ANNAMACHARYA UNIVERSITY::RAJAMPET
(ESTD UNDER AP PRIVATE UNIVERSITIES (ESTABLISHMENT AND REGULATION) ACT, 2016)
HUMANITES AND SCIENCES

ENGINEERING PHYSICS
(24APHY22T)

I B.Tech. & II-Semester

Written by

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ANNAMACHARYA UNIVERSITY

EXCELLENCE IN EDUCATION; SERVICE TO SOCIETY

(ESTD, UNDER AP PRIVATE UNIVERSITIES (ESTABLISHMENT AND REGULATION) ACT, 2016)

Title of the Course: Engineering Physics
Category: BS
Semester: II Semester
Course Code: 24APHY22T
Branch/es: CE & ME

Lecture Hours	Tutorial Hours	Practice Hours	Credits
3	0	0	3

Course Objectives: The course aims to provide a comprehensive understanding of fundamental concepts in Ultrasonics and elasticity, introduce students to crystal structures and X-ray diffraction techniques, and explain key principles of dielectrics, magnetic materials, and various types of sensors. Additionally, the course covers lasers and optical fibers, focusing on their applications and significance in engineering fields.

Course Outcomes:

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

1. apply ultrasonic waves and elastic principles in engineering.
2. explain the types of crystal structures and X-ray diffraction.
3. analyze various types of polarization of dielectrics and magnetic materials.
4. apply laser and fiber optics principles in communication field.
5. describe the various types of sensors in engineering field

Unit 1 Ultrasonics and Elasticity 9

Ultrasonics: Introduction- Properties- Production of ultrasonic waves by magnetostriction and Inverse piezoelectric methods –Detection of ultrasonic waves by Kund's tube and Flame methods - Acoustic grating -Non-Destructive Testing – medical applications (Sonogram).

Elasticity: stress& strain - types of stress and strain- stress & strain curve - Hooke's law- Poisson's ratio- different elastic moduli: expression for young's modulus (Y), bulk modulus (K) and rigidity modulus (η) - strain energy.

Unit 2 Crystallography and X-ray diffraction 9

Crystallography: Space lattice, basis, unit cell and lattice parameters – 7 crystal systems- Bravais Lattices – coordination number – packing fraction of SC, Bcc & Fcc – Miller indices – separation between successive (hkl) planes.

X-ray diffraction: Bragg's law – X-ray Diffractometer –Laue's method and powder method.

Unit 3 Dielectric and Magnetic Materials 10

Dielectric Materials: Introduction – Dielectric polarization – Dielectric polarizability, susceptibility, dielectric constant and displacement vector – Relation between the electric vectors – Types of polarizations– Electronic, Ionic, Orientation (Qualitative) and Space charge (Qualitative) – Frequency dependence of polarization – Lorentz internal field – Clausius-Mossotti equation – Applications of dielectrics.

Magnetic Materials: Introduction – Magnetic dipole moment – Magnetization–Magnetic susceptibility and permeability –Origin of magnetic moments – Classification of magnetic materials: aia, para, ferro, anti-ferro & ferri magnetic materials – Hysteresis – soft and hard magnetic materials – Applications of magnetic materials

Unit 4 LASERs and Fiber Optics **10**

LASERs: Introduction – characteristics of lasers – spontaneous and stimulated emission of radiation – Einstein's coefficients – population inversion – pumping mechanism – He-Ne laser – semiconductor laser – Applications of lasers.

Fiber Optics: Introduction - Optical Fiber construction – Working principle (Total Internal Reflection & critical Angle) – Acceptance angle & Numerical Aperture of optical fiber – Classification of fibers based on Refractive index profile & modes (Step index and Graded index optical fibers) – optical fiber losses – Block diagram of fiber optic communication – Medical and Sensor Applications

Unit 5 Sensors **9**

Sensors: (qualitative description only): Different types of sensors and applications - Strain and Pressure sensors- Piezoelectric sensor - Magnetostrictive sensors - Fiber optic pressure sensor - Temperature sensors (Thermo couple and bimetallic strip) - Hall-effect sensor - pyroelectric sensor

Prescribed Textbooks:

1. M. N. Avadhanulu, P. G. Kshirsagar & T. V. S. Arunmurthy. *A Textbook of Engineering Physics*. 11th ed., S. Chand Publications, 2019
2. K. Thyagarajan. *Engineering Physics.* McGraw Hill Education (India) Private Ltd, 2017
3. P.K. Palanisamy. *Engineering Physics*. Sci. Tech, 2019

Reference Books:

1. K. Vijaya Kumar. *A Textbook of Engineering Physics*. S. Chand Publications, 2018
2. Charles Kittel. *Introduction to Solid State Physics*. Wiley Publications, 2011
3. Neeraj Mehta. *Applied Physics for Engineers*. PHI Learning Private Limited, 2014

CO-PO Mapping:

Course Outcomes	Engineering Knowledge	Problem Analysis	Design/Development of solutions	Conduct investigations of complex problems	Engineering tool usage	The Engineer and world	Ethics	Individual and Collaborative teamwork	Communication	Project management and finance	Life-long learning
24APHY22T.1	3	2	1	2	-	-	-	-	-	-	1
24APHY22T.2	2	2	1	1	-	-	-	-	-	-	1
24APHY22T.3	3	3	2	2	-	-	-	-	-	-	1
24APHY22T.4	3	2	1	2	-	-	-	-	-	-	1
24APHY22T.5	2	2	1	1	-	-	-	-	-	-	1

UNIT—I

ULTRASONICS AND ELASTICITY

Introduction:

ULTRASONICS is the branch of acoustics that deals with sound waves having frequencies greater than 20 KHz, which is the upper limit of human hearing. unlike electromagnetic waves, ultrasonic waves are mechanical waves:

→ They require a material medium.

→ They propagate through elastic vibrations of particles.

ultrasonics waves were first studied extensively during world war I for Submarine detection (SONAR) and today they play a vital role in engineering, medical and industrial applications.

properties of Ultrasonic waves:

* Ultrasonic waves are high frequency, fr and high energetic soundwaves.
* produce negligible diffraction effects because of their small wavelengths.
* They travels longer distances without any energy loss
* The speed of propagation of ultrasonic waves increases with the frequency of the waves.
* at room temp. Ultrasonic welding is possible
* Ultrasonic waves produce cavitation effect in liquids.
* Ultrasonic waves produce acoustic diffraction in liquids.
* Ultrasonic waves cannot travel through the vacuum
* They travels with speed of sound in a given medium.
* It require one material medium for its propagation
* Can produce vibrations in low viscosity liquids.
* produce heat effects passes through the medium.

Production of Ultrasonic waves by Magnetostriction Method:

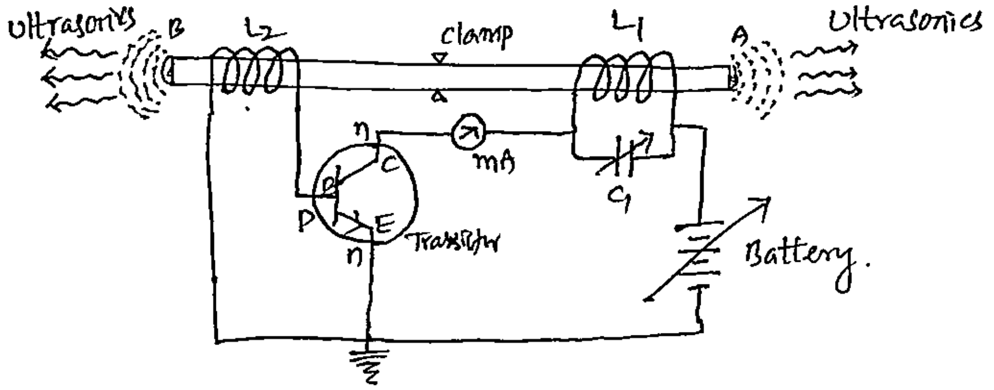
The magnetostriction method is used to produce waves in the frequency range of 20 KHz to 100 KHz.

Principle:

When a ferromagnetic material is subjected to a varying magnetic filed, the length of ferromagnetic material is changed. Ferromagnetic rod is set into resonant vibration, whenever the frequency of the tank circuit coincides with the frequency of vibration of the ferromagnetic rod.

Construction:

A ferromagnetic rod AB is clamped in the middle. Coil wires L1 and L2 are winded at the ends of A & B. One end of the coil L2 is connected to base of the transistor and the other end is connected to emitter and the negative terminal of the battery. A variable capacitor C1 is connected across the coil L1. One end of capacitor is connected to the collector of transistor and other end of capacitor is connected to positive terminal of battery through milliammeter and plug key.



Working :

The magnetostriction oscillator is shown in the figure. When the Key is closed the tank circuit (LC circuit) is set into oscillation with the frequency.

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

Where L1 is the value of inductance of the coil L1 and C1 is the capacitance of the capacitor C1.

An alternating emf is produced due to vibration of the tank circuit. This alternating emf is producing the alternating magnetic field. The length of ferromagnetic rod gets changed due to induced alternating magnetic field. The change in length of magnetic material induced emf in the coil L2. The induced emf produced is fed to the base of the transistor and hence it is amplified and also it is fed to the tank circuit. Thus, the oscillatoion is continuously produced. The frequency of oscillation of the tank circuit is changed by changing the capacity of variable capacitor C1. If the frequency of tank circuit is equal to the frequency of vibration of ferro-magnetic rod, ultrasonic waves will be emitted from the ends of the ferromagnetic rod.

The frequency of ultrasonic waves produced is given by

$$F = \frac{n}{2l}\sqrt{\frac{Y}{\rho}} \quad \text{where } n = 1, 2, 3, \ldots$$

Y = Young's modulus of the rod

ρ = density of rod material

l = length of the rod

Advantages:

1. The design of this oscillator is very simple and its production cost is low.
2. At low ultrasonic frequency, the large power output can be produced without the risk of damage of the oscillatory circuit.

Disadvantages:

1. It has low upper frequency limit and cannot generate ultrasonic frequency above 3000 KHz (i.e 3 MHz)
2. The frequency of oscillations depends on temperature
3. There will be losses of energy due to hysterisis and eddy current.

PIEZOELECTRIC METHOD:

Piezoelectric method is used for the production of waves of frequencies greater than 100 KHz

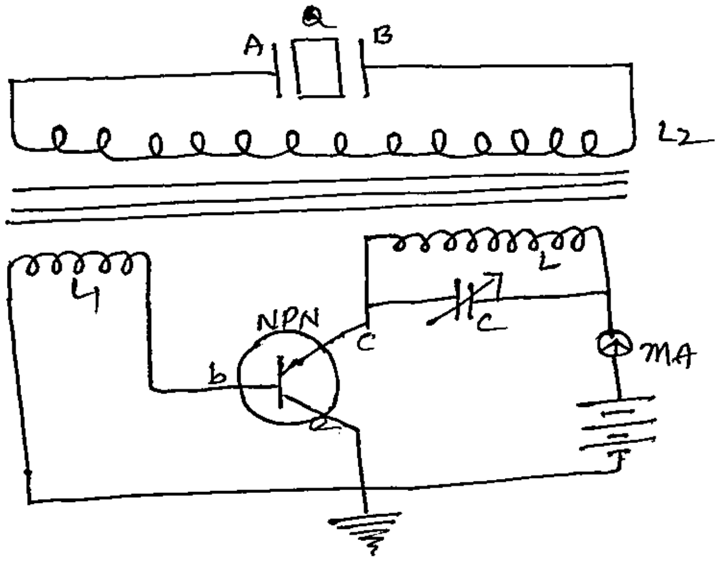
principle:

The piezoelectric oscillator is based on the inverse piezoelectric effect. whenever a piezo electric crystal is subjected to an alternating voltage, the piezoelectric crystal is set into vibration. The resonant vibration of the piezoelectric crystal takes place, whenever the frequency of vibration of the piezoelectric crystal is equal to the frequency of vibration of tank circuit

Construction:

L, L1, & L_2 are coupled together by means of transformer action. A variable capacitor C is connected parallel to the coil L. one end of the variable capacitor is connected to the collector of the transistor and the other end is connected to the battery through the mA & plug key.

One end of the coil L1 is connected to the base of the NPN transistor whereas the other end is connected to the emitter and negative terminal of the battery. Coil L2 is connected connected to the plates A & B. the piezoelectric crystal is placed along its thickness b/w plates A & B.



Working:

When plug key is closed, the tank circuit (LC circuit) is set into vibration. Oscillation of the tank circuit produces alternating emf in the coil L1, this emf is fed to the transistor as input to the base emitter circuit. This input is amplified and fed to the collector circuit. Due to the transformer action, an emf is induced in the coil L2. This induced alternative potential difference is produced across the quartz crystal which sets the crystal into vibrations. By varying the capacity of capacitor C, frequency of alternating potential is changed. At a particular stage the frequency of the alternating potential across the crystal coincides with the natural frequency of the alternating potential across the crystal coincides with the natural frequency of the quartz crystal.

Then in produces ultrasonic waves. This stage is indicated by milliammeter by showing max current.

The natural frequency of quartz crystal of thickness t is given by

$$f = \frac{n}{2t}\sqrt{\frac{Y}{\rho}} \quad \text{where, } n = 1, 2, 3, \ldots$$

Y = youngs modulus

f = Frequency of ultrasonic waves

t = thickness of the quartz plate.

Advantages:

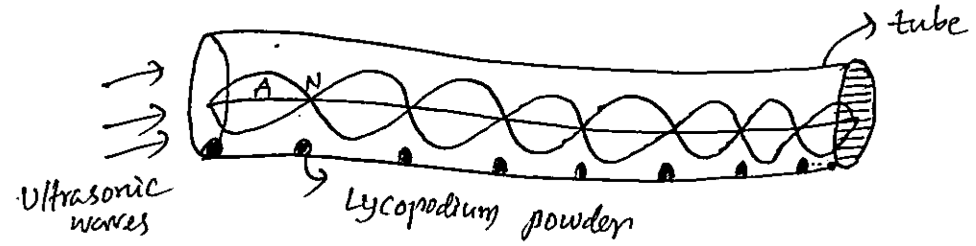
1. Ultrasonic frequencies as high as 500 MHz can be obtained with this arrangement.
2. The output of this oscillator is very high
3. It is not affected by temperature and humidity.

Disadvantages:

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

Detection of Ultrasonic waves by Kundt's tube and Flame method:

Kundt's tubes method :



The transmitted and reflected ultrasonic waves in a Kundt's tube forms a stationary wave pattern with nodes and antinodes. The lycopodium powder present in the bottom portion of the tube will be collected as a heaps at nodes and dispensed at antinodes. By observing the change in the position of powder, we can detect ultrasonic waves in the tube.

A Kundt's tube can be used to detect Ultrasonics of relatively longer wavelength in comparision with adi audible sound. In Kundt's tube lycopodium powder sprinkled uniformly along the inner surface of the tube. When ultrasonic sound waves passes through the tube, the lycopodium powder in the tube collects into small heaps at the nodes and is blown off at the antinodes. The appearance of heaps indicates the presence of waves passing through the tube. The mean distance b/w two successive heaps is equal to $\lambda/2$.

Thus, we can detect the wave

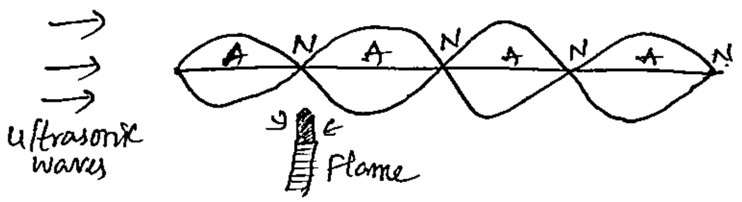
$$\text{velocity} = 2fl$$

f = Frequency

l = length of the tube

Flame method:

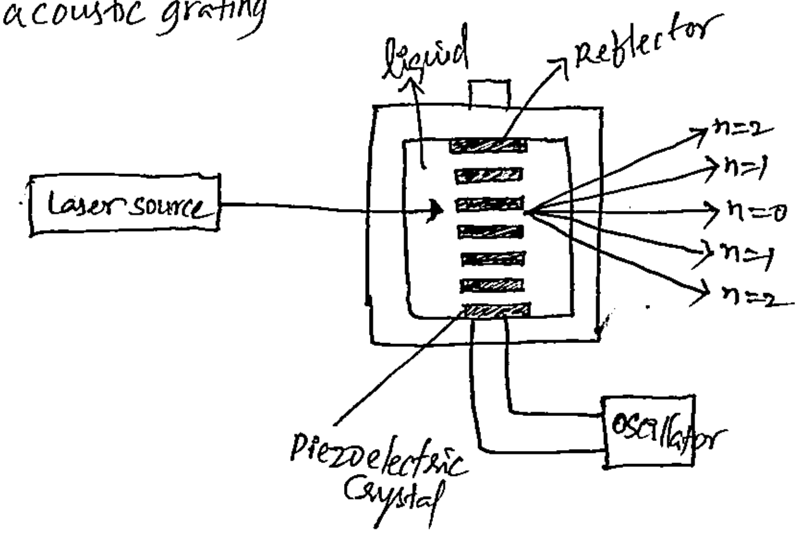
A narrow sensitive flame is moved in ultrasonic media, the flame is flickers at nodes and dispended at antinodes. The distance b/w two successive nodes or antinodes is equal to $\lambda/2$.
By knowing the frequency velocity can be found.



ACOUSTING GRATING:

Principle:

When ultrasonic waves are passed through a liquid, alternate compressions and rarefractions are produced. The density of the liquid varies layer by layer due to the variations in pressure. The compressed portion acts as opaque medium to the ordinary light and rarefied portion acts as a transparent medium for ordinary light. Hence the liquid will act as a diffraction grating, so called acoustic grating



Ordinary light

Construction & working:

The liquids is taken in glass cell. The piezo-electric crystal is fixed at one side of the wall inside the cell and ultrasonic waves are generated. The waves travelling through the liquid get reflected by the reflector placed at the opposite wall. The reflected waves get superimposed with the incident waves producing longitudinal standing wave pattern called acoustic grating. Under this condition when a monochromatic source of light is passed through the acoustical grating, the light gets diffracted. Then by using the condition for diffraction, the velocity of ultrasonic waves can be determined.

The angle b/w the direct ray and the diffracted rays of different orders (θ_n) can be calculated easily.

According to the theory of diffraction,

$$(a+b) \sin\theta_n = n\lambda \quad \text{——— (1)}$$

Where $n = 0, 1, 2, 3, \ldots$ is the order of diffraction, λ is the wavelength of light used and $a+b$ is the grating element.

Knowing n, θ_n and λ, the value of d can be calculated from eq (1) If λ_u is the wavelength of the ultrasonic waves through the medium, then

$$a+b = \lambda_u/2$$

$$\frac{\lambda_u}{2} \sin\theta = n\lambda \quad \text{——— (2)}$$

where λ_u - wavelength of ultrasonic waves

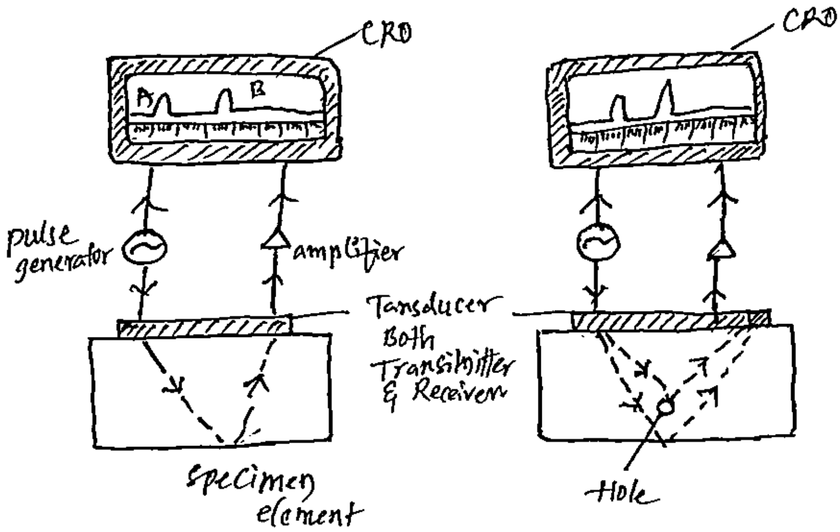
λ - wavelength of incident light ,

n - order of maxima

where, f is the frequency of ultrasonic waves.

NON-DESTRUCTIVE TESTING:

Ultrasonic is extensively used for nondestructive testing of the materials without disturbing the material properties. Non destructive testing system consists of transducers for generation and transmission of ultrasonic waves into the material and also to receive the reflected waves from the defects or flaws. To identify the defect cathode ray oscillascope is used.



When the transducer generates and transmits the ultrasonic waves into the testing material it will be reflected by the other end of the material and is received by the transducer. Corresponding to transmitted and reflected waves we can observe two well resolved signals on the screen of CRO

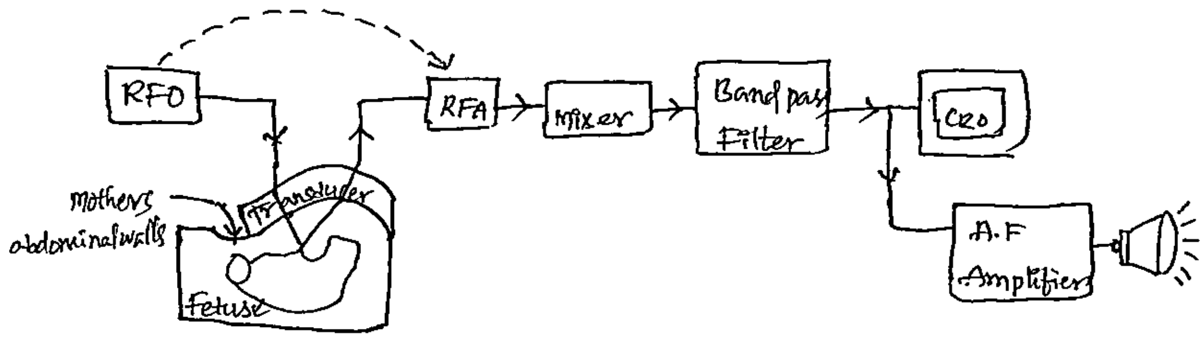
When the material is having a defect inside the material, then on the CRO Screen in addition to the regular transmitted and reflected Signals we get flaw signal. This Signal indicates the pressence of defect inside the material. By adjusting the time base scale to the transmitted Signal, the time elapsed from this Signal to the flaw Signal can be Known. By Knowing the velocity and time taken by the ultra sonic waves, the flaw location can be identified.

SONOGRAM:

principle: It worked under the principle of doppler effect. There is an apparent change in frequency b/w the incident sound waves on the fetus and reflected Sound waves from the fetus.

Description:

It consists of (RFO) radio frequency oscillator for producing 2 MHz fr and radiofrequency amplifier (RFA) to amplify the receiver signals.



working:

The transducer is fixed over the mothers abdominal wall, with the help of a gel or oil. RFO is switched on to drive the pulse and hence the transducer produces Ultrasonic waves of 2MHz.

These ultrasonic waves are made to be incident on the fetus. The reflected ultrasonic waves from the fetus are received by the transducer and are amplified by RFA. Both the incident and the received signals are mixed by the mixer and is filtered to distinguish the various types of sound and finally the Doppler shift or change in frequency is measured. The movement of the heart can be viewed visually by CRO or can be heard by the loud speaker, after necessary amplification by AF

ELASTICITY

Stress:

Stress is the internal resistive force per unit area that develops within a material when subjected to an external force. It is measured in Pascals (Pa).

Formula: $\text{Stress}\ (\sigma) = \frac{F}{A}$

$F \rightarrow$ applied force (N)
$A \rightarrow$ cross-sectional area (m^2).

Strain:

Strain is the measure of deformation in a material due to stress. It is a dimensionless quantity

Formula : $\text{Strain}\ (\varepsilon) = \frac{\Delta L}{L}$

ΔL – change in length (m)
L – Original length (m)

Types of stresses:

There are three basic stresses:

1) normal stress
2) shear stress
3) bulk stress.

1. Normal stress:

If a deforming force is applied normal to the area then the stress is called normal stress.

Normal stress is generally denoted by a Greek letter (σ). Normal stress can be tensile or compressive, developing on the direction of the force applied.

Tensile stress:

A normal stress is called tensile when the body is subjected to a pulling force, leading to an increase in length. Under tensile stress the material undergoes stretching or elongation.

Compressive stress:

A normal stress is called compressive when the body is subjected to a thrusting force, causing a decrease in length. Under compressive stress, the material undergoes shortening.

Definition: when the normal stress changes the length of the body it is called longitudinal stress.

2. Shear stress:

If a deforming force is applied tangentially, the resulting stress is called tangential stress. such forces lead to a shearing effect in the material and are known as shear forces. The corresponding stress is termed shear stress.

The shear stress is given by

$$\tau = F/A$$

Where F is the total force and A is the area over which it act.

Definition: When the stress is tangential to the surface due to the application of a parallel force, it is called shearing stress.

3. Bulk Stress :

If a solid, such as a rectangular block, is immersed in a fluid, it experiences uniform compression on all sides. The applied force acts in a perpendicular direction at every point of the surface, causing the block to undergo compression. This results in a decrease in volume without altering the shape.

Definition : If normal stress alters the volume of a body, it is called volume or bulk stress.

Types of strain :

Strain : Strain is the dimensional response given by a material against mechanical loading i.e deformation produced per unit length. It is a dimensionless quantity and is classified into three types depending upon the change produced in the body.

1. Longitudinal strain :

When the force acts along the length of the body, a change in length is produced without any change in shape. The ratio of change in length to the original length without any change in shape is called longitudinal strain.

$$\text{longitudinal strain} = \frac{\text{Change in length } (\Delta l)}{\text{Original length } (L)}$$

2. Shearing strain :

It is defined as the ratio of relative displacement b/w two layers under the action of tangential force to the distance b/w them. The angular deformation introduces a change in shape, known as shear

$$\text{Shearing strain} = \frac{\text{Displacement of layer } (\Delta x)}{\text{Distance from fixed layer } (L)}$$

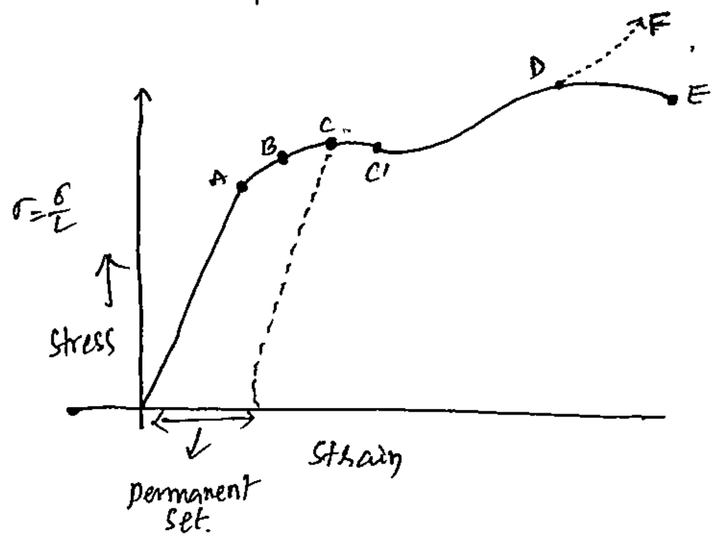
3. Volume Strain:

When forces are applied normal to the surface of a body in all directions, it undergoes a change in volume without any change in shape. The ratio of change in volume to the original volume is

$$\text{Volume Strain} = \frac{\text{Change in volume } (\Delta V)}{\text{Original volume } (V)}$$

Stress - Strain curve:

The stress - strain diagram is a graphical representation of a materials behavior under an applied load, offering valuable insights into its mechanical properties, including elasticity, plasticity and strength. Below is a detailed explanation of the critical points on the stress-strain curve.



A- proportional limit
B- Elastic limit
C- upper yield point
C'- lower yield point
D- ultimate strength.
E- Rupture strength
F- Actual rupture strength.

Hooke's law:

Hookes law states that within the elastic limit, the strain of a material is directly proportional to the applied stress (force). It defines the linear elastic behavior of materials, typically expressed as $F = -Kx$ For springs

For ~~springs~~ solids $\sigma = E\epsilon$

F - Force
K - Stiffness
x - displacement.

It was given by Robert Hookes in 1678

Stress ∝ strain

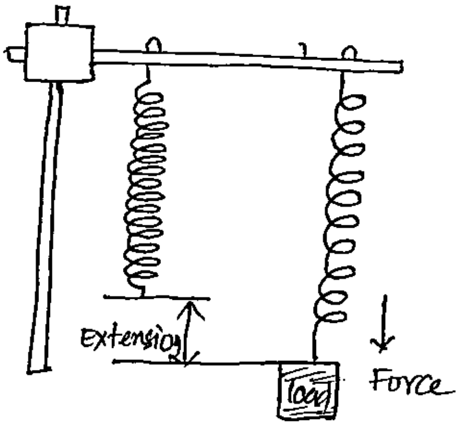
$\sigma \propto \varepsilon$

$\sigma = E\varepsilon$

Where σ = Stress

ε – Strain

E – Young's modulus.



The spring loses its springiness when the force is too larger; we say that the spring has crossed its elastic limit.

The extension, x is found using the formula x =

x = New length of the spring – The original length of the spring.

The equation holds in many situations where an elastic body is deformed. An elastic body or material for which this equation can be assumed is said to be linear-elastic or Hookean. Hooke's law is a first-order linear approximation to the real response of springs and other elastic bodies to applied forces. It fails once the forces exceed some limit, since no material can be compressed beyond a certain minimum size or stretched beyond a max size, without some permanent deformation or change of state. Many materials will noticeably deviate from Hooke's law well before those elastic limits are reached.

Applications:

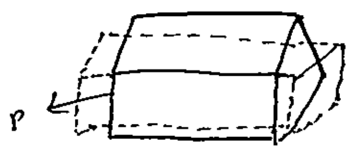
* spring balance
* Structural engineering design
* Bridges and buildings
* Measuring young's modulus.

Poisson's Ratio:

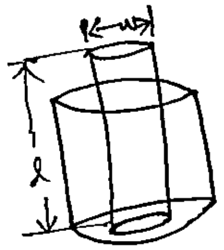
When a bar is subjected to a tensile loading, there is longitudinal elongation (increase in length) of the bar in the direction of the applied load and also a sidewise contraction (decrease in a lateral dimension) perpendicular to the load. As a result the bar becomes longer but also thinner. The strain produced along the direction of the force is called longitudinal strain, and that produced in the perpendicular direction is called lateral strain.

definition: The ratio of the lateral strain to the longitudinal strain is called the poisson's ratio and is denoted by ν.

For most steel, it lies in the range of 0.25 to 0.3, and 0.20 for concrete. If a bar of original length L and width w are subjected to tensile stress in the direction a.



Thinning of bar



Thinning of a rod.

The Length of the bar increases by ΔL from L to $L+\Delta L$

and width decreases from w to $w-\Delta w$.

$$\text{Poisson's ratio } \nu = \frac{\text{Lateral Strain}}{\text{Longitudinal Strain}}$$

$$\nu = \frac{\mu}{\lambda} = \frac{\Delta w}{w} \Big/ \frac{\Delta L}{L}$$

For ex: when an elastic band is stretched, it also gets thinner. Poisson's ratio relates the thinning to the stretching and can be calculated by dividing the change in diameter of the elastic band by the change in length.

Elasticity:

Elastic modulus is a coefficient that relates a particular type of stress to the strain. There are three general types of elastic modulus connected with stresses that create changes in length, shape, or volume known as Young's modulus.

Young's modulus:

The quantity that describes the material response to stresses applied normal to opposite faces is called Young's modulus in honor of the British scientist Thomas Young.

Definition: When a wire or rod is stretched by a longitudinal force the ratio of longitudinal stress to longitudinal strain within the elastic limit is called Young's modulus.

units :- N/m^2

$$Y = \frac{F}{A} \Big/ \frac{\Delta L}{L} = \frac{FL}{A\,\Delta L}$$

F - Applied force
A - Area of cross-section
L - length of the wire
ΔL - change in the length

Bulk modulus:

When a force is applied normally and uniformly to the whole surface of the body such that the shape remains the same but volume changes, the body is compressed. The bulk modulus of elasticity is defined as the ratio of normal stress to the volume strain. represented by K and has same unit as pressure N/m^2

$$K = \frac{\text{Bulk stress}}{\text{Volume strain}} = \frac{F/A}{\Delta V/V} = \frac{P}{\Delta V/V}$$

F — Applied force
A — Area of cross-section
V — volume of the body
ΔV — change in volume
P — Bulk pressure

Rigidity modulus:

The resistance to shear loads in solids is called the modulus of rigidity. The ratio of tangential force per unit area to angular deformation produced is called rigidity modulus. represented by η and has the same unit as pressure N/m^2

$$\theta = l/L$$

$$\eta = \frac{F/A}{\theta} = \frac{\text{Tangential}}{\text{Shearing strain}}.$$

Strain Energy:

Strain Energy is the energy stored in a material due to deformation caused by an applied load. This energy is a function of the stress and strain experienced by the material. It is a fundamental concept in solid mechanics and plays a crucial role in understanding the mechanical properties of solids.

strain energy per unit volume is defined as the work done by the applied forces in deforming a material.

$$U = \int \sigma \, d\varepsilon$$

σ - stress applied to the material

ε - strain produced in the material.

Derivation:

The strain energy per unit volume can be derived in detailed

→ The general formula for strain energy per unit volume is

$$U = \int \sigma \, d\varepsilon$$

→ For a linear elastic material, stress (σ) is proportional to strain (ε) according to Hooke's law.

$$\sigma = E\varepsilon$$

where E is youngs modulus.

→ substituting $\sigma = E\varepsilon$ into the integral

$$U = \int E\varepsilon \, d\varepsilon$$

E is constant for a linear elastic material it can be taken out of the integral

$$U = E \int \varepsilon \, d\varepsilon$$

by integrate with respect to ε

$$U = E \frac{\varepsilon^2}{2}$$

rearrange the terms to express strain energy per unit volume

$$U = \frac{1}{2} E \varepsilon^2$$

Using Hooke's law ($\sigma = E\varepsilon$),

we can also write the strain energy as;

$$U = \left(\frac{1}{2}\right) \sigma \varepsilon .$$

Total Strain Energy:

For a material with volume v, the total strain energy is obtained by multiplying the strain energy per unit volume by the volume.

$$U_{total} = \int_V U \, dv$$

If the stress and strain are uniform, the total strain energy

$$U_{total} = \left(\frac{1}{2}\right) \sigma \varepsilon V$$

Strain energy is a crucial concept in understanding the mechanical behavior of solid under load. The derivation provides a basis for analyzing energy storage, deformation, and failure in materials.

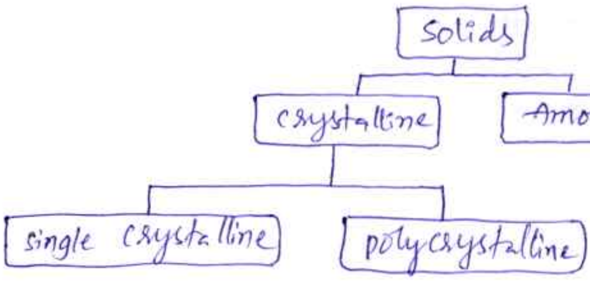
UNIT-II : CRYSTALLOGRAPHY AND X-RAY DIFFRACTION

Introduction: The branch which is studied about the geometry and structural properties of crystal substances is known as Crystallography.

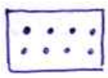
Matter exists in three different states - gas, liquid, and solid.

In gaseous and liquid states the atoms or molecules of the substance move from one place to other, and there is no fixed position of atoms in the substance. In solids, the positions of the atoms or molecules are fixed and may or maynot be present periodically at regular intervals of distances.

solids are classified into two categories based on the arrangement of atoms or molecules. They are crystalline and amorphous solids.

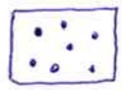


Crystalline solids:

* atoms are arranged regularly 
* True solids.
* Have sharp melting point
* They exhibit different magnitudes of physical properties in different directions.
* These are anisotopic in nature
* If a crystalline solid breaks the broken pieces also have regular shape.
  eg: salt, sugar.

Amorphous solid

* Atoms are arranged randomly.



* Psedo solids (super cooled liquids).

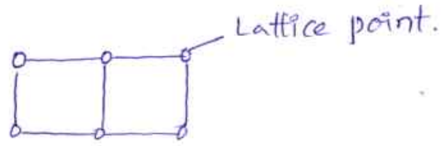
* Doesn't have sharp melting point

* They exhibit same magnitudes of physical properties in different direction.

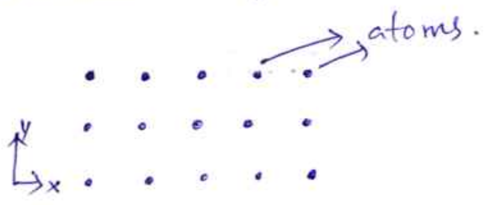
* These are Isotopic nature.

* If an amorphous solid breaks, the broken pieces have irregular shape. ex: Glass, plastic.

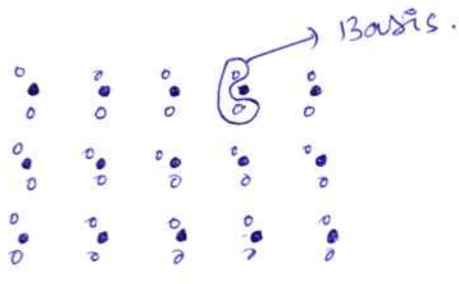
Lattice:- The regular and orderly arrangedment of atoms or molecules in a row is called lattice.



space lattice or crystal lattice:- A space lattice is an array of points showing how particles are arranged at different sites in two or three dimensional spaces.



Basis: A group of identical atoms or molecules in composition is called Basis or pattern.



Crystal structure:

→ Atomic arrangement and symmetry is most important part in crystal structure.

→ crystal structure is a combination of lattice and basis.

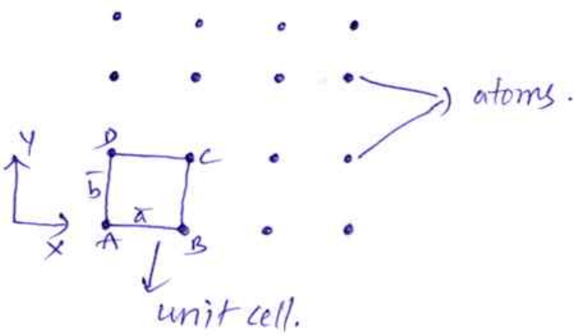
$$\text{Crystal Structure} = \text{lattice} + \text{Basis}.$$

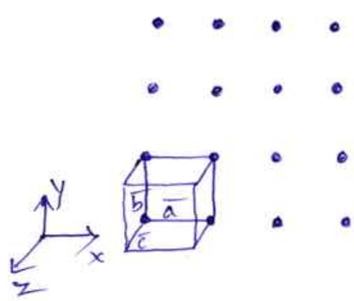
→ Depending upon the crystal structure, the basis may be mono-atomic, diatomic etc.

unit cell:-

→ The crystal structure of a material can be described in terms of its units cell. It is the smallest unit.

→ A unit cell is the smallest geometric structure, which repeated regularly gives the crystal structure is known as unit cell.

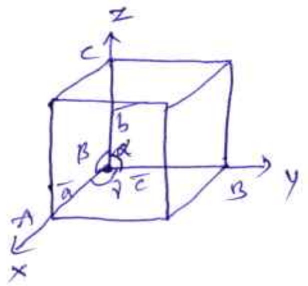




Lattice parameters:

→ A unit cell has 6 lattice parameters to represent the structure and shape, i.e a, b, c and α, β, γ. These quantities are known as lattice parameters.

→ The lattice parameters a, b, c may or may not be equal and α, β, γ may or may not be right angles.



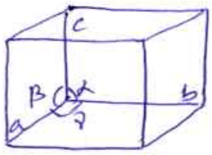
Crystal systems:

→ Crystal systems are classified into seven systems on the basis of the shape of the unit cell or lattice parameters.

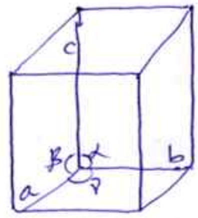
→ These are classified interms of length of unit cells and the angle of inclination b/w them.

Seven Crystal systems

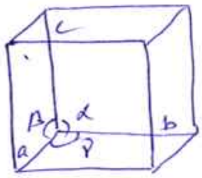
S. No.	Crystal system	Axes	Angles	Examples
1.	Cubic	$a=b=c$	$\alpha=\beta=\gamma=90^\circ$	Fe, Cu
2.	Tetragonal	$a=b\neq c$	$\alpha=\beta=\gamma=90^\circ$	Sn, MnO_2
3.	Orthorhombic	$a\neq b\neq c$	$\alpha=\beta=\gamma=90^\circ$	Iodine, KNO_3
4.	Monoclinic	$a\neq b\neq c$	$\alpha=\beta=90^\circ, \beta\neq 90^\circ$	Sugar
5.	Triclinic	$a\neq b\neq c$	$\alpha\neq\beta\neq\gamma\neq 90^\circ$	$K_2Cr_2O_7$
6.	Hexagonal	$a=b\neq c$	$\alpha=\beta=90^\circ, \gamma=120^\circ$	Quartz
7.	Trigonal	$a=b=c$	$\alpha=\beta=90^\circ, \gamma\neq 90^\circ$	As, Bi.



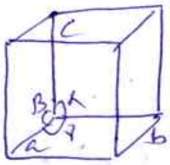
Cubic



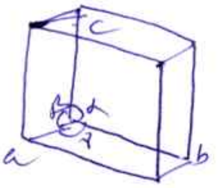
Tetragonal.



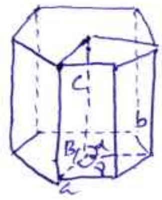
orthorhombic



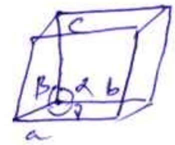
Monoclinic



Triclinic



Hexagonal



Rhombohedral (Trigonal)

Bravais Lattices:

→ If all atoms are identical at lattice points then that lattice knowns as Bravais lattice.

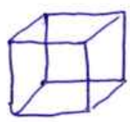
→ Bravais showed that there are 14 different types of unit cells under the seven crystal systems.

→ The classification of Bravais lattice is based on the following crystal lattices.

1. Primitive lattice (P)
2. Body centred Lattice (I)
3. Face centered lattice (F)
4. Base centered Lattice (C)

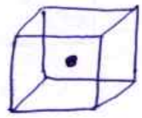
1. primitive Lattice (P)

In this lattice the unit cell consists of eight corners atoms and all these corners atoms contribute only one effective atom for the lattice.



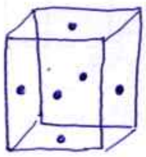
2. Body Centered Lattice (F):

In addition to the eight corners atoms it consists of one complete atom at the center.



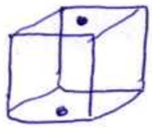
3. Face centered Lattice (F):

Along with corner atoms, each face will have one center atom.



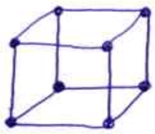
4. Base Centered Lattice (C):

The base and opposite face will have center atoms along with corner atoms.

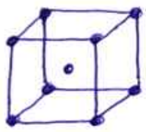


→ Bravais lattices for cubic

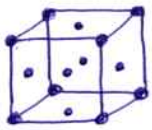
i)



(P)

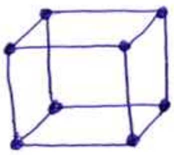


(I)

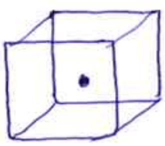


(F)

→ Bravais lattice: Tetragonal

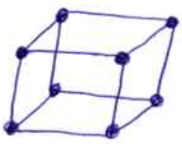


(P)

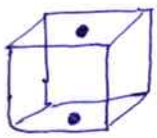


(I)

→ Bravais lattice: mono clinic

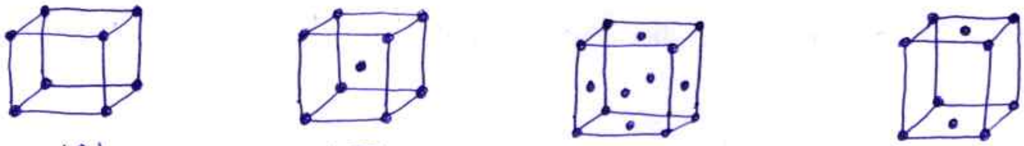


(P)



(C)

→ Bravais lattic: orthorhombic



(P) (I) (F) (C)

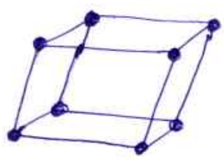
→ Triclinic:

(P)

→ Hexagonal:

(P)

→ Rhombohedral (Trigonal)



(P)

Basic definitions of cubic crystal:

1) Number of atoms per unit cell (n):

The total no. of atoms per unit cell by considering the contribution of corner atoms, center atoms and face centered atoms. for SC, BCC and FCC are 1, 2, and 4.

2. Atomic Radius ($r = \frac{a}{2}$):

It is defined as half of the distance b/w two atoms. $r = \frac{a}{2}$

3. Coordination number (N)

It is number of nearest neighbours that an atom has in given structure. The co-ordination number for SC, BCC and FCC are 6, 8, and 12.

4. Atomic packing Factor (APF):

It is the ratio of volume of atoms in a unit cell to volume of unit cell. The APF for SC, BCC and FCC are 0.52, 0.68, and 0.74 respectively.

$$APF = \frac{\text{Volume of atoms in unit cell}}{\text{Volume of unit cell}} = \frac{\text{No. of atoms} \times \text{volume of each atom}}{\text{Volume of unit cell}}$$

Packing fractions of SC, BCC, and FCC

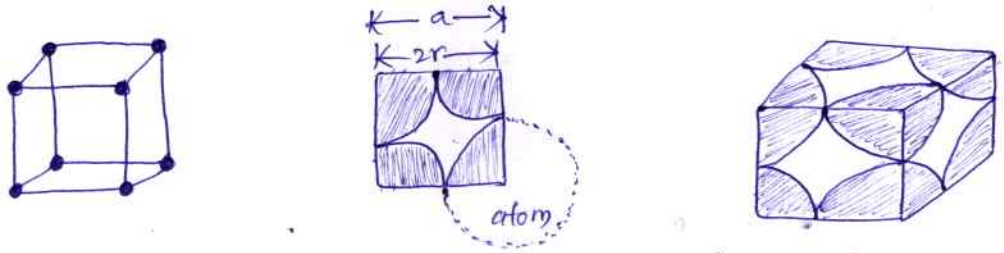
(1) Simple cubic (SC):

→ There are 8 atoms at 8 corners of the cube. The corner atoms touch with each other

→ The 8 corner atoms are shared by 8 unit cells, so that the contribution of a corner atom to a unit cell is $\frac{1}{8}$. Hence the no. of atoms in the unit cells is given as

$$n = 8 \text{ corner atoms} \times \frac{1}{8}$$

$$n = 1 \text{ atom.}$$



Volume of atom $= \frac{4}{3}\pi r^3$

volume of cube $= a^3 = (2r)^3 = 8r^3$

Atomic Packing Factor (APF) $= \dfrac{\text{No. of atoms} \times \text{volume of each atom}}{\text{Volume of unit cell}}$

$$= \frac{1 \times \frac{4}{3}\pi r^3}{8r^3}$$

$$= \frac{4}{3}\pi r^3 \times \frac{1}{8r^3} = \frac{\pi}{6} = 0.52.$$

Thus, the packing fraction of a simple cubic lattice is 0.52. or 52%. This means that only 52%. of the volume is occupied by atoms and remaining 48%. is empty. This empty space inside a crystal lattice is known as 'Void'.

Examples: Barium and polonium.

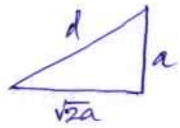
2. Body centered Cubic (BCC):

→ In BCC, there are 8 atoms at 8 corners and 1 atom at the body center.

→ The 8 corners atoms are shared by 8 unit cell, so that contribution of a corner atom to a unit cell is $\frac{1}{8}$, and the center atom is entirely within the unit cell. It is not shared by any surrounding unit cell, Hence, the number of atoms in the unit cell is given as

$n = (1 \text{ body centered atom} \times 1) + (8 \text{ corner atoms} \times \frac{1}{8})$

$n = 1 + 1 = 2$ atoms.



If the sides of the unit cell are 'a' then the length of the face diagonal will be $\sqrt{2}a$ and the length of the body diagonal will be $\sqrt{3}a$. Using pythagoras theorem.

$$d^2 = a^2 + (\sqrt{2}a)^2$$

$$d^2 = a^2 + 2a^2$$

$$d^2 = 3a^2$$

$$d = \sqrt{3}a.$$

Three atoms lie along the body diagonal with the total length being equal to 4r. Thus, we have

$$4r = \sqrt{3}a$$

$$a = \frac{4r}{\sqrt{3}}$$

$\therefore$ volume of cube $= a^3 = \left(\frac{4r}{\sqrt{3}}\right)^3$

Volume of atom (sphere) $= \frac{4}{3}\pi r^3$

Atomic Packing Factor (APF) $= \dfrac{\text{No. of atoms} \times \text{Volume of each atom}}{\text{Volume of unit cell}}$

$$= \frac{2 \times \frac{4}{3}\pi r^3}{\left(\frac{4r}{\sqrt{3}}\right)^3}$$

$$= \frac{8}{3}\pi r^3 \frac{(\sqrt{3})^3}{4^3 r^3}$$

$$= \frac{\sqrt{3}\pi}{8} = 0.68.$$

Thus the packing fraction of a body centered cubic lattice is 0.68 or 68%. i.e only 68% of the volume is occupied by atoms and remaining 32% is empty (void).

Examples: Sodium, potassium, ...

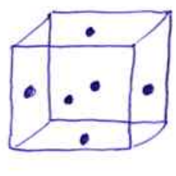
3. Face centered cubic (FCC):

→ In FCC, there are 8 atoms at 8 corners of the unit cell and each face (6 faces) has a center atom.

→ The 8 corner atoms are shared by 8 unit cells, so that the contribution of a corner atom to a unit cell is $\frac{1}{8}$. The face centred atom is shared by 2 unit cells and only $\frac{1}{2}$ of each atom belongs to an individual cell. Hence, the no. of atoms in the unit cells is given as.

$$n = (6 \text{ face centred atom} \times \tfrac{1}{2}) + (8 \text{ corner atoms} \times \tfrac{1}{8})$$

$$n = 3 + 1 = 4 \text{ atoms.}$$



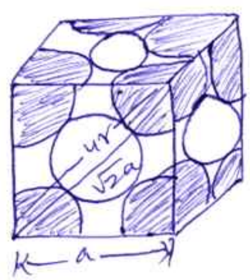
If the sides of the unit cell are 'a' then the length of the face diagonal will be $\sqrt{2}a$.

$$\therefore \quad 4r = \sqrt{2}a$$

$$a = \frac{4r}{\sqrt{2}} = \frac{\sqrt{16}\, r}{\sqrt{2}}$$

$$= \sqrt{\frac{16}{2}}\, r$$

$$= \sqrt{8}\, r$$



$$a^3 = (\sqrt{8}\,r)^3$$

volume of atom (sphere) $= \frac{4}{3}\pi r^3$

$$APF = \frac{\text{No. of atoms} \times \text{volume of each atom}}{\text{volume of unit cell.}}$$

$$= \frac{4 \times \frac{4}{3}\pi r^3}{(\sqrt{8}\,r)^3}$$

$$= 4 \times \frac{4}{3}\pi r^3 \times \frac{1}{8\sqrt{8}\,r^3}$$

$$= \frac{2\pi}{3\sqrt{8}} = \frac{\pi}{3\sqrt{2}} = 0.74.$$

i.e The packing fraction of a face centered cubic lattice is 0.74 or 74%. That is only 74% of the volume is occupied by atoms and remaining 26% is empty (void)

examples: Cu, Ag, Al, ..

Miller Indices:

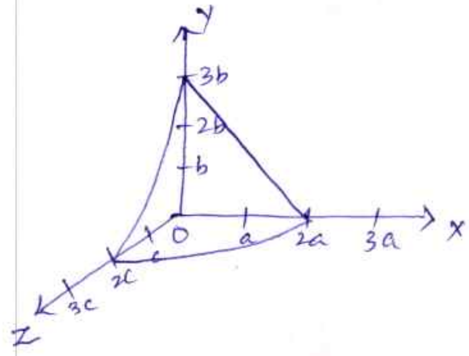
The crystal plane is represented by a set of three smallest integers called "Miller indices" These are denoted as (hkl).

procedure to find Miller Indices:

1. The intercepts made by the crystal plane along x, y, z axis in terms of lattice parameters a, b, c are noted.
2. Express the intercepts as multiple of a, b, c.
3. Take the reciprocals of the intercepts.

4 → Convert the reciprocals into integers by multiplying each of them with their LCM to get smallest number as (hkl) miller indices. This represents the miller indices of the crystal plane.

Example:



→ ABC is the crystal plane which makes intercepts 2a, 3b and 2c. along the x, y, z axes respectively. Where a, b, c are the lattice parameters.

→ The intercepts of the multiples of a, b, c are 2, 3, 2

→ reciprocals of the intercepts are $\frac{1}{2}, \frac{1}{3}, \frac{1}{2}$. Their LCM is 6. multiply the reciporcals by 6, so that they become integers 3, 2, 3.

→ The integers are written within the parenthesis as (323). (323) represents the miller indices of the crystal plane ABC.

Important features of miller indices of crystal planes:

→ Miller indices represents the orientation of crystal planes in a crystal lattice.

→ All equally spaced parallel planes have the miller indices

→ Miller indices does not define particular plane but a set of parallel planes.

→ If a plane cuts an axis on the -ve side of the origin, then the corresponding index is -ve. and is indicating by placing a minus sign above the index. i.e $(\bar{1}00)$ for negative x-axis, $(0\bar{1}0)$ for negative y axis, and $(00\bar{1})$ for negative z axis

→ When the Integers used in the miller indices contain more than one digit, they must be separated by commas.

example (3, 2, 4).

→ If (hkl) is the miller indices of a crystal plane, then the intercepts made by the plane with the coordinate axes are $\frac{a}{h}, \frac{b}{k}, \frac{c}{l}$ where a, b, c are the lattice parameters.

→ For cubic crystal $h:k:l = \frac{a}{p} : \frac{a}{q} : \frac{a}{r}$

For any crystal, $h:k:l = \frac{a}{p} : \frac{b}{q} : \frac{c}{r}$.

→ For a cubic crystal, the inter plannar spacing b/w the adjacent plane is given by

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}}.$$

where a is the lattice constant, and (hkl) is the indices of the crystal plane.

Seperation b/w successive (hkl) planes:

→ Let us consider a rectangular co-ordinate system with origin 'O' at any one of the lattice points.

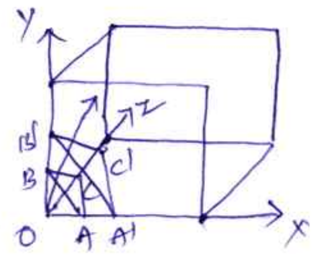
→ Let (hkl) be the miller indices of a plane ABC, which makes intercepts OA, OB, OC on X, Y, Z axes, respectively.

→ Since the plane segment 'a' into 'h' equal parts 'b' into 'k' equal parts, and 'c' into 'l' equal parts, then the intercepts OA, OB and OC are such that

$$OA = \frac{a}{h} \; ; \; OB = \frac{b}{k}, \text{ and } OC = \frac{c}{l}$$

From figure:

Δ ONA, $\cos\alpha = \frac{ON}{OA} = \frac{d}{\frac{a}{h}} = d\left(\frac{h}{a}\right)$



Δ ONB, $\cos\beta = \frac{ON}{OB} = \frac{d}{b/k} = d\left(\frac{k}{b}\right)$

Δ ONC, $\cos\gamma = \frac{ON}{OC} = \frac{d}{c/l} = d\left(\frac{l}{c}\right)$

A/c cosine law of directions,

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$$

$$\left[d\left(\frac{h}{a}\right)\right]^2 + \left[d\left(\frac{k}{b}\right)\right]^2 + \left[d\left(\frac{l}{c}\right)\right]^2 = 1$$

$$\frac{d^2}{a^2}(h^2) + \frac{d^2}{b^2}(k^2) + \frac{d^2}{c^2}(l^2) = 1$$

For a cubic system: $a = b = c$ then the above eq.

$$\frac{d^2}{a^2}(h^2+k^2+l^2) = 1$$

$$d^2 = \frac{a^2}{h^2+k^2+l^2}$$

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}}.$$

The above equation represents the interplanar spacing b/w two parallel planes.

X-RAY DIFFRACTION

X-ray diffraction :

→ The diffraction occurs when the size of obstacle must be comparable with wavelength of the incident light. In crystals the seperation b/w the planes or atomic arrangement is nearly 1-2 A°.

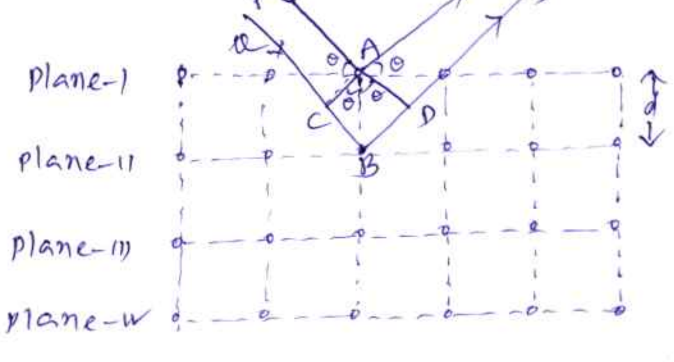
→ If light is allowed will not diffracted because light has wavelength 4000-7000 A°. Thus X-rays are allowed to pass through crystals whose wavelength 1-10 A°. diffraction through crystal is observed. This is called X-ray diffraction.

Bragg's law :

→ Bragg's law was introduced by Sir W.H. Bragg and his son Sir W.L Bragg.

Statement : Bragg's law states that when X-ray is incident onto a crystal surface, its angle of incidence 'θ' will reflect back with a same angle of scattering. θ. (or) Bragg's law states that the diffraction of reflected x-rays occurs at condition of constructive interference.

Derivation :



→ consider a crystal have a planar seperation as 'd' (i.e AB = d) and is allowed to incident with x-rays as ray 1 (PA) and ray 2 (QB).

→ The ray 1 reflected by plane-1 as AR and ray 2 as BS

→ These diffracted (reflected) rays x-rays will interference constructively or destructively depending on the path diff. b/w the x-rays.

→ To calculate the path difference, two normal AC and AD are drawn from A to QB and BS

$$\text{path difference} = CB + BD$$

$$\Delta ACB, \; \sin\theta = \frac{CB}{AB}$$

$$CB = AB \sin\theta = d \sin\theta \quad \text{—— (1)}$$

$$\text{Ily. } \Delta ADB, \; \sin\theta = \frac{BD}{AB}.$$

$$BD = AB \sin\theta = d \sin\theta$$

From eq (1) & (2)

$$\text{path difference} = CB + CD = d \sin\theta + d \sin\theta$$

$$= 2d \sin\theta$$

To get maximum intensity, path difference should be equal to integral multiple of λ

$$\text{path difference} = n\lambda$$

$$2d \sin\theta = n\lambda \qquad \text{where } n = 1, 2, 3, \ldots$$

The above expression represents Bragg's law.

X-ray Diffractometer:

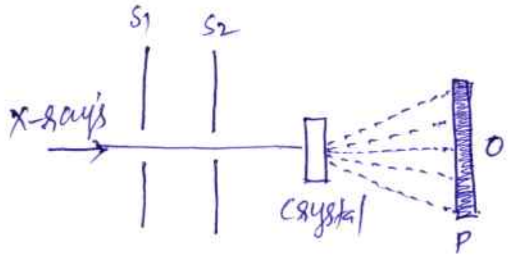
The instrument used to estimate parameters of crystals by applying Bragg's is called X-ray Bragg's spectrometer.

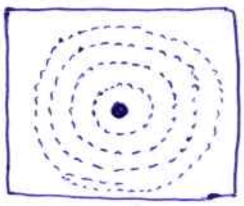
There are 3 diffractometers.

1. Laue method
2. powder method
3. Rotating crystal method

Laue's method:

Construction:-





Laue spot.

→ The laue method is the oldest of the X-ray diffraction method.

→ In this method white X-rays are used to analyse the crystal. structure.

→ The X-rays are converted to parallel beam of X-ray by using parallel slit arrangement S_1 and S_2

→ In the path of X-rays a single crystal is arranged at fixed position.

→ A photographic film is used to record X-ray diffraction pattern at certain distance from crystal as shown in fig

Working :-

→ A collimated beam of continuous (white X-rays) falls on the crystal. The crystal plane in the crystal diffract the X-rays satisfying Bragg's law.

→ The diffracted X-rays are allowed to fall on a photographic plate.

→ The diffraction pattern consists of a series of bright spots corresponding to interference maximum for a set of crystal planes satisfying the bragg's equation $2d \sin\theta = n\lambda$. for a particular wavelength of the incident beam.

→ The distribution of spots depends on the symmetry of the crystal and its orientation with respect to X-ray beam.

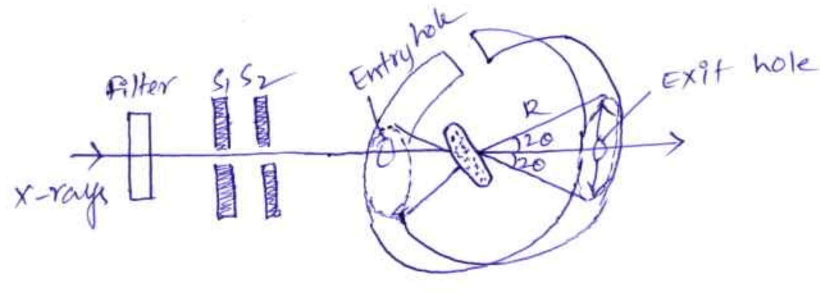
→ Hence various diffraction spots are found in photographic plate as shown in fig.

Powder method:

→ The powder method is an X-ray diffraction ~~teq~~ technique used to study the structure of tiny crystalline in the form of powder.

→ This method developed by Debye and Scherer in Germany also known as Debye and Scherer method

Construction:-



→ The experimental arrangement is shown in fig. It consist of a cylindrical camara, called the Debye-Scherer camera. consisting of a film in the inner portion

→ The finely powdered sample is filled in a thin capillary tube and mounted at the centre of the camera

Working:-

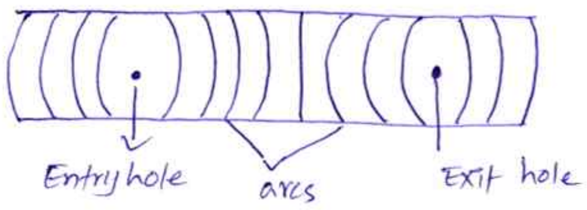
→ The x-rays from the source are made approximately monochromatic by filter.

→ These are collimated by two lead slits S_1, S_2 falls on the powder specimen.

→ Since the powder consists of randomly oriented crystallites, all possible θ and d values are available for diffraction of incident x-rays, which satisfy the Brag's relation $2d\sin\theta = n\lambda$ where λ is constant for monochromatic x-rays.

→ For the values of 'θ', the beam appears at the corresponding 2θ deviation.

→ The transmitted x-rays come out the exit hole. The diffrated x-ray cones make impression on the film in the form of arcs on either side of exit and entry holes. with their center coinciding with hole.



→ If the distance of pair of arcs is 's' and radius of the camera is 'R', then for a crystalline size we have

$$4\theta = \frac{S}{R}$$

From the above expression, θ can be calculated.

Applications:

1. Powder method is useful for chemical Analysis - phase identification.
2. Determination of unit cell dimensions
3. Measurement of sample purity
4. Most useful for cubic crystal
5. Used for determining the complex structure of meterial and Alloys.

DIELECTRIC MATERIALS

Electric Dipole :-

A dipole is defined as a pair of two equal and opposite charges q and -q separated by distance 'r'.

Dipole moment :-

Dipole moment is equal to the product of one of charges and the separation between them

$$\mu = q \cdot r$$

S.I Unit - columb - meter (or Debye

1 Debye $= 3.3 \times 10^{-30}$ C-m

Permitivity :-

Permitivity represents the easily polarizable nature of dielectric medium. permitivity of dielectric is denoted by ε and permitivity of free space is denoted by ε_0.

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

Dielectric Constant :-

The ratio of permitivity of medium to permitivity of free space is called dielectric constant

$$\varepsilon_r = \varepsilon / \varepsilon_0$$

Consider a capacitor with air as medium having charge Q on its plates are separated by a distance 'd'. Let area of cross section of plates is A. V_0 is potential difference and E_0 is the electric field across plates.

Capacity of capacitor is

$$C_0 = Q/V_0 \quad \text{and} \quad C_0 = A\varepsilon_0/d$$

When the dielectric is introduced into the capacitor opposite charges are induced into the two dielectric faces which are close to the charge plates. These induced positive and negative charges act as dipoles and it has net dipole moment. This phenomenon is dielectric polarization. Due to the dipoles, the resultant potential difference decreases, so that capacity increases. Due to polarization, the polarization electric field E_p is induced in opposite direction to applied field E_0.

Resultant electric field is

$$E = E_0 - E_p$$

let V_d is potential difference across capacitors plates Then capacity given by.

$$C_d = Q/V_d \longrightarrow (1)$$

$$\varepsilon_r = \varepsilon/\varepsilon_0$$

The ratio of capacity of capacitor with dielectric to capacity of capacitor without dielectric is called dielectric constant

$$\varepsilon_r = C_d/C_0$$

$$\varepsilon_r = V_0/V_d$$

Dielectric constant has no units

Dielectric Polarization (P) :

Polarization is defined as the dipole moment per unit volume. let N is the no. of molecules per unit volume and μ is dipole moment of molecule.

$$\boxed{P = N.\mu}$$

S.I unit = columb/meter^2 (C/m^2)

Dielectric Susceptibility (χ)

It measures the amount of polarization is given electric field produced in a dielectric polarization. polarization is proportional to the product of permitivity of free space ε_0 and electric field E.

$$P \propto \varepsilon_0 E$$

$$P = \chi \varepsilon_0 E$$

$$\boxed{\chi = P / \varepsilon_0 E}$$

Electric flux density (D):-

The total number of lines passing through unit area of cross section of dielectric is called electric displacement (or) electric flux density.

Consider a dielectric in an electric field E the electric lines of force passing through dielectric and it can be polarized. Electric displacement D is proportional to the applied electric field E.

$$D \propto E$$

$$\boxed{D = \varepsilon E} \longrightarrow (1)$$

Relation between dielectric constant & Susceptibility :-

Electric displacement D is also related to electric field E by.

$$D = \varepsilon_0 E + P \quad \text{—— } (2)$$

From eq. (1) & (2)

$$\varepsilon E = \varepsilon_0 E + P$$

$$\varepsilon_0 \varepsilon_r E = \varepsilon_0 E + P$$

$$P = \varepsilon_0 \varepsilon_r E - \varepsilon_0 E$$

$$P = \varepsilon_0 E (\varepsilon_r - 1)$$

$$(\varepsilon_r - 1) = P / \varepsilon_0 E$$

From definition, $\chi = P/\varepsilon_0 E$

$$\boxed{\chi = \varepsilon_r - 1}$$

This is the relation for susceptibility and relative permitivity ε_r (or) dielectric constant.

Dielectric polarizability (α)

Dielectric polarizability is defined as the net dipole moment per unit applied electric field

Net dipole moment is proportional to the applied electric field

$$\mu \propto E$$

$$\boxed{\mu = \alpha E}$$

S.I unit - $F\text{-}m^2$

Polarization $P = N\mu$

$$P = N\alpha E$$

$$\Rightarrow \alpha = \frac{P}{NE}$$

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

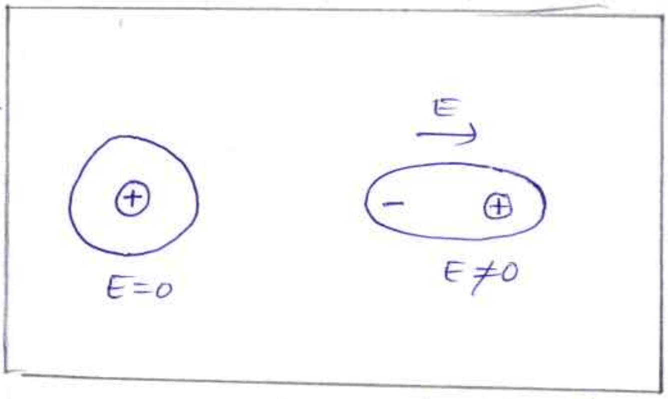
Types of Polarizations :-

Polarization occurs due to several atomic mechanisms. When specimen is placed in dc electric field. 4 types of polarizations occur in dielectric material.

i) Electronic
ii) Ionic
iii) Dipolar / orientation
iv) Space charge polarization

Electronic polarization :

Displacement of nucleus and electron cloud in opposite direction on application of electric field is called electronic polarization.



When electric field is applied on dielectric atom, electron cloud is displaced with respect to the nucleus in a direction opposite to the electric field. This phenomenon is called electronic polarization.

Consider an atom of dielectric material such that its atomic number is z and atomic radius is R. The centers of electron cloud and positive charged nucleus are coincided i.e. Hence there is no dipole moment.

charge density of atom $\rho = \dfrac{-ze}{\frac{4}{3}\pi R^3} \longrightarrow (1)$

When this atom is placed in electric field of strength E, due to Lorentz force, the electron cloud will move in opposite to the electric field. The centers of nucleus and electron cloud do not coincide, columb force develop between them. When columb force and Lorentz force are equal and opposite, then there will be equilibrium between nucleus and electron cloud. Hence dipole moment will be greater than zero. The atom get polarized.

Let the distance between centers of nucleus and electron cloud is 'x'

Total negative charge in the sphere.

$$Q_e = \frac{4}{3}\pi x^3 \rho \longrightarrow (2)$$

$$Q_e = \frac{4}{3}\pi x^3 \left(\frac{-ze}{\frac{4}{3}\pi R^3}\right) \longrightarrow (3)$$

$$Q_e = \frac{-ze\,x^3}{R^3} \longrightarrow (4)$$

The total positive charge of the atom

$$Q_p = +ze \longrightarrow (5)$$

The columb force $F_c = \frac{1}{4\pi\varepsilon_0} \frac{Q_e Q_p}{x^2}$

Substitute eq (3) & (4) in equation (5)

$$F_c = \frac{1}{4\pi\varepsilon_0 x^2}\left[\frac{-zex^3}{R^3}\right][ze]$$

$$= \frac{-z^2e^2x}{4\pi\varepsilon_0 R^3} \longrightarrow (6)$$

Lorentz force $F_L = -zeE \longrightarrow (7)$

At equilibrium, Lorntz force = columb force

$$-zeE = \frac{-z^2e^2x}{4\pi\varepsilon_0 R^3}$$

$$E = \frac{-zex}{4\pi\varepsilon_0 R^3}$$

$$x = \frac{4\pi\varepsilon_0 R^3 E}{ze} \longrightarrow (8)$$

Induced dipole moment $\mu_e = zex \longrightarrow (9)$

Sub. eq (8) in eq (9)

$$\mu_e = ze \frac{4\pi\varepsilon_0 R^3 E}{ze}$$

$$\Rightarrow \mu_e = 4\pi\varepsilon_0 R^3 E \longrightarrow (10)$$

From definition $\mu_e = \alpha_e E \longrightarrow (11)$

From eq. (10) & (11),

Electronic polarizability $\boxed{\alpha_e = 4\pi\varepsilon_0 R^3}$

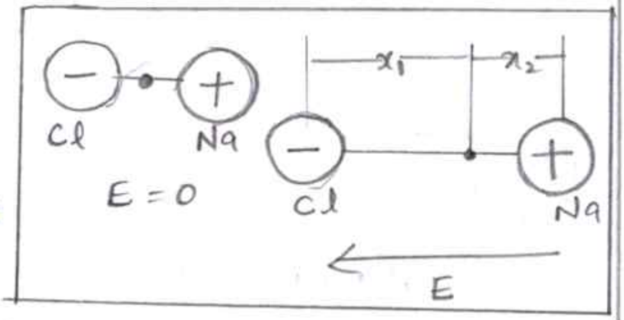
The induced electronic dipole moment per unit volume is called electronic polarization

$$P = N\alpha_e E$$

$$\varepsilon_0 E(\varepsilon_r - 1) = N\alpha_e E$$

$$\alpha_e = \frac{\varepsilon_0 E(\varepsilon_r - 1)}{N}$$

Ionic polarization;



The Ionic polarization is due to the displacement of cations and anions in opposite directions when an electric elec field is applied in the +ve x direction the positive ions move to the right by x_1 distance and negative ions move to left by x_2 distance.

The resultant dipole moment per unit cell is

$$\mu_i = e(x_1 + x_2) \longrightarrow (1)$$

If K_1 and K_2 are restoring force constants of cation and anion, F_R is the force due to applied field

$$F_R = K_1 x_1 = K_2 x_2$$

$$\therefore \quad x_1 = \frac{F_R}{K_1}, \quad x_2 = \frac{F_R}{K_2}$$

where $K_1 = m\omega_0^2$ and $K_2 = M\omega_0^2$ where m is mass of positive ion, M is mass of negative ion and ω_0 is the angular frequency

At equilibrium $F_R = F_L$ (Lorentz force)

$F_L = eE$ then

$$x_1 = \frac{eE}{m\omega_0^2} \quad \text{and} \quad x_2 = \frac{eE}{M\omega_0^2}$$

$$x_1 + x_2 = \frac{eE}{\omega_0^2}\left(\frac{1}{m} + \frac{1}{M}\right) \quad \text{——— (2)}$$

Ionic dipole moment $\mu_i = e(x_1 + x_2)$

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

ionic polarizability $\alpha_i = \frac{\mu_i}{E}$

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

Dipolar (or) Orientational Polarization :-

When an electric field is applied on polar dielectric material, all the dipoles are aligned in the direction of applied field. The polarization produced in polar dielectric material due to the application of electric field is called orientation polarization.

orientational polarization depends on temparature. Thermal energy randomizing the dipoles.

orientational polarization $P_0 = N\mu_0 = N\alpha_0 E$

Therefore, $P_0 = \frac{N\mu^2 E}{3KT} = N\alpha_0 E$

orientational polarizability $\alpha_0 = \frac{P_0}{NE}$

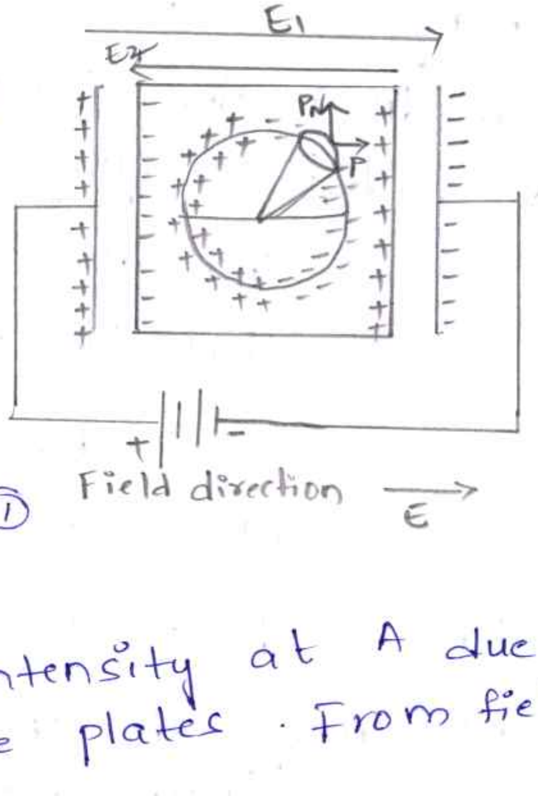
$$\alpha_0 = \frac{\mu_2}{3KT}$$

Therefore, the resultant polarizability due to all the polarizations is given by

$$\alpha = \alpha_e + \alpha_i + \alpha_0 = 4\pi\varepsilon_0 R^3 + \frac{e^2}{\omega_0^2}\left(\frac{1}{M} + \frac{1}{m}\right) + \frac{\mu^2}{3KT}$$

Internal field (or) Local field (Lorentz method):-

Let a dielectric is placed between the plates of a parallel plate capacitor. Let there is an imaginary spherical cavity around an atom A inside the dielectric. The internal field at the atom A is made up of four components.



$$E_i = E_1 + E_2 + E_3 + E_4 \longrightarrow (1)$$

Field E_1:

E_1 is the electric field intensity at A due to the charge density on the plates. From field theory

$$E_1 = D/\varepsilon_0$$

$$D = \varepsilon_0 E + P$$

$$E_1 = \frac{\varepsilon_0 E + P}{\varepsilon_0} \Rightarrow \boxed{E_1 = E + \frac{P}{\varepsilon_0}} \longrightarrow (2)$$

Field E_2 :-

E_2 is the field intensity at A due to the charge density induced on the two sides of the dielectric.

$$E_2 = \frac{-P}{\varepsilon_0} \longrightarrow (3)$$

Field E_3 :-

E_3 is the field intensity at A due to the other atoms contained in the cavity. we are assuming a spherical structure,

$$E_3 = 0$$

Field E_4 :-

E_4 is the field intensity due to polarization changes on the surface of the cavity.

if dA is the surface area of the spherical shell of radius r lying between θ and dθ

Then $dA = 2\pi(Pq)(qr)$

but $\sin\theta = Pq/r$

$\Rightarrow Pq = r\sin\theta$

And, $d\theta = qr/r \Rightarrow qr = r\,d\theta$

Hence, $dA = 2\pi r \sin\theta \, r \, d\theta$

The charge dq on the surface dA is equal to the normal component of the polarization multiplied by the surface.

dq = normal component of P x area of charge

$= P\cos\theta \, dA$

Substitute eq ⑤ in eq ⑥

$$dq = P\cos\theta \,(2\pi r\sin\theta \, r\, d\theta)$$

$$dq = P\,(2\pi r^2 \sin\theta \cos\theta \, d\theta) \longrightarrow ⑦$$

The field due to the charge on A is denoted by dE_4 in the direction $\theta = 0$

$$dE_4 = \frac{dq \times 1 \times \cos\theta}{4\pi\varepsilon_0 r^2}$$

$$= \frac{P\cos\theta \; 2\pi r^2 \sin\theta \, d\theta \, \cos\theta}{4\pi\varepsilon_0 r^2}$$

$$= \frac{P}{2\varepsilon_0}\cos^2\theta \sin\theta \, d\theta$$

Thus the total field due to surface of entire cavity is

$$\int dE_4 = \frac{P}{2\varepsilon_0}\int_0^{\pi} \cos^2\theta \sin\theta \, d\theta$$

$$= \frac{P}{2\varepsilon_0}\int_0^{\pi} \cos^2\theta \, d(-\cos\theta)$$

$$= \frac{-P}{2\varepsilon_0}\left[\frac{\cos^3\theta}{3}\right]_0^{\pi}$$

$$= \frac{-P}{2\varepsilon_0}\left[-1-1\right]$$

$$E_4 = P/3\varepsilon_0 \longrightarrow ⑧$$

The internal field / Lorentz field

$$E_i = E_1 + E_2 + E_3 + E_4$$

$$= E + \frac{P}{\varepsilon_0} - P/\varepsilon_0 + 0 + \frac{P}{3\varepsilon_0}$$

$$\boxed{\therefore E_i = E + P/3\varepsilon_0} \longrightarrow ⑨$$

The above equation is also known as Lorentz relation

Clausius - Mosotti relation :-

Clausius Mosotti relation makes the relationship between microscopic and macroscopic quantities of polarization. The dipole moment is proportional to the internal field (or) Local field.

$$P \propto = N\alpha E_i \longrightarrow (1)$$

$$P = N\alpha\left(E + P/3\varepsilon_0\right)$$

$$P = N\alpha E + \frac{N\alpha P}{3\varepsilon_0}$$

$$\Rightarrow P - \frac{N\alpha P}{3\varepsilon_0} = N\alpha E$$

$$P\left(1 - \frac{N\alpha}{3\varepsilon_0}\right) = N\alpha E$$

$$P = \frac{N\alpha E}{1 - \frac{N\alpha}{3\varepsilon_0}} \longrightarrow (2)$$

we know that $D = \varepsilon_0 E + P$

$$\varepsilon E = \varepsilon_0 E + P$$

$$\varepsilon_0 \varepsilon_r E = \varepsilon_0 E + P$$

$$P = \varepsilon_0 \varepsilon_r E - \varepsilon_0 E$$

$$P = \varepsilon_0 E(\varepsilon_r - 1) \longrightarrow (3)$$

Substitute eq (3) in eq (2)

$$\varepsilon_0 E(\varepsilon_r - 1) = \frac{N\alpha E}{1 - \frac{N\alpha}{3\varepsilon_0}}$$

$$1 - \frac{N\alpha}{3\varepsilon_0} = \frac{N\alpha}{\varepsilon_0(\varepsilon_r - 1)} \Rightarrow 1 = \frac{N\alpha}{3\varepsilon_0} + \frac{N\alpha}{\varepsilon_0(\varepsilon_r - 1)}$$

$$\Rightarrow \frac{N\alpha}{3\varepsilon_0} = \frac{1}{\left(1 + \frac{3}{(\varepsilon_r - 1)}\right)}$$

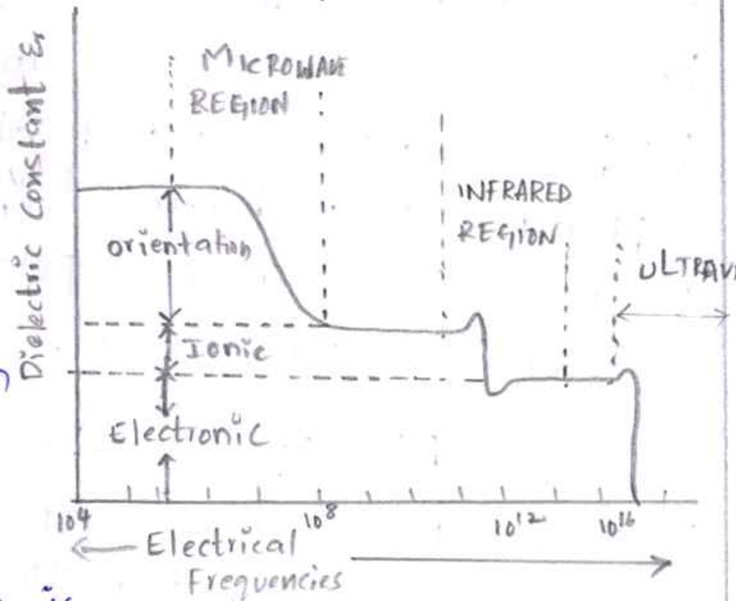
$$\boxed{\frac{N\alpha}{3\varepsilon_0} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}}$$

Frequency Dependence of the Polarizability :-

On application of electric field, polarization process occurs as the function of time

$$P(t) = P[1-\exp(-t/t_r)]$$

where P is maximum polarization and t_r is the relaxation time for particular polarization.



Electronic polarization is extremely rapid. Even when the frequency of the applied voltage is very high in the optical range ($\sim 10^{15}$ Hz), electronic polarization occurs during every cycle of applied voltage.

Ionic polarization is due to displacement of ions over small distances due to applied field. Since ions are heavier the electron cloud, the time taken for displacement is larger. The frequency with which ions are displaced is in the same order of lattice vibration frequency ($\sim 10^{13}$ Hz). At optical frequencies ions do not respond. If frequency of applied voltage is less than 10^{13} Hz, the ions responds. Hence at 10^{13} Hz, we have both electronic & ionic polarizations.

Orientation polarization is even slower than ionic polarization. The relaxation time for orientation polarization in liquid is less than that in a solid. orientation polarization occurs, when the frequency of applied voltage is in the order of audio frequency.

Space charge polarization is the slowest process, as it involves the diffusion of ions over several inter atomic distances. The relaxation time for this Process is related to the frequency of Successful jumps of ions under the influences of the applied field having frequency in the order of 10^2 Hz. Space charge polarization occurs at power frequencies (50-60 Hz).

At optical frequencies (10^{15} Hz) only electronic polarization occurs. At 10^{13} Hz, ionic polarization is occurs in addition to electronic polarization. At 10^6 Hz range, dipolar polarization occurs in addition to electronic and ionic polarizations. At 10^2 Hz, Space charge polarization also contributes.

Applications :-

1) Capacitors with vacum, air or inert gas as dielectric these are used in radio frequency circuits and in low frequency measuring circuits

2) capacitors with mineral oils as dielectrics: these are used in high voltage applications.

3) capacitors with solid as dielectric : these are used standard capacitors because dielectric constant does not vary with temperature.
ex : glass, mica etc.

4) capacitors with both solid and liquid dielectrics : these are used in power distribution system for power factor correction
Ex : Combinations of Solids Such as papers, glass, mica etc.

UNIT-III Magnetic Materials

Magnetic Dipole moment :-

When an electric current of I ampere flows through a circular wire of one turn having an area of cross section Am^2, it is said to have a magnetic moment of

$$\mu_m = I \times A$$

It is expressed in Am^2. It is a vector quantity pointing from South to north pole

Magnetization :-

The magnetization M is defined as the magnetic moment per unit volume. It is expressed in Am^{-1}

Magnetic Susceptibility :-

The magnetic susceptibility χ is defined as the ratio of the magnetization produced in a sample to the magnetic field strength

$$\chi = M/H$$

χ has no units.

Magnetic permeability :-

The magnetic permeability μ is measure of the amount of magnetic lines of forces penetrating through a material.

$$\mu = B/H \Rightarrow B = \mu H$$

Magnetic flux density :-

Number of magnetic lines per unit area of cross section is called magnetic flux density.

$$B = \phi / A$$

S.I unit = web/m^2 (or) Tesla

Magnetic field intensity :-

Force experienced by unit north pole is called magnetic field intensity.

$$H = F/m$$

Relative Permeability :-

The ratio of permeability of free space and permeability of material

$$\mu_r = \mu / \mu_0$$

It has no units.

Relation between B, H & M :-

$$B = \mu H$$

$$B = \mu_0 \mu_r H$$

$$B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$$

But, $M = H(\mu_r - 1)$

$$B = \mu_0 H + \mu_0 M$$

$$B = \mu_0 (H + M)$$

Relation between χ and μ_r :-

$$B = \mu_0 (H + M)$$

$\mu_r = \mu / \mu_0$ $\qquad \mu_r = \dfrac{B/H}{B/(H+M)}$

$$\mu_r = \frac{H+M}{H}$$

$$\mu_r = 1 + M/H$$

$$\mu_r = 1 + \chi$$

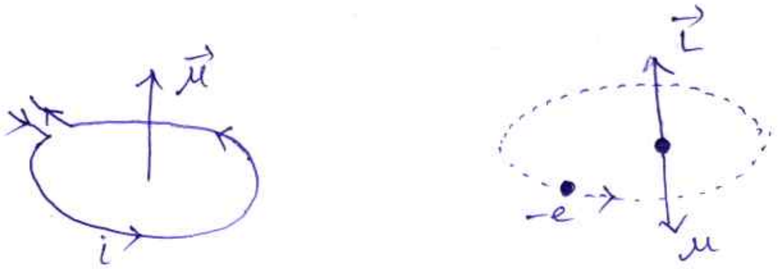
Origin of magnetic moment - Bohr magneton :-

Magnetic moment arises to the atom due to

1. Orbital motion of electron
2. Spin motion of electron
3. Spin motion of nucleus

Orbital magnetic moment :-

The electron of charge '$-e$' moves in circular orbit around the nucleus.



The magnitude of the orbital moment dipole moment for a current loop is

$$\mu_m = I \times A$$

where I is the current and A is the area of loop.

$$I = -e/T$$

where e is the magnitude of the electron charge and T is its time period

If we assume that the electron travels in a perfectly circular orbit, the time period is

$$T = 2\pi/\omega \quad \Rightarrow I = -e\omega/2\pi$$

where r is the radius of the orbit and v is the speed of the electron in its orbit. Given that the area of a circle is πr^2, the absolute magnetic moment is

$$\mu_m = -\frac{e\omega r^2}{2}$$

$$\mu_m = \frac{-em\omega r^2}{2m}$$

$$\mu_m = -\frac{eL}{2m}$$

Where -ve sign indicates that magnetic moment and orbital. ~~Given that~~ area A_θ angular momentum are in opposite directions.

Orbital angular momentum $L = \frac{lh}{2\pi}$

where l = orbital quantum number 1, 2, 3 . . . .

$$\mu_m = -\frac{elh}{4\pi m}$$

where, Bhor magneton $\mu_B = \frac{eh}{4\pi m}$

$$\mu_m = -\mu_B l$$

$$\mu_m = -\mu_B, -2\mu_B, -3\mu_B \dots \quad [\because l = 1, 2, 3]$$

Spin magnetic moment :-

The spinnig of electron about its own axis establishes the magnetic moment called spin magnetic moment.

Spin magnetic moment $\mu_{spin} = \gamma \frac{e}{2m} S$

where γ is the spin gyro magnetic ratio.

For an electron $S = \frac{h}{4\pi}$

$$\mu_{spin} = \gamma \left(\frac{e}{2m}\right)\left(\frac{h}{4\pi}\right)$$

Magnetic moment due to nulear spin :-

Spin motion of nucleus contributes magnetic moment to atom.

Nuclear spin magnetic moment $\mu_{nuclear} = \frac{eh}{4\pi M_P}$

where M_p is the mass of proton.

Types of Magnetic Materials :-

Depending upon the magnetic moment of materials, they can be classified in to the following 5 types.

1. Diamagnetic Materials
2. Paramagnetic materials
3. Ferro magnetic material
4. Ferri magnetic Material
5. Anti Ferro magnetic Materials.

Dia magnetic material :-

1. Diamagnatism is a weak magnetism and is the fundamental property of all matter.
2. Diamagnetism is mainly due to the non-cooperative behaviour of the orbital electrons under the application of external magnetic field.
3. In dia magnetism substances, all the atoms have paired electrons and there are no

unpaired electrons in the shells. Thus the net magnetic moment of the atom of a diamagnetic substance is zero

4) However, when an external magnetic field is applied on these substances, these materials are magnetized opposite to the field direction. Thus they have negative magnetization.

5) Relative permeability is small and less than one.

$\mu_r < 1$

6) Susceptibility is negative and susceptibility is independent of temperature (χ)

Example

organic materials.

Paramagnetic materials :-

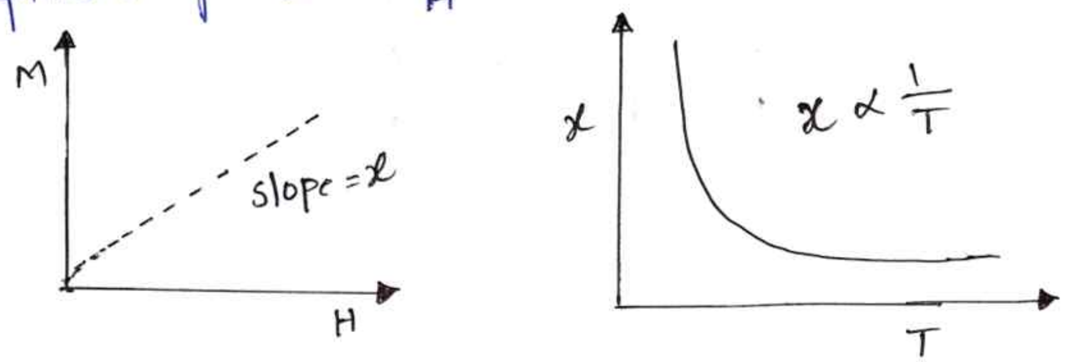
1. In these materials, the atoms or ions have unpaired electrons in partially filled orbitals.
2. That means each atom in a paramagnetic substance has a small net magnetic moment.
3. But, there is no interaction between these atomic magnets
4. In the presence of an external magnetic field there will be a partial allignment of these atomic magnetic moments in the direction of applied magnetic field resulting in a net positive magnetization.

5. Relative permeability μ_r and susceptibility χ is small and positive.

6. When the applied field is zero, the magnetization also becomes zero

7. The susceptibility is inversly proportional to the absolute temparature.

Susceptibility $\chi = \frac{M}{H}$



$M = \chi H$

$\chi > 0$

Paramagnetism

Example :

Alkali metals, transition metals, rare earth metals.

Ferro magnetic materials :-

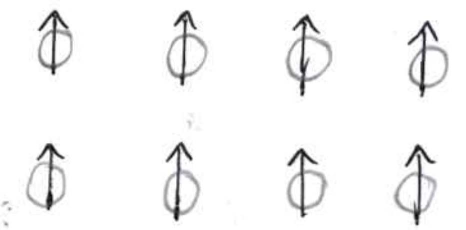
In these Substances

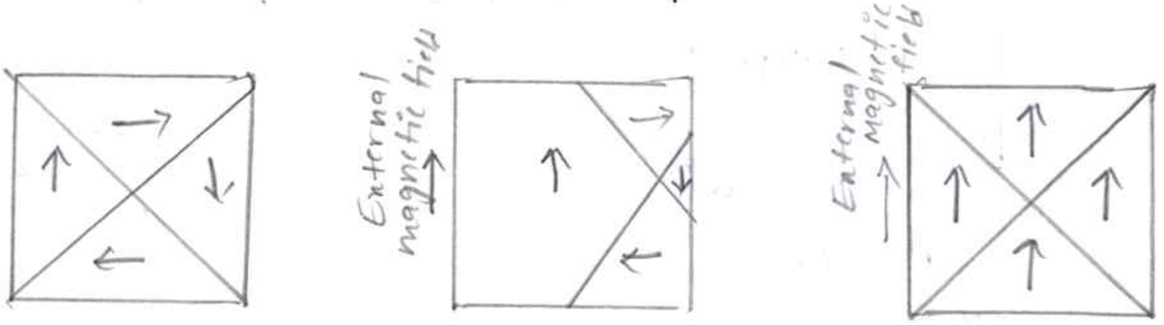
1. The materials that are effected strongly with external magnetic field and have permanent dipoles

2. A spinning electron behaves as a tiny magnet there exist a strong interaction between the atomic magnets. These interaction forces are exchange type of forces. The interaction force between the atoms is due to exchange of electrons.

3. Atomic magnets are aligned parallel to each other. under the influence of these exchange forces even in the absence of external magnetic field. These atomic magnets are aligned parallel to each other

Parallel alignment





(a) (b) (c)

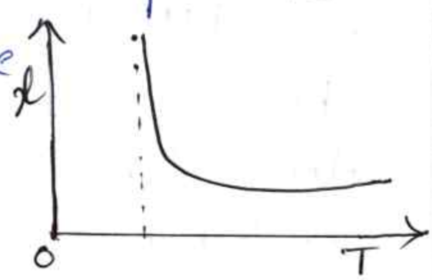
4. Ferromagnetic susceptibility is high and positive

5. In ferromagnetic substances at a particular temparature called curie temparature and above curie temparature, the ferromagnetic is disordered and work as para magnet. But below curie temparature, it is ordered and has ferromagnetic nature. The saturation magnetization becomes zero at the curie temparature.

6. Relative permeability is very high and positive

7. Suceptibility depends on temparature as shown below

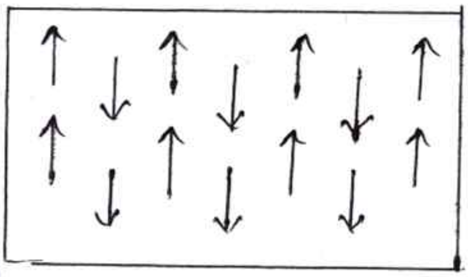
Susceptibility χ =



Example :- Iron, Nickel & Cobalt

Antiferro·magnetic material :-

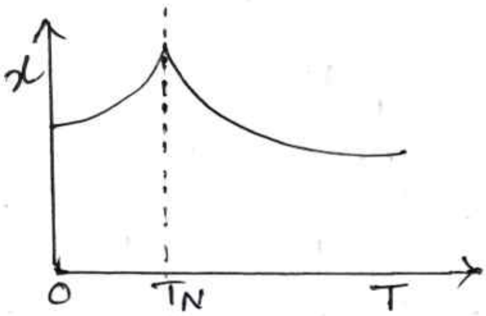
1. Spin dipoles are equal and oriented in opposite direction as shown



2. The net magnetic moment is small
3. Net magnetic moment is zero in the absence of external magneti field
4. Net magnetization is induced in the direction of external magnetic field
5. It allows magnetic lines of forces to through it
6. Intensity of magnetization is positive and moderate
7. Relative permeability μ_r is greater than one $\mu_r > 1$
8. Susceptibility is low and positive
9. Susceptibility depends on temparature

Susceptibility χ =

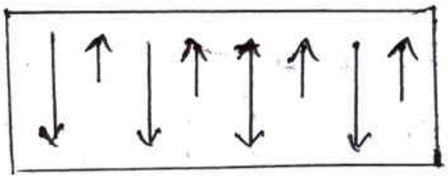
10 When $T < T_N$, the material is a antiferromagnetic. When $T > T_N$ the material is paramagnetic



Ex : Salts of Transition metals

Ferrimagnetic materials :-

1. Ferrimagnetic substance also exhibits spontaneous magnitization
2. Spin dipoles are unequal and oriented in opposite direction due to super exchange interactions
3. There is a net magnetic moment even in the absence of external magnetic field.



5. It allows magnetic lines of forces to pass through it

6. Intensity of magnetization is positive and high

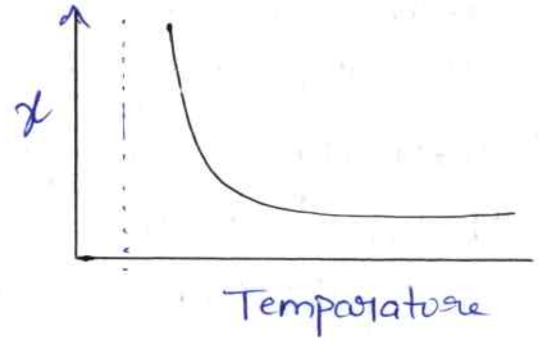
7. Relative permeability is small and greater than one

8. Susceptibility is high and positive

9. Susceptibility depends on temparature.

Susceptibility $\chi =$

10. When $T < T_N$, the material is ferromagnetic. When $T > T_N$, the material is paramagnetic



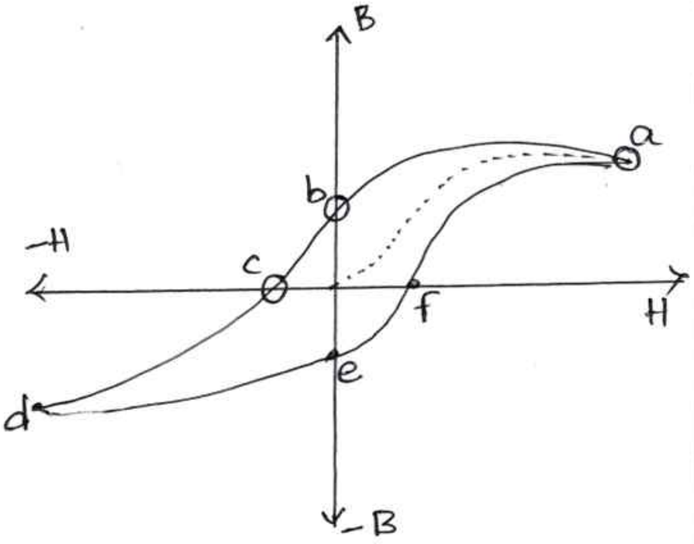
Ex : Ferrites.

Hysteresis :-

When a specimen of ferromagnetic material is placed in a magnetic field, the specimen is magnetized by induction. As the magnetic intensity H changes, the flux density does not change linearly with H. The variation of B with H is shown in the fig. The point O represents intially unmagnetized specimen and a zero magnetic intensity as H is increased, the magnetic flux density B increasing noonlinearly and reaches saturation point 'a'. If H is dicreased, B also decreases but following the path 'ab'. Thus B lags behind H. This property is called hysterisis.

When H becomes zero, B still has a value 'Ob'. The magnetic flux density remaining in the specimen in the absence of external magnetic intensity is called remanence magnetism or residual magnetism B_r. This property is called retentivity. If the magnetic intensity is increased in opposite direction, the value of B decreases and becomes zero when H has the value equal to 'OC'. This magnetic intensity is called coercive force. The coercivity (H_c) is measure of the magnetic intensity required to destroy the residual magnetism of the specimen. As H is increased beyond OC, the specimen is increasingly magnetized in opposite direction and reached the saturation point 'd'

By taking H back from its negative maximum value to its original positive value through O, a similar curve will be obtained.



Hysteresis curve

The closed curve 'abcdefa' which represents a cycle of magnetization of the specimen is known as hysterisis curve (loop) of the specimen.

Soft and Hard magnetic materials :-

(x The magnetic materials are heated to required temparature and cool)

The magnetic materials are classified based on hysteresis loop into two types

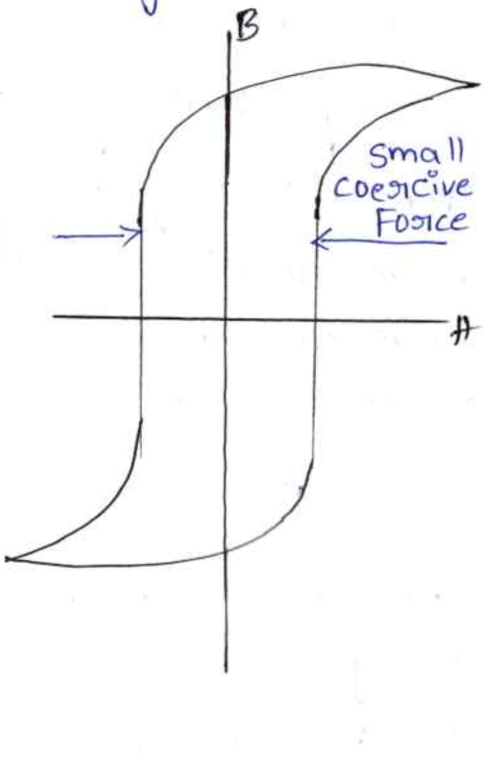
1. Soft magnetic materials.
2. Hard magnetic materials.

Soft magnetic materials :-

The magnetic materials are heated to required temparature and cooled slowly them to prepare soft ferromagnetic materials.

Properties :-

1. They are easily magnetized and demagnetized
2. Their hysteresis loop is steep
3. The area of hysteresis loop is
4. They have high magnetic succeptibility and permeability
5. They exhibit lower retentivity and coercivity
6. They exhibit high resistivity
7. They require low magnetic field to magnetize



Example :

1. Iron - silicon alloys
2. Nickel - iron alloys
3. Iron - cobalt alloys.

Applications :-

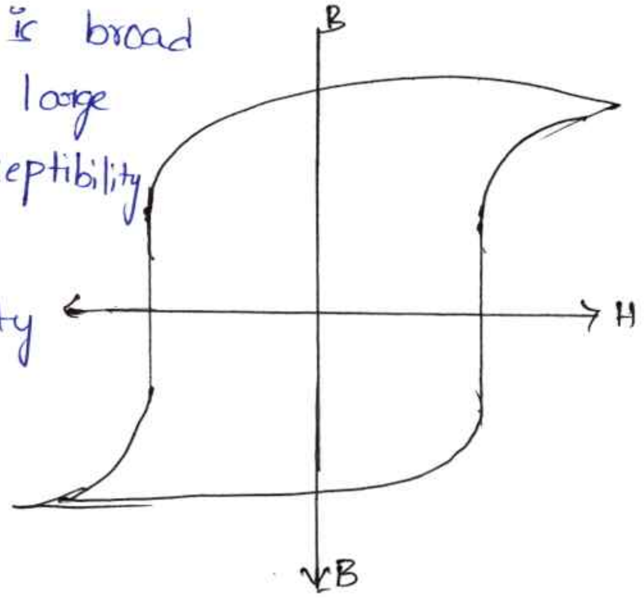
1. They are used in electric equipment and magnetic cores of transformers.
2. They are used in motors, relays & sensors
3. They are used in microwave isolators.

Hard magnetic materials :-

The magnetic materials are heated to required temperature and suddenly cooled by dipping into cold solution to prepare hard magnetic material.

Properties :

1. They are hard to magnetize and demagnetize.
2. Their hysteresis loop is broad
3. The area of hysteresis loop is broad large. hence hysteresis loss is large
4. They have low magnetic susceptibility and permeability
5. They exhibit high retentivity and coercivity
6. They exhibit low resistivity
7. They require high magnetic field to magnetize



example :
1. carbon steel alloys, 2. Tungsten steel alloys etc.

Applications :-

1. They are used to make permanent magnets
2. They are used in speedometers and sensors in automobiles, motors etc.
3. They are used in meters and measuring devices.

LASERS

Lasers :-

Laser means light amplification by stimulated emission of radiation

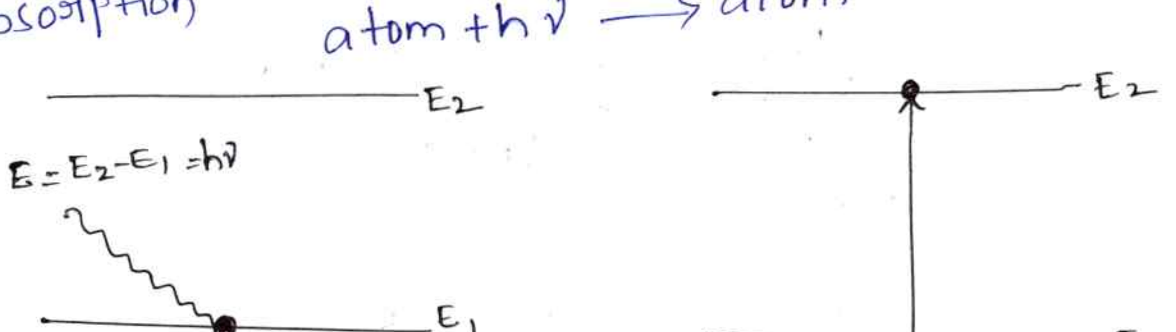
Speciality of Lasers :

Any light beam is composed of photons, two photons are said to be coherent if they have same energy, phase and direction. Laser beam is composed of such coherent photons where as ordinary light contain incoherent photons. So the property of coherence adds special characteristics to LASER beam such as high directionality, high intensity, monochromaticity and penetration.

Spontaneous Absorption :-

When an atom absorbs amount of energy $h\nu$ in the form of photons from the external agency and excited into the higher energy level from ground state, then this process is known as absorption

$$atom + h\nu \longrightarrow atom^*$$

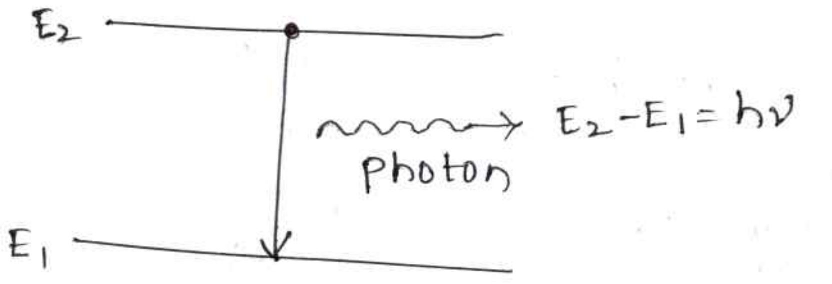


Before Absorption   After Absorption

Spontaneous Emission :-

When an atom in the excited state emits a photon of energy . $h\nu$ coming down to ground state by itself without any external agency, such an emission is called spontaneous emission.

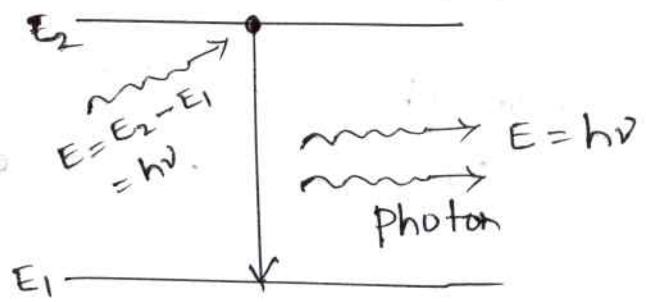
$$atoms^* \longrightarrow atom + h\nu$$



Photons released in spontaneous emission are not coherent. Hence spontaneous emission is not useful for producing Laser.

Stimulated Emission :

When an atom in the excited state, emits two photons of same energy ; $h\nu$ while coming to down to ground state with the influence of an external agency, such an emission is called stimulated emission.



$$atom^* \longrightarrow atom + 2h\nu$$

In the two photons one photon induces stimulated emission and the second one is released by the transition of atom from higher energy level to lower energy level. Both the photons are strictly coherent. Hence Stimulated emission is responsible for Laser production.

Characteristics of LASER Beam

Some of the special properties which distinguish Lasers light from ordinary light sources are characterised by

1. Directionality
2. High intensity
3. Monochromaticity
4. Coherence

Directionality :-

Laser emits radiation only in one direction. The directionality of Laser beam is expressed in terms of angle of divergence i.e., it is twice the angle that the outer edge of the beam makes with the axis of the beam with reference to emitting source. The outer edge of the beam is defined a point at which the intensity of beam falls to 1/37 times to that of value at the centre.

Divergence or angular speed is given by

$$\delta = \frac{a_2 - a_1}{d_2 - d_1}$$

where d_1 d_2 are any two distances for the Laser source emitted.

a_1 a_2 are the radii of the beam spots at a distance d_1 and d_2 respectively.

High Intensity :

Generally light from conventional source spred uniformly in all directions. For ex. take 100 watt bulb and look at a distance of 30 cm, the power enter into the eyes is less than thousand of a watt. This is due to uniform distribution of light in all directions. But in case of Lasers light is a narrow beam and its energy is concentrated within the small region. The concentration of energy accounts for greater intensity of Lasers.

Monochromaticity :-

The light emitted by Laser is highly monochromatic than any of the other conventional monochromatic light. A comparision b/w normal light and laser beam ordinary Sodium (Na) light emits radiation at wavelength of 5893 Å with the line width of 1Å. But He-Ne Laser of wave length 6328 Å with a narrow width of only 10^{-7} Å i.e., monochromaticity of Laser is 10 million times better than normal light. The degree of monochromaticity of the light is estimated by line of width.

Coherence :-

If any wave appears as pure sine wave is perfectly for longtime and infinite space, then it is said to be perfectly coherent. partially no wave is perfectly coherent including Lasers. But compared to other light Sources, Lasers have high degree of coherence because all the energy is concentrated within the small region. There are two independent concepts of coherence

i) Temporal coherence

2) spacial coherence

Laser Production Principle :-

Two coherent photons produced in stimulated emission, interacts with other two excited atoms resulting in four coherent photons. Thus, coherent photons are multiplied in a Lasing medium. The continuous successive emission of photons results for the production of Laser beam.

Laser Action ;

Laser production is the Laser action which involves the following 4 steps

1. Absorption (or) pumping process
2. population inversion
3. stimulated Emission
4. Amplification

1. Pumping process :- This process is required to achieve population inversion. pumping process is defined as The process which excites the atoms from ground state to excited state to achieve

population inversion". Pumping can be done by number of ways.

i) Optical pumping → excitation by strong source of light

ii) Electrical pumping → Excitation by electron impact

iii) Chemical pumping → Excitation by chemical reactions

iv) Direct conversion → Electrical energy is directly converted in to radiant.

Energy in devices like LED's, population inversion is achieved in forward bias.

Population Inversion :-

Generally number of atoms in the ground state is greater than the number of atoms in higher energy state. But in order to produce a Laser beam the minimum requirement is stimulated emission. Stimulated emission takes place only if the number of atoms in the higher energy level is greater than the number of atoms in the lower energy level. Simply population inversion is nothing but number of atoms in higher energy level is greater than the number of atom in lower energy level.

If N_1 represents number of atoms in the ground state and N_2 represents number of atoms in the excited state. than the amplification of light takes place only when $N_2 > N_1$.

If $N_2 > N_1$ there will be population inversion so induced emission and beam are in the same directions and strictly coherent than the resultant laser is said to be amplified.

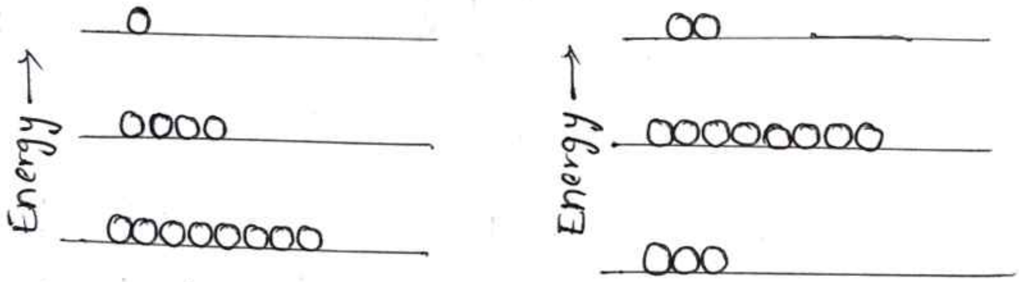
Boltzmann's principle gives the information about the fraction of atom found on avarage in any particular energy state at equilibrium temparature as

$$\frac{N_1}{N_2} = \exp(E_2 - E_1)/KT$$

$$= \exp \Delta E/KT$$

where $N_1 = N_0 \exp(-h\nu/KT)$ and

$$N_2 = N_0 \exp(-h\nu/KT)$$



Normal Distribution

population inversion

3. Stimulated Emission :-

If majority of atoms are present in higher energy state than the lower energy state then the process becomes very easy. so, if there is a population inversion there by only stimulated emission will able to produce Laser beam. Emission of radiation by transition of electron from higher to lower with supplying photon is called stimulated emission.

4. Amplification :-

The process of multiplying the energy is called amplification

Principle of Spontaneous and Stimulated Emission - Einstein's Co-efficients :-

In 1917, Einstein predicted the existence of two different kinds of processes by which an atom emits radiation. Transition b/w the atomic energy states is statistical process. It is not possible to predict which particular atom will make a transition from one state to another state at a particular instant. For an assembly of very large number of atoms it is impossible to calculate the rate of transitions b/w two states.

Einstein was the first to calculate the probability of such transition, assuming the atomic system to be in equilibrium with electromagnetic radiation.

Let us consider an atom exposed to light photons of energy $h\nu$. three distinct processes take place

a) Absorption

b) Spontaneous emission

c) Stimulated emission

An atom in the lower energy level or ground state energy level E_1 absorbs the incident photon radiation of energy and goes to the higher energy level (or) excited level E_2 as shown in figure

Before Absorption After Absorption

Where N_1 = Number of atoms in state E_1 H $\nu(Q)$ = Energy density of induced beam B_{12} = Probability of an absorption coefficient.
The number of spontaneous transitions N_{sp} taking place in time "Δt" depends on only no. of atoms N_2 lying in excited state.

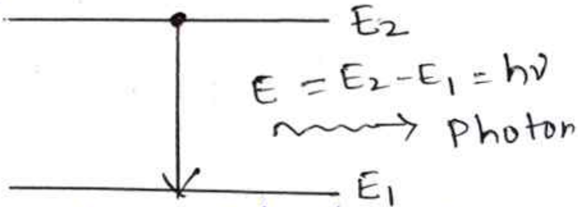
The rate of absorption (R_{12}) is proportional to the following factors. i. N_1 and Q

$$R_{12} = B_{12} N_1 Q \text{ ---------- } 1$$

Where B_{12} = Probability of spontaneous transition.

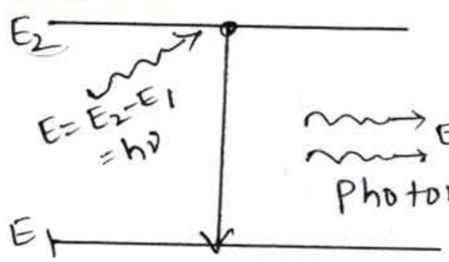
The number of spontaneous transitions N_{st} occuring during the time Δt may be written as

$$R_{sp} = A_{21} N_2 \text{ ---------- } 2$$



The number of stimulated transitions N_{st} occuring during the time Δt may be written as:

$$R_{st} = B_{21} N_2 Q \text{ ---------- } 3$$



Where B_{21} = Probability of stimulated emission
Under the thermal equilibrium number of upward transitions = number of downward transitions per unit volume per second.

So, we can write:

$$A_{21} N_2 + B_{21} N_2 Q = B_{12} N_1 Q \longrightarrow 4$$

The co-efficients A_{21} B_{12} B_{21} are known as Einstein cofficients

Number of atoms excited into higher energy level = Number of atoms that made. Trancition into lower energy level

$$B_{12} = B_{21} \quad \text{i.e. absorption = stimulated emission}$$

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

Rearranging the eq. ④, we have

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

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

$$Q = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2} \longrightarrow ⑥$$

Dividing numerator and denominator by $B_{12} N_2$ we have,

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

$$Q = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{B_{12}}{B_{21}}\right)\frac{N_1}{N_2} - 1} \longrightarrow ⑦$$

on substituting $\frac{N_1}{N_2} = e^{h\nu/KT}$ [∵ Boltzmann distribution]

$$Q = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{B_{12}}{B_{21}}\right) e^{h\nu/KT} - 1} \longrightarrow ⑧$$

Planks radiation formula for energy distribution

$$Q = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1} \longrightarrow (9)$$

Comparing the eq (8) & eq (9) we have

$$\frac{B_{21}}{B_{12}} = 1 \longrightarrow (10)$$

and $\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$ (or) $\frac{8\pi h}{\lambda^3}$ ——— (11)

Since $B_{12} = B_{21}$,

Einsteins coefficients are termed as A & B coefficient

Conclusion :-

- The Spontaneous emission is more predominant than the stimulated emission. The Laser light is due to stimulated emission. Therfore, stimulated emission should be greater than spontaneous emission. To achieve this population inversion is required.

- The equation (11) gives the relation between spontaneous emission and stimulated emission coefficients. Since this ratio is proportional to ν^3, the probability of spontaneous emission increases with the energy differences between the two states.

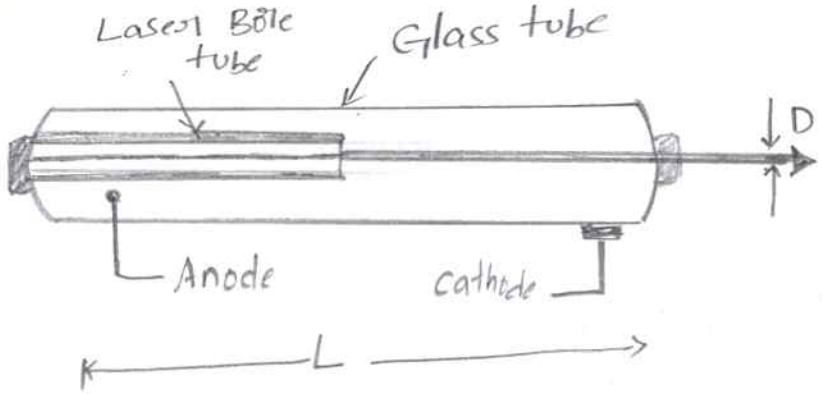
He-Ne Laser :-

The first gas laser to be operated successfully was the He-Ne laser in 1961 by the Scientist A Jawan. In this method, two gases helium & Neon were mixed in the ratio 10:1 in a discharige tube made of quartz crystal. The dimensions of the discharge tube are nearly 80 cm length and 1.5 cm diameter, with its windows Substances. The purpose of placing Brewster windows on either side of the discharge tube is to get plane polarized Laser output. windows slanted at Brewsters angle. $\theta = Tan^{-1}(n)$ where n = refractive index of the window substance. Two concave mirrors M_1 & M_2 are made of dielectric material arranged on both sides of the discharge tube so that their focci lines within the interior of discharge tube. One of the two concave mirrors M_1 is thick so that all the incident photons are reflected back into lazing medium. The thin mirror M_2 allows part of the incident radiation to be transmitted to get laser output.

Working :-

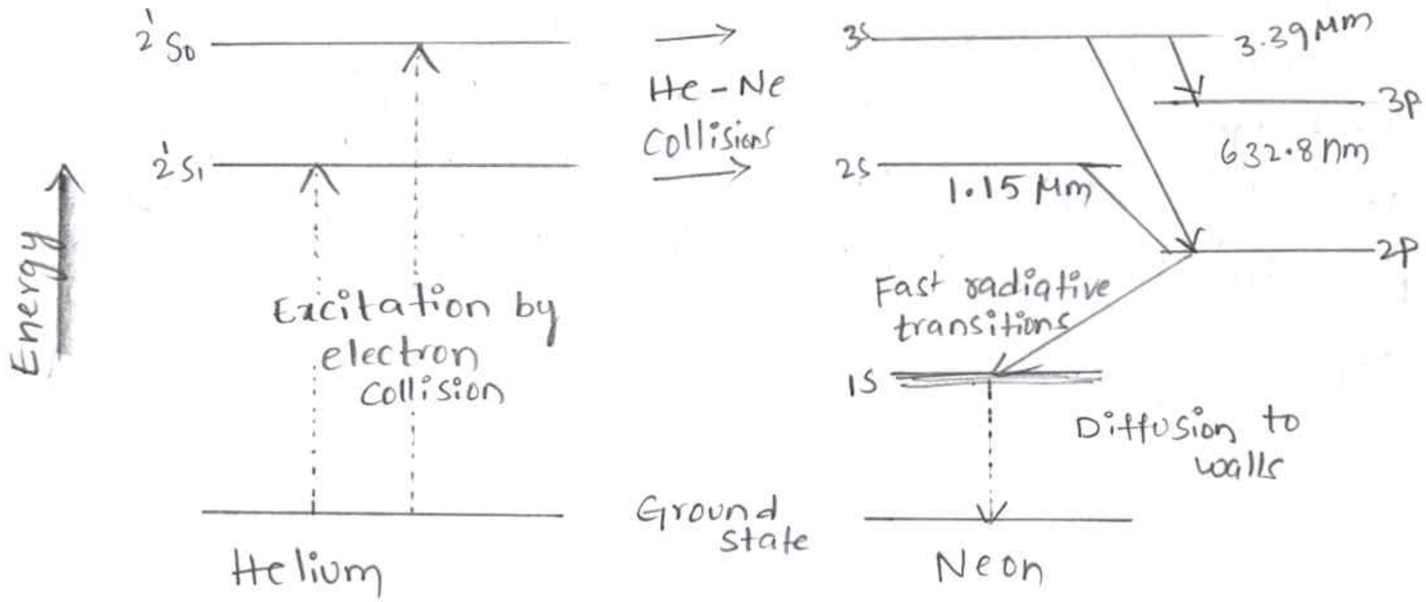
The discharge tube is filled with Helium at a pressure of 1mm of Hg and Neon at 0.1 mm of Hg. The gas discharge is established by the application of large Potential difference between the two electrodes of the discharge tube. The atoms are easily excited to higher energy levels by colliding with each other

Neon atoms present in less concentration, to excite the Ne atoms pumping process must be required. The exited He atoms collide with Ne atoms and transfer the exitation energy to the Ne atoms. Because both the atoms having higher energy levels very close to each other i.e., 20.61 ev & 20.66 ev for He and Ne respectively. Here He is the pumping medium and Ne is the Lasing medium. Neon atoms undergo a radioactive transfer through 18.7 ev energy level by emitting photons of wavelength 6328 Å. Ne atoms are pumped into higher energy levels continuously.



Description of Energy Levels :-

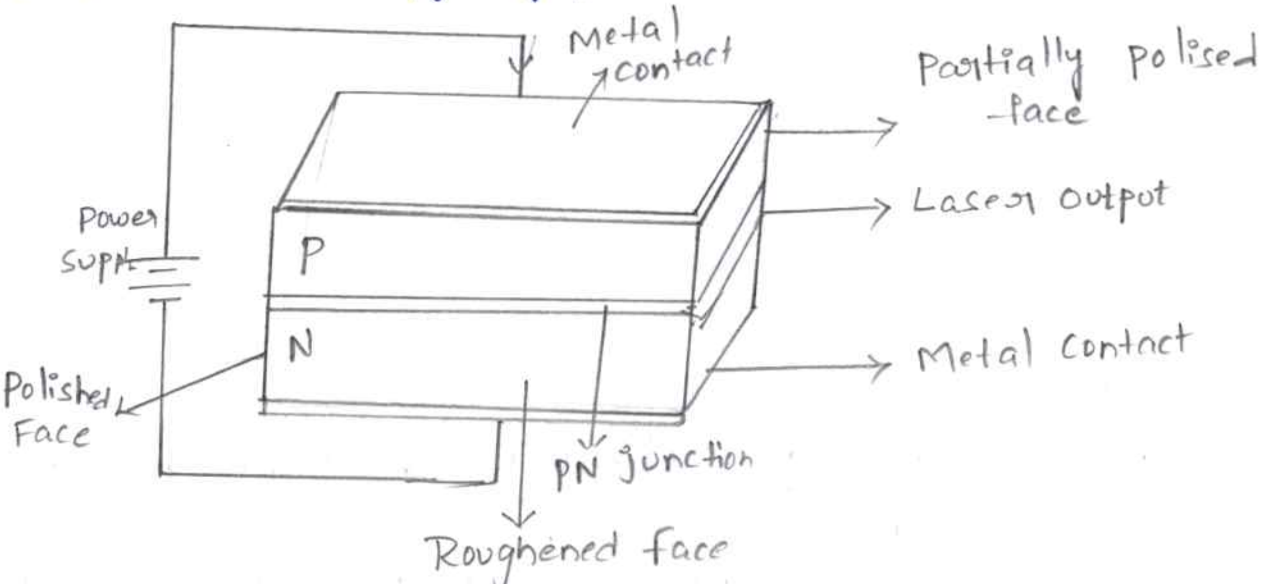
When electric discharge is set up in the tube, collisions b/w the atoms raises the amount of He & Ne atoms to the higher energy levels F_1 F_2 and E_4 E_6 respectively. Ne has two energy levels E_4 E_5 at nearly same energy level of F_2 to He. The Ne atoms drop down to the levels E_3, E_5 a radiative trasfer and reaches to the level E_2 through no radiative transfer. From level E_2 Ne atoms are brought back to the ground state through collisions with walls of the discharge tube. The transition from $E_6 \rightarrow E_5$, $E_4 \rightarrow E_3$ and $E_6 \rightarrow E_3$ emit radiations corresponding to the wavelength 3390 Å 1150 Å and 6328 Å respectively. 6328 Å is the well Known red light of He-Ne laser because other two wavelengths are not in the region of electromagnetic radiation (visible region)



Semi Conductor Laser

Principle and working:

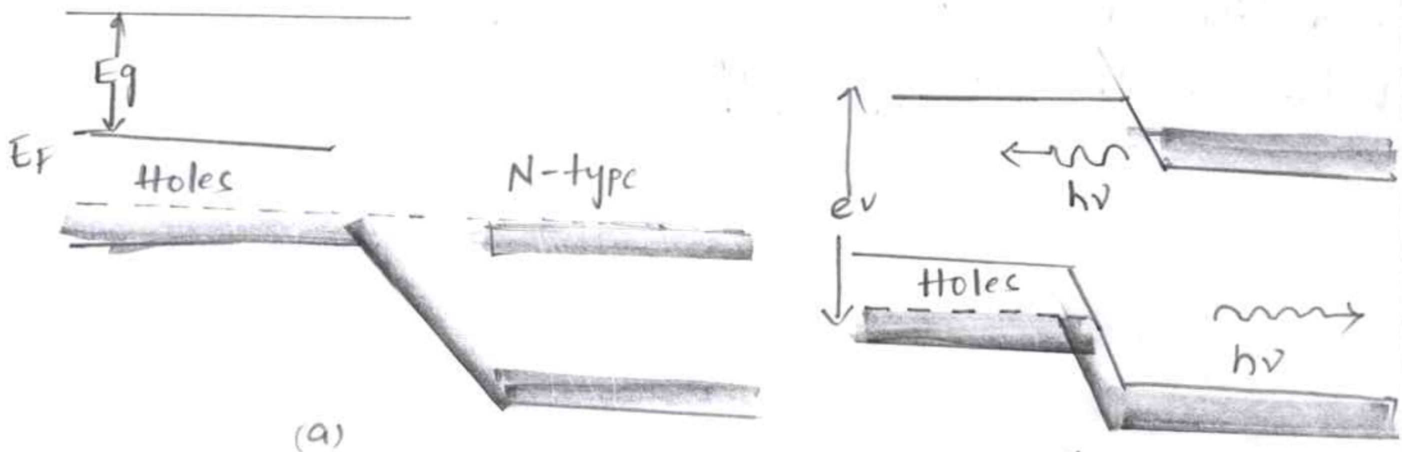
After the invention of He-Ne Laser in 1961, Laser have become at common use. In Conventional Lasers, Lasers are generated due to transition of e's from higher to lower energy level. But in semi conductor laser transitions takes place from conduction band to valancy band. The basic machanism responsible for light emission from a semi conductor laser is the recombination of electrons and holes at PN junction when current is passed through the diode. Stimulated emission can occur when the incident radiation stimulates an electron in conduction band to make a transition in to valancy band in that process radiation will be emitted As the current is further increased at some threshold value of current the amplification will takes place and laser begin to emit coherent radiation. The properties of semiconductor laser depends upon the energy gap i.e., the induced radiation must have a frequency greater than the value of the energy gap.



CONSTRUCTION OF SEMICONDUCTOR LASER

Working :-

Ga-As is heavily doped impurities in both P&N regions. N region is doped with tellorium & P region by Zn. When a forward bias with the source is applied to a semiconductor, electrons from N-region and holes from P-region move to cross the junction in opposite directions. In neutral region the electrons and holes recombination is possible due to transition of electron from CB to VB. For low currents the population inversion does not take place hence only spontaneous emission takes place and photon released are not coherent. when forward current is further increased beyond the certain threshold value population inversion takes place and coherence photons are released. The energy gap of Gallium Arsenide (Ga-As) is 1.487 ev and corresponding wavelength of radiation is 6435Å which is responsible for Laser medium.



(a) (b)

Applications :-

Lasers have wide applications in different branches of Science and engineering.

1. Lasers are used in optical communications, due to narrow band width
2. The laser beam can be used for communication b/w earth and moon (or) other satellites.
3. By the use of Lasers, the storage capacity of information in computers is greatly improved.
4. Lasers have industrial applications. They can make holes in diamond & hard steels
5. Lasers have wide medical applications, military purpose
6. These are used to find the size, shape biological cells such as erythrocytes.

UNIT-IV FIBER OPTICS

Optical fiber :-

A thin flexible and transparent cylindrical waveguide prepared for light propagation is called optical fiber and also called a light pipe. It is made up from the dielectric materials like glass and plastic.

Construction of an optical Fiber :-

Structure of an optical fiber consists of three parts : core, cladding and outer jacket. Core diameters range from 5 to 100 μm while cladding diameters vary from 125 to 750 μm

Core :

- The core is a cylindrical rod of dielectric material
- Light propagates mainly along the core of the fiber
- The core is generally made of glass or plastic
- The core is described as having an index of refraction n_1
- Refractive Index : The refractive index of a substance is a measure of the speed of light in that substance. It is expressed as a ratio of speed of light in vacuum relative to that in the considered medium ($n = c/v$)

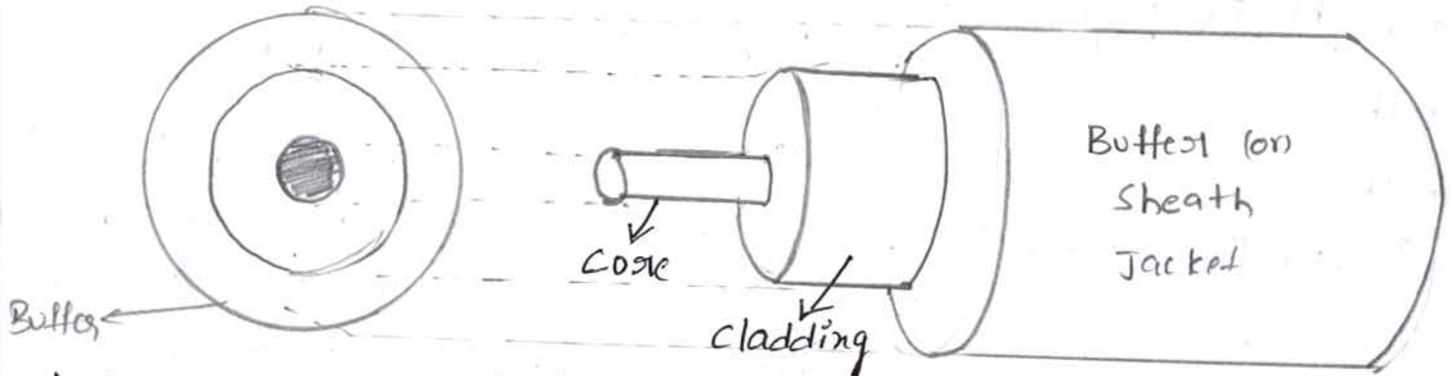
Cladding :

* The core is sorrounded by a layer of material called the cladding which is generally made of glass or plastic.

* The cladding layer is made of a dielectric material with an index of refraction n_2.
* The index of refraction of the cladding material is less than that of the core material.
* The cladding performs the following functions.
  1. Reduces loss of light from the core in to air
  2. Reduces scattering loss at the surface of the core
  3. protects the fiber from absorbing surface contaminants
  4. Adds mechanical strength.

Buffer :-

* The coating or buffer is a layer of material used to protect an optical fiber from physical damage.
* The material used for a buffer is a type of plastic
* The buffer is elastic in nature and prevents abrasions.



Working of optical fiber

The light propogates through optical fiber by the principle "Total internal reflection"

Total internal reflection appears due following reasons. When light travel from optically denser

~~denser~~ rarer medium to ~~rarer~~ denser medium the refracted ray moves towards normal drawn on the interface of media as in Snell's law. Conversly, if light traverse from denser to optically rarer medium, the refracted ray moves away from the normal drawn on the interface of the medium. If the angle of incidence increases as shown in fig (b) to certain value for which the refracted ray happen to be on the interface of medium with $r = 90°$. This angle of incidence is known as critical angle (θ_c) if the incident angle $i > c$ as shown in fig c.

Conditions for total internal reflections:

1. The ray of light should be traverse from denser to rarer medium
2. The incident angle should be more than the critical angle ($\theta_i > \theta_c$)

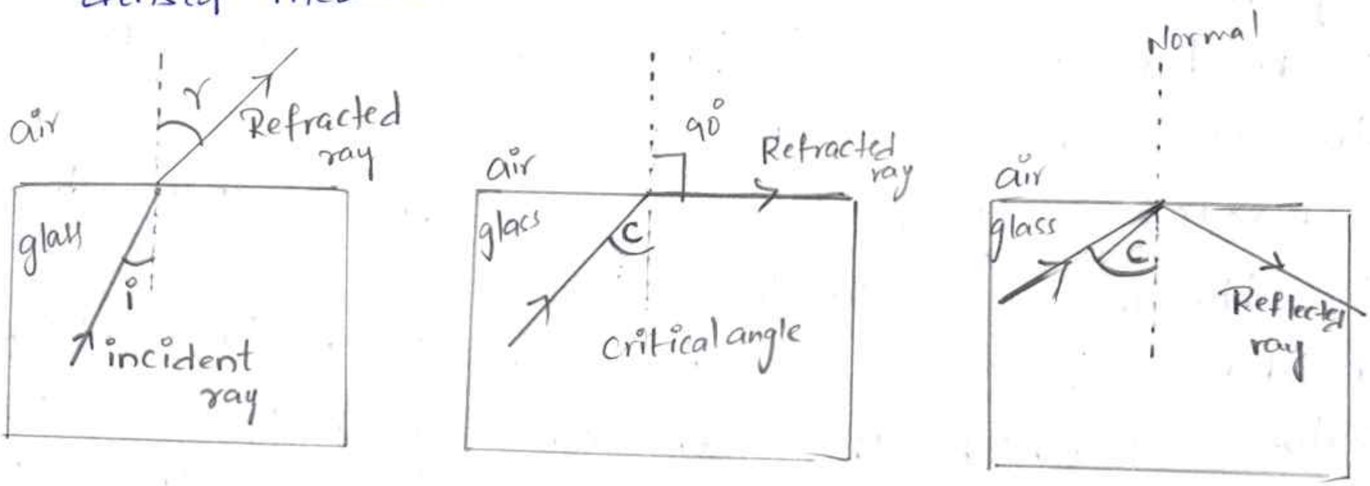
Total internal reflection :-

When light travels from denser to rarer medium it the incident ray exceeds the critical angle then refraction would be turned into reflection is called total internal reflection. If 'i' is the angle of incidence less than critical angle and reflection will not takesplace.

From figure

a. when $i < c$, it is refracted into rarer medium
b. when $i = c$, it traverses along the interface so that angle of refraction is $r = 90°$

c. when $i > c$, it is totally reflected back into the denser medium itself.



(a) when $i < c$ no reflection

(b) $i = c$ critical angle

(c) $i > c$ Total internal reflection

When $i = c$ then at critical angle, using Snells law

According to law of refraction

$$n_1 \sin\theta = n_2 \sin r$$

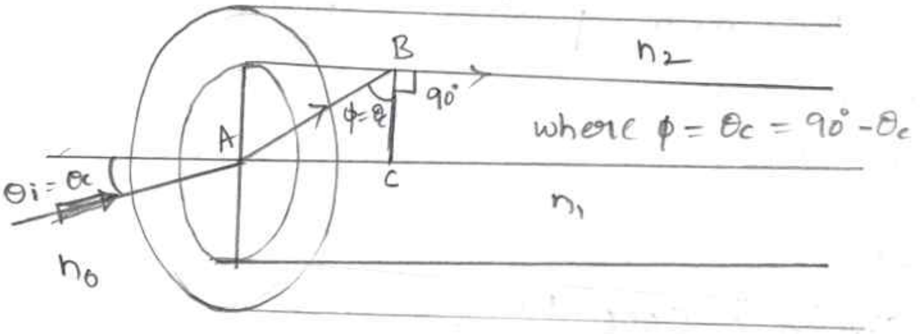
$$\theta = \theta_c \longrightarrow r = 90^\circ$$

$$\sin\theta_c = \frac{n_2}{n_1}\sin 90^\circ$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

Expressions for Acceptance angle (i_m) & Numerical Aperture (NA) :-

All light rays falling on the optical fiber are not transmitted through the fiber. only those light rays making $\theta_i > \theta_c$ at the core-cladding interface are transmitted through the fiber by undergoing TIR. For which angle of incidence, the refraction angle is greater than 900 will be propagated through TIR. Acceptance Angle (AA) : The maximum angle of incidence to the axis of optical fiber at which the light ray may enter the fiber so that it can be propagated through interface of core & cladding.



Consider an optical fiber through which the light is being sent. The end at which light emits enters is called louncking end. Let the refractive indices of the core and cladding be n_1 and n_2 respectively, $n_1 > n_2$. Let refractive index of the medium from which the light is launched ben 0. Let the light ray enter at an angle i to the axis of the fiber. The ray refracts at an angle r. The ray strikes the core-cladding interface at an angle θ. If θ is greater than the critical angle θ_c, the ray undergoes TIR at the surface. Let us now find out up to what maximum value of i at A, the TIR at B is possible

In triangle ABC, $90 - r = \theta \longrightarrow (1)$

From Snells law

$$\frac{\sin i}{\sin r} = \frac{n_1}{n_0}$$

$$\frac{\sin i}{\sin(90-\theta)} = \frac{n_1}{n_0}$$

$$\sin i = \cos\theta\left(\frac{n_1}{n_0}\right) \longrightarrow (2)$$

If θ is less than the critical angle θ_c, the ray will be lost by refraction. Therefore, limiting values for containing the beam inside the core by TIR is θ_c.

when $i = i_m$ the maximum possible angle of incidence at the fiber end face A, then $\theta = \theta_c$.

From equation (2)

$$\sin i_m = \cos\theta \frac{n_1}{n_0} \longrightarrow (3)$$

But from the interface of core & cladding at critical angle,

$$\sin\theta_c = n_2/n_1$$

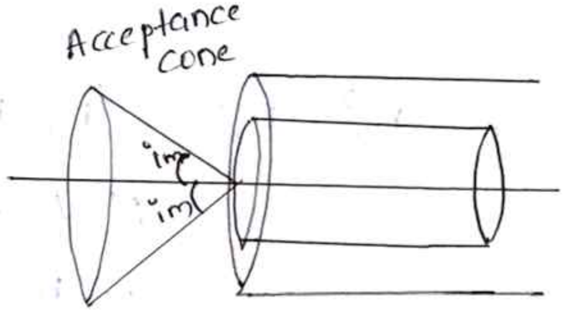
$$\cos\theta_c = \sqrt{(n_1^2 - n_2^2)}/n_0$$

by sub. this in eq (3) one can get

$$i_m = \sin^{-1}\sqrt{(n_1^2 - n_2^2)}/n_0$$

This angle i_m is the maximum acceptance angle.

Maximum Acceptance angle :-



Acceptance angle is defined as the maximum angle that a light ray can have relative to the axis of the fiber and propagate down the fiber. or the maximum angle or below which the light can suffer TIR is called acceptance angle.

Acceptance Cone :-

An optical fiber accepts only those rays which are incident within a cone having a semi full angle 2 im are accepted and transmitted along the fiber. Therefore the cone is called the acceptance cone. Light incident angle beyond im refracts through the cladding and the corresponding optical energy is lost.

Numerical Aperture :-

The numerical aperture NA is defined as the sine of the acceptance angle.

$$NA = \sin(i_m) = \sqrt{(n_1^2 - n_2^2)}\, n_0$$

NA determines the light gathering capability of the fiber. It is a measure of amount of light that can be accepted by a fiber.

Fractional index Change :-

It is the ratio of refractive index difference in core and cladding to the refractive index.

$$\text{Fractional index change } \Delta = \frac{n_1 - n_2}{n_1}$$

$$n_1 - n_2 = \Delta . n_1$$

$$n_1^2 - n_2^2 = (n_1 - n_2)(n_1 + n_2) \approx (n_1 - n_2)(2n_1)$$

$$\approx \Delta \cdot 2n_1^2 \text{ NA}$$

$$= n_1\sqrt{2\Delta}.$$

Classification of optical fibers :-

Based on variation in the core refractive index(n_1) optical fibers are devided in to two types.

1. Step index fiber
2. Graded index fiber

Based on mode of propagation, fibers are furthur classified 2 types as.

1. Single mode propagation and multimode propagation Step index fiber propagations.
2. whereas graded index fibers have multimode propagation only.

All together in total 3 types of fibers

1. Single mode step index fiber
2. Multimode step index fiber
3. Multimode graded index fiber.

Transmission of signal in optical fibers

Step index Fiber :-

Refractive index of core material is uniform throughout and undergoes a sudden change in the form of step at the core-clad interface.

Single Mode Step index fiber :-

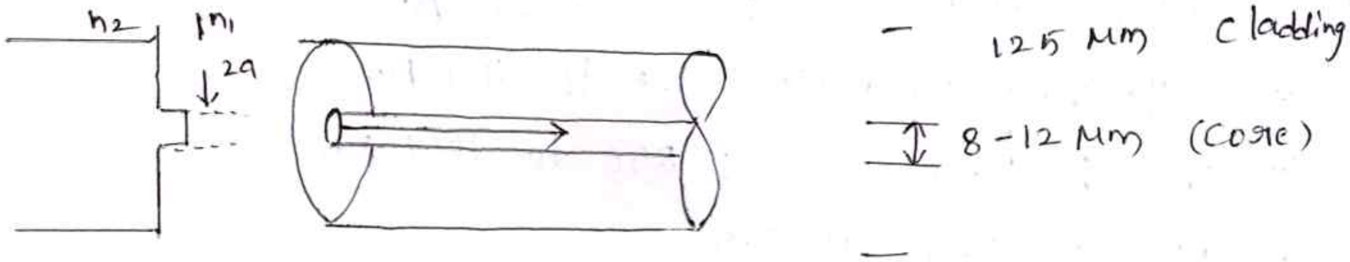
It has longitudinal cross section and the variation of the refractive index in step manner is called step index optical fiber. The refractive index of this optical fiber as a function index of distance can be mathematically represented as refractive index profile in single mode step index fiber

$$n(r) = n_1 \quad \text{when } r < a$$
$$= n_2 \quad \text{when } r > a$$

where r is radial distance and a is radius of core

For glass fiber

* Core diameter : 8 to 12 μm , usally 8.5 μm
* Cladding Diameter : Around 125 μm
* Sheath Diameter : 250 to 1000 μm
* NA : 0.15 to 0.25 usally 0.22.



For single mode step index fiber, It might appear that for V = 2.405 , i.e., N~2 This is not a mistake . It simply reflects the fact that the single mode contains two polarizations, which are indistinguishable from each other because of circular symmetry of the optical fiber. In other words, a single mode fiber contains two modes that are together.

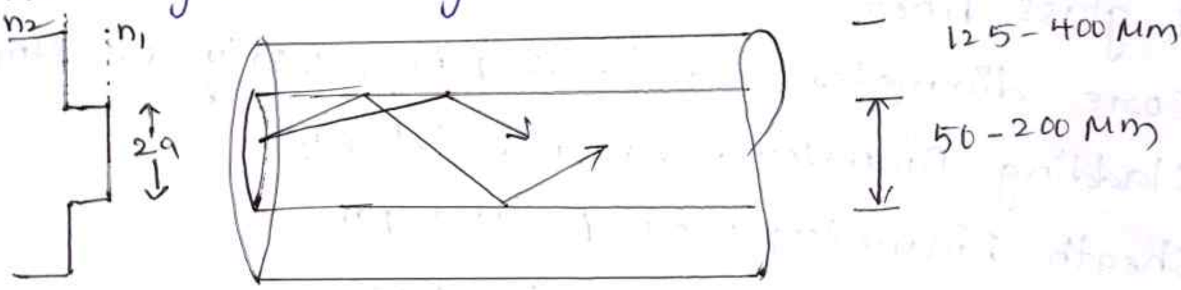
$V \text{ number} = \frac{2\pi}{\lambda} \cdot NA$

Number of mode propagation in S.I Single mode

$N_{SI} = V^2/2$

Multi Mode Step Index fibers :-

These fibers resonably large core diameters and large NA to facilitate efficient transmission to Coherent or coherent sources. These fibers allow finite number of modes. Normalized frequency is the cut-off frequency, below which a particular mode cannot exist. This is related to NA, Radius the core and wavelength of light



i) core diameter : 50 to 200 μm

ii) Cladding Diameter : 125 to 400 μm

iii) Sheath Diameter : 250 to 1000 μm

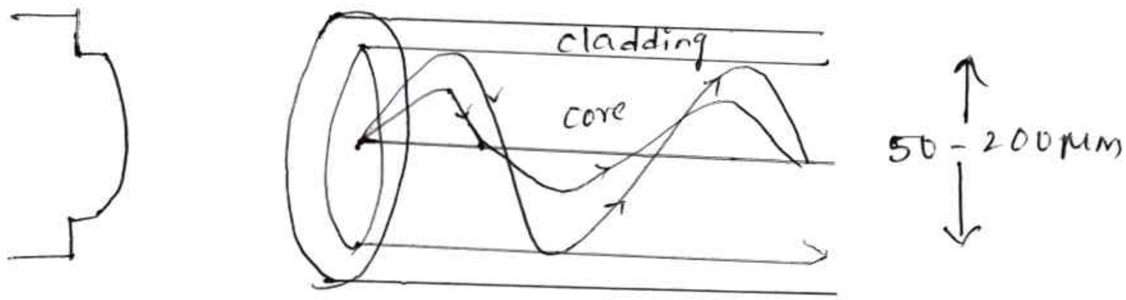
iv) NA : 0.16 to 0.5

Multimode Graded Index fibers :-

In case of graded index fiber, the refractive index of core is made to vary as a function of radial distance from the center of the optical fiber. Refractive index increases from one end of core diameter to centre and attains maximum value at the center. Again refractive index decreases as as moving away from center to towards the other end of the core diameter. The refractive index variation is represented as refractive index profile in multimode graded index fiber

$$n(r) = n_1 \sqrt{1 - 2(r/a)^{\alpha} \cdot \Delta} \quad \text{when } r<a$$

$$= n_2 \quad \text{when } r>a$$



$$V\text{-number} = (2\pi/\lambda) \cdot NA$$

Number of mode propagation in G.I multimode

$$N_{GI} = N_{SI}/2$$

i) Core Diameter : 30 to 100 μm

ii) Cladding Diameter : 105 to 150 μm

iii) Sheath Diameter : 250 to 1000 μm

iv) NA : 0.2 to 0.3

Attenuation and Losses in Fibers :-

When the light signal propagates in the optical fiber, losses arise due to different factors and these losses are referred to attenuation in optical fiber. The various factors causing attenuation in optical fiber are :

1. Material dispersion (or) impurity losses
2. Scattering losses
3. Absorption losses
4. Bending losses
5. Radiation induced losses
6. Inherent defect losses
7. Inverse squre law losses
8. Transmission losses
9. core and cladding losses.

Loses are expressed in describes per kilometer (dm/km)
The attenuation is given by

$$P_{out} = P_{in}\, 10^{-\alpha L/10}$$

wher P_{out} = Power at a distance L from the input P_{in} amount of power coupled in to fiber α = fiber attenuation factor in dB/km and L = Length of the optical fiber.

1. Material (or) impurity losses :-

The doped impurities present in the fabrication of an optical fiber in order to vary the refractive index causes, losses

2. Scattering losses :-

In a glass fiber, the glass contains many microscopic inhomogeneties and material content. Due to this a portion of the light Signal passing through the glass fiber gets Scattered. This Scattering losses vary inversly with the fourth power of wavelength.

3. Absorption losses :-

It is caused by the nature of the core material and varies inversly to the transparency of the material. For glass fibers, ion-resonance absorption ultraviolet absorption and infrared absorption are the three separate mechanisms which contributes to total absorption losses.

4. Bending losses :-

Whenever a fiber deviates from a straight line path radiate losses occur. These losses are prominent in improperly installed single mode optical cable.

5. Radiation induced losses :-

When the glass molecular matrix interacts with electrons, neutrons, X-rays and gamma rays, the structure of the glass molecules is altered and the fiberdarkness.

6. Inherent defect losses :-

The inherent defect present in the core-cladding causes losses of the propagating light signal through it. The surface defect in the core causes losses.

7. Transmission losses :-

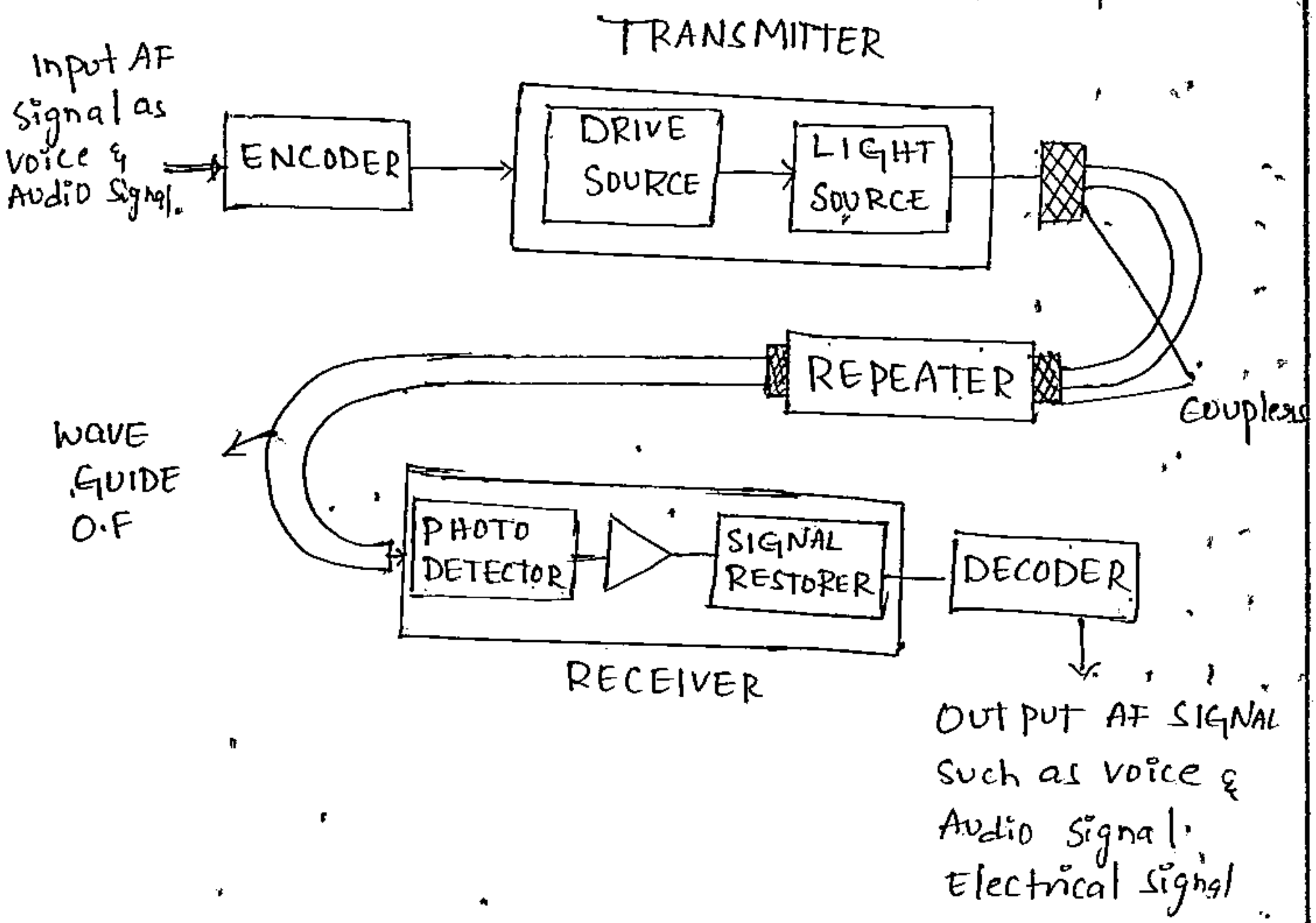
The losses are caused by light which is caught in the cladding material of the optical fibers. This light is either lost or trapped in the cladding layer.

Optical Fiber Communication System :-

Optical fiber communication system essentially consists of three parts namely

a) Transmitter
b) Optical fiber
c) Receiver

The transmitter includes modulator, encoder light source, drive circuit and couplers. Basically the fiber optic system simply converts an electrical signal to binary ~~data~~ a by an encoder



Transmitter :-

The transmitter consists of an analog to digital A/D converter called a decoder, and a light source. The A/D converter is used to convert continuous analog signals as voice or video (TV) signals into a series of digital pulses. This binary data comes out as a stream of electrical pulses and these pulses are converted into pulses of optical power, by modulating light source is either a light emitting diode LED or an injection laser diode (ILD). Then the drive circuit directly modulates the intensity of the light with the encoded digital signal. This digital optical signal is launched into the optical fiber cable. The light beam pulses are then fed into a fiber-optic cable using couplers, where they are transmitted over long distances.

Optical fiber :-

The optical fiber consists of a glass or plastic fiber core, a cladding and a protective jacket. To transmit signals to long distances, repeaters are used after certain lengths in the optical fiber. Finally at the end of the optical fiber, the signal is fed to the receiver.

Receiver :-

The receiver includes a light detector or photocell and a decoder. The light detector is very often either a PIN diode or an APD. The light detector, acting as the receiving element, converts the received light pulses back to pulses of electrical current. The electrical pulses are amplified and reshaped.

Medical applications of optical fiber:-

Fiber optic Scope in endoscope is one of the widely used optical technique to view the internal parts of the disease affected body.

The basic principle is the light from the source is transmitted through the outer fibers which falls on the inner portions of the body. The reflected light from the inside is carried by the inner fiber to the observer eye to observe the image of the illuminated portion.

optical fibers in sensors:-

Temparature sensor: The light from the source passes through the upper fiber, and then through the silicon layer having reflective coating at the end placed in the temparature field to be sensed. There reflected light after passing through the bottom fiber is detected by the photo detector.

When light passes through the silicon layer it absorbs certain light and hence, received intensity varies. The amount of light absorbed by the silicon varies with temparatur.

Unit-5:

SENSORS

Introduction:

The five senses - vision, hearing, smell, taste and touch - are universally recognized as the means by which humans and most animals perceive their universe. They do so through optical sensing, acoustic sensing, chemical sensing and mechanical sensing. But humans, animals, and even lower level organisms rely on many other sensors as well as on actuators.

Sensor:

→ It is a device that converts signals from one energy domain to electrical domain. The definition of the sensors can be understood if we take an example into consideration.

→ A device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism or a particular motion) and transmits a resulting impulse (as for measurement or operating a control)

→ In simple a device which provides a usable output in response to a specified input physical quantity. It acquires a physical quantity and converts it into a signal suitable for processing.

Sensor element:

Active element of a sensor is called a transducer. The fundamental transduction mechanism (eg a material) that converts one form of energy into another. Some sensors may incorporate more than one sensor element (eg. a compound sensor)

Sensor system:

A sensor and its assorted signal processing hardware (analog or digital) with the processing either in or on the same package or discrete from the sensor itself.

Types of sensors and Application:

Sensors may be classified in any number of ways. In general, sensors can be classified as passive and active sensors.

1. Passive sensors:

It is a sensor operate by changing one or more of their own properties to generate an electric signal. Passive sensors are sensors that do not require external power sources. These are also called self-generating sensors. Examples are thermoelectric sensors, solarcells, magnetic microphones, and piezoelectric sensors.

2. It is a sensor that requires an external power source. Active sensors are also called parametric sensors because of the dependence of their output on changes in sensor properties.

Examples are strain gauges, thermistors and capacitive or Inductive proximity sensors. In all of these, the sensing function is a change in the device properties, but they can only be used after a source is connected so that an electric signal can be modulated by the respective property change. Sensors are sometimes classified as absolute and relative.

3. Absolute Sensor:

An absolute sensor reacts to a stimulus in references to an absolute scale. An example is the thermistor. That is resistance relates to the absolute temperature.

4. Relative sensor:

A relative sensor's output depends on a relative scale. for example the output of a thermocouple depends on the temparature difference b/w two junctions.

another distinction That can be made is b/w contact and non contact sensors.

5. contact sensors:

A sensors that requires physical contact with the stimulus.

Eg: strain gauges, most temperature sensors.

6. Non-contact sensors:

Requires no physical contact. Examples: most optical and magnetic sensors, infrared, thermometers and etc. Some of the possible classifications are 5'

Applications of sensors:

* Transportation: weigh sensors, speed sensor, oxygen sensors, pressure sensors and etc
* Telecom: Photo detectors, current sensors
* Industrial: oxygen sensors for combustion optimization. Gas sensors, liquid level sensor. Temperature sensor, pressure sensors, fire and smoke detection and etc.
* Aviation: oxygen sensors used in OBBIGGS and OBOGGS aerospace applications. level sensors for hydraulic fuel reservoirs.
* Marine: Depth sensors, pressure sensors, wind sensors, Humidity sensors etc.

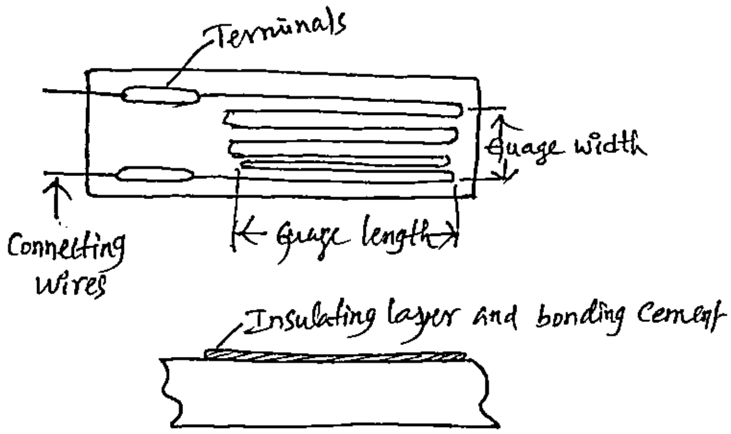
*Medical: Control of tank level in water baths. oxygen sensors for incubators and respiratory system.

*Agriculture: Humidity sensors, flow control sensors, gas sensors, automatic switch devices, photoelectric sensors, liquid level sensors, wet sensors and etc.

Strain and pressure Sensors:

The property called "strain" is considered to be the ratio of change in length compared to the original unstressed length of an object.

Strain gauge sensors ("strain gauge transducers") can measure this change in length caused by an external force and convert it into an electrical signal, which can then be converted to digital values, displayed, captured and analyzed. This works because a strain gauge sensors experiences a change in resistance as it is stretched or compressed.



It measures strain by means of a change in resistance. In a single sensor strain gauge, a metal foil pattern is mounted on a flexible substrate, which also serves to insulate the metal from the object under test. A current is run through the foil pattern.

When the object under test is stressed in the axis parallel with the foil pattern there is a change in resistance which is proportionate to the amount of deflection.

The strain gauge is also sometimes called an electrical resistance strain gauge or simply a resistance strain gauge.

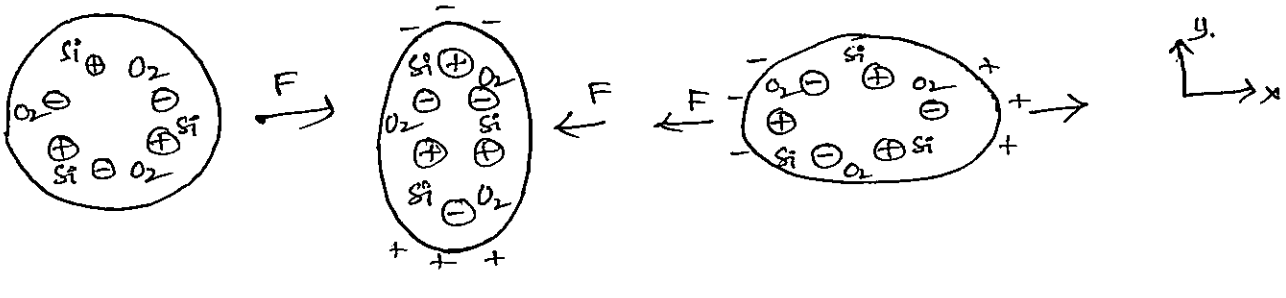
They are used for measuring deflection, vibration, load, torque, pressure, stress and strain. In short, they are employed for the measurement of forces. Strain gauge sensors can measure this change in length caused by an external force and converted it into an electrical signal, which can then be converted to digital values, displayed, captured and analyzed. This works because a strain gauge sensor experiences a change in resistance as it is stretched or compressed.

PIEZOELECTRIC EFFECT:

The piezoelectric effect is the generation of electric charge in crystalline materials upon application of a mechanical stress. The opposite effect, often called electrostriction, is equally useful. The application of a charge across the crystal causes mechanical deformation in the material. The piezoelectric effect occurs naturally in materials such as quartz and has been used for many decades in so-called crystal oscillators.

The piezoelectric effect can be explained in a simple model by deformation of crystals. Starting with a neutral crystal, a deformation in one direction displaces the molecular structure so that a net charge occurs as shown. In this case the net charge on top is negative. Deformation on a perpendicular axis generates charges on the perpendicular axis.

These charges can be collected on electrodes deposited on the crystal and measurement of the charge is then a measure of the displacement or deformation. In addition, the behavior of the crystal depends on how the crystal is cut, and different cuts are used for different applications.



The polarization vector in a medium is related to stress through the following simple relation.

$$P = d\,\sigma \quad cm^2$$

where d is the piezoelectric constant and σ is the stress in the material. In reality the polarization is direction dependent in the crystal and may be written as.

$$P = P_{xx} + P_{yy} + P_{zz}$$

Where x, y, z are the standard axes in the crystal. The relation above now becomes

$$P_{xx} = d_{11}\sigma_{xx} + d_{12}\sigma_{yy} + d_{13}\sigma_{zz}$$

$$P_{yy} = d_{21}\sigma_{xx} + d_{22}\sigma_{yy} + d_{23}\sigma_{zz}$$

$$P_{zz} = d_{31}\sigma_{xx} + d_{32}\sigma_{yy} + d_{33}\sigma_{zz}$$

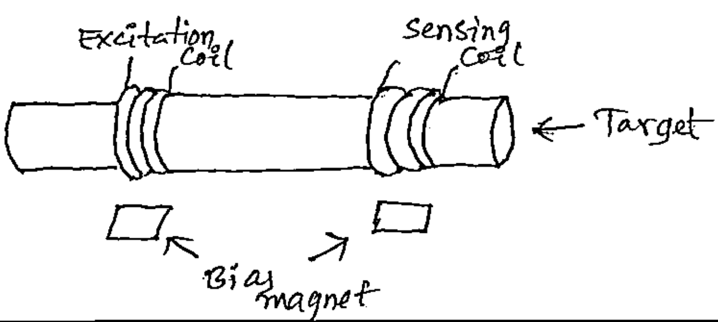
Now d_{ij} are the piezoelectric coefficients along the orthogonal axes of the crystal. Clearly then the coefficient depends on how the crystal is cut.

MAGNETOSTRICTION SENSOR:

Magnetostriction materials converts magnetic energy to mechanical energy and vice versa. As a magneto-strictive material is magnetized, it strains. If an external force produces a strain in a magneto-strictive material, the materials magnetic state will change. This bi-directional coupling b/w the magnetic and mechanical states of the material provides a transduction capability that can be used in a variety of ways to measure a property of interest. The magneto-strictive process relating the magnetic and mechanical states can be described with two coupled linear equations. These equations of states for a magnetostrictive element are expressed in terms of mechanical parameters.

NONCONTACT MAGNETOSTRICTIVE SENSOR:

It uses the magnetostrictive properties of the target material to excite elastic waves which can be measured and monitored to characterize the target. The system can be used directly on a target made of ferromagnetic material or by attaching a magnetostrictive material to a nonferromagnetic specimen. The magnetostrictive sensor has the advantage of being less intrusive and more simply implemented than traditional inspection methods. The sensors; shown in figure consists of a transmitting element (pulse generator excitation coil, power amplifier and bais magnet) surrounding the object, which generates the mechanical wave via magnetostrictive excitation. A receiving or sensing coil located at a distance from the excitation coil mesures a signal due to magnetostrictive waves.



changes in the material geometry will generate signals. These signals can be used to characterize the material and identify the onset of corrosion or measure internal stresses. Defects, such as pitting, wall thinning, and cracks can be detected. Experimentation has shown that the wave attenuation increases with the degree of corrosion. This method has been used successfully to identify corrosion in strands, reinforced bars, water pipes and other system where noninvasive monitoring techniques are preferred.

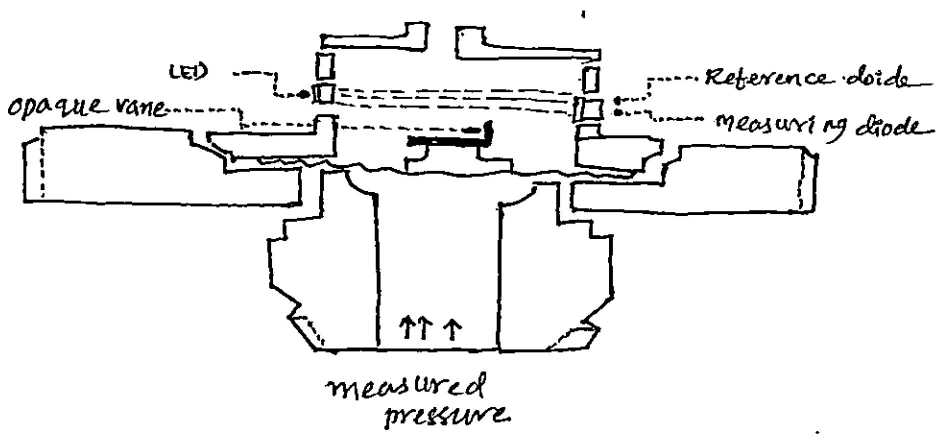
MAGNETOSTRICTIVE FIBER OPTIC SENSOR:

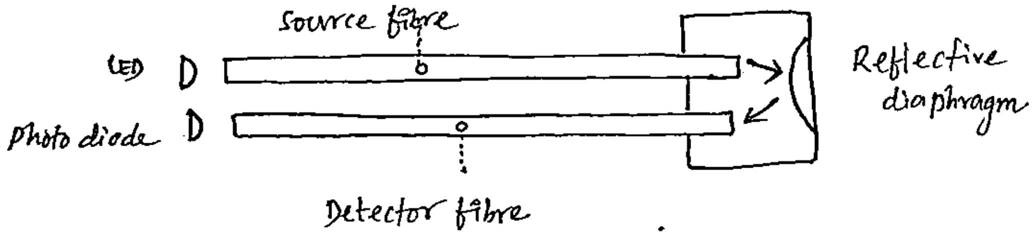
An in situ fiber optic sensor coupled to a magnetostrictive element has been used for composite resin characterization. Thermoset polymer matrix composite cures can be monitored to allow adaptive control of the cure process, thus optimizing mechanical properties and reducing costs. The fiber optic sensor is coated with a magnetostrictive material, such as Metglass, and embedded in the composite resin. The magnetostrictive material is excited during the cure and the loss tangent, the ratio of the dissipated viscous energy to the stored mechanical energy, is measured. The loss tangent decreases to a minimum following solidification at which time the fiber optic sensor can be used for inservice health monitoring. This method of monitoring the cure process, known as dynamic mechanic analysis (DMA), is insensitive to the fiber optic sensor output.

FIBER OPTIC PRESSURE SENSOR:

Optical pressure sensors detect a change in pressure through an effect on light. In the simplest case this can be a mechanical system that blocks the light as the pressure increases. In more advanced sensors, the measurement of phase difference allows very accurate measurement of small pressure changes.

Working principle: intensity-based optical pressure sensor, an increase in pressure will cause the source of light to be progressively blocked. The sensor then measures the change in light received.





For example, in the simple mechanism shown above, the pressure moves a diaphragm and the attached opaque vane blocks more of the light from the LED. The fall in light intensity is detected by the photodiode and gives a direct measurement of pressure.

A simple optical pressure sensor like this needs a reference photodiode which is never blocked by the vane. This allows the sensor to correct for changes in the light output due to other factors, like aging of the light source, variations in supply voltage, etc.

These mechanical systems are relatively large. Much smaller versions can be constructed with a reflective membrane and two optical fibres, one as a source of light and the other to receive the reflected light. Pressure bends the membrane and changes the amount of light reflected back to the dectector.

Other fibre-optic sensors use interferometry to measure changes in the path length and phase of the light caused by changing pressure.

Fibre-optic pressure sensors can be classified as either extrinsic, where the sensing takes place outside the fibre, or intrinsic, where the fibre itself changes in response to pressure.

Very sensitive optical measurements can be made by exploiting interferometry: measuring the change of phase between light that has taken two different paths. This can detect changes in distance corresponding to a fraction of the wavelength of light. This is one of the best optical sensor technologies. It is simple, accurate and easily scaled for different sizes and pressure ranges.

TEMPERATURE SENSORS:

The most commonly used type of all the sensors are those types of sensors which detect Temperature or heat

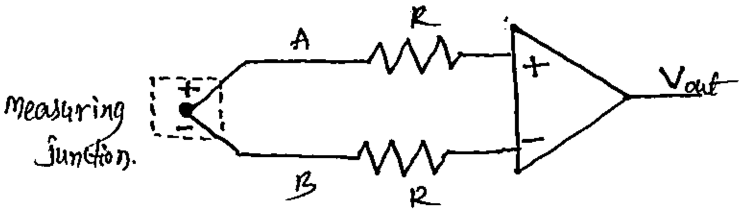
Temperature indicates:

- Shock by measuring the big-toe temperature
- infection by measuring skin temp.
- Arthritis by measuring temp. at the joint
- Body temp during surgery
- Infant body temp. inside incubators.

Temperature Sensors:

Measure the amount of heat energy or even coldness that is generated by an object or system, allowing us to "sense" or detect any physical change to that temperature producing either an analogue or digital output.

Thermocouple Amplification Sensor:



The type of amplifier, either discrete or in the form of an operational Amplifier needs to be carefully selected, because good drift stability is required to prevent recalibration of the thermocouple at frequent intervals. This makes the chopper and instrumentation type of amplifier preferable for most temperature sensing applications.

There are many different types of Temp. Sensors available and all have different characteristics depending upon their actual applications. A temperature sensor consists of two basic physical types.

1. Contact Temperature Sensor Types.

These types of temperature sensors are required to be in physical contact with the object being sensed and use conduction to monitor changes in temperature. They can be used to detect solids, liquids or gases over a wide range of temperatures.

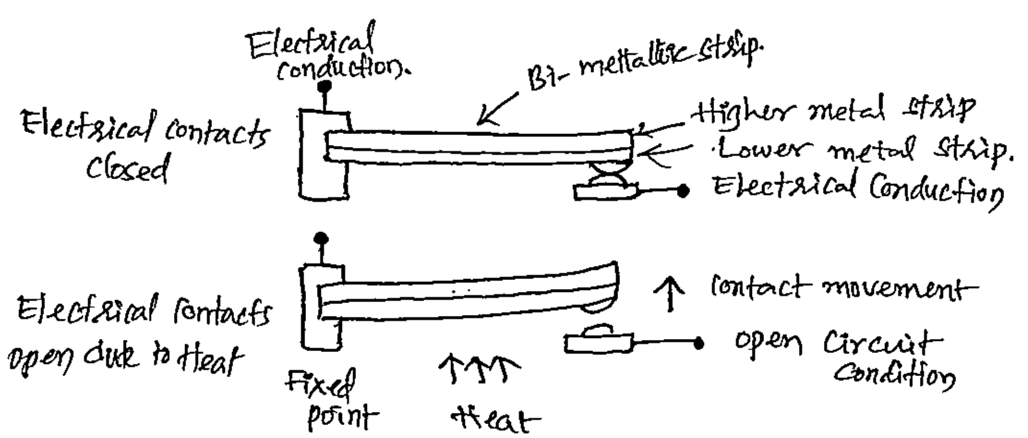
2. Non-Contact Temp. Sensor Types:

These types of temperature sensor use convection and radiation to monitor changes in temperature. They can be used to detect liquids and gases that emit radiant energy as heat rises and cold settles to the bottom in convection currents or detect the radiant energy being transmitted from an object in the form of infra-red radiation (the sun).

The Bi-metallic Thermostat Sensor:

The Thermostat is a contact type electro-mechanical temperature sensor or switch, that basically consists of two different metals such as nickel, copper, tungsten or alluminium etc, that are bonded together to form a Bi-metallic strip. The different linear expres expansion rates of the two dissimilar metals produces a mechanical bending movement when the strip is subjected to heat.

The bi-metallic strip can be used itself as an electrical switch or as a mechanical way of operating an electrical switch in thermostatic controls and are used extensively to control hot water heating elements in boilers, furnaces, hot water storage tanks as well as in vehicle radiator cooling systems



The thermostat consists of two thermally different metals stuck together back to back. When it is cold the contacts are closed and current passes through the thermostat. When it gets hot, one metal expands more than the other and the bonded bi-metallic strip bends up (or down) opening the contacts preventing the current from flowing.

There are two main types of bi-metallic strips based mainly upon their movement when subjected to temperature changes. There are the "snap-action" types that produce an instantaneous "ON/OFF" or "OFF/ON" type action on the electrical contacts at a set temperature point, and the slower "creep-action" types that gradually change their position as the temperature changes.

Snap-action type thermostats are commonly used in our homes for controlling the temperature set point of ovens, irons, immersion hot water tanks and they can also be found on walls to control the domestic heating system.

Creeper types generally consists of a bi-mettalic coil or spiral that slowly unwinds or coils-up as the temperature changes. Generally, creeper type bi-metallic strips are more sensitive to temperature changes than the standard snap ON/OFF types as the strip is longer and thinner making them ideal for use in temp gauges and dials etc.

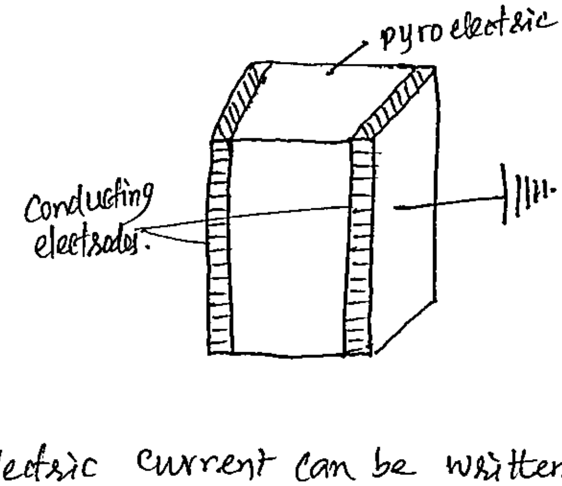
although very cheap and are available over a wide operating range, one main disadvantage of the standard snap-action type thermostats when used as a temp sensor, is that they have a large hysterisis range from when the electrical contacts open until when they close again. For ex: it may be set to 20°c but may not open until 22°c or close again until 18°c.

PYROELECTRIC SENSOR:

The magnitude of spontaneous polarization is dependent on temperature. On changing the temparature, electrical changes can be detected across the crystal faces perpendicular to the polar axis. The effect is called the PYRO electric effect. However, there is a difference b/w a pyroelectric crystal and a ferroelectric crystal. In some pyro electrics, the direction of polarization can be reversed by the application of an electric field. These are then referred to as ferroelectric and a plot of applied electric field and spontaneous polarization exhibits hysterisis. It is called a P-E loop and is analogous to the B-H loop in magnetism. Thus all ferroelectric crystals are pyroelectric but not all pyroelectric crystals are ferroelectric.

A simple model will serve to illustrate the principle of operation of a pyroelectric detector. Consider a thin flat slice of a pyroelectric crystal as shown in below fig. with conducting electrodes of area A and with a spontaneous polarization P oriented normal to A. The bound surface charge on the crystal is given by

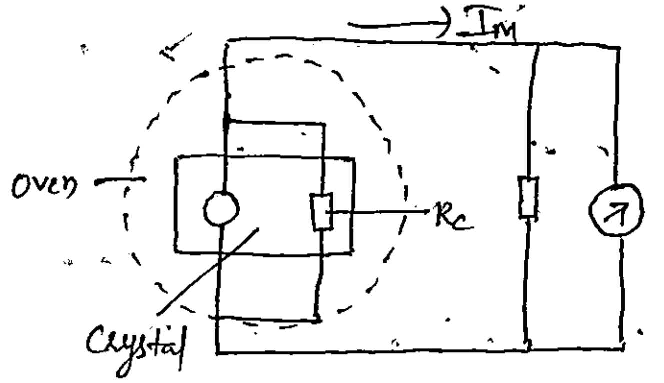
$$Q = AP \quad \text{where } P = P = \chi E + P \text{ is total polarization.}$$



The pyroelectric current can be written as $I = pA\left(-\frac{dT}{dt}\right)$

where $p = \partial P / \partial T$ is the pyroelectric Coefficent.

So, the pyroelectric current depends on the pyroelectric co-efficient which is a property of the material, electrode area, and the rate at at which the thermal signal is modulated or chopped.

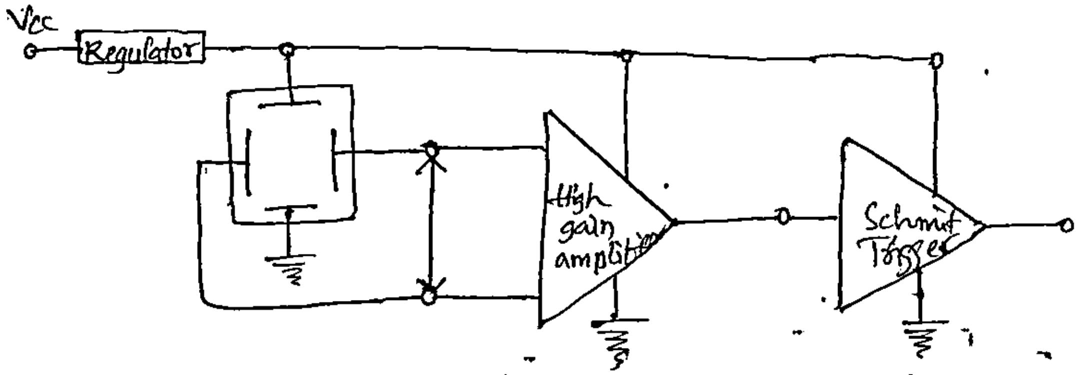


HALL EFFECT SENSOR:

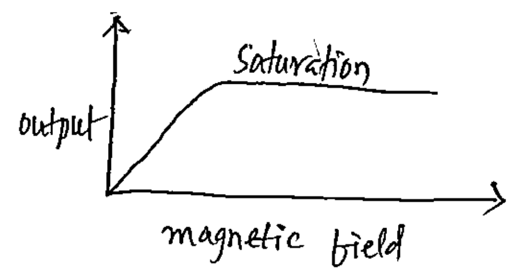
Development of hall voltage by applying electric and magnetic field perpendicular to each other to semiconductor is called Hall effect.

The basic Hall element of the Hall effect magnetic sensors mostly provides very small voltage of only a few micro volts per Gauss; so therefore, these devices are usually manufactured with built-in high gain amplifiers.

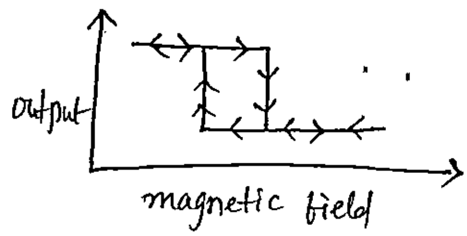
There are two types of Hall effect sensors, one providing analong and the other digital output. The analog sensor is composed of a voltage regulator, a Hall element and an amplifier from the circuit schematics we can see that the output of the sensor is analog and proportional to the Hall Element output or the magnetic field strength. These type of sensors are suitable and used for measuring proximity because of their continuous linear output.



On the other hand, the digital output sensors provide just two output states, either "ON" or "OFF". These type of sensors have an additional element as illustrated in the circuit schematics. That's the Schmitt Trigger which provides hysterisis or two different thresholds levels so the output is either high or low. An example of this type of sensors is the Hall effect switch. They are often used as limit switches, for ex: in 3D prints and CNC machines, as well as for detection and positioning in industrial automation systems.



Analog output



Digital output.