecular species in the atmosphere, e.g. methane and the aerosol loading, can be measured. Rain droplets in the atmosphere can be measured to estimate the distance of a storm and the rain fall rate.

Other LiDAR systems provide profiles of three-dimensional surfaces in the object space. In these systems, the probing laser beams are not tied to specific spectral features. Instead, the wavelength of the laser beams may be chosen to ensure eye safety or to avoid atmospheric spectral features. The probing beam encounters and is reflected by a "hard target" back to the LiDAR receiver.

LiDAR can also be used to determine the velocity of a target. This can be done either through the Doppler technique or measuring the distance to a target in rapid succession. For example, atmospheric wind velocity and the velocity of an automobile can be measured by a LiDAR system.

Applications:

The application areas for LiDAR are deep and varied. In atmospheric sciences, LiDAR has been used for the detection of many types of atmospheric constituents. It has been used to characterize aerosols in the atmosphere, investigate upper atmospheric winds, profile clouds, aid the collection of weather data, and many other applications. In astronomy, LiDAR has been used to measure distances, both for distant objects such as the moon and for very near objects. In fact, LiDAR is a crucial device for improving the measurement of the distance to the moon up to millimeter precision. LIDAR has also been used to create guide stars for astronomy applications.

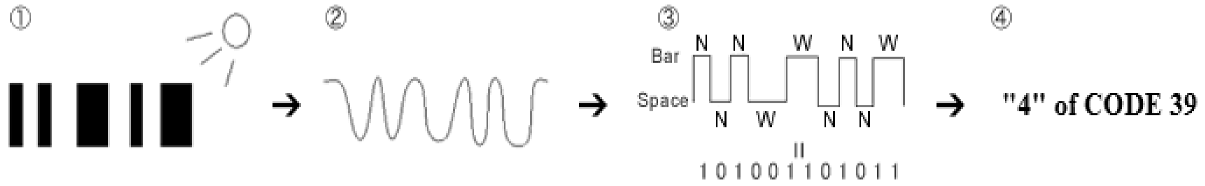
Furthermore, topographic LiDAR uses a near-infrared laser to map the land and buildings, and bathymetric LiDAR uses water-penetrating green light to map seafloor and riverbed. In agriculture, LiDAR can be used to map topology and crop growth, which can provide information on fertilizer needs and irrigation requirements. In archaeology, LiDAR has been used to map ancient transportation systems under thick forest canopy.

Today, LiDAR is frequently used to create a three-dimensional model of the world around the LiDAR sensor. Autonomous navigation is one application that uses the point cloud created by a LiDAR system. Miniature LiDAR systems can even be found in devices as small as mobile phones.

In addition, LiDAR systems can be used to create a three-dimensional model of a dynamic scene, such as what may be encountered by an autonomous driving vehicle. This can be done in various ways, usually using a scanning technique.

4.12 BARCODE SCANNER

Principle:



1. A bar code consists of white and black bars. Data retrieval is achieved when bar code scanners shine a light at a bar code, capture the reflected light and replace the black and white bars with binary digital signals.
2. Reflections are strong in white areas and weak in black areas. A sensor receives reflections to obtain analog waveforms.
3. The analog signal is converted into a digital signal via an A/D converter. (Binarization)
4. Data retrieval is achieved when a code system is determined from the digital signal obtained. (Decoding process)

Compoments:

The scanner itself has a three part system that facilitates the capturing and transferring of the information within the barcode:

Illumination System

In order to read the code and relay the image back to be processed, the barcode must be illuminated. This used to be done using traditional lamps. Now barcode scanners will have built in LED or lasers that act as illuminators.

Sensor or Lens

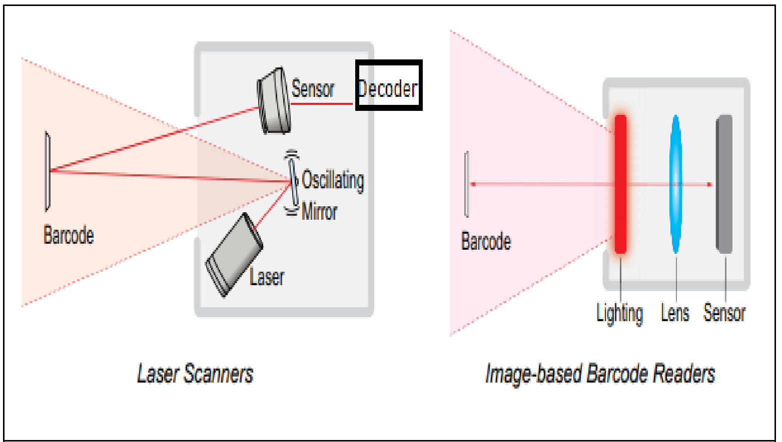
A light sensor called a "photodiode" takes the image that is collected and converts it into a corresponding electrical signal. It appears and functions almost as a reverse LED, capturing light and putting it into a wire.

The Decoder

Many modern barcode scanners contain decoders built directly into the handle of the gun. These decoders take the binary code that is read by the scanner and convert it into a usable piece of information for whatever software you're using. Some scanners will require the use of a "keyboard wedge," which acts as an external decoder between the actual scanner hardware and the computer.

Working:

Barcode scanners capture the reflected light and decode it into a numerical sequence of binary code. Traditionally, barcode scanners use laser or LCD light. By capturing the black and white pattern on a barcode, they process and relay that information back to the POS or computer connected to them.



4.15 Barcode Scanner Block Diagram

Sophisticated types of scanners can read a whole barcode at once while more traditional and basic models have to be dragged across in order to physically scan the code. Today, we are seeing an increasing use of camera technology for barcode capture.

These barcode scanners convert the shapes of lines, squares, and numbers into binary code which can then drop data directly into Excel, Accel, and POS software. Thus, they are a vital tool for both inventory management and executing sales.

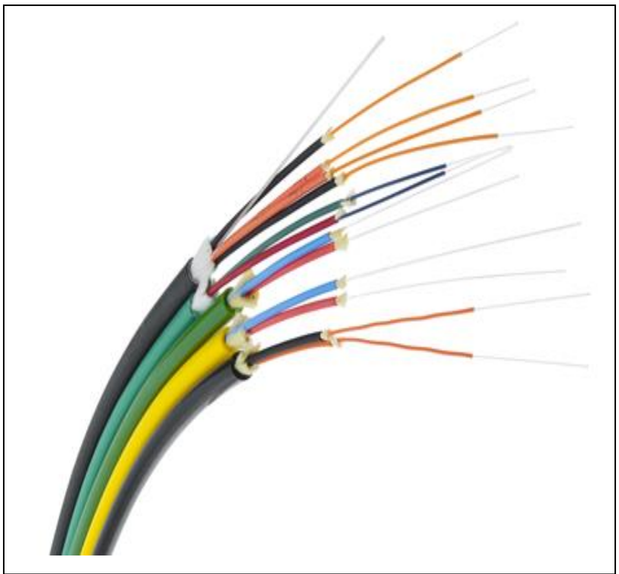
Applications:

1. The barcode scanner can be used in the collection of waybill data of couriers, transfer yards, and warehouses. By scanning the express barcode, the waybill information can be directly transmitted to the back-end server through wireless transmission, and at the same time, it can realize functions such as query of related business information.
2. Barcode scanners can be used in chain stores, stores, and special counters, which can realize the collection and transmission of data such as store purchases, sales, storage, inventory, transfer, refund, subscription, and membership management.
3. The barcode scanner can be used for wireless ordering fairs in the footwear and apparel industry, and orders can be done by scanning the barcode with a handheld terminal.
4. In the process of investigating and punishing illegal parking, the police can use barcode scanners to query vehicle information anytime and anywhere, upload various illegal information, and fix evidence on the spot to investigate and punish illegal parking.
5. The barcode scanner uses GPS positioning to ensure that the inspection is in place, and the meter reader checks the model and records it so that the work can be completed easily and efficiently.

UNIT IV FIBER OPTICS OR OPTICAL FIBER

5.1 INTRODUCTION

John Tyndall, a British physicist demonstrated that light could be guided by well-known phenomenon of total internal reflection.



5.16 Fibre optics

Optical fiber was discovered by Kao, Newnes and Beales in 1966. A light beam acting as a carrier wave is capable of carrying the information at a much faster rate than radio waves and microwaves.

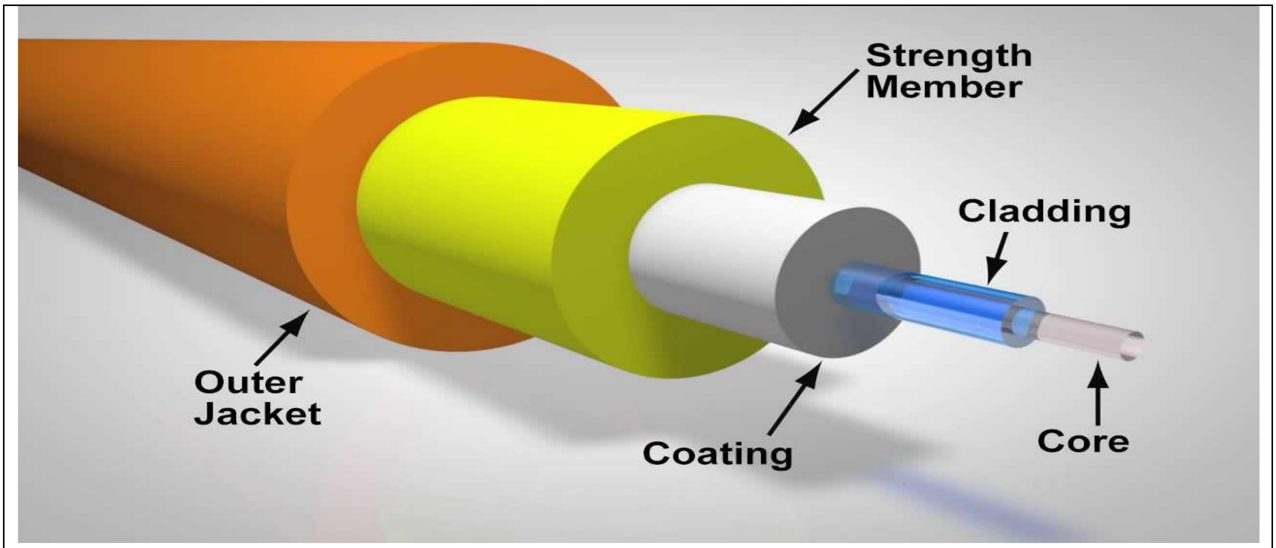
Fibre optic communications make use of guided light signals to transfer information from a sender to a receiver at high speeds. In our demanding world for fast data transfer, we heavily rely on fibre optic communications to transmit dense information, rapidly and over long distances.

The exceptional abilities of light make it a superior choice over other transmission technologies. The uniqueness of using a light-based communication carrier over the conventional method of copper wires or radio systems can be easily noted when we look at the properties of light.

An optical signal can travel long distances without the need for regeneration. In addition, fibre optic cables are much lighter and smaller than copper cables, provide a higher bandwidth capacity than copper or coaxial cables, and are immune to electromagnetic interference.

5.2 STRUCTURE

- Optical fiber is a wave guide, made up of transparent dielectrics like glass or plastics. A practical optical fiber has in general three coaxial regions as shown in fig.
- The inner most region is the light guiding region known as the core.
- It is surrounded by a coaxial middle region known as the cladding.
- The outermost region is called a strength member (buffer) and outer jacket. It is made up of polyurethane material.
- The refractive index of cladding is always lower than that of the core. The purpose of the cladding is to make the light to be confined to the core.



5.1Structure of Fibre optics

5.3 ADVANTAGES OF OPTICAL FIBRE

An optical fiber or fiber optic cable is a flexible, transparent fiber made by drawing glass, which are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data rates) than wire cables.

Bandwidth

Fiber optic cables have a much greater bandwidth than metal cables. The amount of information that can be transmitted per unit time of fiber over other transmission media is its most significant advantage.

Low Power Loss

An optical fiber offers low power loss, which allows for longer transmission distances. In comparison to copper, in a network, the longest recommended copper distance is 100m while with fiber, it is 2km.

Interference

Fiber optic cables are immune to electromagnetic interference. It can also be run in electrically noisy environments without concern as electrical noise will not affect fiber.

Size

In comparison to copper, a fiber optic cable has nearly 4.5 times as much capacity as the wire cable has and a cross sectional area that is 30 times less.

Weight

Fiber optic cables are much thinner and lighter than metal wires. They also occupy less space with cables of the same information capacity. Lighter weight makes fiber easier to install.

Security

Optical fibers are difficult to tap. As they do not radiate electromagnetic energy, emissions cannot be intercepted. As physically tapping the fiber takes great skill to do undetected, fiber is the most secure medium available for carrying sensitive data.

Flexibility

An optical fiber has greater tensile strength than copper or steel fibers of the same diameter. It is flexible, bends easily and resists most corrosive elements that attack copper cable.

Cost

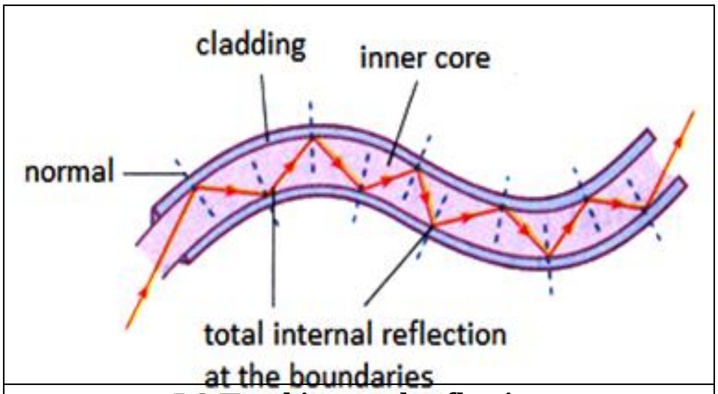
The raw materials for glass are plentiful, unlike copper. This means glass can be made more cheaply than copper

Safety

It does not affected by fog, rain, humidity…

5.4 PRINCIPLE AND PROPAGATION OF LIGHT THROUGH OPTICAL FIBRE

The light wave enters at one end of the fiber and it strikes the interface of the core and cladding at large angles of incidence. The light beam undergoes total internal reflection and passes through the length of the cable as shown in fig. Fiber obeys the laws of reflection and refraction of light waves.



5.2 Total internal reflection

Principle:

The principle of optical fiber communication is total internal reflection.

Total Internal Reflection

The phenomenon of total internal reflection takes place when it satisfies the following two conditions.

- Light should travel from denser medium to rarer medium

  i.e. $n_1 > n_2$

  Where, n_1-refractive index of core

  n_2 -refractive index of cladding

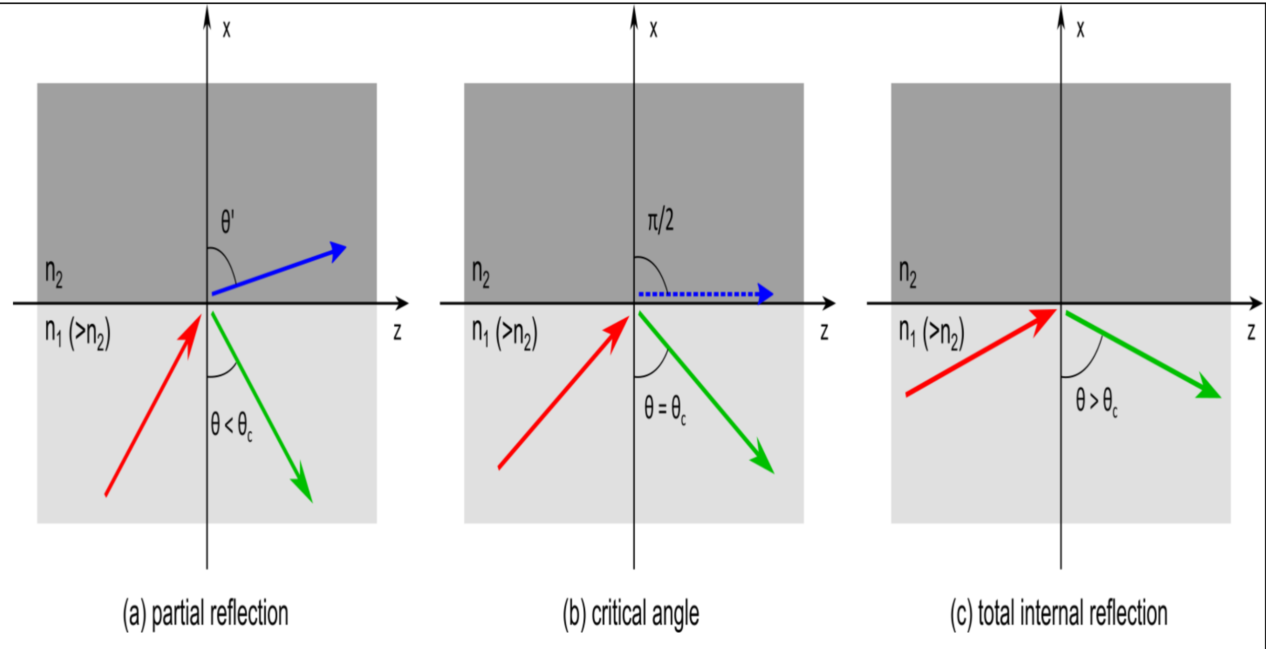
- The angle of incidence on core should be greater than the critical angle

  i.e. $\theta > \theta_c$

  Where θ –angle of incidence

  θ_c – critical angle

Propagation phenomenon



5.3 Light propagation phenomena

Let the light ray passes from denser medium (n_1) to rarer medium (n_2).

Condition 1: Partial reflection

When $\theta < \theta_c$, the ray is refracted into the rarer medium (n_2).

Condition 2: Critical angle

When $\theta = \theta_c$, the ray passes along the interface. So, that the angle of refraction is 90°. This angle (θ_c) is called as critical angle.

Condition 3: Total internal reflection

When $\theta > \theta_c$, the ray is totally reflected back into the denser medium (n_1).

Applying Snell's law in fig (b)

$$n_1 \sin\theta = n_2 \sin 90°$$

Rearranging we get

$$\frac{\sin\theta}{\sin 90°} = \frac{n_2}{n_1} \text{ --(1)}$$

But angle of incidence is equal to critical angle. i.e. $\theta = \theta_c$. Also sin 90°=1. Then, equation 1 becomes

$$\sin\theta_c = \frac{n_2}{n_1}$$

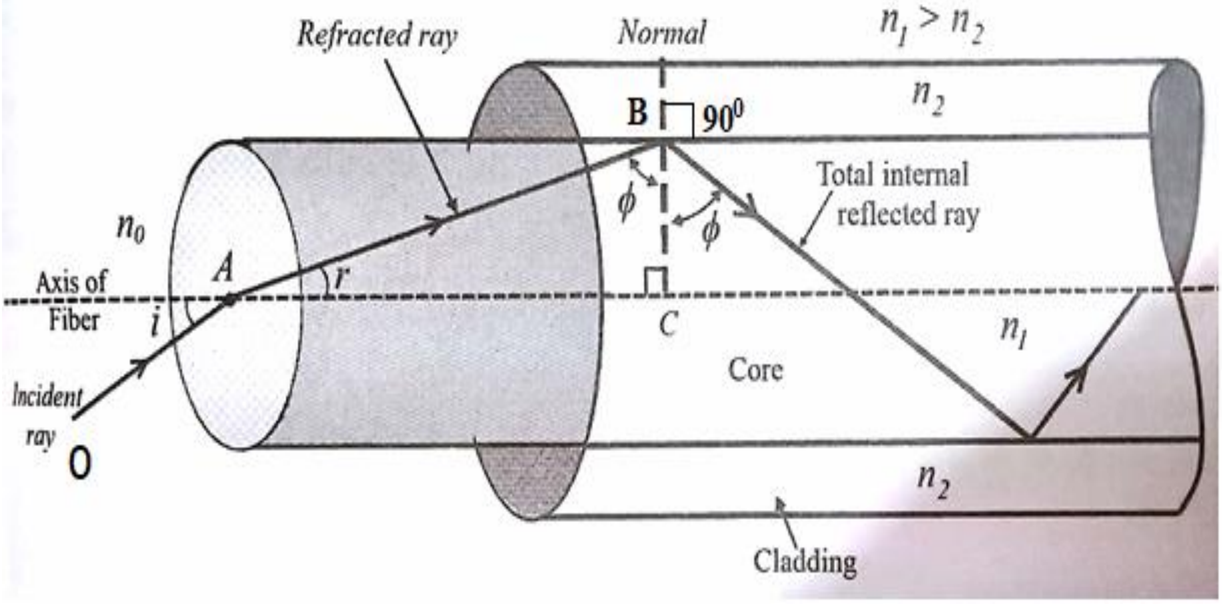
$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) \text{ ---(2)}$$

Equation 2 is used to find critical angle (θ_c).

5.4.1 ACCEPTANCE ANGEL AND NUMERICAL APERTURE

Let us consider an optical fiber. Let n_1 be the core refractive index, n_2 be the cladding refractive index and n_0 be the refractive index of the medium (air).

The incident ray (OA) enters the core at an angle 'i' to the fiber axis. The ray is refracted along AB at an angle 'ϕ' in the core as shown in fig.



5.4 Numerical aperture and acceptance angle

Hence, the angle of incidence at the interface of core and cladding will be more than the critical angle. Hence the ray is totally internally reflected.

Applying Snell's law, at point of entry of ray OA

$$n_0 \sin i = n_1 \sin r$$

Rearranging, $\sin i = \frac{n_1}{n_0} \sin r$ ------------------------------------(1)

We know, $\sin r = \sqrt{1 - \cos^2 r}$ ---(2)

Subs eqn 2 in 1

$$\sin i = \frac{n_1}{n_0} \sqrt{1 - \cos^2 r}$$ ------------------------------------(3)

Applying Snell's law at point B (on interface)

$$n_i \sin \phi = n_2 \sin 90°$$ -------------------------------------(4)

At point B, $\phi = 90° - r$ and sin 90°=1

Equation 4 becomes

$$n_i \sin(90° - r) = n_2$$

$$n_i \cos r = n_2$$

Or $$\cos r = \frac{n_2}{n_1} \text{ ---(5)}$$

Subs eqn 5 in 3, we get,

$$\sin i = \frac{n_1}{n_0}\sqrt{1-\left(\frac{n_2}{n_1}\right)^2}$$

$$\sin i = \frac{n_1}{n_0}\sqrt{1-\left(\frac{n_2^2}{n_1^2}\right)}$$

$$\sin i = \frac{n_1}{n_0}\sqrt{\left(\frac{n_1^2 - n_2^2}{n_1^2}\right)}$$

$$\sin i = \frac{n_1}{n_0}.\frac{1}{n_1}\sqrt{n_1^2 - n_2^2} \text{ ------------------------------(6)}$$

We know refractive index for air medium is 1. So n_0=1.

Equation 6 can be written as

$$\sin i = \sqrt{n_1^2 - n_2^2}$$

The maximum value of sin i is given as

$$\sin i_{max} = \sqrt{n_1^2 - n_2^2} \text{ ---------------------------------------(7)}$$

Equation 7 represents angle of acceptance.

Acceptance angle

The maximum angle at which a ray of light can enter through the fiber so that the light will be totally internally reflected is called acceptance angle.

Numerical Aperture (NA)

It is the measure of amount of light rays that can be accepted by the fiber. The sine of the acceptance angle of the fiber is called numerical aperture.

$$NA = \sin i_{max} = \sqrt{n_1^2 - n_2^2} \text{ -----------------(8)}$$

Fractional index change (Δ):

It is the ratio of refractive index difference in core and cladding to the refractive index of core.

i.e. $$\Delta = \frac{n_1 - n_2}{n_1} \text{------------------------}(9)$$

relation between NA and Δ.

$$n_1\Delta = n_1 - n_2 \text{-----------------------}(10)$$

We know $$NA = \sqrt{n_1^2 - n_2^2}$$

(Or) $$NA = \sqrt{(n_1 + n_2)(n_1 - n_2)} \text{---------}(11)$$

Substituting eqn (9) in eqn. (11), we have

$$NA = \sqrt{(n_1 + n_2)(n_1\Delta)}$$

If $n_1 \approx n_2$, then $$NA = \sqrt{(2n_1)(n_1\Delta)}$$

$$NA = \sqrt{2n_1^{\,2}\Delta)}$$

$$NA = n_1\sqrt{2\Delta)} \text{-----------------------}(12)$$

Equation 12 represents the relation between NA, fractional index change and refractive index of core.

5.5 FABRICATION OF OPTICAL FIBER – DOUBLE CRUCIBLE METHOD

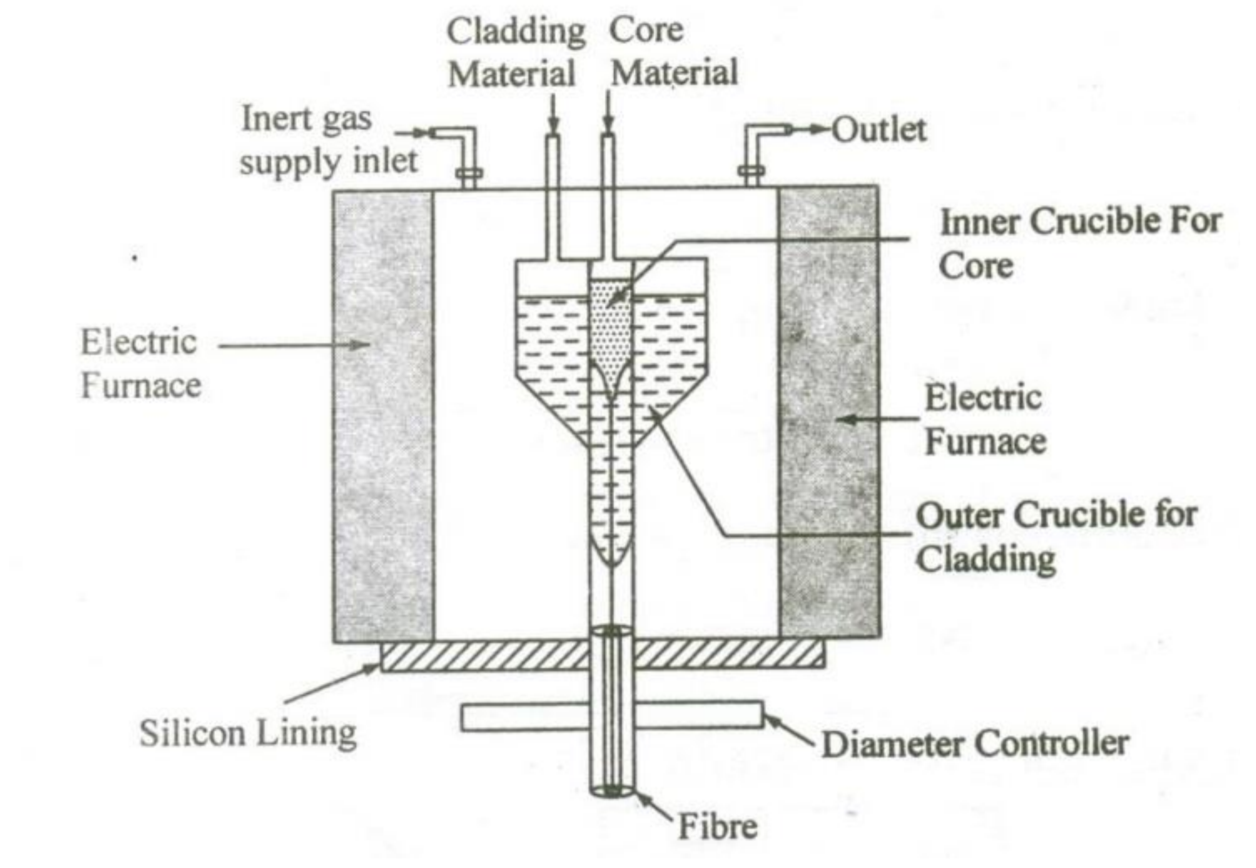
It is also called as crucible- crucible method

Principle

The raw material for core and cladding are separately placed in the crucibles kept one inside the other and is heated to a very high temperature using a furnace. The molten materials are drawn out together to form the fiber.

Description

- The experiment consists of inner and outer crucibles made by platinum or silica.
- An electric furnace is used to melt the material of core and cladding.
- The inner crucible is kept inside the outer crucible and is placed inside an electric furnace, which is capable of heating up to 1200ºC.
- The diameter of the fiber can be controlled with the help of a diameter controller.
- The various refractive indices of core and cladding are obtained by adding the doping materials.
- Inert gas inlet and outlet are used to circulate inert gas in between furnace and crucible. The inert gas environment inside the crucible is used to maintain constant temperature.



5.5 Double crucible method

Working

- The core glass powder is taken in inner crucible and cladding glass powder is taken in outer crucible.
- The electric furnace is switched ON and materials are heated to the higher temperature and are melted.
- The molten material is allowed to emerge out through the nozzle of the crucible.
- Now the core material will start diffusing into the cladding material to form an optical fiber and fiber is drawn out through the bottom of the outer crucible.
- Finally the fiber is coated by the polymer and protective layers.
- Diameter of the optical fiber can be controlled by diameter controller.

Advantages

- Fabrication cost is low.
- Fibers can be fabricated continuously.

Disadvantages

- Materials used for making core and cladding should be pure, else contamination will occur.
- It is difficult to produce graded index fibers.

- Silica crucibles should not be used more than once; in such cases crucibles made up of platinum should be used, which is costly.

5.6 CLASSIFICATION OF OPTICAL FIBERS

Optical fibers are classified into the following categories based on the

- Material,
- Number of modes and
- Refractive index profile

5.6.1 Material based fiber:

Based on the materials, it can be classified into two types,

Glass fibers:

If the fibers are made up of mixture of metal oxides and silica glasses are called as glass fibers.

Eg: Core: SiO_2 Cladding: P_2O_3- SiO_2

Plastic fibers:

If the fibers are made of plastics which can be handled without any care (toughness and durability) is called as plastic fibers.

Eg: Core: Polystyrene; Cladding: methyl methacrylate

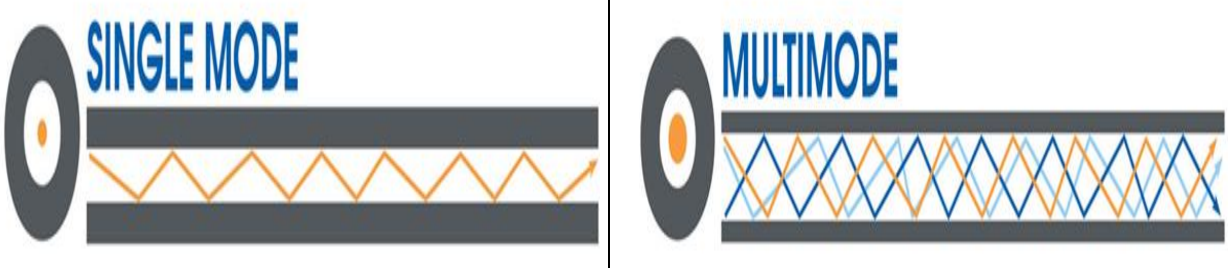
5.18.2 **Mode based fiber:**

Based on the modes of propagation, the fibers are classified into two types,

Single mode fiber:

An optical fiber can allow only one mode of propagation through core is known as single mode fiber.

It has smaller core diameter than the cladding diameter, so that the optical loss is very low. These types of fiber are made from doped silica and the refractive index of core and cladding is small. The structure of the single mode fiber is shown in.



5.6 SMF and MMF

Structure:

Core diameter : 5-10 μm

Cladding diameter : around 125μm

Band width : more than 50 MHz km

It is used for long haul communication.

Multi-mode fibers:

An optical fiber can allow more than one mode of propagation through core is known as single mode fiber.

The multi-mode fibers are made by Glass-clad Glass, Silica-clad Silica etc., and diameter of the core will be higher. The structure of the multi- mode fiber is shown in fig.

Structure

Core diameter : 50-350 μm

Cladding diameter : 125-500 μm

Band width : less than 50MHz km

It is used for short haul communication.

Differences between Single and Multi-Mode Fiber

BASIS OF COMPARISON	**SINGLE MODE FIBERS**	**MULTIMODE FIBER**
Diameter	Single mode fiber optic cable has a small diameter core that only allows one mode of light ray to propagate.	Multimode fiber optic cable has a large diameter core that allows multiple modes of light to propagate.
Transmission Capacity	Signal transmission capacity in single mode fibers is less.	Signal transmission capacity is more in multimode fibers.
Suitability	Single mode fibers are suitable for long distance communication and for carrying high bandwidth signal with the help of laser diode as optical transmission system equipment,	Due to large dispersion and attenuation, multimode fibers are suitable for short distance communication with LED based fiber optic equipment.
Diameter Of The Core	Single mode step index fibers have less core diameter (<10μm) and the difference between	Multimode step index fibers have larger core diameter (50 to 200 μm) and the difference between the

	refractive indices of the core and cladding is very small.	refractive indices of the core and cladding is large.
Signal Dispersion And Distortion	In single mode fibers, there is no signal dispersion and distortion.	In multimode fibers, there is signal distortion and dispersion.
Cost	Single mode fibers provide higher performance but building the network is relatively expensive.	Fabrication of the multimode fiber is more costly; however, the deployment of the network is relatively inexpensive.
Broadband Radio Frequency (RF)	Broadband Radio Frequency (RF) signals can be propagated through single mode fiber optical cable.	Broadband RF signals cannot be propagated through multimode fiber optical cable.
Application	Major applications of single mode are CATV, Telcos, universities as well as collages.	Multimode fiber is used for short distance communication mainly for video/audio/data based wireless LAN application.
Color	Single mode fiber is usually yellow in color.	OM1 and OM2 fibers are usually orange, OM3 aqua, OM4 aqua or pink and OM5 light green.

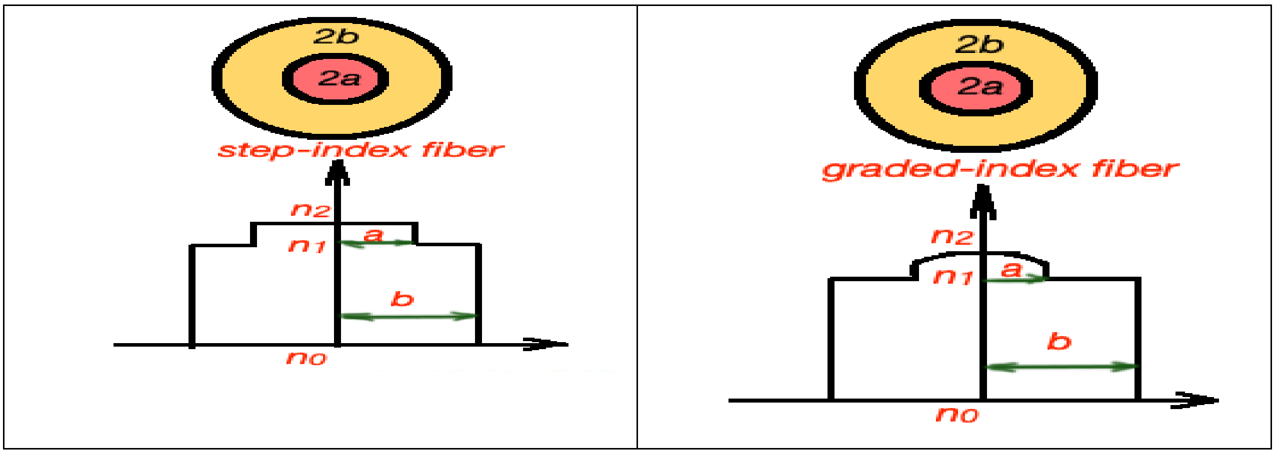
5.6.2 Refractive index based fiber:

Step index fiber:

The refractive index of air, cladding and core varies by step by step and hence the fiber is called as step index fiber.

Graded index fiber:

The refractive index of the core varies radially from the axis of the fiber and hence the fiber is called graded index fiber. The refractive index of the core is maximum along the fiber axis and it gradually decreases towards the cladding.



5.7 SIF and GIF

Differences between Step Index Fiber and Graded Index Fiber

BASIS OF COMPARISON	STEP INDEX FIBER	GRADED INDEX FIBER
Description	Step index fiber is a fiber in which the core is of a uniform refractive index and there is a sharp decrease in the index of refraction at the cladding.	Graded index fiber is a type of fiber where the refractive index of the core is maximum at the center core and then it decreases towards core-cladding interface.
Types	Step index fiber is found in two types, that is mono mode fiber and multi mode fiber.	Graded index fiber is of only one type, that is, multi mode fiber.
Index Profiles	Index profiles are in the shape of step.	Index profiles is in the shape of a parabolic curve (for α=2).
Light Rays Propagation	The light rays propagate in *zig–zag* manner inside the core.	The light rays propagate in the form of skew rays or helical rays. They will not cross the fiber axis.
Signal Distortion	Signal distortion is more in case of high-angle rays in multimode step index fiber. In single mode step index fiber, there is no distortion.	Signal distortion is very low even though the rays travel with different speeds inside the fiber.
Bandwidth Size	The fiber has lower bandwidth.	The fiber has higher bandwidth.
Diameter Of The Core	The diameter of the core is between 50-200µm in the case of multimode fiber and 10µm in the case of single mode fiber.	The diameter of the core is about 50µm in the case of multimode fiber.
Application	Used for short distance communication.	Used for long distance communication.
Attenuation Of Light Rays	Attenuation of light rays is more in multimode step index fibers but for single mode step index fibers, it is very less.	Attenuation of light rays is less in graded index fibers.

Cost	Less expensive	Highly expensive.
NA	NA of multimode step index fiber is more whereas in single mode step index fibers, it is very less.	NA of graded index fibers is less.
Pulse Broadening	Pulse broadening and inter modal dispersion is present.	No pulse broadening and inter modal dispersion due to periodic self-focusing.

5.7 FIBER OPTICAL COMMUNICATION SYSTEM

Optical Fiber Communication is the method of communication in which signal is transmitted in the form of light and optical fiber is used as a medium of transmitting those light signal from one place to another. The signal transmitted in optical fiber is converted from the electrical signal into light and at the receiving end, it is converted back into the electrical signal from the light.

The data sent can be in the form of audio, video or telemetry data that is to be sent over long distances or over Local Area Networks. Optical fiber communication having good results in long-distance data transfer at high speed, it has been used as an application for various communication purposes.

Principle:

Basic principle of optical fiber communication system is total internal reflection.

Construction and working:

The Optical fiber communication process transmits a signal in the form of light which is first converted into the light from electrical signals and transmitted, and then vice versa happens on the receiving side.

Transmitter side:

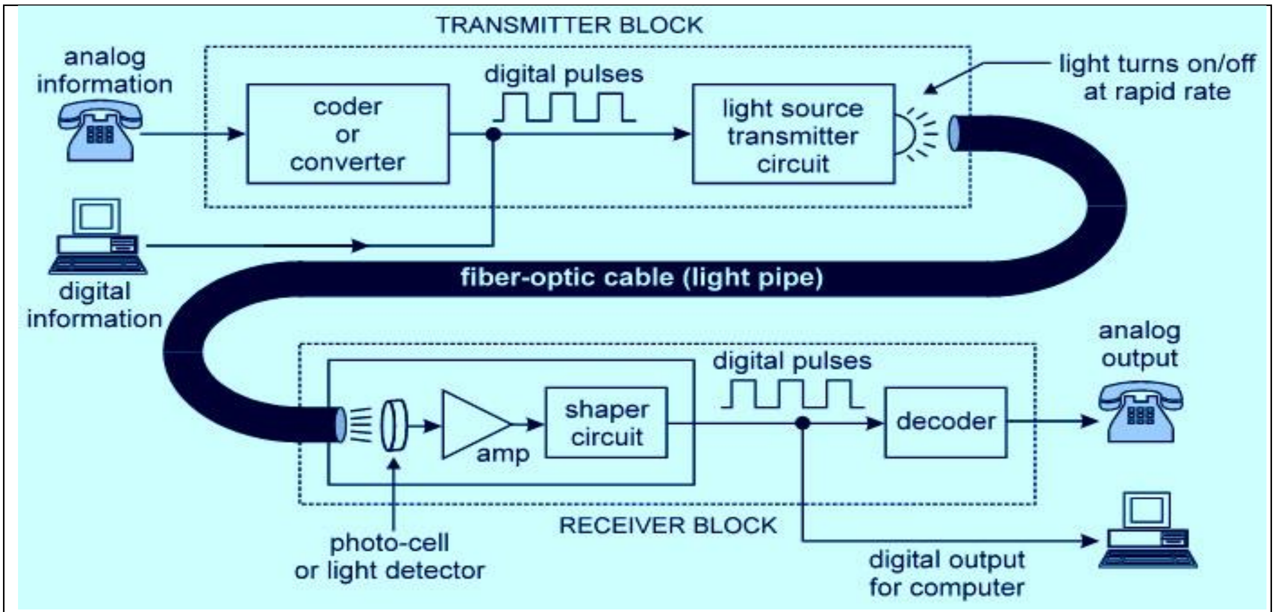
On the transmitter side, first if the data is analog, it is sent to a coder or converter circuit which converts the analog signal into digital pulses of 0,1,0,1…(depending on how the data is) and passed through a light source transmitter circuit. And if the input is digital then it is directly sent through the light source transmitter circuit which converts the signal in the form of light waves.

Optical Fiber Cable:

The light waves received from the transmitter circuit to the fiber optic cable is now transmitted from the source location to the destination and received at the receiver block.

Receiver Side:

Now on the receiver side the photocell, also known as the light detector, receives the light waves from the optical fiber cable, amplifies it using the amplifier and converts it into the proper digital signal.



5.8 Optical fiber communication system

Now if the output source is digital then the signal is not changed further and if the output source needs analog signal then the digital pulses are then converted back to an analog signal using the decoder circuit.

The whole process of transmitting an electrical signal from one point to the other by converting it into the light and using Fiber optic cable as transmission source is known as Optical Fiber Communication.

5.8 FIBER OPTICS MEDICAL ENDOSCOPE

- Optical fibers are very much useful in medical field.
- Using low quality, large diameter and short length silica fibers we can design a fiber optic endoscope or fibroscope.
- A medical endoscope is a tubular optical instrument, used to inspect or view the internal parts of human body which are not visible to the naked eye.
- The photograph of the internal parts can also be taken using this endoscope.

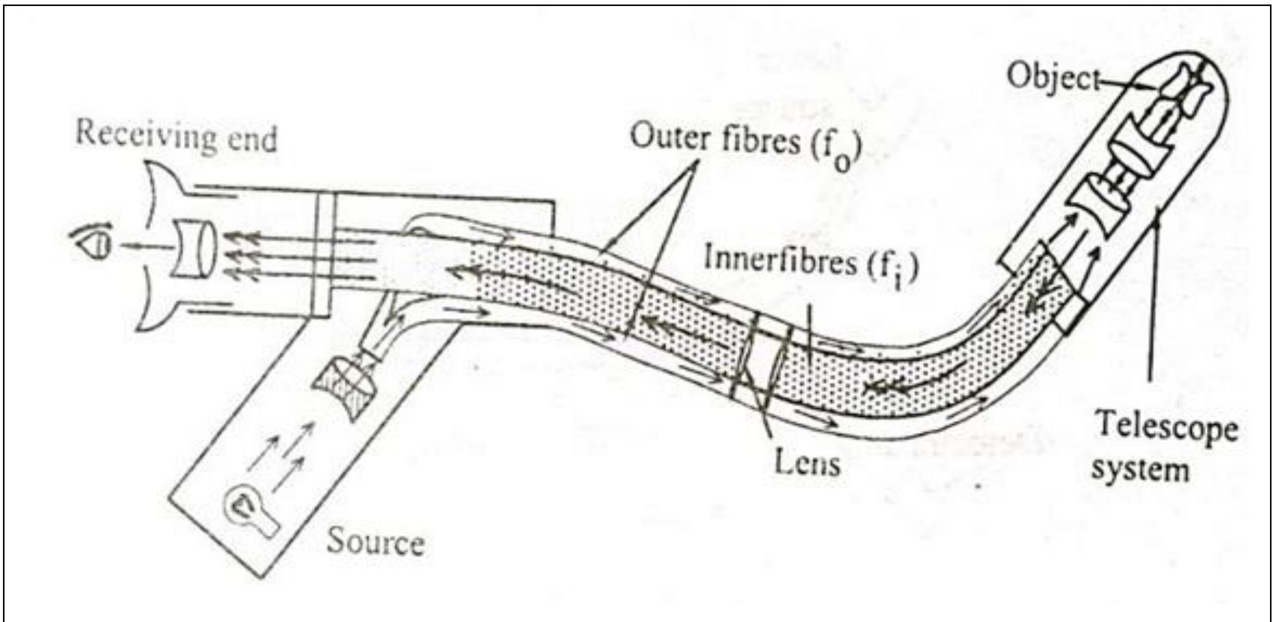
Construction:

Figure shows the structure of endoscope. It has two fibers viz.,

1. Outer fiber (f_0)
2. The inner fiber (f_i).

Outer fiber:

The outer fiber consists of many fibers bundled together without any particular order of arrangement and is called incoherent bundle. These fiber bundles as a whole are enclosed in a thin sleeve for protection. The outer fiber is used to illuminate or focus the light onto the inner parts of the body.



5.9 Optical fiber medical endoscope

Inner fiber:

The inner fiber also consists of a bundle of fibers, but in perfect order. Therefore this arrangement is called coherent bundle. This fiber is used to collect the reflected light from the object. A tiny lens is fixed to one end of the bundle in order to effectively focus the light, reflected from the object. For a wider field of view and better image quality, a telescope system is added in the internal part of the telescope.

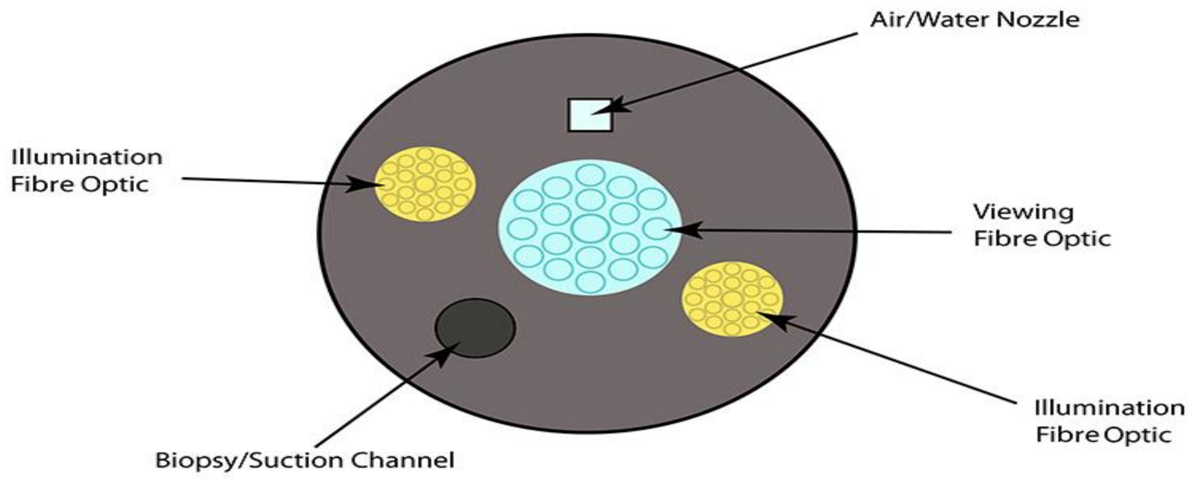
Working:

Light from the source is passed through the outer fiber (f_0). The light is illuminated on the internal part of the body. The reflected light from the object is brought to focus using the telescope to the inner fiber (f_i).

Here each fiber picks up a part of the picture from the body. Hence the picture will be collected bit by bit and is transmitted in an order by the array of fibers.

As a result, the whole picture is reproduced at the other end of the receiving fiber as shown in the figure. The output is properly amplified and can be viewed through the eye piece at the receiving end.

The cross sectional view is as shown in the figure 5.24.



5.10 Endoscope channels

In figure, we can see that along with input and output fibers, we have two more channels namely, (i) Instrumental Channel (C1) and (ii) Irrigation channel (C2) used for the following purposes.

Instrumentation channel or suction channel:

It is used to insert or take the surgical instruments needed for operation.

Irrigation channel (air/water nozzle):

It is used to blow air or this is used to clear the blood in the operation region, so that the affected parts of the body can be clearly viewed.

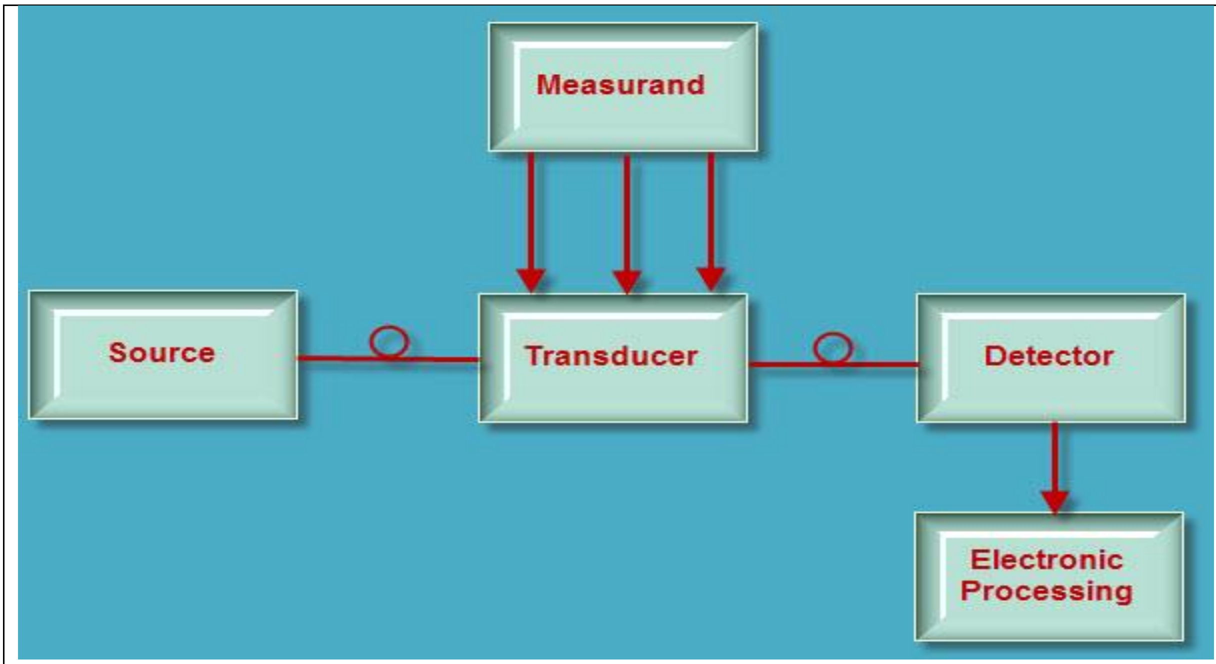
5.9 FIBER OPTIC SENSORS

The fiber optic sensors also called as optical fiber sensors use optical fiber or sensing element. These sensors are used to sense some quantities like temperature, pressure, vibrations, displacements, rotations or concentration of chemical species.

Fibers have so many uses in the field of remote sensing because they require no electrical power at the remote location and they have tiny size.

Fiber optic sensors are supreme for insensitive conditions, including noise, high vibration, extreme heat, wet and unstable environments. These sensors can easily fit in small areas and can be positioned correctly wherever flexible fibers are needed.

The wavelength shift can be calculated using a device, optical frequency-domain reflectrometry. The time-delay of the fiber optic sensors can be decided using a device such as an optical time-domain Reflectometer.



5.11 Block diagram of Fiber optic sensors

The general block diagram of fiber-optic sensor is shown 5.25. The block diagram consists of optical source (Light Emitting Diode, LASER, and Laser diode), optical fiber, sensing element, optical detector and end-processing devices (optical-spectrum analyzer, oscilloscope).

Applications of Fiber Optic Sensors

Fiber optic sensors are used in a varied range of applications such as

- Measurement of physical properties such as temperature, displacement, velocity, strain in structures of any size or any shape.
- In real time, monitoring the physical structure of health.
- Buildings and bridges, tunnels,Dams, heritage structures.
- Night vision camera, electronic security systems, Partial discharge detection and measuring wheel loads of vehicles.

Thus, an overview of fiber optic sensors and applications has been discussed. There are many advantages of using fiber optic sensors for long distance communication that include small in size, light in weight, compactness, high sensitivity, wide bandwidth, etc.

5.10 APPLICATIONS OF OPTICAL FIBER:

- **Medical**

  Used as light guides, imaging tools and also as lasers for surgeries
- **Defense/Government**

  Used as hydrophones for seismic waves and SONAR , as wiring in aircraft, submarines and other vehicles and also for field networking

- **Data Storage**

  Used for data transmission

- **Telecommunications**

  Fiber is laid and used for transmitting and receiving purposes

- **Networking**

  Used to connect users and servers in a variety of network settings and help increase the speed and accuracy of data transmission

- **Industrial/Commercial**

  Used for imaging in hard to reach areas, as wiring where EMI is an issue, as sensory devices to make temperature, pressure and other measurements, and as wiring in automobiles and in industrial settings

- **Broadcast/CATV**

  Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video on-demand and other applications

U23PHT13 – PHYSICS FOR ENGINEERS AND TECHNOLOGISTS

UNIVERSITY REPEATED QUESTIONS

UNIT I ELASTICITY

1. A cantilever clamped horizontally at one end and loaded at other end. Obtain the relation between the depression at the loaded end and the load applied. Also find Young's modulus value of beam using this method.
2. Derive the expression for the young's modulus of a uniform bending of a rod and describe the experiment to determine the young's modulus of that rod using this method.
3. What is stress strain diagram? What do you infer from it? Explain in detail about the diagram. And also explain the factor affecting the elastic material.
4. Derive the expression for moment of inertia of disc and find the rigidity modulus of a cylindrical wire by torsional pendulum.
5. (i)With neat diagram, arrive the expression for twisting couple in produced in a cylindrical wire.
   (ii)Write short notes on I shaped girders.

UNIT II ULTRASONICS

1. Explain with neat diagram, principle, construction, working of magnetostriction method to produce ultrasonics. Also discuss their merits and demerits.
2. With a neat circuit diagram, explain the principle, working and production of ultrasonics by a Piezo electric oscillator. How it is useful than magnetostriction oscillator.
3. What is an acoustic grating? How it is used in determining the velocity of ultra sound?
4. Explain the process of non-destructive testing of materials using ultrasonic waves by pulse-echo method.
5. (i)Explain the types of ultrasonic imaging systems.
   (ii) With necessary diagram, explain principle, instrumentation, working and diagnosis of sonogram.

III MODERN PHYSICS

1. Using quantum theory, derive an expression for the average energy limited by a block body and arrive at planks radiation law in terms of frequency. State the assumption before stating the derivation.
2. What is Compton effect? Derive an expression for the wavelength of the scattered photon. How it is verified experimentally?
3. Derive Schrödinger time dependent and time independent equation for matter wave.
4. Drive an expression for the energy of a particle in a one dimensional box. Also arrive an expression for its normalization wave function.
5. State and explain Einstein's photo electric effect equation. How are the different laws of photo electric effect explained by this equation?

IV LASERS

1. For atomic transitions, derive Einstein relations and hence deduce the expressions for the ratio of spontaneous emission to the stimulated emission rate.
2. Describe with necessary energy level diagram, the construction and working of He-Ne laser. Mention its applications.

3. Describe the construction and working of homo-junction and hetero-junction semiconductor lasers.
4. Explain the construction and reconstruction of hologram with neat diagram.

UNIT V FIBER OPTICS AND ITS APPLICATIONS

1. Derive an expression for acceptance angle and Numerical aperture.
2. Explain in detail how optical fibers are classified according to the material, refractive index and modes of propagation.
3. Describe the principle of fibre optic sensors. Explain the fibre optic displacement sensor and fibre optic temperature sensor.
4. (i) With block diagram, Explain the fibre optical communication system.
   (ii) Explain the construction and working of fibre-optic medical endoscope.

IMPORTANT TWO MARK QUESTIONS:

UNIT-I ELASTICITY What is elastic body(2)

1. Define elasticity? (2)
2. Define plasticity(2)
3. Define stress and give its unit (2)
4. Define strain and giveits unit (2)
5. State Hooke's law(2)
6. Elastic limit and elastic fatigue (2)
7. What is stress – strain diagram? (2)
8. Define Young's modulus. Mention its unit(2)
9. Define rigidity modulus. Mention its unit(2)
10. Define bulk modulus. Mention its unit(2)
11. State Poisson's ratio. Mention its limit. (2)
12. What are the factors affecting elastic property of a body?(2)
13. Define bending moment of beam. (2)
14. What is I shaped girders? (2)
15. What are the advantages of I shaped girders? (2)
16. What are the applications of I shaped girders? (2)
17. What is called uniform bending? (2)
18. What is called non-uniform bending? (2)
19. Define torsional pendulum. (2)

UNIT-II ULTRASONICS

1. How sound waves are classified based on frequency? Mention its frequency range.(2)
2. Give some properties of audible wave. (2)
3. What is magnetostriction effect?(2)
4. Can we produce ultrasonic wave using PNP transistor? (2)
5. Can we produce ultrasonic wave using para and diamagnetic materials? Give explanation.(2)
6. Mention the advantages and disadvantages of magnetostriction generator.(2)
7. Define piezo electric effect.(2)

8. State the principle behind piezo electric generator.(2)
9. Can we produce ultrasonic wave using NaCl crystal?(2)
10. What is inverse or converse piezo electric effect? (2)
11. Mention the advantages and disadvantages of piezo electric generator.(2)
12. What is acoustical grating?(2)
13. Write the general applications of ultrasonics?(2)
14. What is the principle of ultrasonic flaw detector / pulse echo system?(2)
15. What is transducer?(2)
16. Differentiate A, B and C scan displays.(2)
17. What is principle behind sonogram?(2)
18. How will find the depth of the sea using ultrasonics.(2)
19. What is heart sound and murmers?(2)
20. State Doppler Effect. (2)

UNIT –III MODERN PHYSICS

1. State black body and black body radiation(2)
2. Define Kirchoff's law for black body radiation.(2)
3. Define Stefan's law for black body radiation.(2)
4. Define Wien's law for black body radiation.(2)
5. Define Rayleigh- Jean's law for black body radiation.(2)
6. State Planck's hypothesis or assumptions(2)
7. What is called photon?(2)
8. Give the properties of photons. (2)
9. Define photo electric effect. (2)
10. Mention the laws of photo electric effect.(2)
11. What are matter waves? (2)
12. How de-Broglie justified his dual nature concept of material particle? (2)
13. State the properties of matter waves? (2)
14. Can we call matter wave is an electromagnetic wave? Justify. (2)
15. Mention the physical significance of wave function(2)
16. What are eigen values and eigen function? (2)
17. Energy levels of an electron cannot be zero. Why?(2)
18. Define degeneracy and non-degeneracy states. (2)

UNIT-IV LASERS

1. What are the characteristics of laser? (2)
2. Why the lasers are called as non-metal knife. (2)
3. Compare the characteristics of ordinary and laser light. (2)
4. Differentiate spontaneous and stimulated emission. (2)
5. What is stimulated absorption? (2)
6. What is spontaneous emission? (2)
7. What is stimulated emission? (2)
8. What is population inversion? (2)
9. What is the principle of semiconductor laser? (2)
10. Write are the applications semiconductor laser. (2)
11. Draw energy level diagram of He-Ne laser. (2)

12. Mention the applications of lasers in industry and medical field(2)

UNIT-V OPTICAL FIBER AND ITS APPLICATIONS

1. Explain the structure of optical fiber. (2)
2. Define acceptance angle and numerical aperture of a fibre(2)
3. What are the advantages of optical fibre? (2)
4. What are the conditions to be satisfied total internal reflection? (2)
5. What are the differences between step index and graded index fibre? (2)
6. What is the principle behind the fibre optical communication system? (2)
7. Give the applications of fibre optic sensors(2)
8. What is medical endoscope (2)

Refer Solved Problems from Engineering Physics I (R-2009, Published Year Between 2009-2013) written by Dr. P. Mani or Dr. G. Senthilkumar or Dr. Muthukumaran.