2020-21 Onwards (MR-20)	MALLA REDDY ENGINEERING COLLEGE (Autonomous)	B.Tech. I Semester		
Code: A0B12	**Engineering Physics** (Common for ME, CE and M Eng.)	**L**	**T**	**P**
Credits: 4		**3**	**1**	**-**

Prerequisites: Fundamentals of Physics

Course Objectives:

The main objective of this course is to provide the basic physics principles, would help engineers to understand the tools and techniques used in the industry and provide the necessary foundations for inculcating innovative approaches. This would create awareness about the vital role played by science and engineering in the development of new technologies.

Module – I: Waves and Oscillations **[10 Periods]**

Simple harmonic Oscillator; damped harmonic oscillator; types of damping – heavy, critical and light damping; energy decay in a damped harmonic oscillator; relaxation time, quality factor; Forced harmonic Oscillator; electrical and mechanical analogy for a simple oscillator.

Module – II **[12 Periods]**

Acoustics: Introduction, Reverberation and Reverberation time; Basic requirements of acoustically good hall; Absorption coefficient, Jaeger's method for derivation of Sabine's formula; factors affecting the architectural acoustics and their remedies.

Ultrasonics: Introduction, Production of Ultrasonic Waves - Piezo Electric Effect, Inverse piezo electric effect, Piezo-Electric crystal Method, Magnetostriction effect, Magnetostriction Method; Detection of Ultrasonic waves - Piezo Electric detector, Kundt's tube method, Sensitive Flame method and Thermal Detection Method; Applications of Ultrasonics - Medical, SONAR, Ultrasonic drilling and welding,

Module – III: LASERs and Optical Fibers **[10 Periods]**

LASER: Introduction, Characteristics of LASER; Absorption, spontaneous and Stimulated emission; Einstein's coefficients Derivation; population inversion; pumping mechanisms; Basic components of a laser system; three and four level laser systems; Ruby LASER; He-Ne LASER; Semiconductor diode LASER (Homo junction); Applications of LASER - Computers, Medical, Military.

Optical Fibers: Introduction to Optical fibers, total internal reflection; Acceptance angle, and acceptance cone; numerical aperture; types of optical fibers; Losses in optical fibers - absorption losses, scattering losses and bending losses; Applications of optical fibers - Communications, Level Sensor, LASER angioplasty.

Module – IV **[10 Periods]**

Non-destructive Testing: Introduction; Objectives of Non-destructive testing; Types of defects – Cracking, Spalling, Staining, Construction and Design defects, Honey combing, Dusting, Blistering, Rain damage; Methods of Non-destructive testing – Liquid penetrant testing, Magnetic particle testing, Ultrasonic inspection method and Radiography testing.

Module – V **[10 Periods]**

Dielectric Properties: Electric dipole, Dipole moment, Dielectric constant, Polarizability, Electric Susceptibility, Displacement Vector; Determination of dielectric constant by resonance method; Electronic, Ionic and Orientation Polarizations and Calculation of Polarizabilities - Electronic and ionic; Internal field (qualitative treatment); Clausius-mossotti equation; Applications of Dielectric materials.

Nanomaterials: Introduction to nanomaterials, Types of nano materials; factors affecting the properties of nano materials - surface area to volume ratio and Quantum confinement effect; Properties of nano materials; Synthesis of nanomaterials - Sol-gel and Chemical vapour deposition method; Applications of Nanomaterials.

Course Outcomes:

At the end of the course, student will be able to

1. Distinguish free, damped and forced vibrations.
2. Using the knowledge of acoustics in designing acoustically important buildings and ultrasonics for designing materials.
3. Understand the concepts and applications of LASER and Optical fibers.
4. Apply the knowledge of Ultrasonic to understand non-destructive testing.
5. Understand the importance of dielectric and nanomaterials and their properties.

Text Books:

1. M N Avadhanulu, P G Kshirsagar, "**A Textbook of Engineering Physics"**, Revised Edition 2014.
2. K Vijaya Kumar, S Chandralingam, "**Modern Engineering Physics**'' Volume I & II, S. Chand, 1st Edition, 2017.
3. B K Pandey and S. Chaturvedi, "**Engineering Physics**" Cengage Learning India
   Revised Edition, 2014.

References:

1. P K Palanisamy, "**Engineering Physics"**, 4th Edition, SciTech Publications, 2014.
2. G Prasad and Bhimashankaram, "**Engineering Physics"**, B S Publications, 3rd Edition, 2008.
3. M.K.Verma, "Introduction to Mechanics", Universities Press.
4. Ajoy Ghatak, "Optics", McGraw-Hill Education, 2012

e-RESOURCES

1. http://www.gistrayagada.ac.in/gist_diploma/PHYSICS-StudyMaterial.pdf
2. http://www.faadooengineers.com/threads/3300-Applied-Physics-Ebooks-pdf-free-download?s=1b6cb6b1de4e7152298bd9d60156cd11

Journals:

1. http://aip.scitation.org/journal/jap
2. http://www.springer.com/physics/journal/340

NPTEL VIDEOS:

1. http://nptel.ac.in/courses/115106061/13
2. https://nptel.ac.in/courses/115/106/115106119/

MODULE -I

Waves
&
Oscillations

* A motion which repeats itself after equal intervals of time is called a periodic motion or harmonic motion.

  Example :- spin of earth, motion of satellite around a planet, vibrations of atoms in molecules.

* A body or a particle is said to possess oscillatory or vibratory motion if it moves back and forth repeatedly about the mean position.

  Example :- pendulum of a clock, prongs of tuning fork, motion of pendulum.

i, Periodic time :- The 'periodic time' T of an oscillatory motion is defined as the time taken for one oscillation.

ii, Frequency :- The 'frequency' n or ν is defined as the number of oscillations in one second. It is reciprocal of time. i.e. $n = \frac{1}{T}$ cycles per sec.

iii, Displacement :- The distance of the particle in any direction from the equilibrium position at any instant is called the displacement of the particle at that instant.

iv, Amplitude :- The maximum displacement or the distance between the equilibrium position and the extreme position is known as amplitude a of the oscillation.

v, Phase :- The phase of an oscillatory particle at any instant defines the state of the particle as regards its position and direction of motion at that instant.

vi, Restoring force :- In the equilibrium position of the oscillating particle, no net force acts on it. When the particle is displaced from its equilibrium position, a periodic force acts on it in such a direction as to bring the particle to its equilibrium position. This is called restoring force F.

vii, Simple Harmonic motion :- This is a special type of periodic motion in which the body moves again and again over the same path about a fixed path (equilibrium position). It is defined as the motion of an oscillatory particle which is acted upon by a restoring force which is directly proportional to the displacement but opposite in direction.

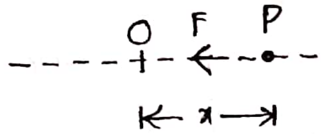
Following are the characteristics of SHM:

a) The motion is periodic
b) The motion is along a straight line about mean or equilibrium position
c) The acceleration is proportional to displacement
d) Acceleration is directed towards the mean or equilibrium position.

THE SIMPLE HARMONIC OSCILLATOR :-

When a particle or body moves such that its acceleration is always directed towards a fixed point and varies directly as its distance from that point, the particle or body is said to execute SHM. The particle or body executing SHM is called a simple oscillator.

Consider a particle P of mass m executing SHM about equilibrium position O along X-axis as shown below. By definition, the force under which the particle is oscillating is proportional to its displacement directed towards mean position.

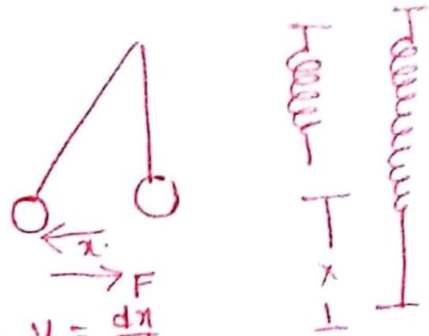


WAVES & OSCILATIONS

Equation of SHM :-

$F = -Kx \longrightarrow (1)$

K - force constant $\quad K = \frac{F}{x} \cdot \frac{\text{force}}{\text{unit displacement}}$



From Newton's II Law $\quad F = ma$

But. Velocity $v = \frac{dx}{dt}$

acceleration $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$

$\therefore F = m \cdot \frac{d^2x}{dt^2} \longrightarrow (2)$

From (1) & (2).

$$m \frac{d^2x}{dt^2} = -Kx$$

$$\frac{d^2x}{dt^2} + \frac{K}{m}x = 0$$

or $\boxed{\frac{d^2x}{dt^2} + \omega^2 x = 0} \longrightarrow (3) \quad$ where $\omega^2 = \frac{K}{m}$

solution of SH equation :-

$$\frac{d^2x}{dt^2} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{dv}{dt} = \frac{dv}{dx}\frac{dx}{dt} = v\frac{dv}{dx}$$

$\therefore \quad v\frac{dv}{dx} = -\omega^2 x \quad$ [from eqn (3)]

$v\,dv = -\omega^2 x\,dx \cdot \longrightarrow (4)$

Integrating both sides,

$\frac{v^2}{2} = -\omega^2 \cdot \frac{x^2}{2} + c_1 \quad$ c_1 - Integrating constant.

To calculate c_1, consider at extreme position, max displacement.

i.e. at $x = a$, $v = 0$

$$\therefore \quad 0 = -\frac{\omega^2 a^2}{2} + c_1$$

$$c_1 = \frac{\omega^2 a^2}{2}$$

Sub the value of c_1 in above equation.

$$\frac{v^2}{2} = -\frac{\omega^2 x^2}{2} + \frac{\omega^2 a^2}{2}$$

$$v^2 = \omega^2(a^2 - x^2)$$

$$v = \sqrt{\omega^2(a^2-x^2)} = \omega\sqrt{(a^2-x^2)} \longrightarrow (5)$$

$\because v = \frac{dx}{dt}$ | $\therefore \frac{dx}{dt} = \omega\sqrt{a^2-x^2}$

$$\frac{dx}{\sqrt{a^2-x^2}} = \omega\, dt \longrightarrow (6)$$

To integrate eqn (6); we put $x = a\sin\theta$, Hence $dx = a\cos\theta\, d\theta$

$$\frac{a\cos\theta\, d\theta}{\sqrt{a^2 - a^2\sin^2\theta}} = \omega dt$$

$$d\theta = \omega dt \longrightarrow (7)$$

Now Integrating on b.s.

$$\theta = \omega t + \phi$$

$\therefore$ displacement $\boxed{x = a\sin(\omega t + \phi)}$ along x-direction

and $\boxed{y = a\sin(\omega t + \phi)}$ along y-direction.

Characteristics of simple harmonic motion :-

1. Displacement : The displacement of any particle at any instant executing SHM is given by $x = a\sin(\omega t + \phi)$
The maximum displacement from the mean position is called amplitude. Here the amplitude is 'a'.

2. Velocity : The velocity v of the oscillating particle can be obtained by differentiating $x = a\sin(\omega t + \phi)$. Thus

$$v = \frac{dx}{dt} = \omega a\cos(\omega t + \phi) = \omega\sqrt{(a^2 - x^2)}$$

At the mean position i.e. at $x = 0$, the velocity is maximum (ωa), so $V_{max} = \omega a$. The velocity is zero at the extreme positions.

3. Periodic time : Time taken for one complete oscillation is called as periodic time and is denoted by T.

Let t be increased by $\frac{2\pi}{\omega}$ in $x = a\sin(\omega t + \phi)$, then

$$x = a\sin\left[\omega\left(t + \frac{2\pi}{\omega}\right) + \phi\right]$$

$$= a\sin(\omega t + 2\pi + \phi) = a\sin(\omega t + \phi)$$

This shows that the displacement repeats itself after a time $\left(\frac{2\pi}{\omega}\right)$.

Therefore $\left(\frac{2\pi}{\omega}\right)$ is known as periodic time.

$$T = \left(\frac{2\pi}{\omega}\right)$$

$$\because \omega = \left[\left(\frac{d^2x}{dt^2}\right)/x\right]^{1/2}$$

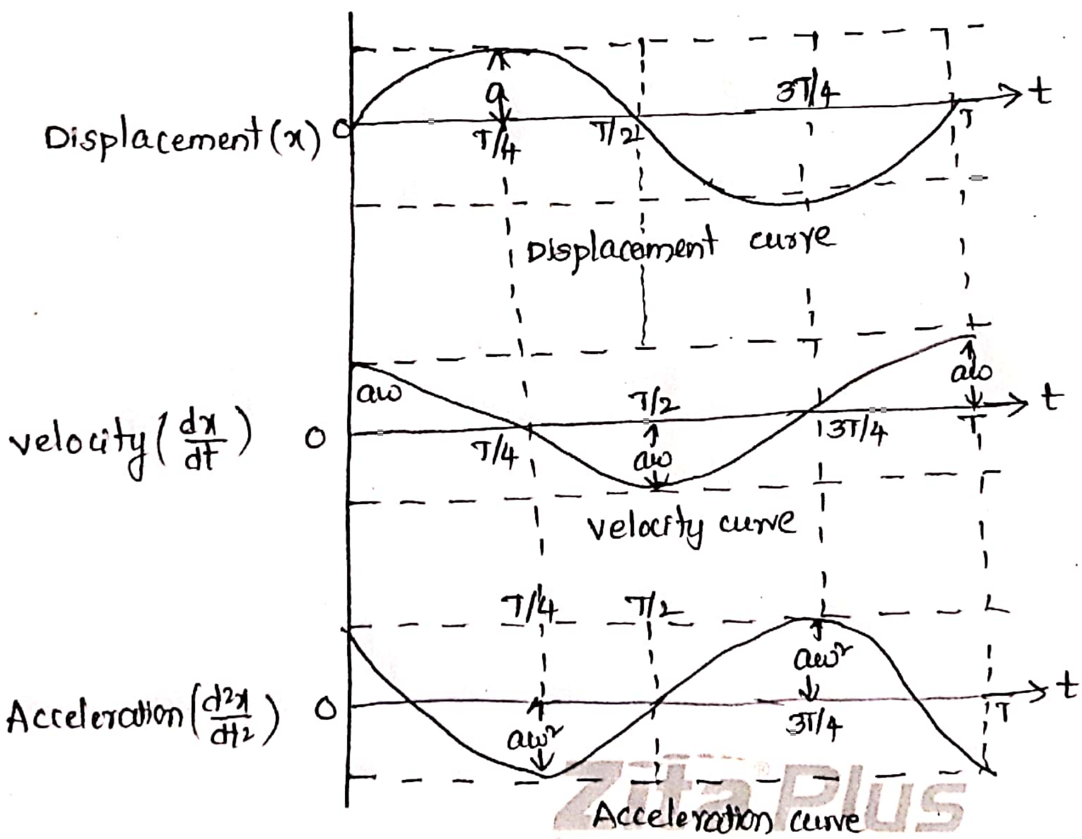
Now, $T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\left(\frac{d^2x/dt^2}{x}\right)}}$

$$= 2\pi \sqrt{\left[\frac{x}{(d^2x/dt^2)}\right]} = 2\pi \sqrt{\left(\frac{\text{displacement}}{\text{acceleration}}\right)}$$

4. <u>Frequency</u> :- The number of oscillations made in one second is called frequency and is denoted by n or ν. Hence

$$n \text{ or } \nu = \frac{1}{T} = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\left(\frac{K}{m}\right)}$$

T =	0	T/4	T/2	3T/4	T
x	0	a	0	−a	0
dx/dt	ωa	0	−ωa	0	ωa
d^2x/dt^2	0	$-\omega^2 a$	0	$\omega^2 a$	0



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Energy of a SHO :-

To calculate the energy of a SHO, always we should consider that the Energy is conserved.

Total energy = KE + P.E.

Consider the equation of SHM.

$$x = a\sin(\omega t + \phi)$$

To calculate KE, we know that $KE = \frac{1}{2}mv^2$.

$$v = \frac{dx}{dt} = a\omega\cos(\omega t + \phi)$$

$$\therefore \quad KE = \frac{1}{2} m a^2 \omega^2 \cos^2(\omega t + \phi) \longrightarrow (1)$$

To calculate PE, let us consider the workdone on the body is due to potential energy

$$dW = -F \cdot dx \qquad \text{Bcoz} \quad W = F \cdot x \ \& \ dW = dU$$

$$\text{i.e.} \quad dU = -F \cdot dx$$

$$\therefore \quad F = -\frac{dU}{dx} \longrightarrow (2)$$

But we know $F = -Kx \longrightarrow (3)$

Equating eqn (2) & (3)

$$\frac{dU}{dx} = Kx$$
~~~

Integrating the above equation.

$$U = K \cdot \frac{x^2}{2} + C$$

ie $U = \frac{1}{2} Kx^2 + C$, C is constant of integration, which can be neglected.

$$\therefore U = \frac{1}{2} Kx^2$$

i.e., $U = \frac{1}{2} K (a \sin(\omega t + \phi))^2$

$$= \frac{1}{2} K a^2 \sin^2(\omega t + \phi)$$

$$\omega^2 = \frac{K}{m} \Rightarrow K = \omega^2 m$$

$$\therefore U = \frac{1}{2} \omega^2 m a^2 \sin^2(\omega t + \phi). \longrightarrow (4)$$

From eqns (1) & (4)

Total energy T.E = K.E + P.E

$$E = \frac{1}{2} m\omega^2 a^2 \cos^2(\omega t + \phi) + \frac{1}{2} m\omega^2 a^2 \sin^2(\omega t + \phi)$$

$$E = \frac{1}{2} m\omega^2 a^2$$

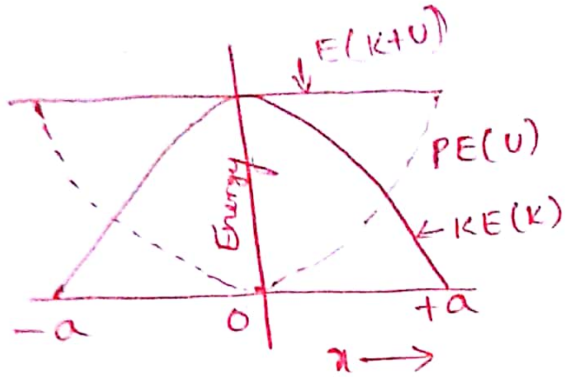
But $\omega = 2\pi n$., , freq on oscillator.

$$\therefore E = \frac{1}{2} m a^2 \cdot 4\pi^2 n^2$$

ie. $E = 2\pi^2 m a^2 n^2$

T.E is 1) directly proportional to square of amplitude (a^2)

2) directly proportional to square of frequency (n^2)



→ **Linear superposition of two waves of same frequency :-**

Let us consider the case of two SH waves of same period ie., same frequency moving in same positive direction of x with amplitudes a_1 and a_2 and having a phase difference ϕ.

The equations of two waves are

$$y_1 = a_1 \sin \omega t \quad \rightarrow (1)$$

$$y_2 = a_2 \sin(\omega t + \phi) \quad \rightarrow (2)$$

The resultant displacement is given by

$$y = y_1 + y_2 = a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$$

$$= a_1 \sin \omega t + a_2 \sin \omega t \cos\phi + a_2 \cos \omega t \sin\phi$$

$$= \sin \omega t (a_1 + a_2 \cos\phi) + \cos \omega t \cdot a_2 \sin\phi$$

Let $a_1 + a_2 \cos\phi = A \cos\theta \quad \rightarrow (3)$

$a_2 \sin\phi = A \sin\theta \quad \rightarrow (4)$

where A and θ are constants. Now

$$y = \sin\omega t \cdot A\cos\theta + \cos\omega t \cdot A\sin\theta$$

$$= A\sin(\omega t + \theta)$$

This eqn shows that the resultant displacement is also SHM of amplitude A and phase θ.

To findout the value of A, squaring & adding eqns (3) & (4), we have

$$(a_1 + a_2\cos\phi)^2 + (a_2\sin\phi)^2 = A^2\cos^2\theta + A^2\sin^2\theta$$

$$a_1^2 + a_2^2\cos^2\phi + 2a_1a_2\cos\phi + a_2^2\sin^2\phi = A^2$$

$$a_1^2 + a_2^2 + 2a_1a_2\cos\phi = A^2$$

$$A = (a_1^2 + a_2^2 + 2a_1a_2\cos\phi)^{1/2} \longrightarrow (5)$$

Thus, the resultant amplitude at any point depends on the phase difference of the two waves meeting at that point.

The value of θ can be obtained by dividing eqn (4) by eqn (3), Hence

$$\tan\theta = \frac{a_2\sin\phi}{a_1 + a_2\cos\phi}$$

$$\theta = \tan^{-1}\left[\frac{a_2\sin\phi}{a_1 + a_2\cos\phi}\right] \longrightarrow (6)$$

Special cases :-

1) Superposition of two waves in same phase ie $\phi = 0$.

The resultant amplitude in this case is given by.

$$A = (a_1^2 + a_2^2 + 2a_1a_2 \cos 0)^{1/2}$$

$$= (a_1^2 + a_2^2 + 2a_1a_2)^{1/2}$$

$$= (a_1 + a_2)$$

2) Superposition of two waves in opposite phase ie $\phi = \pi$.

The resultant amplitude in this case is given by.

$$A = (a_1^2 + a_2^2 + 2a_1a_2 \cos \pi)^{1/2}$$

$$= (a_1^2 + a_2^2 - 2a_1a_2)^{1/2}$$

$$= (a_1 - a_2)$$

Thus if two sound waves of same frequency and having amplitudes a_1 and a_2 are travelling along the same line reach a certain point exactly in phase, then the resultant amplitude at this point would be $(a_1 + a_2)$ and hence a loud sound. But, if they arrive in opposite phase, the resultant amplitude will be $(a_1 - a_2)$ and hence a feeble sound. For intermediate phase difference, the resultant amplitude lies between $(a_1 + a_2)$ and $(a_1 - a_2)$.

→ combination of two mutually perpendicular SH vibrations with equal frequencies :-

Let us consider the case of two simple harmonic motions have the same frequency (or time period) one acting along x-axis and other acting along y-axis. Let the two vibrations are represented by

$$x = a\sin(\omega t + \phi) \longrightarrow (1)$$

$$y = b\sin(\omega t) \longrightarrow (2)$$

where a and b are amplitudes of x and y vibrations. The x motion is ahead of y motion by an angle ϕ ie the phase difference between two vibrations is ϕ.

From eqn (2), we have $\sin\omega t = \frac{y}{b}$

$$\cos\omega t = \sqrt{1-\sin^2\omega t} = \sqrt{1-(y^2/b^2)}$$

Expanding eqn (1) and substituting the values of $\sin\omega t$ & $\cos\omega t$, we get

$$\frac{x}{a} = \sin\omega t\cos\phi + \cos\omega t\sin\phi$$

$$\frac{x}{a} = \frac{y}{b}\cos\phi + \sqrt{1-\frac{y^2}{b^2}}\sin\phi$$

$$\frac{x}{a} - \frac{y}{b}\cos\phi = \sqrt{1-\frac{y^2}{b^2}}\sin\phi$$

squaring on bothsides, we have

$$\left(\frac{x}{a} - \frac{y}{b}\cos\phi\right)^2 = \left(1 - \frac{y^2}{b^2}\right)\sin^2\phi$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2}\cos^2\phi - 2\frac{xy}{ab}\cos\phi = \sin^2\phi - \frac{y^2}{b^2}\sin^2\phi$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2}\cos^2\phi + \frac{y^2}{b^2}\sin^2\phi - 2\frac{xy}{ab}\cos\phi = \sin^2\phi$$

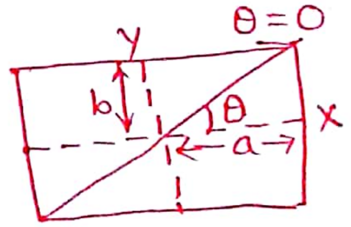
$$\boxed{\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\phi = \sin^2\phi} \longrightarrow (3)$$

This eqn represents an oblique ellipse, which is the resultant path of the particle.

<u>case 1)</u> when $\phi = 0$ (two vibrations are in phase)

In this case, $\sin\phi = 0$ and $\cos\phi = 1$

Eqn (3) becomes $\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab} = 0$



$$\left(\frac{x}{a} - \frac{y}{b}\right)^2 = 0$$

or $\pm\left(\frac{x}{a} - \frac{y}{b}\right) = 0$

or $\pm y = \pm \frac{b}{a}x$

This represents two coincident straight lines passing through the origin and inclined to x-axis at angle θ, given by $\theta = \tan^{-1}\left(\frac{b}{a}\right)$

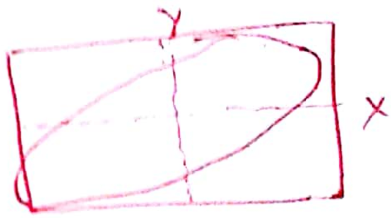
case 2) when $\phi = \pi/4$, we have

$$\sin\phi = \frac{1}{\sqrt{2}}, \quad \cos\phi = \frac{1}{\sqrt{2}}$$

New eqn (3), becomes

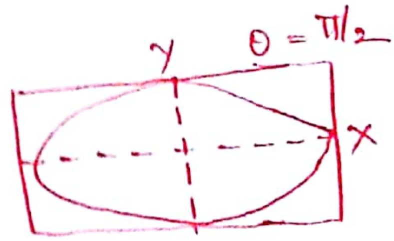
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cdot\frac{1}{\sqrt{2}} = \frac{1}{2}$$

This represents an oblique ellipse.



case 3) when $\phi = \pi/2$, we have

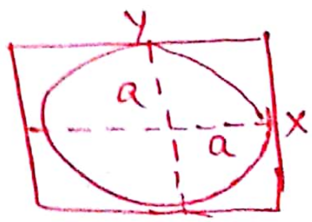
$$\sin\phi = 1 \text{ and } \cos\phi = 0$$



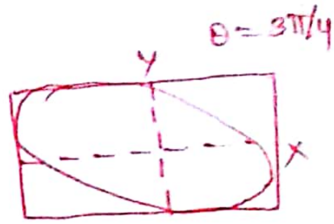
Then eqn (3) reduces to

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

The resultant path is an ellipse whose major axis coincide with the coordinate axis.



If $a = b$, then $x^2 + y^2 = a^2$, so the resultant path of the particle is a circle of radius a case 4) when $\phi = \frac{3\pi}{4}$ we have



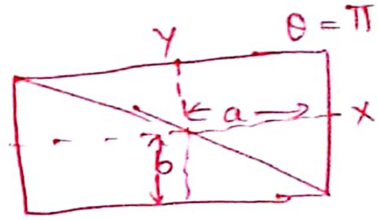
$$\sin\phi = \frac{1}{\sqrt{2}}, \quad \cos\phi = -\frac{1}{\sqrt{2}}$$

Then eqn (3) becomes

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\left(-\frac{1}{\sqrt{2}}\right) = \frac{1}{2}$$

This shows the oblique ellipse

case 5) when $\phi = \pi$; we have



$$\sin\phi = 0$$

$$\cos\phi = -1$$

Now the eqn reduces to

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{2xy}{ab} = 0$$

$$\left(\frac{x}{a} + \frac{y}{b}\right)^2 = 0$$

$$\pm\left(\frac{x}{a} + \frac{y}{b}\right) = 0$$

$$\pm y = \mp \frac{b}{a} x$$

This again represents a pair of coincident straight lines passing through the origin and inclined to x axis ~~and at~~ an angle θ given by $\theta = \tan^{-1}(b/a)$

→ Damped and Forced Oscillations :—

When a body capable of vibration is displaced from its position of equilibrium and then released, it begins to vibrate. In the case of an ideal harmonic oscillator, the amplitude of vibration remains constant for an infinite time. Such vibrations are called free vibrations, and the frequency of vibration is called natural frequency.

In practise, ~~a~~ the vibrations of a freely ~~falling~~ ~~body~~ vibrating body (such as pendulum or spring) gradually diminish in amplitude and ultimately die away. The reason being that the oscillating system is always subjected to frictional forces. arising from air resistance. Such vibrations are known as damped vibrations. When a body is made to vibrate by an external periodic force (which may or may not have its frequency equal to natural frequency of the body), the body at first tries to vibrate with its own natural frequency but ultimately it vibrates with the frequency of applied force. Such vibrations are called forced vibrations. The forced vibrations, after removal of external periodic force, becomes free and die out in due course of time.

When a body is set into oscillations by an external periodic force of the same frequency as the natural frequency of the body, the amplitude of the body is very much increased. Such vibrations are called as resonant vibrations. The phenomenon is called as resonance.

→ Distinction between Free and Forced Vibrations

Free Vibrations	Forced Vibrations
1. Free vibrations of a body take place under the influence of its own elastic forces without being acted upon by any external force.	1. The forced vibrations of a body take place due to the action of periodic force applied externally.
2. Due to damping effect of frictional forces, the free vibrations die in course of time.	2. The forced vibrations persist as long as the applied periodic force acts on the body.
3. The frequency of vibrations depends upon the mass, shape and elasticity of the body.	3. The frequency of forced vibrations is independent of mass, shape and elasticity of the body but is equal to the frequency of applied periodic force.
4. Free vibrations may occur with any amplitude (small or large). In the presence of damping forces, the amplitude goes on decreasing.	4. In forced vibrations, the amplitude is small except in the special stages when resonance takes place.

Damped Harmonic oscillator :-

For an ideal harmonic oscillator, the amplitude of vibration remains constant for an infinite time. When a body vibrates in air or any other medium which offers resistance to its motion, the amplitude of vibration decreases gradually and ultimately the body comes to rest. This is due to the fact that the body is subjected to frictional forces arising from air resistance. The motion of the body known as damped simple harmonic motion. As an example, if we displace a pendulum from its equilibrium position it will oscillate with a decreasing amplitude and finally comes to rest in equilibrium position.

Equation of damped harmonic oscillator :-

The damped system is subjected to

i, A restoring force which is proportional to displacement but oppositely directed. This is written as $-kx$, where k is a constant of proportionality or force constant.

ii, A frictional force proportional to velocity but oppositely directed. This may be written as $-r(\frac{dx}{dt})$, where r is frictional force per unit velocity.

Since force = mass x acceleration = $ma = m\frac{d^2x}{dt^2}$

Therefore the equation of motion of a particle is given by

$$m\frac{d^2x}{dt^2} = -kx - r\frac{dx}{dt}$$

$$\frac{d^2x}{dt^2} + \frac{r}{m}\frac{dx}{dt} + \frac{K}{m}x = 0$$

$$\boxed{\frac{d^2x}{dt^2} + 2b\frac{dx}{dt} + \omega^2 x = 0} \longrightarrow (1)$$

where $\frac{r}{m} = 2b$ and $\frac{K}{m} = \omega^2$.

This is the differential equation of damped harmonic motion.

Solution of the equation :-

Eqn (1) is a differential equation of second degree. Let its solution be

$$x = Ae^{\alpha t} \longrightarrow (2)$$

where A and α are arbitary constants.

Differentiating eqn (2) w.r.t 't', we get

$$\frac{dx}{dt} = A\alpha e^{\alpha t} \quad \text{and} \quad \frac{d^2x}{dt^2} = A\alpha^2 e^{\alpha t}$$

substituting these values in eqn (1), we have

$$A\alpha^2 e^{\alpha t} + 2b.\, A\alpha e^{\alpha t} + \omega^2 A e^{\alpha t} = 0$$

$$Ae^{\alpha t}(\alpha^2 + 2b\alpha + \omega^2) = 0$$

$$Ae^{\alpha t} \neq 0 \quad \therefore \alpha^2 + 2b\alpha + \omega^2 = 0$$

To find the roots.

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$a = 1$ $b = 2b$ $c = \omega^2$

$$\frac{-2b \pm \sqrt{4b^2 - 4\omega^2}}{2}$$

This gives $\alpha = -b \pm \sqrt{b^2 - \omega^2}$

The general solution of eqn(1) is given by

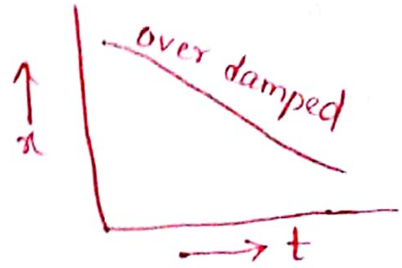
$$x = A_1 e^{(-b + \sqrt{b^2 - \omega^2})t} + A_2 e^{(-b - \sqrt{b^2 - \omega^2})t} \longrightarrow (3)$$

where A_1 and A_2 are arbitary constants.

Depending on the relative values of b and w three cases are possible.

Case I: Overdamped motion, when $b^2 > \omega^2$.

In this case $\sqrt{b^2-\omega^2}$ is real and less than b. Now the powers $[-b+\sqrt{b^2-\omega^2}]$ and $[-b-\sqrt{b^2-\omega^2}]$ in eqn (3) will be negative. Thus the displacement x consists of two terms, both dying off exponentially to zero without performing any oscillations as shown.



The rate of decrease of ~~amplitude~~ displacement is governed by the term $[-b+\sqrt{b^2-\omega^2}]t$ as the other term reduces to zero quickly relative to it. In this case, the body once displaced returns to its equilibrium position quite slowly without performing any oscillation. This type of motion is called as over damped of dead beat.

This type of motion is shown by a pendulum moving in a thick oil or by a dead beat moving coil galvanometer.

Case II :- Critical damping, when $b^2 = \omega^2$

If we put $b^2 = \omega^2$ in eqn(3), then this solution does not satisfy the differential equation (1). Let us consider that $\sqrt{b^2-\omega^2}$ is not zero but this is equal to a very small quantity h i.e. $\sqrt{b^2-\omega^2} = h \to 0$

Now eqn(3) reduces to

$$x = A_1 e^{(-b+h)t} + A_2 e^{(-b-h)t}$$

$$= e^{-bt}\left[A_1 e^{ht} + A_2 e^{-ht}\right]$$

$$= e^{-bt}\left[A_1(1+ht+\cdots)+A_2(1-ht+\cdots)\right]$$

$$= e^{-bt}\left[(A_1+A_2)+ht(A_1-A_2)+\cdots\right]$$

$$= e^{-bt}\left[p+qt\right] \longrightarrow (4)$$

where $p=(A_1+A_2)$ and $q=h(A_1-A_2)$

Eqn (4) represents a possible form of solution. It is clear from eqn (4) that if t increases, the factor $(p+qt)$ increases but the factor e^{-bt} decreases. In this way the displacement x first increases due to the factor $(p+qt)$ but at the same time reversal occurs due to the exponential term e^{-bt} and the displacement approaches zero as t increases. It is also clear that in this case the exponent is $-bt$ while in the first case it was more than $-bt$, hence in this case the particle tends to acquire its position of equilibrium much rapidly than in case I. Such a motion is called critical damped motion.

Case III: Under damped motion, when $b^2<\omega^2$

In this case $\sqrt{b^2-\omega^2}$ is imaginary.

Let us write $\sqrt{b^2-\omega^2} = i\sqrt{\omega^2-b^2} = i\beta$

where $\beta=\sqrt{\omega^2-b^2}$ and $i=\sqrt{(-1)}$

Eqn (3) now becomes

$$x = A_1 e^{(-b+i\beta)t} + A_2 e^{(-b-i\beta)t}$$

$$= e^{-bt}\left[A_1 e^{i\beta t} + A_2 e^{-i\beta t}\right]$$

$$= e^{-bt}[A_1(\cos\beta t + i\sin\beta t) + A_2(\cos\beta t - i\sin\beta t)]$$

$$= e^{-bt}[(A_1+A_2)\cos\beta t + i(A_1-A_2)\sin\beta t]$$

$$= e^{-bt}[a\sin\phi\cos\beta t + a\cos\phi\sin\beta t]$$

where $a\sin\phi = (A_1+A_2)$ and $a\cos\phi = i(A_1-A_2)$

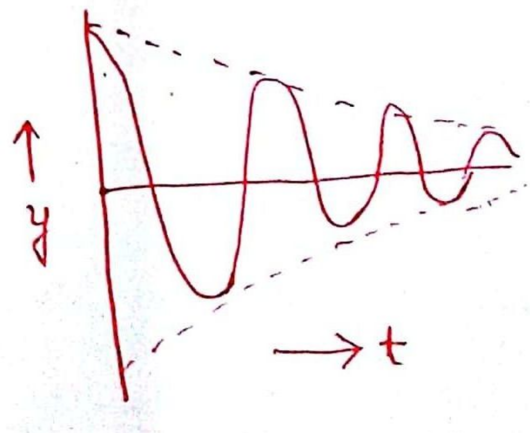
$$= e^{-bt}\, a\sin(\beta t+\phi)$$

$$= ae^{-bt}\sin[(\sqrt{\omega^2-b^2})t + \phi] \longrightarrow (5)$$

This equation represents the simple harmonic motion with amplitude ae^{-bt} and time period

$$T = \frac{2\pi}{\beta} = \frac{2\pi}{\sqrt{(\omega^2-b^2)}}$$

The amplitude of the motion is continuously decreasing owing to the factor e^{-bt} which is called as damping factor. Because of the value of $\sin[\sqrt{(\omega^2-b^2)}t+\phi]$ varies between +1 and −1, therefore the amplitude also varies between ae^{-bt} and $-ae^{-bt}$. The decay of the amplitude depends upon the damping coefficient b. It is called under damped motion as shown in fig, in this case the period is slightly increased or frequency decreased because the period is now $2\pi/\sqrt{(\omega^2-b^2)}$ while in the absence of damping it was $2\pi/\omega$.



Motion of a pendulum in air is an example of this type of motion.

→ Forced Vibrations :-

A different situation arises when the body is subjected to an external force. For example consider the vibrations of bridge under the influence of marching soliders or vibrations of a tuning fork when exposed to the periodic force of sound waves. In both the cases, the body vibrates because it is subjected to an external periodic force. Such vibrations are called Forced vibrations.

Forced vibrations can be defined as the vibrations in which the body vibrates with a frequency other than its natural frequency under the action of an external periodic force.

Equation of forced vibrations :-

The forces acted upon the particle are :

(i) a restoring force proportional to the displacement but oppositely directed, given by $-kx$, where k is force constant

(ii) a frictional force proportional to velocity but oppositely directed, given by $-r\frac{dx}{dt}$, where r is frictional force per unit velocity and

(iii) the external periodic force, represented by $F \sin pt$

where F is the maximum value of the force and $P/2\pi$ is its frequency.

so the total force acting on the particle is given by

$$-kx - r\frac{dx}{dt} + F\sin pt$$

By Newton's second law of motion this must be equal to the product of mass m of the particle and its instantaneous acceleration ie, $\frac{d^2x}{dt^2}$,

Hence,

$$m\frac{d^2x}{dt^2} = -kx - r\frac{dx}{dt} + F\sin pt$$

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + kx = F\sin pt$$

$$\frac{d^2x}{dt^2} + \frac{r}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F}{m}\sin pt$$

$$\boxed{\frac{d^2x}{dt^2} + 2b\frac{dx}{dt} + \omega^2 x = f\sin pt} \longrightarrow (1)$$

where $\frac{r}{m} = 2b$, $\frac{k}{m} = \omega^2$ and $\frac{F}{m} = f$

Eqn (1) is the differential equation of the motion of the particle.

Amplitude and Phase of Forced Vibrations :-

In this case, when the steady state is set up, the particle vibrates with the frequency of applied force, and not with its own natural frequency. The solution of differential equation (1) must be of the type

$$x = A\sin(pt - \theta) \longrightarrow (2)$$

where A is steady amplitude of vibrations and θ is the angle by which the displacement x lags behind the applied force $F\sin pt$. A and θ are being arbitrary constants.

Differentiating eqn (2) we have

$$\frac{dx}{dt} = Ap\cos(pt - \theta)$$

and $$\frac{d^2x}{dt^2} = -Ap^2\sin(pt - \theta)$$

substituting these values in eqn (1) we get

$$-Ap^2 \sin(pt-\theta) + 2bAp\cos(pt-\theta) + \omega^2 A\sin(pt-\theta) = f\sin pt$$
$$= f\sin\{(pt-\theta)+\theta\}$$

$$A(\omega^2-p^2)\sin(pt-\theta) + 2bAp\cos(pt-\theta) = f\sin(pt-\theta)\cos\theta + f\cos(pt-\theta)\sin\theta$$

If this relation holds good for all values of t, the coefficients of $\sin(pt-\theta)$ and $\cos(pt-\theta)$ terms on both sides of this equation must be equal i.e., comparing the coefficients of $\sin(pt-\theta)$ and $\cos(pt-\theta)$ on both sides, we have

$$A(\omega^2-p^2) = f\cos\theta \longrightarrow (3)$$

and

$$2bAp = f\sin\theta \longrightarrow (4)$$

Squaring eqn (3) and (4) and then adding, we get

$$A^2(\omega^2-p^2)^2 + 4b^2A^2p^2 = f^2$$

$$A^2\left[(\omega^2-p^2)^2 + 4b^2p^2\right] = f^2$$

$$\boxed{A = \frac{f}{\sqrt{(\omega^2-p^2)^2 + 4b^2p^2}}} \longrightarrow (5)$$

while on dividing eqn (4) by eqn (3), we have

$$\tan\theta = \frac{2bAp}{A(\omega^2-p^2)} = \frac{2bp}{(\omega^2-p^2)}$$

$$\boxed{\theta = \tan^{-1}\left(\frac{2bp}{\omega^2-p^2}\right)} \longrightarrow (6)$$

Substituting the value of A from eqn (5) in eqn (2) we get

$$x = \frac{f}{\sqrt{[(\omega^2 - p^2)^2 + 4b^2p^2]}} \sin(pt - \theta) \longrightarrow (7)$$

Eqn (5) gives the amplitude of forced vibrations while eqn (6) its phase.

→ **Resonance :—**

If we bring a vibrating tuning fork near another stationary tuning fork of the same natural frequency as that of vibrating tuning fork, we find that stationary tuning fork also starts vibrating. This phenomenon is known as resonance.

" The phenomenon of making a body vibrate with its natural frequency under the influence of another vibrating body with the same frequency is called resonance.".

Consider three springs S_1, S_2 and S_3 suspended from a flexible rod AB such that S_1 and S_2 are identical in all aspects and carrying equal masses at the ends, while S_3 has different spring constant and carries different mass. Now if S_1 spring is set in vibration by pulling down the attached mass and let go, we find that springs S_2 and S_3 also start vibrating. The vibrations in S_3 die out quickly while the vibrations set in spring S_2 keeps on increasing its amplitude till it is very nearly equal to the amplitude of the spring S_1. The vibrations of spring S_2 have the same frequency as that of S_1 and are called resonant vibrations and this phenomenon is called resonance.

→ **Amplitude Resonance :-**

The amplitude of forced vibrations varies with the frequency of applied force and becomes maximum at a particular frequency. This phenomenon is known as amplitude resonance.

condition of amplitude resonance :

In case of forced vibrations, we have

$$A = \frac{f}{\sqrt{[(\omega^2-p^2)^2+4b^2p^2]}} \longrightarrow (1)$$

and

$$\theta = \tan^{-1}\left[\frac{2bp}{(\omega^2-p^2)}\right] \longrightarrow (2)$$

The expression (1) shows that the amplitude varies with the frequency of the force p. For a particular value of p, the amplitude becomes maximum. The phenomenon is known as amplitude resonance.

The amplitude is maximum when $\sqrt{(\omega^2-p^2)^2+4b^2p^2}$ is minimum.

or $\frac{d}{dp}\left[(\omega^2-p^2)^2+4b^2p^2\right]=0$

or $2(\omega^2-p^2)(-2p)+4b^2(2p)=0$

or $\omega^2-p^2=2b^2$

or $p=\sqrt{(\omega^2-2b^2)} \longrightarrow (3)$

Thus the amplitude is maximum when frequency $p/2\pi$ of the impressed force becomes $\sqrt{(\omega^2-2b^2)}/2\pi$. This is resonant frequency. This gives frequency of the system both in presence of damping ie. $\sqrt{(\omega^2-2b^2}/2\pi$ and in absence of damping ie $\omega/2\pi$.

If the damping is small then it can be neglected and the condition of maximum amplitude reduces to $p = \omega$

putting condition (3) in eqn (1) we get

$$A_{max} = \frac{f}{\sqrt{\{(\omega^2 - \omega^2 + 2b^2)^2 + 4b^2(\omega^2 - 2b^2)\}}}$$

$$= \frac{f}{\sqrt{(4b^2\omega^2 - 4b^4)}} = \frac{f}{2b\sqrt{(\omega^2 - b^2)}}$$

$$= \frac{f}{2b\sqrt{(p^2 + b^2)}} \qquad [\because p^2 = \omega^2 - 2b^4]$$

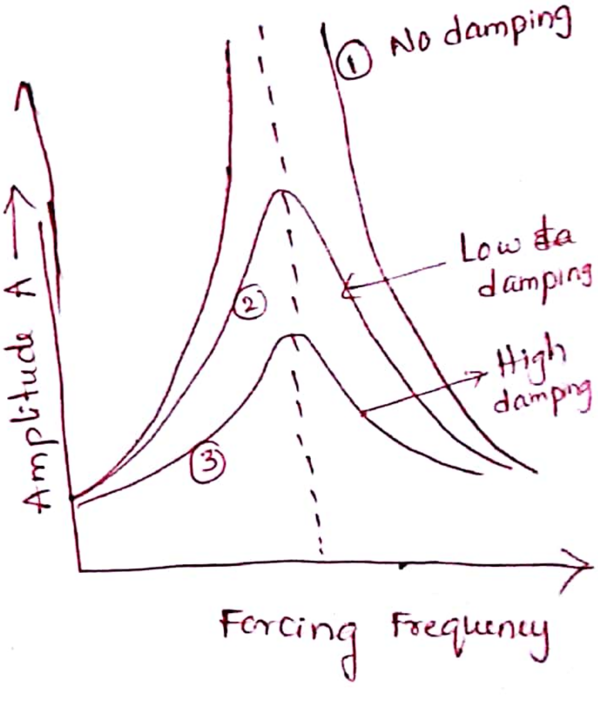
and for low damping it reduces to

$$A_{max} = \frac{f}{2bp}$$

showing that $A_{max} \to \infty$ as $b \to 0$

→ Sharpness of Resonance :-

Figure shows the variation of amplitude with forcing frequency at different amounts of damping.



Curve (1) shows the amplitude when there is no damping ie $b = 0$, In this case the amplitude becomes infinite at $p = \omega$. This case is never attained in practice due to frictional resistance.

As slight damping is always present curves (2) and (3) show the effect of damping on the amplitude.

The term sharpness of resonance means the rate of fall in amplitude, with the change of forcing frequency on each side of resonance frequency.

Figure shows the variation of amplitude with forcing frequency at different amounts of damping. It is obvious from the figure that the resonance is sharp when fall in amplitude for a small change from resonant frequency is sufficiently large (ie small damping) and flat when fall in amplitude for a small change from resonant frequency is very ~~large~~ small (ie large damping).

"Hence smaller is damping, sharper is resonance or larger is the damping, flater is resonance."

→ **Logarthemic decrement :-**

Logarthemic decrement measures the rate at which the amplitude dies away. The amplitude of damped harmonic oscillator is given by

$$\text{amplitude} = a e^{-bt}$$

at $t = 0$, amplitude $a_0 = a$.

Let $a_1, a_2, a_3, \dots$ be the amplitudes at time $t = T, 2T, 3T, \dots$ respectively where T = period of oscillation. Then

$$a_1 = a e^{-bT}, \quad a_2 = a e^{-b(2T)}, \quad a_3 = a e^{-b(3T)}, \dots$$

From these equations we get

$$\frac{a_0}{a_1} = \frac{a_1}{a_2} = \frac{a_2}{a_3} = \cdots = e^{bT} = e^{\lambda} \quad (\text{where } bT = \lambda)$$

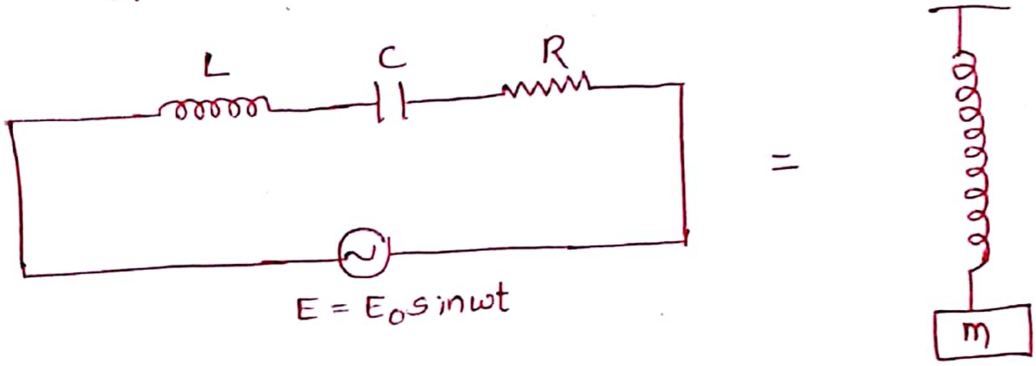
λ is known as logarithemic decrement.

Taking the natural logarithm, we get

$$\lambda = \log_e \frac{a_0}{a_1} = \log_e \frac{a_1}{a_2} = \log_e \frac{a_2}{a_3} = \cdots$$

Thus logarithemic decrement is defined as the natural logarithm of the ratio between two successive amplitudes which are separated by one period.

→ **Analogy between Mechanical and Electrical oscillator :-**



Above fig. shows the comparision between electrical oscillator (consisting of Resistance R, Inductance L, capacitor C and supplied with the potential $E = E_0 \sin \omega t$) and mechanical oscillator (consisting of mass m suspended by the string).

Due to the applied voltage e.m.f induced in the LCR circuit.

EMF is defined as the electrical potential for a source in a circuit.

EMF induced in the capacitor (E_c) is given as

$$q \propto E_c$$

$$q = C E_c$$

$$E_c = \frac{q}{C} \longrightarrow (1)$$

where q is charge, C - capacitance

EMF induced in the inductor (E_L) is given as,

$$E_L \propto \frac{d\phi}{dt} \propto \frac{dI}{dt}$$

$$E_L = -L \frac{dI}{dt} \longrightarrow (2)$$

where ϕ is the magnetic flux, I - current, L - Inductance
-ve is the direction of the current by Lenz law.

Potential across resistor (R) is given as

$$V = IR \longrightarrow (3)$$

Overall potential in the circuit will be,

$$L \frac{dI}{dt} + \frac{q}{C} + RI = E_0 \sin\omega t \longrightarrow (4)$$

we know, $I = \frac{dq}{dt}$

$$L \frac{d^2q}{dt^2} + R \frac{dq}{dt} + \frac{q}{C} = E_0 \sin\omega t \longrightarrow (5)$$

Equation for Forced harmonic oscillator is,

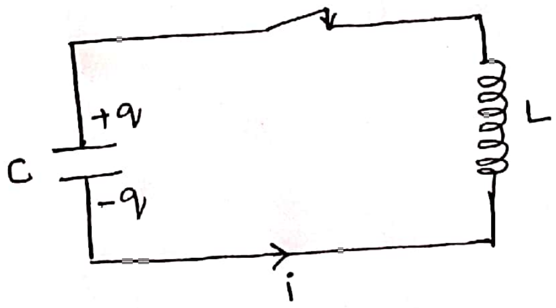
$$m \frac{d^2x}{dt^2} + r \frac{dx}{dt} + kx = F \sin pt \longrightarrow (6)$$

comparing equations (5) & (6), we conclude

Mechanical oscillator	Electrical Oscillator.
1. x – displacement	1. q – charge.
2. M – Mass	2. L – Inductance
3. r – frictional force per unit velocity	3. R – Resistance.
4. K – force constant	4. C – capacitance
5. dx/dt – velocity	5. dq/dt – current.

Electrical Harmonic Oscillator :-

The simplest example of an oscillating electrical circuit consists of an inductor L and capacitor C connected together in series with a switch as shown below.



Here We assume the ideal situation that the resistance in the circuit is negligible. This is analogous to the assumption of a mechanical system without frictional forces. Initially, the switch is open and the capacitor is charged to voltage V_c. The charge on the capacitor is given by $q = V_c C$ where C is capacitance

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When the switch is closed the charge begins to flow through the inductor and a current I flows in the circuit.

$$I = \frac{dq}{dt}$$

This is time-varying current and produces a voltage across the inductor given by

$$V_L = L\frac{dI}{dt}$$

We can analyse the LC circuit using Kirchoff's law, which states that the sum of the voltages around the circuit is zero i.e.,

$$V_C + V_L = 0$$

$$\Rightarrow \frac{q}{C} + L\frac{dI}{dt} = 0$$

$$\Rightarrow \frac{q}{C} + L\frac{d^2q}{dt^2} = 0$$

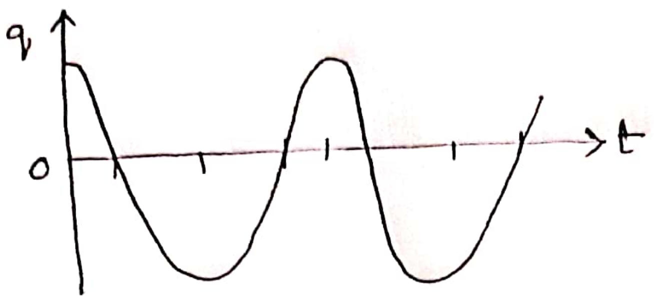
$$\Rightarrow \frac{d^2q}{dt^2} = -\frac{1}{LC}q$$

This equation describes how the charge on a ~~particle~~ plate of the capacitor varies with time. It is of the same form of equation of SHM.

The frequency of the oscillator is given directly by

$$\omega = \sqrt{\frac{1}{LC}}$$

Since we have the initial condition that the charge on the capacitor has its maximum value at $t=0$, then the solution to equation $\frac{d^2q}{dt^2} = -\frac{1}{LC}q$ is the initial charge on the capacitor. The variation of charge q with respect to t is shown below and is analogous to the way the displacement of a mass on a spring varies with time.



Quality factor :-

The quality factor is defined as 2π times the ratio of the energy stored in the system to the energy lost per period.

$$Q = 2\pi \frac{\text{energy stored in system}}{\text{energy lost per period}}$$

$$= 2\pi \frac{E}{PT}$$

where P is Power dissipated and T is periodic time

We know that $P = \frac{E}{\tau}$, where τ is relaxation time.

so $Q = 2\pi \frac{E}{\left(\frac{E}{\tau}\right) T} = \frac{2\pi\tau}{T} = \omega\tau$

$$\boxed{Q = \omega\tau}$$

where $\omega = \frac{2\pi}{T}$ = angular frequency.

MODULE-II

Introduction :

The branch of physics that deals with the process of generation , propagation and reception of sound in a room , be it a small room or an auditorium is called acoustics. This covers many fields and is closely related to various branches of engineering such as

(1) design of acoustical Instruments

(2) electro - acoustics (i.e brach relating to the methods of sound production and recording (micro - phones, amplifiers , Loud speakers etc)

(3) Architectual acoustics dealing with the design and Construction of buildings , music halls , sound recording rooms to provide best audiable sound to the audiance .

(4) musical Instruments .

Reverberation :-

"The prolongation of sound inside a room or hall even after the source producing the sound is turned off is called reverberation".

This is due to multiple reflections from the walls , ceiling , floor and other reflecting materials present in the hall .

Reverberation time :

"The reverberation time for a room is the time required for the Intensity to drop to one millionth (10^{-6}) of its Intial value".

Reverberation time can be expressed interms of sound level (in dB) rather than Intensity. If the Intial Intensity is I_i, and the final Intensity I_f is $10^{-6} I_i$, then.

$$dB_i = 10 \log I_i / I \text{ (standard)}$$

$$dB_f = 10 \log I_f / I \text{ (standard)}$$

$$dB_i - dB_f = 10 \log (I_i / I_f)$$

$$\text{since } I_i / I_f = 10^6$$

$$dB_i - dB_f = 10 \log 10^6$$

$$= 6 \times 10 = 60$$

"The reverberation time is the time required for the Intensity to drop by 60 decibels".

It depends on the volume V of the room. It also depends on the absorption of all parts of the room. Walls, furniture, people and so forth. Some parts may be highly absorbent, and some absorb only a little.

Basic Requirements of Acoustically Good Hall.

The Reverberation of sound in an auditorium is mainly due to multiple reflections at various surfaces. Inside. The volume and the shape of the auditorium and the sound absorption inside influence the behaviour of sound. By varying the absorption of sound inside the hall, the reverberation time can be brought to optimum value. The following are the basic requirements of acoustically good hall.

(i) The Volume of the auditorium is decided by the type of programme to be conducted there and also the number of seats to be accomodated. A musical hall requires a large volume where as a lecturer hall requires a smaller volume. In deciding the volume of the hall, its height plays an important role than its length and breadth. The ratio between the celing height and breadth should be 2:3.

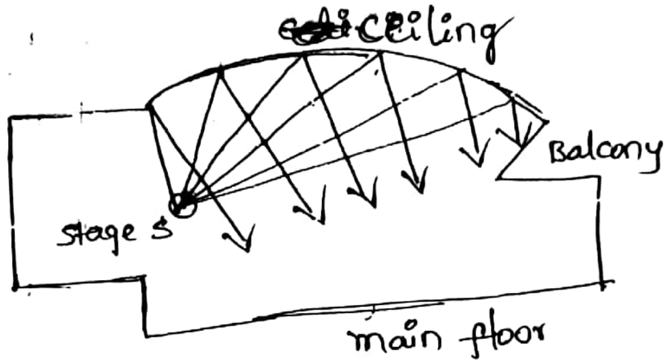
In deciding the volume of the hall, the following guidelines may be followed.

(i) In cinema theaters - 3.74 to 4.2 m^3 per seat.

(ii) In lecturer halls :- 2.8 to 3.7 m^3 per seat.

(iii) In musical halls - 4.2 to 5.6 m^3 per seat.

(2) The shape of the wall and ceiling should be so as to provide uniform distribution of sound throughout the hall. The design of a hall requires smooth decay and growth of sound. To ensure these factors the hall should have scattering objects. Walls should have Irregular surface and walls must be fixed with absorptive materials.



A good design of an auditorium

(3) The reverberation should be optimum i.e neither too Large nor too small. The reverberation time should be 1 to 2 seconds for music and 0.5 to 1 second for speech. To control the reverberation the sound absorbing materials are to be chosen carefully.

(4) The sound heard must be sufficiently loud in every part of the hall and no echoes should be present.

(5) The total quality of the speech and music must be unchanged i.e. the relative Intensities of the several components of a complex sound must be maintained.

(6) For the sake of clarity, the successive syllables spoken must be clear and distinct. i.e there must be no confusion due to overlapping of syllables.

(7) There should be no concentration of sound in any part of the hall.

(8) The boundaries should be sufficiently sound proof to exclude extraneous noise.

(9) There should be no Echelon effect.

(10) There should be no resonance with in the building

(11) The hall must be full of audience.

Sabine's formula:

According to sabine's law, the reverberation time T in seconds (the time taken by the Intensity of sound to fall to one millionth 10^{-6} of its original value after the source of sound is cut off) is expressed as

$$T = \frac{0.165V}{\Sigma as} \quad \text{(or)} \quad T = \frac{0.16V}{A}$$

Proof:- Let's say we play a steady tone for a long time in our room the sound energy will build up and we will call the energy density : E. we will assume the energy density is constant through out the room.

E = sound energy density J/m^3

The power being dissipated in the walls will be the area of the walls times the Intensity of the sound hitting the walls.

$$P = AI$$

The power lost to the walls must equal the time rate of change of the energy.

$$\frac{d}{dt}(EV) = -P = -AI$$

V → constant and the Intensity equals the energy density times the speed of sound divided by 4.

We divid by 4 because sound is going out in all directions left, right, forward, backward. We do not divide by 6. Why because 4 gives a better answer.. physical Reason is sound really not radiating in all directions. So that number must be less than 6.

$$V\frac{dE}{dt} = \frac{-AE}{4} I$$

$$\frac{dE}{dt} = \frac{-Av}{4V} E$$

The solution for eq above

$$E = E_0 \exp\left(\frac{-Av}{4V} t\right)$$

$$\log\left(E/E_0\right) = \frac{-Av}{4V} T$$

but we have $\frac{E}{E_0} = 10^{-6}$ (6)

Therefore $T = \frac{4V}{-Av} \log 10^{-6}$

$v = 344$ m/s (or) velocity of sound.

and $\log 10^{-6} = -13.8$

$$T = \frac{-4V}{A(344)} (-13.8)$$

$$\boxed{T = \frac{0.161V}{A}}$$

Factors Affecting the Architectural Acoustics and their Remedies :

The Reverberation can be controlled by the following factors :-

(i) By providing windows and ventilators which can be opened and closed to make the value of the time of Reverberation optimum.

(ii) Decorating the walls by pictures and maps.

(iii) using heavy curtains with folds

(iv) By lining the walls with absorbent materials such as felt, celotex, fibre board, glass wool. etc.

(v) Having full capacity of audience

(vi) By covering the floor with carpets

(vii) By providing acoustic tiles.

(2) Loudness.

With large absorption the time of reverberation will be smaller. This will minimise the chances of confusion between the different syllables but the Intensity of sound may go below the level of Intelligibility of hearing. sufficient Loudness at every point in the hall is an Important factor for satisfactory hearing.

Remedy:- The Loudnes may be Increased by

(i) Using Large sounding boards behind the speakers and facing the audience. Large polished wooden reflecting surfaces Immediately above the speaker are also helpful.

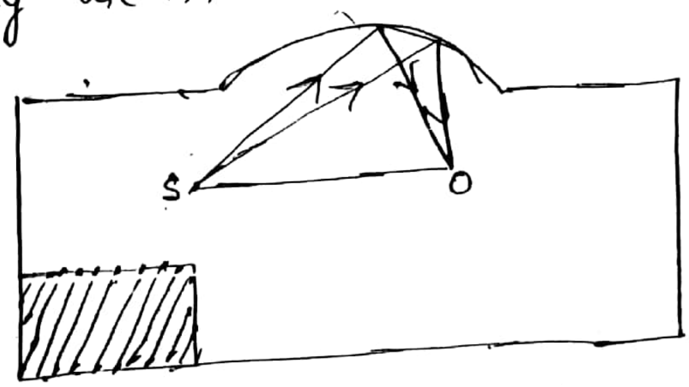
(ii) Low ceilings are also of great help in reflecting the sound energy towards the audience.

(iii) By providing additional sound energy with the help of equipments like Loud speakers. To achieve uniform distribution of Intensity through out the hall. Loudspeakers are to be positioned carefully.

Scanned with CamScanner

Focussing:-

Reflecting concave surfaces cause concentration of reflected sound, creating a sound of 'Larger Intensity at the focal point O. These spots are known as sound foci such concentrations of sound Intensity at some points leads to deficiency of reflected sound at other points. The spots of sound deficiency are known as dead spots.



Remedy: for uniform distribution of sound energy in the hall.

(1) There should be no curved surfaces. if such surfaces are present, they should be covered with absorbent material.

(2) ceiling should be low.

(3) A paraboloidal reflected surface arranged with the speaker at the focus is also helpful in sending a uniform reflected beam of sound in the hall.

Echoes: An echo is heard when direct sound wave coming from the source and its reflected wave reach the listner with a time interval of about 1/7 second

Remedy: Echoes may be avoided by covering the long distant walls and high ceiling with absorbent material.

Echelon effect: If a hall has a flight of steps, with equal width, the sound waves reflected from them will consist of echoes with regular phase difference. These echoes combine to produce a musical note which will be heard along with the direct sound. This is called echelon effect.

Remedies: It may be remedied by having steps of unequal width.

The steps may be covered with proper sound absorbing materials, for examples with a carpet.

Noise: Generally there are three types of noises which are very troublesome. They are (a) Air-borne noise, (b) structure borne noise and (c) Inside noise.

(a) **Air-borne noise**: The noise which commonly reaches the hall from outside through open windows, doors and ventilators is known as air-born noise. Since this noise is transmitted through the air, it is called so.

Remedy: Sound Insulation for the reduction of air-borne noise can be achieved by the following methods.

(i) By allotting proper places for doors and windows

(ii) By making arrangements for perfectly shutting doors and windows

(III) using heavy glass in doors, windows and ventilators.

(IV) ~~Using~~ using double doors and windows with seperate frames and having Insulating materials between them.

(V) By providing double wall construction, floating floor construction, suspend ceilling construction, box type construction.

(VI) By avoiding openings for pipes and ventilators

b) Structure borne noise :- The noises which are conveyed through the structure of the building are known as structural noises.

For eg :- sound are foot steps, street traffic. moving of furniture.

Remedy :- Sound Insulation for the reduction of structure -borne noise is done in the following ways.

(I) Breaking the continuity by Interposing Layers of some acoustical Insulators.

(II) using double walls with air space between them.

(III) soft floor finish.

(c) Inside noise :- The noises which are produced inside the hall or rooms in big offices are called as inside noises.

Remedy : following methods are used for sound Insulation of inside noise.

(i) Noise free air conditioners are to be used.

(ii) The machinery like type-writers etc. should be placed on absorbent pads.

(iii) Any engine Inside the hall should be fitted on the floor with a Layer of wood (or) felt between them

(iv) The floor should be covered with carpet.

Absorption coefficient

The coefficient of absorption of a material is defined as the Ratio of the sound energy absorbed by the surface to that of the total sound energy Incident on the surface.

$$\text{Absorption coefficient } (a) = \frac{\text{Sound energy absorbed by surface}}{\text{Total sound energy Incident on surface}}.$$

All sound waves falling on an open window pass through, an open window is taken to be a perfect absorber of sound and absorption coefficient of all substances are measured in terms of open window (O.W.U)

"Absorption coefficient of a surface is also defined as the Reciprocal of its ~~areal~~ area, which absorbs the same sound energy as absorbed by unit area of an open window."

→ Absorption co-efficient of a given material depends on the frequency of the sound also. It is higher at higher frequenci

Material	Absorption coefficient (O.W.U)
Marble	0.01
concrete	0.17
carpet	0.30
Heavy curtains	0.50
Fiber glass	0.75
Human body	0.50
open window	1.0

Determination of Absorption coefficient :-

~~Method~~

Consider a room with and without the sample of the material. If T_1 is reverberation time without the sample Inside the room, then applying sabine's formula

$$\frac{1}{T_1} = \frac{A}{0.165V} = \frac{\Sigma as}{0.165V}$$

Now with the sample Inside the room. Reverberation time. T_2 is

$$\frac{1}{T_2} = \frac{\Sigma as + a_1 s_1}{0.165V}$$

Where a_1 is the absorption coefficient of the area s_1.

From the above equations. We have.

$$\frac{a_1 s_1}{0.165V} = \left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

(or)

$$\boxed{a_1 = \frac{0.165V}{s_1}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$$

Ultrasonics

Introduction: Sound waves of frequencies ranging from 20 Hz to 20 KHz are called Sonic waves or audible waves, as they are perceived by human ear. Sound waves with the frequencies lesser than 20Hz are called Infrasonics, while those whose frequency is greater than 20KHz (i.e., beyond the audible limit) are called Ultrasonic waves or Supersonics. Though humanbeings are not capable of hearing Ultrasonic waves, certain animals like dogs, bats, and marine animals like whales, sharks, dolphins have the ability to hear the high frequency sounds.

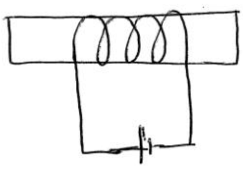
Bats and dolphins are known to generate ultrasonic waves and use the reflections of the waves to find their way. The waves reflected from the surrounding objects are perceived by the bats and from the time elapsed between the generation and reflection of the pulses, the direction and distance of the objects are determined. The large ears of bats are specialised to detect these sounds.

Light is strongly absorbed by sea-water and hence the radius of visibility is limited. Relatively, ultrasonic waves are less absorbed by sea-water. Thus marine animals use ultrasonic pulses to locate fish, to avoid obstacles.

In this chapter we will be learning production, detection of ultrasonic waves. Also we will be learning the properties of ultrasonics and their applications.

Magnetostriction effect :-

When a ferromagnetic rod such as iron, or nickel is kept in a magnetic field parallel to its length, the rod suffers a change in its length. This phenomenon is known as magnetostriction effect. This change in length depends on the magnitude of the field and the nature of the material. This effect was discovered by Joule in 1847.

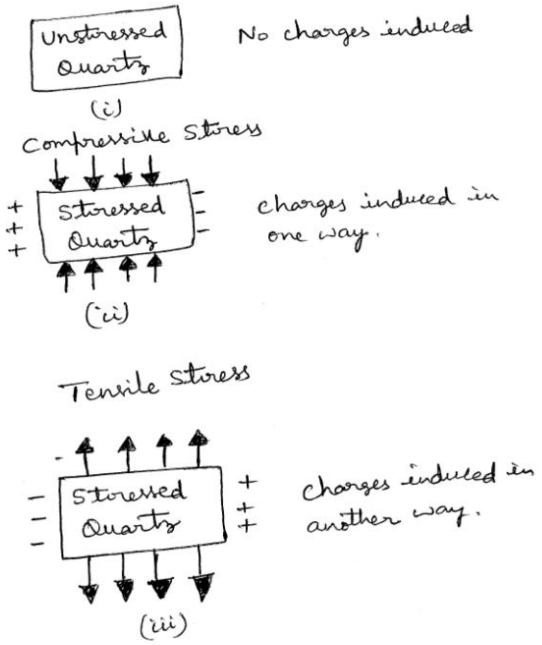


Explanation : The adjacent figure shows a wire wound around the ferromagnetic rod. When the D.C field is turned on current flows through the wire. Let the magnetic field associated with this d.c. current increases the length of the rod. When the polarity of the d.c. field is reversed then length of the rod decreases. When an A.C. field is applied ~~the length of~~ the rod elongates and contracts for each half cycle of the A.C. signal i.e., the rod vibrates with a frequency twice that of the A.C. signal. The amplitude of vibration is usually small, but if the frequency of the A.C. signal coincides with the natural frequency of the rod, the amplitude of vibration increases due to resonance.

~~Piezoelectric effect~~ :-

Piezo electric effect:

When crystals like quartz or tourmaline are stressed along any pair of opposite faces, electric charges of opposite polarity are induced in the opposite faces perpendicular to the stress. This is known as Piezo electric effect.



Explanation:

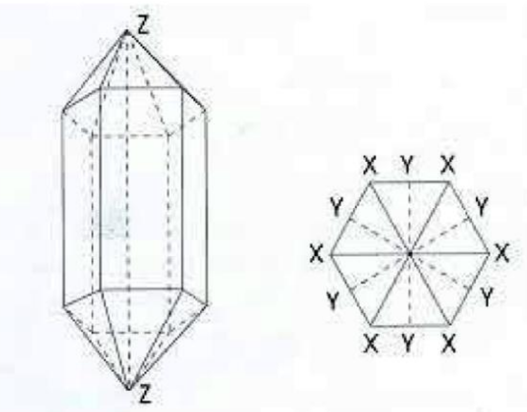
Fig (i) shows an unstressed quartz crystal. As there is no mechanical stress, electrical charges are not induced.

When a compressive stress is applied on the quartz crystal, electrical charges will be induced on two opposite faces, perpendicular to the direction of the mechanical stress. Let the charges be induced as shown in fig (ii).

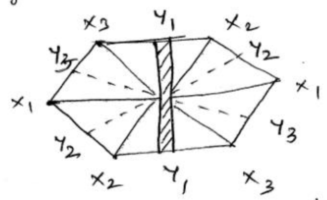
When the direction of the mechanical stress is reversed, ie; if a tensile stress is applied instead of compressive stress then the electrical charges will be induced in a way opposite to that of the previous case, as shown in fig(iii).

Piezo electric crystal (Additional information).

Quartz crystal is the most popular Piezo electric crystal. It has the shape of a hexagonal prism with a pyramid attached to each end; as shown in the adjacent figure. The axis along the longest dimension of the natural crystal is called Optic axis or Z-axis. The three lines, which pass through the opposite corners of the crystal, constitute its three x-axes or electrical axes. Similarly, the three lines which are perpendicular to the sides of the hexagon ~~form~~ form the three Y-axes which are known as Mechanical axes.

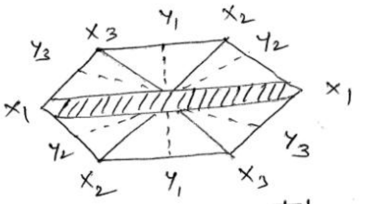


Thin plates of the quartz crystal cut perpendicular to one of its X-axis are known as X-cut plates. Similarly thin plates cut perpendicular to one of its Y-axis are known as Y-cut plates.



X- cut crystal

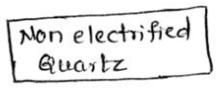
X-cut plates generate longitudinal mode of Ultrasonic vibrations while Y-cut plates generate transverse mode of vibrations.



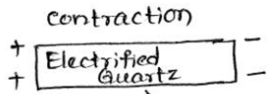
Y- cut crystal

Inverse Piezo electric effect:

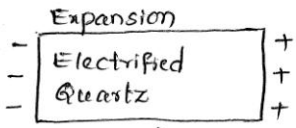
When crystals like Quartz or Tourmaline are subjected to electric field on the opposite faces then they undergo either contraction or expansion in a perpendicular direction. This is known as ~~piezo~~. Inverse piezo electric effect.



(i)



(ii)



(iii)

Explanation :-

Fig (i) shows a non-electrified quartz crystal. As there is no electrical field, neither contraction nor expansion is observed.

When an electric field is applied as shown in fig(ii), a compressive force acts on the crystal such that the crystal is subjected to contraction.

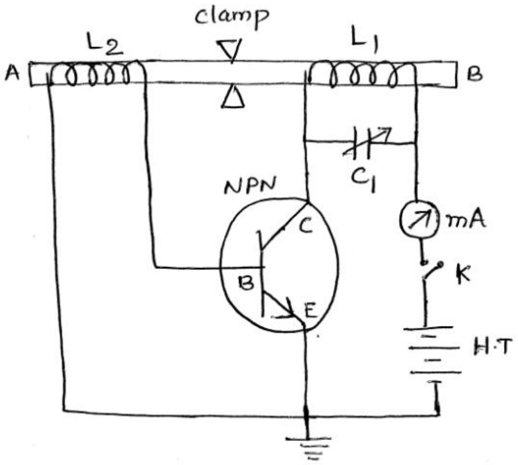
When the electric field is reversed as shown in fig (iii), a tensile force acts on the crystal such that the crystal is subjected to expansion.

When an A.C. field is applied to the opposite faces of the crystal, it undergoes contraction and expansion alternatively in the perpendicular direction.

Production of ultrasonic waves :-

1. Magnetostriction Method :-

The general principle involved in generating ultrasonic waves is to cause some dense material to vibrate very rapidly. The vibrations produced by this material then cause the air surrounding the material, to begin vibrating with the same frequency. These vibrations then spread out in the form of ultrasonic waves.



Construction :

1. Figure shows the ferro magnetic rod AB would by the coils L_1 & L_2.
2. A variable capacitor C_1 is connected parallel to the coil L_1. One end of the capacitor (C_1) is connected to the collector (C) of the n-p-n transistor. The other end of the capacitor (C_1) is connected to battery via the milli Ammeter and the Key (K). The battery helps in providing necessary biasing.
3. Clamp helps in properly holding the rod AB. The coil L_2 is connected to the base (B) and the emitter (E) of the ~~n-p-n~~ NPN transistor, as shown in the figure.

Working:

When the Key (K) is on, a D.C. current is passed through the L_1 coil which produces a stationary magnetic field around it and it induces an emf in L_2 coil. The induced emf is fed to the base of the transistor and amplified and again gives to the

L_1 coil. Due to the additional emf in L_1 coil, the magnetic field in L_1 coil is changed. In this way a varying magnetic field is produced around the specimen which produces mechanical vibrations and generates Ultrasonic waves. If the frequency of the oscillator circuit (which can be varied by changing C_1) is equal to the natural frequency of the specimen, then it vibrates with maximum amplitude and ~~they~~ their frequencies can be represented as

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

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

where l - length of ferromagnetic rod

Y - Young's modulus of the material of the specimen.

ρ - density of the rod

Advantages :-

1, By using this method we can produce ultrasonic waves of frequency upto 300KHz.

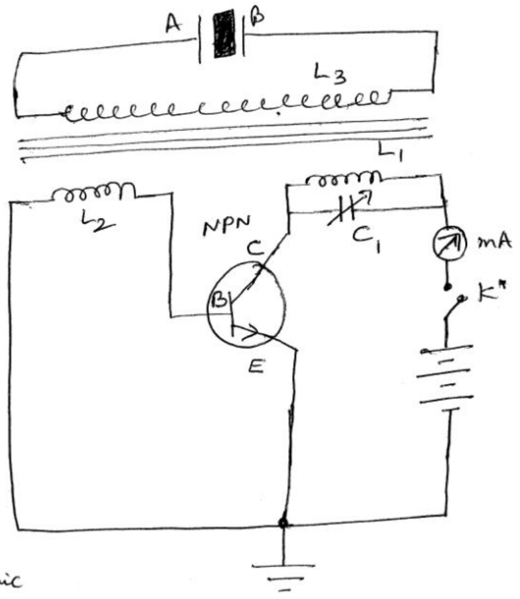
2, Magnetostrictive materials are easily available and inexpensive.

Disadvantages :-

1, Frequencies beyond 300KHz can not be generated.

2, As the rod dimensions are influenced by the temperature, production of constant single frequency is not possible.

2. Piezo electric method :



Principle:

Piezo electric speimen is subjected to an A.C. electric field, which induces mechanical vibrations in the speimen. In short, Inverse Piezo electric effect is the principle behind this method of generating Ultrasonics.

Construction

1. Figure shows a Piezo electric speimen placed between the plates ~~of~~ A and B of the capacitor which are in turn connected to the coil (L_3).
2. The variable capacitor (C_1) is connected parallel to the coil (L_1). One end of the capacitor (C_1) is connected to the collector (C) of the NPN transistor while the other end is connected to the battery, via milli ammeter and key (K). The battery helps in providing necessary biasing.
3. Coil (L_2) is connected to the base (B) and emitter (E) of the NPN transistor, as shown in the figure.

Working:

When the key (K) is turned ON, current starts flowing and the capacitor (C_1) gets charged. This capacitor (C_1) then discharges through the coil (L_1). The discharge through the coil (L_1) produces a magnetic field, which induces an emf in the coil (L_2). The induced emf in the coil (L_2) is fed to the base (B) of the NPN transistor. This acts as feedback to the transistor. Thus the oscillations in the ~~coil~~ coil (L_1) and (L_2) are sustained. These electrical oscillations in (L_1) and (L_2)

induce emf in the coil (L_3) by means of mutual induction. The induced emf is applied to the Piezo electric specimen via the plates A and B of the capacitor. The alternating emf thus applied on the Piezo electric specimen induces mechanical vibrations in the specimen, thereby producing Ultrasonic waves.

~~Merits~~ If (l) is the length of the Piezo electric specimen, (Y) and (ρ) are the Young's modulus and density of the specimen respectively, then the frequency of the Ultrasonics produced is given by.

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

Merits:

1. High frequency waves upto 500 KHz frequency can be produced.

Demerits:

1. It is relatively expensive.

Detection of Ultrasonic waves:

1. Piezo electric detector:

In this method, Ultrasonic waves are applied to one pair of faces of a quartz crystal. As a result, opposite charges are induced on the other pair of opposite faces. These charges, being small, are amplified and detected.

2. Kundt's tube:

A Kundt's tube can be used to detect Ultrasonic waves of relatively longer wavelengths. Stationary Ultrasonic waves are produced in air contained in a long tube. Lycopodium powder sprinkled along the inner surface of the tube collects into small heaps at the nodes and is blown off at the antinodes. The distance between two successive heaps is equal to ($\lambda/2$). Thus by knowing the frequency of the wave, velocity of the Ultrasonic waves can be calculated.

Sensitive flame method:

When a narrow sensitive flame is moved ~~through~~ in a ~~the~~ medium where ~~of~~ Ultrasonic waves are present, it is observed that the flame remains steady at the positions of antinodes and flickers at the nodes. By measuring the distance between the adjacent nodes, the value of $(\lambda/2)$ can be determined. Thus velocity can be calculated by knowing the frequency of the ultrasonic wave.

Thermal detector method:

A fine platinum wire probe is used in this method. When stationary Ultrasonic waves are produced in a medium, there occurs a change in temperature at nodes. As the Platinum probe moves through the medium, its resistance changes at nodes. The change in the resistance of Platinum wire is detected by using a sensitive Wheatstone bridge.

Properties of Ultrasonic Waves:

1. Ultrasonic waves have high frequencies and therefore they are highly energetic

2. The speed of Ultrasonic waves depends on their frequency. It increases with increase in frequency.

3. Owing to their small wavelengths, Ultrasonic waves can be transmitted over long distances without any appreciable loss of energy.

4. When Ultrasonic waves are passed through a liquid, stationary Ultrasonic waves are set up in the liquid due to the incident and reflected waves. This standing wave forms compressions and rarefactions in the liquid medium which act as parallel rulings of a diffraction grating.

Applications of ultrasonic waves :—

Ultrasonic waves have a variety of applications in different branches of science and technology. Some important applications are:

(1) Communication :

a) SONAR: The word SONAR stands for sound navigation and ranging. The highly directional ultrasonic waves can be used for locating objects submerged under sea water. In SONAR, an Ultrasonic beam is directed in different directions into sea. In the absence of an obstacle, the ultrasonic pulses do not return to the ship. In the presence of an obstacle, pulses are reflected from the obstacle and are ~~back~~ picked up by the receiver. If the speed of the Ultrasonics in sea water is known, distance of the object, (l) is determined using the equation

$$l = \frac{(v)(t)}{2}$$

where (v) is the velocity of Ultrasonic waves

(t) is the time elapsed between the transmitted and reflected pulses.

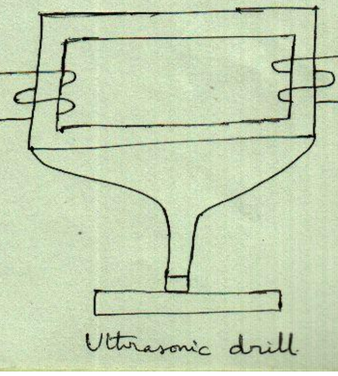
b) Fish finder:

Ultrasonics can be used to locate shoals of fish, utilising the fact that the swimming bladder of fish is filled with air, that scatters ultrasonic waves. ~~Some of the sea~~ Some of the sea animals such as whales and dolphins use Ultrasonics to locate their prey and even to converse with each other. In the depths of the sea, visibility is highly restricted because of the strong absorption of light by water. It may be therefore that these animals use Ultrasonics that ~~is~~ are relatively less absorbed.

(2) Industrial applications:

a) Ultrasonic Drilling:

The magnetostriction vibrator is made of thin isolated ferromagnetic plates of high magnetostriction, such as Nickel. A coil is wound on the needle through



Ultrasonic drill

which alternating current is passed. The resulting magnetic field magnetises the core and changes the length of the vibrator. This action rapidly chips away the work-piece in a pattern controlled by the tool shape.

(b) Ultrasonic welding:

The surfaces of the work pieces are cleaned and held together. They are subjected to Ultrasonic oscillations ~~where the~~ at the spot where they are welded. The Ultrasonic energy converts to heat at the contact area as a result of friction arising between the surfaces. As the temperature of surface layers exceeds the recrystalisation point, the layers melt and bond together to form a strong joint.

(3) Biological and medical applications:

(i) High intensity Ultrasonic waves are used for killing bacteria, germs and insects. Therefore they are used to sterilise milk.

(ii) These waves are used to destroy diseased tissues. This use of Ultrasonic waves is known as Knifeless surgery.

(iii) Ultrasound is widely available, easy-to-use and lesser expensive than other imaging methods. It gives a clear picture of soft tissues that do not show up well on X-ray images. Ultrasound scanning is the preferred imaging method for the diagnosis and monitoring of pregnant women.

MODULE -III

Chapter. 12

LASERS

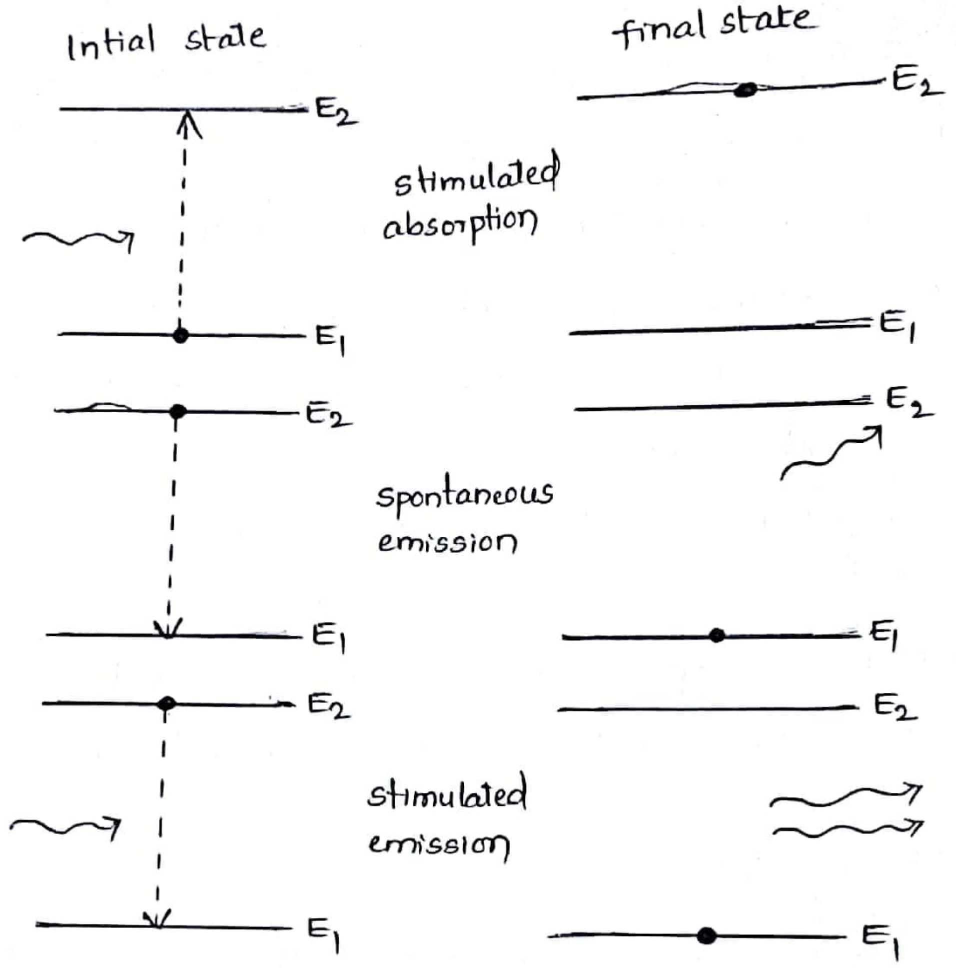
- The word LASER is an acronym for "Light Amplification by stimulated Emission of Radiation".
- Einstein in the year 1917 theoritically proved that the process of stimulated emission must exist. But only in 1954, Charles H. Townes operated a microwave device for "Microwave Amplification by Stimulated Emission of Radiation (MASER)".
- In 1960, T.H. Maiman first achieved laser action at optical frequency in ruby.
- Since 1960 the development of lasers has been extremely rapid and new applications are being found even now almost every day.

Spontaneous & Stimulated Emission of Radiation :—

Let us see what happens when radiation interacts with matter. For interaction to occur, first the energy of the interacting photon $h\nu$ must match with energy difference between the two states of the atoms involved in the interaction.

Under this condition, if the radiation interacts with atoms in the lower energy state E_1, the atoms absorb energy and get excited to the higher energy state E_2 by a process called "stimulated absorption". Instead if the radiation interacts with atoms which are already in the excited state E_2, then de-excitation of those atoms to the lower energy state E_1 occurs with emission of photons of energy $h\nu$. This process is called "stimulated emission". Yet another emission process called "spontaneous emission" is also possible wherein atoms in the excited state drop to the lower energy state after they have stayed in the excited state for a short duration of time called their 'life time'.

During this process also photons of energy $h\nu$ $(= E_2 - E_1)$ are emi...
The absorption and emission processes are shown below.



Einstein coefficients :—

In a collection of atoms, all the three transition processes – stimulated absorption, spontaneous emission, and stimulated emission – occur simultaneously. Let N_1 be the number of atoms per unit volume with energy E_1 and N_2 be the number of atoms per unit volume with energy E_2. Let 'n' be the number of photons per unit volume at frequency ν such that $h\nu = E_2 - E_1$. Then the energy density of interacting photons $\rho(\nu)$ is given by

$$\rho(\nu) = n h\nu \qquad \longrightarrow (1)$$

~~when~~ when these photons interact with atoms, both upward (absorption) and downward (emission) transitions occur. At equilibrium these transition rates must be equal

Upward transition

Stimulated absorption rate depends on the number of atoms available in the lower energy state for absorption of these photons as well as the energy density of interacting radiation.

i.e. stimulated absorption rate $\propto N_1$

$$\propto \rho(\nu)$$

$$= N_1 \rho(\nu) B_{12}$$

where the constant of proportionality B_{12} is the Einstein coefficient of stimulated absorption.

Downward transition

Once the atoms are excited by stimulated absorption, they stay in the excited state for a short duration of time called the life time of the excited state. After their life time they move to their lower energy level spontaneously emitting photons. This spontaneous emission rate depends on the number of atoms in the excited energy state.

i.e., spontaneous emission rate $\propto N_2$

$$= N_2 A_{21}$$

where the constant of proportionality A_{21} is the Einstein coefficient of spontaneous emission.

Before excited atoms de-excite to their lower energy states by spontaneous emission, they may interact with photons resulting in stimulated emission of photons. Therefore stimulated emission rate depends on the number of atoms available in the excited state as well as the energy density of interacting photons.

i.e. stimulated emission rate $\propto N_2$

$$\propto \rho(\nu)$$

$$= N_2 \rho(\nu) B_{21}$$

where the constant of proportionality B_{21} is the Einstein coefficient of stimulated emission.

During stimulated emission, the interacting photon called the stimulating photon and the photon due to stimulated emission are in phase with each other. Please note that during stimulated absorption, the photon density decreases whereas during stimulated emission it increases.

For a system in equilibrium, the upward and downward transition rate must be equal and hence we have

$$N_1 \rho(\nu) B_{12} = N_2 \rho(\nu) B_{21} + N_2 A_{21} \longrightarrow (2)$$

Hence

$$\rho(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} \longrightarrow (3)$$

or

$$\rho(\nu) = \frac{A_{21}/B_{21}}{\frac{N_1}{N_2}\frac{B_{12}}{B_{21}} - 1} \longrightarrow (4)$$

The population of the various energy levels of a system in thermal equilibrium is given by Boltzmann distribution law (as shown below).

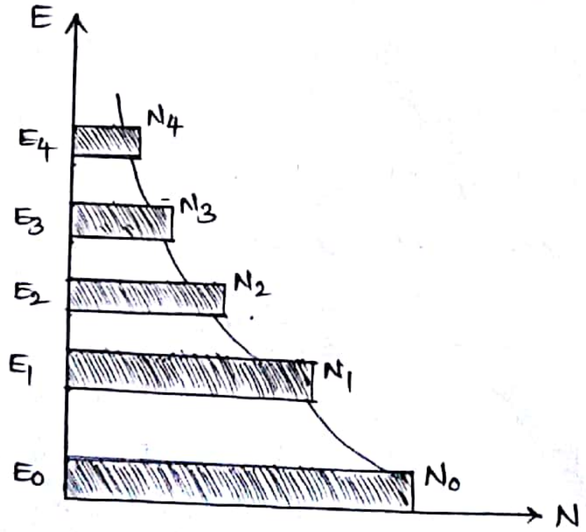
$$N_i = g_i N_0 \exp\left(-E_i/KT\right) \longrightarrow (5)$$

where N_i - population density of E_i energy level

N_0 - population density of ground state at temperature T

g_i - the degeneracy of the i^{th} level

K - Boltzmann constant $(= 1.38 \times 10^{-23}$ joule/K$)$



Boltzmann distribution for several energy levels

Hence $N_1 = g_1 N_0 \exp(-E_1/KT)$

$N_2 = g_2 N_0 \exp(-E_2/KT)$

$$\frac{N_1}{N_2} = \frac{g_1}{g_2} \exp\left(\frac{E_2 - E_1}{KT}\right)$$

$$\Rightarrow \quad \frac{N_1}{N_2} = \frac{g_1}{g_2} \exp\left(\frac{h\upsilon}{KT}\right) \longrightarrow (6)$$

Substituting eqn (6) in eqn (4)

$$\rho(\nu) = \frac{A_{21}/B_{21}}{\left[\frac{g_1}{g_2}\frac{B_{12}}{B_{21}} \exp\left(\frac{h\upsilon}{KT}\right) - 1\right]} \longrightarrow (7)$$

From Planck's law of black body radiation, the radiation density is given by

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

comparing eqns (7) and (8)

$$\frac{g_1}{g_2}\frac{B_{12}}{B_{21}} = 1$$

$$g_1 B_{12} = g_2 B_{21} \longrightarrow (9)$$

and $$\frac{A_{21}}{B_{21}} = \frac{8\pi h\upsilon^3}{c^3} \longrightarrow (10)$$

Equations (9) and (10) are referred to as Einstein relations.

In practice, the absorption and emission processes occur simultaneously. Let us consider the ratio of stimulated emission rate to stimulated absorption rate.

$$\frac{\text{stimulated emission rate}}{\text{stimulated absorption rate}} = \frac{N_2\, \rho(\nu)\, B_{21}}{N_1\, \rho(\nu)\, B_{12}}$$

$$= \frac{N_1}{N_2} \quad (\text{as } B_{21} = B_{21} \text{ ignoring degeneracy})$$

At thermal equilibrium $\frac{N_2}{N_1} \ll 1$

Thus at thermal equilibrium stimulated absorption predominates over stimulated emission. Instead if we create a situation that $N_2 > N_1$, stimulated emission will predominates over stimulated absorption. If stimulated emission predominates the photon density increases and Light Amplification by Stimulated Emission of Radiation (LASER) occurs. Therefore, in order to achieve more stimulated emission, population of the excited state (N_2) should be made larger than the population of the lower state (N_1) and this condition is called population inversion. Hence, if we wish to amplify a beam of light by stimulated emission then we must

1) create population inversion and
2) increase the energy density of interacting radiation.

Population Inversion :-

The population inversion condition required for light amplification is a non-equilibrium distribution of atoms among the various energy levels of the atomic system. Boltzmann distribution law specifies what fraction of atoms are found in any particular energy state for any given equilibrium temperature. If N_0 is the number of atoms in the ground state, N_i is the number of atoms in the excited state of energy E_i measured relative to the ground state, then (ignoring degeneracy)

$$\frac{N_i}{N_0} = \exp\left(-\frac{E_i}{KT}\right) \longrightarrow (1)$$

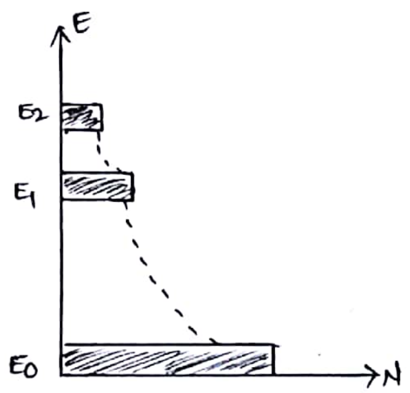
where T- is the absolute temperature

$K = 1.38 \times 10^{-23}$ J/K (Boltzmann constant)

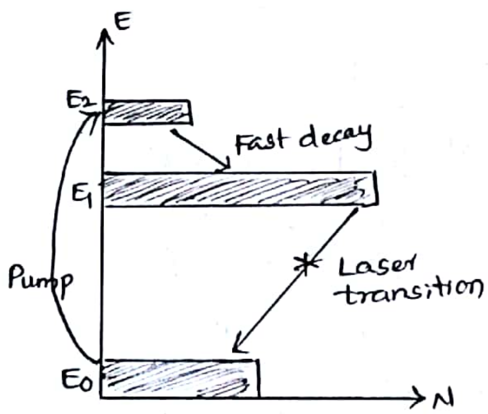
Since the right hand side of the above equation is exponential of a negative quantity, maximum possible value attainable is 1. That happens when $KT >> E_i$. Even then at this extreme (impossible) case, N_i can be equal to N_0 but it will never exceed N_0. Hence from this it is very obvious that by feeding energy required for exciting the atoms from lower energy level to the higher energy level, higher energy level can never be made more populated than the lower level i.e. by direct pumping population inversion is not possible.

From the above we have understood that if two energy levels are involved, by direct pumping the higher energy level cannot be made more populated than the lower level. The restrictions imposed on a two level scheme have been overcome in three and four level schemes by pumping atoms in the active medium indirectly to the upper state of transition involving more than two energy levels.

Three level scheme :-



(a) No pumping

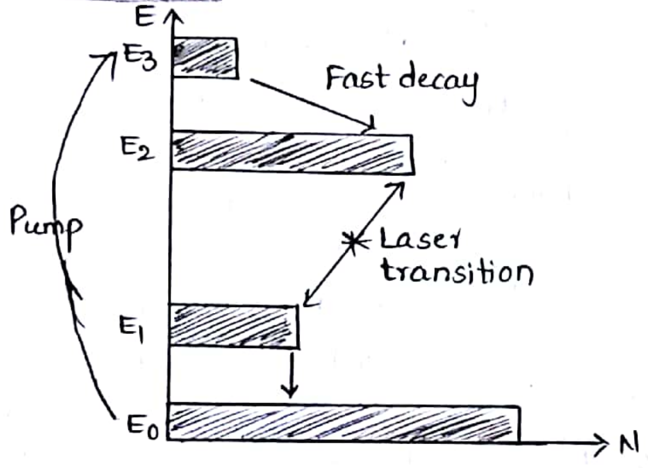


(b) Intense pumping

In the above fig (a) shows the distribution of atomic state population decay obeying Boltzmann law. If the collection of atoms is intensely pumped - for example, with Xenon flash lamp - a large number of atoms are excited through stimulated absorption to the highest energy level E_2. If the energy level E_2 has very short ~~time~~ life time, the atoms decay fast to level E_1. If the level E_1 has relatively longer life time (a state known as metastable) atoms tend to accumulate at E_1. With intense pumping from E_0 to E_2, because of rapid decay to E_1, it is possible to bring in non-equilibrium distribution of atoms viz E_1 more populated than E_0 and laser transition takes place between level E_1 (called upper laser level) and level E_0 (called lower laser level) as shown in fig (b).

Since ground level E_0 happens to be the lower laser level, more than one-half of the ground state atoms must be pumped to the upper state to acheive population inversion ($N_1 > N_0$). Therefore, three level pumping schemes generally require very high pump powers. If pumping continues when the condition ($N_1 > N_0$) is reached, stimulated emission rate exceeds stimulated absorption rate. This immediately depopulates the upper laser level and populate the lower laser level. Hence it is not possible to continuously maintain the upper laser level more populated than the lower laser level. Such a system therefore works in pulsed mode only. The Ruby laser is the best example for a three level system.

Four level scheme :-



Population of energy levels in a four-level system.

In four level scheme as shown above, on pumping, the atoms are lifted from the ground state to the highest of the four levels involved in the process. From this level, the atoms decay to the metastable state E_2, and the population of this state grows rapidly. If the lifetime of the ($3 \rightarrow 2$) transition is short and that of the ($2 \rightarrow 1$) is long, a population inversion on the ($2 \rightarrow 1$) transition can be acheived and maintained with moderate pumping. Since ground level is not the lower laser level there is no need to pump more than one-half of the population to the higher level. Since in this scheme level E_1 is the lower laser level, it is relatively easier to maintain population inversion between levels E_2 and E_1 continuously with moderate pumping and get continuous wave (cw) output. For this to happen $(1 \rightarrow 0)$ transition must be very fast. If this transition is relatively slow, even four level laser will work in pulsed mode only. He-Ne laser is a good example for a four level laser working in cw mode while N_2 laser is an example for a pulsed mode of operation.

→ There are different mechanisms applied to pump the atoms of the active medium to higher energy states to create population inversion. They are

i) optical pumping
ii) electrical discharge
iii) chemical reaction
iv) injection current etc.

→ Lasers are the light sources having high monochromaticity, high Intensity, high directionality and high degree of coherence. Laser emits pure sine waves having constant phase difference with respect to space and time. Lasers are used in many fields of science and technology like optical fiber communication, satellite communication, holography, radio astronomy, data processing, and in welding of materials. Lasers have varied applications in medicine. In the laser, the principle of MASER is employed in the frequency range of 10^{14} to 10^{15} Hz and is termed as optical maser. Laser principle now-a-days is extended to γ-rays. Hence Gamma ray lasers are called as Grazers.

The first two succesful lasers developed during 1960 were Ruby laser and He-Ne laser. Laser action has been obtained with atoms, molecules in gases, ions, liquids, solids, glasses, semiconductors and plastics at different wavelengths. Some lasers emit light in pulses while others emit as a continuous wave.

→ Characteristics of Laser Radiation :—

The important characteristics of a laser radiation over conventional light sources are

i) Laser is highly monochromatic
ii) Laser is highly directional
iii) Laser is highly coherent
iv) The intensity of laser is very high.

Monochromaticity :- (Monochromatic – containing one colour)

We have assumed that the energy levels of the atoms are discrete and sharp. In fact it is not so. Hence transition of an atom between two energy levels will result in emission (or absorption) of photon whose frequency lies between ν and $\nu + d\nu$. This is called Spectral broadening.

The three most important mechanisms which give rise to the spectral broadening are Doppler broadening, collision broadening and natural broadening.

- Since the atoms which emit radiation are not at rest at the time of emission, depending on their velocities and the direction of motion, the frequency of the emitted radiation changes slightly and this is called 'Doppler broadening'.
- If the atoms undergo collision at the time of emitting radiation there will be change in the phase of the emitted radiation. This effect results in 'collision broadening'.
- In solid materials an electron of an atom emitting energy in the form of a photon leads to an expontential damping of the amplitude of the wave. This effect is similar to the collision broadening in shortening the wave train and produce broadened spectral line. This phenomenon is called 'natural broadening'.

To speak more quantitatively on the degree of mono chromaticity of light from some source, we make use of line width (spectral width) of the source $\Delta\nu$ which is the frequency spread of a spectral line.

Frequency spread $\Delta\nu$ is related to the wavelength ~~length~~ spread as

$$\Delta\lambda = -\left(\frac{c}{\nu^2}\right)\Delta\nu$$

To appreciate the relatively better monochromaticity of a laser let us compare wavelength spreads of white light, light from a commercial discharge lamp and a laser.

For a white light source $\Delta\lambda \simeq 300$ nm

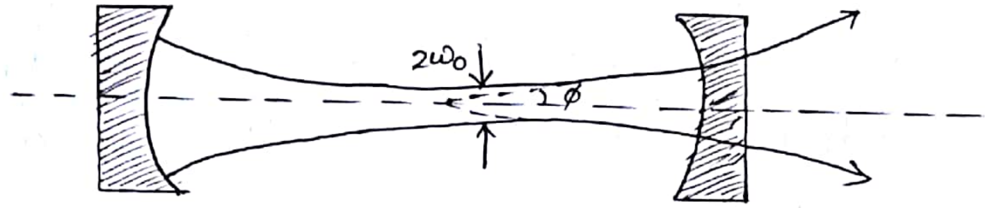
where as for gas discharge line $\Delta\lambda \simeq 0.01$ nm

and for a laser $\Delta\lambda \simeq 0.001$ nm and using the techniques to control the output still much narrower linewidths are possible.

Directionality :-

In the case of a laser, the active medium is mostly a cylindrical cavity which is placed between two reflecting resonator mirrors. Resonator mirrors are generally coated with multilayer dielectric materials to reduce the absorption loss in the mirrors. Moreover these resonators acts as frequency selectors and also give rise to directionality to the output beam.

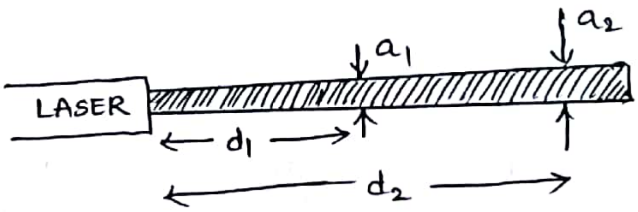
Stimulated photons travel back and forth between the mirrors many times, amplifying each time they transeverse the medium. Any photon travelling in a direction away from the cavity axis is reflected away by the mirrors within few reflections and is thus not allowed to propagate further. Thus the beam drawn from the output mirror is highly parallel and directional, The degree of directionality is expressed in terms of divergence. The curvature of the mirrors keep the light within the cavity and causes the beam to narrow down to a radius w_0, called minimum spot size as shown below.



The beam divergence ϕ is given in terms of the minimum spot size w_0 as

$$\phi = \frac{1.22\lambda}{2w_0}$$

The divergence tells how rapidly the beam spreads when it is emitted from the laser.



At d_1 and d_2 distances from the laser window, if the diameter of the spots are measured to be a_1 and a_2 respectively, then the angle of divergence (in degrees) can be expressed as

$$\phi = \frac{a_2 - a_1}{2(d_2 - d_1)}$$

Coherence:

A predictable correlation of the amplitude and phase at any one point with any other point is called coherence. There are two types of coherence

i) temporal coherence

ii) spatial coherence

Temporal coherence

The displacement and phase at any point 'x' on the wave train at any instant of time 't' is given by

$$y = a \sin\left(\frac{2\pi}{\lambda}(ct - x)\right)$$

where c is the velocity of wave. Since the two points P_1 and P_2 are on the same wave train which is continuous as shown in fig(a), they have correlation. If the phase and amplitude at any one point is known, we can calculate the same for any other point on the same wave train using the wave equation given above. This predictable correlation of the amplitude and phase between any two points on a wave train is called 'temporal coherence or longitudinal coherence'. If two points on two different wave trains are chosen as in fig (b), then they have no correlation, and are said to be incoherent.

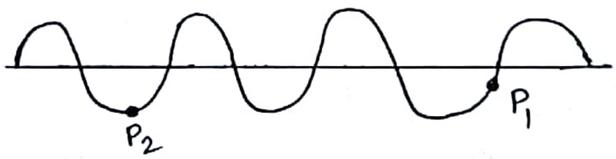
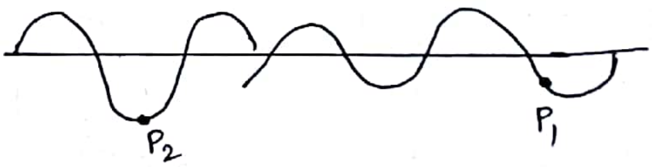
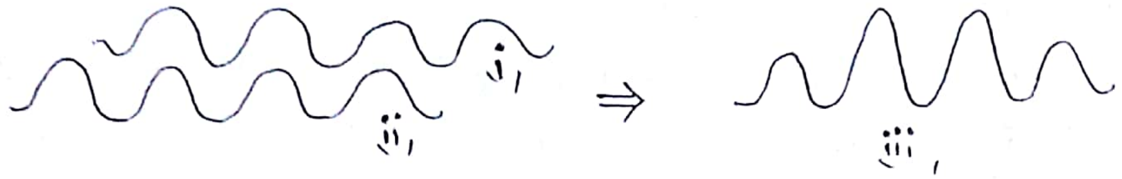


fig (a) continuous wave



fig(b) discontinuous wave

In any conventional source, light waves emitted are at random since they are spontaneously emitted and there is absolutely no correlation between the individual waves. But in lasers, the waves corresponding to the stimulating and stimulated photons are in phase with each other and super impose resulting in increase of the wavelength of the wave, as shown below.



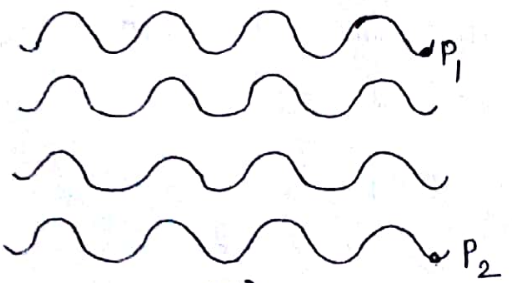
Since very large number of such stimulated emissions takes place, the effective length of the wave increases and the maximum length of the resulting wave is called Coherent length 'l_c'.

White light (Say sunlight) has coherent length of nearly few hundreds of nm while traditional monochromatic source has a coherent length of about few hundreds of microns.

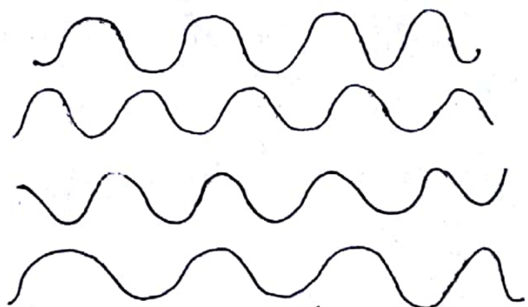
Spatial coherence :-

When we consider the cross section of the output beam of a laser, the maximum separation between any two points on the cross section of the wavefront is called Spatial or transverse coherence.

During stimulated emission both the stimulating and stimulated photons are inphase with each other. Also both travel along the same direction of stimulating photon. Those photons travelling in any direction other than optic axis are not reflected back by the end mirrors and thus leave the active medium. Only those which are along the optic axis stimulate further and amplify, thus making all the photons to be in phase with each other. Hence when we choose two spatial points P_1 and P_2 on the cross section of the output beam, they are spatially coherent. Below fig. illustrates the difference between ~~the two slits~~ spatially coherent and incoherent waves.



(a)
Spatially coherent waves



(b)
Spatially Incoherent waves

Brightness :-

Lasers are bright and intense light sources. In fact, an one milli-watt He-Ne laser is brighter than the sun. This is because of coherence and directionality. We know than when two photons each of amplitude 'a' are in phase with each other, then by Young's principle of super-position the resultant amplitude is 2a and the intensity is proportional to $(2a)^2$ i.e., $4a^2$. Since in laser many no. of photons (say n) are in phase with each other, the amplitude of the resulting wave becomes na and hence the intensity is proportional to n^2a^2. Thus due to coherent addition of amplitude and negligible divergence the intensity increases enormously. We are able to directly view a glowing 100 watts electric bulb but we cannot see 1mW He-Ne laser which has 10^5 times lesser power. A 1mW He-Ne can be shown to be 100 times brighter than the sun.

Output power of lasers :-

Laser systems exist from milliwatt power up to tetrawatt power. Low power lasers are mainly used for purposes such as metrology, interferometry, etc. while high power lasers are used for industrial applications such as cutting, welding, drilling, remote sensing app-lications, medical applications, nuclear fusion etc. The output may be either continuous wave (CW) or pulsed.

Modification of laser output :-

The output of the lasers may be continuous or pulsed, and are not always highly coherent and monochromatic. Even within a pulse, it may consist of large no. of spikes.

As in the case of vibrations of streched strings where in addition to the fundamental frequency, higher harmonic are possible.

These harmonics differ in frequency by $(c/2L)$, where L is the length of the cavity and c is the velocity of light. These are called 'Longitudinal Modes'. Also, not only the group of photons travelling back and forth exactly along the optic axis of the laser cavity contribute for the output; but even the photons very slightly off the axis by making sufficient no. of trips within the cavity may also contribute for the output. These are called 'Transverse Modes'. Thus the output consists of several longitudinal and transverse modes of slightly different wave lengths.

Q- Switching :-

Q- switching is a technique for obtaining short, intense bursts of pulses from Lasers. We know that to get laser action mere population inversion is not sufficient. Since there are losses, the inversion density must be high enough to produce gain compensating the losses. The inversion density for which gain is equal to the loss is called threshold inversion density. If we deliberately introduce some losses inside the cavity, the threshold inversion density increases. Hence we can build up the inversion density to a high value and correspondingly gain also increases but since gain is less than the deliberately introduced loss no collision takes place. Now suddenly removing the introduced loss, the threshold inversion density switches back to its original value. Under this condition the gain is very much higher than the loss and intense amplification takes place and all the available energy is emitted as a single large pulse. Since in this process the quality Q of the cavity is switched to a high value. This technique is called Q- switching. There are different methods of Q- switching.

Laser Systems :-

The first laser was constructed by Maiman in 1960 employing a crystal of ruby as the active medium. Since that time there has been a rapid increase in the types of lasers and in the range of lasing materials. Lasers are broadly classified as

i, Solid state lasers : Ruby laser, Nd: YAG laser (Neodymium-Yttrium Aluminium Garnet)

ii, Gas lasers : He-Ne laser, CO_2 laser, Argon-ion laser

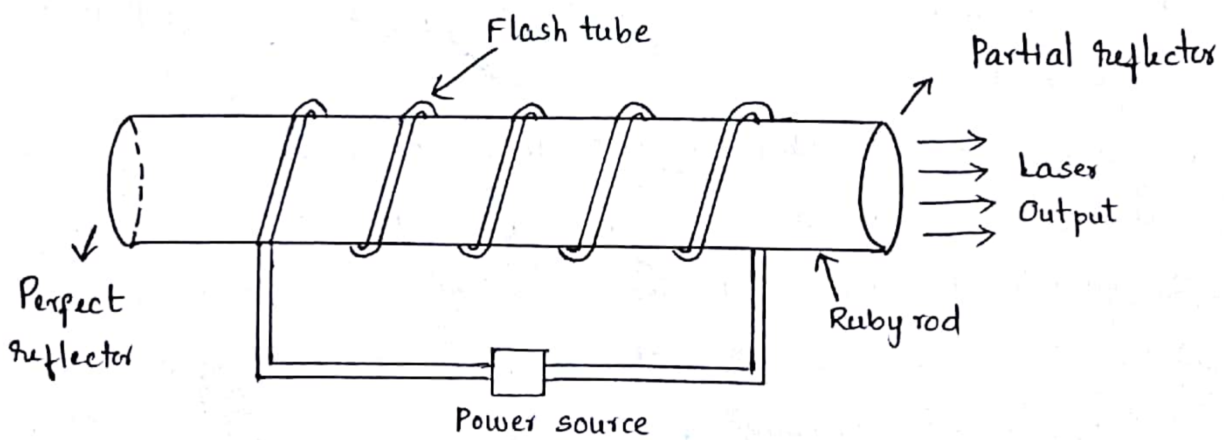
iii, Liquid lasers : Se OCl_2 laser, Europium chelate laser

iv, Dye lasers : Rhodamine 6G laser, Coumarin dye laser

v, Semi conductor lasers : Ga As laser , In P laser.

Ruby laser :-

Ruby laser is a three level solid state laser and was constructed by Maiman in 1960. It is a pulsed laser having very high power of hundreds of Mega Watt in a single pulse with 10 nano second duration. It is used for various industrial applications like surface hardening, hard facing, cladding of various industrical products, etc. Recently erbium (Er^{3+}) doped ruby lasers are available and have higher merits than ordinary chromium (Cr^{3+}) doped ruby laser.



Construction:-

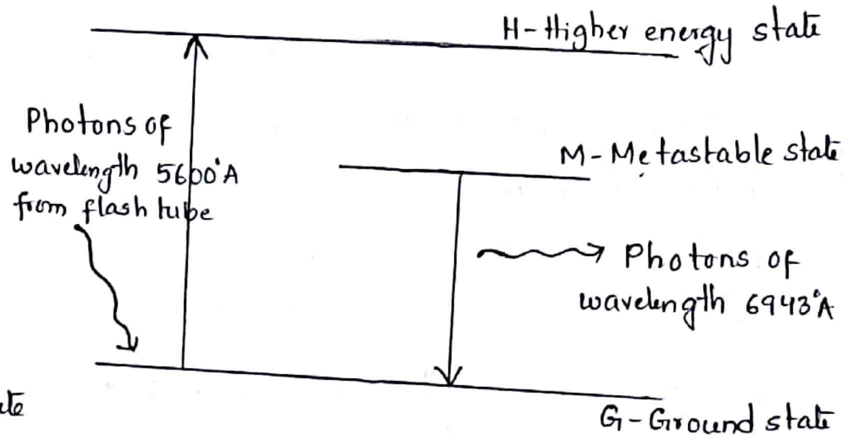
In ruby laser the active element is pure aluminium oxide (Al_2O_3) with 0.05% of chromium and it is shaped into cylinder with parallel transparent sides and reflectors at both ends. Among the two end reflectors, one is a perfect reflector and other is a partial reflector.

The diameter of the active medium is about 0.5 cm and its length is about few centimeters. Pumping source is a flash lamp. Chromium atoms are particularly responsive to light having a wavelength 5600 Å. Most flash lamps like Xenon flash lamps are able to supply energy in this wavelength range.

Flash lamp tube is spirally wound over the curved surface of the ruby rod and is connected to a power supply as shown above.

Working:-

i, One chromium atoms have been excited to an upper energy level 'H' by absorbing photons of wavelength 5600 Å from the flash lamp they require two steps to return to their ground state 'G'. First step is from 'H' state to metastable state 'M' which is a shorter jump and energy emitted in this transition is passed to the crystal lattice as heat.



ii, The chromium atoms returned to M level can remain in this state for several milliseconds. The accumulation of excited atoms at M level increases the population at M level and then transition occurs from M to G level emitting out some photons by spontaneous emission initially in a random manner.

iii, Due to continuous working of flash lamp, the chromium atoms are continuously raised to higher energy state H and then to M level.

iv, At a particular stage population of excited chromium atoms are more at M than at G. Hence there is population inversion. The emitted photons of wave length 6943 A° stimulate to undergo transition. This results in stimulated emission of other identical photons and a cascade begins.

v, The photons travelling parallel to the axis of the ruby rod are used for stimulation while the photons travelling in other directions will pass out from the ruby rod. In the mean time, the photons undergo multiple reflections from the mirrors placed at the ends of the ruby rod and the intensity of the laser radiation grows to a higher value and some of its bursts is coming out through the partial reflector and it servers as output laser beam.

vi, The emitted photon and stimulated photon are in phase and have same frequency and are travelling in the same direction. Thus the laser beam has directionality along with spatial and temporal coherence.

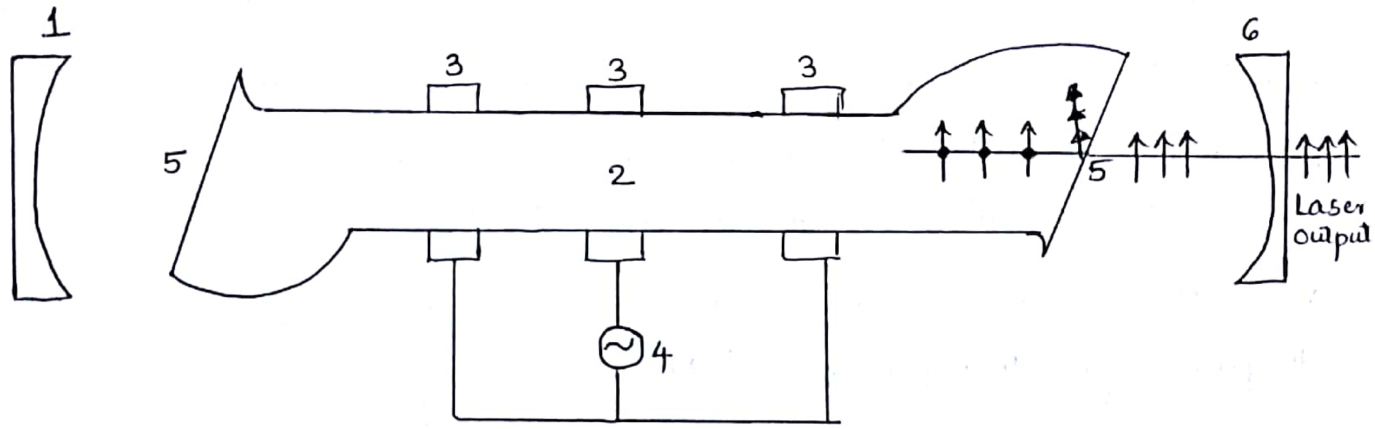
vii, The output beam has red wavelength 6943 A° and frequency 4.32×10^{14} Hz. Its power is more than few hundred Mega watt.

Helium – Neon laser :–

Helium – Neon Laser is a Gas laser and is used for continuous laser beam. Light radiations with high coherence, high directionality and high monochromaticity can be obtained from it. But the output power is generally few milliwatts. Helium – Neon lasers are very useful in making holograms and for interferometric experiments. In medicine, this acts as an aiming laser which is normally used to identify the spot where the laser surgery has to be performed.

Construction :–

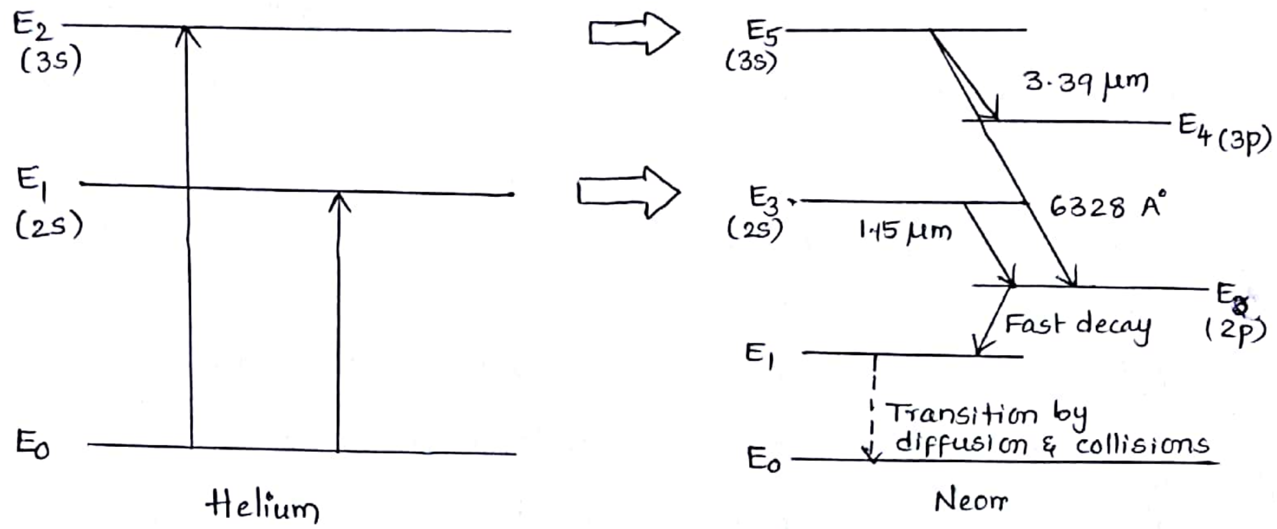
The He–Ne laser system consists of a gas discharge tube which is the active medium. The tube is made up of quartz and is filled with the mixture of Neon under a pressure of 0.1 mm of mercury and Helium under a pressure of 1mm of mercury. The ratio of Helium-Neon mixture is 10:1 i.e., the no. of Helium atoms is greater than the no. of Neon atoms. The power output from these lasers depends upon the length of the discharge tube and pressure of gas mixture. Further electrodes at the ends of the discharge tube are connected to a radio frequency oscillator to produce electrical discharge in the Helium-Neon mixture so as to pump the He atoms to higher energy states.



1. Perfect concave reflector 2. Active medium 3. Electrodes 4. R.F Oscillator
5. Brewster angle windows 6. Partially reflecting concave mirror

The end faces of the gas discharge are tilted at the Brewster angle as shown above. These are called Brewster angle windows. An emitted unpolarised light wave consists of two components called perpendicularly polarised wave and parallel polarised wave. The perpendicularly polarised wave is completely attenuated by the window plate while the parallel polarised wave is transmitted by the window in the same direction. The parallel polarised wave is repeated reflected by the concave mirrors situated behind the Brewster angle windows and correspondingly it passes repeatedly through the active medium. Among these concave mirrors, one is partially reflecting and the other is perfectly reflecting.

Working :-



1) By the electrical discharge in the gas tube, the ground level(E_0) helium atoms are excited to higher levels E_1 and E_2 of helium. This process of excitation is called electron excitation.

2) By resonance collisional transfer method, the helium atoms at E_2 give up their excitation energy to the ground state neon atoms. Thus the neon atoms are excitated to their higher energy level E_5. Meanwhile these helium atoms are de-excited and returned to their ground state.

3) Similarly the helium atoms at E_1 give up their excitation energy to the ground state neon atoms and the neon atoms are excited to another higher energy level E_3 as shown. The helium atoms are de-excited and returned to their ground state.

4) Since E_5 and E_3 of Neon atoms are metable states, population inversion takes place at these levels. Any one of the spontaneously emitted photons will trigger the laser action.

5) Thus the stimulated emission takes place between E_5 and E_2 giving a laser light of wavelength 6328 A°.

6, Similarly the stimulated emission between E_5 and E_4 gives a laser light of wavelength 3.39 μm and between E_3 and E_2 gives a laser light of wavelength 1.15 μm.

7, The neon atoms undergo transition from E_2 to E_1 and from E_4 to E_1 in the form of fast decay giving photons by spontaneous emission.

8, The neon atoms are returned to the ground state from E_1 by non-radiative diffussion and collision process. Therefore there is no emission of radiation.

9, After arriving the ground state, once ~~the ne~~ again the neon atoms are raised to E_5 and E_3 by excited helium atoms. Thus one can get continuous output from the He-Ne laser.

10, Some optical elements placed inside the laser system are used to absorb the infrared laser wavelengths 3.39 μm and 1.15 μm.

11, Hence the output of He-Ne laser contains only a single wavelength of 6328 Å and the output power is about few milli watts.

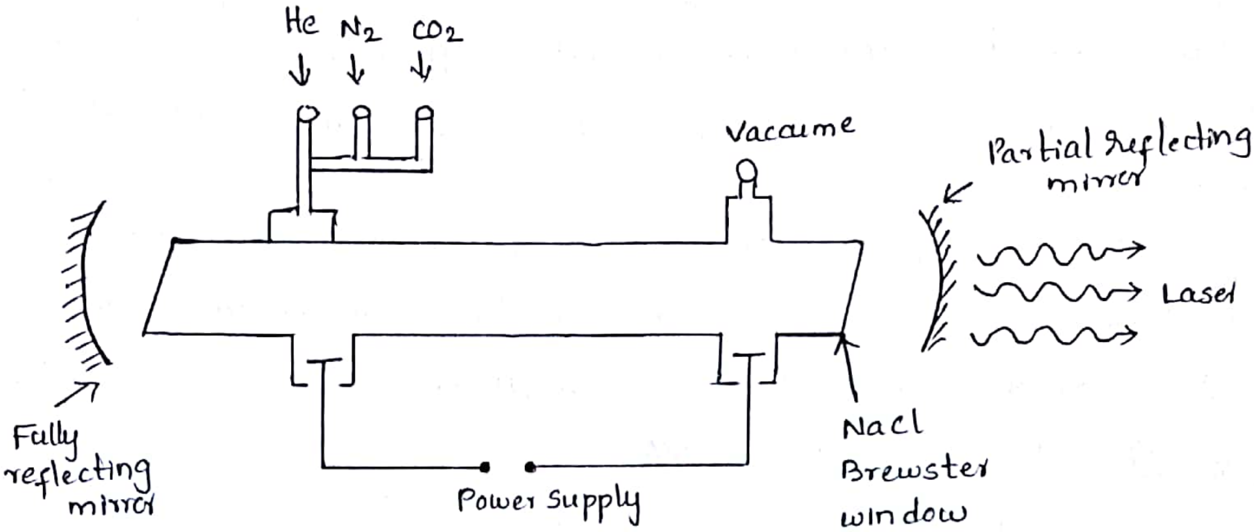
Carbon di-oxide Laser :-

In the Nd YAG laser or He-Ne laser, the transitions takes place among the various excited electronic states of an atom or an ion.

In CO_2 lasers, the laser transitions are occuring between different vibrational states of the carbon di-oxide molecule. An Indian Engineer, Patel was the first person who designed CO_2 laser.

Construction :-

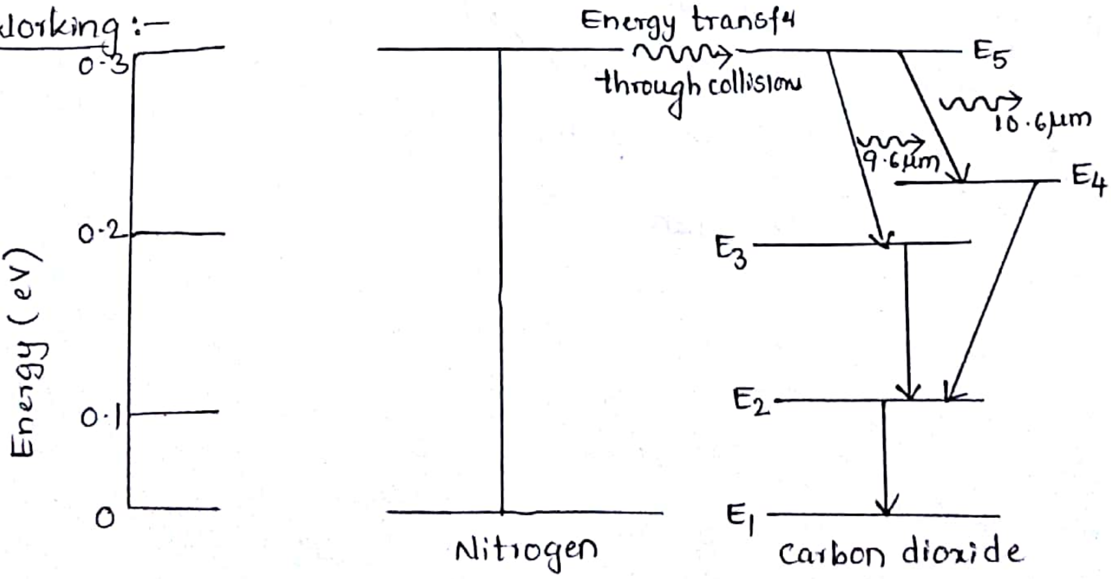
The below figure shows the schematic diagram of a CO_2 laser. Along with CO_2, there are also nitrogen and helium gases in the apparatus. Nitrogen helps to increase the population of the upper level of CO_2, while helium helps to depopulate the lower level. This is achieved due to high thermal conductivity of helium. Further helium helps to conduct heat away to the walls of the discharge tube keeping CO_2 cold.



The discharge tube is of 2.5 cm in diameter and 5 m in length and discharge is produced by d.c. excitation. Sodium chloride Brewster windows are used at the end. The partial pressures of CO_2, N_2 and He are around 0.33 torr, 1.2 torr and 7 torr respectively. The partial pressure values depend on the diameter of the tube. To remove the dissociation products which may contaminate the laser, the continuous flow of the gas mixture is maintained in the tube.

[1 torr = 1 mm height of mercury column].

Working :-



1, When a discharge is passed through the tube, the nitrogen molecules are excited and are raised to higher excited state.

2, The excited energy of nitrogen molecules is transfered to carbon-dioxide molecules through collisions and CO_2 molecules are raised to their excited vibrational energy level E_5 from their ground state.

3, The energy level E_5 is a metastable state. Hence there is population inversion.

4, stimulating photons of wave length 10.6 μm and 9.6 μm induce the CO_2 molecules to undergo stimulated emission by laser transitions from E_5 to E_4 giving laser wavelength of 10.6 μm and from E_5 to E_3 giving laser wavelength of 9.6 μm.

5, since the laser transition from E_5 to E_4 has higher gain than from E_5 to E_3, the laser usually oscillates at 10.6 μm.

6, The CO_2 molecules from E_4 to E_3 are returned to their ground through fast decay and diffusion.

7, when there is longitudinal flow of gases, the maximum power obtained is about 50-60 W/m.

8, If the gas flow is perpendicular to the discharge the output power can be raised to about 10 kilowatt/m. This type of CO_2 laser is known as Transversely Excited Atmospheric pressure laser or TEA laser. Thus the gas flow is maintained along the axis of the tube at normal atmospheric pressure and the current in the arc flows at right angles to the axis of the laser.

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→ Applications of Lasers :–

→ Lasers in Industry :–

In manufacturing industry lasers are used for welding, cutting and drilling applications.

Welding :

- Very high welding rates are possible.
- Dissimilar metals can be welded.
- Microwelding is done with great ease.

Cutting :

Lasers cut through a wide variety of materials, rapidly and precisely.

- with low-power CO_2 laser, insulation from electrical wires and cables are striped off. Hence without any damage to the electrical wire the insulation can be removed.
- with high power levels, glass and quartz are easily cut with CO_2 laser.
- Any desired shape can be cut, even complicated shapes cut using lasers.
- cut finish used to be very smooth requiring no further treatement.

Drilling:

Most drilling systems operate in a pulsed mode. To get the drill of desired depth and size, no. of pulses, and energy of each pulse are to be controlled.

- One of the first application of the laser was to drill diamond dies.
- Lasers are used to drill holes in 'difficult to drill' materials such as ceramics etc.
- Holes of micron order can be easily drilled using lasers.

→ Laser in Medicine :-

The very first application of laser was in the field of medicine.

- Opthomalagists started using Argon Ion lasers for welding retina detachment

- Laser are used in cataract removal.
- Using ultra violet radiation from Excimer laser, eye lens curvature correction is carried out.
- Laser scaples are used for bloodless surgery.
- In dermatology, lasers are used to remove freckles, acne, birth marks and tattoo.
- Lasers are used in destroying kidney stones and gallstones.
- Lasers are used in cancer diagnostic and therapy.

→ Lasers in scientific fields :-

- Lasers in metrology.
- Lasers in defence.
- Lasers in nuclear energy.
- Lasers in optical communications.
- Lasers in consumer electronics Industry.

13a

FIBER OPTICS

Introduction:

Fiber optics is a branch of physics that deals with the optical fibers, their working principle, their types, different parameters and factors that influence the propagation of light through the optical fibers and applications in different areas of science & technology.

Total internal reflection:

Light is propagated through optical fiber cable by means of a phenomenon called Total Internal Reflection.

Consider two media of refractive indices (n_1) and (n_2). Let (θ_1) and (θ_2) be the angles of incidence and refraction respectively at the ~~Interpha~~ interface (ie, boundary) of the two media.

From Snell's law, we have

$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

case (i):

Consider the case of a light propagating from rarer medium to denser medium. ie, refractive index of medium 1, (n_1) is lesserthan that of medium 2, (n_2).

From Snell's law, we have

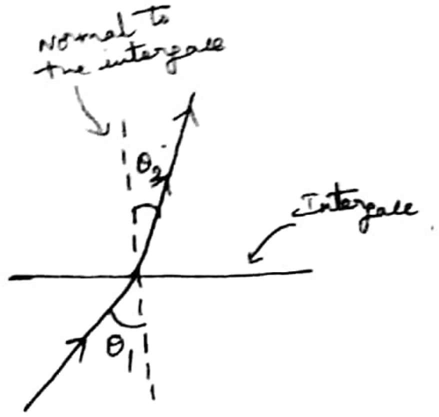
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\Rightarrow \frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

$$\Rightarrow \frac{\sin\theta_2}{\sin\theta_1} < 1 \quad (\because n_1 < n_2 \text{ in this case})$$

$$\Rightarrow \sin\theta_2 < \sin\theta_1$$

$$\Rightarrow \boxed{\theta_2 < \theta_1}$$



$n_1 < n_2$

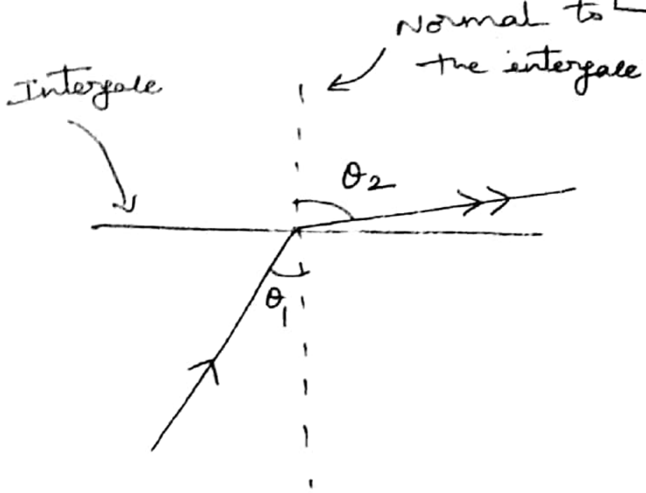
$\Rightarrow \theta_2 < \theta_1$

ie; angle of refraction is lesser than angle of incidence

$\Rightarrow$ the light ray refracts TOWARDS the normal.

Case(ii):

Consider the case of a light ray travelling from denser medium to rarer medium ie; the refractive index of medium 1, (n_1) is GREATER than that of medium 2, (n_2).



From Snell's law, we have

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\Rightarrow \frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

$$\Rightarrow \frac{\sin\theta_2}{\sin\theta_1} > 1 \quad \left(\because \frac{n_1}{n_2} > 1\right)$$

$$\Rightarrow \sin\theta_2 > \sin\theta_1$$

$$\Rightarrow \boxed{\theta_2 > \theta_1}$$

$n_1 > n_2$

$\Rightarrow \theta_2 > \theta_1$

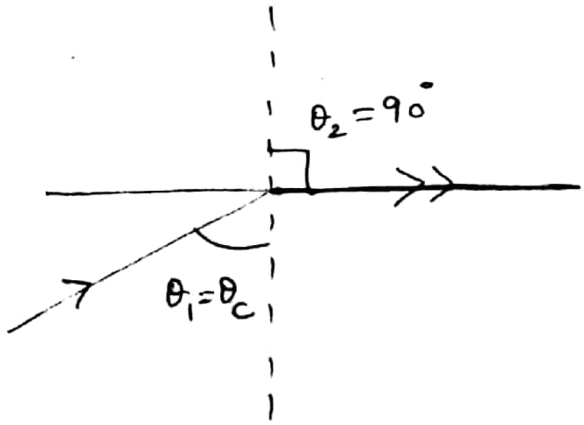
ie; angle of refraction is GREATER than angle of incidence.

$\Rightarrow$ the light ray refracts AWAY from the normal.

Case(iii):

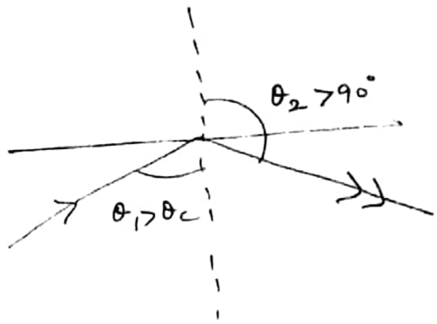
From case(ii), we understood that when $n_1 > n_2$, angle of refraction (θ_2) is greater than the angle of incidence (θ_1).

As (θ_1) is increased, (θ_2) also increases. For a particular angle $\theta_1 = \theta_C$, the angle of refraction, $\theta_2 = 90^\circ$.



Thus the angle of incidence for which the angle of refraction is equal to ninety degrees, is defined as CRITICAL ANGLE.

Case (iv):



Again consider the same case of $n_1 > n_2$. From case (iii), we understood that when $\theta_1 = \theta_c$ then $\theta_2 = 90^\circ$

From Snell's law, it is clear that when $\theta_1 > \theta_c$ then $\theta_2 > 90^\circ$.

When the light ray is incident at an angle greater than the critical angle then the light ray refracts at an angle greater than 90° i.e; the light ray refracts internally into the same medium, resembling the reflection of light. Hence it is called INTERNAL REFLECTION.

As the incident light is 100% refracted internally into the same medium, this phenomenon is called TOTAL INTERNAL REFLECTION

Thus the two conditions that need to be satisfied for the Total internal reflection to take place are

(i) $n_1 > n_2$ and

(ii) $\theta_1 > \theta_c$

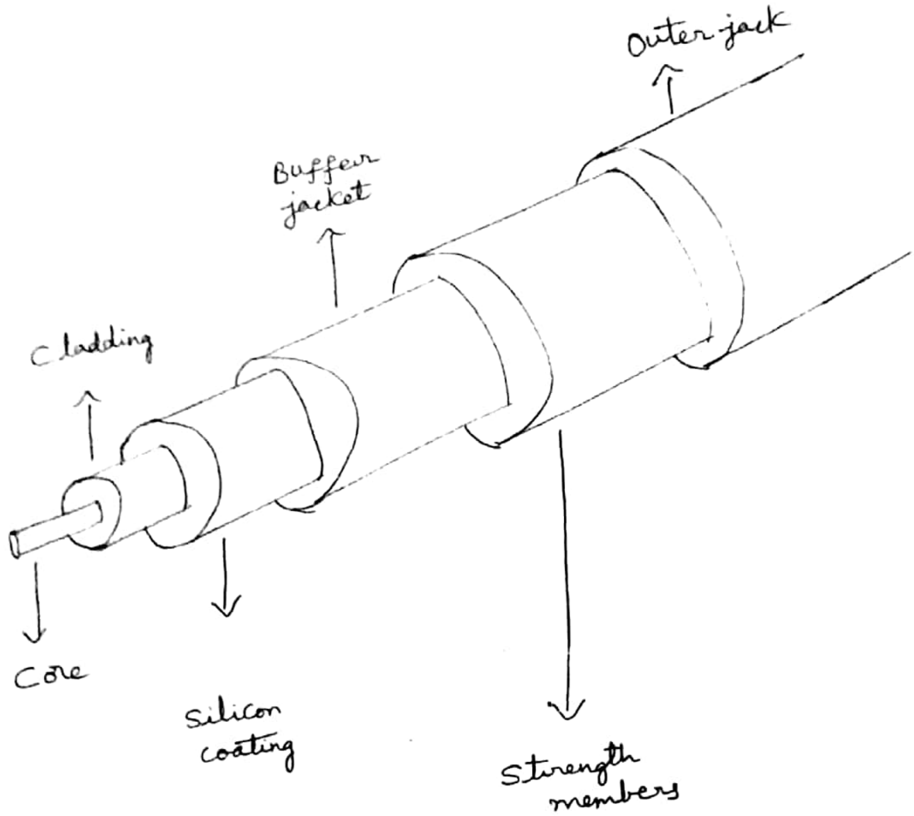
~~Acceptance~~

Construction of optical fiber:

The optical fiber mainly consists of the following six parts.

1. Core 2. Cladding 3. Silicon coating
4. Buffer jacket 5. Strength members 6. Outer jacket.

* A typical glass fiber consists of a central core of 50μm thickness surrounded by cladding.



* Cladding is of glass with refractive index slightly lesser than that of the core and over all diameter of 125 to 200 μm.
* Silicon coating is provided between buffer jacket and cladding in order to improve the quality of transmission of light.
* Buffer jacket over the optical fiber is made of plastic and protects the fiber from moisture and abrasion.
* Surrounding the buffer jacket, a layer of strength member is arranged, in order to provide the necessary toughness and tensile strength.
* Finally the fiber cable is covered by black polyurethane outer jacket. Owing to this arrangement, fiber cable will not be damaged during hard pulling, bending, stretching or rolling, though the fiber is made up of brittle glass.

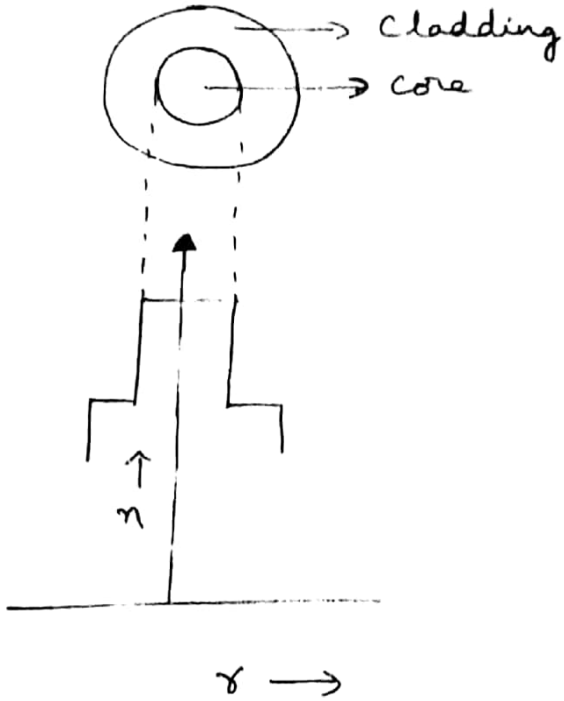
Classification of fibers:

Based on the refractive index profile of the core, ~~and~~ optical fibers are classified into two categories. They are:

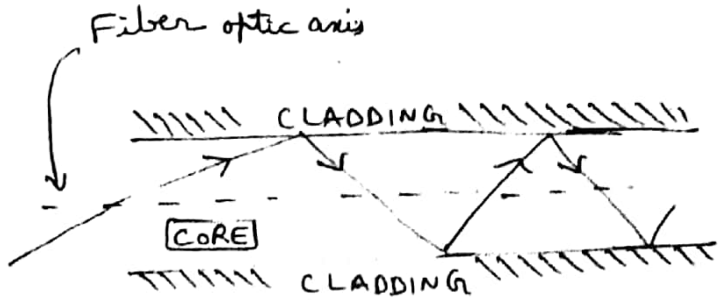
(i) Step index fiber (ii) Graded index fiber

Step index fibers:

In Step index fibers, the refractive index of the core medium is uniform throughout and undergoes an abrupt change at the interface of the core and cladding, as shown in the adjacent figure.

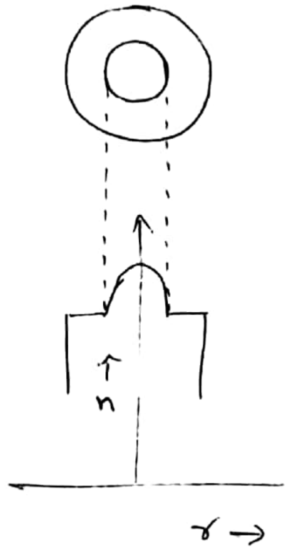


The light ray gets transmitted through this optical fiber in the form of meridional ray, i.e., the light ray crosses the fiber axis after each total internal reflection, as shown in the adjacent figure.

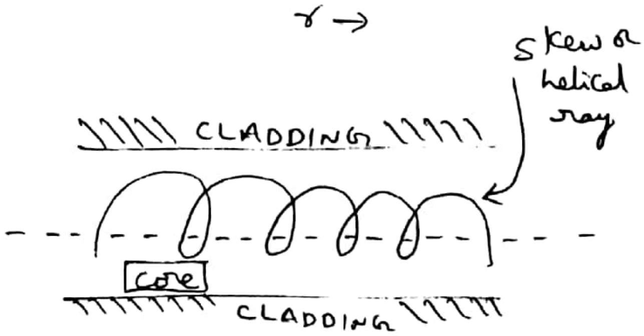


Graded index fiber:

In graded index fiber, the refractive index of the core medium is such that it is maximum at the centre and decreases in a parabolic manner as we move toward the cladding, as shown in the adjacent figure.



The light ray propagates through this optical fiber, in the form of skew or helical ray, as shown in the adjacent figure. From the figure, it is clear that this light ray never touches the fiber optic axis.



Acceptance angle, acceptance cone and numerical aperture:

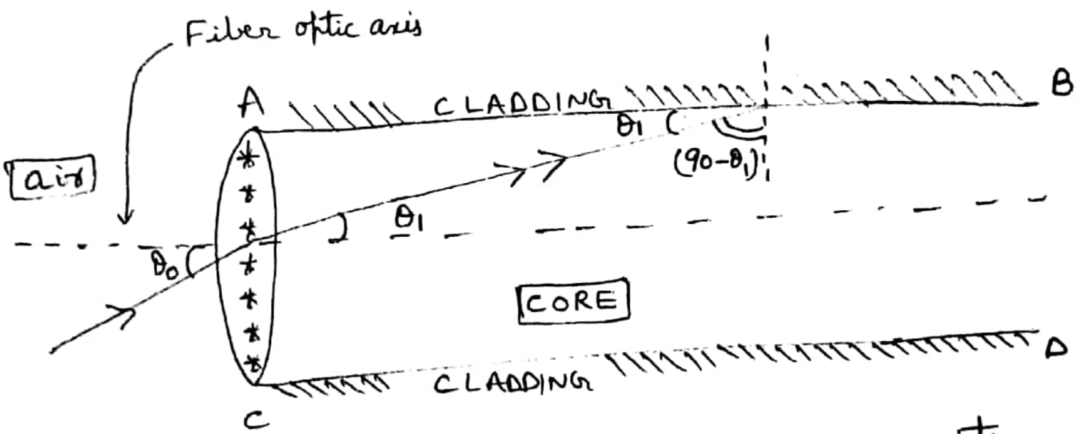


Figure shows an optical fiber cable ABCD. AC represents air-core interface. Let (n_0), (n_1) and (n_2) be the refractive indices of air, core and cladding respectively.

~~Let (θ_0) be the angle of incidence.~~

Let the light ray be incident at an angle (θ_0) at the air-core interface. Let (θ_1) be the angle of refraction at air-core interface. Then from Snell's law, we have

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

$$\Rightarrow \boxed{\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1} \longrightarrow (1)$$

From the figure it is clear that, the light ray refracted at the air-core interface will be incident at core-cladding interface, at an angle $(90-\theta_1)$. If this angle of incidence is critical angle, then the angle of refraction at core-cladding interface will be equal to 90°.

From Snell's law, we have

$$n_1 \sin(90-\theta_1) = n_2 \sin 90^\circ \qquad \left[\because \sin(90-\theta_1) = \cos\theta_1,\ \sin 90^\circ = 1.\right]$$

$$\Rightarrow n_1 \cos\theta_1 = n_2$$

$$\Rightarrow \boxed{\cos\theta_1 = \frac{n_2}{n_1}} \longrightarrow (2).$$

From (1),

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1$$

$$= \frac{n_1}{n_0}\sqrt{1-\cos^2\theta_1}$$

$$= \frac{n_1}{n_0}\sqrt{1-\frac{n_2^2}{n_1^2}} \qquad (\because \text{using } (2))$$

$$= \frac{n_1}{n_0}\frac{\sqrt{n_1^2-n_2^2}}{n_1}$$

$$\Rightarrow \boxed{\sin\theta_0 = \sqrt{n_1^2 - n_2^2}} \rightarrow (3) \quad (\because n_0 \cong 1)$$

where (θ_0) is called the acceptance angle.

It is defined as the maximum limit of the angle of incidence at air-core interface for which the light ray propagates through the optical fiber cable, by means of Total internal reflection.

If the angle of incidence is beyond the acceptance angle then the ~~light~~ light ray refracted at air-core interface, will be incident at core-cladding interface at such an angle that it does not fulfill the conditions for Total internal reflection. Thus the light ray, instead of traversing through the optical fiber cable, gets leaked into the cladding region.

<u>Additional information:</u>

S.no.	θ_0	θ_1	$(90-\theta_1)$	θ_2
1.	30°	25°	90°-25° = 65°	90°
2.	35°	30°	90°-30° = 60°	<90°

Let $\theta_0 = 30°$ be the acceptance angle then. Let $\theta_1 = 25°$ be the angle of refraction at air-core interface. Then angle of incidence at core-cladding interface is 65° (90°-25°). As this is assumed to be critical angle, the angle of refraction at core-cladding interface will be 90°.

case (ii): Let the angle of incidence at air-core interface be slightly greater than the acceptance angle. Let us say 35°. Let θ_1 be 30° then the angle of incidence at core-cladding interface is 60° ie, (90°-30°) which is clearly lesser than the critical angle. Since the light ray is incident at an angle lesser than critical angle, it surely gets refracted into the second medium ie, cladding, without undergoing total internal reflection into core medium. Hence acceptance angle has got maximum limit.

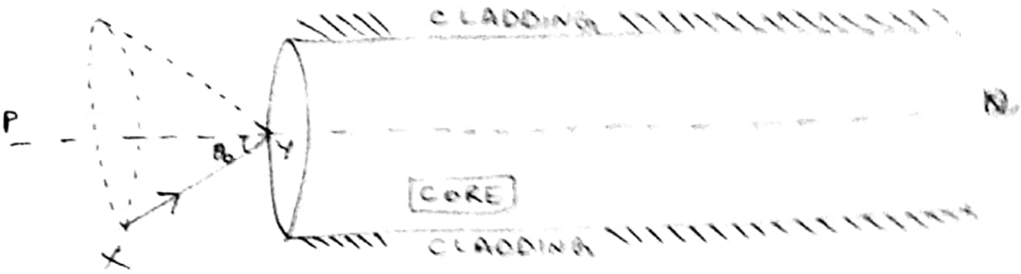


Figure shows the light ray (XY) incident at the air-core interface. Imagine, this XY ray is rotated about the ~~fiber optic~~ optical fiber axis, say (PQ). ~~Then this rotation~~ Let (θ_0) be the angle made by the incident ray w.r.t the optical fiber axis. Let this angle be the acceptance angle. Then the rotation of this XY ray about the optical fiber axis, describes a cone as indicated by smaller dashed line in the figure. This cone is called Acceptance cone. The light ray incident at the air-core interface, with in this acceptance cone alone can traverse through the optical fiber cable by means of Total internal reflection. Otherwise, it will be discarded / leaked into cladding region.

Finally, Numerical aperture is defined as the light gathering capacity of the optical fiber cable. Mathematically it is defined as the sine of the acceptance angle. Therefore from eq ③, we have

$$\text{Numerical aperture, } \boxed{NA = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}} \longrightarrow (4)$$

where (n_1) and (n_2) are the refractive indices of core and cladding respectively.

<u>Problem:</u> ~~A~~ The refractive indices of core and cladding of an optical fiber cable are 1.3 and 1.2 respectively. Determine the ~~so~~ numerical aperture and acceptance angle of the optical fiber.

<u>Solution:</u> Given, $n_{core} = n_1 = 1.3$; $n_{cladding} = n_2 = 1.2$.

$$\text{Numerical aperture, } NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.3)^2 - (1.2)^2} = \sqrt{1.69 - 1.44}$$

$$= \sqrt{0.25} = 0.5$$

$$\text{Acceptance angle, } \theta_0 = \sin^{-1}(NA) = \sin^{-1}(0.5) = \sin^{-1}\left(\tfrac{1}{2}\right)$$

$$\boxed{\theta_0 = 30^\circ}$$

Attenuation in optical fibers:

Though the phenomenon of Total internal reflection assures the lossless transmission of light signal through its optical fibers, there are few factors that result in the attenuation of the light signal. A proper study of these attenuation factors helps us in finding the ways out, to minimise the losses and increase the efficiency of the optical fibres. The following are the different attenuation factors.

Absorption losses:

Every material has a characteristic of absorbing a fraction of the incident light. optical fibers is no exception this property is called Intrinsic absorption. ~~Ea~~ ~~ad~~ Besides the intrinsic absorption, the impurities whatsoever present in optical fibers also absorb light which is called Impurity absorption. Such absorptions result in the reduction of the strength of the light signal propagating through the optical fiber cable.

Scattering losses:

The light signal propagates through the core of the optical fiber cable, by means of Total internal reflection. Presence of any kind of impurities in the core medium would certainly scatter the light signal in an unexpected direction and there is ~~any~~ every possibility of losing the signal due to the light signal refracted into cladding region. This is called Scattering ~~losses~~ loss.

Bending losses:

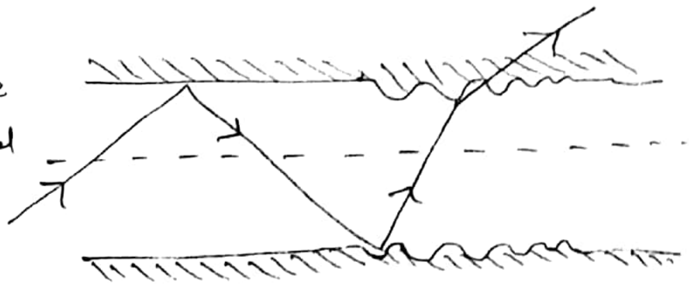
There are two kinds of bending losses –

(i) Macroscopic bending losses and
(ii) Microscopic bending losses.

If the radius of curvature of the bending of the optical fiber is greater than the radius of the optical fiber cable, then it is called macroscopic bending.

As shown in the above figure, the light ~~ray~~ signal, when it propagates through the bent optical fiber, gets leaked into cladding region as the conditions for total internal reflection ($\theta_1 > \theta_c$) is not satisfied, in the bent region.

Same is the reason for leakage of signal into cladding region, even in the case of microscopic bending losses. If the radius of curvature of the bending of the optical fiber is ~~gr~~ lesser than the radius of the optical fiber cable, then it is called Microscopic bending.



Applications of optical fibers:

1. Communication:

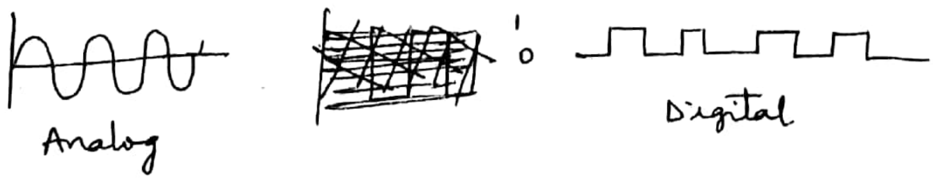
optical fibers are used as wave guides in the communication system. A typical optical fiber communication System is as shown in the following figure. It mainly consists of the following parts:

(i) Encoder (ii) Transmitter

(iii) Waveguide

(iv) Receiver (v) Decoder.

(i) Encoder: Initially the audio signal (i.e., the words spoken by us) is converted into electrical signal which is an analog signal. Encoder is an electronic system that converts this analog signal into binary or ~~digitl~~ digital signal.



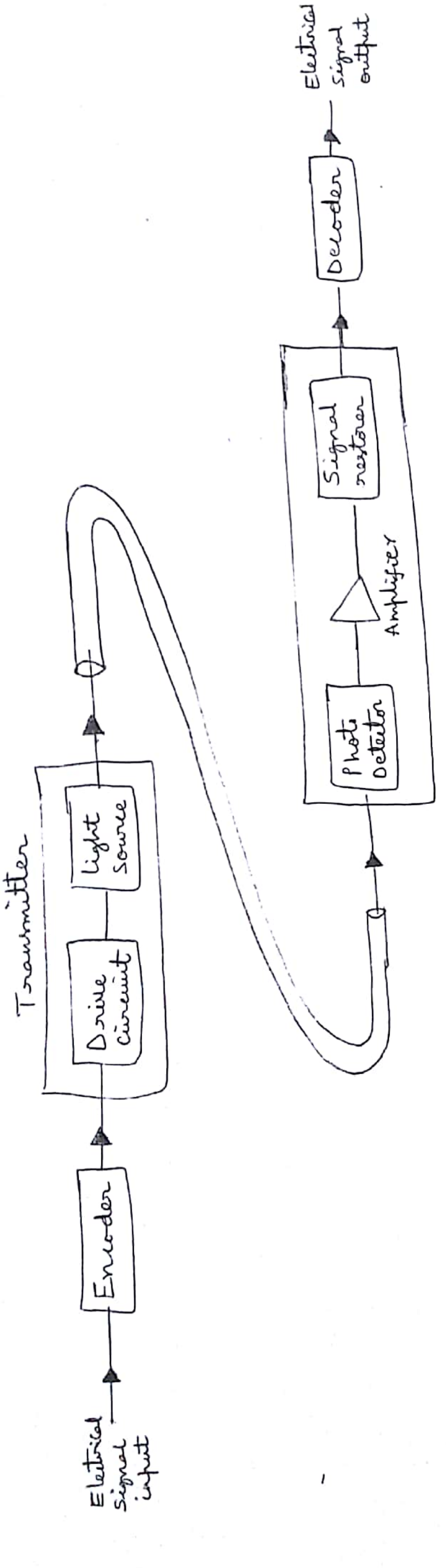


Fig: Optical Fiber Communication System

(ii) Transmitter: The digital signal from the Encoder is fed to the Transmitter which consists of two parts - Drive Circuit and light Source. Drive circuit receives the digital signal from Encoder and feeds it to the light source. Light source is usually LED or a diode LASER. ~~If it receives a digital '0' signal~~ If digital '0' is received then light source will be turned OFF. If digital '1' is received then light source will be turned ON. Thus light source converts ~~do~~ electrical signals into optical signals.

(iii) Wave guide: Now the optical signals generated by the transmitter are fed to an optical fiber which acts as wave guide. The signal traverses over longer distance through these wave guides

(iv) Receiver: on the other side of the wave guide, the optical signal is received by the Receiver which consists of Photo detector, amplifier and a signal restorer. The Photodetector receives the optical signals and generates the equivalent electrical signals. These electrical signals are amplified by the Amplifier. The signal restorer keeps all the electrical signals in a sequential form and supplies to Decoder.

(v) Decoder: It is an electronic system that converts the digital signal to analog signal.

2. Medical:

optical fibers are used in Endoscopy. They are also used in LASER Angioplasty. A three channel catheter is used in LASER Angioplasty. The three channels are nothing but three optical fiber cables. Channel 1 is used to observe where exactly the Cholesterol deposits are present. LASER of suitable power is sent through channel 2 to destroy the cholesterol deposits. Channel 3 is used to suck out the debris.

3. Level sensor:

A Chamfered optical fiber, consisting of core alone is used a level sensor. The condition here is that the refractive indices of air, core and liquid should be such that $n_{air} < n_{core} < n_{liquid}$

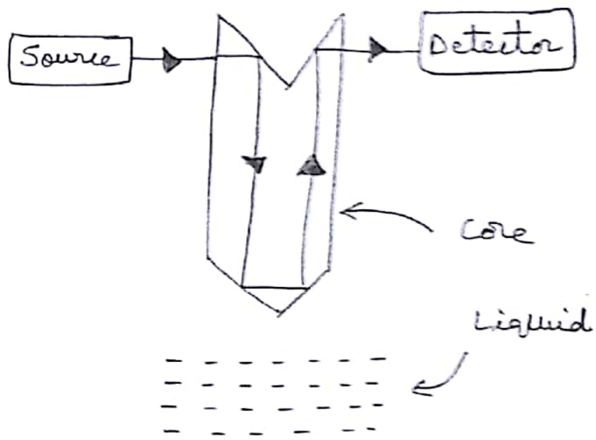


Fig (i)

A light signal from Source is fed to the core as shown in figure(i). The light signal reaches the Detector after getting subjected to Total internal reflections in the core. It is observed here that the liquid level did not touch the tip of the optical fiber yet and hence the light signal smoothly reaches the detector.

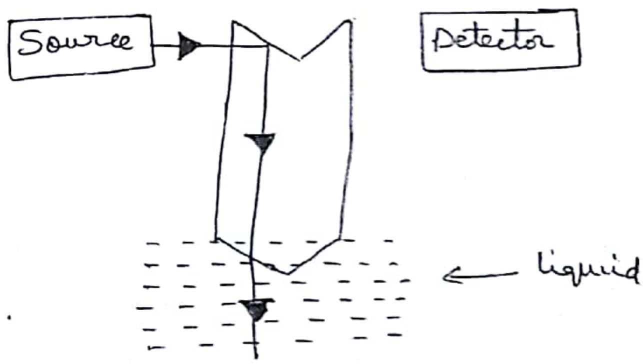


Fig (ii)

When the liquid raises to sufficient level as shown in fig (ii), at the point of core-liquid interface, Total internal reflection cannot take place. The reason is $n_{core} < n_{liquid}$. Therefore the light signal gets leaked into liquid without reaching the Detector.

Thus the light signal reaching the detector indicates lower liquid level while the detector does not receive the light signal, indicates sufficient level of the liquid.

MODULE-IV

NON-DESTRUCTIVE TESTING

Objective

To gain experience with and understanding of the types, advantages and applications of various NDT methods. To be able to choose the best NDT method for a given part.

Introduction

Up to this point we have learnt various testing methods that somehow destruct the test specimens. These were, tensile testing, hardness testing, etc. In certain applications, the evaluation of engineering materials or structures without impairing their properties is very important, such as the quality control of the products, failure analysis or prevention of the engineered systems in service.

This kind of evaluations can be carried out with Non destructive test (NDT) methods. It is possible to inspect and/or measure the materials or structures without destroying their surface texture, product integrity and future usefulness.

The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. Certain standards has been also implemented to assure the reliability of the NDT tests and prevent certain errors due to either the fault in the equipment used, the miss-application of the methods or the skill and the knowledge of the inspectors.

Successful NDT tests allow locating and characterizing material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and variety of less visible, but equally troubling events. However, these techniques generally require considerable operator skill and interpreting test results accurately may be difficult because the results can be subjective.

These methods can be performed on metals, plastics, ceramics, composites, cermets, and coatings in order to detect cracks, internal voids, surface cavities, delamination, incomplete c defective welds and any type of flaw that could lead to premature failure. Commonly used NDT test methods can be seen in table 1. These are universal NDT methods; however, very special tests have been developed for specific applications.

Table 1 Commonly used NDT techniques

Technique	Capabilities	Limitations
Visual Inspection	Macroscopic surface flaws	Small flaws are difficult to detect, no subsurface flaws.
Microscopy	Small surface flaws	Not applicable to larger structures; no subsurface flaws.
Radiography	Subsurface flaws	Smallest defect detectable is 2% of the thickness; radiation protection. No subsurface flaws not for porous materials
Dye penetrate	Surface flaws	No subsurface flaws not for porous materials
Ultrasonic	Subsurface flaws	Material must be good conductor of sound.
Magnetic Particle	Surface / near surface and layer flaws	Limited subsurface capability, only for ferromagnetic materials.
Eddy Current	Surface and near surface flaws	Difficult to interpret in some applications; only for metals.
Acoustic emission	Can analyze entire structure	Difficult to interpret, expensive equipments.

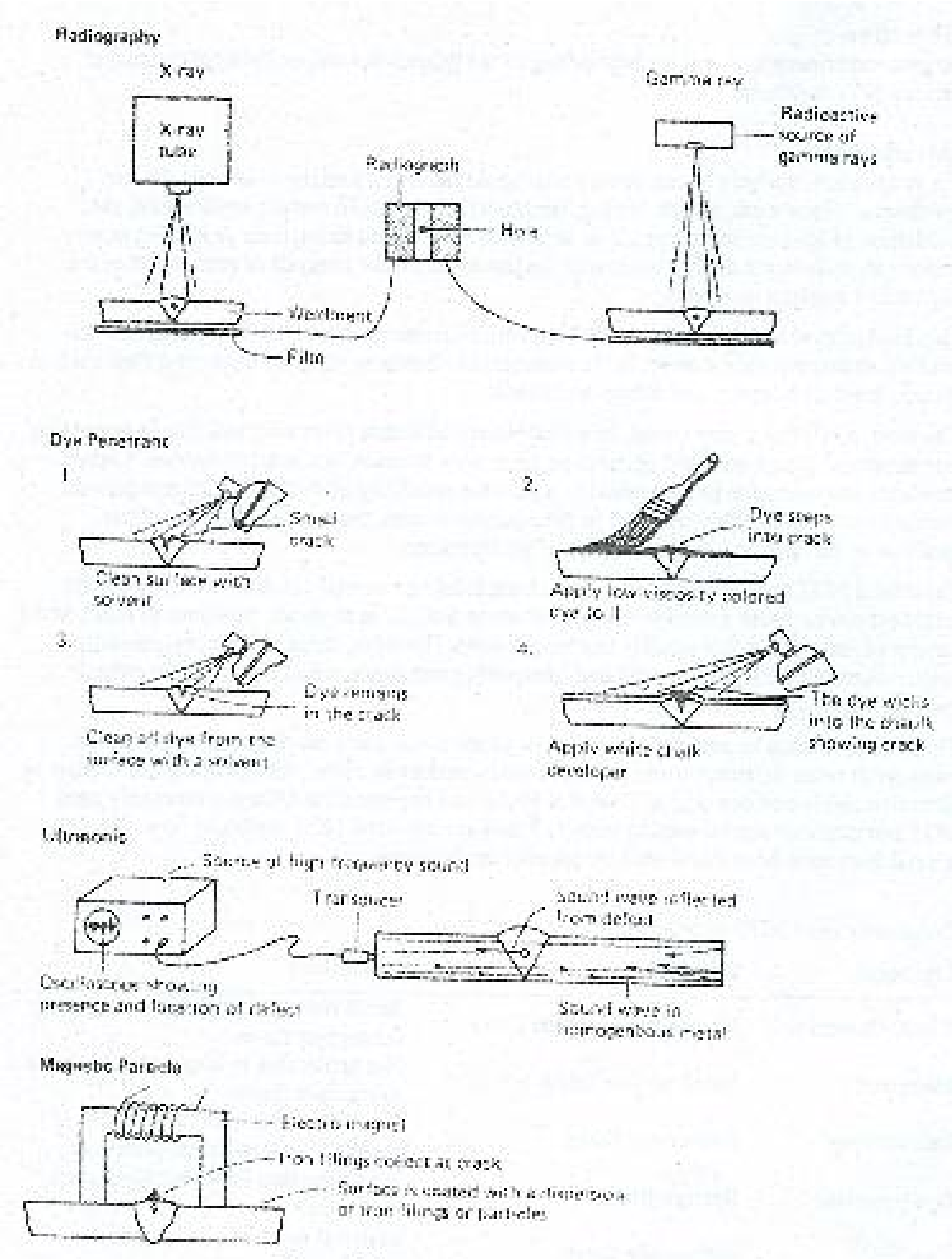


Figure: Schematic of NDT techniques.

Visual inspection:

VI is particularly effective detecting macroscopic flaws, such as poor welds. Many welding flaws are macroscopic: crater cracking, undercutting, slag inclusion, incomplete penetration welds, and the like. Like wise, VI is also suitable for detecting flaws in composite structures and piping of all types. Essentially, visual inspection should be performed the way that one would inspect a new car prior to delivery, etc. Bad welds or joints, missing fasteners or components, poor fits, wrong dimensions, improper surface finish, delaminations in coatings, large cracks, cavities, dents, inadequate size, wrong parts, lack of code approval stamps and similar proofs of testing.

Radiography:

Radiography has an advantage over some of the other processes in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed.
The x-ray emitted from a source has an ability to penetrate metals as a function of the accelerating voltage in the x-ray emitting tube. If a void present in the object being radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure than in the non-void areas. The sensitivity of x-rays is nominally 2% of the materials thickness. Thus for a piece of steel with a 25mm thickness, the smallest void that could be detected would be 0.5mm in dimension. For this reason, parts are often radiographed in different planes. A thin crack does not show up unless the x-rays ran parallel to the plane 0 the crack. Gamma radiography is identical to x-ray radiography in function. The difference is the source of the penetrating electromagnetic radiation which is a radioactive material such m Co 60. However this method is less popular because of the hazards of handling radioactive materials.

Liquid (Dye) penetrant method:

Liquid penetrant inspection (LPI) is one of the most widely used nondestructive evaluation (NDE) methods. Its popularity can be attributed to two main factors, which are its relative ease of use and its flexibility. The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. .
This method is an inexpensive and convenient technique for surface defect inspection. The limitations of the liquid penetrant technique include the inability to inspect subsurface flaws and a loss of resolution on porous materials. Liquid penetrant testing is largely used on nonmagnetic materials for which magnetic particle inspection is not possible.
Materials that are commonly inspected using LPI include the following; metals (aluminum, copper, steel, titanium, etc.), glass, many ceramic materials, rubber, plastics.
Liquid penetrant inspection is used to inspect of flaws that break the surface of the sample. Some of these flaws are listed below; fatigue cracks, quench cracks grinding cracks, overload and impact fractures, porosity, laps seams, pin holes in welds, lack of fusion or braising along the edge of the bond line.

Magnetic particles:

Magnetic particle inspection is one of the simple, fast and traditional nondestructive testing methods widely used because of its convenience and low cost. This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components. The only requirement from an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such iron, nickel, cobalt, or some of their alloys, since these materials are materials that can be magnetized to a level that will allow the inspection to be effective. On the other hand, an enormous volume of structural steels used in engineering is magnetic. In its simplest application, an electromagnet yoke is placed on the surface of the part to be examined, a kerosene-iron filling suspension is poured on the surface and the electromagnet is energized. If there is a discontinuity such as a crack or a flaw on the surface of the part, magnetic flux will be broken and a new south and north pole will form at each edge of the discontinuity. Then just like if iron particles are scattered on a cracked magnet, the particles will be attracted to and cluster at the pole ends of the magnet, the iron particles will also be attracted at the edges of the crack behaving poles of the magnet. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection. For the best sensitivity, the lines of magnetic force should be perpendicular to the defect.

Eddy current testing:

Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field develops in and around the conductor. This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close proximity to this changing magnetic field, current will be induced in this second conductor. These currents are influenced by the nature of the material such as voids, cracks, changes in grain size, as well as physical distance between coil and material. These currents form an impedance on a second coil which is used to as a sensor. In practice a probe is placed on the surface of the part to be inspected, and electronic equipment monitors the eddy current in the work piece through the same probe. The sensing circuit is a part of the sending coil.

Eddy currents can be used for crack detection, material thickness measurements, coating thickness measurements, conductivity measurements for material identification, heat damage detection, case depth determination, heat treatment monitoring.

Some of the advantages of eddy current inspection include; sensitivity to small cracks and other defects, ability to detect surface and near surface defects, immediate results, portable equipment, suitability for many different applications, minimum part preparation, no necessity to contact the part under inspection, ability to inspect complex shapes and sizes of conductive materials.

Some limitation of eddy current inspection; applicability just on conductive materials, necessity for an accessible surface to the probe, skillful and trained personal, possible interference of surface finish and roughness, necessity for reference standards for setup, limited depth of penetration, inability to detect of the flaws lying parallel to the probe coil winding and probe scan direction.

Ultrasonic Inspection:

Ultrasonic Testing (UT) uses a high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection I evaluation, dimensional measurements, material characterization, and more. A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulse. Driven by the pulser, the transducer of various types and shapes generates high frequency ultrasonic energy operating based on the piezoelectricity technology with using quartz, lithium sulfate, or various ceramics. Most inspections are carried out in the frequency rang of 1 to 25MHz. Couplants are used to transmit the ultrasonic waves from the transducer to the test piece; typical couplants are water, oil, glycerin and grease.

The sound energy is introduced and propagates through the materials in the form of waves and reflected from the opposing surface. An internal defect such as crack or void interrupts the waves' propagation and reflects back a portion of the ultrasonic wave. The amplitude of

the energy and the time required for return indicate the presence and location of any flaws in the work-piece.
The ultrasonic inspection method has high penetrating power and sensitivity. It can be used from various directions to inspect flaws in large parts, such as rail road wheels pressure vessels and die blocks. This method requires experienced personnel to properly conduct the inspection and to correctly interpret the results.
As a very useful and versatile NDT method, ultrasonic inspection method has the following advantages; sensitivity to both surface and subsurface discontinuities, superior depth of penetration for flaw detection or measurement, ability to single-sided access for pulse-echo technique, high accuracy in determining reflector position and estimating size and shape, minimal part preparation, instantaneous results with electronic equipment, detailed imaging with automated systems, possibility for other uses such as thickness measurements.
Its limitations; necessity for an accessible surface to transmit ultrasound, extensive skill and training, requirement for a coupling medium to promote transfer of sound energy into test specimen, limits for roughness, shape irregularity, smallness, thickness or not homogeneity, difficulty to inspect of coarse grained materials due to low sound transmission and high signal noise, necessity for the linear defects to be oriented parallel to the sound beam, necessity for reference standards for both equipment calibration, and characterization of flaws.

Acoustic Method:

There are two different kind of acoustic methods: (a) acoustic emission; (b) acoustic impact technique.

Acoustic emission:

This technique is typically performed by elastically stressing the part or structure, for example, bending a beam, applying torque to a shaft, or pressurizing a vessel and monitoring the acoustic responses emitted from the material. During the structural changes the material such as plastic deformation, crack initiation, and propagation, phase transformation, abrupt reorientation of grain boundaries, bubble formation during boiling in cavitation, friction and wear of sliding interfaces, are the source of acoustic signals. Acoustic emissions are detected with sensors consisting of piezoelectric ceramic elements. This method is particularly effective for continuous surveillance of load-bearing structures.

Acoustic impact technique:

This technique consists of tapping the surface of an object and listening to and analyzing the signals to detect discontinuities and flaws. The principle is basically the same as when one taps walls, desktops or countertops in various locations with a finger or a hammer and listens to the sound emitted. Vitrified grinding wheels are tested in a similar manner to detect cracks in the wheel that may not be visible to the naked eye. This technique is easy to perform and can be instrumented and automated. However, the results depend on the geometry and mass of the part so a reference standard is necessary for identifying flaws.

Procedure

Liquid penetrant method:

In this method the surfaces to be inspected should be free from any coatings, paint, grease. dirt, dust, etc., therefore, should be cleaned with an appropriate way. Special care should be taken not to give additional damage to the surface to be inspected during the cleaning process. Otherwise, the original nature of surface could be disturbed and the results could be erroneous with the additional interferences of the surface features formed during the cleaning process. Surface cleaning can be performed with alcohol. Special chemicals like cleaner-remover can also be applied if needed. In the experiment, only cleaner-remover will be sufficient. Subsequent to surface cleaning, the surface is let to dry for 2 minutes.

Commercially available cans of liquid penetrant dyes with different colors are used to reveal the surface defects.

Steps used in the experiment:
1. Clean the surface with alcohol and let surface dry for 5 min.
2. Apply the liquid penetrant spray (red can) to the surface and brush for further penetration. Then, wait for 20 min.
3. Wipe the surface with a clean textile and subsequently apply remover spray (blue can) to remove excess residues on the surface and wait for a few min.
4. Apply the developer spray (yellow can) at a distance of about 30cm from the surface. The developer will absorb the penetrant that infiltrated to the surface features such as cracks, splits, etc., and then reacted with it to form a geometric shape which is the negative of the geometry of the surface features from which the penetrant is sucked.
5. The polymerized material may be collected on a sticky paper for future evaluation and related documentation, if needed.

Magnetic particle:

In this experiment, commercially available magnetic powder manufactured for NDT inspection will be used. A strong U shape magnet will be used to provide the necessary magnetic field at the inspected area.

The following steps are applied during the experiment;
1. The surface of the specimen will be roughly cleaned wiping with a piece of textile.
2. The fluorescent magnetic spray will be applied on the surface being inspected.
3. Magnetic field will be applied with a strong magnet to the location of interest.
4. The spots where the fluorescent magnetic particles accumulated will be inspected under UV light.

Eddy current inspection:

For this experiment, Magnefest ED-51 0 type unit will be used. A pencil type prop will be used for the inspections. The inspection is performed with 2 MHz frequency and at the related calibration settings. The test blocks were previously prepared for this experiment. Any coatings or paints on the surface of inspected specimens should be treated with special procedures.

The following steps should be applied during the experiment:

l. Inspection area should be clean, smooth, free from any irregular or uneven paint, dirt, grease, etc.
2. There shouldn't be any visible damage or discontinuity.
3. During the inspection procedure the probe will be positioned near the inspection area, on the compensation point and lift off and zero will be adjusted if necessary.
4. The inspection will be carried out by using probe scans. The probe tip will be always at a right angle the inspection surface.
5. Any indication with indicator deflection to the right should be evaluated. All evaluated indications should be measured.
6. After this procedure, all evaluated indications with indicator deflections, will be classified as cracks and be recorded.

Ultrasonic inspection:

For this experiment,USM-2 type ultrasonic unit will be used. The props used supports to work at frequency of 5 MHz. Echo techniques will be employed to find the cracks.
Instrument will be tuned to a frequency of 5 MHz. An appropriate couplant used should not cause corrosion or other damage. During the inspection the calibration will be done on the reference standard, if needed. Two different test blocks will be employed in this test, sufficient amount of couplant will be applied to the transducer scan areas on the forward and after sides of the support fitting. The display will be monitored for crack indications. A crack signal will be similar to the following:

The following steps should be applied during the experiment:

1. The couplant should be applied on the inspected area.
2. For the circular test specimen, the prop will be placed in the corresponding space in the supporting fitting tool. Enough couplant should be used between the probe and tool.
3. For the flat specimen, no tool is needed, couplant only applied between the inspected surface and the probe.
4. Special attention should be paid on the location where possible cracks exist.
5. A discontinuity like a crack produces a peak on the screen.
6. Attention should also be given to the movement of the possible peak caused by the cracks on the specimen.

Report:

You are supposed to prepare a test report for this experiment obeying the report preparation rules. So your report should contain abstract, introduction, experimental procedures, results, discussion, conclusion and references. The advantages and disadvantages of each NDT method must be stated precisely in your reports. You should also answer the questions asked to you at the end of the experiment installing the related parts of your report. You must return your report on time.

MODULE -V

Dielectric Properties

Materials which prevent flow of current through them are called Non-Conducting materials. when the mainfunction of non-conducting materials is to provide electrical isulation they are called Insulators when these non-conducting materials are used for the purpose of charge storage They are called Dielectrics.

For a materials to be good dielectric, it should have a very high dielectric constant and very low dielectric loss.

Dielectric Constant :

It is the ratio of the capacitance of a capacitor with a dielectric to the capacitance of the capacitor with air (or) vaccum in between. let the two capacitances be denoted by 'C' and 'C_0' respectively, then the dielectric constant

$$\epsilon_r = \frac{C}{C_0} \quad (or) \quad \frac{\epsilon}{\epsilon_0}$$

It is also called Relative Permitivity. It is usually greater than unity in the case of dielectrics.

The most important property of dielectrics in their ability to become polarised under the action of an electrical field The atoms and molecules of diectrics are influenced by an external field and hence the +ve particles are pushed in the direction of the field while the -ve particles in the opposite direction from their equilibrium position Hence dipoles are produced and they produce a field of their own

The process of producing electric dipoles out of neutral atoms and molecules is referred to as polarisation.

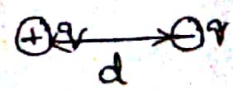
Electric dipole :-

A pair of electric charges of a equal magnitude but of opposite polarity, separated by a small distance is called an electric dipole.

Dipole moment (μ) :-

The Product of charge and distance between two charges is called dipolemoment.

If 'q' is the charge and 'd' is the distance between the charges then the dipole moment



$$\mu = qd \quad \text{Coulomb-meter}$$

Polarisability (α) :-

The average dipolemoment of a system is propotional to the electric field (E) applied.

i.e $\mu \propto E$

$$\therefore \mu = \alpha E$$

where 'α' is Polarisability. Hence it can be defined as ratio of average dipolemoment to the electric field applied. Its units is Farad / m^2.

Types of Polarization :-

The three basic Types of polarization

a) Electronic polarization
b) Ionic polarization
c) Dipolar (or) orientational polarization

electronic polarization :-

Electronic polarization is the displacement of electrons with respect to the nucleus. It occurs in a Dieetric under the action of an electric field. This Type of Polarization occurs during a very short interval of time of the order of 10^{-15} sec.

Expression for electronic Polarisability :-

Consider an atom of a dielectric material placed in a D.C electric field. The nucleus gets displaced in the direction of the applied field. while the electrons cloud displaces in the opposite direction due to Lorentz forces. when this displacement takes place from the equilibrium position an attractive coulomb force is created which tends to retain the original equilibrium position Thus a final equilibrium position is reached due to both Lorentz and Coulomb forces.

when there is no external field, the centres of the electron cloud and the nucleus of the atom are one and the same

Let us assume that the electron charge is distributed uniformly over a sphere of radius 'R'

The negative charge density of the sphere of radius 'R' is given

$$\rho = \frac{\text{total charge}}{\text{total volume}} = -\frac{Ze}{\frac{4}{3}\pi R^3} \quad \text{— ①}$$

where 'Z' is the no. of electrons

The atom before and after the application of electric field is as shown

The charge within the sphere of the radius 'x' is given by

$$Q_e = \text{charge density} \times \text{volume of the sphere}$$

$$= \frac{-Ze}{\frac{4}{3}\pi R^3} \times \frac{4}{3}\pi x^3$$

$$\therefore Q_e = -Ze\left(\frac{x^3}{R^3}\right) \quad \text{— ②}$$

The total Positive charge within the sphere of radius 'x' is given by

$$\therefore Q_p = Ze \quad \text{— ③}$$

According to Gauss theorem, the number of electrons in the sphere of radius (x)

$$F_c = \frac{1}{4\pi\epsilon_0}\frac{Q_e Q_p}{x^2} \quad \text{— ④}$$

using equation ② and equation ③ we get

$$F_c = \frac{1}{4\pi\epsilon_0} \cdot Ze \cdot -Ze\left(\frac{x^3}{R^3}\right) \cdot \frac{1}{x^2}$$

$$F_c = -\frac{Z^2e^2x}{4\pi\epsilon_0 R^3} \quad \text{— ⑤}$$

The Lorentz force between the nucleus and the electron cloud is given by

$$F_L = ZeE \quad \text{— ⑥}$$

At equilibrium the coulomb force and the Lorentz force must be equal and opposite. ($\because F_L = -F_c$)

$$ZeE = \frac{Z^2e^2x}{4\pi\epsilon_0 R^3}$$

$$\therefore \quad E = \frac{Zex}{4\pi\epsilon_0 R^3} \quad - (7)$$

Due to the application of electric field on the atom. The charge centers are distributed from equilibrium position. Atoms gains a displacement.

$$\mu = qd = Zex \quad - (8)$$

Also dipolemoment interms of polarisability is given by

$$\mu = \alpha_e E \quad - (9) \quad \because \alpha_e = \text{Electronic polarisability}$$

From equation (8) and equation (9)

$$Zex = \alpha_e E$$

$$E = \frac{Zex}{\alpha_e} \quad - (10)$$

From equation (7) and (10)

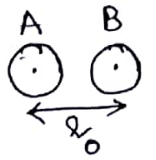
$$\frac{Zex}{\alpha_e} = \frac{Zex}{4\pi\epsilon_0 R^3}$$

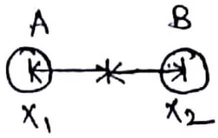
$$\boxed{\therefore \quad \alpha_e = 4\pi\epsilon_0 R^3} \quad - (11)$$

Thus the electronic polarisability depends on the volume of the atom and independent of temp.

<u>Ionic</u> <u>polarisability</u> :- (α_i)

When electric field is applied on an ionic dielectric, Ionic polarisation takes place resulting in the displacement of +ve ion and -ve ions.





Consider an ionic dielectric AB. Let 'M' and 'm' be the masses of the +ve ion 'A' and -ve ion 'B' respectively. When an electric field 'E' is applied on the dielectric, the +ve ion displaces in the direction of the field. while -ve ion displaces in the direction opposite to the field. Let x_1 and x_2 be the displacements of the +ve ion and -ve ions respectively

Let the net distance between the two ions be (x)

$$\therefore \quad x = x_1 + x_2 \quad -(1)$$

The Lorentz force acting on the +ve ion = eE

and

The Lorentz force acting on the -ve ion = -eE ⎭ (2)

In order to bring back the ions to the mean position, a restoring force acts on the ions in the direction opposite to their displacement.

Restoring force acting on the +ve ion $= -k_1 x_1$

and Restoring force acting on the -ve ion $= +k_2 x_2$ ⎭ (3)

where k_1 and k_2 are Restoring force constants

At equilibrium Lorentz force and restoring forces will be equal and opposite Hence from equation (2) and (3)

$$eE = k_1 x_1 \quad \text{and} \quad eE = k_2 x_2 \quad -(4)$$

$$\Rightarrow \quad x_1 = \frac{eE}{k_1} \quad \text{and} \quad x_2 = \frac{eE}{k_2} \quad -(5)$$

Here $k_1 = M\omega_0^2$ and $k_2 = m\omega_0^2$ (ω_0 be the angular velocity of ions)

Now from (1) and equation (5) we get

$$x = \frac{eE}{M\omega_0^2} + \frac{eE}{m\omega_0^2}$$

$$\therefore \quad x = \frac{eE}{\omega_0^2}\left[\frac{1}{M} + \frac{1}{m}\right] \quad -(6)$$

we know that the dipolemoment

$$\mu = e.x$$

$$= e.\frac{eE}{\omega_0^2}\left[\frac{1}{M} + \frac{1}{m}\right] \quad -(7)$$

The dipolemoment 'μ' is propotional to the applied electric field

$$\mu = \alpha_i E \quad -(8)$$

Comparing equation (7) and (8) we get

$$\boxed{\alpha_i = \frac{e^2}{\omega_0^2}\left(\frac{1}{M} + \frac{1}{m}\right)}$$

Orientation polarisation :- (α_0)

The orientation polarisation is characteristic of polar dielectrics which consist of molecules having permanent dipole-moment. In the absence of external field the orientation of dipoles is random resulting in a complete cancellation of each others.

The process of orientation polarisation, involves rotation of molecules. It takes relatively longer time than the other two polarisations.

The orientation polarizability 'α_0' is calculated to be

$$\alpha_0 = \frac{\mu^2}{3kT}$$

which states that the orientation polarisation is inversely propotional to the temp and propotional to the square of the perment dipolemoment.

~~Frequency dependence of the dielectric constant :- (ϵ_r)~~

~~we know that the alternating electric field changes its direction with time taken. When a polar dielectric is subjected to an a.c field.~~

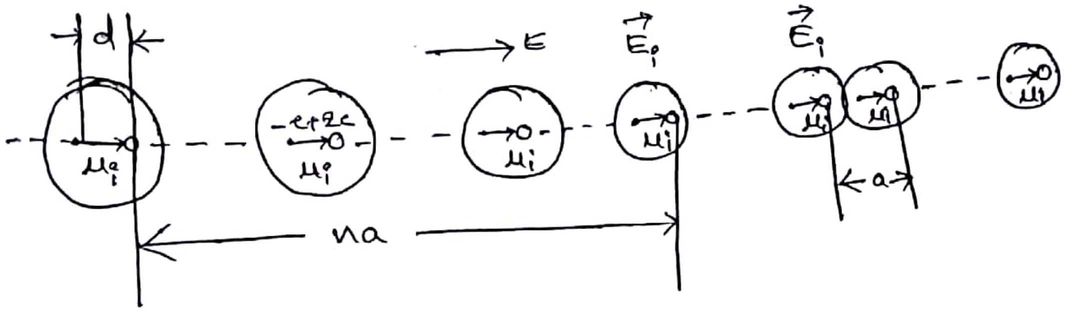
Local field (or) Internal fields in solids:-

In gases the atoms are in constant random motion and are separated by large distances As such the interaction b/w the atoms can be neglected when an external field 'E' is applied the intensity of the electric field felt by a given atom in the gas will be equal to the applied field E. In solids and liquids the atoms are so close that they touch each other leading to a strong interaction between them, As the atoms are surrounded on all sides by other polarized atom, the internal intensity of the electric field at a given point of the material is in general not equal to the intensity of the applied field 'E'.

The internal field 'E_i'' which is defined as the electric field acting at the location of a given atom, is given by the sum of the electric fields created by the neighbouring atoms and the applied field.

The effective field intensity 'E_i' in the dielectric is given by

$$E_i = E + E'$$



The value of E' can be evaluated by the summation of all the effects of the surrounding atoms [To illustrate the method of evaluation let us consider a one-dimensional solid consisting of a string of equidistant identical atoms] ×

The internal field (E_i) is given by $E_i = E + \frac{\gamma P}{\varepsilon_0}$ Lorentz field. where (γ) is called Internal field constant.

For 1-D infinite chain of atoms (or dipoles); $\gamma = \frac{1}{3}$ $\therefore E_i = E + \frac{P}{3\varepsilon_0}$.

Clausius - Mosotti Equation:-

Let us consider now the simple case of an elemental solid dielectric which exhibits only electronic polarizability solids such as diamond, silicon and germanium crystals are made up of single type of atoms. If 'α_e' is the electronic polarizability per atom, it is related to the bulk polarization 'p' through the relation

$$\alpha_e = \frac{P}{NE_i}$$

'N' is Number of atoms per m^3 and E_i is the local field

$$\alpha_e = \frac{P}{N\left(E + \frac{P}{3\varepsilon_0}\right)}$$

$p = \epsilon_0(\epsilon_r - 1)E$

'D' is displacement vector

$D = \epsilon E$

(or)

$D = E\epsilon_0 + P$

$E\epsilon_0 + P = \epsilon E$

$P = E\epsilon - E\epsilon_0$

$= E\epsilon_r\epsilon_0 - E\epsilon_0$

$P = E\epsilon_0(\epsilon_r - 1)$ $\left(\because \epsilon_r = \frac{\epsilon}{\epsilon_0}\right)$

$\therefore E = \frac{P}{\epsilon_0(\epsilon_r - 1)}$

$$\therefore \alpha_e = \frac{P}{N\left[\frac{P}{\epsilon_0(\epsilon_r-1)} + \frac{P}{3\epsilon_0}\right]}$$

$$\frac{N\alpha_e}{\epsilon_0} = \left[\frac{1}{\frac{1}{(\epsilon_r-1)} + \frac{1}{3}}\right]$$

$$\frac{N\alpha_e}{\epsilon_0} = \left[\frac{1}{\frac{\epsilon_r+2}{3(\epsilon_r-1)}}\right]$$

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha_e}{3\epsilon_0}$$

This is clausius - mosotti equation

It relates macroscopic property (ϵ_r) with the microscopic property (α_e) of the dielectric.

Ferroelectrics:-

Ferroelectrics constitute a very important group of dielectrics. They are anisotropic crystals which exhibit "spontaneous polarization".

Spontaneous polarization: It is the dielectric polarization which occurs under the action of internal processes and without the influence of an external electric field.

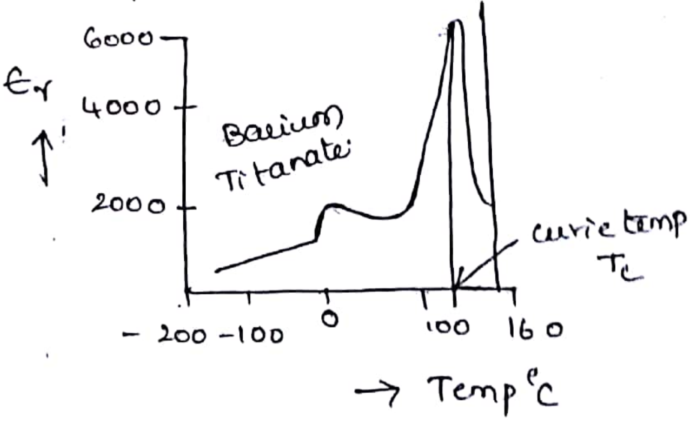
Ex: Rochelle salt, barium titanate, Potassium phosphate, Potassium niobate are examples of ferroelectrics.

(1) The primary feature of a ferroelectric is the anomalous dependence of its dielectric constant on temp.

'ϵ_r' of ordinary dielectrics donot change much with temp.

In case of ferroelectric crystals 'ϵ_r' exhibits one (or) more sharp maxima where ϵ_r reaches a value of several thousands. The temperature at which these maxima occur are called Curie temperatures. Rochelle salt exhibits two curie temp's + 22.5°c and −15°c while barium titanate at room has only one Curie temp at +120°c.

The value of ϵ_r for barium titanate at room temp is about 5000



(2) <u>Second feature</u> of ferroelectric is a non-linear dependence of its polarization on the external electric field In ordinary dielectrics, the polarization 'p' varies linearly with 'E', according to

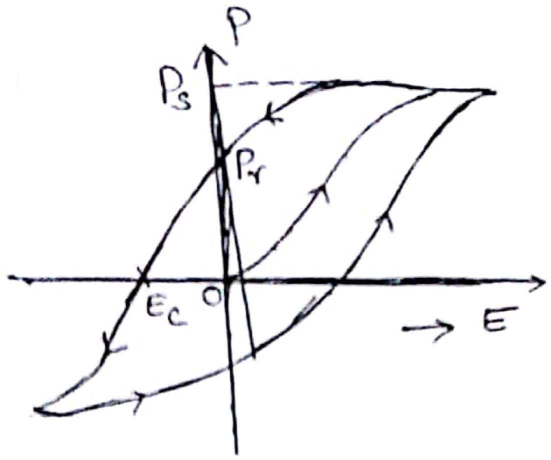
$$p = N \alpha_e E$$

Therefore the ordinary dielectrics are often called <u>linear dielectrics</u>. On other hand, the relationship between 'p' and 'E' is complex in nature and therefore non linear. In view of this ferroelectrics are known as <u>non linear dielectrics</u>

(3) The third feature of ferroelectrics exhibit hysteresis, when a virgin ferroelectric crystal is subjected to an alternating electric field, the polarization 'p' versus electric field 'E' describes a closed loop called the hysteresis loop.

The polarization will rise nonlinearly and reach saturation at a certain value of 'P_s' The polarization will not change even if 'E' is increased further If the field is decreased, the polarization vs E will not flow the same path as that obtained for increasing 'E' when the external is switched off.

The value of polarization does not return to zero and the ferroelectric retains a residual polarization (P_r). To bring back the polarization to zero value a field (E_c') known as coercive field, must be applied in the opposite direction. It is that the nonlinear dielectrics are called ferroelectrics.



Hysteresis loop of a ferroelectric material.

<u>**Physics of Nanomaterials**</u>

Definition of Nanotechnology: "Nano Materials are the materials which have structure components with size less than 100nm at least in one dimension"

"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale." At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

Important:

1-Dimension : Thin films or surface coatings

2-Dimension : Nano Wires, Nano Tubes

3-Dimension : Nano Crystalline materials, Quantum Dots (Tiny Semiconducting Device)

Why the properties of nano particle are different from macroscopic particles ?

1. <u>Surface to Volume Ratio</u> : In the case of a spherical particle

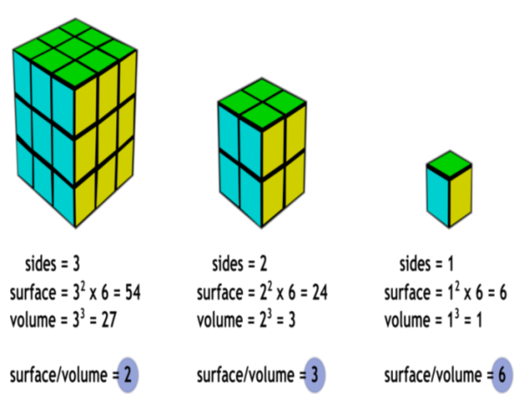
Surface area = $4\prod r^2$

Volume $=$ $(4/3) \prod r^3$

Surface area to Volume Ratio = $3/r$

"Lesser the radius , Greater the ratio"

Similarly in the case of cube we have



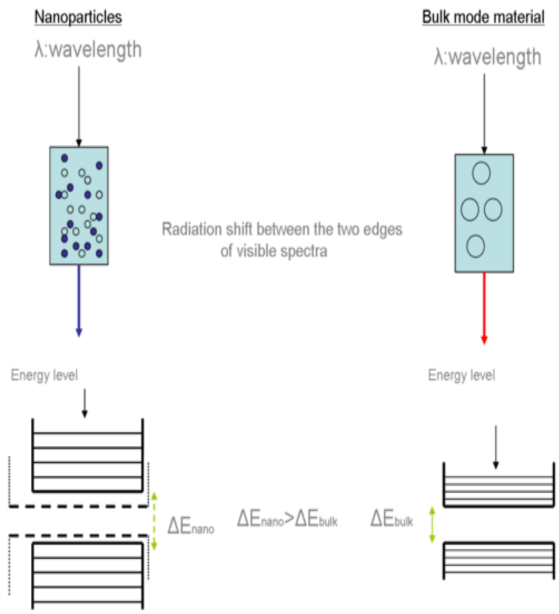
2. **Quantum confinement in nano particles**

Nano technology an emerging technology which has gained fame in every field of life from an excellent sunscreen to an electronic chip. This emerging technology has given excellent properties to even those elements which at one time were thought of being useless. For example Carbon is a non metal but when considered at the nano scale the carbon nano tubes are the best conductors .But what is the enigma beyond size if this size can make a non conductor an insulator what is the basic physics beyond it .Well the answer is simple and that is Quantum confinement.

When atoms are isolated energy levels are discrete. When atoms are closely packed, the energy levels splits and bands will be formed . Nano materials represents intermediate stage. When the materials sufficiently small in size (<10 nm), Organization of energy levels into which electrons can change. This phenomenon results from electrons and holes being squeezed into a dimension, called exciton Bohr radius.

The quantum confinement effect is observed when the size of the particle is too small to be comparable to the wavelength of the electron. To understand this effect we break the words like quantum and confinement, the word confinement means to confine the motion of randomly moving electron to restrict its motion in specific energy levels (discreteness) and quantum reflects the atomic realm of particles. So as the size of a particle decrease till we a reach a nano scale the decrease in confining dimension makes the energy levels discrete and this increases or widens up the band gap and

ultimately the band gap energy also increases. Since the band gap and wavelength are inversely related to each other the wavelength decrease with decrease in size and the proof is the emission of blue radiation .Comparison of a bulk material and nano particle reveals that too from the diagram the blue wavelength and the red wavelength



Electrical, optical and magnetic properties of nano particles:

Various properties of the materials like electrical, optical and magnetic are sensitively depend on the size of the matter. Thus the above properties greatly vary for a material in the bulk size to the same material in nano size.

Electrical properties:

If the material has at least one of the dimensions of the order of nano metre then it is called Quantum well. We know the energy of the particle inside the potential box is

$$E = \frac{n^2h^2}{8mL^2}$$

Considering L = 1 cm, for electron the separation between the consecutive energy levels will be of the order of 10^{-14} eV which is quasi – continuous. In the case of L = 100 nm, the separation between consecutive energy levels is around 10^{-4}eV. Thus in nano scale range the energy levels are discrete.

However, the change in electrical properties cannot be generalized. In nano ceramics and magnetic nano composites, the electrical conductivity increases with the decrease in particle size whereas in metals electrical conductivity decreases with the reduction in particle size.

Optical properties:

In some of the materials, energy is related to wavelength (colour). Therefore the optical properties of the particle can be finely tuned depending on its size. Thus particles can be made to emit or absorb specific wave lengths of light by merely controlling their size. Gold nano spheres of 100 nm appear in Orange while 50 nm nano spheres appear in Green.

Magnetic properties:

The strength of a magnet is measured in terms of coercivity and saturation of magnetization. These values increase, with the decrease in the grain size and an increase in the specific surface area of the grain. Thus nano particles possess good magnetic properties.

Synthesis of Nanomaterials:

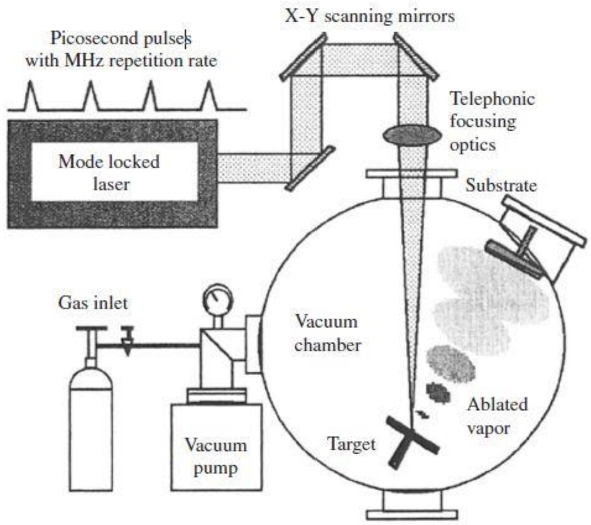
1). Physical Method
2). Chemical method

Physical Method:

Synthesis of Nanomaterials by Laser Ablation:

Since the discovery of laser decades ago, laser has been intensively used and studied for various applications including laser ablation. Even though the first experimental paper about laser ablation was reported as early as 1963, laser ablation was not employed for synthesizing nanomaterials with the purpose for gas sensing until mid 1990s.

Laser ablation means the removal of material from a surface by means of laser irradiation. The term “laser ablation” is used to emphasize the nonequilibrium vapor/plasma conditions created at the surface by intense laser pulse, to distinguish from “laser evaporation,” which is heating and evaporation of material in condition of thermodynamic equilibrium. A typical schematic diagram of laser ablation is shown in the following figure. Briefly, there are two essential parts in the laser ablation device, a pulsed laser (CO_2 laser, Nd-YAG laser etc) and an ablation chamber. The high power of the laser beam induces large light absorption on the surface of target, which makes temperature of the absorbing material increase rapidly. As a result, the material on the surface of target vaporizes into laser plume. In some cases, the vaporized materials condensate into cluster and particle without any chemical reaction. In some other cases, the vaporized material reacts with introduced reactants to form new materials. The condensed particle will be either deposited on a substrate or collected through a filter system consisting of a glass fiber mesh. Then, the collected nanoparticle can be coated on a substrate through drop-coating or screen-printing process.



BALL MILLING: Ball milling is a method of production of nano materials by the process of a mechanical crushing. The mills are equipped with grinding media composed of wolfram carbide or steel. Small balls inside a drum-like cavity are rotated at high speeds and by gravity actions, they settle on a solid layer where they crushed into nanocrystals.

The following are the various types of ball mills:

1) Attrition ball mill
2) Planetary ball mill
3) Vibrating ball mill
4) Low and high energy ball mills

The significant advantage of this method is that it can be readily implemented commercially. Ball milling can be used to make carbon nanotubes and boron nitride nanotubes. It is a preferred method for preparing metal oxide nano crystals like Cerium (CeO2) and Zinc Oxide (ZnO).

Chemical method:

Chemical Vapour Deposition Method:

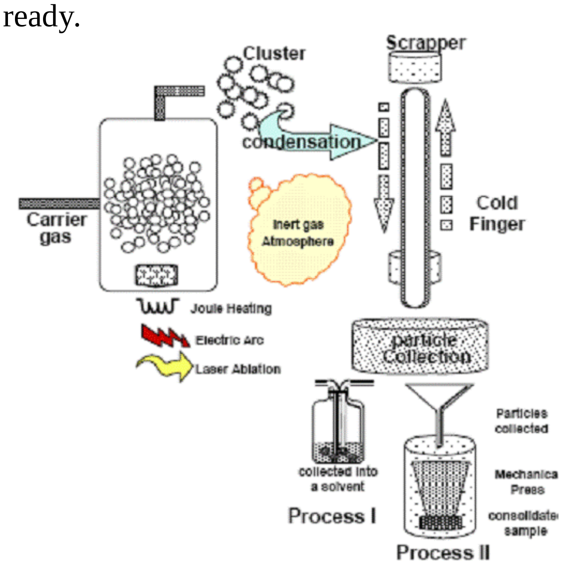
1.The vapour of the heated precursor is carried into the reaction chamber by the carrier gas (inert gases like Argon Neon).

2. The atoms in the vapour are relatively hotter when they enter into chamber.

3. They agglomerate around the relatively cooler atoms present in the reaction chamber forming nano clusters.

4. Once the required size dusters are formed they are sent on to the scraper and collected in particle collector.

5. In a different kind of arrangement, a substrate will be present in the reaction chamber and the hot atoms in the vapour get accumulated on the substrate.They involve in a chemical reaction either with the substrate or with a second kind of atoms taking the substrate as the platform.Thus atoms will be deposited layer by layer and the substrate is taken out once the thin film of required thickness is ready.



<u>Sol-Gel Method</u>:

Colloid suspended in a liquid is called Sol. A suspension that keeps it shape is called Gel.

Steps Involved in Sol-Gel Method:

Step-1: Formation of different stable solutions of alkoxide or solvated metal precursors.(a **precursor** is a compound that participates in the chemical reaction that produces another compound)

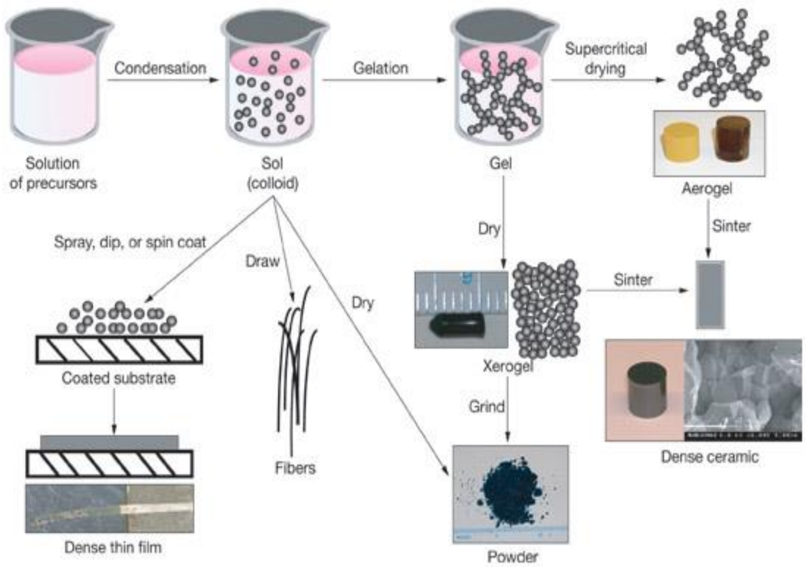
Step 2: By Dehydration reaction ,we can form a Gel which results dramatic increase in viscosity of the solution.

step 3: Drying the gel, when water and other volatile liquids are removed from gel network.

The resulting monolith is termed a ‘Xerogel’.

step 4: In Dehydration,the surface bound M-OH groups are removed by calcining at a temparature upto 800^0 C.

Step-5: Densification and decomposition of Gels at high temparatures ($T>800^0$ C).The pores of Gel network will collapse.



Carbon nanotubes (CNTs):

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than for any other material. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials.

Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete ("chiral") angles, and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized assingle-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).

Most single-walled nanotubes (SWNTs) have a diameter of close to 1 nanometer, and can be many millions of times longer. The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder. SWNTs are an important variety of carbon nanotube because most of their properties change significantly. In particular, their band gap can vary from zero to about 2 eV and their electrical conductivity can show metallic or semiconducting behavior. Single-walled nanotubes are likely candidates for miniaturizing electronics. The most basic building block of these systems is the electric wire, and SWNTs with diameters of an order of a nanometer can be excellent conductors.

Multi-walled nanotubes (MWNTs) consist of multiple rolled layers (concentric tubes) of graphene. There are two models that can be used to describe the structures of multi-walled nanotubes. The interlayer distance in multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.4 Å.

Carbon Nanotubes Properties and Applications

There are numerous carbon nanotubes applications which take full advantage of CNTs unique properties of aspect ratio, mechanical strength, electrical and thermal conductivity. We've compiled the list below for you.

Properties:

- CNTs have High Electrical Conductivity
- CNTs have Very High Tensile Strength
- CNTs are Highly Flexible- can be bent considerably without damage
- CNTs are Very Elastic ~18% elongation to failure
- CNTs have High Thermal Conductivity
- CNTs have a Low Thermal Expansion Coefficient
- CNTs are Good Electron Field Emitters
- CNTs Aspect Ratio

Applications:

- CNTs Thermal Conductivity
- CNTs Field Emission
- CNTs Conductive Properties
- CNTs Energy Storage
- CNTs Conductive Adhesive
- Molecular Electronics based on CNTs
- CNTs Thermal Materials
- CNTs Structural Applications
- CNTs Fibers & Fabrics
- CNTs Catalyst Supports
- CNTs Biomedical Applications
- CNTs Air & Water Filtration

- Other CNT Applications