UNIT-III : Opto Electronics

Date/ [redacted]

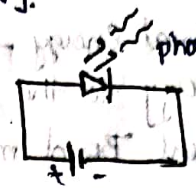
→ Opto: Which are using the light energy.

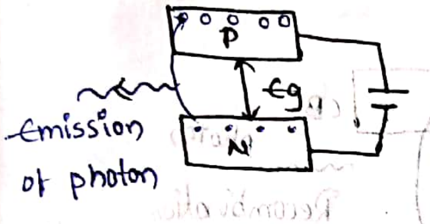
→ electronics: Deals the working of devices.

light Energy $\xrightarrow[\longleftarrow]{\text{converted}}$ electrical energy.

LED light Emitting diode → photons.

works under F.B (Forward Bias)





Syllabus

⇝ Radiative and Non-radiative recombination mechanism in semi conductors

⇝ LED and Semiconductor lasers : Device structure, Materials, characteristics and figures of merit
electrical energy converted into light energy (F.B)

⇝ S.C photo detectors: Solar cell, PIN and Avalanche & their structure, materials, working principle and characteristics
Light energy converted into electrical energy (R.B)

Laser : Input → output.

photons → photon I, photon II

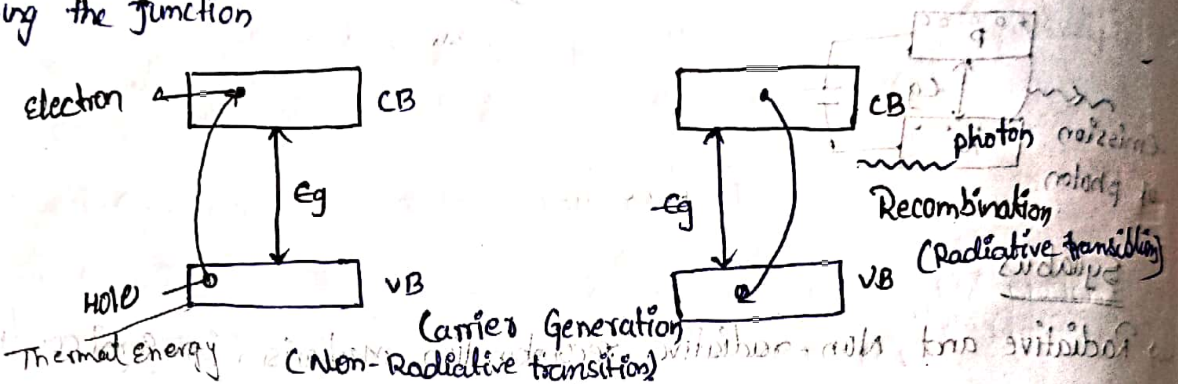
→ Radiative and Non-Radiative :-

Q) What is Radiative & Non-Radiative Recombination mechanism in S.C?

→ In S.C Breaking of covalent Bond leads to the Generation of a charge carriers i.e ē - hole pair Generation. this process may be Represented as [Covalent Bond + Thermal energy]

∴ Covalent Bond + Thermal energy —Rupture→ (Electron + Hole) pair

→ By given the thermal Energy to the S.C covalent bond is Broken & The ē's is released from the covalent Bond moving like a free ē & recombine with the hole (by crossing the Junction



Condition :- $\boxed{E_g = h\nu}$

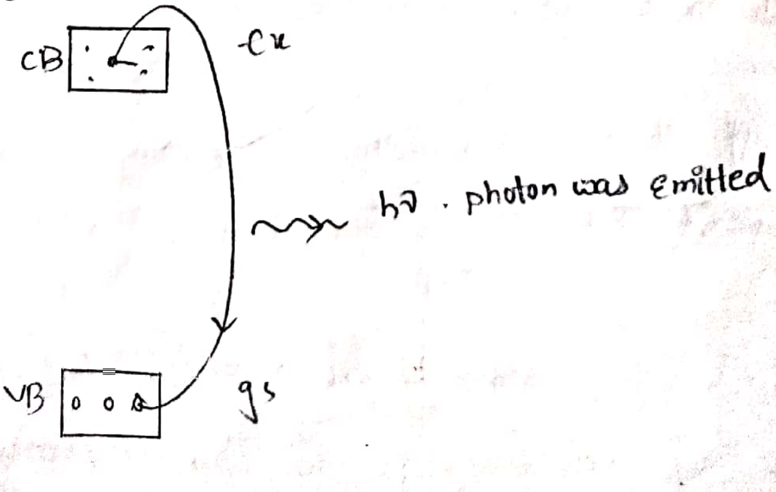
Where E_g is known as Energy gap, $h\nu$ is the Energy of Emitted photon

$$\therefore \quad E_g = \frac{hc}{\lambda} \left[\nu = \frac{c}{\lambda}\right]$$

λ is the wave length of emitted photon
c is the velocity of light
h is the plank's constant

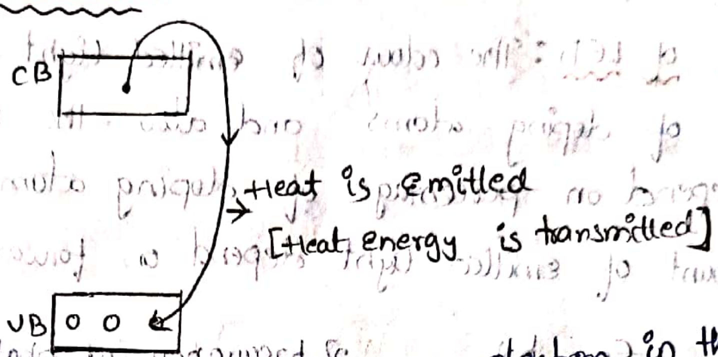
⇒ E_g values are 1.7eV to 3eV [depending on the type of the Diode E_g values changes]

⇒ Radiative Recombination :-



→ Radiative Recombination Occurs when an electron in the conduction Band Recombines with a hole in the valancy Band and the Excess is emitted in the form photon.
(In recombination Process if their exist a emission of photon it is known as Radiative Recombination)

Non - Radiative Recombination :-

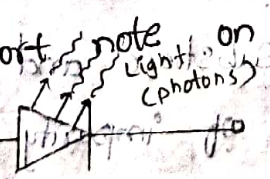


→ Non-Radiative Recombination occurs when an electron in the CB recombines with a hole in the VB and the excess in energy is transmitted (emitted) in the form of Heat in the S.C Crystal lattice.
(In recombination. Process only heat is the transmitted to the S.C crystal is known as non - radiative Recombination)

Note 1 :- 1) Spontaneous Emission & Stimulated Emission is case of laser diode is known as Radiative Recombination Process
2) In Hetro junction Diode laser their exist a leakage of current due to Heat energy transmitted to the crystal. This is the phenomenon of non-radiative recombination.

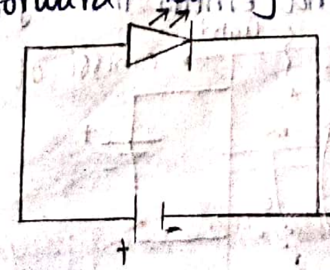
Q) What is LED ? write short note on construction & working of LED.

LED:



Light emitting Diode: which converts the electrical energy into light energy

→ LED works under forward Biasing condition.



→ NOTE :- The Amount of light Emitted by the LED under forward Bias in condition is directly proportional to forward current (I_f)

→ Fabrication of LED :- It is fabricated by using 3^{rd} (III) - IV compound semiconductors such as GaAs which have direct bonding

→ Ga (which is direct band gap s.c), Ga_xAs_xP (Gallium, arsenite, phosphite) GaP (Gallium phosphide)

→ Out Put of LED : The colour of emitted light by the LED is depend on Percentage of doping atoms and also the wave length of emitted light is also depend on percentage of doping atoms.

→ The Amount of emitted light depend on forward current (I_f)

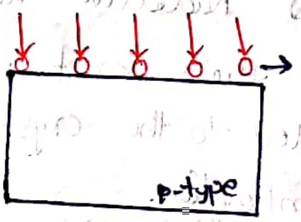
Equation :- $E_g = h\nu$ ν frequency of photon.

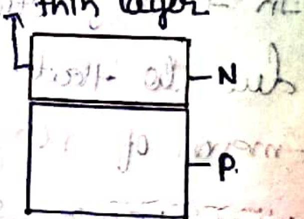
$$\boxed{E_g = \frac{hc}{\lambda}}$$ $\nu = \frac{c}{\lambda}$, λ wavelength of emitted photon

$$\boxed{\lambda = \frac{hc}{E_g}}$$ E_g - energy gap (eV)

Construction :~

Diffusion method :

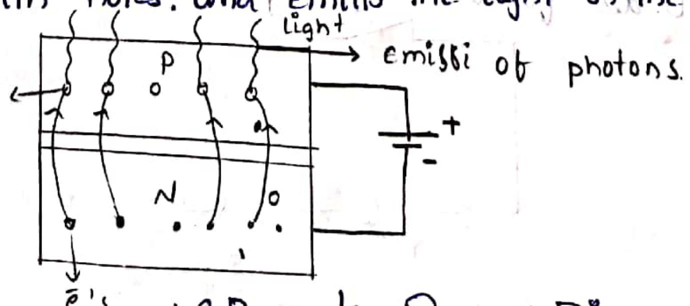




→ N- layer is grown on the substrate and also p-layer is grown which is contact By diffusion of impurity atoms P & N layers are developed

Working :-

→ electrons Recombines with holes. and Emitts the light in the form of photons.



LED under Forward Bias

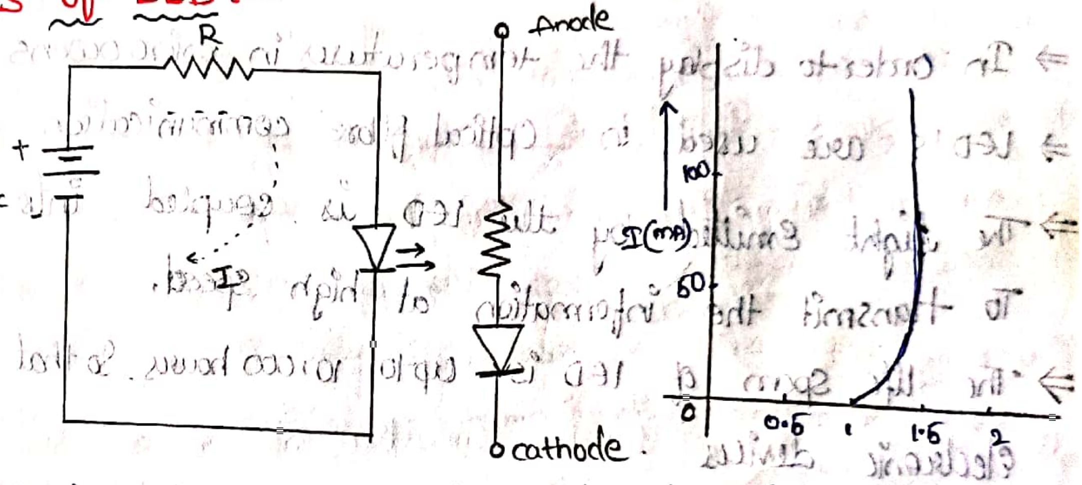
→ LED is always forward Bias to give the out put in the form of photons the light energy is realesed at the junction when the recombination of $\bar{e}$'s with holes takes place.

→ The difference of energy in case of $\bar{e}$'s which are recombine with the holes is radiated in the form of light Energy

NOTE:- i) in ordinary diodes the difference of energy in case of Electron hole recombination is radiated in the form of heat

ii) Ordinary diode works under forward & Reverse Biase but LED works under forward Bias in condition only.

V-I characteristics of LED :~



⇒ the out put is constant emitted by the LED is depend on input voltage & current supplied to the diode.

⇒ The intensity of the light is depend on magnitude of forward current (I_f)

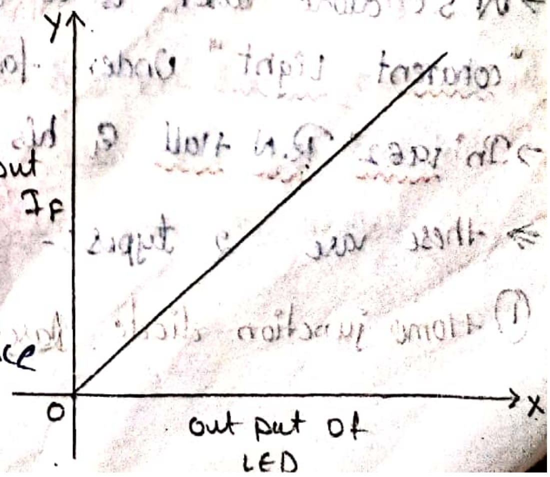
⇒ The break down voltage of LED is different as compare to normal diode [voltage drop V_D = 1.5 V to 2.5 V] current = 10 mA to 50 mA

⇒ LED's are not able with stand Reverse Bias of even very small voltages. for this Reason it is neccessary to Assure that Reverse bias is never applied to an LED

⇒ Applications of LED :-

↪ LED used Burgulars Alarm which make Emits light in IR region

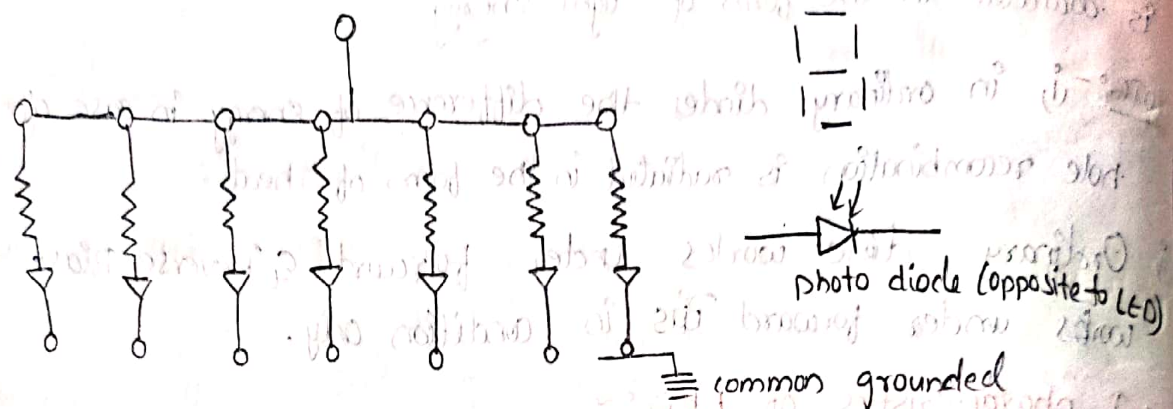
↪ LED can be used as indicator weather the device is in on (or) off condition.



~> CRT's are replaced By LED's is solid state video display.

~> LED's can be used in display sigment

~> In order to display the number [α numaric] LED's are used in seven sigment display.



⇒ In order to display the temperatures in micro owens LED are used

⇒ LED's are used in optical fibre communication system.

⇒ The light emitted by the LED is coupled into the optical fibre To transmit the information at high speed.

⇒ The life span of LED is upto 10,000 hours. So that it can be used in electronic devices

⇒ With nano second there exist a out put from the LED so that LED operation quick process. It is used to trasfer the energy one circuit to another

Semiconductor laser:- (Semiconductor, Diode laser)

⇒ What is Semiconductor laser? write a note on construction & working of S.C laser with neccessary diagrams what are the applications of S.C laser

⇒ A S.C diode laser is a specially made P-N Junction Diode that emits "coharent Light" Under forward bias

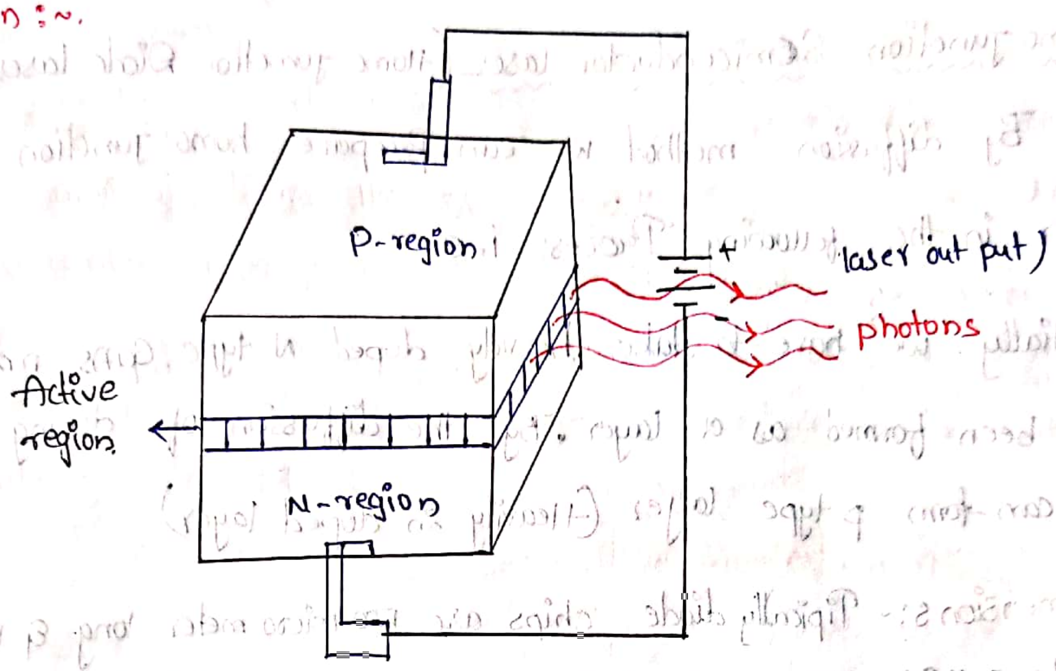
⇒ In "1962" R.N Hall & his co-workers made the first S.C laser.

⇒ these are 2 types:-

① Homo junction diode laser:- P&n materials prepared from same material.

(2) Hetero junction diode lasers:- p & n materials prepared from different materials

Construction :~.



⇒ Semiconductor laser is also called as diode laser.

⇒ The light Emitting diodes are basically S.C laser.

⇒ Semiconductor lasers are classified as homo junction Semiconductor laser & Hetero Junction S.C laser

⇒ Ga As is well known Example of direct band gap Semiconductor So that GaAs Semiconductor diode laser having the important applications

Construction of Semiconductor laser :-

As shown in the above figure, the p-type & N-type materials are prep. -ared by adding suitable dopent elements.

The shaded Area is known as "depletion layer" (Active region)

The thick ness of the depletion layer is usually very small (0.1 micro meter)

To obtaine the laser action the end phases are polish flat & ||^{lel}

the other two phases are left unpolished to suprus the Oscillation

Working of Semiconductor lasers:~ (working of GaAs laser) (or) (Homojunction S.C laser):~

⇒ Homo Junction Semiconductor laser (Homo junction Diode laser)

By diffusion method we can prepare homo junction S.C laser in the following process i.e

i) Initially we have to take heavily doped N-type GaAs material it has been formed as a layer. By the diffusion of doping atoms we can form p-type layer (Heavily Zn doped layer)

ii) Dimensions:~ Tipically diode chips are 500 micro meter long & 100 micro meter wide & thick the top & bottom phases are mettalised to connect to the Battery terminals

working:-

i) Under forward Biasing condition electrons are injected from N-region to p-region & also holes are injected from p-region to N-region, so that the "population inversion" was achieved, it is neccessary for the laser. Operation (for emission of out put from laser)

ii) In Order to achieve the population inversion pumping mechanism is required. In case of S.c laser electrical pumping mechanism was used

iii) The $\bar{e}$'s & holes recombine & releases the light energy in the form of photons that is knowns as out put of the S.C laser.

Recombination of electron with hole:-

when electron recombine with the hole the excessive energy is emitted in the form of photon. On

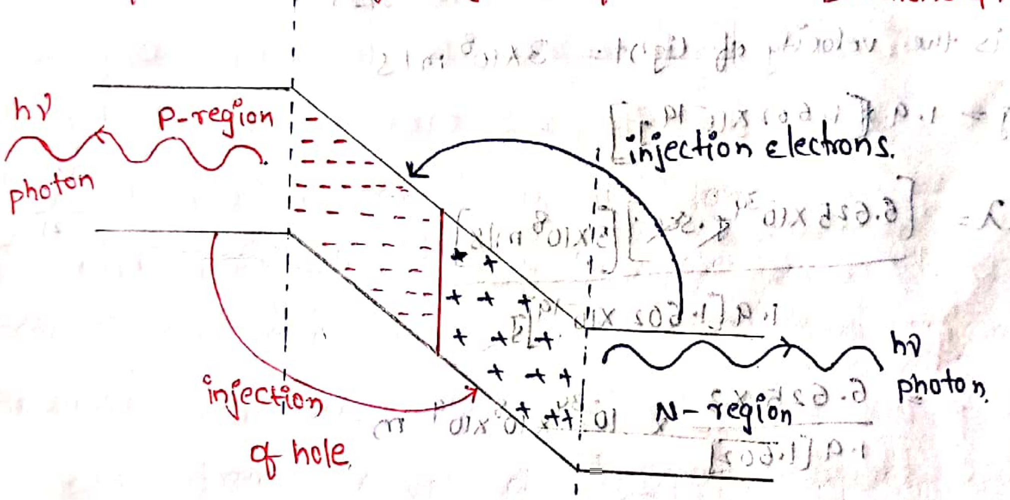
→ under forward biasing condition there exist a more recombinations. So that more no. of photons are emitted as out put

→ Due to the External voltage the recombination takes place in case of minority charge carriers also.

→ The operation point of Semiconductor laser is controlled by input voltage

→ The intesity of light depend on the input voltage

→ Schematic Reprasentation of Injection of carriers:- [electrons & holes]



Applications of Semiconductor diode laser:-

→ S.C lasers are the chiepest & smallest lasers so that they are employed in various speed fields [S.C lasers occupies less space; small in size so that they are preferable]

→ The light emitted from the semiconductor laser can be used as input for the Optical fibre in modren communication field can be.

→ In Order to launch the light in electronic circuits. S.C lasers are used.

→ In Order to Read the data which is in the enolog form (or) in binary form. S.C lasers are used.

→ S.C laser emitts the light in the range of UV region - IR region used in detecting circuits.

→ S.C lasers are employed in computer field

Problems:- Based on:- $E_g = \frac{hc}{\lambda}$, $E_g = h\nu$

$\lambda = \frac{hc}{E_g}$

*****

Q) A light Emitting diode is made up of GaAsP having a band gap of 1.9 eV determine the wavelength & colour of Radiation emitted.

Sol: Given: $E_g = 1.9\,eV$

let λ be the wave length of Emitted hole

Formula $\lambda = \frac{hc}{E_g}$

h planck's constant $h = 6.625 \times 10^{-34}$ J.sec

c is the velocity of light $= 3 \times 10^{8}$ m/s

$E_g = 1.9\,[1.602 \times 10^{-19}\,J]$

$\lambda = \frac{[6.625 \times 10^{-34}\,J.sec][3 \times 10^{8}\,m/s]}{1.9\,[1.602 \times 10^{-19}]\,J}$

$= \frac{6.625 \times 3}{1.9\,[1.602]} \times 10^{-34} \times 10^{8} \times 10^{19}$ m

$= \frac{6.625 \times 3}{1.9\,[1.602]} \times 10^{-7}$

$\lambda = 6.529 \times 10^{-7}$ m

$1 A^{\circ} = 10^{-10}$ m

$\lambda = 6.529 \times 10^{-7}\,m \times \frac{10^{3}}{10^{3}}$

$\lambda = 6.529 \times 10^{3} \times 10^{-10}$

$\lambda = 6.529 \times 10^{3} A^{\circ} = 6529 A^{\circ}$

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↓ 5500 to 6000 yellow
↑ 6000 → Red

∴ The colour of Radiation (out put of the laser is in red colour)

Q) calculate the wave length of Emission from GaAs diode laser, if the band gap in GaAs is 1.44 eV

$\rightarrow E_g = 1.44 eV$

$= 1.44 \times 1.602 \times 10^{-19} J$

$$\lambda = \frac{hc}{E_g}$$

$$\lambda = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{1.44 \times 1.602 \times 10^{-19}}$$

$$= \frac{6.625 \times 3}{1.44 \times 1.602} \times 10^{-34+8+19}$$

$$= 8.6156 \times 10^{-7} \; m \; \frac{10^{-3}}{10^{-3}} \frac{m}{m}$$

$$\lambda = 8.6155 \times 10^{-10} \times 10^{+3} m$$

$$\lambda = 8.6155 \times 10^{3} A^{o}$$

Q) The InGaAsP diode laser has peak emission wavelength of 1.55 μm. determine its Band Gap.

Sol:- $\lambda = 1.55 \mu m$

$= 1.55 \times 10^{-6} M$

$$E_g = hc/\lambda$$

$$E_g = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{1.55 \times 10^{-6}}$$

$$= \frac{6.625 \times 3}{1.55} \times 10^{-34} \times 10^{8} \times 10^{6}$$

$= 12.822 \times 10^{-20}$ Joules $\longrightarrow$ (1)

Generally eg was expressed in eV

$1 eV = 1.6023 \times 10^{-19}$ Joule

$$1 \text{ Joule} = \frac{1}{1.6023 \times 10^{-19}} eV \longrightarrow (2)$$

$$\therefore E_g = 12.822 \times 10^{-20} \times \frac{1}{1.6023 \times 10^{-19}}$$

$$E_g = 0.8002 eV$$

Semi Conductor photodetectors:-

→ These are the devices that absorb optical energy (light energy) and convert into to electrical energy.

→ The operation of photodetectors is based on the "internal photo electric effect"

characteristics of photodetectors:-

→ The maximum photocurrent flows when each incident photon produces one electron hole pair contributing to the photo current.

→ photo current depends on absorption of photons recombination electron hole pair surface area of the light incidented region

* What is solar cell? write a note on construction and working of Solar cell?. what are the v-I characteristics. and applications of Solar cell?

The cell which converts light energy into electrical energy is known as "Solar cell"

→ Solar cell is also known as "photo voltaic cell", which converts solar Energy into electrical energy.

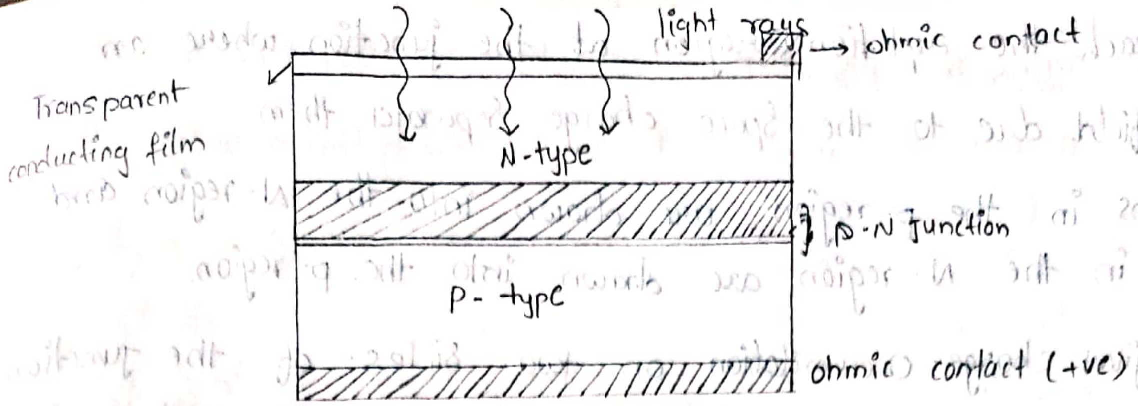
→ History of solar cell:.

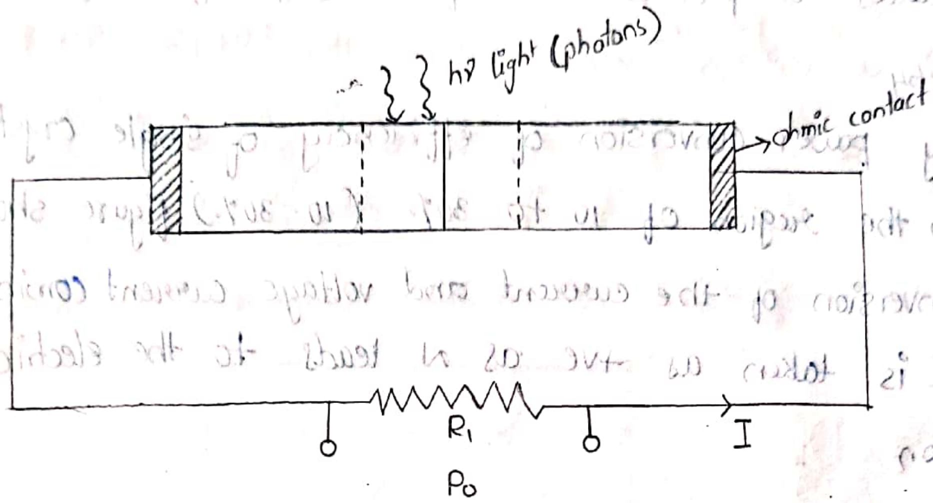
→ In 1839, "Edmond Becquere" french scientist built the words first Solar cell based on photo voltaic effect.

construction:-

⇒ with the help of p-type and N-type layers prepared from a Si or Ge are fabricated into a solar cell;

⇒ By attacting the ohmic contacts to p-type and n-type layers Solar cell was constructed.





⇒ The Skematic diagram of solar cell is shown in the above figure.

It consists p-type chip and which a thin layers of N-type material is grown by diffusion method.

<u>Note:-</u>

⇒ P-layers prepared with dopant atoms Boron atoms added to Si crystal water.

⇒ N-type layer was prepared by adding phosphorous atoms to Si-crystal water.

<u>Working:-</u>

⇒ It consists of a p-type chip on which a thin layer of N-type material is grown

→ when the Solar radiation is incidented on the cell electron, hole pairs are generated in the N & P region

⇒ They reach the depletion region at the junction where an electric field due to the space charge separates them.

⇒ Electrons in the p-region are drawn into the N-region and holes in the N-region are drawn into the p-region.

This gives charge occumilation on two sides of the junction and produces a p.d called a photo EMF of magnitude of order 0.64

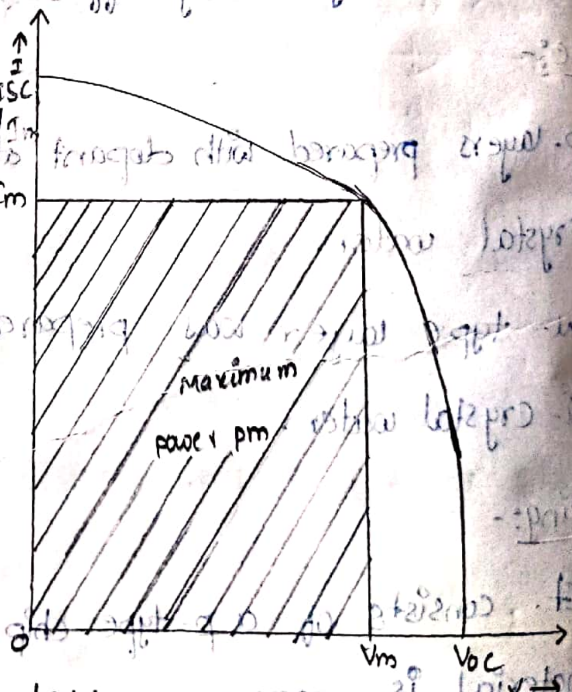
⇒ Generally power conversion of efficiency of single crystal solar cells in the region of 10 to 30% (10-30%) figure shown the sign conversion of the current and voltage current coming out of the cell is taken as +ve as N leads to the electrical power generation

⇒ The power generator depends on solar cell it self and the load connected to it

V-I characteristics of Solar cells:-

* The open circuit voltage across the illuminated cell at zero current and the short circuit current (Isc) is the current through the illuminated cell if the voltage across the cell is zero.

* The short circuit current is close to the photocurrent while the open circuit voltage is close to the turn on voltage of the diode.



Light → Voltage – current

* The maximum power is attained at V_m (maximum voltage) with I_m (maximum power)

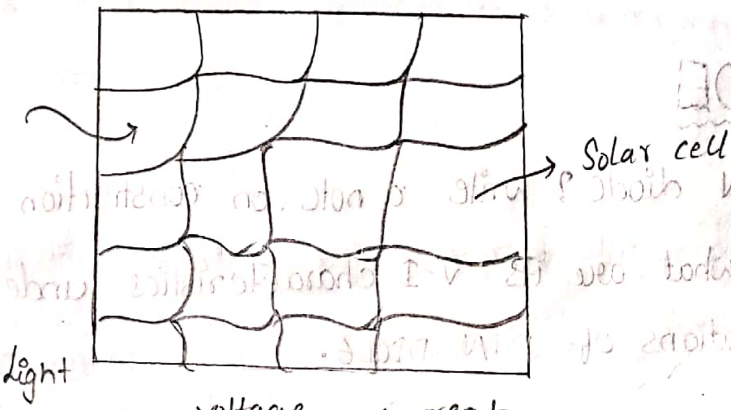
$$\text{Maximum power} \cdot P_m = I_m \cdot V_m \quad \text{---(1)}$$

$$P = IV$$

* Solar cell can be connected in parallel (or) series into solar pannels. which can delives power output of several kilowatts.

* conversion efficiency of Solar cell is defined. as

$$\eta = \frac{\text{electrical power delivered}}{\text{Solar power received (or) (incident)}}$$



Note :-

Single crystal Solar cell has efficiency of 30% only.

Applications of Solar cell in various fields :-

a) Industrial applications:-

cathode protection to prevent corossion of pipelines.

b) Space applications:

Solar cells are used in Satellites and Space vehicles to supply. to electronic and charge storage batteries.

c) Ocean navigation aids:-

Number of light houses are powered by Solar cells.

d) Teli communication Systems:-

Radio trans Receivers on - Mountain tops (or) teliphone boxes are powered by Solar cells.

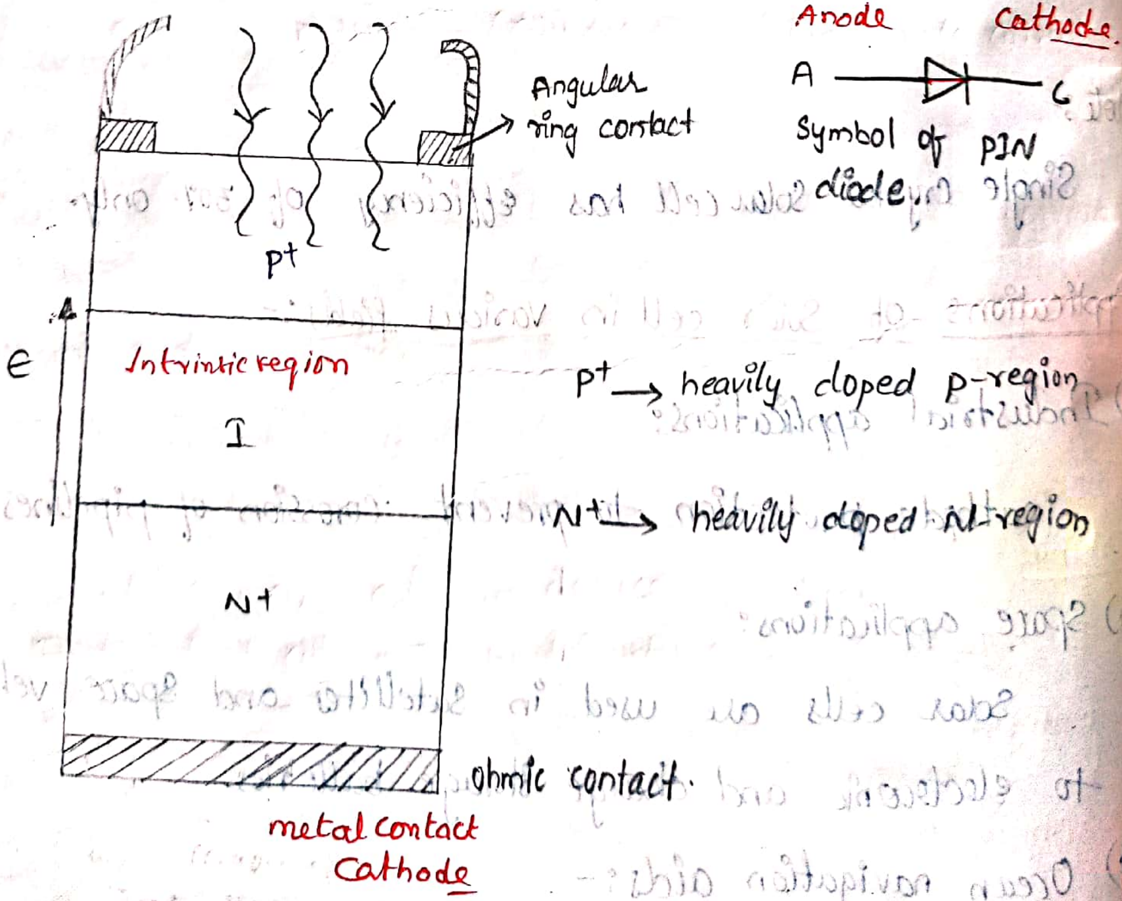
e) Social applications:-

electrical power to the remoted villages was provided with the help of Solar pannels (pv power water pumps, pv powered refrigerators, washing machines) Solar cells are used to Supply the power to the calculators to the rist watches.

Solar cells are used to provide commercial electricity.

PIN DIODE

What is PIN diode? write a note on construction and working of PIN diode what are its v-I characteristics under biasing conditions write the applications of PIN DIODE.



* PIN diode is known as positive intrinsic negative diode.
* It consists of P & N regions separates by a intrinsic region
* P & N regions are heavily doped because they are used used for ohmic contact attachment and intrinsic region is very lightly doped.

* PIN diodes are usually made up of silicon (Gallium Arsendine is also to be used)

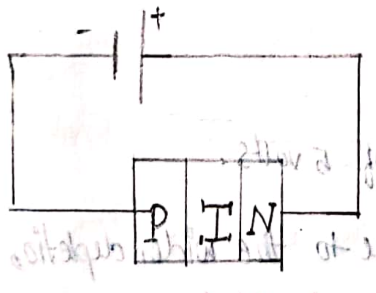
* PIN diode structure is planes structure in this structure epitaxial film as grown on substrate material and p+ region is introduced by diffusion method.

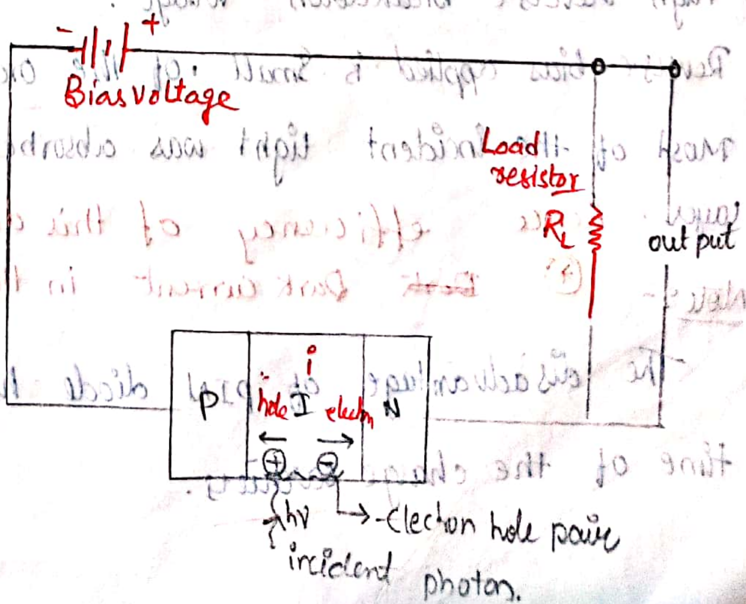
Note:-

Thickness of the intrinsic layer is about 10 microns - 200 microns.

working of PIN Diode:-

It works under reverse biasing condition (p-region is connected to -ve terminal & n-region was connected to +ve terminal)





* The light is allowed to incident on intrinsic region then eletron hole pairs are created in the depleted intrinsic region.

* The high electric field in the depletion region causes the free carriers to seperate and move across the reverse bias junction

* This gives rise to a current flow in the external circuit.

V-I characteristics:-

* There exists a reverse break down voltage due to intrinsic layer
* There exist a low level of capacitance when it is in forward bias
* There exists a low level of carries storage in forward bias
* Under reverse biasing condition there exists a greter seperation b/w P&N regions.

Applications:-

* Used as high voltage rectifies (due to intrinsic region it is possible)
* PN diode makes an Ideal RF switch (Radio frequency switch.
* It can be used as photo detector. (Conversion of Light into current)

Advantages:-

* Reverse bias need not be varied to change the width of the depletion layer.
* High reverse breakdown voltage.
* Reverse bias applied is small, of the order of 5 volts.
* Most of the incident light was absorbed due to the widen depletion layer. hence efficiency of this device is high

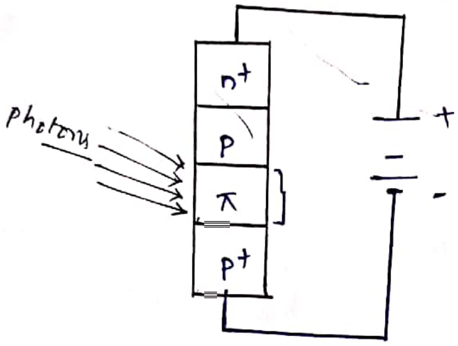
Note:- * ~~Dark~~ Dark current in this device is smaller.

The disadvantage of PIN diode high reverse recovering time of the charge carriers.

Avalanch photodiode (APD):-

⇒ The number of carriers multiplies in Geometrical progression and this phenamenon is called Avalanch effect. It has been absorved in case Avalanch photo Diode

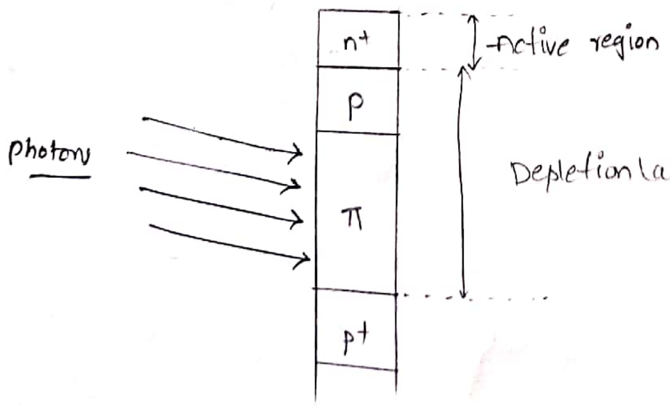
⇒ Avalanch → Suddenly more no. of charge carriers released, it is in Riverse Biased.



APD:- APD is highly sensitive semiconductor electronic device that Exploiseds the photo electric effect to convert light into electricity thought of as photodetector that provide a built in - first stage of gain through avalanche multiplication.

Structure and Construction of APD:-

it has $p^+ \pi p n^+$ configuration of different layers



all the absorption takes place in depletion region.

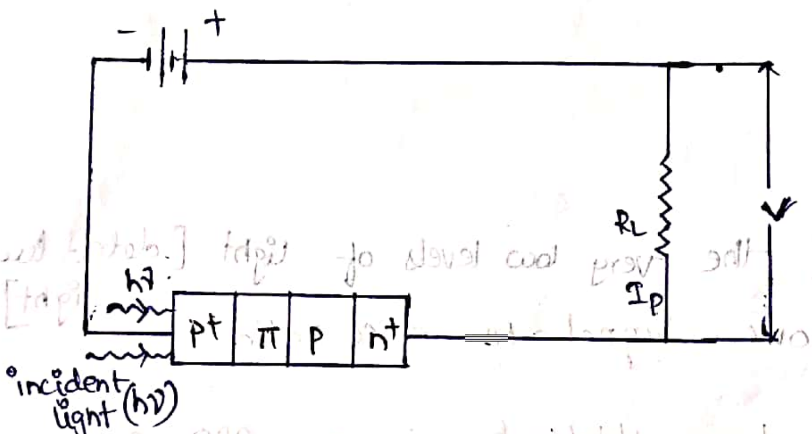
p^+ - heavily doped p region.

→ π region very lightly doped region (It can be an n-type material make a low resistance contact).
→ n^+ region heavily doped n-rgion.

The materials used for the preparation of APD is Si, Ge, crystal & III-V group compounds

→ The device is essentially reverse Biased p-N Junction
→ The π region is very lightly doped and Hence is nearly intrinsic. Most of the incident light passes into intrinsic region through the p^+ region so that Electron hole pairs are Generated in the intrinsic region. (π-region)

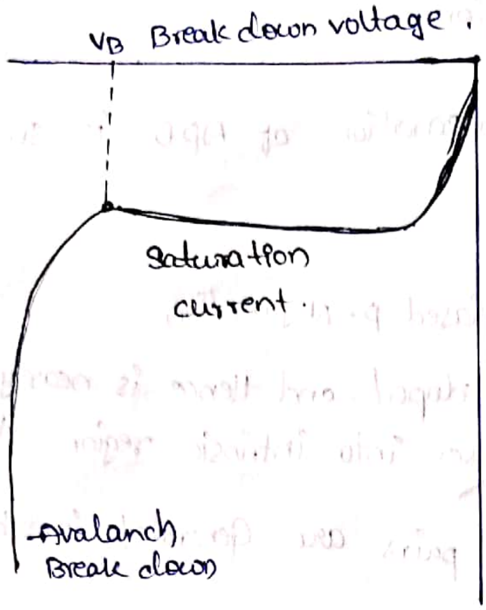
Working:-



→ In the RB most of the applied voltage Drops across the $p\pi n^+$ region (Junction). By increasing the Reverse Bias voltage the depletion region across this junction widens. [width increases]
→ In this condition the internal field intensity near the junction becomes very high and the junction approches the Break down condition. there fore electrons & holes Generated in the depletion layer. they acquires sufficient energy from the field to liberate secondary electrons & holes. with in the layer by a process of impact ionization.

→ The newly generated carriers also accelerated by the high electric field, thus gaining enough energy. to cause further impact ionisation.

V-I characteristics :-



→ Their exist a sudden change in the current after the Break down voltage

→ The sudden change in the current is due to liberation of more no. of electron hole pairs

Application of APD:-

1) photo detector

2) it is used to identify the very low levels of light [detect low level of light]

(3) APD Can Improve Signal-to-noise ratio

Increasing avalanch multiplication in an APD can improve the signal-to-noise ratio (S.N.R) of an optical receiver as long as the APD noise is less than the preamplifier noise floor.

LASERS

Introduction Laser, is an acronym for Light Amplification by Stimulated Emission of Radiation

The first two successful lasers developed during 1960 were. the pulsed ruby laser with wavelength 6943A° and Helium - Neon gas laser with wavelength 11500 A°.

→ A Laser, strictly speaking, is an amplifier of Light.

→ practical utility of laser is an oscillator - a generator of coherent light

→ Lasers are also Known as generators of Light

Laser action has been obtained with atoms, ions and molecules in gases, liquids solids, glases, and Semi conductors at wave length spanning from ultraviolet to Radio frequency regions.

Laser output power ranging from a few milliwatts to Several megawatts

Some lasers emit light in pulses while other emit radiations as a continuous wave

Laseraction The following are the steps involved in the lasing atom (i) Excitation (ii) population inversion (iii) Light amplification.

Excitation when an electromagnetic wave interact with matter (solid, liquid, gas) then the atoms (or) electrons from lower energy level must be excited (or) puped to a higher energy level

populationinversion: It is a process achieved by pumping process { i opticalpumping, ii Electrical pumping

The process which makes the number of atoms (or) electrons in excited level is greater than the Lower for a instant of time. For this to occur a continuous pumping of energy into the system is needed.

Light amplification It is achieved in a resonant cavity where laser action is activated.

Radiation-Interaction: The interaction of radiation with the matter will results the (i) absorption (ii) Spontaneous emission (iii) Stimulated emission

(Q) Explain the characteristics of a Laser-beam

(or) Mention the important characteristics of laserbeam and explain? what are differences between ordinarylight and Laser beam.

Laser is compared with any conventional light (ordinary light), it has few outstanding characteristics.

→ Ordinary Light is distributed Uniformly in all directions from the Source. It is not possible to make the light (ordinary Light) to travel in a single direction but in case of lasers it is possible.

→ Ordinary light illuminates various objects equally that are at equal distance from the lightsource.

The important characteristics of laser beam over the conventional light sources are (i) Laser is highly monochromatic (ii) Laser is highly directional (iii) Laser is highly Coherent (iv) Intensity of laser is very high.

(i) Laser is Highly Monochromatic [Monochromaticity]

Laser is more monochromatic than that of a conventional monochromatic light source.

This is due to stimulated characteristic of the light (laser light)

It has single wavelength ie the line width of laser beam are extremely narrow

The property is Monochromatic is attained by laser beam due to following reseaon

(i) only an electromagnetic wave of frequency ν_{12} can be amplified.

(ii) Since the mirror arrangement forms a resonant cavity, oscillations can occurs only at resonant frequencies of this cavity.

(ii) Laser is Highly directional. [Divergence]

Divergence is the significance of the directionality of the laser beam.

If the divergence is small then the directionality of laser beam is high.

$\therefore$ Divergence $\Delta\theta = \dfrac{r_2 - r_1}{D_2 - D_1}$ where r_2, r_1 are the radii of laserbeam - spots at Distances of D_2 and D_1 resply from the laser source.

For laser beam $\Delta\theta = 0.01$ milliradian.

ie the laserbeam spread less than 0.01 mm. for a distance of one meter

The property of directionality is due to the stimutated emission

ie Laser emit light only in one direction, along cavity direction.

explanation As the active material is placed between plane parallel reflecting surfaces, only electromagnetic wave which is propagated along cavity direction. Thus high directionality (single direction) is achieved.

(iii) Laser highly coherent [coherence] It is a significance of constant phase difference

In case of laserbeam the property coherence exist between any two (or) more lightwaves of same type.

That is coherence property is the significance about "existence of zero (or) constant phase angle difference between two (or) more wave. for laser beam.

coherence is of two types (i) Spatial coherence.
(ii) Temporal coherence.

(iv) Intensity of laser beam is very high [Brightness]

In a laser beam lot of energy is concentrated in a small region. Therefore the intensity of laser beam is very high, its brightness is more.

The intensity of laserbeam is very high due to the high directional property of the laser beam.

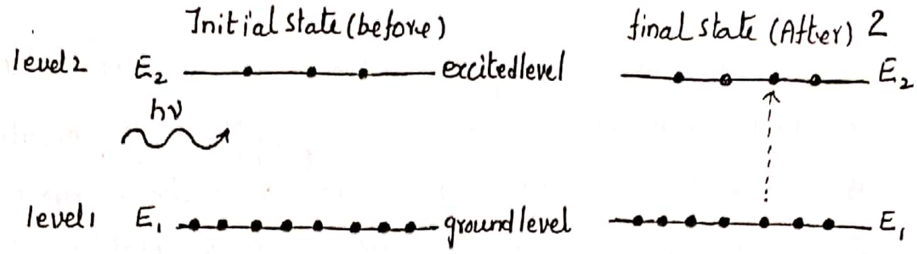
A laser source has brightness many orders of magnitude greater than that of ordinary source.

(Q) Explain with neat diagrams (i) Absorption (ii) Spontaneous emission and (iii) Stimulated emission of Radiation. Derive Einstein coefficients

The interaction of radiation (incident radiation) with the matter will results the processes absortion and emission

emission → Spontaneous, Stimulated.

Absorption



In the above diagram if the number of atoms in ground level be N_1 and Number of atoms in the excited level be N_2. Let E_1 be the energy of the groundlevel and E_2 be the energy of excited level.

If An electromagnetic wave of frequency $h\nu$ is incidenting on the atomic system. Then the atoms in the ground level will absorb the incident frequency of radiation and raised to the excited level. This process is Known as absorption.

ie $h\nu = E_2 - E_1$ $h\nu$ is equal to energy difference of level 1 and level 2.

This process is non radiative decay.

The number of atoms undergoing absorption per unit volume per second from Level E_2 to Level E_1 $= N_1 \rho(\nu) B_{12} \longrightarrow (1)$

where N_1 be the number of atoms in the groundlevel (level E_1)

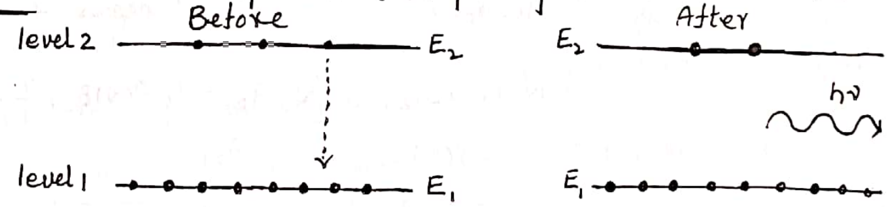
$\rho(\nu)$ is radiation density

B_{12} represents probability of absorption per unit time.

→ Absorption: from level 1 to level 2 depends on the frequency of incident radiation and on the properties of level 1 and level 2 respectively.

Spontaneous emission

: It is independent of frequency of incident radiation



Consider the two atomic level Let level 1 be the ground state having energy E_1 and level 2 be the excited level. N_1 be the number of atoms in level 1 and N_2 be the number of atoms in level 2. $N_1 > N_2$;

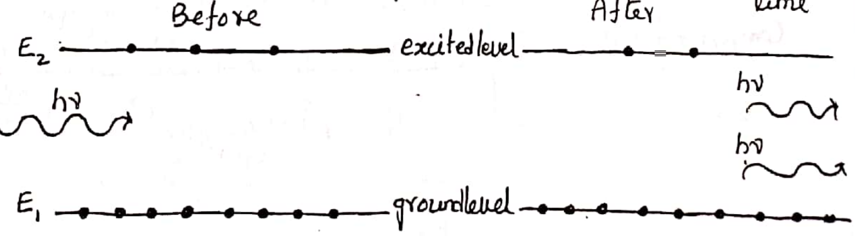
The atom in the level 2 [decay] undergoing transition to the level 1 and emits the electromagnetic wave of energy $h\nu$. This process is called. spontaneous emission. The spontaneous process will occur with any input external frequency of incident radiation

Ther number of atoms making spontaneous emission per unit volume per second from level 2 to level 1 ie E_2 to E_1 $= N_2 A_{21} \longrightarrow (2)$

N_2 be the number of atoms present in the level 2

A_{21} represents the probability of spontaneous emission per unit time.

Stimulated emission



Let us consider level 1 and level 2 are the two levels of the atomic system N_1 be the number of atoms in level 1 and N_2 be the number of atoms in level 2. By incidenting frequency of radiation $h\nu$ on atomic system, the atoms in the level 2 decay to the level 1 and emits two photons which are in phase. This process is known as <u>stimulated emission</u>.

$$h\nu = E_2 - E_1$$

The number of stimulated emissions per unit volume per second from levels 2 to 1

$E_2 \to E_1 \therefore = N_2 \rho(\nu) B_{21} \longrightarrow (3)$ — B_{21} represents probability of stimulated emission per unit time.

Derivation of Einstein's coefficients

(or) Derive the relation between probabilities of spontaneous emission and stimulated emission in terms of Einstein coefficients

For the atomic system total atoms in the two level be N.

$\therefore N = N_1 + N_2$ — where N_1 be the number of atoms in the level 1, N_2 be the number of atoms in the level 2.

<u>Equilibrium</u>: In thermal equilibrium the rate of transition from E_1 to E_2 is equal to E_1 to E_1

$\therefore$ Number of atoms undergoing absorption per second = Number of atoms undergoing emission per second.

Hence we have Absorption = Spontaneous emission + Stimulated emission

from (1), (2) and (3)

$$N_1 \rho(\nu) B_{12} = [N_2 A_{21} + N_2 \rho(\nu) B_{21}] \longrightarrow (4)$$

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

$$\rho(\nu)[N_1 B_{12} - N_2 B_{21}] = N_2 A_{21} \longrightarrow (5)$$

Deviding equation (5) on both sides with $N_2 \Rightarrow \frac{\rho(\nu)[N_1 B_{12} - B_{21} N_2]}{N_2} = \frac{N_2 A_{21}}{N_2}$

$$\Rightarrow \rho(\nu)\left[\frac{N_1}{N_2} B_{12} - B_{21}\right] = A_{21}$$

$$\Rightarrow \rho(\nu) = \frac{A_{21}}{\left[\frac{N_1}{N_2}\right] B_{12} - B_{21}} \longrightarrow (6)$$

From Boltzmann distribution law we know that $\frac{N_1}{N_2} = e^{(E_2 - E_1)/K_BT} \longrightarrow (7)$

But energy difference $E_2 - E_1 = h\nu \Rightarrow \frac{N_1}{N_2} = e^{h\nu/K_BT} \longrightarrow (8)$

From eq (8) substitute $\frac{N_1}{N_2}$ value in eq (6) $\quad \because B_{12} = B_{21}$

$$\therefore \text{we have } \rho(\nu) = \frac{A_{21}}{[e^{h\nu/K_BT}] B_{12} - B_{21}} \longrightarrow (9) \quad \rho(\nu) = \frac{A_{21}}{\left[e^{\frac{h\nu}{K_BT}}\right] B_{21} - B_{21}} \longrightarrow (9)$$

From planck's radiation law, we have $\rho(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{(e^{h\nu/K_BT} - 1)} \longrightarrow (10)$

Comparing (9) and (10)

$$\frac{A_{21}}{\left[(e^{h\nu/K_BT}) - 1\right] B_{21}} = \frac{8\pi h\nu^3}{c^3} \frac{1}{(e^{\frac{h\nu}{K_BT}} - 1)} \longrightarrow (11)$$

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

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3} \rightarrow (12)$$ where μ is ~~refractive~~ index of the medium
~~λ is wavelength of light in air~~
c Speed of Light.

Let ~~λ_m be the wavelength of light in medium~~ $\therefore$ ~~$\lambda_m = \frac{\lambda}{n}$~~

$\therefore$ ~~$\frac{1}{\lambda_m} = \frac{n}{\lambda} \Rightarrow \frac{1}{\lambda_m^3} = \frac{n^3}{\lambda^3}$~~ $\rightarrow (13)$

~~from equations (12) and (13) we have~~ $\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}} \rightarrow (14)$

Here A_{21} and B_{21} are called Einstein's coefficients of Spontaneous emission - probability per unit time and Stimulated emission probability per unit time respectively

For Stimulated emission to be predominant we need $\frac{A_{21}}{B_{21}} << 1$

The function $\frac{1}{(e^{\frac{h\nu}{K_BT}} - 1)}$ represents the ratio of stimulated emission rate to spontaneous emission

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(Q) What do you understand by "Population inversion"? How it is achieved

(or)

What is population inversion? Explain various methods to achieve population - inversion?

Under ordinary conditions of thermal equillibrium the number of atoms in the higher energy state is considerbly smaller than the number of atoms in the lower energy state ie $N_2 < N_1$

N_2 is the number of atoms in higher - energy state

At temperature 17°C $\frac{N_2}{N_1} = 10^{-32}$

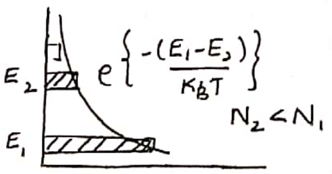
N_1 is the number of atoms in lower - energy state

$\frac{N_2}{N_1}$ is known as ratio of population densities

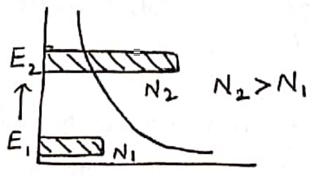
Population inversion: The population inversion is the achievement to obtain the number of atoms in upperstate is more than the number of atoms in the lowerstate ie It is simply the process of achievement that number of atoms in excited state is greater than the number of atoms in ground state.

The process by which population inversion is achieved is known as pumping process

The pumping is achieved through following two ways (i) optical pumping
(ii) Electrical pumping.



Population $N_1 N_2$



After achievement of population inversion.

N_2 be the number of atoms in upper level

N_1 = Number of atoms in lower level

The above two diagrams represents the levels of atomic system and their population densities [Number of atoms in the level]

The population inversion condition achieved on a steady state basis gives rise to continuous wave laser action

~~Ka~~

From Boltzman's Distribution function $N = N_0 \exp\left(\frac{-E}{K_B T}\right)$

$$N_1 = N_0 \exp\left[\frac{-E_1}{K_B T}\right] \rightarrow (1)$$

N_1 be the number of atoms in energy level (lower) E_1

$$N_2 = N_0 \exp\left[\frac{-E_2}{K_B T}\right] \rightarrow (2)$$

N_2 be the number of atoms in the energy (higher) level E_2

$$\frac{N_2}{N_1} = \frac{N_0 \exp\left(\frac{-E_1}{K_B T}\right)}{N_0 \exp\left(\frac{-E_2}{K_B T}\right)} \rightarrow (3)$$

$$N_2 = N_1 \exp\left(-\frac{(E_2 - E_1)}{K_B T}\right) \rightarrow (4)$$

$E_2 > E_1$ and $N_1 > N_2$.

Population inversion : It is nothing but making $N_2 > N_1$ i.e the number of atom in higher energy level to be greater than the number of atoms in the lower energy level with the help of pumping method (i) Optical pumping (ii) Electrical pumping (iii) Inelastic collision of atoms (iv) Chemical reaction (v) Direct Conversion

A system in which population-inversion is achieved is called as an Active system

The method of raising the atoms (particles) from lower energy state to higher energy state is called pumping.

Optical pumping method (Used for solid state laser)

Light sources used for optical pumping are (i) Xenon flash lamp (for Ruby Laser) (ii) Tungsten-iodine Krypton (or) high pressure mercury capilliary lamps (for continuous wave laser)

Lamp → Transfer System → Active material

Optical pumping system

In this pumping process energy in the form of light radiation is absorbed by the active material and there by that energy pumps the atoms in to the higher energy level from lower energy level

Electrical pumping method : Electrical pumping is used for gas laser (He-Ne, CO_2) and Semiconductor lasers.

In this case pumping is achieved by allowing a current of suitable value to pass through the gas. It results in to the generation of ions and electrons. The electrons are accelarated by the electricfield and gain enough additional Kinetic energy from the field to excite the neutral atom by collisions.

Pumping Scheme : Creation of Population Inversion

If we consider a two level system in thermal equilibrium consisting of populations N_1 and N_2. The incoming wave will produce transition $1 \rightarrow 2$ and then $2 \rightarrow 1$, hoping to achieve population inversion

Thus two level system is not appropriate for population inversion and hence multi level system is employed. Three level system and Four level system are commonly employed systems.

(Q) With neat diagrams, describe the construction and action of Ruby laser

(or)

State and explain the construction and working of Ruby laser

Type : Solid state laser

Year : 1960 constructed by T. H. Maiman

Active material : Ruby Crystal in the form of cylindrical ruby rod

pumping : Optical pumping System is used → Xenon flash discharge tube.

Laser level : Three level laser System.

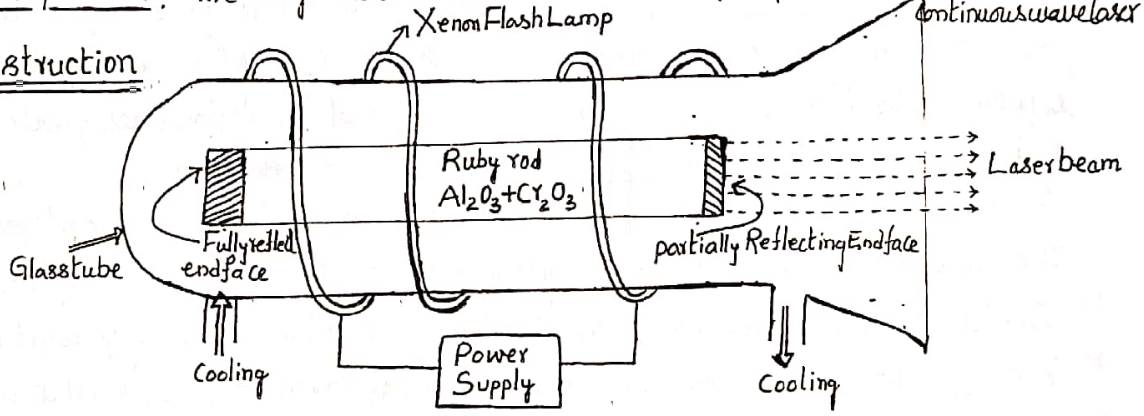
Ruby rod : It is prepared by doping technique i.e Ruby rods are prepared from aluminium oxide (Al_2O_3) doped with 0.05% chromium Cr^{3+} replacing Al. This is done by adding small amounts of Cr_2O_3 in the melt of highly purified Al_2O_3.

Due to the chromium ions ruby rod appeared in pink colour. The chromium ions are responsible for emission of light by ruby

Resonant cavity : A fully reflecting surface at the left end of the ruby crystal and partially reflecting end at the right side of the ruby crystal. Both the reflecting surfaces are optically flat and exactly parallel to each other.

Laser operation : The ruby laser is used in the form of pump laser as well as continuous wave laser

Construction



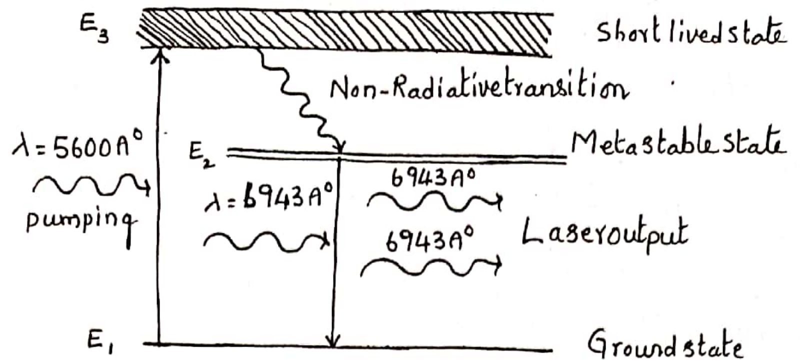
--:-Ruby Laser-:--

Ruby laser consist of a ruby cylindrical rod whose ends are optically flat and parallel. The ruby rod is 4 cm in length and 0.5cm in diameter. One end is fully silvered and the other end is partially silvered. The rod is surrounded by Glass tube and glass tube is surrounded by a helical Xenon flash tube. Xenon flash tube is acts as the optical pumping system. The laser medium being to be a solid, the laser is also called solid state laser

The ruby rod is crystal of Aluminium Oxide (Al_2O_3) doped with 0.05% of Chromium Oxide (Cr_2O_3). So that the some of the aluminium atoms in the crystal lattice are replaced by Cr^{3+} ions.

Optical pumping system is in the form of helical xenon discharge tube, at the axis of which is placed the ruby rod. The flash tube consist of gas and which is connected to power supply.

Working



Energy level diagram of Cr^{+3} ion

Ruby is madeup of aluminium oxide as host lattice with small percentage of Cr^{+3} ions replacing aluminium ions in the crystal. Chromium acts as dopant. A dopant produces lasing action ie chromium ions are responsible for the emission of laser output. The pumping source for ruby material is Xenon flash lamp which will be operated by some external power supply

The chromium ions are excited from level 1 (E_1) to level 3 (E_3) by the absorption of Light from the Xenon flash discharge tube. The extited ions quickly undergo non radiative transitions with a transfer of energy to the lattice thermal motion to the level 2 (E_2). The level 2 is Metastable state with a lifetime about 3×10^{-3} sec. Now the population of level 2 becomes greater than that of level 1. Thus population inversion is achieved.

Some photons are produced by spontaneous transition from level 2 to level 1. The ends of ruby rod acts as reflecting mirrors. The photons that are not moving parallel to the ruby rod escape from the side, but those are moving parallel to the rubyrod are reflected back and these stimulate the emission of similar other photons ($6943 A^\circ$). The chain reaction quickly develops a beam of photons all moving parallel to the ruby rod, which is mono chromatic and Coherence It emerges through the partially silvered end.

Once all the Cr^{+3} ions are in the metastable level returned to ground state Then one more flash has pumping radiation is sent through the rod. Thus the ruby laser operate only is pulses and so ruby lasers are called pulsed lasers From the metastable state all the Cr^{+3} ions are returned to ground state they will emit laser output. After this action laser action stops. After recieving the flash light energy from xenon flash lamp radiation is sent through the rod. And then the process is continued for the emission of laser output. So that ruby laser is pulsed laser

Draw backs of Ruby laser (i) It requires high pumping power (ii) Ruby laser is pulsed laser. The xenon pulse is of several millisecond duration and the laser pulse is much shorter, less than a millisecond. The power of each peak is of the order of 10^4 to 10^5 watts
→ output power is not continuous.

Uses of Ruby Laser : welding and Drilling : pulsed ruby laser is used successfully for precision welding and drilling of metal, for drilling of industrial diamonds,

It is used for holography and photography of moving objects.

It is for repairing of detached retinas in ophthalmology.

(Q) State and Explain the construction and working of Helium-Neon gas laser.

He - Ne laser is the first gas laser. For continuous laser beam gas lasers are used

Pumping : Electrical pumping system is used.

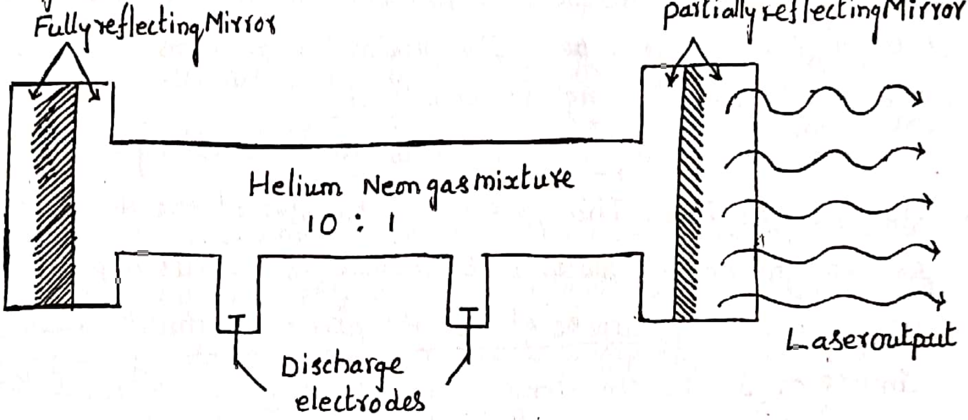
Year : In 1961, Fabricated by Ali Javan and others in Bell Telephone Laboratory

Level : He - Ne gas laser is a Four level laser system

Active medium 10 : 1 Ratio of Helium Neon gas mixture in a Quartz tube

Output power : It depends upon the length of discharge tube and the pressure of gas mixture. The output power for this laser is continuous

Construction :



The Helium - Neon laser system consist of a gas discharge tube (Quartz tube) of length about 80 cm and diameter of 1 cm. This tube is filled with the mixture of gas He - Ne at ratio 10 : 1 hence the number of Helium atoms are greater than Neon atoms. Made the arrangement of two mirrors at the both ends of the gas tube. One of the mirror is completely reflecting and the other is partially reflecting in order to amplify the output laser beam.

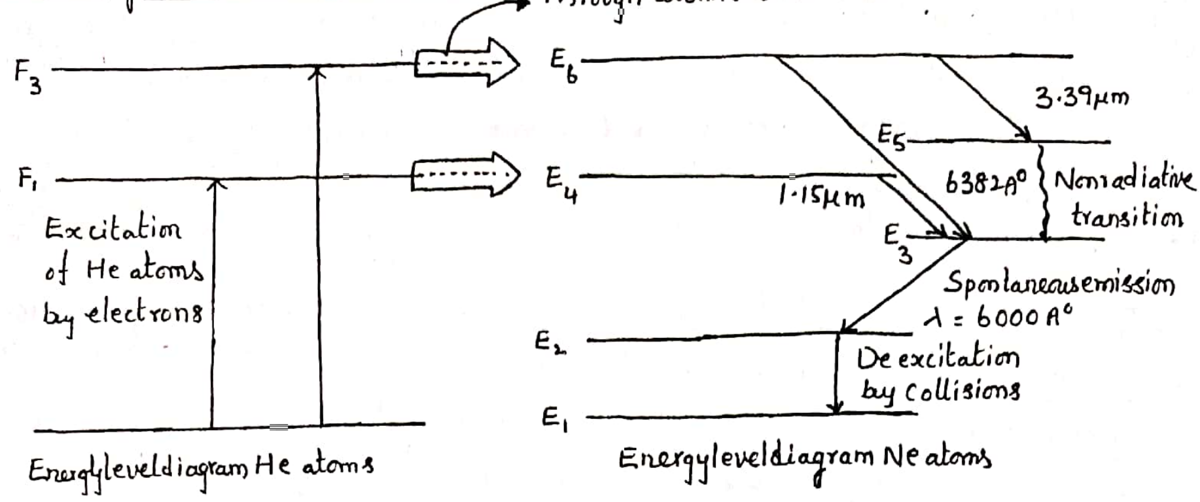
Made the arrangement of two Discharge electrodes connected to tube usually with d.c power supply. By making the mirror arrangement one end of the tube is a perfect reflector while the other end is a partial reflector.

These two mirrors at both sides are parallel to each other with respect to the gas tube.

The gas discharge tube is ionised by passing a DC current through the gas.

So that for case of He - Ne gas laser the pumping method is electrical pumping method.

Working of Helium-Neon Laser



The output power from these lasers depends upon the length of the dischargetube and the pressure of gas mixture.

when a discharge is passed through the gaseous mixture, electrons are accelarated down the tube. The accelarated electrons collide with the Heliumatoms and excite them to higher energy levels.

Hence the energy of the Heliumatoms is easily transfered to the Neon atoms when they Collide. This preferential transfer of the Neon atoms to Energystate E_6 so that Neonatoms placed at Energylevel E_6 results a population inversion is achieved. The purpose of the He atoms is thus to help achieve population inversion in the Ne atoms. The spontaneous transition takes place from the level E_6 to level E_2 produce wavelength $6000 A^{\circ}$

The stimulated transition photons travelling parallel to the tube are reflected back and between the mirrors placed at the ends and rapidly build up into an intense beam. The photons which are escape through the end with low reflectivity. The Brewster mirrors are allow to pass through without any reflection losses.. The electrons impacts at excite the He and Ne atoms occurs all the time. Due to this reason He-Ne laser operates continuously

After achieving the population inversion. The various transitions $E_6 \rightarrow E_5$ $E_4 \rightarrow E_3$, $E_6 \rightarrow E_3$ leads to the emission of wave lengths 3.39μm, 1.15μm and $6328 A^{\circ}$.

The excited Neon atoms drop down from the level E_3 to the level E_2 by spontaneously emitting a photon around wavelength $\lambda = 6000 A^{\circ}$. By the effect of pressure the energy is transfered from Helium atoms to the Neonatoms.
E_2 is a metastable state, in this state atoms (Ne) stay for short time and excite to level E_3 leading to population inversion leads to continuous operation

Advantages of He-Ne Laser: The light from the gas laser as compared to that from solid state lasers are found to be more directional and much more monochromatic.

As compared to Ruby laser the Helium-Neon gas laser has the output characteristics that the output laser beam is much more monochromatic.

The He-Ne laser produce a continuous laser beam without the need of cooling arrangement.

Disadvantage: using internal mirrors is that the mirrors are usually eroded by the gas discharge and have to be replaced regularly. when external mirrors are used, the ends of discharge tube also cause an additional loss due to reflections

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(Q) State and explain the construction and working of Semiconductor laser?

(or)

State and explain the construction and working of Gallium Arsenide laser

(or) working of Diode laser (p-n junction laser) GaAs laser [light emitting diode]

Semiconductor laser is also called as diode laser. The light emitting diodes are basically semiconductor laser. These are have important applications in fiberoptic communication

GaAs (Gallium Arsenide) is well known example of a direct band gap semiconductor and hence it is used widely to prepare LED's (light emitting diodes) and laser.

The wavelength of emitted light depend upon the band gap of the material

$$E_g = \frac{hc}{\lambda} \rightarrow (1)$$ E_g is energy gap. λ is wavelength of photon, c is velocity of light

$E = h\nu$

But $\nu = \frac{c}{\lambda}$

$E = \frac{hc}{\lambda} \Rightarrow E_g = \frac{hc}{\lambda}$

from (1) $\lambda = \frac{hc}{E_g} \Rightarrow \lambda = \frac{1.24}{E_g}\ \mu m$

As E_g increases, it emits shorter wavelengths.

Operation: The Diode lasers are always operated in forward bias

If p and n type materials are prepared from the same material then the p-n junction is called as Homojunction semiconductor laser source.

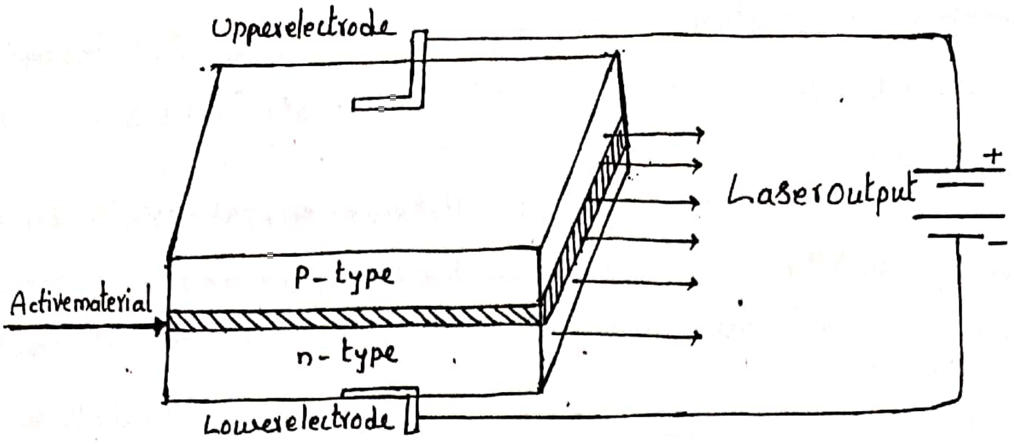
If p and n type materials are prepared from different materials then they are called as Heterojunction semiconductor laser source.

Construction of GaAs Semiconductor diode laser

Mechanism Recombination of electrons and holes at p-n junction when a current is passed through the diode.

Active medium: The active medium is a p-n junction diode made from crystalline Gallium Arsenide. The p-region and n-region in the diode are obtained by heavily doping with suitable dopants.

Since the refractive index of GaAs is high



The arrangements for the construction of GaAs semiconductor diode laser is shown in the figure. Take the p type and n-type materials prepared by adding with suitable dopant elements. The shaded area (the shaded layer) is known as the depletion layer. The thickness of the depletion is usually very small (0.1 μm). To obtain laser action end faces are polished flat and parallel. The other two faces are left unfinished to suppress the oscillations. The active layer consists of a layer of thickness of the order 1 μm, a little wider than the depletion region.

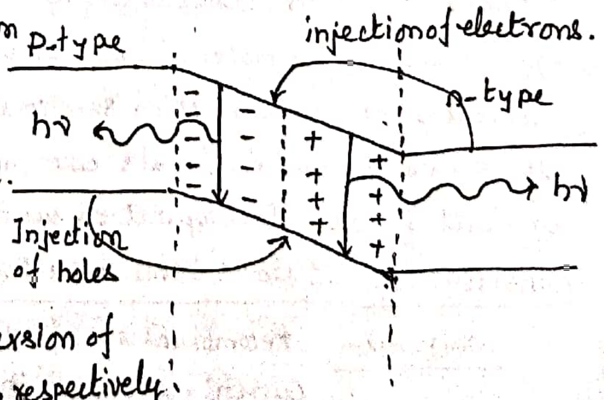
The p-type material is connected to positive terminal of (battery) source and n is connected to negative terminal, which is known as forward bias.

The allowed current for junction is of order of 10^4 amp/cm² is passed through the narrow junction.

Working (operation): Population inversion in semiconductor is achieved is due to heavily doping and due to the operation in forward bias.

when a current is passed through a p-n junction P region is connected to positive terminal of current source and n-region is connected to the negative terminal of the current source. Holes are injected from P-region into n-region and electrons are injected from n-region into p-region.

The electrons and holes recombine and release of light energy takes place in (or) near the junction.



The electron-hole recombination takes place in the active region of the device.

The continuous injection of charge carriers creates the population inversion of minority carriers in n and p sides respectively.

The excess minority charge carriers diffuse away from the junction & recombining with majority carriers of n and p material, resulting in the release of photons. Further, the emitted photons increase the recombination of injected electrons from the n-region and holes in p region by inducing more recombinations.

Semiconductor laser applications: Semiconductor lasers are the cheapest and smallest lasers available. They are easily fabricated into arrays using the same techniques developed for transistor.

The laser output can be easily modulated by modulating the current through the laser diode. Also they are small in size and highly efficient. These properties have made these lasers well suited as light sources for fiber optic communication system.

(Q) State and explain the construction and working of CO_2 laser.

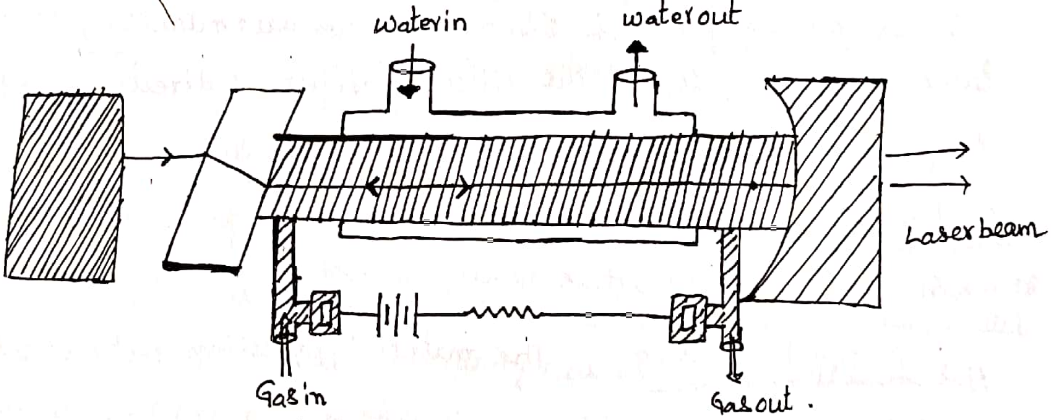
CO_2 laser invented in the year 1963 by C K N patel

CO_2 has more industrial applications.

Activemedium : The active medium is CO_2 gas.

In CO_2 laser for efficient excitation of CO_2 molecules N_2 (nitrogen) molecules are used.

By the addition of He to gas mixture enhances the efficiency. The ratio of pressure $CO_2 : N_2 : He$ is 1:4:5, optimum value of pressure -tube diameter is around 33 torr mm.



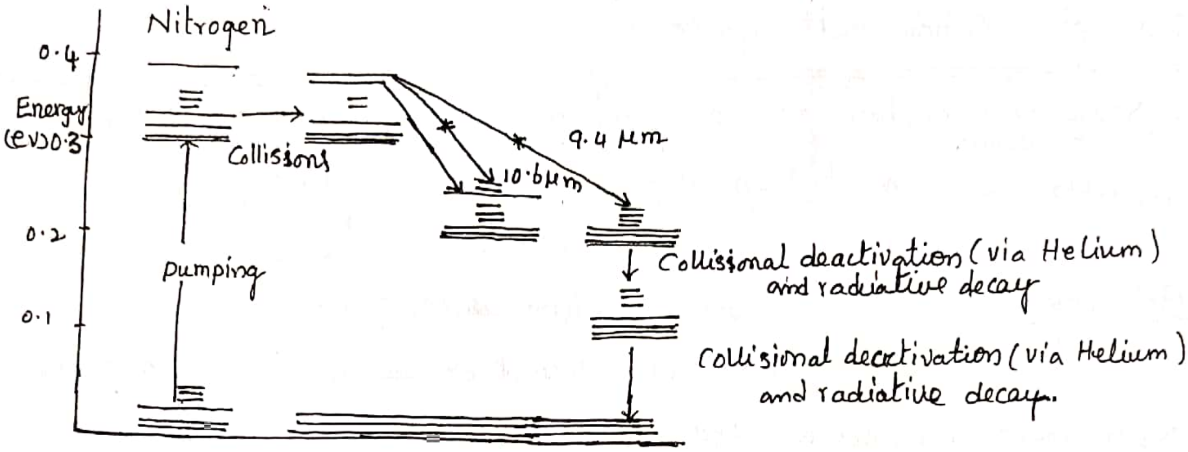
A schematic of a typical CO_2 laser

The construction of CO_2 laser is made from the special materials must be used for windows, mirrors and other laser components. Germanium gallium arsenide, zinc sulphide, zinc selenide and various alkali halides are used as optical materials. The power output of the CO_2 laser is approximately propotional to the tube length (which contains the gas mixture). For the cooling environment water is circulating around the tube. The gas tube is connected to the electrodes in order to supply the current. So that the pumping system is electrical pumping. The CO_2 laser has continuous wave output.

Working : In CO_2 laser, the excitation is provided by electric discharge. The pumping system is electrical pumping.

[Helium is used for excitation of Neon atoms incase of He-Ne laser
In case of CO_2 laser for exitation of CO_2 molecules N_2 molecules are used.
The N_2 molecules transfer energy to the CO_2 molecules in resonant collission.
Due to these collissions all these are exited to the metastable levels with longer lifetime.

with sufficient pumping, a population is produced and laser oscillations begi



Simplified Energyleveldiagram for the CO_2 laser

The He increases the lasere fficiency at 10.6 μm by speeding up the transition there by maintaining a large population

It is relatively easy to obtain continuous wave outputs of 100 w from a laser 1m Long. so that the efficiency of laser is directly propotional to the length of the gas tube.

Applications of CO_2 laser: CO_2 laser are very widely used in industry and in recent years, these lasers are used in the field of medicine also.

(1) Material processing: The material processing such as cutting, drillin, welding, etching, surface hardening etc.

(2) In the field of medicine _ medical CO_2 laser is used as scalpel for bloodless surgery

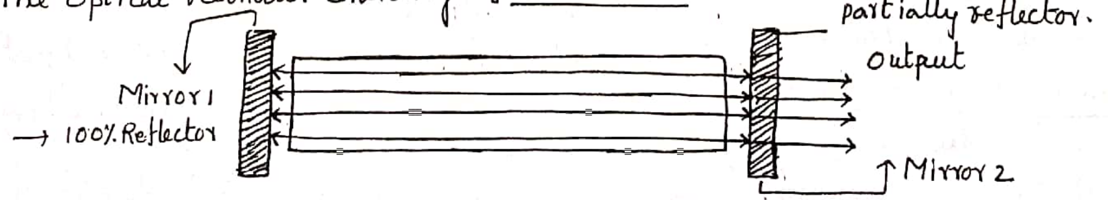
(3) CO_2 laser are used for pollution monitoring and remote sensing.

(Q) Explain the need of cavity resonator in a laser

Need of cavity resonator : To make stimulated emission in more number of atoms. To obtain directionality to the out put beam. To increase the intensity of the laser beam.

Since the resonators mirrors provide positive feedback to the photons amplified by the activemedium, this can be called as "laser oscillator".

The optical resonator consisting of two mirrors

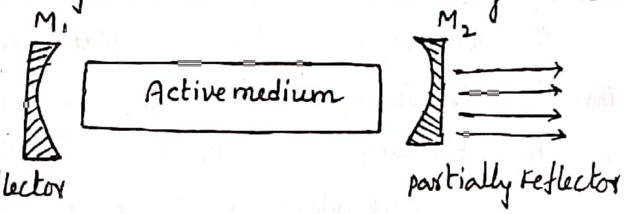


Cavity resonator in a laser essentially consist of two mirrors facing each other. The active medium is placed between two mirrors. One of the mirror is 100% reflecting ie fully reflecting mirror. The other mirror is partially reflecting mirror, which is transperent to let some of the radiation pass through it.
The resonant cavity is used to make stimulated emission possible in more number of atoms in the active medium. This naturally increase the intensity of the laser beam

when the active medium is placed inside an optical resonator, the system acts as an oscillator. A part of the output energy must be feed back into the system. Such a feed back is brought out by placing an active medium between a pair of silver coating mirrors, which are facing each other. The mirrors could be either plane (or) curved deping up on the use.

Such a system formed by a pair of mirrors is reffered to as a cavity resonator. The emerging beam from the resonator after the amplification through material from the two reflectors is known as laser.
Resonator mirrors are generally coated with multilayer dielectric materials to reduce the absorption loss in the mirrors. Moreover these resonators act as frequency selector and also gives rise to directionality to the output beam

Curved mirrors



The schematic diagram consist of two curved mirrors in case of optical resonators with plane mirrors, it is extremely difficult to allign the beam exactly parallel to each other and perpendicular to the cavity axis of the active medium. This problem is overcome by use of curved mirrors to form the resonator cavity instead of plane parallel mirrors.

(Q) Explain the purpose of an active medium in a laser?

The active medium may be a solid, liquid or gas.
The active plays the role in order to achieve population inversion and output of the laser beam. The output of laser be may continuous wave (or) pulsed laser beam it is depend on the nature of the materials taken in active medium.

Ex: Ruby laser Active medium the mixture of Al_2O_3 and Cr_2O_3
The output power in case of Ruby laser is 100 mega watts [10000 watt]
The laser pulse with a width of 10^{-4} sec. The duation of output flash is about 300 microseconds.

Exp 12   He-Ne laser
The He-Ne laser emits power in the range 0.5 mW to 50 mW
The laser(He-Ne) has a coherence length of 300 meter which is used in holography.

The active medium which when excited achieves population inversion and subsequently causes energy levels to rise. The active medium may be a solid (or) liquid (or) gas and it may be one of the thousands of materials that have been found to be large.

The energy due to pumping is confined to the active medium, then population inversion is achieved. The entire medium is like a cavity resonator that emits energy. In a laser system the active medium is placed between reflectors like a pair of mirrors making the active medium as a sort of cavity resonator. Oscillations are set in active medium and sustained in the cavity. A laser source is a quantum oscillator

The resonators mirrors provide positive feed back to the photons amplified by the active medium, this can be called as "laser oscillator"

(Q) Applications of Lasers?
(or)
Mention the applications of Lasers in various fields?

Due to the special features of Laser beam that
(i) narrow bandwidth,
(ii) Due to narrow angular spread
(iii) coherence.
(iv) Directionality
(v) High intensity

The Lasers are used in various fields
(a) Industries
(b) Scientific research
(c) Communication System
(d) In Medicine

Applications of Lasers in Industries : In manufacturing industry lasers are used for welding, cutting and drilling applications.

Welding : with increased power output, it is possible to use the laser (CO_2) as a welding tool.

Laser welding has certain advantages over gas welding such as
(i) purity of the material is not altered [purity of material after welding is unchanged]
(ii) Accurate operation : Localized heating by small spot size can be accurately controlled by programming with computer to reproduce exact characteristics.

Example : CO_2 laser with 10 kW output is employed in case of welding of 5mm thickness stainless steel plates can be welded at a speed of 10 cm/sec.

Cutting Lasers cut through a wide variety of materials, rapidly without noise, Due to high intensity of laserbeam.

example: CO_2 laser employed for cutting of glass, quart, Diamons etc.

with high power levels, 250 watt CO_2 laser 3mm thick quartz plate can be cut at a rate of 2cm/sec.

→ Lasers can be used to blast holes in diamonds and hard steel.

→ A CO_2 laser of 100 w continuous output can cut a cloth at a speed of 1m/sec

→ A CO_2 laser of 3Kw continuous output cuts titanium sheet of 50 m thickness at a velocity of 0.5/minute.

Drilling: Most drilling systems operate in pulsedmode [pulsed lasers are employed]

To get the drill of desired depth and size, number of pulses, and the energy of each pulse are to be controlled.

→ One of the first application of the laser was to drill diamond makes small holes.

Scientific research Applications of Lasers (i) with the help of laser, it is possible to inverstigate the struct of molecules

(ii) Lasers can be used in rangefinder to find the position of distant object

(iii) Laser is a very useful tool to initiate a fusion reaction.

(iv) with the help of laser it is possible to seperate the isotopic species of an element available in an isotopic combination.

(v) It has been observed that fingerprints can be detected under laser light.

(vi) A compact disc Read only memory is (CDROM) is prepared by using a highpower laser to burn one micron (10^{-6}m) holes in a master disk

(vii) Due to narrow, angular spread, the laserbeam has become a means of communication between earth and moon (or) other satillites.

Communication System - Laser applications (i) using laser, it is possible to transmit thousands of television programmes simultaneously to the various places.

(ii) Using laser, it is possible to make communication between the Moon and the earth [to another satillites also]

(iii) Lasers are used in optical range finders which not only give accurate ranging but also size and shape of object with orientation

(iv) Radio telescopes fitted with a ruby laser can amplify very faint radio signals from space, thus extending the range of observation.

In Defence: A Laser beam can be used to destroy very big objects like aircrafts, missiles etc, in a few seconds by directing the laser beam into the target

A laser ~~be~~ can be used for detection and ranging like RADAR, The only difference is it uses light instead of Radio waves. Hence it is called as Light Detecting And Ranging (LIDAR)

Applications of Laser in Medicine [Mention the medical applications of laser]

Laser	Applied field
Argon	→ Neuro surgery, ophthalmology, dermotology, biological research
Helium-Neon	→ laser holography, Diagnostic applications, permeability of blood containing tissues.
Ruby	→ Ophthalmology and dermatology
CO_2	→ treatment of liver and lungs, elimination of tumors, Nuero surgery, dermotology, microsurgery
Nd-YAG	→ Neurosurgery, Dermatology.
ultra violet excimer laser neodymium	→ Treatement of liver cancer

→ Argon ion laser : Ophthalmologists used argon ion lasers for welding retinal detachment
The Green beam of Argon ion laser is strongly absorbed by red blood cells of the retina and welds the retina back to the eye ball

Cataract operation For cataract removal lasers are used.

Blood less Surgery : Laser scapels are used for bloodless surgery. when the tissues are cut the blood veins cut are fused at their tips by the infrared laser and hence there is no blood loss.

Angioplasty & ~~By pass~~ Nd-YAG laser application : The Nd YAG laser are used in angioplasty for removal of artery block. The laser radiation is sent through fiber to the region of block, burns the excess growth and regulates the blood flow with out need of bypass surgery.

Destroying Kidney stones and gall stones [CO_2 laser] Lasers are used in destroying Kidney stones and gallstones. Laser pulses sent through optical fibers shatter the stones into small pieces.

Dermotology In dermatology, lasers are used to remove freckles, acne and tattoo. When such regions are illuminated with blue-gree laser light, the radiation is absorbed by the blood and heats up. The blood vessels are closed and excess blood flow is stopped.

Cancer diagnosis and Therapy : For the treatment of cancerous tissues, skin tumors laser are widely used.
when suscept areas are illuminated with laser of approximate wavelength, cancer cells are destroyed.

Laser therapy is completely painless and more advisable for children.

Scaning : Laser is used in endscopy to scan the inner parts of the stomach

Fiberoptics

Introduction → Optical fibers used in signal transmission for communications

→ These are used to transmit light in the manner metal wires are used to transmit electricity.

→ Best features (i) Much greater band width

(ii) Smaller and lighter ie light in weight and small in size

(iii) Immunity from electromagnetic interference

(iv) stable (or) declining price

(v) These are having capability of carrying a huge amount of information

(vi) No possibility of internal noise

(vii) Small diameter of individual fiber channel

(viii) Can be used very safely even in explosive environment

(ix) Immune to moisture and temperature variation

(x) No dangers of short circuits.

Because of these advantages, fiber optic communication is used in telephones such as loops, trunks, terminals and exchanges, computers, Space vehicles, ships, cable TV, submarines, security, medical field, industrial automations and process controlls, alarm systems.

The fibers are transmitting information on a light beam over very long distances Hundreds of telephone conservations can be transmitted simultaneously at microwave frequencies, many thousands of signals can be carried as a Lightbeam through a fiber optic cable using multiplexing techniques.

Laws are used in fiberoptics The transmission of light in an optical fiber is based on the phenomenon of Total internal reflection

Snell's law $n_1 \sin i = n_2 \sin r$ n_1 n_2 are Refractive indices of rarer and denser medium.

i is angle of incidence.

r is angle of refraction.

The refracted ray bends towards the normal as the ray travels from low dense medium to high dense medium.

The refracted ray bends away from the normal as it travels from high dense medium to low dense medium.

Total internal reflection: There is a possibility to occur total internal reflection provided the angle of incidence is greater than critical angle θ_c

ie $\theta_i < \theta_c$

Critical angle : θ_c : we are incidenting at the critical angle the angle of refraction will be 90° if $\theta_i = \theta_c \Rightarrow \theta_r = 90^\circ$

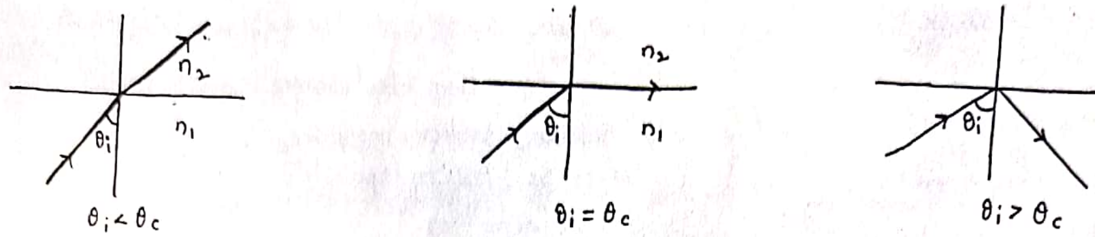
According to Snell's law $n_1 \sin i = n_2 \sin r$

if $i = \theta_c \Rightarrow$ Then $r = 90^\circ \Rightarrow n_1 \sin\theta_c = n_2 \sin 90^\circ$

$\therefore n_1 \sin\theta_c = n_2(1) \Rightarrow \boxed{\sin\theta_c = \frac{n_2}{n_1}}$ $\boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$

Let n_1 be the Refractive index of core; and n_2 be the Refractive index of the cladding

case a: $\theta_i < \theta_c$ Case b: $\theta_i = \theta_c$ case c: $\theta_i > \theta_c$



If the angle of incidence is increased ($\theta_i > \theta_c$) then the ray is totally reflected

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(Q) Describe the construction of a typical optical fiber and give the dimensions of various parts.

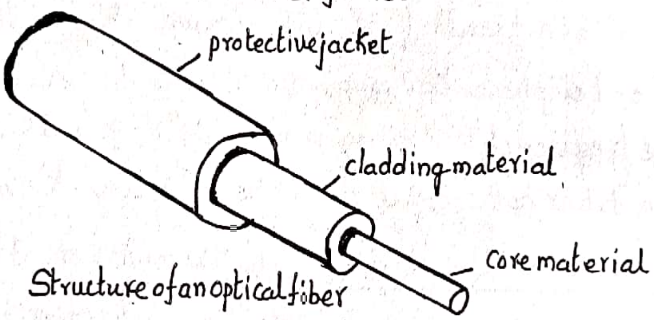
(or)

With the help of a suitable diagram explain the principle, construction and working of an optical fiber as a waveguide.

Optical fiber is a very thin and flexible medium having a cylindrical shape consisting of three section

(i) The core material
(ii) The cladding material
(iii) The outer jacket

Construction:



Structure of an optical fiber

Optical fiber is a cylinder of transparent dielectric medium and designed to guide visible and infrared light over long distances.

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

The cladding is a material having slightly lower refractive index than core's refractive index. The core material is made from glass. The cladding materials are made by the process adding of impurities like Boron, phosphorus (or) germanium are doped.

Silicon coating is provided between buffer jacket and cladding in order to improve the quality of transmission of light.

Finally the fiber cable is covered by black polyurethane outer jacket, because of this arrangement fiber cable will not be damaged during

Main parts of Optical fiber: (i) The core material.
(ii) The cladding material
(iii) Outer jacket.

Core: it is made with Silica. It has high refractive index than cladding. The diameter of the core is of few micrometers. It is denser material than cladding. Core is central part of the optical fibre is made of high refractive index glass, to propagate the light by total internal reflection.

Cladding: It is a material, which is having low refractive index than core. The cladding is Silica doped with suitable amounts of germanium and fluorine to control the refractive index [Refraction index of cladding is always less than the core]

Diameter: The diameter of the outer cladding is of the order of 100 – 125 μm

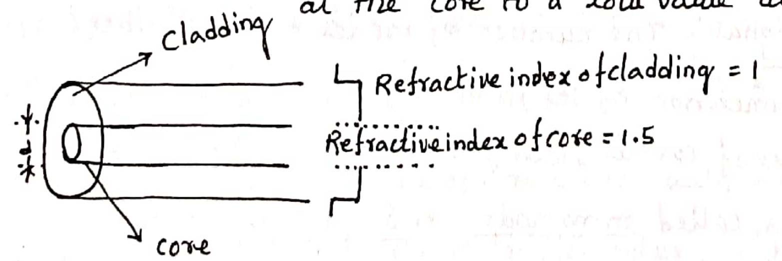
Outer jacket [protective outer covering layer] It is madeup thickness about 60 μm. The outer protective covering is made of polymer. It protects the fibre from the environmental effects.

(Q) How the optical fibres are classified? (or) Types of optical fibers (or) Describe different types of fibres by giving the Refractive index profiles and propagation detail?

Depending upon the Refractive index profile of the core optical fibres are classified in two categories (i) Step index fibre
(ii) Graded index fibre

Depending upon the number of modes of propagation optical fibres are classified into two categories (i) Single mode optical fibres
(ii) Multimode optical fibres.

STEP INDEX FIBRE: The refractive index changes abruptly from a high value at the core to a low value at the cladding



Its structure is like two concentric cylinders. The inner cylinder is called core. The outer one is cladding (air (or) plastic material (or) glass)

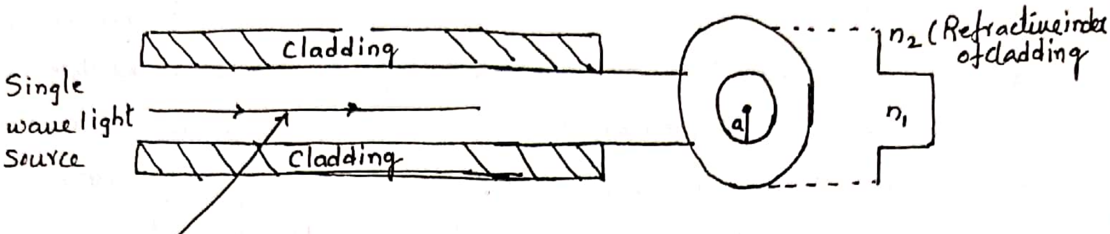
Step index fiber: Fibers in which core of constant refractive index n_1 is surrounded by cladding of slightly lower refractive index at the interface core - clad is known as Step index fiber.

The core diameter will be of the order of 2 - 10 mm.

Light beams entering the fiber at different angles will transvers different total distances before they arrive at the other end of the fiber

Step index fibre Support the transmission of transverse electromagnetic radiation

Stepindex Single mode fibre (or) Stepindex monomode fibre



In the case of Single mode stepindex fiber the core has small diameter and the cladding is kept very thick

The characteristics of this type
(i) Very small core diameter
(ii) Low Numerical aperture
(iii) Low attenuation
(iv) Very high band width

Single mode fibers transmit single ray along the axis of the fiber

Advantages of Single mode fibers have the following advantages

(i) Low intermodal dispersion and lower broadening of Light pulses being transmitted

(ii) Larger bandwidth can be attained in these.

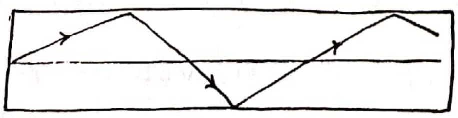
Disadvantage: In single mode fiber, a significant amount of the power resides outside the fiber core.

In this type a single light ray is transmitted. In step index single mode fiber core has small diameter and cladding has large diameter than core.

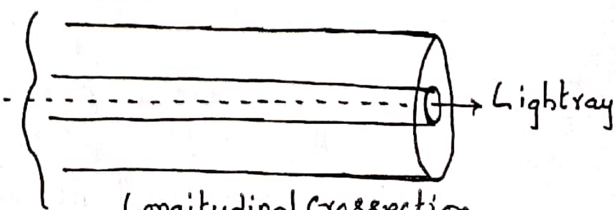
Transmission of Signal: The number of modes that the fiber supports depend on the dimension of the fiber. If the thickness of the fiber is so small (Diameter of core is small) that it supports only one mode then the fiber is called monomode (or) Singlemode fiber

The mono mode fiber has very small core diameter of the order 2 to 8 μm

It requires coherent Light source like laser



Signal transmission

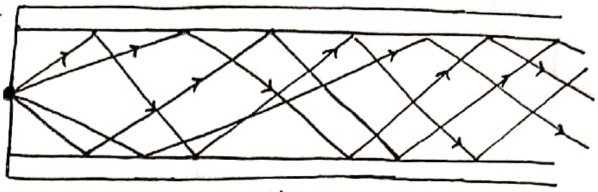


Longitudinal crossection

Multimode fibre : The fibre which supports more than one mode then it is called multimode fibre.

The core diameter of multimode fiber is of the order of 50 μm

ie the core diameter is large



Multimode stepindexfiber

Multimode step index fiber :

Multimode step index fibers allow finite number of guided modes

Thus, the various lightwaves (incoherent sources) travelling along the core, will have propagation paths of different lengths. Hence they will take different times to reach a given destination

The direction of polarization, alignment of electric and magnetic fields will be different in rays of different modes in multimode fiber. These modes depend on the boundary conditions. Mode volume of a multimode fiber is the number of modes the fiber can support

Advantages : The multimode fibers have the following advantages.

(i) Source : we can ordinary Multimode fibers can use spatially incoherent sources of light like LED's

(ii) Easy to Couple : Due to large Numerical aperture and core diameters it is easy to couple them with other fibers and sources of light.

(iii) Low tolerance requirements : These fibers have lower tolerance requirements on their properties.

GRADED INDEX FIBERS [The refractive index of the core varies Continuously]

In graded index multimode fiber, the refractive index of the core varies radially. The refractive index of core is maximum at its centre, which gradually falls (decrease) with increase of radius and at the core.

ie Refractive index of core varies with respect to distance (radial)

Let n be the refractive index, 'r' be the radial distance.

n be the function of r ie $n = n(r)$

$$n(r) = n_1 \left[1 - 2\Delta \left(\frac{x}{a}\right)^{p} \right]^{2}$$

n_1 refractive index at the centre of the core

p : graded profile index number.

γ: radial distance
a: core radius
Δ: index difference.
$\Delta \simeq \frac{n_1 - n_2}{n_1}$ $(n_1 > n_2)$
P: index profile

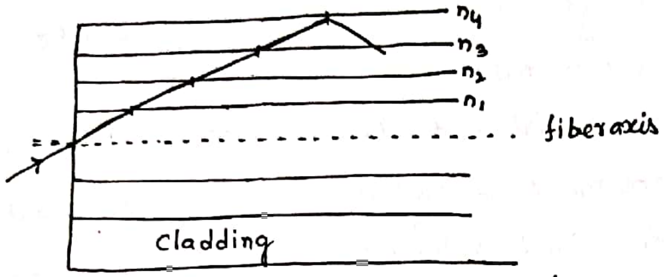
$\Delta = \frac{n_1 - n_2}{n_1}$ $n(\gamma) = n_1\left(1 - 2\Delta\left(\frac{\gamma}{a}\right)^P\right)^{1/2}$

Case (a) $\gamma > a$ $n(\gamma) = n_1(1 - 2\Delta)^{1/2} = n_2$

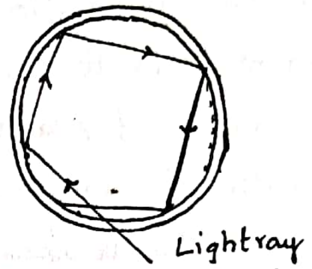
Case (b) $\gamma \ngtr a$

NOTE: The refractive index of the core material is varies with respect to the distance. So that there exist Multiple refractions in graded index fiber with in core material

Advantage: Distortion is minimized by making the variation of the refractive index gradual from the axis of the core



Multiple refractions in graded index fiber with core material



Cross-Section View.

Graded index fiber have the following characteristics

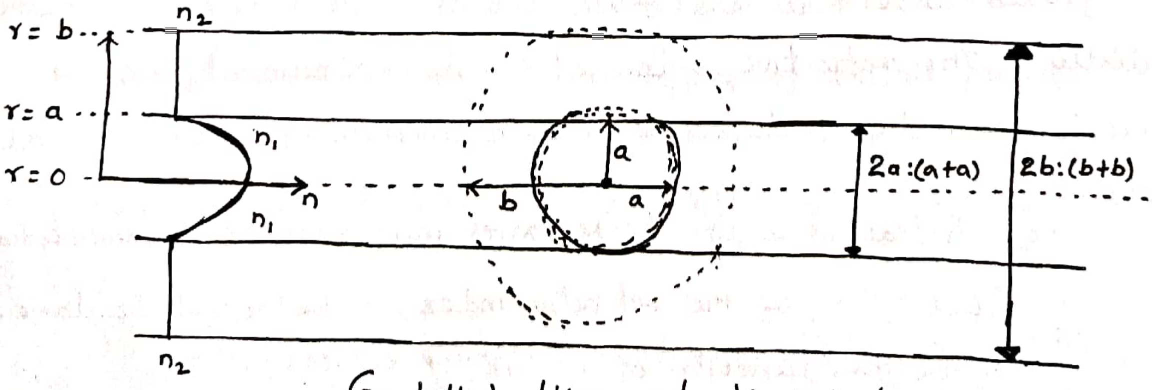
(i) Refractive index profile is circularly Symmetric
(ii) Fiber is multimodal with large core diameter
(iii) Total internal reflection and refractive index change with in the core region slowly.
(iv) Refractive index variations are small

Multimode - Graded index fiber

A Graded index fiber is a multimode fiber with a core consisting of concentric layers of diffrent refractive indices $(n_1, n_2, n_3, n_4 \cdots)$ $n_1 > n_2 > n_3 > n_4$

ie Refractive index of the core decreases with distance from the fiber axis $n \propto \frac{1}{\gamma}$

$n \propto \frac{1}{\gamma}$ where γ is the radial distance from the fiber axis



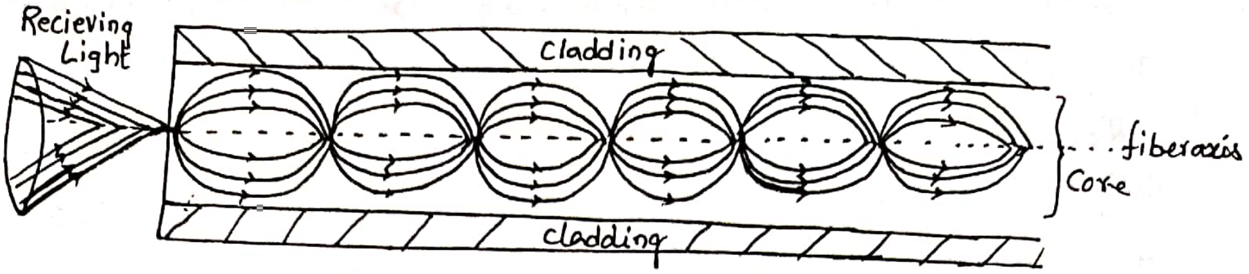
Graded index fiber - refractive index profile

n_1 - Refractive index of core: [it is Nonuniform]

n_2. Refractive index of Cladding

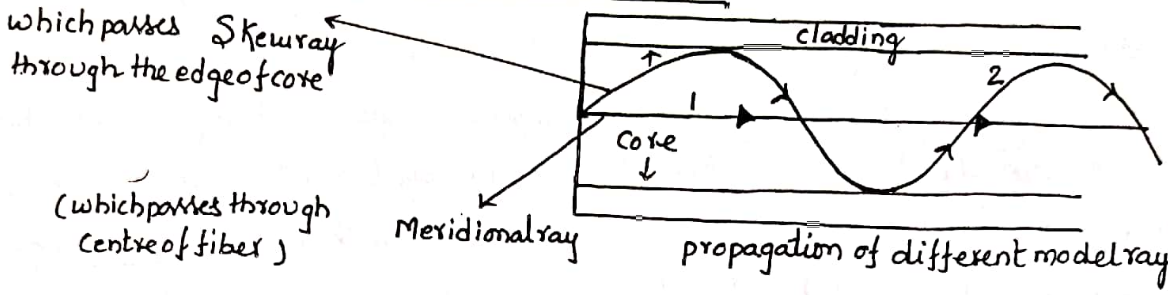
$\gamma \rightarrow 0$: at fiber axis $\gamma \rightarrow b$ cladding
$\gamma \rightarrow a$ with in core (a: core radius)

In Graded index fiber Numerical aperture decrease with radial distance from the axis



Typical Light ray paths in Graded index fiber

Transmission of Signal in Graded index fiber



propagation of different model rays.

Graded index fiber is a <u>multimode fiber</u> that Supports propagation of meridional rays. Signal pulse represented by 1^* travelling along the axis of fiber, The Meridional rays travels through a medium of high refractive index, which are parallel to fiber axis. Advantage: <u>Less inter modal dispersion</u> (Than Step index multimode fiber)

<u>Skew rays</u>: (refraction takes place): The other pulse represented by 2^*, travelling away from axis, through the edge of the core (from ~~to~~ high refractive index to low refractive index vice versa)
The path of this (Skew ray) ray is Sinusoidal in nature. It travels longer distance

<u>Advantage of G.I fiber</u> Inter model dispersion is reduced to <u>minimum</u>

<u>Disadvantage of G.I fiber</u>: propagate only half the power carried by the Step index fiber (power loss is takes place)

<u>propagation of Modes in the core</u>: The number of possible propagation modes in the core is Known as V-number of fiber

V- <u>number</u> for graded index fiber $V = \frac{2\pi}{\lambda} a(NA)$ λ: wavelength
a: radius of core
NA Numerical aperture.

Total Number of Modes through Step index fiber $\boxed{N = V^2} \Rightarrow \boxed{N_{SI} = V^2}$

Total Number of modes through Graded index fiber $N = \frac{V^2}{2} \Rightarrow \boxed{N_{GI} = \frac{V^2}{2}}$

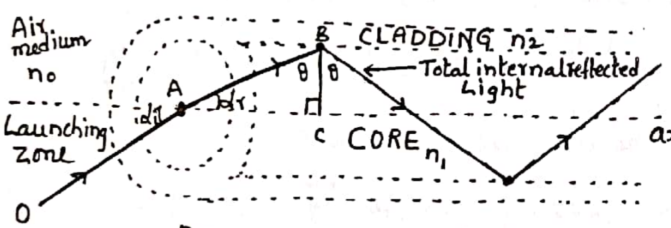
$$\therefore \boxed{N_{GI} = \frac{N_{SI}}{2}}$$

(Q) what is acceptance angle? what is acceptance cone? Derive an expression for acceptance angle? Derive expression for Numerical aperture

The light is incident at the face of optical fiber at different angles. only a particular amount light is only recieved by the fiber which travels along the interface of core and cladding. For total internal reflection: the incident light is greater than critical angle (θ_c) will undergo total internal reflection and propagate through the core. The other rays are refracted into the cladding material and are lost.

All the incident light rays are not accepted by fiber only particular rays are accepted for propagation. Acceptance angle is nothing but, at which angle the light is accepted for the propagation [* Greater than θ_c]

Acceptance angle (α_m) : Acceptance angle is defined as the maximum angle of incidence at the interface of air medium and core medium for which the light ray enters (coupled) into the core and travels along the interface of core and cladding and will propagate along the fiber.



PATH OF A TYPICAL LIGHT RAY LAUNCHED into FIBER

OA : incident light ray from a medium of Refractive index 'n_0'
α_i : Angle of incidence
α_r : Angle of refraction
n_1 : Refractive index of core
n_2 : Refractive index of cladding

CASE STUDY : Entering of Light ray to the axis of fiber * Generally $n_1 > n_2$

Let a Light ray OA enters the fiber at an angle α_i to the axis of the fiber (Launching) Consider the light ray enters from a medium of refractive index n_0

The light ray refracts at an angle α_r and strikes the core-cladding -interface at angle θ

*Condition If the angle 'θ' is greater than its critical angle θ_c, the light ray undergoes TOTAL INTERNAL REFLECTION at the interface

According to Snell's law $n_0 \sin\alpha_i = n_1 \sin\alpha_r \rightarrow (1)$

[$\because \mu_1 \sin i = \mu_2 \sin r$
$\mu_1 = n_0$; $i = \alpha_i$
$\mu_2 = n_1$; $r = \alpha_r$]

From the right angled triangle ABC $\alpha_r + \theta = 90^\circ \rightarrow (2)$

$\alpha_r = 90^\circ - \theta \rightarrow (3)$

[$\because$ Total Subtend angle 180°
'a' Right angle: 90°
'b+c' other two angles : 90°
$90^\circ + 90^\circ = 180^\circ$]

Substitute α_r value in (1) $n_0 \sin\alpha_i = n_1 \sin(90^\circ - \theta)$

$n_0 \sin\alpha_i = n_1 \cos\theta \rightarrow (4)$ [$\because \sin(90-\theta) = \cos\theta$]

from (4) $n_0 \sin\alpha_i = n_1 \sin(90-\theta)$

$n_0 \sin\alpha_i = n_1 \cos\theta$

$\sin\alpha_i = \frac{n_1}{n_0}\cos\theta \longrightarrow (5)$

[As per condition] when $\theta = \theta_c$; $\alpha_i = \alpha_m$ = maximum α value

$\therefore$ from (5) $\sin\alpha_m = \frac{n_1}{n_0}\cos\theta_c \rightarrow (6)$ [α_m : Maximum value of angle of incidence]

If n_1 and n_2 are refractive indices of core and cladding

If the angle of incidence = θ_c ; then angle of refraction = $90°$

According to law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow (7)$

Here $\theta_1 = \theta_c \Rightarrow \theta_2 = 90°$ [As per Definition of critical angle]

$\therefore n_1 \sin\theta_c = n_2 \sin 90° \rightarrow (8)$

$\therefore n_1 \sin\theta_c = n_2(1) \Rightarrow \sin\theta_c = \frac{n_2}{n_1} \rightarrow (9)$

* from equation (9) we can find $\cos\theta_c$ value ie $\cos\theta_c = \sqrt{1-\sin^2\theta_c}$

$\therefore \cos\theta_c = \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$

$\therefore \cos\theta_c = \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \longrightarrow (10)$

* from equation (10) we can substitute $\cos\theta_c$ value in equation (6)

$\therefore \sin\alpha_m = \frac{\cancel{n_1}}{n_0}\left[\frac{\sqrt{n_1^2 - n_2^2}}{\cancel{n_1}}\right]$

* For a medium $\Rightarrow$

$\therefore \boxed{\sin\alpha_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}} \longrightarrow (11)$

If the medium surrounding the fiber is air then $n_0 = 1$

For air medium $\Rightarrow \therefore \sin\alpha_m = \frac{\sqrt{n_1^2 - n_2^2}}{1} \Rightarrow \boxed{\sin\alpha_m = \sqrt{n_1^2 - n_2^2}}$

$\therefore \boxed{\alpha_m = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)}$

Above expression represent acceptance angle

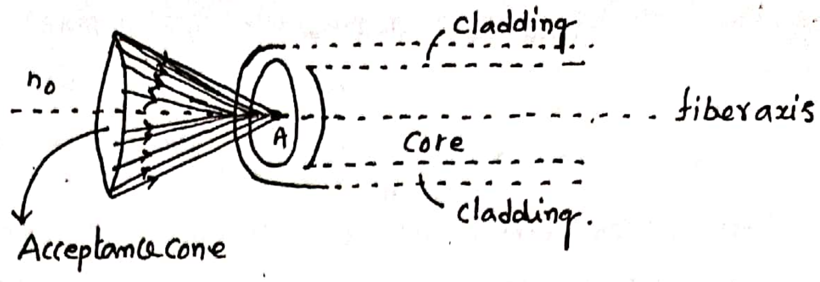
This maximum angle (α_m) is called the acceptance angle

* Acceptance angle (α_m) : Acceptance angle is the angle at which light should be incidented on the fiber for the propagation through it by satifiying the condition total internal reflection (TIR)

NOTE 1 : Light is incident at angle θ greater than θ_c ($\theta > \theta_c$) it undergoes total internal reflection.

NOTE 2 : $\theta < \theta_c$ then the incident light will be lost in the cladding

NOTE 3 propagation of Light through fo as a result of Multiple total internal reflections



For the Light rays to propagate through opticalfiber by total internal -reflection, they must be incident on the fiber core with in acceptance angle defined by conical half angle.

Light launched at the fiber end with in this acceptance cone alone will be accepted and propagated to the other end of the fiber by total -internal reflection

Rotating the acceptance angle about the fiber axis describes the acceptance -Cone. - of the fiber

Numerical Aperture Light gathering capacity of the fiber is expressed, interms of maximum acceptance angle (α_m) and is termed as 'Numericalaperture'

or, Numerical Aperture is a measure of its Lightgathering power.

The Numerical Aperture (NA) is defined as the sine of the maximum acceptance angle thus Numerical Aperture (NA) = $\sin\alpha_m$

Derivation is Specified in above question. Derive for $\sin\alpha_m$.

$\therefore$ $NA = \sin\alpha_m \longrightarrow (1)$

we know that $\sin\alpha_m = \sqrt{n_1^2 - n_2^2} \longrightarrow (2)$

In case we consider air medium Light is Launched from air to fiberendface

from (1) and (2) $NA = \sqrt{n_1^2 - n_2^2}$

$\therefore$ $NA = \sqrt{(n_1+n_2)(n_1-n_2)} \longrightarrow (3).$

$\Delta = \dfrac{n_1 - n_2}{n_1}$ where Δ is the relative refractive indexdifference of an optical fiber.

$\therefore \Delta = \dfrac{n_1 - n_2}{n_1} \longrightarrow (4)$

$\therefore n_1 - n_2 = \Delta n_1 \longrightarrow (5)$

$\therefore$ $\boxed{NA = \sqrt{(n_1+n_2)\Delta n_1}}$

Numerical aperture is depend on n_1, n_2 and independent on the fiber dimensions.

Value of NA ranges from 0.1 to 0.5

If NA Value is large then the fiber will accept Large amount of Light from the Source.

(Q) Define the relative refractive index difference of an optical fiber. Show that it is related to Numerical aperture.

Let us consider the refractive index of core material is n_1 and refractive index of cladding material is n_2.

Relative refractive index difference : It is defined as ~~fractional~~ difference in refractive indices n_1 and n_2 are the refractive indices of core and cladding material respectively.

Let Δn be the relative refractive index difference.

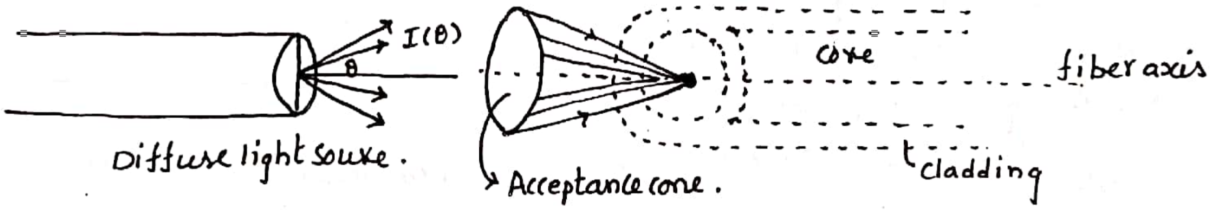
$\Delta n = n_1 - n_2$ ie Δn is related to Numerical aperture of the fiber as $\boxed{NA = \sqrt{2n_1\Delta n}}$

Let Δ be the fractional difference in refractive indices of core & cladding

$$\Delta = \frac{n_1 - n_2}{n_1} \Rightarrow \Delta = \frac{\Delta n}{n_1} \longrightarrow (1)$$

$\therefore$ from (1) $\Delta n_1 = \Delta n \rightarrow (2)$

Light Source : It emits the power which is coupled by the end face of fiber for propagation. only some amount power can be collected by fibe and propagated along the fiber ie $(NA)^2$ can be colled by the fiber and propagated along the fiber



Consider a small diffuse light source as the isotropic (same in all directions) radiator as shown in above figure is Captured by end face of fiber. Light emitted Normal to end surface of fiber. ie In which the power radiated per unit Solid angle in the direction θ to the normal to the surface is given by $I(\theta) = I_0 \cos\theta \longrightarrow (3)$

$\therefore$ Total power emitted by light source is $\Phi_0 = \int_0^{\pi/2} I(\theta) d\Omega \rightarrow (4)$ [$d\Omega$: Small element of Solid angle.]

$$\therefore \quad \Phi_0 = \int_0^{\pi/2} (I_0 \cos\theta)\, d\Omega \rightarrow (4)$$

$$\therefore \quad d\Omega = 2\pi \sin\theta \, d\theta \longrightarrow (5)$$

$$\therefore \Phi_0 = \int_0^{\pi/2} I_0 \cos\theta \, 2\pi \sin\theta \, d\theta = \int_0^{\pi/2} I_0 (2\sin\theta\cos\theta)\pi \, d\theta$$

$$\therefore \Phi_0 = I_0 \pi \int_0^{\pi/2} \sin 2\theta \, d\theta \qquad [\because \pi, I_0 \text{ constants}]$$

$$\therefore \Phi_0 = I_0 \pi \left[-\frac{\cos 2\theta}{2}\right]_0^{\pi/2} = \frac{I_0\pi}{2}\left[\cos 2\theta\right]_{\frac{\pi}{2}}^{0}$$

$$\Phi_0 = \frac{I_0 \pi}{2}[1+1] \Rightarrow \Phi_0 = \pi I_0$$

$\therefore \phi_0 = \pi I_0 \longrightarrow (6)$

If α_m is acceptance angle, the angle at which the power is accepted by the fiber for propagation

But the power from such a source that can be collected by an adjacent fiber whose core diameter is greater than the diameter of the source is given by ϕ $\Rightarrow \phi = \int_0^{\alpha_m} I(\theta)\, d\Omega = \int_0^{\alpha_m} (I_0 \cos\theta) 2\pi \sin\theta\, d\theta$.

$$\therefore \phi = \int_0^{\alpha_m} (I_0 \cos\theta)\, 2\pi \sin\theta\, d\theta \longrightarrow (7)$$

$$\therefore \phi = \int_0^{\alpha_m} I_0 \pi\, 2\sin\theta\cos\theta\, d\theta.$$

$$\therefore \phi = \pi I_0 \sin^2\alpha_m \longrightarrow (8)$$

we know that $\phi = \pi I_0$ [from (6)] substitute in eq (8)

$$\therefore \phi = \phi_0 \sin^2\alpha_m \longrightarrow (9)$$

we know that Numerical aperture $(NA) = \sin\alpha_m \rightarrow (10)$

ie Numerical aperture is directly related to acceptance angle

$$\therefore NA = \sin\alpha_m \Rightarrow \sin^2\alpha_m = (NA)^2 \rightarrow (11)$$

$\therefore$ from (9) and (11) $\phi = \phi_0 (NA)^2 \rightarrow (12)$

$$\therefore \frac{\phi}{\phi_0} = (NA)^2 = \sin^2\alpha_m \rightarrow (13)$$

we know that $\sin\alpha_m = \sqrt{n_1^2 - n_2^2} = \sqrt{(n_1+n_2)(n_1-n_2)}$

$$\sin^2\alpha_m = (n_1+n_2)(n_1-n_2) \rightarrow (14)$$

Substitute $n_1 - n_2 = \Delta n =$ Relative refractive index difference of the fiber

$$\therefore \sin^2\alpha_m = (n_1+n_2)\Delta n \longrightarrow (14)$$

$$\therefore \Delta = \frac{n_1 - n_2}{n_1} \Rightarrow \Delta = \frac{\Delta n}{n_1} \Rightarrow \Delta n_1 = \Delta n \rightarrow (15)$$

from (14) and (15) $\sin^2\alpha_m = (n_1+n_2)\Delta n_1 \rightarrow (15)$

As $n_1 \approx n_2$ we can take $n_1 + n_2 = 2n_1 \rightarrow (16)$

from (15) and (16) $\sin^2\alpha_m = (2n_1)\Delta n_1$

$$\therefore \sin^2\alpha_m = 2n_1^2 \Delta \longrightarrow (17)$$

$\therefore$ from equations (13) and (17) we can write $\frac{\phi}{\phi_0} = (NA)^2 = 2n_1^2\Delta \rightarrow (18)$

$\therefore$ Numerical aperture $(NA)^2 = 2n_1^2 \Delta \rightarrow (19)$

But $\Delta = \frac{n_1 - n_2}{n_1} = \frac{\Delta n}{n_1} \longrightarrow (20)$

from (19) & (20) $(NA)^2 = (2n_1^{\cancel{2}})\left(\frac{\Delta n}{\cancel{n_1}}\right)$

$$\therefore (NA)^2 = 2n_1 \Delta n \Rightarrow NA = \sqrt{2n_1 \Delta n}$$

$$\boxed{NA = \sqrt{2n_1 \Delta n}}$$ Δn is relative refractive index difference

From above equation Numerical aperture of fiber (NA) is related to the relative refractive index difference of an optical fiber.

(Q) Explain the advantages of optical Communication System.
[or] Discuss the various advantages of communication with optical fiber over the conventional coaxial cables.

Conventional coaxial cables constitutes copper (or) Aluminium basic raw materials are high cost, and having *disadvantages in communication process as compared to optical fiber (fabrication of fibers with silica)

Conventional coaxial cables:- Communication * — loss of power; dispersion; insecurity, high cost; maintenance is difficult; they may pickup line currents Interfering with electromagnetic signals; Leakage of signals; Distortions due to Geographical effects

Optical fiber communication: advantages over conventional coaxial cables
→ Enormous Bandwidth (10^{14} Hz); Low transmission loss.
→ Immunity to crosstalk (crosstalk is negligible)
→ Electric Isolation (No effect by electric and magnetic field)
→ Small size and weight (Easy installation: 10 μm: 50μm
→ Signal Security (Does not radiate 100% signal security)
→ Ruggedness and Flexibility (Damage rate is very less)
→ Low cost and availability (Compare to copper: Aluminium Cables.
→ Reliability

Let us see the advantages of optical fiber communication over conventional Communication System.

Optical fibers are dielectric waveguides (silica glass) so that optical signals (or) Data can be transmitted through the fiber over a very long distances with low loss, low attenuation, low dispersion. Thus one can achieve very high band width (or) high data rate using fiber optic cables.

(a) Enormous Bandwidth: The band width of the optical communication channel is very large as compared to conventional coaxial communication channel. Due to high band width (10^{14} Hz) optical carrier frequency there exist possibility of greater information carrying capacity. There are transmitting different signals with different wavelengths in parallel to the same optical fiber. A fiber has a capacity of 500 channels and its external diameter is not more than 0.5mm.

~~b~~ (b) Low transmission loss : Optical fibers have very low transmission losses Due to the usage of ultra low loss fibers and erbium doped silical fibers as optical amplifiers, one can achieve almost lossless transmission. The repeaters can be kept at a very long distance like 45 Kms. The coaxial cables requires repeater repeater at every 1.6 Kms. This saves considerable cost

(c) Immunity to crosstalk optical fibers are made out of dielectric materials Hence they are free from electrical and electromagnetic interference (EMI) Since optical interference among different fibers is not possible, crosstalk is neglisible even many fibers are cabled together.

(d) Electrical Isolation : Unlike their metallic counterparts optical fibers are electrically insulated. Optical fibers are made from silica which is an electrical insulator. Therefore they donot pickup any current. This makes optical fibers suitable for use in electrically hazardous environments.

(e) Small size and weight : The size of the fiber ranges from 10 µm to 50 µm Hence they are compact and little weight in comparision with copper cables. These advantages make them to use in aircrafts and satellites.

(f) Signal security The transmitted signal through the fiber does not radiate Thus, the optical cable is superior than coaxial conventional cables. This feature (signal security) is attractive for milatary, banking and general secured data transmission applications.

(g) Flexibility The fiber cable can be easily bend or twisted without damaging it. where as conventional cables (Metallic cables) are not flexible It is easy to handle, installation, storage, transportation, mainteinence

(f) Low cost and availability Optical fibers are made out of Silica which is glass. available in abundance. Hence they are cheaper compared to metallic wave guides and coaxial cables. optical fibers offer low cost communication

(g) Reliability The optical fibers are made from silicon glass which does not undergo any chemical reaction or corrosion. Its quality is not affected by external radiation

Due to All the above factors ~~ab~~ Optical fiber communication have the advantages over the conventional coaxial cables (copper and metallic(Al) cables)

Describe the Communication process using optical fibers

(or) Draw the Block diagram of an optical fiber communication system explain function of each block.

In practice, the optical fibers positioned in supporting cables.

The Signals can be directly transmitted upto 40 Km without much attenuation.

Beyond this distance (40 Km) "Amplifier (or) Repeaters" are used to amplify the signals at suitable distances.

The optical communication system comprises with Transmitter section, Receiver section.

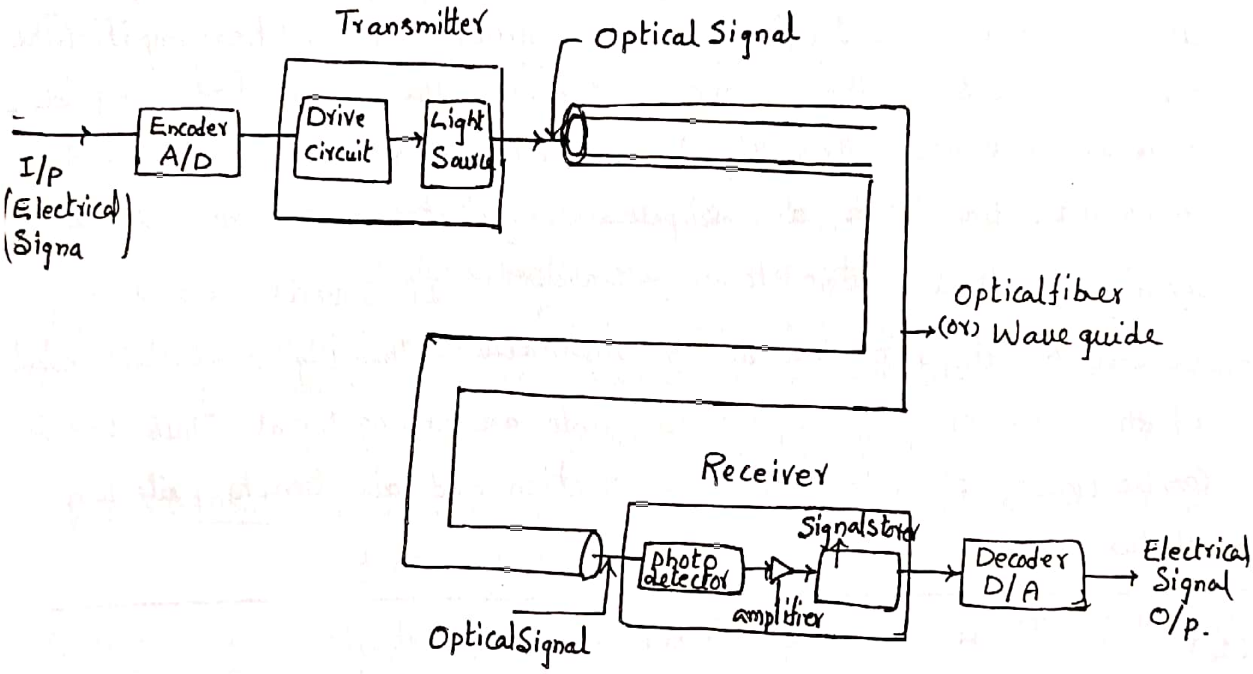


Fig: Block Diagram of fiber Optic Communication System

Function of each block is explained as follows.

Input: The input analog electrical signal which is the information to be carried is converted to digital signal in A/D converter.

Encoder: It is an electronic system that converts the analog information like voice, figures, objects etc into binary data. This binary data contains a series of electrical pulses. The information is converted to digital signal in Encoder for transmission. The Digital data is converted in to suitable optical signal in the form of light pulses using the Laser Source

Transmitter: It consists of two parts, they are drive circuit and Light Source. Light Source is a semiconductor infrared laser (or) LED's are used. The light pulses are transmitted through long optical fibers The electrical signals are converted in to optical signals. with the help of specially made connector optical signal will be received by the (receiver) (from the) waveguide from the transmitter.

waveguide (or) optical fiber : It is a non metallic wave guide which carries information in the form of optical signals with the help of specially made connector optical signal will be received by the receiver from the wave guide.

Receiver : It consists of three parts, they are photodetector, amplifier and signal restorer. The photodet converts the optical signals into the equivalent electrical signals and supply them to amplifier. The amplifier amplifies the electric signals as they become weak during the journey through wave guide over long distance. The signal restorer keeps all the electric signals in a sequential form and supplies to detector in the suitable way.

Decoder (D/A convertor Digital to analog convertor) It converts the received electric signals into the analog information. The Digital electrical output of the detector is then converted into an analog signal. Thus signals can be transmitted without much attenuation and distortion to quite long distances.

(Q) what are important features of optical fibers
write the uses of fiber optics in different fields
applications of optical fibers in various fields.

Optical fibers are employed in in various fields.

(i) Communication System
(ii) Sensors. (fiber optic sensors)
(iii) Medical [gastroscopes and other medical instruments]
(iv) Industrial applications.

Communication System Optical fibers are very attractive alternatives to twisted wire or coaxial cables in communication links.

→ They carries information, ie Information-carrying capacity is high as compared to conventional cables [Bandwidth of the order 10^{14} Hz]

→ Fibers are Dielectric wave guides which transmit the optical the optical signal or data through them with very low attenuation and very low dispersion

Thus one can achieve very high band width (or) high data rate using fiber optic cables.

Low transmission loss For long distance communication fibers of 0.002 dB/Km are used. So that one can achieve almost loss less transmission.

Signal Security : Optical fiber communication provides 100% signal security

Enormous Bandwidth The data rate (or) information carrying capacity of optical fibers is enhanced to many orders of magnitude

Sensors : Fiber optics are used as sensor

Sensors : There are two types of fiber optic sensors → Intrinsic → extrinsic

Sensors are the devices used to measure (or) monitor quantities such as displacement, pressure, temperature, flow rate, liquid level, chemical composition etc. A smoke detector and pollution detector can be made from fibers. Intrinsic Sensors [produce the macroscopic results]

Intensity-modulated Sensors works on the principle of intensity variation Represents variation of Intensity of light.

phase sensor It is a temperature sensor which utilizes the principle of phase variations.

Extrinsic Sensors [produce the microscopic results] ex: Magnetic field Sensors

Fiber optic Sensors

Measured parameter	Modulation effect in optical fiber
1. Temparature	Thermoluminescence
2 Magneticfield	Magneto - optic effect
3. pressure	Piezo - optic effect
4 Mechanical force	Stress birefringence.
5 Electric current	Electroluminescence
6 Electric field	Electro optic effect
7. Density	Triboluminescence
8 Nuclear radiation	Radiation induced luminescence

Industrial applications: In laser processing of materials like drilling welding and cutting, the high power laser is located at one place and the laser radiation will be transmitted to different locations in the shop floor through optical fiber cables.

Medical application of fiberoptics [write a Note on fiber optic medical endoscopy]

optical fibers are used in endoscopes to get the image of the particular part of the body. In laser, optical fibers are used to transmit the laser beam to the point of interest where surgery is to be done.

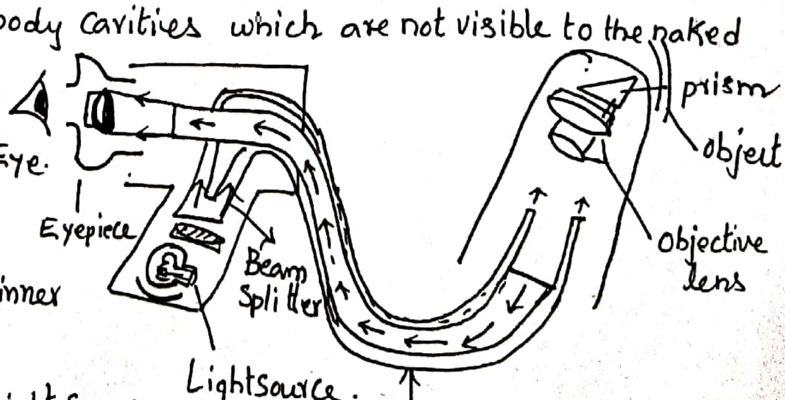
Fiber scopes are employed widely in endoscopic applications.

Fiberoptic endoscope: To view internal body parts without performing surgery

Fiberoptic endoscopes:	Application (use).
(a) Gastroscope: It consists of a long flexible rubber tube and a rigid metal section that has a lens and various contols	→ To examine the Stomach → photograph tumors, and ulcers → To remove objects that have been swallowed
(b) Branchoscope →	To view the upper passages of Lungs
(c) Anthoscope →	To study the small spaces within joints.
(d) Cardioscope →	heart cavities; operation ⇉ aspiration of mucus. valvular defects septal defect
(e) Cytoscope →	examine tumors, inflammation, Stones
(f) protoscop →	Range of use Rectum Operation hemorrhoids

Working of Endoscopes: The endoscope is a tubular optical instrument to inspect (or) view the body cavities which are not visible to the naked eye normally.

Usually in each endscope there are two fiber bundles. One is used to illuminate the object and other is to view the inner structure of



Light rays emitted from the Light Source are focussed and coupled to the illuminating fiber bundle and finally incident on the object surface.

Chapter - I Dielectricproperties

Introduction The dielectrics are the substances which dont contain free electrons under Normal conditions, Insulators do not have free electrons (or) Conduction electrons So that Dielectrics are basically electrical insulating materials.

The dielectric materials are considered as materials in which electrostaticfields can persist for a longtime. The dielectrics are electrically insulators, because electrons are bound to their parent molecule

Examples of Dielectrics : Mica, glass, plastic, natural rubber, paper, backelite polymermaterials, vegitable oils. transformer oil.

Importance of Dielectrics : The dielectricmaterials play a vital role in many electronic applications Such materials in capacitors, ferroelectric, antiferroelectric, piezoelectric and magneticmaterials

[1] Explain the polarization mechanism in dielectrics?

Dielectrics exibit the phenomenon of electronic polarization in the presence of the electricfield and have high resistivities.

when an electricfield is applied on dielectrics then the positive charges displace in the direction of the field, while negative charges are displaced in the oppositedirection. The displacement of charges produce localdipoles throughout the solid

Electricpolarization : The process of producing dipoles by the influence of an applied electricfield is electricpolarization in case of Dielectrics

Due to the polarization the +ve and -ve ions displaced, then dipoles will exist. Due to applied field the dipolemoment will present. The process of polarization is contribution of electronic, ionic and orientational polarization

when a dielectric is placed in an externalfield the polarized charges produce dipolemomentum. There exist dipolemoment on the presence of Electricfield.

P is dipolement $\therefore P = \frac{q_i b}{A b}$ $q_i b = \mu_e$ electric dipolement.

The induced charge produce polarization Ab = volume of slab.

The polarization may also be defined as the electric dipolemoment perunitvolume

ie Polarization $P = \frac{\vec{\mu}_e}{V}$; $\vec{E}, \vec{D}, \vec{P}$ are related by $D = \varepsilon_0 E + P$

Consider an isolated atom is placed under E, the light electrons move much more than the heavynucleus. Hence the centre of the electroncloud shifts in the opposite direction of E

Due to the effect of an applied electricfield on dielectric there exist displacement in between centres of +ve and -ve charge. So that due to the displacement of charge each atom becomes a dipole. The localfield will developed individually

Total polarization $P = N \alpha_t E$

where α_t = Total polarizability $\therefore \alpha_t = \alpha_e + \alpha_i + \alpha_o$

where α_e is electronic polarizability; α_i = ionic polarizability ; α_o: orientational polarizability

Due to presence of external field dipoles are rotate and tend to allign in line with field E.

α_e & α_i are independent of Temperature; Dielectricconstant depend on temperature

Some important definitions ; (a) permittivity : permittivity is a quantity which represents the dielectric property of medium . permittivity of a material indicates the easily polarisable nature of material . It is denoted by ε

For vaccum ε is called permittivity of freespace ie $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m [Farad/meter]

(b) Relative permittivity : It is the ratio between the permittivity of medium and permittivity of Vaccum

Denoted by $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$ [ε_r is constant for isotropic material]

(C) Dielectric constant (K) The dielectric constant is defined as the ratio between the permittivity of that medium and permittivity of freespace $K = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r$

K has no units

(d) Dielectric strength : It can be defined as the minimum voltage required to produce dielectric breakdown unit volt/meter

(e) Polarization : The process of producing electric dipoles which are oriented along the field direction is called polarization. This phenomena observed with the effect of external field

(f) Polar molecules They have unsymmetrical structure and have perminent dipolemoment

Examples H_2O, HCl, CO, N_2, NH_3 etc . Incase of these molecules the centres of gravity of +ve and -ve charges are seperated

(g) Non Polar molecules : These are having zero electrical dipolemoment [H_2, O_2, SO_2, C_6H_6]

In case of these molecules the centres of gravity of +ve and -ve charges are coincide.

(h) Dipolemoment . $\mu = qd$ [where q is the magnitude of charge d is seperation of +ve and -ve charge]

units for μ is colulom-meter

(i) polarizability It can be defined as the ratio of average dipolemoment to the electric field applied

It is denoted by 'α' $\therefore \alpha = \frac{\mu}{E}$ Units [Farad m^2]

(j) polarization vector P : It is defined as the average dipolemoment present per unit volume of a dielectric . It is denoted by P Units Colulomb/m^2

$P = N\mu$ when N : number of atoms present per unit volume; μ is average dipole moment

(K) Electric displacement vector : The number lines of forces recieved by unit Area is is called flux density is denoted by electric displacement vectors . $\therefore D = \frac{q}{4\pi r^2}$: Charge / Area

Relation between E and D & K $E = \frac{1}{4\pi\varepsilon}\frac{q}{r}$: $D = \frac{q}{4\pi r^2}$ $\therefore \frac{E}{D} = \frac{\frac{q}{4\pi\varepsilon r^2}}{\frac{q}{4\pi r^2}} = \frac{1}{\varepsilon}$

$\therefore \frac{E}{D} = \frac{1}{\varepsilon} \Rightarrow \boxed{D = \varepsilon E} \rightarrow (1)$

But $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \Rightarrow \varepsilon = \varepsilon_r\varepsilon_0 \rightarrow (2)$ from (1) & (2) $D = \varepsilon_r\varepsilon_0 E$

$\boxed{D = \varepsilon_r\varepsilon_0 E} \rightarrow (3)$

But $K = \varepsilon_r$ Sub in (3) $\therefore \boxed{D = K\varepsilon_0 E}$ For isotropic materials

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[2] with usual notation show that $P = \varepsilon_0(\varepsilon_r - 1)E$ (or) Obtain a relation between D, P, E for dielectrics (or) obtain a relationship between electric displacement vector D, polarization P, applied electric field strength E incase of Dielectric material

For many of the crystal D varies non linearly with E

$\therefore D = \varepsilon E \rightarrow (1)$ But $\varepsilon = \varepsilon_r\varepsilon_0$ $\therefore D = \varepsilon_r\varepsilon_0 E \rightarrow (2)$

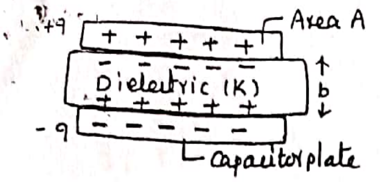
ε_r is equal to dielectric constant ie $\varepsilon_r = K$

$\therefore$ eq(2) can be written as $D = K\varepsilon_0 E \rightarrow (3)$

But polarization is defined as $P = \left(\frac{q_i}{A}\right)\hat{i} \rightarrow (4)$

where q_i is the magnitude of the induced charge developed at and interior to the surface of Area 'A' of the dielectric

$\hat{i}$ is a unitvector along the linejoining negative and positive induced charges



Let us consider parallel plate capacitor placed by Dielectric slab between the plates

Due to the external field exist dipolemoment and the induced charges developed near the surfaces of parallel plates. There exist electric dipolemoment (μ_e)

The polarization $P = \frac{\mu_e}{V}$; D, E, P are related by $D = \varepsilon_0 E + P$

$\therefore D = \varepsilon_0 E + P \rightarrow (5)$ in this equation $D = K\varepsilon_0 E$ substitute the value in (5)

$\therefore K\varepsilon_0 E = \varepsilon_0 E + P \Rightarrow (KE - E)\varepsilon_0 = P \Rightarrow P = \varepsilon_0(K-1)E \rightarrow (6)$

But ε_r is equal to dielectricconstant ie $\varepsilon_r = K$.

$\therefore$ substitute $K = \varepsilon_r$ in equation (6) $\therefore \boxed{P = \varepsilon_0(\varepsilon_r - 1)E}$

<u>Relation between electric polarization and electric susceptability of the dielectric medium</u>

Electronic polarization $P_e = N\alpha_e E$

α_e is electronic polarizability

N : is number of molecules perunitvolume in Dielectricmaterial

The polarization generated by the seperation of the effective centre of the electroncloud from the nucleus of the atom is called the electronic polarization, it is denoted by P_e $\therefore P_e = N\alpha_e E \rightarrow (1)$

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

$\therefore \frac{P_e}{E} = \varepsilon_0(K-1) \Rightarrow \boxed{\frac{P_e}{\varepsilon_0 E} = (K-1)} \Rightarrow \boxed{\chi_e = (K-1)}$ $\because P_e = \varepsilon_0(K-1)E \rightarrow (2)$

$\therefore \frac{P_e}{\varepsilon_0 E}$ is called the electric susceptibility of the dielectricmedium

$\therefore \boxed{\frac{P_e}{E} = \varepsilon_0(K-1)}$ if χ_e is the electrical susceptability of Dielectricmaterial

$\therefore \chi_e = \varepsilon(K-1)]$ $\therefore P_e = \varepsilon(K-1)E$

$\boxed{P_e = K\varepsilon_0\chi_e E} \rightarrow$ Required Relation between P_e & χ_e

For vaccum $\chi_e = 0$

$\because \chi_e = [\varepsilon(K-1)]$ In case of vaccum $\varepsilon = \varepsilon_0$

$\chi_e = \varepsilon_0[K-1] \rightarrow (3)$ but $K = 1 \Rightarrow \chi_e = \varepsilon_0[1-1] = 0$

<u>Relation between susceptability, Dielectric constant and ε_0:</u> $P = \varepsilon_0(\varepsilon_r - 1)E$

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

(or) <u>Relation between χ, K, ε_0 :</u>

$\chi = \varepsilon_0(K-1) \rightarrow (1)$

$\chi = \varepsilon_0 K - \varepsilon_0 \rightarrow (2)$

$K = \frac{\varepsilon}{\varepsilon_0}$ from definition

$\therefore K\varepsilon_0 = \varepsilon$ substitute in eq(2)

$\because \chi = \varepsilon - \varepsilon_0 \Rightarrow \varepsilon = \varepsilon_0 + \chi \rightarrow (3)$

$\therefore \varepsilon = \varepsilon_0 * \chi \rightarrow (3)$

deviding the eq(3) on bothsides with ε_0

$\therefore \frac{\varepsilon}{\varepsilon_0} = \frac{\varepsilon_0 + \chi}{\varepsilon_0} \Rightarrow \boxed{K = \frac{\varepsilon_0}{\varepsilon_0} + \frac{\chi}{\varepsilon_0}} \Rightarrow \boxed{K = 1 + \frac{\chi}{\varepsilon_0}}$

---

[3] Explain electronic polarization in atom and Obtain an expression for electronic -polarizability in terms the radius of the atom?

<u>Electronic polarization</u> : The polarization generated by the seperation of the effective centre of the electron cloud from the nucleus of the atom is called the electronic polarization.

It is denoted P_e $\therefore P_e = N\alpha_e E$

where α_e is electronic polarizability

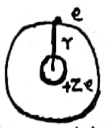
N is number of atoms perunitvolume of Dielectricmaterial

E is applied electricfield intensity

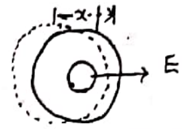
consider a simple atom, it contains alight electron cloud of negative charge uniformly distributed overasphere of radius 'a' and positive charges concentrated at the centre of the sphere

The polarization in atomic view gives the result that is the centres of the positive and negative charges in atom displaced by the applied field.

The applied electricfield E seperates the equal and opposite charge centers within the atom so that the atom become a dipole. This happens to all the atoms in the material



Atom without field(E=0)



Atom with the field.

Consider an isolated atom is placed under electricfield E, the light electrons move much more than the heavy nucleus

Hence the centre of the electron cloud shifts (displace) in the opposite direction of $\vec{E}$

By the application external field the atom becomes a dipole and possess dipolemoment

Consider an atom with atomic number Z then the charge on its nucleus is +Ze

when this atom is subjected to electricfield the nucleus and the electron cloud are pulled apart by an amount x

Then the force along the direction of the field is

$$F_1 = Ze \cdot E \longrightarrow (1)$$

The nucleus is surrounded by electron cloud of charge $-Ze$ distributed over a sphere of radius r, the charge density is given as $\rho = \frac{\text{Charge}}{\text{Volume}} = \frac{-Ze}{\frac{4}{3}\pi r^3} = -\frac{3}{4}\left[\frac{Ze}{\pi r^3}\right] \to (2)$

Assuming uniform distribution of electroncloud, the total charge in the electroncloud is $\frac{4}{3}\pi x^3 \rho = \left[\frac{4}{3}\pi x^3\right]\left[-\frac{3}{4}\frac{Ze}{\pi r^3}\right] = \frac{-Zex^3}{r^3} \to (3)$

[attractive]

The coulomb force between the nucleus and the electroncloud is F_2

$$\therefore \quad F_2 = \frac{Ze}{4\pi\epsilon_0 x^2}\left[-\frac{Zex^3}{r^3}\right] = \frac{-Z^2e^2x}{4\pi\epsilon_0 r^3} \longrightarrow (4)$$

In equilibrium condition, the forces F_1 and F_2 are equal ie $ZeE = \frac{-Z^2e^2x}{4\pi\epsilon_0 r^3}$

$$\therefore \quad x = \frac{4\pi\epsilon_0 r^3}{Ze} E \longrightarrow (5)$$

Electronic dipolemoment peratom $P_e = Ze(x) \longrightarrow 6)$

Substitute thevalue of x in eq(6) $\therefore P_e = Ze\left[\frac{4\pi\epsilon_0 r^3}{Ze}\right]E$

$$\therefore \quad P_e = 4\pi\epsilon_0 r^3 E \longrightarrow (7)$$

By definition $P_e = \alpha_e E \longrightarrow (8) \quad [\because P = \alpha E]$

$\therefore$ Comparing (7) and (8) $\boxed{\alpha_e = 4\pi\epsilon_0 r^3}$

α_e is known as electronic polarizability ~~it a exprese~~ electronicpolarizability is expressed in terms of radius of atom

[$\alpha_e \propto r^3$] where 'r' radius of atom

[4] Explain the ionicpolarization ?

<u>Ionic polarization</u>: The polarization produced by the relative displacement of the ions is called the ionic polarization

It is an additional polarization due to relative displacement of the atomic components of the molecule in the presence of Electricfield

when an electricfield $\bar{E}$ is applied to such a material, the opposite

Kind of ions are pulled apart and the normal seperation of the ions increases

when a field is applied the original form of the molecule is distrubed, and dipoles are formed and polarized under E. Sothat this induced dipolemoment is propotional to the applied field ie $\mu_i = \alpha_i E$ where α_i ionicpolarizability [$\because \mu = \alpha E$]

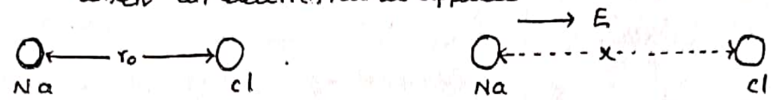
For mostofmaterials the ionic polarizability is less than the electronic polarizability ie $\alpha_i << \alpha_e$ where α_e is the electronic polarizability

$\alpha_i \approx 0.1\,\alpha_e$

and $(\alpha_e + \alpha_i)$ is sometimes called as the deformation polarizability

The ionicpolarizability is independent of temperature

Example The phenomena of ionic polarizability is observed incase of NaCl molecule when an electricfield is applied



when a field E is applied the original formof the molecule is dristrubed the dipoles areformed and polarized under E.

That is Sodium(Na) and chlorine atoms are displace in oppositedirections until ionic binding forces stop the process, thus increasing the dipolemoment $\mu_i = \alpha_i E$ sothat this induced dipolemoment is propotional to the appliedfield

---

[5] what is orientational polarization? Derive an expression for the mean dipolemoment when a polarmaterial is subjected to an externalfield?

This type of polarization occurs in polar substances

Definition: The polarization arising due to the alignment of already existing but randomly oriented dipoles in the polar substance is called the orientational polarization (or) Dipolar polarization. The orientationalpolarizability is denoted by α_o. α_o depends on temperature T, It decreases with Increase of T

$\therefore$ Total polarization in dielectrics is thus contributed by electronic, ionic and orientational polarizations ie $P = N\alpha_t E$

where $\alpha_t = \alpha_e + \alpha_i + \alpha_o$

polarsubstance [polyatomic molecules] like water, these molecules posses a perminent dipole moment. Even though dipoles will exist in such materials they orient randomely so that the net dipolemoment in any specimen of the material is zero

when this specimen is place in an externalfield E dipoles rotate and tend to allign in line with the field E. This is resisted by the thermal agitations

The ~~ab~~ orientational polarizablity depend on temperature ie At highertemperature the thermal agitations are high that leads to lowering of polarizability

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

But $\varepsilon_r = K$ $\quad \therefore P = \varepsilon_0(K-1)E \rightarrow (2)$

$P = N\alpha E \rightarrow (3)$

From (2) and (3)

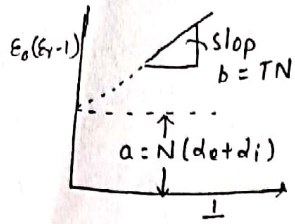
$\varepsilon_0(K-1)E = N\alpha E$

$\varepsilon_0(\varepsilon_r - 1) = N\alpha \rightarrow (4)$

But $\alpha = \alpha_t$ $\quad \varepsilon_0(\varepsilon_r - 1) = N\alpha_t \rightarrow (5)$

ε_r is measured for different kinds of dielectrics at at different temperatures : α_e, α_i are independent of Temperature

ε_r depends on T in case of polar substance.



ie The dielectric constant K is depend on the temperature in case of orientational polarization

$\therefore$ ε_r is a function of Temperature $T \Rightarrow \varepsilon = \varepsilon_r(T)$

$\therefore \varepsilon_0(\varepsilon_r(T)-1) = N(\alpha_e+\alpha_i) + N\alpha_0(T)$

$\varepsilon_0(\varepsilon_r(T)-1) = a + \frac{b}{T}$ where $a = N(\alpha_e+\alpha_i)$

$\frac{b}{T} = N\alpha_0(T)$

According to Langevin - Debye theory the polarization of polar substances is a function of Temperature

That is given by $P(T) = [N(\alpha_e+\alpha_i) + N\alpha_0(T)]E$

$\alpha_0(T)$ is orientational polarizability

$$\alpha_0(T) = \frac{\mu_m^2}{(3K_BT)} \Rightarrow \boxed{\mu_m = \sqrt{\frac{3K_BT}{N}}}$$

μ_m is called meandipolemoment of polarsustance.

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[6] Obtain an expression for the internal field seen by an atom in an infinite array of atoms subjected to an external field.

[OR] Explain the concept of internalfield in solids [Local field],

The total electricfield at the site of the atom with in the dielectric is called the local field (or) the internalfield. The internalfield is denoted E_i

The internal field is due to neighbouring dipoles in the specimen. The Internalfield. is also called as Lorentzfield

In dense substance like liquids and solids the atoms (or) molecules are much closer to eachother, when an external field E is applied to such a dielectric the dipoles are created.

Thus for an atom inside the dielectric it is effected by all the neighbouring dipoles causes to interfield. The internal field (E_i) is different from the applied field E. For the calculation of polarization (E_i) internalfield must be considered than applied field.

For denser dielectrics Polarization $P = N\alpha E_i \rightarrow (1)$

But $D = \varepsilon_0 E + P \longrightarrow (2)$

Substitute the value $P = N\alpha E_i$ in eq(2) $\Rightarrow D = \varepsilon_0 E + N\alpha E_i \rightarrow (3)$

But $D = \varepsilon E$ Sub in eq(3) $\therefore \varepsilon E = \varepsilon_0 E + N\alpha E_i \longrightarrow (4)$

$\therefore$ But $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \Rightarrow \varepsilon = \varepsilon_r\varepsilon_0$ Sub this value in equation (4)

$\therefore \varepsilon_r\varepsilon_0 E = \varepsilon_0 E + N\alpha E_i \longrightarrow (5)$

$\varepsilon_r\varepsilon_0 E - \varepsilon_0 E = N\alpha E_i \Rightarrow \varepsilon_0(\varepsilon_r-1)E = N\alpha E_i$

$$\therefore \boxed{E_i = \frac{\varepsilon_0(\varepsilon_r-1)E}{N\alpha}}$$ This represent the polarization due to the internalfield.

we can observe the internal field is due to the combined effect of external field E and polarization 'p' which itself is also due to E.

we know that $D = \varepsilon_0 E + P \longrightarrow (6)$

devide by ε_0 on both sides of eq(6) $\Rightarrow \frac{D}{\varepsilon_0} = \frac{\varepsilon_0 E}{\varepsilon_0} + \frac{P}{\varepsilon_0} \Rightarrow \frac{D}{\varepsilon_0} = E + \frac{P}{\varepsilon_0}$

Thus $P = N\gamma\mu_a$ where γ is dimensionless constant that depend on the symmetry of the crystal (dielectric) structure. $\therefore \gamma = \frac{1}{3}$. $E_i = E + \frac{\gamma P}{\varepsilon_0}$

$$\therefore \frac{D}{\varepsilon_0} = E + \frac{N\gamma\mu_a}{\varepsilon_0} \Rightarrow \boxed{E_i = E + \frac{\gamma N\mu_a}{\varepsilon_0}} \quad \boxed{E_i = E + \frac{P}{3\varepsilon_0}}$$

(Q) 'Explain the phenomena of Piezoelectricity? write the important application of the piezoelectric materials:

The electrical charges induced on the surfaces of the crystals by the application of mechanical stress on the crystals this phenomenon is called piezoelectricity.
It is observed incase of piezoelectric materials. These materials are polarised when they subjected to mechanical deformation (it is possible for ionic solids).
" All Ferroelectric crystals exhibit piezoelectricity but all piezo electricmaterials need not exhibit ferroelectricity. Example Quartz - piezoelectriccrystal not ferroelectric.
→ Piezo electric materials are in form polycrystalline.

Applications of piezo electric materials as (a) Sensors, (b) Transducers (c) amplifiers (d) detectors. (e) oscillators (f) ultrasonic waves generator

Medical diagnosic: Ultrasonic Sources & Detectors.

Transducers Piezoelectric materials are used as transducers for the conversion of electrical energy in mechanical-energy and mechanical energy into electrical energy.
Example: Quartz crystal, ceramics, and ferroelectricmaterial ($BaTiO_3$, $LiNbO_3$)

Sensors: Piezo electric materials used as sensors which measure pressures very accurately.

amplifiers: piezo electric semiconductor Gas, zno, cds amplifiers of ultrasonic waves (MHz

detectors: Quartz crystals are also used in selective band pass filters in Submarines and in telephone industry, ie generation and reception of Soundwave in nature.

oscillators: Most important material for such ause being Quartz, it has an extremely high dielectric strength. So that it is used frequently to control frequency in circuits.

Industrial application: Finds internalcracks, hiddendefects.

Ultrasonic waves generator: we can employ the piezo electric materials to produce the ultrasonicwaves [By Specially prepared Quartz slices of the order of 0.1 nm] (or) Tourmaline crystal slices, frequency of about 1 MHZ Canbe obtained by piezo electric oscillatory circuit]

Electro optic modulator $LibNO_3$ material is used as electro optic modulator.

Space application The T_c of $LibNO_3$ is 1210°c So this is the suitable piezoelectric material for space application ie parametric oscillator & amplifier

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(Q) Explain the phenomena of pyroelectricity? write the important applications of Pyroelectricmaterials?

Pyroelectric effect: It is the change in spontaneous polarization when the temperature of the specimen is changed. and also in PVDF, Triglicine sulphate
This effect was first discovered in minerals such as in Quartz, tourmaline and in other ionic crystals. (PVDF materials)

Fact about pyroelectricity By changing the temperature produces surface charges which attracts other charged materials.

All the ferroelectric materials are pyroelectric materials the converse is need not be true.

Example Turmoline crystal is pyroelectric material, but it is not ferroelectric. material

The property of pyroelectricity is the measured change in net polarization P_s) propotional to change in temperature $\boxed{I_p = P_i A \frac{dT}{dt}}$ $\frac{dT}{dt}$: Rate of ~~heat~~ heating.

I_p : pyroelectric current, P_i : pyroelectric coefficient, A : Area of crossection

$\frac{dT}{dt}$ is rate of heating normally $3-5°C/m$ ie 3°c to 5°c perminute

$P_i = \frac{dP_{si}}{dT}$: Spontaneous polarization At $T = T_c$ $P_i \approx 0$

Application of pyroelectricmaterials :(a) Used inburgular alarms (b) detectors (c) Sensors (d) Industrial applications (e) Domestic applications (f) infrared photography :

(a) : Burgular alarms : Poly vinyleden di Fluoride (PVDF), Turmoline crystals used in buerqular alarms that based on temperature changes

(b) Detectors [Detect Temperature change of a microdegree Change about 10^{-6}°C because pyroelectrics are highly sensitive to temperature changes

Industrial applications : pyroelectrics are used to monitor levels of pollution through IR detection.

Polycrystalline samples in thin film form (or) Ceramic discs (thinplates) are employed.

→ They are used in multilayer capacitors

Infrared photography : Pyroelectrics are excellent detectors of infrared radiation and they make excellent devices for infrared photography and Nightphotography in the dark.

Domestic applications : The pyroelectricmaterials are sensitive to infrared radiation The pyroelectric materials are used in burglars alarm. (Variation of temperature functioning) ~~the burglarsalarm~~

The pyroelectricdetectors are useful in powermeters for laser radiation and they are useful in microelectronics.

They make perfect devices for testing the level of IR radiation that passes through a gas sample.

¶ Locate the trapped people Under rubble : Triglicine sulphate, It has pyrocoefficient $-5.5 \times 10^{-4} C m^{-2} K^{-1}$ measured at 30°C. It is used in Pyroelectric 'Vidicon'

Pyroelectric vidicon is a device (or) a camera useful for thermal imaging. This camera is highly helpful for disaster teams to locate the trapped people under rubble.

(Q) Explain the phenomenon of Ferroelectricity? write the applications of ferroelectric materials? (or) Explain the characteristics of ferroelectric materials based on Hysterisis curve ? (or) Mention the ferroelectric characteristics of Barium titanate ($BaTiO_3$)

Materials which exhibit electric polarization even in the absence of the applied electric field are known as Ferroelectric materials. 

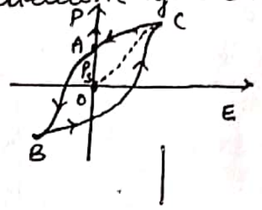
These have permanent dipolemoment in each atom (or) molecule $E_{ex}=0$.

<u>Examples of ferroelectric materials</u> $BaTiO_3$, $SrTiO_3$, $PbTiO_3$, $LiNbO_3$, $LiTaO_3$, Rochelle salt ($NaKC_4H_4O_6 \cdot 4H_2O$), phospate (KH_2PO_4)

Ferroelectric materials exhibit piezoelectricity and pyroelectricity converse need not be true.

<u>Ferroelectricity</u>: It refers to the creation of enormous value of induced dipole moment in a weak dielectric field as well as <u>existence of electric polarization</u> even in the absence of applied electric field.

<u>Hysteresis effect</u>: Ferroelectricity is a result of dielectric hysteresis. Since these materials exhibit hysteresis effects.



OA: P_s
OA Represents Spontaneous polarisation

By observing ~~an~~ Hysteresis Curve, they show the P_s value in the absence of External applied electric field.

* irreversal process *

E increases the path BC – increasing order of P

E decreases then we observe the CAB path even $E=0$: $P_s \neq 0$. This is important property of ferroelectric material

$P_s \neq 0$: ie Ferroelectric materials posess Spontaneous polarization due Perminent electric dipoles.

All ferroelectric exhibit polarization reversal.

<u>Characteristics of Ferroelectric materials</u>

(i) They are easily polarized in a weak field.
(ii) They exhibit spontaneous polarisation ($P_s \neq 0$ at $E=0$)
(iii) They posess very high dielectric constants.
(iv) They exhibit piezo electric & pyroelectric effects.
(v) They exhibit dielectric hysteresis (P-E curve).
(vi) Centre of gravity of +ve & -ve charges donot coincidence even in the absence of external field.
(vii) Hysteresis Curve: P is not linear function of E
(viii) $T > T_c$ ferro — converted in paraelectric material. $T > T_c$ P Varies linearly with E.
(ix) The area of Hysteresis curve change w.r.t Temperature

<u>Applications of Ferroelectric materials</u>

(a): They exhibit piezo, pyroelectric effects due to that they are used as detectors, sensors
(b) They are used as Transducers: $E_{mech} \leftrightarrow E_{electri}$
(c) They are used in multilayer capacitors.
(d) They are useful in microelectronics
(e) Due to high dielectric constant they are useful for storing energy in small size capacitors in electrical circuits.
(f) Optical communications ferroelectric crystals are used for optical modulation
(g): pressure transducers, microphones. ultrasonic transducers

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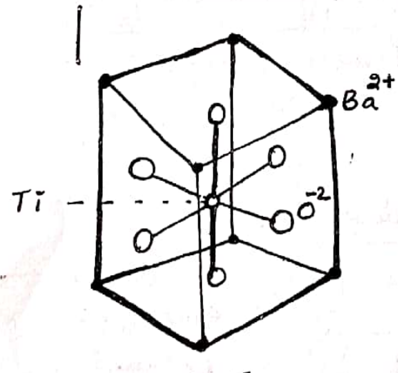
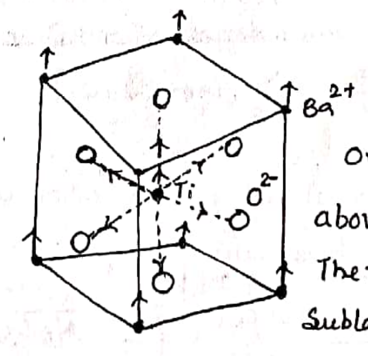
Explain the Structural changes of ferroelectric material

ie Behaviour of $BaTiO_3$ (ferroelectric material) with temperature [$T = T_c$ & $T > T_c$]



(a) $T > T_c$
ie at high temperature



$T < T_c$
ie at low temperature

with respect to the temperature there exit a change in the structure of $BaTiO_3$

Original structure of $BaTiO_3$ <u>perovskite</u>

above structure change with temperature

The relative displacement of the two Sublattices is 0.01nm. This is responsible for the spontaneous polarization

ie <u>At high temperature</u> ($T > T_c$) : $BaTiO_3$ - has Cubic structure with Titanium ions at body centre. Barium ions at the body corners and oxygen ions at face centres

<u>At low temperature (if the crystal is cooled)</u> ($T < T_c$) The Sublattice containing Ba^{2+} & Ti^{4+} ions Shifts Upward along c-axis w.r.t Oxygen Sublattice

This displacement responsible for Spontaneous polarization [creates electric dipoles]

[7] .. Derive classius - Mosottic relation? Explain classius-Mosotti relation in dielectrics subjected to staticfields?

14

For an atom inside the dielectric it is effected by all the neighbouring dipoles causes to internalfield. E_i be the internalfield $\therefore E_i = E + \frac{\gamma P}{\varepsilon_0} \rightarrow (1) \Rightarrow E_i = \frac{\varepsilon_0 E + \gamma P}{\varepsilon_0}$

$\therefore E_i \varepsilon_0 = E\varepsilon_0 + \gamma P \Rightarrow E_i\varepsilon_0 - \gamma P = E\varepsilon_0 \rightarrow (2)$

But $P = N\alpha E_i$ substitute in eq(2) $\Rightarrow E_i\varepsilon_0 - \gamma[N\alpha E_i] = E\varepsilon_0$

$\therefore E_i[\varepsilon_0 - \gamma N\alpha] = E\varepsilon_0 \Rightarrow E_i = \frac{\varepsilon_0 E}{\varepsilon_0 - \gamma N\alpha} \rightarrow (3)$

But $E_i = \frac{\varepsilon_0(\varepsilon_r - 1)E}{N\alpha} \rightarrow (4)$ γ is dimensionless constant.

From (4) and (5)

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

$\gamma = \frac{1}{3}$ for an isotropic dielectric of cubic system

$$\therefore \frac{\varepsilon_r - 1}{N\alpha} = \frac{1}{\varepsilon_0 - \frac{1}{3}N\alpha} \Rightarrow \varepsilon_r - 1 = \frac{3N\alpha}{3\varepsilon_0 - N\alpha} \rightarrow (5)$$

Adding 3 on both sides of eq(5)

$$\Rightarrow \varepsilon_r - 1 + 3 = \frac{3N\alpha}{3\varepsilon_0 - N\alpha} + 3 \Rightarrow \varepsilon_r + 2 = \frac{3N\alpha + 9\varepsilon_0 - 3N\alpha}{3\varepsilon_0 - N\alpha}$$

$$\therefore \varepsilon_r + 2 = \frac{9\varepsilon_0}{3\varepsilon_0 - N\alpha} \rightarrow (6)$$

The equation (6) may be written

$$\varepsilon_r + 2 = \frac{9\varepsilon_0 \times \frac{1}{3N\alpha}}{3\varepsilon_0 - N\alpha \times \frac{1}{3N\alpha}} \Rightarrow \varepsilon_r + 2 = \frac{\frac{3\varepsilon_0}{N\alpha}}{\frac{3\varepsilon_0 - N\alpha}{3N\alpha}} \rightarrow (7)$$

$$\therefore \varepsilon_r + 2 = \frac{3\varepsilon_0}{N\alpha} \times \left[\frac{3N\alpha}{3\varepsilon_0 - N\alpha}\right] \rightarrow (8)$$

in equation (8) $\frac{3N\alpha}{3\varepsilon_0 - N\alpha} = [\varepsilon_r - 1]$ $\left[\because \text{from (5) } \varepsilon_r - 1 = \frac{3N\alpha}{3\varepsilon_0 - N\alpha}\right]$

$\therefore$ equation (8) becomes $\varepsilon_r + 2 = \frac{3\varepsilon_0}{N\alpha}[\varepsilon_r - 1] \Rightarrow \frac{\varepsilon_r + 2}{\varepsilon_r - 1} = \frac{3\varepsilon_0}{N\alpha} \rightarrow (9)$

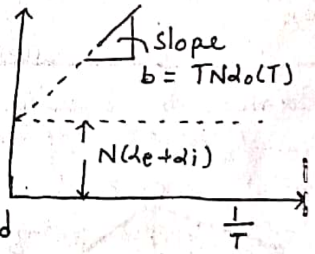
From equation (9) $\Rightarrow$ $\boxed{\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha}{3\varepsilon_0}} \rightarrow (10)$ $n = \sqrt{\varepsilon_r}$ $\therefore$ $n^2 = \varepsilon_r$ $\boxed{\frac{n^2 - 1}{n^2 + 2} = \frac{N\alpha}{3\varepsilon_0}}$

$\boxed{\frac{n^2 - 1}{n^2 + 2} = \frac{N\alpha}{3\varepsilon_0}}$ Lorentz-Lorentz equation

This is known as the classius - Mosotti relation

n is refractive index of medium

Explanation of Classius - Mosottic relation (Importance)



It gives the relation between ε_r and α

ie It Gives relation between the microscopic polarizability α and the macroscopic dielectric ε_r of dielectric solid(or) liquid

From classius - Mosotti relation the molar polarization (P_m) is calculated

$$\therefore P_m = \left[\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right]\frac{M}{\rho} = \frac{N_A}{3\varepsilon_0}[(\alpha_e + \alpha_i) + \alpha_0]$$

where $\alpha = (\alpha_e + \alpha_i) + \alpha_0$ $\qquad \because \alpha = \alpha_0(T)$

Since α_0 is orientational polarizability it is depent on temperature ie $\alpha_0 = \frac{\mu_m^2}{3K_BT}$

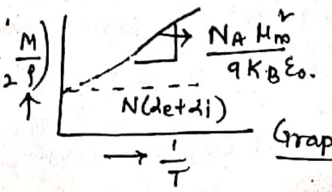
So that P_m is a function of temperature $\boxed{\therefore P_m = \frac{N_A}{3\varepsilon_0}\left[(\alpha_e + \alpha_i)\right] + \frac{\mu_m^2}{9K_BT}}$ This is debyes equations

with the help of Debyes equation we can determine the dipolement per molecule. $\boxed{P_m = \frac{N_A(\alpha_d)}{3\varepsilon_0} + \frac{\mu_m^2}{9K_BT\varepsilon_0}}$ — Debyes equation.

using classium - mosottirelation we can calculate the dielectric constant of materials and also gives the variation of Dielectric constant with temperature of substances and helps to determine molecular structure of the dielectrics

$\alpha_0 = \frac{\mu_m^2}{3K_BT}$ $\qquad \mu_m = 3\sqrt{\alpha_0 K T \varepsilon_0}$ $\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\frac{M}{\rho}\right)$

$\mu_m \propto \sqrt{T}$



Graph T Vs Dielectric constant

∵ Dielectric material is subjected to high frequency the dipole will no longer be able to rotate sufficiently rapidly. So that their oscillations will begin to lag behind those of the field.

∴ So that the orientation of the dipoles will result the polarization will tend to reverse everytime, then the polarity of field changes.

As the frequency is further increased the dipoles will be completely unable to follow the field

<u>Effect on orientational polarization</u> By the increasing of frequency the orientational - polarizational ceases, this usually occurs in the range above 10^6 cycles/sec

At infrared frequency heavy positives and negative ions can not follow the field variations So that the contribution to the permittivity from the atomic (or) ionic polaration ceases and only the electronic polarization remains

So that the permittivity of a dielectric material vary with increasing frequency this phenomenon is known as Anamalous Dielectric dispersion.

---

[10] Explain piezo electricity phenomenona?

The electrical charges induced on the surfaces of the crystals by the application of mechanical stress on the crystals this phenomenon is called piezo electricity

Example Quartz (SiO_2) Lithium Niobate ($LiNbO_3$), Barium titate ($BaTiO_3$) <u>Titanate</u> <u>Barium</u>

Materials which are polarised when subjected to mechanical deformation are called piezo electric materials. All ferroelectric crystals exhibit peizoelectrocity but all piezo electric crystals need not exhibit ferroelectricity

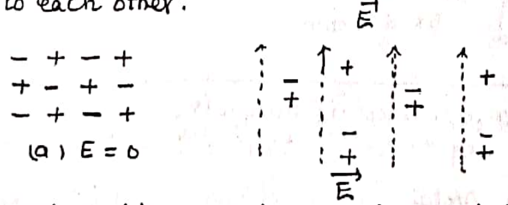
<u>uses</u> piezoelectric materials are very important since they permit the conversion of the mechanical energy into electrical energy and vice-vers.

<u>Explanation:</u> Quartz crystal Suitably prepared slices of the quartz crystal we observe the piezo electric effect. Quartz crystal consist of three axes, X-axis is known as electrical axis, Y-axis is known as mechanical axis and Z-axis is known as optical axes.

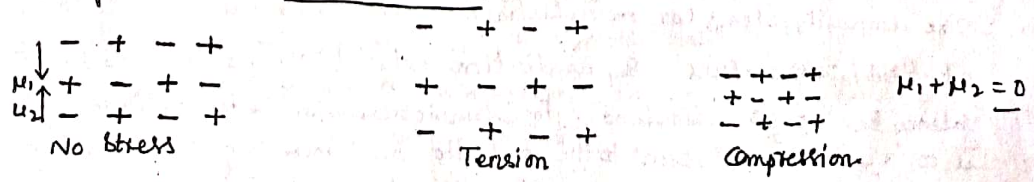
In the absence of the external stress, all the charges are balanced, net polarization is Zero.

But when external stress is applied to the crystal the balance is disturbed and the crystal is polarized. As a result, electrical charge is developed on the faces.

Electricfield is inducing an electric dipolemoment in a dielectrice and displaces ions relative to each other.



The dimensions of the crystal have increased in the field direction this physical property is called <u>electrostriction</u>



If the crystal under stress posses the centre of symmetry these crystals donot exhibit the piezo electricity

On the other hand the stress will produce a dipole moment in a crystal whose changes do not possess the centre line of symmetry. Such crystals show the piezo electric effect

− + − +
+ − + −
(a) No stress

− + − +
+ − + −
(b) Tension

∓ ± ∓ ±
(c) Compression

Fig Origin of the piezo electric effect

[11] what is dielectric breakdown? Explain briefly the various factors contributing to breakdown in dielectrics?

For many materials there is a maximum field intentensity beyond which damage occurs that results in breakdown phenomena.

At relatively highfields, the electrons in the dielectric gain enough energy to knock other charged particles and make them available for conduction.

Although many theories exist regarding the breakdown of solids, the failure of solid insulation in practice is almost always due to entirely different reasons. Electricstrength of solid dielectrics depend on many extraneous factors,

(i) Defects and inhomogeneity of the material
(ii) thickness area and volume of the specimen
(iii) the surface conditions and the method of placing the electrodes
(iv) the type and application of test voltage and test duration
(v) moisture and other contaminations

A number of fundamental breakdown mechanisms in solids can distinguished.

(i) Intrinsic breakdown : electronic innature and depends on the presence of electrons capable of migrating through the lattice.

(ii) Thermal breakdown : when the local heat generated by losses exceeds that when the rate of heat generation is greater than the rate of dissipation.

(iii) Discharge breakdown Depends upon the presence of voids etc

(iv) Electrochemical breakdown : is cumulative in nature and gradually builds upto breakdown

[12] what is intrinsic breakdown in dielectric materials?

In a perfect dielectric there are no free electrons and the conductivity is almost zero. In general all crystals contain imperfections of one (or) more of the following types.

The impurity atoms (or) molecules traps for the conduction electrons upto certain ranges of field / Temperature. By application external field the electrons jump from valency band to conduction band. For intrinsic breakdown : effect of increased temperature is to eject more electrons to the conduction band increasing the conductivity

Low temperature breakdown under this condition, the number of electrons will be few and interaction of electrons with the lattice will be predominant.

when electricfield is applied electrons gain energy after collision they will loss their energy

Some important definitions:

Magnetic induction: It is defined as the number of magnetic lines of force passing perpendicularly through unit area $\therefore B = \phi/A$ units weber/m^2 (or) Tesla

(or) It is defined as the magnetic force experienced by unit northpole placed at a given point in a magnetic field $\therefore B = \frac{F}{m}$ units $\frac{\text{Newton}}{\text{ampere - meter}}$.

Magnetic field intensity: The magnetic field intensity at any point in the magnetic field is force experienced by an unit northpole placed at that points

$$H = \frac{F}{\mu m} \Rightarrow H = \frac{B}{\mu} \quad \text{units } \frac{\text{ampere turn}}{\text{meter}}$$

Permeability (μ) permeability of the medium is defined as the ratio between magnetic field induction and magnetic field intensity at a given point in that medium

$\therefore \mu = \frac{B}{H}$ for free space μ becomes μ_0 and the value of μ_0 $4\pi \times 10^{-7}$ Henry/m

Relative permeability: It is defined as the ratio of the permeability of medium to the permeability of freespace $\therefore \mu_r = \frac{\mu}{\mu_0}$

Magnetization (or) Intensity of magnetization: It is defined as the average magnetic moment present per unit volume in a system. $\therefore M = N\bar{\mu}$; where N = Number of atoms (or) molecules per unit volume

I & H have same units and dimensions $\bar{\mu}$ is the average dipole moment

Susceptability (χ) It may be defined as the ratio of intensity of magnetization to applied magnetic field intensity $\chi = \frac{M}{H}$ χ has no units

χ is a measure of magnetization produced in the specimen per unit field strength when a material has high susceptability then it can be easily magnetized.

Relation between B & H: $H = \frac{B}{\mu} \Rightarrow \{B = \mu B\}$ But $\mu = \mu_0\mu_r \therefore B = \mu_0\mu_r H$

$$\therefore \begin{cases} B = \mu_0\mu_r H + \mu_0 H - \mu_0 H \\ B = \mu_0 H + \mu_0 H(\mu_r - 1) \\ B = \mu_0 H + \mu_0\{H(\mu_r - 1)\} \end{cases}$$

where $[H(\mu_r - 1)] = M$

$\therefore B = \mu_0 H + \mu_0 M \Rightarrow \boxed{B = \mu_0[H + M]} \rightarrow (1)$

$\mu_r = \frac{\mu}{\mu_0}$ and $\left[\mu = \frac{B}{H} \text{ \& } \mu_0 = \frac{B}{H+M}\right]$

$$\therefore \mu_r = \frac{B/H}{\frac{B}{M+H}} \Rightarrow \mu_r = \frac{M+H}{H} \Rightarrow \mu_r = \frac{M}{H} + 1 \quad \left[\frac{M}{H} = \chi\right]$$

$\Rightarrow \mu_r = \chi + 1$

$\Rightarrow \boxed{\chi = \mu_r - 1} \rightarrow (2)$

Relation between M and H

M and H are Related by $M = \chi H$

$\mu = \frac{B}{H} \Rightarrow B = \mu H \rightarrow (3)$ Comparing (3) and (4)

But $B = \mu_0[H + M] \rightarrow (4)$ $\mu H = \mu_0[H + M] \rightarrow (5)$

Substitute $\mu = \mu_0\mu_r$ in equation (5)

$\mu_0\mu_r H = \mu_0[H + M]$

$\therefore \mu_0\mu_r H = \mu_0 H + \mu_0 M$

$\mu_0\mu_r H - \mu_0 H = \mu_0 M \Rightarrow \cancel{\mu_0}[\mu_r - 1]H = \cancel{\mu_0}M \Rightarrow M = [\mu_r - 1]H$

where $\mu_r - 1 = \chi$ $\therefore$ $\boxed{M = \chi H}$

[1] Define magnetic moment? Explain the origin of magnetic moment at the atomic level:
what is Bohr magnetorn?

The origin of magnetism is due to the (i) orbital motion of electrons in their orbits
(ii) Spinning of electrons (spin motion)
(iii) contribution from nucleons spin

The revolving and rotating electrons constitute current loops. Each loop is like a magnet with one face behaves as a north pole while the other face as a south pole. So that due to above reason there exist a dipoles in the magnetic material and they will interact with the applied field gives more strength to the magnet.

The magnetic moment is mainly due to orbital magnetic moment and spin magnetic moment

→ The atoms having incomplete electronic shells and so they do have resultant magnetic moment

→ According to quantum mechanical concept the magnetic moment is being due to the rotation of electric charge about one of the diameters of the electron. In a manner similar to that ~~spin~~ spinning motion around its north-South axis.

Bohr magnetorn : The quantity $\mu_B = \frac{eh}{4\pi m}$ is an atomic unit called bohr magnetorn

According to modern atomic theory the angular momentum of an electron in the orbits is determined by the orbital quantum number 'l' which is

$l = 0, 1, 2, \ldots (n-1)$

where 'n' is the principal quantum number which determines the energy of the orbit. It can accept only the intervalues $n = 1, 2, 3, 4 \ldots$ the corresponding electronic shells are called K, L, M, N ... shells

The angular momentum of the electrons associated with a particular value of 'l' is given by $l\left[\frac{h}{2\pi}\right]$ ∴ The strength of perminent magnetic dipole is given by

$\therefore \mu_{el} = -\left[\frac{e}{2m}\right]$ [angular momentum]

$\therefore \mu_{el} = -\left[\frac{e}{2m}\right]\left[\frac{lh}{2\pi}\right] = \frac{-ehl}{4\pi m}$

$\mu_{el} = -\frac{eh}{4\pi m}l$

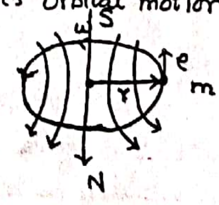
$\therefore \mu_{el} = -\left[\frac{eh}{4\pi m}\right]l$

$\therefore \mu_{el} = -[\mu_B]\,l$

∴ The quantity $\mu_B = \frac{eh}{4\pi m}$ is an atomic unit called Bohr magneton

if $l = 0 \Rightarrow \mu_B = 0$ $\left[l = 0 \Rightarrow \mu_B = \left[\frac{eh}{4\pi m}\right]0 \Rightarrow \mu_B = 0\right]$

[2] In hydrogen atom an electron having charge 'e' revolves around the nucleus at a distance of 'r' meter with an angular velocity 'ω' rad/sec. Obtain an expression for magnetic moment associated with it due to its orbital motion.



Let us consider the simplest atom of hydrogen in which one electron revolves round the proton. electron revolves on a circular path of radius 'r'

At any instant the electron at a point 'p' and proton at centre form an electric dipole, the direction of dipole goes on changing as the electron moves

Let 'e' and m be respectively the charge and mass of the electron.

Also let its speed be 'v' in an orbit of radius

Then the area A of the orbit is πr^2 and its circumference is $2\pi r$

(Q) Classification of Magnetic materials:

Dia magnetic Materials:-

⇒ If the Sum of magnetic moment ~~of~~ is zero. These type of material is known as Dia magnetic. [due to opposite spin allignment of $\bar{e}$'s in the atoms the resultant magnetic moment is zero]

Examples of Dia magnetic materials:-

Bismulth(Bi), ~~platinum (pt)~~ Zn, H_2O, Hg (mercury), Nacl, inert gases, Ag, cu, Au

⇒ χ is negative for Dia magnetic material

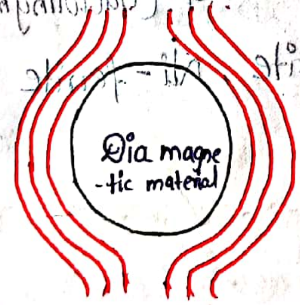
⇒ χ is independent of temperature.

⇒ χ is independent of applied magnetic field strength.

⇒ μ_r is less than 1 ($\mu_r < 1$)

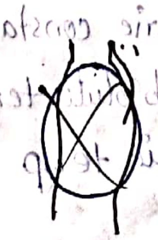
⇒ Spin allignment of the neighbouring atoms is in opposite direction

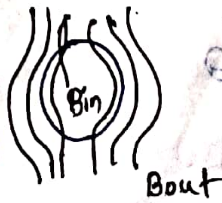
⇒ Dia magnetic materials are placed in an external magnetic field the magnetic lines of force are pushed away by the diamagnetic

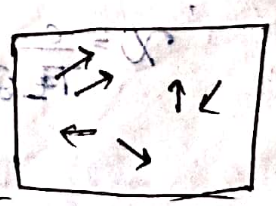


Para magnetic Materials:

eg:- O_2, ~~Silver (Ag)~~, $CuCl_2$ (copper chloride), sol'n of ~~salt~~ salts of Fe, platinum, Al, manganise (Mn), N_2, tungstun







Bin < Bout.

⇒ The vector sum of magnetic moment is not equal to zero. These type of materials is known as Para magnetic material

⇒ χ is Positive

⇒ χ is slightly greater than '1'

⇒ μ_r is greater than 1

⇒ χ depend on temperature $\left[\chi = \frac{C}{T} ; \frac{\chi_1}{\chi_2} = \frac{T_2}{T_1}\right]$

⇒ $B_{in} < B_{out}$ [when Para magnetic material placed in external magnetic field]

Ferro Magnetic Materials -

$$\boxed{\uparrow \uparrow \uparrow \uparrow \uparrow}$$

→ Spin allignment in same direction.

→ All the Orbits of single $\bar{e}$'s are Oriented in a Systematic manner such that the atom as a hole Possess a large magnetic moment, then the substance is known as ferro magnetic material

Examples: Ferrum (Fe), cobalt (Co), Ni, Gd (Gadolinym), * Dy Sprosium (Dy) (Strongest magnet)

MnO (manganise Oxide), Zn-ferrite, Ni-ferrite

Mn-ferrite, Magnetite (Fe_3O_4)

Characteristics

⇒ Ferro magnetic material Possess "Enormous" Perminant dipole moment (or) Perminant magnetic moment even in the absence of External field

⇒ Ferro magnetic materials obey's curie-weiss-law

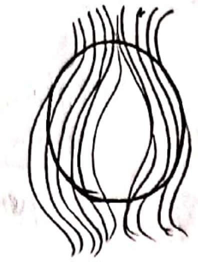
$$\boxed{\chi = \frac{C}{T - \theta}}$$

C → curie constant

T → absolute temp

θ → curie temp

⇒ Ferro magnetic material placed under external magnetic field



$B_{in} >> B_{out}$

⇒ It strongly attracted the magnetic lines of the force ;

⇒ $\mu_r >> 1$

⇒ $\chi >> 1$, χ is always positive (χ depend on temperature.

⇒ Ferro magnetic material behaves the Para magnetic material when its temperature is greater than curie temperature.

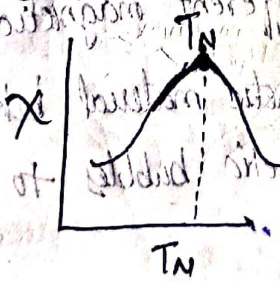
$\boxed{\upharpoonleft\downharpoonright\ \upharpoonleft\downharpoonright\ \upharpoonleft\downharpoonright\ \upharpoonleft\downharpoonright\ \upharpoonleft\downharpoonright}$

Anti Ferro Magnetic Material:-

$\boxed{\uparrow\downarrow\ \ \uparrow\downarrow\ \ \uparrow\downarrow\ \ \uparrow\downarrow\ \ \uparrow\downarrow}$

In Sum magnetic materials due to exchange forces there exist a anti Parallel allignment from neighbouring atoms, these are known as anti ferro magnetic materials.

Note:- In case anti ferro magnetic materials χ becomes maximum at a Perticular temperature is known as T_N (Neel Temperature)



Eg:-

Properties:-

⇒ χ depend on temperature

⇒ ~~skin~~ spin allignment is Anti parallel

$$\chi = \frac{C}{T+\theta}$$

⇒ electrons spin of neighbouring atoms are allign anti parallel

⇒ χ increases up to the neel temperature, beyond the Neel temperature decreases

Ferri Magnetic Materials:-

$$\boxed{\uparrow\downarrow \ \uparrow\downarrow \ \uparrow\downarrow \ \uparrow\downarrow \ \uparrow\downarrow}$$

This is a special case of anti ferro magnetism, Even though there exist anti Parallel allignment the net magnetic moment is not equal to zero

⇒ [un equal magnetic moment in case of neighbouring atoms]

⇒ $\chi = \frac{C}{T \pm \theta}$ eg: [$MeO\,Fe_3O_4$
$MnFe_2O_4$ (manganese ferrite]

Characteristics :-

⇒ Spin allignment is anti parallel of different magnitudes

⇒ Above curie temperature Ferri magnetic material behaves as para magnetic

⇒ Ferri magnetic domains become magnetic bubbles to act as memory elements

⇒ These are Possess net magnetic moment

⇒ χ depend on temperature

⇒ χ is large when $T > T_N$

χ is +ve when $T < T_N$

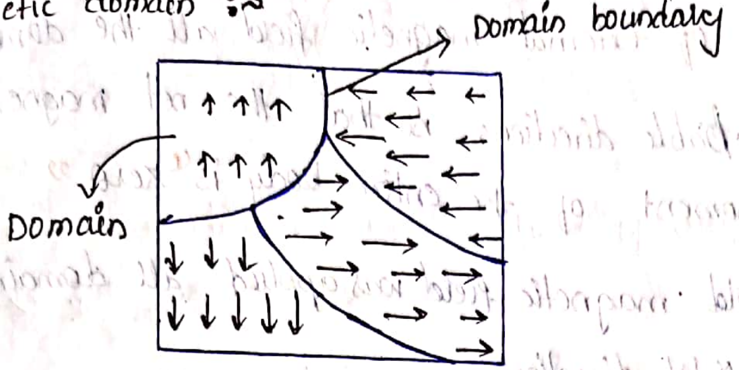
eg: YIG (Yttrium Iron Garnete)

Ferrites composed of Iron oxides and other elements such as Al, Co, Ni, Mn, Zn

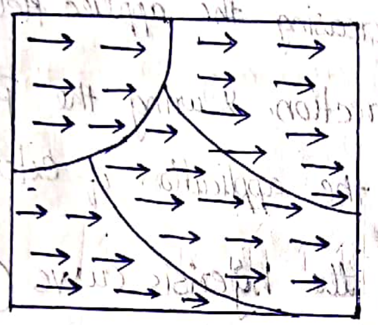
Fe_2O_3, Fe^{2+}, Co^{2+}, Mn^{2+}, Zn^{2+}

write a note on Ferromagnetic domains? write a note on hysteresis Curve (B-H Curve) 28

Ferro magnetic domain :-



Ferro magnetic.
Substance with out any External magnetic field.



under external Magnetic field [Orientation is in same direction]

⇒ In 1907 P. Weiss ~~Explain~~ Proposed the domain theory to explain the magnetic behaviour Ferro magnetic materials.

Domains :-

The entire Ferro magnetic material volume splits into ~~a large~~ no. of small regions. of spontaneous magnetisation, the regions are called ferro magnetic domains.

⇒ Each domain shows the spontaneous magnetisation even in the absence of external magnetic field.

⇒ In each domain the allignment is in the same direction with respect to spin of electrons in atoms. the neighbouring domains are having the different Orientations So that the net magnetisation is 'zero'

[Due to the opposite allignment of neighbouring domains]

⇒ Effect of External magnetic field:-

In the absence of External magnetic field all the domains are oriented in all probable directions so that the net magnetic orientation is "zero" moment of the entire body is "zero"

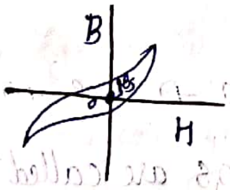
⇒ When an external field magnetic field was applied all domain are oriented in applied field direction

⇒ By the application of external magnetic field some domains are unfavourable to change their direction, but by increasing the applied field intensity these domains are allign in the field direction. During the process there exist a loss of internal energy. By the application of external field

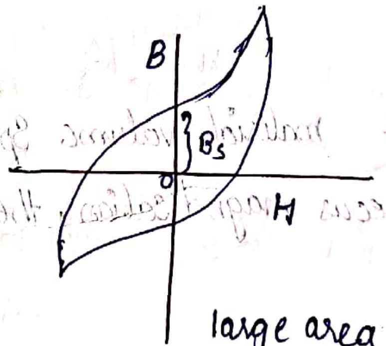
⇒ The loss of energy is estimated by the hysterisis curve (B-H curve)

Note 1:- Hysterisis curve Area is small, the loss of energy is small

2:- Hysterisis curve area is large, then the loss of magnetic is high.



Small area



large area

At origin $H=0$ But $B \neq 0$
$B = B_s$

→ B & H are along X & Y axis

→ H - applied external magnetic field intensity

→ B - magnetic field induction receiving flux

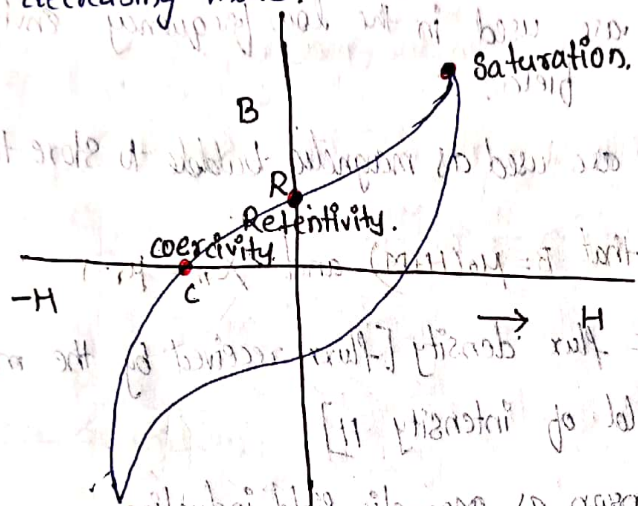
→ B_s - Spontaneous magnetisation

→ It is an irreversiable curve which was exhibited by a ferro magnetic material under external magnetic field.

→ If the applied field intensity increases then B is also increases.

→ If the applied field intensity is reduced to minimum values B does not posses zero value

⇒ B-H curve has 2 paths One path is in increasing mode & another Path is in decreasing mode.



Retentivity:- It is known as ferro magnetic material ability to retain a certain amount of Redual magnetic field when the magnetising force is removed after achieving Saturation

Coercitivity:- In the B-H curve the value of H at the point "C" is known as coercivity [coercive force]

⇒ The amount of Reverse magnetic field (-H) must be applied to a ferro magnetic material to make the magnetic flux return to "zero."

Applications of magnetic materials:-

Because of the special properties of magnetic materials, they are used in.

i) Digital computersii) in transiducers

(ii) they are used in magnetic tape

⇒ they are used for making perminant magnet
⇒ they are used in electro magnets
⇒ they are used in A/c current machinary. ~~Closer~~ manufacture inner parts of the transformers
⇒ they are use in communication System (communication acquipment)
⇒ they are used in Audio & video transformers.

⇒ $MeO\,Fe_3O_4$, $MnFe_2\cdot O_4$ } these are used in the low frequency environment field.

Feeri magnetic materials are used as magnetic bubble to store the data

⇒ With usual notation show that $B = \mu_0(H+M)$ and $\chi_m = \mu_r - 1$

⇒ B is known as magnetic flux density [flux received by the material when it was placed in an external field of intensity H]

B is also known as Magnetic field induction

Units for B : "Weber/meter²" (or) "Tesla"

$$\left[B = \frac{\phi}{A} = \frac{\text{Magnetic flux}}{\text{Area}}\right]$$

⇒ $B = \mu H \longrightarrow ①$ since $\left[\mu = \frac{B}{H}\right]$

μ_r : Relative Permeability

$$\mu_r = \frac{\mu}{\mu_0} \longrightarrow (2) \quad [\mu_0 = \text{Permeability of free Space}]$$

$$\mu = \mu_0\mu_r \longrightarrow (3)$$

*

Rewrite eqn ① as $B = \mu H + \mu_0 H - \mu_0 H \longrightarrow (4)$

Substitute eqn ③ in eqn ④ & follows

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

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

$B = [\mu_0[(\mu_r - 1)H] + \mu_0 H$

we know that $(\mu_r - 1)H = M$

$B = \mu_0 M + \mu_0 H$

$\boxed{B = \mu_0 [H + M]}$

$\left[\begin{array}{l} \chi = \frac{M}{H} \\ \chi = \mu_r - 1 \end{array}\right]$

$\left[\begin{array}{l} \frac{M}{\mu} = \mu_r - 1 \\ M = (\mu_r - 1)\mu \end{array}\right]$

Prove that $\chi_m = \mu_r - 1$

$B = \mu H$ so that $\mu = B/H \longrightarrow ①$

we know that $B = \mu_0 (H + M) \longrightarrow ②$

$\mu_0 = \frac{B}{H+M} \longrightarrow ③$

$\frac{Eq ①}{Eq ②} - \frac{\mu}{\mu_0} = \frac{B/H}{B/H+M} = \frac{H+M}{H} = \frac{H}{H} + \frac{M}{H}$

$\frac{\mu}{\mu_0} = 1 + \frac{M}{H} \longrightarrow (4)$

as per definition

$\frac{\mu}{\mu_0} = \mu_r$

$\mu_r = 1 + \frac{M}{H} \longrightarrow ⑤ \Rightarrow (\mu_r - 1)H = M$

$\frac{M}{H} = \chi_m \longrightarrow (6)$

$\mu_r = 1 + \chi_m$

$\boxed{\chi_m = \mu_r - 1}$

Q) find the Relative permeability of a ferro magnetic material if a field of strength 220 A/mtr Produces a magnetisation 3300 A/mtr in it.

Given data

magnetisation $(M) = 3300$ A/mtr

magnetic field strength (or) Applied magnetic field intensity $H = 220$ A/mtr

Let μ_r be the Relative Permeability.

$\boxed{\mu_r - 1 = \frac{M}{H}} \Rightarrow \mu_r = \frac{M}{H} + 1$

$\mu_r = \frac{\cancel{220}}{330\cancel{0}} + 1$, $\quad \mu_r = \frac{330\cancel{0}}{22\cancel{0}} + 1$

$\mu_r = \frac{\cancel{22}\,2}{330} + 1$ $\quad \mu_r = \frac{330}{22} + 1$

$= \frac{16}{15} = 1.066$ $\quad \boxed{\mu_r = 16}$

In a magnetic material the field strength is found to be 10^6 A/mtr. If the magnetic susceptibility is 0.5×10^{-5}, calculate the intensity of magnetisation and flux density inside the material.

Given data $\quad H = 10^6$ A/mtr = Magnetic field strength.

magnetic susceptibility $\chi = 0.5\times10^{-5}$

let M be the intensity of magnetisation = ?

let B be the magnetic flux density = ?

from the formula $\chi = \frac{M}{H}$

$M = \chi H = (0.5\times10^{-5})\times10^{6}$

$= 0.5\times10$

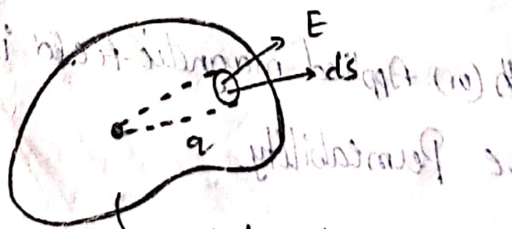
$= 5$ A/mtr.

$B = \mu_0 (H+M)$

$\mu_0 = 4\pi\times10^{-7}$ Henry/metr

$B = 4\pi\times10^{-7}(5+10^6) = 1.257$ weber/m² (or) Tesla,

- State & Explain the laws of Electrostatics
- Gauss law :-



ϕ_E = electric flux

q = charge.

$\boxed{\phi_E = \frac{q}{\varepsilon_0}}$

⇒ It frames the relation b/w charge enclosed by the closed surface and the electric flux [electric lines of force]

Gauss law statement:- The total electric flux through a closed surface enclosing a charge is equal to $1/\varepsilon_0$ times the magnitude of charge enclosed,

$$\phi_E = \frac{1}{\varepsilon_0}[q] \longrightarrow ①$$

let us consider the small area "ds" the flux through the small area

$$ds = d\phi_E = \vec{E}\cdot\vec{ds} \longrightarrow (2)$$

Total flux through the surface S

$$\int d\phi = \oint_S \vec{E}\cdot\vec{ds} \rightarrow (3) \left[\oint_S \rightarrow \text{Represent closed surface}\right]$$

$$\phi_E = \oint_S \vec{E}\cdot\vec{ds} = \frac{q}{\varepsilon_0} \longrightarrow ④$$

Re write Eqn ④

$$\phi_E = \oint_S \vec{E}\cdot\vec{ds}\ \varepsilon_0 = q$$

$$\oint_S (\varepsilon_0\vec{E})\cdot\vec{ds} = q$$

$$\oint_S (\vec{D})\cdot\vec{ds} = q$$

⇒ Gauss law in differential form:-

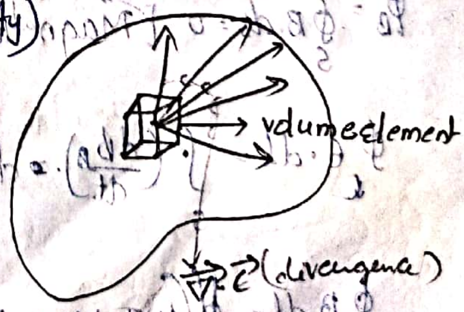
let us consider ρ : volume charge density

Electric flux $\nabla\cdot E = \frac{\rho}{\varepsilon_0}$ $\frac{1}{\varepsilon_0}$ (volume charge density)

divergence of

$$\nabla\cdot\varepsilon_0 E = \rho$$

$$\boxed{\nabla\cdot D = \rho}$$



Gauss law in magnetism :-

The magnetic flux from a closed surface is equal to zero ("0")

it was represented in the form of equation $\phi_B = \oint B\cdot ds$

In differential form.

$$\boxed{\nabla \cdot B = 0}$$

(Divergence of magnetic flux is always zero incase of closed surface)

→ State & explain Maxwell's equation

Maxwell's frame the relation b/w electric field and magnetic field & the Explains that variation electric & magnetic fields.

⇒ Maxwell's equations are liked with $\{E, D, \vec{J}, \varepsilon_0\} \rightarrow$ electric field ($\vec{J}$ → current density)

$\{B \ H \ \mu_0\}$ magnetic field

J: current density

$$J = \frac{I}{A}$$

Maxwell's equations In differential form:-

$$\nabla \cdot E = \frac{\rho}{\varepsilon_0} \quad (\text{or}) \quad \nabla \cdot D = \rho$$ (known as Gauss law in electrostatics)

$$\nabla \cdot B = 0$$ (Gauss law in magnetism)

$$\nabla \times E = \frac{-\delta(B)}{\delta t} = \frac{-\delta B}{\delta t}$$ ~~Amperes law~~ Maxwells-Faradays law

$$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\delta E}{\delta t}$$ Maxwell-Amperes law.

Maxwell's equations In Integral form:-

$$\phi_E = \oint_S E \cdot ds = \frac{q}{\varepsilon_0}$$

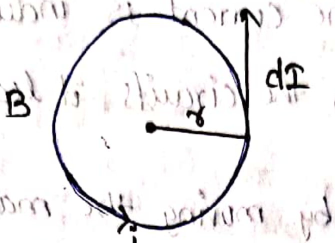
$$\phi_B = \oint_S B \cdot ds = 0$$ [Magnetic flux is '0'] (divergence of) ϕ_B = magnetic flux.

$$\oint_C E \cdot dl = \int_S \left(\frac{d\phi_B}{dt}\right) \cdot ds$$ [Rate of chang of magnetic flux related to Emf (E)]

$$\oint_C B \cdot dl = \iint_S \left(\mu_0 J + \mu_0 \varepsilon_0 \frac{d}{dt}(E)\right) \cdot ds$$

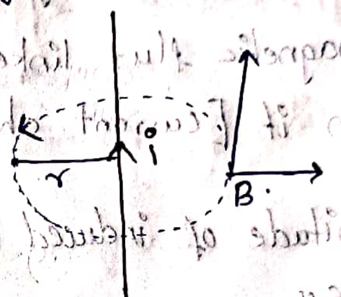
State and Explain Amperes law ?-

Amperes law gives the relation b/w current and magnetic field induction while current is passing through a conductor.



Amperes law Statement:- the magneto motive force Arround a closed path. is equal to the current Enclosed by the path

$$\boxed{B = \frac{\mu_0 i}{2\pi r}}$$

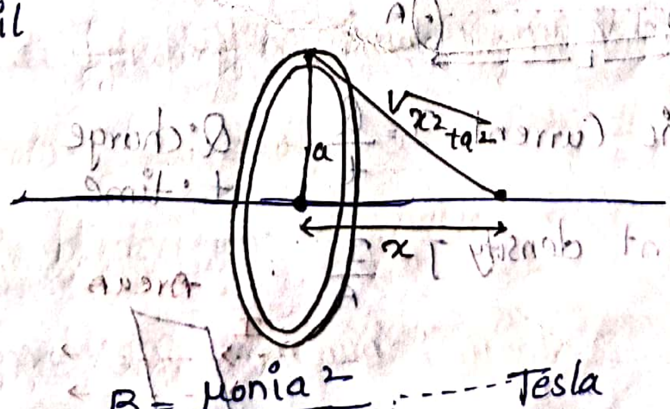


⇒ lets consider a conductor carrying a current "i", there exist a magnetic field arround the current carrying conductor which is $\perp^{lar}$ to the electric field

⇒ According to the amperes law $\oint_C B \cdot dl = \mu_0 i$

Amperes law in Integral form: $\oint_C B \cdot dl = \mu_0 i$

Special case of Amperes law:- Amperes law is also used to calculate magnetic field along the horizental axis of circular coil



$$B = \frac{\mu_0 n i a^2}{2\pi (a^2+x^2)^{3/2}} \text{ ----- Tesla}$$

State and Explain Faraday's law?

Faraday's law gives the relation b/w Emf (electro motive force) and Rate of change of magnetic flux

→ By changing the magnetic flux the current is induced i.e

By changing the magnetic flux in the circuits it leads to the changes emf in the circuit

→ magnetic flux can be changed by moving the magnet in away (or) towards the circuit, By introducing the no of turns

I law of faraday's laws electro magnetic induction:-

Whenever the magnetic flux linked with a circuit changes, an emf is always induced in it [current changes]

II law:- The magnitude of induced emf is equal to the time rate of change of the magnetic flux linkage

$-\varepsilon$ of the magnetic flux linkage

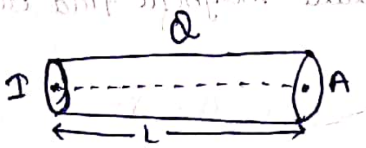
induced Emf $= -\frac{d}{dt}(\phi_B)$ ϕ_B : Magnetic flux

$\frac{d}{dt}(\phi_B)$ Rate of change of magnetic flux

$-\varepsilon = -N\frac{d}{dt}(\phi_B)$ N = No. of circular loops associated with electric circuit

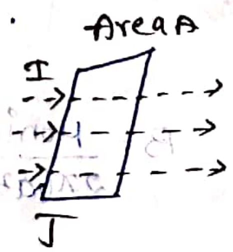
What is electric current derive the continuity equation.

Electric Current:-

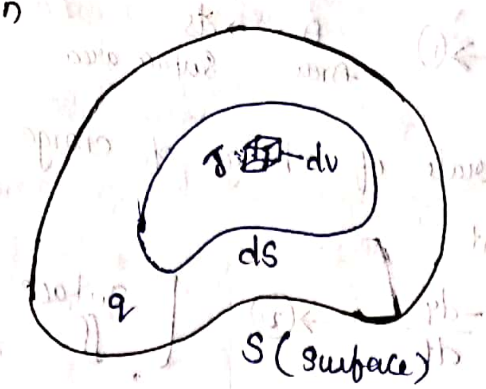


Electric Current $I = \frac{Q}{t}$ Q: charge, t: time.

Current density $J = \frac{I}{A}$



continuity Equation



ds → Small Surface
dv → Small volume element.

⇒ The external electric field accelerates the charges, due to the displacement of charges there exist a current

⇒ The phenamenon of drifting of charges is known as drift current or electric current under external electric field.

continuity :-

$$\boxed{\nabla \cdot J + \frac{d\rho}{dt} = 0}$$

J: Current density.
ρ: charge density.
$\frac{\delta \rho}{\delta t}$ Rate of change of ρ with time t

⇒ let us consider a closed Surface S, with in the Surface ds be the Small area.

let us consider dv be the Small volume in ds.

let q be the total charge enclosed by the ~~total~~ Surface

due to the displacement of charge there exist a current density (J) in volume element (ds) and Strength of Current is I

∴ Current $I = J \cdot A$

Total Current through the Surface

$$I = \oiint_S J \cdot ds \longrightarrow (1) \quad A \rightarrow ds$$

Area Surface area

we know that the rate of change of charge w.r.t time is Equal to current

$$I = \frac{-dq}{dt} \longrightarrow (2) \quad \left[\begin{array}{cc} \text{Surface} & \text{volume} \\ \iint & \iiint \end{array} \right]$$

$$\therefore q = \iiint_V \rho \, dv$$

ρ: charge density with in dv

$$I = \frac{-d}{dt}\left(\iiint_V \rho \, dv\right) = -\int \left(\frac{\delta \rho}{\delta t}\right) dv$$

$$\cancel{I = \frac{d}{}} \quad I = -\iiint_V \left(\frac{\delta \rho}{\delta t}\right) dv \longrightarrow (3)$$

We know that $I = \oiint_S J \cdot ds \longrightarrow (4) = \iiint_V (\nabla \cdot J) dv. \text{---}(4)$

Becaus From Gauss divergence theorem $\boxed{\oiint_S J \cdot ds = \iiint_V (\nabla \cdot J) dv}$

from eqn (3) & (4) By comparision of R.H.S

$$\iiint_V (\nabla \cdot J) dv = -\iiint_V \left(\frac{\delta \rho}{\delta t}\right) dv$$

$$\iiint_V \left((\nabla \cdot J) + \left(\frac{\delta \rho}{\delta t}\right)\right) dv = 0 \text{---}(5) \quad \iiint_V dv \neq 0.$$

So that $\nabla \cdot J + \frac{\delta \rho}{\delta t}$ must vanish

$$\nabla \cdot J + \frac{\delta \rho}{\delta t} = 0$$

volume integral is Orbitory therefore $\iiint_V dv \neq 0$ so that in Order

$$\nabla \cdot J + \frac{\delta \rho}{\delta t} = 0$$

charges are displaced from one surface to another surface constitute electric current. This continuity equation enables conservation of charge i.e electrical can neither be created nor be destroy and the net charge in an isolated system remains constant

Significance of continuity Equation:-

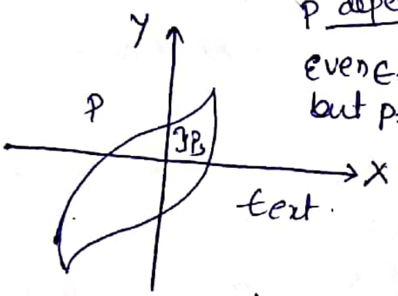
charge can not flow away from a given volume without deminishing the Amount of charge Existing with in the volume.

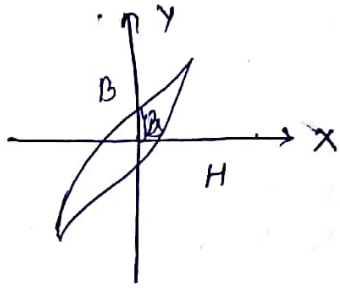
deminishing means decreasing.

Important Points – UNIT – V

Polarization		Magnetization
P	$\longrightarrow$	B
$\epsilon_r = \frac{\epsilon}{\epsilon_0}$	$\longrightarrow$	$\mu_r = \frac{\mu}{\mu_0}$
E_{ext}	$\longrightarrow$	H_{ext}
$P = \epsilon_0(\epsilon_r - 1)E$	$\longrightarrow$	$B = \mu_0(H+M)$. $\chi = \mu_r - 1$, $\chi = \frac{M}{H} - 1$
Ferro Electric	$\longrightarrow$	Ferro magnetic
Spontaneous (P)		Spontaneous (B)

P depend E
even $E=0$
but $P = P_s$ $\longrightarrow$





B depen H
at $H=0$
$B = B_s \neq 0$

Ferro electric

Electric dipole

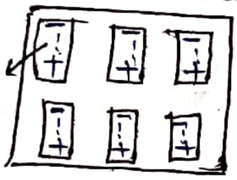


Fig 1 (a) $E_{ext} = 0$

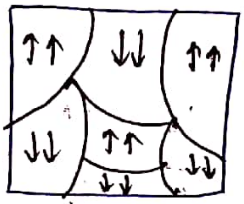
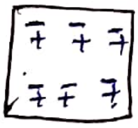


Fig 1 (b) Ferromagnetic Domain
$H=0$

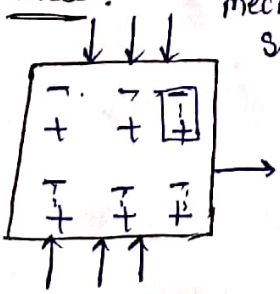
Piezo electric effect.

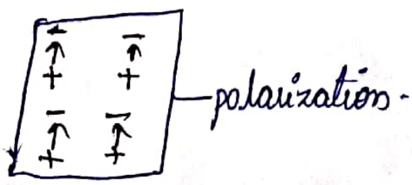
Mechanical Stress:

Stress:



Stress = 0





Eext.

$\leftarrow \rightarrow$	Dia
$\nearrow \searrow \swarrow \uparrow$	Para
$\uparrow\uparrow\uparrow\uparrow$	Ferro
$\uparrow\downarrow\uparrow\downarrow$	antiferro
$\uparrow\!\downarrow\ \uparrow\!\downarrow\uparrow\!\downarrow$	Ferri magnetic