# UNIT-I

- **Blackbody:** Absorbs all the radiation which is incident on it.
- **Photoelectric effect:** When electromagnetic radiation shines on a clean metal surface, electrons are emitted from the surface.
- **Compton effect:** when a monochromatic beam of light is scattered by a substance, the scattered radiation contains two type of wavelengths.
- **The wavelength of the Matter Wave is given by**; $\lambda = \frac{h}{mv} = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{12.26}{\sqrt{V}}$ Å
- **Heisenbergs uncertainity principle:** it is impossible to measure position and momentum of a particle simultaneously and accurately : $\Delta P \, \Delta X \geq \frac{h}{4\Pi}$
- **Schrodinger's time independent wave equation :** $\partial^2\psi / \partial x^2 + [8\pi^2 m(E-V) / h^2] \psi = 0$
- **Allowed energies for a particle in a box** $E_n = n^2 h^2 / 8mL^2$

## Short Answer Questions

**1.What is Compton effect?**

A. H. Compton observed that "when a monochromatic beam of high frequency (lower wavelength) radiation (e.g., X-rays and γ-ray) is scattered by a substance, the scattered radiation contains two type of wavelengths one having same wavelength as that of incident radiation while the other having the wavelength greater (or lower frequency) than that of incident radiations. This effect is known as Compton Effect.

**2. What is wave and particle duality? (MAY-2019 SUPPLY)**

A wave is spread out over a relatively large region of space and it cannot be said to locate just here and there. Actually a wave is nothing but rather a spread out disturbance. A wave is specified by its Frequency, Wavelength, Phase, amplitude or Intensity etc.

According to Classical mechanics the radiation behave as Waves in experiments Interference, Diffraction etc.

According to Quantum mechanics the Radiations behave as Particles in experiments Photo Electric Effect, Compton Effect.

**3.Write the characteristics of matter waves.**

1) Lighter is the Particle, greater is the Wavelength associated with it i.e. $\lambda \, \alpha \, \frac{1}{m}$
2) Smaller is the Velocity of the particle, greater is the wavelength associated with it i.e., $\lambda \, \alpha \, \frac{1}{v}$
3) When v = 0 then $\lambda = \infty$ , i.e., waves becomes in determine and if $v = \infty$ then $\lambda = 0$
4) The waves are produced whether the particles are charged or uncharged, but electromagnetic waves are produced only by the motion of charged particles. So, in this case new kind of matter waves are produced, these waves are called Matter Waves.
5) The velocity of matter Waves always greater than velocity of light.
   Kinetic energy of particle is $E= \frac{1}{2}mv^2$,
   According to Einstein relation $E = mc^2$

$$\frac{1}{2}mv^2 = mc^2; \; v^2 = 2c^2$$
$$v = \sqrt{2}\,c, \text{ So } v > c.$$

**4.State Heisenbergs uncertainity principle. (MAY-2019)**

Ans. According to Heisenberg's it is impossible to measure position and momentum of a particle simultaneously and accurately.

If two physical variable of a particle are considered as measurable quantities the uncertainties or errors will be exerting in which the product of two uncertainties will be greater than or equal to order of $\frac{h}{4\Pi}$, where 'h' is planks' constant.

If we consider uncertainties with respect to position and momentum then

$$\Delta P \, \Delta X \geq \frac{h}{4\Pi}$$

where $\Delta P$ is the uncertainty or error of momentum of the particle.
$\Delta X$ is the uncertainty or error of position of the particle.

**5.Write about borns interpretation of wave function.(MAY-2019)**

Ans.

- The wave function **Ψ** enables all possible information about the particle.
- **Ψ** is a complex quantity and has no direct physical meaning.
- It is only a mathematical tool in order to represent the variable physical quantities in quantum mechanics.
- Born suggested that, the value of wave function associated with a moving particle at the position co-ordinates (x,y,z) in space, and at the time instant "t" is related in finding the particle at certain location and certain period of time "t".
- If **Ψ** represents the probability of finding the particle, then it can have two cases.
  Case 1: certainty of its Presence: +ve probability
  Case 2: certainty of absence: - ve probability, but –ve probability is meaningless, hence the wave function is complex number and is of the form a+ib.
- Even though **Ψ** has no physical meaning, the square of its absolute magnitude $|\Psi^2|$ gives a definite meaning and is obtained by multiplying the complex number with its complex conjugate.

**6. Calculate the debroglie wave length of an electron raised to a potential of 1600V.**

Ans. We know $\lambda = \frac{12.26}{\sqrt{V}}\ A^o$

V=1600V

$\lambda = \frac{12.26}{\sqrt{1600}}\ A^o$

$\lambda$=0.3065 $A^o$

**7. Calculate the kinetic energy and velocity of a electron of wavelength $1.66X10^{-10}$m.**

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

$v = \frac{h}{m\lambda}$

$= \frac{6.626X10^{-34}}{mv9.1X1X1.66X10^{-10}}$

= 0.4386km/s

Kinetic energy $= \frac{1mv2}{2}$

= $(1/2)X9.1X10^{-31}x0.4386X0.4386X10^{14}$

= 54.71 eV

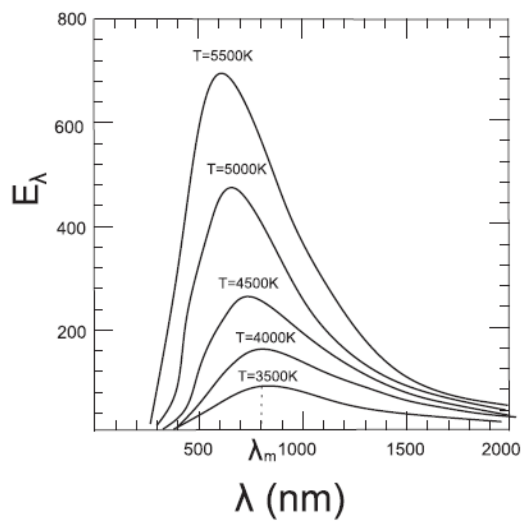
## Essay Type Questions

**1. What is the concept of Black Body Radiation?(May-2019)**

Ans . Blackbody is one which absorbs all the radiations which is incident on it

1). Since a perfect blackbody cannot be realized in practice, a body which absorbs radiations in the visible region together I radiation in the ultraviolet and infrared regions is considered as perfect blackbody. A good absorber of radiation is also a good emitter of radiation. Thus, when a blackbody iskept at high temperature compared to its surroundings it emits radiation in all regions.

2.Energy distribution is not uniform. Energy emitted by the blackbody increases with wavelength, becomes maximum ($E_m$) for a particular wavelength, $\lambda_m$and then decreases with the wavelength.

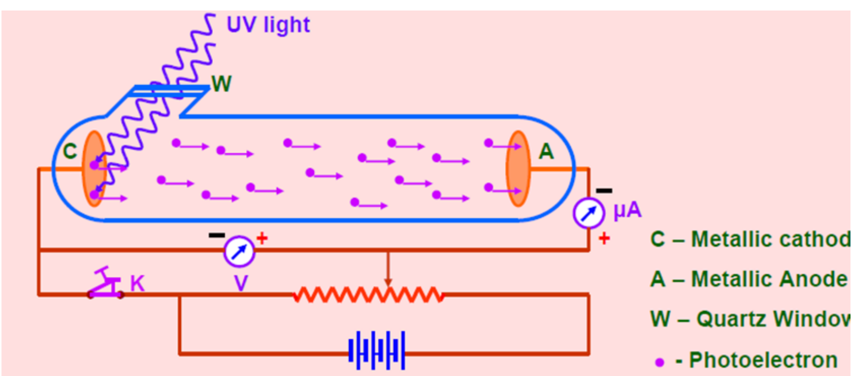



**2.What are the physical assumptions needed to explain the characteristics of photo electric effect? (May-2019)**

Ans. When electromagnetic radiation shines on a clean, metal surface, electrons are emitted from the surface. This phenomenon is called the photoelectric effect.

The electrons emitted by this effect are called photoelectrons. The current constituted by photoelectrons is known as photoelectric current.

Note: Non-metals also show photoelectric effect. Liquids and gases also show this effect but to limited extent.



**3. Derive Schrodinger's time independent wave equation for the motion of for free particle. (May-2019)**

Ans. Schrödinger, in 1926, developed wave equation for the moving particles. One of its forms can be derived by simply incorporating the deBroglie wavelength expression into the classical wave eqn.

If a particle of mass 'm' moving with velocity 'v' is associated with a group of waves.

Let $\psi$ be the wave function of the particle. Also let us consider a simple form of progressing wave like the one represented by the following equation,

$\Psi = \Psi_0 \sin (\omega t - k x)$ --------- (1)

Where $\Psi = \Psi (x, t)$ and $\Psi_0$ is the amplitude.

Differentiating $\Psi$ partially w.r. to x,

$\partial \Psi / \partial x = \Psi_0 \cos (\omega t - k x) (- k) = -k \Psi_0 \cos (\omega t - k x)$

Once again differentiate w.r. to x

$\partial^2\psi / \partial x^2 = (- k) \Psi_0 (- \sin (\omega t - k x)) (- k) = - k^2 \Psi_0 \sin (\omega t - k x)$

$\partial^2\psi / \partial x^2 = - k^2 \psi$ (from eqn (1))

$\partial^2\psi / \partial x^2 + k^2 \psi = 0$ ----------- (2)

$\partial^2\psi / \partial x^2 + (4 \Pi^2 / \lambda^2) \psi = 0$ --------- (3) (since $k = 2 \Pi / \lambda$)

From eqn. (2) or eqn. (3) is the differential form of the classical wave eqn. now we 5incorporated Broglie wavelength expression $\lambda = h / m v$.

Thus we obtain

$\partial^2\psi / \partial x^2 + (4 \Pi^2 / (h / m v)^2) \psi = 0$

$\partial^2\psi / \partial x^2 + 4 \Pi^2 m^2 v^2 \psi / h^2 = 0$ -------------- (4)

The total energy E of the particle is the sum of its kinetic energy K and potential energy V ie; $E = K + V$ -------------- (5), $K = mv^2/2$ ---------- (6)

Therefore $m^2v^2 = 2m(E - V)$ ------------ (7)

From (4) and (7)

$\Rightarrow \partial^2\psi / \partial x^2 + [8\pi^2 m(E-V) / h^2] \psi = 0$ ------------ (8)

In quantum mechanics, the value $h/2\pi$ occurs more frequently. Hence denote, $\hbar = h/2\pi$. Using this notation, we have

$\partial^2\psi / \partial x^2 + [2m(E - V)/\hbar^2] \psi = 0$ ------------ (9)

For simplicity, we considered only one – dimensional wave. Extending eqn. (9) for a three – dimensional, we have

$\partial^2\psi / \partial x^2 + \partial^2\psi / \partial y^2 + \partial^2\psi / \partial z^2 + [2m(E - V)/\hbar^2]\psi = 0$ ------------ (10)

Where $\Psi = \Psi (x, y, z)$.

Here, we have considered only stationary states of ψ after separating the time dependence of Ψ.
Using the Laplacian operator,

$\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2$ ------------- (11)

Eqn. (10) can be written as

$$\boldsymbol{\nabla^2\Psi + [2\, m\, (E - V) / \hbar^2]\, \psi = 0}$$

This is the Schrödinger Time Independent Wave Equation.

**4.Derive an expression for the wavelength of the matter waves. (May-2019)**

Ans. The energy exhibits wave particle duality. i.e., sometimes behave as a wave and at some time as a particle. According to De-Broglie Electromagnetic waves behave like particles and particles like electrons will behave like waves Matter Waves. The wavelength of the matter wave is givenby

$$\lambda = \frac{h}{mv} = \frac{h}{p} \text{ ----- (1)}$$

Where 'm' is Mass of the particle and 'v' is Velocity and 'p' is Momentum.

According to Planck's theory of radiation the energy of radiation is given by

$$E = h\nu = \frac{hc}{\lambda} \qquad [\nu = \frac{c}{\lambda}]$$

Where 'c' is the Velocity of light and 'λ ' is the Wavelength

But According to Einstein's Energy-Mass relation E= $mc^2$

$$\text{So } \frac{hc}{\lambda} = mc^2 \quad ; \quad \lambda = \frac{h}{mc}$$

If we consider the case of material particle of mass 'm' and moving with a velocity 'v' then the wavelength of that particle is given as follows.

According to De-Broglie $\lambda = \frac{h}{mv} = \frac{h}{p}$ (1)

The Kinetic energy of that particle is $E = \frac{1}{2}mv^2$

Multiply and divide with Mass 'm'

$E = \frac{m^2v^2}{2m} = \frac{p^2}{2m}$ [p = mv]

P = $\sqrt{2mE}$ , substitute this value in equation (1) we get

$$\lambda = \frac{h}{\sqrt{2mE}} \qquad (2)$$

Let us consider the case of electron of mass 'm' and charge 'e' which is accelerated by a potential 'V' volts from rest to velocity 'v' then

$$\textit{Kinetic Energy } E = \frac{1}{2}mv^2; \text{ energy of electron} = \text{Ev}$$

$\frac{1}{2}mv^2$ = Ev; $v = \sqrt{\frac{2eV}{m}}$, But $\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2eV}{m}}}$ ; $\lambda = \frac{h}{\sqrt{2meV}}$

Where h = $6.625 \times 10^{-34}$ Joule-Sec
e = $1.6 \times 10^{-19}$ c
m = $9.1 \times 10^{-31}$ kg

By substituting all the values in above equation we get

$$\lambda = \frac{12.26}{\sqrt{V}} \text{ A}^o \text{ ; if V = 100 volts then } \lambda = 1.226 \text{ A}^o$$

This shows that the wavelengths associated with an electron accelerated to 100 volts is 1.226 $A^o$

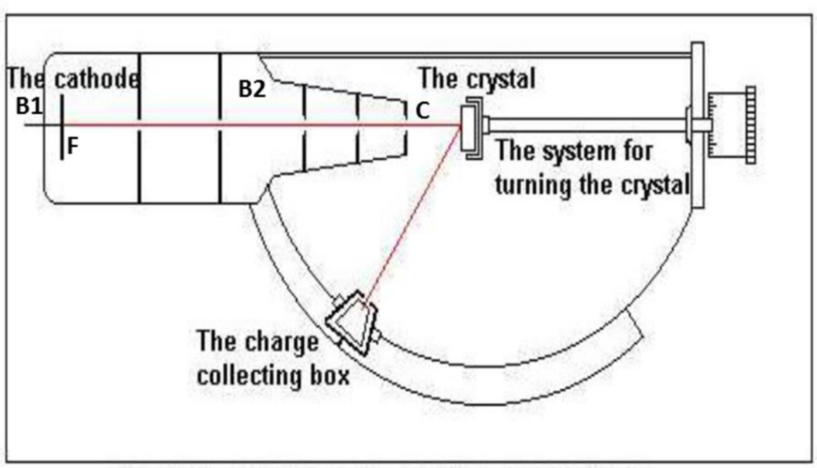
**5. Describe an experiment to verify the existence of matter waves.**

Ans. Davision and Germer's Experiment

Principle:- Based on the concept of wave nature of matter fast moving electrons behave like waves. Hence accelerated electron beam can be used for diffraction studies in crystals.

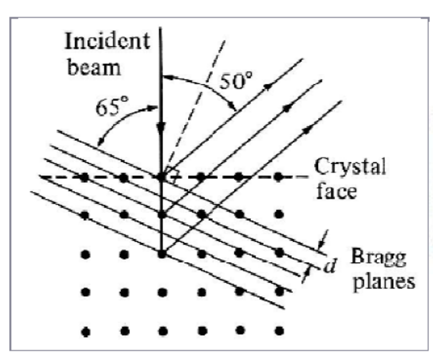
An electron gun which consists of a tungsten filament F heated by a low battery B1,produces electrons. These electrons are accelerated to a desired velocity by applying suitable potential from high tension source B2. The accelerated electrons are collimated into a fine beam by allowing them to pass through a system of pin holes provided in the cylinder 'C'.

The fast moving electrons is made to strike the target (Ni crystal) capable of rotating about an axis perpendicular to the plane of the diagram i.e. incident ray direction. The electrons are now scattered in all directions by the atomic planes of the crystal. The intensity of the electron beam scattered in direction can be measured by the electron collector which can be rotated about I axis as the target. The collector is connected to a sensitive Galvanometer whose deflection is proportional to the intensity of the electron beam entering the collector. The instrument is kept in an evacuated chamber.




The diagram for the Davisson-Germer experiment.

In an investigation, the electron beam accelerated by 54V was directed to strike the given Nickel crystal are a sharp maximum electron distribution occurred at an angle of $50^0$ with the incident beam. The incident and diffracted beam in the experiment make an angle of $65^0$

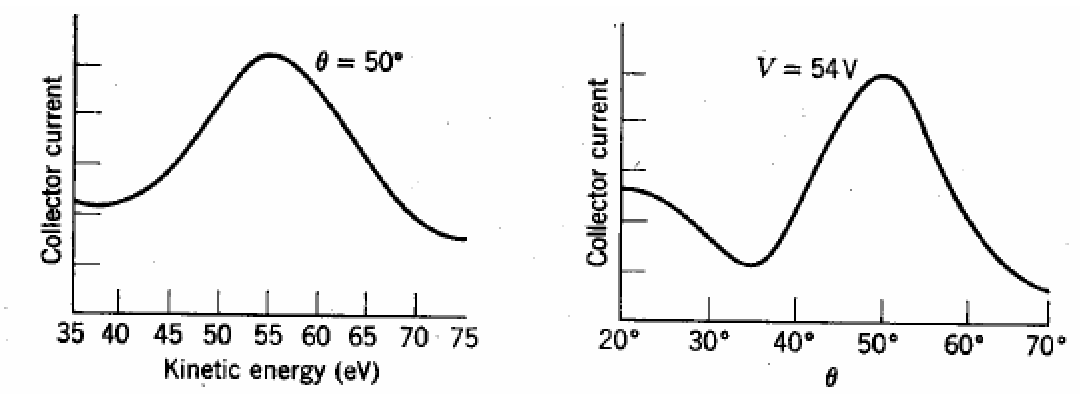


with the Bragg's planes. The spacing of planes in this Bragg's planes by X-Ray diffraction is 0.91 nm.

According to Bragg's law $2d \sin\theta = n\lambda$

$2\times0.91\times10^{-10} \times\sin 65^0 = \lambda \times1$ ($\because$ n =1)

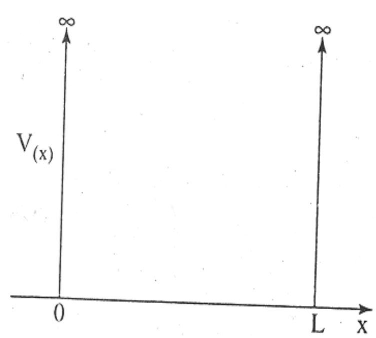
$\lambda = 1.64\times10^{-1} \times10^{-9}$m$= \frac{1.64}{10} nm$ =0.164 nm




For 54V electron the de Broglie wavelength associated with the electron is given by
$\lambda = \frac{12.25}{\sqrt{54}}A^o$; $\lambda = 1.66\times10^{-10}$m; $\lambda$ = 0.166nm
This is excellent agreement with experimental value. The Davission-Germer experiment provides a verification of de-Broglie hypothesis of the nature of moving particle.

**6 . Show that the particle trapped in a potential box possess discrete energy levels. (May-2019)**

Ans. Consider the motion of electrons in one-dimensional deep potential well bounded by high potential barriers. Electrons can propagate along *X*-axis and can get reflected from the walls at $x = 0$ and $x = L$ as shown in Figure and thus it can propagate both in positive and negative *x* directions within the well the potential energy is zero and at the boundaries, i.e., $x = 0$ and $x = L$, potential is very high almost ∞. Therefore, the probability of finding the electron outside the well must be zero, i.e., $\psi = 0$ at $x \le 0$ and $x \ge L$.




V = 0 inside well and V = ∞outside the well.

The time independent Schrödinger wave equation in one dimensional case

$$\nabla^2\Psi + [2m(E - V)/\hbar^2]\psi = 0 \quad (1)$$

For a particle present inside the well where V=0 and $\psi = 0$

**$\nabla^2\Psi + [2\ m\ E / \hbar^2]\ \psi = 0$ (2)**

Let the general solution of eq (2) be

$\Psi(x) = A \sin kx + B \sin kx$

Where A and B are constants which can be determined from boundary conditions

$\Psi(x) = 0$ at $x = 0$ and $\Psi(x) = 0$ at $x = L$

Since $\Psi(x) = 0$ at $x = 0$

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

Since $\Psi(x) = 0$ at $x = L$

$0 = A \sin k(L)$

Which mean A = 0 or sin Kl = 0 since both A and B cannot be zero. $A \neq 0$.

If A = 0, then $\Psi = 0$ everywhere. This means that the particle is not in the well. The only meaningful way to satisfy the condition is

Sin Kl = 0, or $Kl = n\pi$ n = 1, 2, 3,,,

Then $k = n\pi/L$

$[8\pi^2 mE / h^2]^{1/2}$ $L = n\pi$ where n = 1, 2, 3,,…

Solving for the energy of each $\Psi$ to get the allowed energies for a particle in a box

$E_n = n^2 h^2 / 8mL^2$

Hence the energy of a particle is quantized.

# UNIT-II

**1.Write the differences between intrinsic and extrinsic semiconductors.(DEC-2018)**

Ans. **Intrinsic Semiconductor**

A semiconductor which is in its extremely pure form is known as an intrinsic semiconductor. Silicon and germanium are the most widely used intrinsic semiconductors.

Both silicon and germanium are tetravalent, i.e. each has four electrons (valence electrons) in their outermost shell. Each atom shares its four valence electrons with its four immediate neighbours, so that each atom is involved in four covalent bonds.

**Extrinsic Semiconductor / Doping**

Pure semiconductors have negligible conductivity at room temperature. To increase the conductivity of intrinsic semiconductor, some impurity is added. The resulting semiconductor is called impure or extrinsic semiconductor.

Impurities are added at the rate of ~ one atom per $10^6$ to $10^{10}$ semiconductor atoms. The purpose of adding impurity is to increase either the number of free electrons or holes in a semiconductor.

**2.Define Fermi level. (MAY-2019)**

Ans. **Fermi Energy**

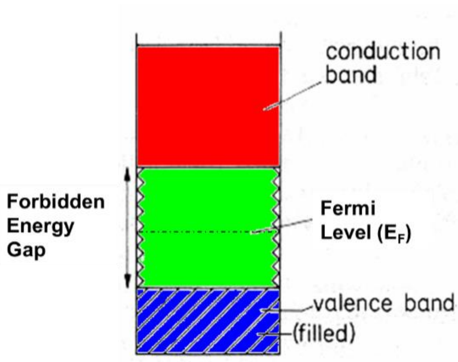
The Fermi energy is a quantum mechanical concept and it usually refers to the energy of the highest occupied quantum state in a system of fermions at absolute zero temperature.

**Fermi Level**

The Fermi level ($E_F$) is the maximum energy, which can be occupied by an electron at absolute zero (0 K).

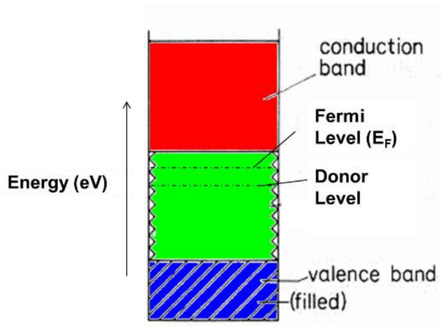
**3.Represent how the Fermi level of an intrinsic semiconductor and extrinsic semiconductor. (MAY-2019)**

Ans. **Fermi Energy Diagram for Intrinsic Semiconductors:**



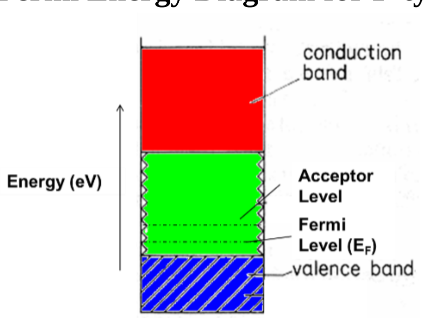

The Fermi level ($E_F$) lies at the middle of the forbidden energy gap.

**Fermi Energy Diagram for N-type Semiconductors:**




The Fermi level ($E_F$) shifts upwards towards the bottom of the conduction band.

**Fermi Energy Diagram for P-type Semiconductors**




The Fermi level ($E_F$) shifts downwards towards the top of the valance band.

**4.Write the applications of hall effect. (MAY-2019)**

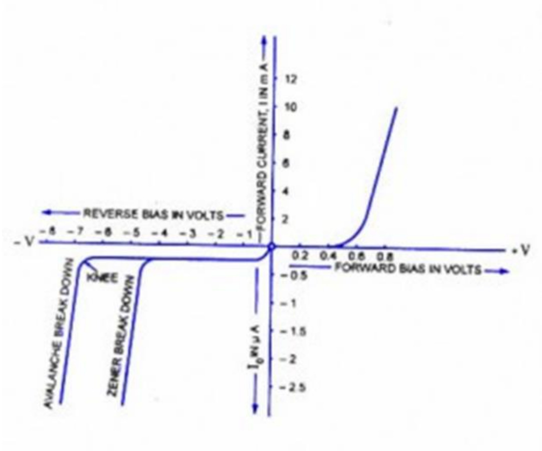
Ans. Application:-

Nature of semiconductor (p-type or n-type)
Carrier concentration

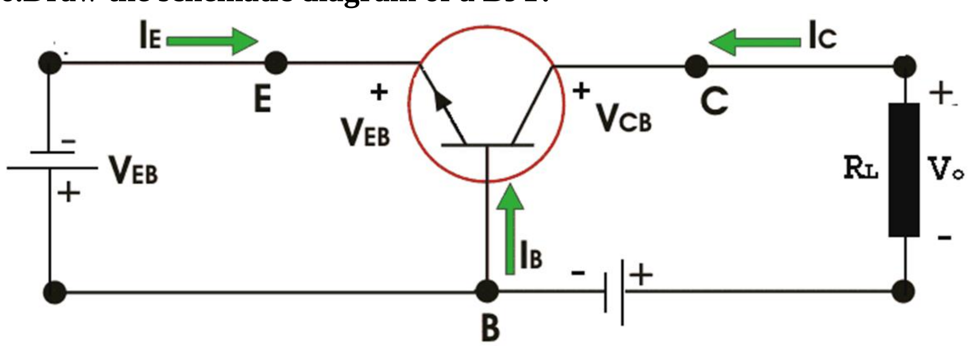
Conductivity

Mobility

**5.Draw the I-V characteristics of a PN diode. (MAY-2019)**




**6.Draw the schematic diagram of a BJT.**




**1.Write the differences between N-type Semiconductor and P-type Semiconductor.**

Ans:Two types of impurity atoms are added to the semiconductor.

**N-type Semiconductor:**

The semiconductors which are obtained by introducing pentavalent impurity atoms are known as N-type semiconductors.

Examples are P, Sb, As and Bi. These elements have 5 electrons in their valance shell. Out of which 4 electrons will form covalent bonds with the neighbouring atoms and the 5$^{th}$ electron will be available as a current carrier. The impurity atom is thus known as donor atom.

In N-type semiconductor current flows due to the movement of electrons and holes but majority of through electrons. Thus electrons in an N-type semiconductor are known as majority charge carriers while holes as minority charge carriers.

**P-type Semiconductor**

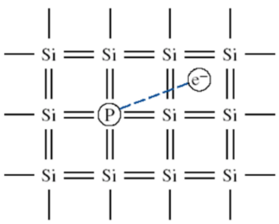
The semiconductors which are obtained by introducing trivalent impurity atoms are known as P-type semiconductors.

Examples are Ga, In, Al and B. These elements have 3 electrons in their valance shell which will form covalent bonds with the neighbouring atoms.

The fourth covalent bond will remain incomplete. A vacancy, which exists in the incomplete covalent bond constitute a hole. The impurity atom is thus known as acceptor atom.

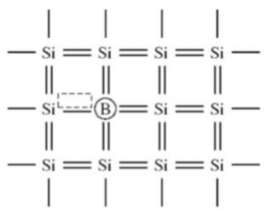
In P-type semiconductor current flows due to the movement of electrons and holes but majority of through holes. Thus holes in a P-type semiconductor are known as majority charge carriers while electrons as minority charge carriers.

N-Type




Two-dimensional representation of a silicon lattice doped with a phosphorus atom

P-Type




Two-dimensional representation of a silicon lattice doped with a boron atom

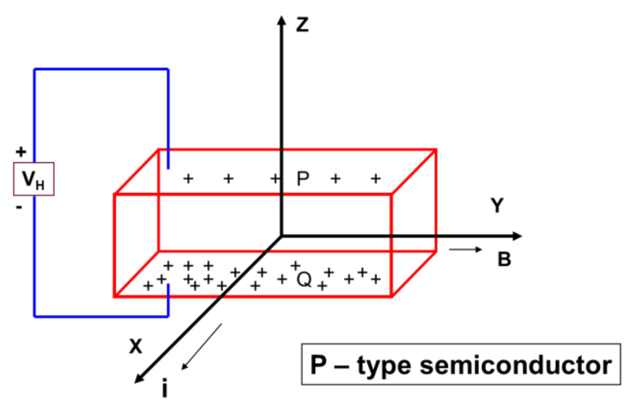
## 2.What is Hall effect? Derive an expression for hall coefficient of a given semiconductor.

When a **magnetic field** is applied perpendicular to a current carrying conductor or semiconductor, **voltage** is developed across the specimen in a direction perpendicular to both the current and the magnetic field.

This phenomenon is called the **Hall effect** and voltage so developed is called the **Hall voltage**.

Application:-

- ❖ Nature of semiconductor (p-type or n-type)
- ❖ Carrier concentration
- ❖ Conductivity
- ❖ Mobility




### Experimental Determination of Carrier concentration and Mobility

Consider a semiconductor (P-Type or N-types) in which current I and Magnetic field B is applied, a force is act on the charge carriers. This force pushing the charge carriers towards the back of the semiconductor.

When the mobile carriers (i.e. electrons or holes) are pushed towards the back, the front becomes depleted and the semiconductor loss it neutrality.

Now there is an excess of mobile charge carriers at the back and an excess of opposite charge due to impurity atom at the front.

If the semiconductor is N-type,

The electron will be in excess at the back surface and the surface becomes negatively charged with respect to front. This gives rise to a potential difference called Hall voltage between front and back

If the semiconductor is P-type,

The hole will be in excess at the back surface and the surface becomes positively charged with respect to front. The polarity of Hall voltage is in reverse direction

At equilibrium, the force exerted on electrons due to electric field and magnetic field must balance each other.

$$F_{(electric)} + F_{(magnetic)} = 0$$

$$\text{n.q.E} + \text{B.J} = 0 \Rightarrow E = -\frac{\text{B.J}}{\text{n.q}}$$

The hall coefficient $R_H = -\frac{1}{\text{n.q}}$

$$E = \text{B.J.R}_\text{H};\ E = {V_H}/{d}$$

$V_H$ = Hall Voltage, d = Distance between front & back surface

Current density can be written as

$$J = \frac{I}{A} = \frac{I}{d.t}$$

Where t is the thickness of the semiconductor

$$\frac{V_H}{d} = B \times \frac{I}{d.t} \times \frac{1}{n.q}$$

$$V_H = \frac{B.I}{n.q.t} \text{ or } n = \frac{B.I}{V_H.q.t}$$

The concentration of holes in a P-type semiconductor can be given by

$$p = \frac{B.I}{V_H.q.t}$$

The Hall coefficient for a P-type semiconductor is given by

$$R_H = +\frac{1}{\text{n.q}}$$

The electrical conductivity for an extrinsic semiconductor is

$\sigma = n.q.\mu_n$ For N-type semiconductor

$\sigma = p.q.\mu_p$ For P-type semiconductor

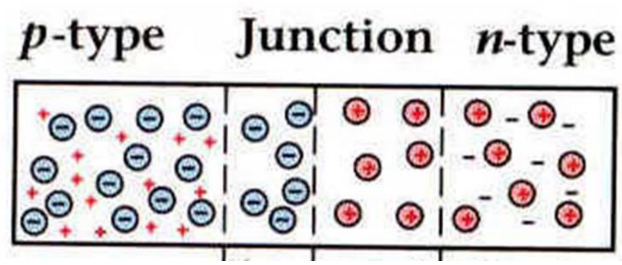
If the conductivity and Hall coefficient are given

$\mu_n = \frac{\sigma}{n.q} = \sigma.R_H$ For N-type semiconductor

$\mu_p = \frac{\sigma}{p.q} = \sigma.R_H$ For P-type semiconductor

**3.How is a PN-junction diode formed? Draw the I-V characteristics of the diode.**

The holes from p-side diffuses to the n-side while the free electrons from n-side diffuses to the p-side. This movement occurs because of charge density gradient. This leaves the negative acceptor ions on the p-side and positive donor ions on the n-side uncovered in the vicinity of the junction.




Thus there is negative charge on p-side and positive on n-side.This sets up a potential difference across the junction and hence an internal Electric field directed from n-side to p-side. Equilibrium is established when the field becomes large enough tostop further diffusion of the majority charge carriers. The region which becomes depleted (free) of the mobile chargecarriers is called the depletion region. The potential barrieracross the depletion region is called the potential barrier.
Width of depletion region depends upon the doping level. The higher the doping level, thinner will be the depletion region.

**Forward Bias P-N Junction**

When an external voltage is applied tothe P-N junction making the P side positive with respect to the N side the diode is said to be forward biased.

The barrier potential difference is decreased by the external applied voltage. The depletion band narrows which urges majority carriers to flow across the junction.
A Forward biased diode has a very low resistance.

**Reverse Bias P-N Junction**

When an external voltage is applied to the P-N junction making the P side negative with respect to the N side the diode is said to be Reverse Biased.

The barrier potential difference increases. The depletion band widens preventing the movement of majority carriers across the junction.

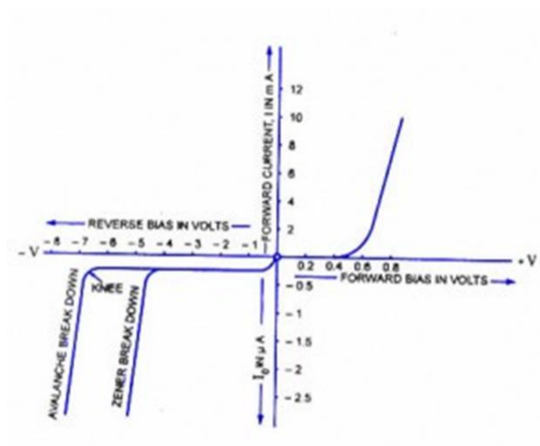
A Reverse Bias diode has a very high resistance

**Breakdown in P-N junction diode**

In Electronics, the term "breakdown" stands for release of electron-hole pairs in excess.
The critical value of the voltage, at which the breakdown of a P-N junction diode occurs is called the *breakdown voltage.* The breakdown voltage depends on the width of the depletion region, which, in turn, depends on the doping level.
There are two mechanisms by which breakdown can occur at a reverse biased P-N junction:
1. Avlanche Breakdown (uncontrolled)
2. Zener Breakdown (controlled)

**Avalanche breakdown**

If the reverse bias is made very high, the thermally generated electrons and holes get sufficient K.E from applied voltage to break the covalent bonds near the junction and a large no. of electron-hole pairs are released. These new carriers, in turn, produce additional carrier again by breaking bonds. Thus reverse current then increase abruptly and may damage the junction by the excessive heat generated.
The avalanche breakdown occurs in lightly doped junctions, which produce wide depletion region.
The avalanche breakdown voltage increases as the temperature of the junction increases due to the increased probability of collisions of electron and holes with crystal atoms.

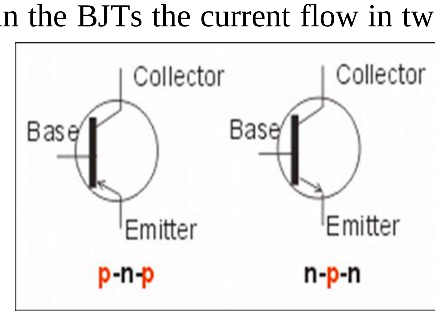



## 4.Explain about BJT and its working process.

BJT was invented in 1948 by William Shockley, Brattain, and John Bardeen which has remolded not only the world of electronics but also in our day to day life. TheBipolar junction transistors uses both charge carriers that are electron and holes. Indifference the unipolar transistors such as field effect transistors use only one kind of charge carriers. For the operation purpose BJT uses two semiconductor type n-type and p- type between two junctions. The main basic function of a BJT is to amplify current it will allow BJTs are used as amplifiers or switches to produce wide applicability in electronic equipment include mobile phones, industrial control, television, and radio transmitters. There are two different types of BJTs are available, they are NPN, and PNP.

**Bipolar Junction Transistors**

The Bipolar junction transistor is a solid state device and in the BJTs the current flow in two terminals, they are emitter and collector and the amount of current controlled by the third terminal i.e. base terminal. It is different to the other type of transistor i.e. Field effect transistor which is the output current is controlled by the input



voltage. The basic symbol of the BJTs n-type and p-type is shown in Fig.

**Types of Bipolar Junction Transistors**

As we have seen a semiconductor offer less resistance to flow current in one direction and high resistance is another direction and we can call transistor as the device mode of the semiconductor. The bipolar junction transistors consist of two types of transistors. Which, given us, Point contact and Junction transistor

By comparing two transistors the junction transistors are used more than point type transistors. Further the junction transistors are classified into two types which are given below. There are three electrodes for each junction transistor they are emitter, collector, and base

PNP junction transistors
NPN junction transistors

**PNP Junction Transistor**

In PNP transistor, the emitter is more positive with base and also with respect to the collector. The PNP transistor is a three terminal device which is made from the semiconductor material. The three terminals are collector, base, and the emitter and the transistor are used for switching and amplifying applications.

The operation of PNP transistor is shown below.

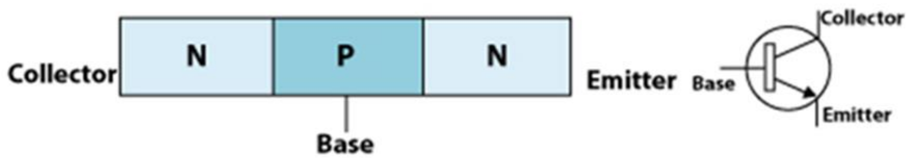
Generally the collector terminal is connected to the positive terminal and the emitter to a negative supply with resistor either the emitter or collector circuit. To the base terminal the voltage is applied and it operates transistor as an ON/OFF state. The transistor is in OFF state when the base voltage is same as the emitter voltage. The transistor mode is in ON state when the base voltage decreases with respect to the emitter. By using this property the transistor can act on both applications like switch and amplifier. The basic diagram of PNP transistor is shown below.


**NPN Junction Transistor**

The NPN transistor is exactly opposite to the PNP transistor. The NPN transistor contains three terminals which are same as the PNP transistor which are emitter, collector, and base.

The operation of the NPN transistor is

Generally the positive supply is given to the collector terminal and the negative supply to the emitter terminal with a resistor either the emitter or collector or emitter circuit. To the base terminal the voltage is applied and it operated as an ONN/OFF state of a transistor. The transistor is in OFF state when the base voltage is same as the emitter. If the base voltage is increased with respect to the emitter then the transistor mode is in ON state. By using this condition the transistor can act like both applications which are amplifier and switch. The basic symbol and the NPN configuration diagram as shown below.




**Working Principle of BJT**

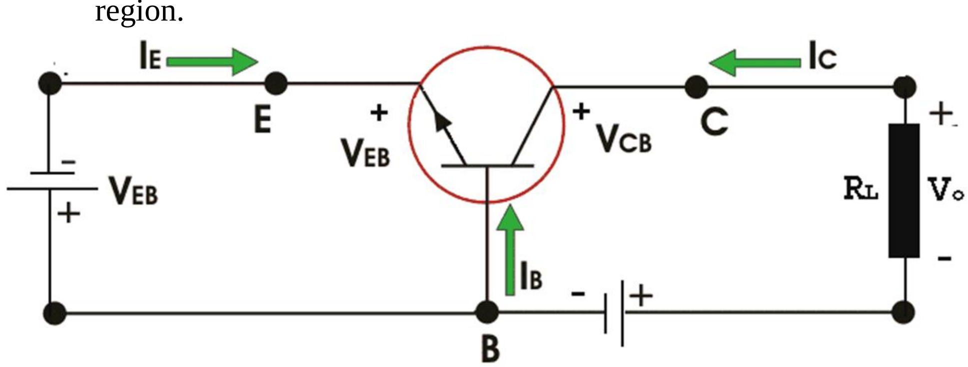
The BE junction is a forward bias and the CB is a reverse bias junction. The width of the depletion region of the CB junction is higher than the BE junction. The forward bias at the BE junction decreases the barrier potential and produces electrons to flow from the emitter to the base and the base is a thin and lightly doped it has very few holes and less amount of electrons from the emitter about 2% it recombine in the base region with holes and from the base terminal it will flow out. This initiates the base current flow due to combination of electrons and holes. The left over large number of electrons will pass the reverse bias collector junction to initiate the collector current. By using Kirchhoff's laws we can observe the mathematical equation

$\mathbf{I_E = I_B + I_C}$

The base current is very less as compared to emitter and collector current

$\mathbf{I_E \sim I_C}$

Here the operation of PNP transistor is same as the NPN transistor the only difference is only holes instead of electrons. The below diagram shows the PNP transistor of the active mode region.




1. **Write about diffusion current.**

   Due to thermally induced random motion, mobile particles tend to move from a region of high concentration to a region of low concentration.

   Current flow due to mobile charge diffusion is proportional to the carrier concentration gradient.

   The total current flowing in a semiconductor is the sum of drift current and diffusion current:

$$J_{tot} = J_{p,drift} + J_{n,drift} + J_{p,diff} + J_{n,diff}$$

   The characteristic constants for drift and diffusion are related by the Einstein's Relation: $D/\mu = kT/q$

$kT/q$ = 26 mVat room temperature (300K)

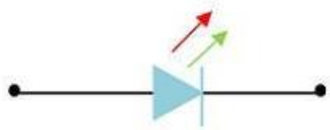
This is often referred to as the **“thermal voltage”**.

# UNIT-III
# OPTOELECTRONICS

- **Radiative recombination :** An electron in the conduction band recombines with a hole in the valence band and the excess energy is emitted in the form of a photon.

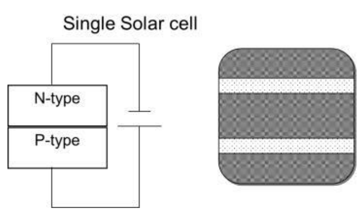
- **Non Radiative recombination:** An electron in the conduction band recombines with a hole in the valence band and the excess energy is emitted in the form of heat in the semiconductor crystal lattice.

- **LED:** (Light Emitting Diode) is an optoelectronic device which works on the principle of electro-luminance.

- **Symbol of LED:** 

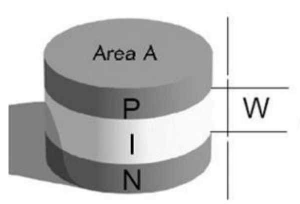
- **Solar cell** It is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

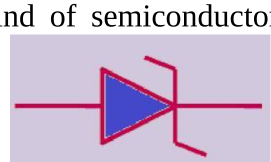
- **Symbol of Solar cell:**




- **PIN diode** is a one type of photo detector, used to convert optical signal into an electrical signal. The PIN diode comprises of three regions, namely P-region, I-region and N-region.

- **Symbol of PIN diode:**




- **Avalanche diode** is a one kind of semiconductor device specially designed to work in the reverse breakdown region.
- 
- **Symbol of Avalanche diode** 

## Short Answer Questions

### 1.What is Radiative Recombination.

**Ans: Recombination**: A process whereby electrons and holes (carriers) are annihilated or destroyed.

Classification:

1. Radiative Recombination: Photon
2. Nonradiative Recombination: Phonon or Lattice vibration

1. Radiative Recombination occurs when an electron in the conduction band recombines with a hole in the valence band and the excess energy is emitted in the form of a photon.

Optical processes associated with radiative transitions are:

a. spontaneous emission
b. absorption or gain
c. stimulated emission,

### 2.What is Nonradiative Recombination

**Ans: Nonradiative Recombination**

An electron in the conduction band recombines with a hole in the valence band and the excess energy is emitted in the form of heat in the semiconductor crystal lattice.

Characterized by the absence of any useful emitted photons in the recombination process. Affecting performance of injection laser by increasing the threshold current

Nonradiative Recombination processes include:

Auger Recombination, Surface Recombination, Recombination at defects

**3.Write the applications of LED.**

**Ans: Applications of LED**

1. Indicator in AC circuit
2. Display Panel Indicator
3. Digital Watches, Calculators & Multimeters
4. Remote Control Systems

**4.What is a solar cell? Explain**

**Ans:**Solar cell is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

***Principle:*** The solar cells are based on the principles of photovoltaic effect. The photovoltaic effect is the photo generation of charge carriers in a light absorbing material as a result of absorption of light radiation**.**

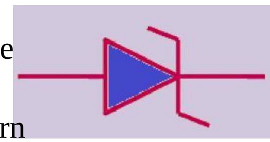
**5.What is a PIN Diode?**

**Ans:**The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal.The PIN diode comprises of three regions, namely P-region, I-region and N-region.Typically,

both the P and N regions are heavily doped due to they are utilized for Ohmiccontacts. The intrinsic region in the diode is in contrast to a PN junction diode.
This region makes the PIN diode a lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.

**6.What is an Avalanche Diode?**

**Ans:**An avalanche diode is a one kind of semiconductor device specially designed to work in the reverse breakdown region.
The symbol of this diode is same to as Zener diode. The avalanche diode comprises of two terminals namely anode and cathode.
The avalanche diode symbol is alike to the normal diode but with the turn edges of the vertical bar that is shown in the following figure.



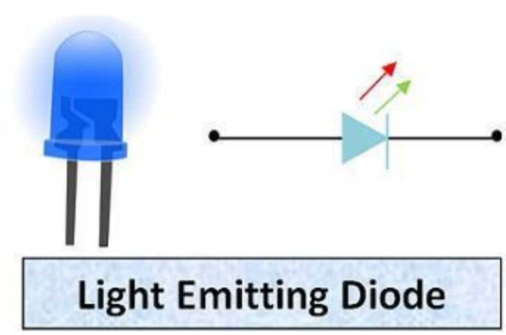
**7.Write the applications of** Avalanche Diode**.**
**Ans:** a**.**The Avalanche diode is used to protect the circuit.
b.Designers employ the diode more for protecting the circuit against unwanted voltages.
c.These diodes are used as white noise generators.
d.Avalanche diodes produce RF noise, they are generally used as noise sources in radio gears.
e.Avalanche diodes are used to generate microwave frequency.

## <u>Long Answer questions</u>

## 1.Explain the construction and working of an LED.

**Ans:**LED (Light Emitting Diode) is an optoelectronic device which works on the principle of electro-luminance. Electro-luminance is the property of the material to convert electrical energy into light energy and later it radiates this light energy. In the same way, the semiconductor in LED emits light under the influence of electric field.

The symbol of LED is formed by merging the symbol of P-N Junction diode and outward arrows. These outward arrows symbolise the light radiated by the Light emitting diode.




**Construction of LED**

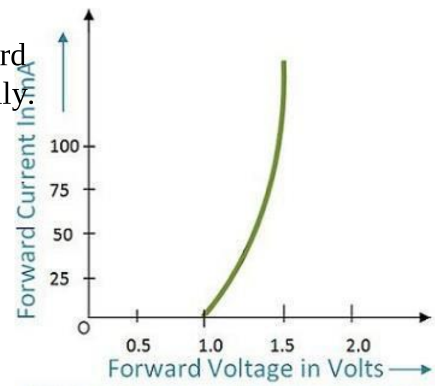
The semiconductor material used in LED is Gallium Arsenide (GaAs), Gallium Phosphide (GaP) or Gallium Arsenide Phosphide (GaAsP). Any of the above-mentioned compounds can be used for the construction of LED, but the colour of radiated light changes with the change in material. Below are some of the material and their respective colour of light which they emit. In addition to it, the ranges of typical forward voltage are also given below.

**Working of LED**

The electrons are majority carriers in N-type and holes are majority carriers in P-type. The electrons of N-type are in the conduction band and holes of P-type are in the valence band. The energy level of the Conduction band is higher than the energy level of the Valence band. Thus, if electrons tend to recombine with holes they have to lose some part of the energy to fall in lower energy band.

**I-V Characteristics of LEDs**

The characteristics curve of the LED shows that the forward bias of **1 V** is sufficient to increase the current exponentially.



Forward Bias V-I Curve

**Applications of LED**

5. Indicator in AC circuit
6. Display Panel Indicator
7. Digital Watches, Calculators & Multimeters
8. Remote Control Systems

## 3.Explain the construction and working of a Semiconductor Laser diode.

**Ans:**LASER is an acronym of Light amplification by stimulated emission of radiation. A laser diode emits radiation of a single wavelength or sometimes a narrow band of closely spaced wavelength. It emits light due to stimulated emission, in this when an incident photon strike semiconductor atom, the electrons at higher energy level recombine with lower energy level hole. Due to this two photons are emitted one incident photon and other is emitted due to recombination of electrons and hole.

Due to its structure Laser diode emits coherent & monochromatic light (Single colour). The light emitted by Laser diode consists of single wavelength while LEDs emit light consisting of a wide band of wavelengths. Thus, the light emitted by LED is incoherent.

**Construction of Laser diode**

The Laser diode is made up of two layers of Semiconductors i.e. P-type and N-type. The layers of semiconductors are made up of GaAs doped with materials like selenium, aluminium or silicon. The construction is same as that of LED except the channels used in Laser are narrow to produce a single beam of light.
And one more difference in a Laser diode is that an intrinsic layer of GaAs (undoped) is also present. This layer is called active layer. The active layer is enclosed by layers of lower refractive index. This act as optical reflectors.

These layers along with active layer form a waveguide so that light can travel only in a single path in a single and fixed direction. The beam of light is produced in this section. The metal contacts are provided to facilitate biasing.

**Working of Laser diode**

The laser diode works on the principle that every atom in its excited state can emit photons if electrons at higher energy level are provided with an external source of energy.

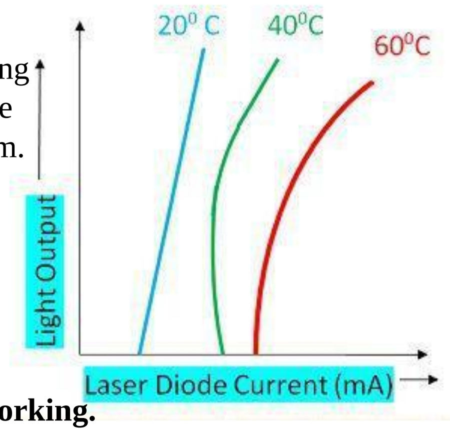
**Population inversion**

The density of electrons at energy levels is the population of electrons and it is more in valence band or lower energy band and less in the conduction band or higher energy level. If the population of electrons increases at higher energy level or the lifetime of higher energy states is long then stimulated emission will increase. This increase of population at higher energy level is termed as population inversion.

And this is the requisite state for Laser diode. More the population inversion more will be the electrons at higher and meta stable state and more will be the stimulated emission. The photons emitted are in the same phase with the incident photons. And these photons travel as a single beam of light and thus produce coherence.

**I- V Characteristics of Laser diode**

The forward voltage of laser diode is generally around 1. 5 V. Although the forward voltage depends on operating temperature. The variance of current in the diode with the voltage can be understood with the help of below diagram.



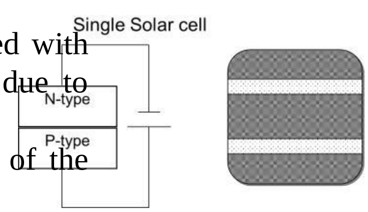

**4.What is a solar cell? Explain its construction and working.**

**Ans:**Solar cell is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

***Principle:*** The solar cells are based on the principles of photovoltaic effect. The photovoltaic effect is the photo generation of charge carriers in a light absorbing material as a result of absorption of light radiation**.**

***Construction*** Solar cell (crystalline Silicon) consists of a *n-type semiconductor (emitter)* layer and *p-type semiconductor layer (base).* The two layers are sandwiched and hence there is formation of p-n *junction.* The surface is coated with *anti-refection coating* to avoid the loss of incident light energy due to reflection.

A proper metal contacts are made on the n-type and p-type side of the semiconductor for electrical connection.




***Working:***

When a solar *panel exposed to sunlight*, the light energies are absorbed by a semi-conduction materials. Due to this absorbed energy, the electrons are liberated and produce the external DC current.

The DC current is converted into 240-volt AC current using an inverter for different applications.

**Mechanism:**

First, the sunlight is absorbed by a solar cell in a solar panel.

The absorbed light causes electrons in the material to increase in energy. At the same time they make free to move around in the material.

However, the electrons remain at this higher energy for only a short time before returning to their original lower energy position.

Therefore, to collect the carriers before they lose the energy gained from the light, a PN junction is typically used.

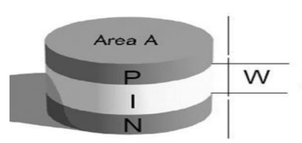
A PN junction consists of two different regions of a semiconductor material (usually silicon), with one side called the p type region and the other the n-type region.

During the incident of light energy, in p-type material, electrons can gain energy and move into the n-type region.

Then they can no longer go back to their original low energy position and remain at a higher energy. The electrons that leave the solar cell as current give up their energy to whatever is connected to the solar cell, and then re-enter the solar cell. Once back in the solar cell, the process begins again:

The process of moving a light- generated carrier from p-type region to n-type region is called collection. These collections of carriers (electrons) can be either extracted from the device to give a current, or it can remain in the device and gives rise to a voltage

5. **What is a PIN Diode? Explain its construction and working.**

- **Ans:**The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal.
- The PIN diode comprises of three regions, namely P-region, I-region and N-region.
- Typically, both the P and N regions are heavily doped due to they are utilized for Ohmic contacts.
- The intrinsic region in the diode is in contrast to a PN junction diode.
- This region makes the PIN diode a lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.
- 


**Structure and Working of PIN Diode**

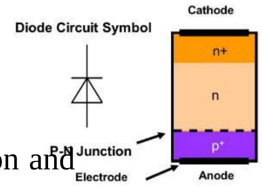
The term PIN diode gets its name from the fact that includes three main layers. Rather than just having a P-type and an N-type layer, it has three layers such as P-type layer

Intrinsic layer

N-type layer

The working principle of the PIN diode exactly same as a normal diode. The main difference is that the depletion region, because that normally exists between both the P & N regions in a reverse biased or unbiased diode is larger. In any PN junction diode, the P region contains holes as it has been doped to make sure that it has a majority of holes. Likewise the N-region has been doped to hold excess electrons.

The layer between the P & N regions includes no charge carriers as any electrons or holes merge. As the depletion region of the diode has no charge carriers it works as an insulator. The depletion region exists within a PIN diode, but if the




PIN diode is forward biased, then the carriers come into the depletion region and as the two carrier types get together, the flow of current will starts.

**PIN Diode Characteristics**

The PIN diode characteristics include the following

This obeys the typical diode equation for small frequency signals. At higher frequencies, PIN diode appears like an approximately perfect resistor. There is a set of stored charge in the intrinsic region. At small frequencies, the charge can be detached and the diode switched OFF.

At higher frequencies, there is not sufficient time to eliminate the charge, so the PIN diode never switched OFF. The diode has a reduced reverse recovery time. A PIN diode properly biased, therefore performs as a variable resistor. This high-frequency resistance may differ over a broad range (from 0.1 Ω-10 kΩ in some cases; the practical range is slighter, though).

The wider intrinsic area also means the PIN diode will have a low capacitance when reverse-biased. In this diode, the depletion region exists completely in the intrinsic region. This depletion region is much better than in a PN-diode, and nearly constant-size, independent of the reverse bias applied to the PN-diode.

This increases the amount where pairs of electron-hole can be produced by an occurrence photon. Some photo detector devices like photo transistors and PIN photodiodes employ a PIN-junction in their construction.

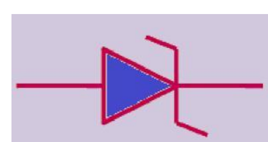
The design of the PIN-diode has some design tradeoffs. Rising the magnitudes of the intrinsic region permits the diode to appear like a resistor at minor frequencies. It harmfully affects the time required to switch off the diode & its shunt capacitance. Therefore, it is essential to choose a device with the most suitable properties for a particular use

**6.What is an Avalanche Diode? Explain its construction and working.**

**Ans:**An avalanche diode is a one kind of semiconductor device specially designed to work in the reverse breakdown region.

The symbol of this diode is same to as Zener diode. The avalanche diode comprises of two terminals namely anode and cathode.

The avalanche diode symbol is alike to the normal diode but with the turn edges of the vertical bar that is shown in the following figure.



**Avalanche Diode Construction**

Generally, avalanche diode is made from silicon or other semiconductor materials. The construction of this diode is similar to the Zener diode, except doping level in this diode changes from Zener diode. These diodes are doped heavily. Thus, the depletion region width in this diode is very slight. Because of this region, reverse breakdown happens at lower voltages in this diode.

On the other hand, avalanche diodes are doped lightly. So, the depletion layer width of an avalanche diode is very large evaluated to the Zener diode. Because of this large depletion region, reverse breakdown take place at higher voltages in the diode. The breakdown voltage of this diode is cautiously located by controlling the doping level in the manufacture.

**Working of an Avalanche Diode**

The main function of the normal diode is to allow electrical current in only one direction i.e., forward direction.

Whereas, avalanche diode allows the current in both the directions. But, this diode is specially designed to work in reverse biased condition when the voltage surpasses the breakdown voltage in the reverse biased condition.

The voltage at which electric current enhances unexpectedly is called breakdown voltage. When the voltage in reverse bias condition applied to this diode then it surpasses the breakdown voltage, a breakdown of the junction will be occurs. This junction breakdown is named
as an avalanche breakdown.

Whenever the forward bias voltage is applied to this diode, then it starts working like a regular p-n junction diode by permitting an electric current through it.

When the reverse biased voltage is applied to the avalanche diode, then the majority charge carriers in the P-type and N-type semiconductors are moved away from the PN- junction. As a result, the depletion region’s width increases.

So, the majority carriers will not allow electric current. Though, the minority charge carriers knowledge a repulsive force from exterior voltage.

As a result, the flow of minority charge carriers from p-type to n-type & n-type to p-type by moving the electric current.

Though, the current moved by minority charge carriers is very little. The small current passed by minority charge carriers is termed as reverse leakage current.

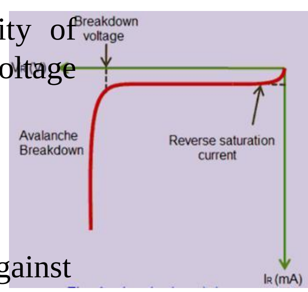
If the reverse bias voltage is applied to this, further the diode is increased, the minority charge carriers will get a large amount of energy and go faster to better velocities.

The free moving electrons at high speed will crash with the atoms then transfers the energy to the valence electrons. The valence electrons which gets sufficient energy from the rapid electrons will be separated from the parent atom & turn into free electrons. Again, these electrons are accelerated. When these free electrons collide with other atoms, they knock off more electrons. Because of this constant collision with the molecules, a huge number of free electrons or holes are produced. These huge number of free electrons hold overload current in the diode.

Whenever the reverse voltage applied to the diode, then it continuously increases. At some end, the avalanche breakdown and junction breakdown occur. At this point, a tiny increase in voltage will rapidly increase the electric current. This unexpected increase of current may lastingly destroy the regular junction diode. Though, avalanche diodes may not be damaged because they are cautiously designed to function in avalanche breakdown region.

Breakdown Voltage of the Diode

The avalanche diode breakdown voltage depends on the density of doping. Rising the density of doping will reduces the breakdown voltage of the diode.




Applications of Avalanche Diode

- The Avalanche diode is used to protect the circuit.
- Designers employ the diode more for protecting the circuit against unwanted voltages.
- These diodes are used as white noise generators.
- Avalanche diodes produce RF noise, they are generally used as noise sources in radio gears.

- Avalanche diodes are used to generate microwave frequency.

**UNIT-V**

# Electromagnetism and Magnetic Properties of materials

- **Electric current** is defined as the rate of flow of electric charge through any cross sectional area of the conductor.
- **Equation of Continuity:**

Integral form

$$\oint \vec{E} \cdot \vec{ds} = -\frac{d\Phi_B}{dt}$$

Differential form

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

- Ampere's law **:** A magnetic field exerts a force on a straight wire that is carrying current. With Ampère's circuital law, the strength of the magnetic field can be determined by:

$$B = \frac{\mu_0 I}{2\pi r}$$

- **Maxwell's Equations**

Integral form in the absence of magnetic or polarizable media:

I. Gauss' law for electricity $$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$$

II. Gauss' law for magnetism $$\oint \vec{B} \cdot d\vec{A} = 0$$

III. Faraday's law of induction $$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

IV. Ampere's law $$\oint \vec{B} \cdot d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int \vec{E} \cdot d\vec{A}$$

- **Dielectricconstant :**defined as the ratio between the permittivity of the medium to the permittivity of the freespace.

- **Polarizability :** It can be defined as induced dipole moment per unit electricfield.
- **Electric Susceptibility:** The polarization proportional to the total electronic flux density E and is in the same direction of E.
- **ElectronicPolarization** : The displacement of the positively charged nucleus and the negative electrons of an atom in opposite directions, on application of electric field, result in electronic polarization.
  $\alpha_e = \varepsilon_0 (\varepsilon_r - 1) / N$ .
- **IonicPolarization** : It is due to the displacement of cations and anions in opposite directions and occurs in an ionic solid.
  $\alpha_i = (e2 / \omega_0) [1/M + 1/m]$
- **OrientationalPolarization** : In the absence of an electric field, this molecule carries a dipole moment, and they tend to align themselves in the direction of applied field.
  $\alpha_0 = Po/NE = \mu^2/3kT$
- Internal field or Local field or Lorentz field : $E_i = E + P / 3 \square_0$
- **Clausius – MosottiRelation : $(\varepsilon_r + 2) / (\varepsilon_r - 1) = N \alpha_e / 3 \varepsilon_0$**
- **Piezoelectricity :** These materials have the property of becoming electrically polarized when mechanical stress is applied.
- **Pyroelectricity:** It is the change in spontaneous polarization when the temperature of specimen is changed.
- **Magnetic dipole**: it is a system consisting of two equal and opposite magnetic poles separated by a finite distance.
- **Magnetic Induction(B) :**It is defined as the number of magnetic lines of force passing perpendicularly through unit area.

  i .e . B = magnetic flux / area .

  Units: Weber /metre$^2$ or Tesla
- **Magnetic Field Intensity(H) :** The magnetic field intensity at any point in the magnetic field is the force experienced by a unit north pole placed at that point.
  Units: Ampere / meter
- **Magnetization** : It is the process of converting a non – magnetic material into a magnetic material. $B = \mu_0 (H + M)$
- **Relation between $\mu_r$ and □:** $\mu_r = 1 + \square$
- **Diamagnetic materials :**Diamagnetic materials are those which experience a repelling force when brought near the pole of a strong magnet.
- **Paramagnetic materials :** Paramagnetic materials are those which experience a feeble attractive force when brought near the pole of a magnet.
- **FerromagneticMaterials :** Ferromagnetic materials are those which experience a very strong

attractive force when brought near the pole of a magnet.

- **Hysteresis curve** : The hysteresis of ferromagnetic materials refers to the lag of magnetization behind the magnetization field.

**Short Answer Questions**

**1. Write four Maxwell's Equations of Electromagnetism.**

I. Gauss' law for electricity $$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$$

II. Gauss' law for magnetism $$\oint \vec{B} \cdot d\vec{A} = 0$$

III. Faraday's law of induction $$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

IV. Ampere's law $$\oint \vec{B} \cdot d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int \vec{E} \cdot d\vec{A}$$

2.What is Faradays laws of electro magnetic induction?
*emf* induced in a circuit equals the rate of change of magnetic flux through the circuit.

3. Define Dielectric constant and polarizability.
The dielectric characteristics are determined by the dielectric constant. The dielectric constant or relative permittivity of a medium is defined as the ratio between the permittivity of the medium to the permittivity of the freespace.

$$\varepsilon_r = \varepsilon_s / \varepsilon_0 = C / C_0$$

When the strength of the electric field E is increased the strength of the induced dipole μ also increases. Thus the induced dipole moment is proportional to the intensity of the electric field.
$\mu = \alpha E$,whereα theconstantofproportionalityiscalledpolarizability. Itcanbedefinedasinduced dipole moment per unit electricfield.

$$\alpha = \mu / E$$

4.Show that $P = \varepsilon_0(\varepsilon_r - 1) E$.
The Electric Flux Density orElectric Displacementat a point in the material is given by,

$$D = \varepsilon_r\varepsilon_0 \, E \text{ -------------(1)}$$

Where, E is electric field strength, $\varepsilon_r$ is relative permittivity of material and $\varepsilon_0$ is permittivity of free space.As polarization measures additional flux density arising from the presence of the material as compared to free space, it has same units as D.

Hence $D = \varepsilon_0 E + P$-----------(2)

Since $D = \varepsilon_0 \varepsilon_r E$

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

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

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

5.What are various types of polarization process ?

Polarization occurs due to several atomic mechanisms. When a specimen is placed in a dc electric field, polarization is due to four types ofprocesses.

They are

1. Electronicpolarization
2. Ionicpolarization
3. Orientation polarizationand
4. Space chargepolarization

6**.**Derive Clausius – Mosotti Relation.

Let us consider the elemental dielectric having cubic structure. Since there are no ions and perment dipoles in these materials, then ionic polarizability $\alpha_i$ and orientationalpolarizability $\alpha_0$ arezero.i.e. $\alpha_i = \alpha_0 = 0$

Hence polarization $P = N \alpha_e E_i$

$= N \alpha_e (E + P / 3\varepsilon_0)$

i.e. $P [1 - N \alpha_e / 3 \varepsilon_0] = N \alpha_e E$

$P = N \alpha_e E / P [1 - N \alpha_e / 3 \varepsilon_0]$ -------------1

$D = P + \varepsilon_0 E$; $P = D - \varepsilon_0 E$

Dividing on both sides by E

$P / E = D / E - \varepsilon_0 = \varepsilon - \varepsilon_0 = \varepsilon_0 \varepsilon_r - \varepsilon_0$

**7.** Define Piezoelectricity.

These materials have the property of becoming electrically polarized when mechanical stress is applied. This property is known as Piezo – electric effect has an inverse .According to inverse piezo electric effect, when an electric stress or voltage is applied, the material becomes strained. The strain is directly proportional to the applied field E. When piezo electric crystals are subjected to compression or tension, opposite kinds of charges are developed at the opposite faces perpendicular to the direction of applied force. The charges produced are proportional to the applied force.

8.Define Magnetic induction and Magnetic field Intensity.

It is defined as the number of magnetic lines of force passing perpendicularly through unit area.

i .e . . B = magnetic flux / area = 0 / A

Units: Weber /metre$^2$ or Tesla.

The magnetic field intensity at any point in the magnetic field is the force experienced by a unit north pole placed at that point.

Units: Ampere / meter

9.Write the relation between B,H and M.

*Relation between B, H and M :* We know,

$$B = \mu H = \mu_0 \mu_r H$$

i.e $B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$

$= \mu_0 H + \mu_0 H ( \mu_r - 1 )$

$= \mu_0 H + \mu_0 M$ where M is magnetization = $H ( \mu_r - 1)$

i.e $B = \mu_0 ( H + M )$----------(2)

The first term on the right side of eqn (2) is due to external field. The second term is due to the magnetization.

Hence $\mu_0 = B/H+M$

***Relation between $\mu_r$ and $\chi$:***

Relative Permeability, $\mu_r = \mu / \mu_0 = (B / H) / ( B / H + M ) = H + M / H = 1 + M / H$

$\mu_r = 1 + \chi$ ---------(3)

10.How are magnetic materials classified.

**Diamagnetic materials**

Diamagnetic materials are those which experience a repelling force when brought near the pole of a strong magnet. In a non-uniform magnetic field they are repelled away from stronger parts of the field.In the absence of an external magnetic field, the net magnetic dipole moment over each atom or molecule of a diamagnetic material is zero.

Ex: Cu, Ag, Au, Bi, Sb, Pb, NaCl, $H_2O$, Zn and rare gases.

**Paramagnetic materials**

Paramagnetic materials are those which experience a feeble attractive force when brought near the pole of a magnet. They are attracted towards the stronger parts of magnetic field. Due to the spin and orbital motion of the electron, the atoms of paramagnetic material possess a net intrinsic permanent moment.Susceptibility $\chi$ is positive and small for these materials. The susceptibility is inversely proportional to the temperature T.

**FerromagneticMaterials**

Ferromagnetic materials are those which experience a very strong attractive force when brought near the pole of a magnet. These materials, apart from getting magnetized parallel to the direction of the applied field, will continue to retain the magnetic property even after the magnetizing field removed. The atoms of ferromagnetic materials also have a net intrinsic magnetic dipole moment which is due to the spin of the electrons.

## Long Answer Questions

1.Derive an expression for Electronic polarization in dielectrics.

The process of producing electric dipoles which are oriented along the field direction is called polarization in dielectrics. Consider an atom placed inside an electric field. The centre of positive charge is displaced along the applied field direction while the centre of negative charge is displaced in the opposite direction .thus a dipole is produced.The displacement of the positively charged nucleus and the negative electrons of an atom in opposite directions, on application of electric field, result in electronic polarization.

Induced dipole moment

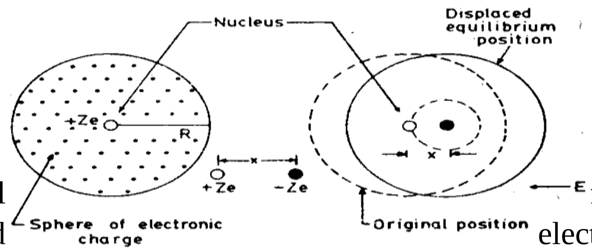
$\mu \propto E$ or $\mu = \alpha_e E$ where $\alpha_e$ is electronicpolarizability.

Electronic polarizability is independent of temperature.

***Derivation:*** Consider the nucleus of charge Ze is surrounded by an electron cloud of charge -Ze distributed in a sphere of radius R.

Charge density $\rho$ is given by

$$\rho = -Ze \ / \ ( {}^{4}/_{3}\pi R^3 ) \ = \ - (3/4) \ (Ze / \pi R^3) \qquad \text{----------(1)}$$




When an external field of intensity E is applied, the nucleus and electrons experiences Lorentz forces in opposite direction. Hence the nucleus and electron cloud are pulled apart. Then Coulomb force develops between them, which tends to oppose the displacement. When Lorentz and coulomb forces are equal and opposite, equilibrium is reached.

Let x be the displacement

Lorentz force = -Ze E ( since = charge x applied field )

Coulomb force = Ze x [charge enclosed in sphere of radius 'x' / $4 \pi\varepsilon_0 x^2$ ] Charge enclosed = $( 4 / 3 ) \pi x^3 \rho$

$= ( 4 / 3 ) \pi x^3 [( - 3 / 4 ) ( Z e / \pi R^3 ) ] = - Z e x^3 / R^3$

Therefore Coulomb force = $( Ze )( - Z e x^3 / R^3 ) / 4 \pi\varepsilon_0 x^2 = - Z^2 e^2 x / 4 \pi\varepsilon_0 R^3$

At equilibrium, Lorentz force = Coulomb force

$-ZeE = - Z^2 e^2 x / 4 \pi\varepsilon_0 R^3$; $E = -Ze\, x / 4 \pi\varepsilon_0 R^3$ or $x = 4 \pi\varepsilon_0 R^3 E / Ze$

Thus displacement of electron cloud is proportional to applied field.

The two charges +Ze and -Ze are separated by a distance 'x' under applied field constituting induced electric dipoles .

Induced dipole moment $\mu_e = Ze\, x$

Therefore $\mu_e = Ze\, (4 \pi\varepsilon_0 R^3 E / Ze ) = 4 \pi\varepsilon_0 R^3 E$

Therefore $\mu_e \propto E$ ; $\mu_e = \alpha_e E$ where $\alpha_e = 4 \pi\varepsilon_0 R^3$ is electronic polarizability

**The dipole moment per unit volume is called electronic polarization. It is independent of temperature.**

$P = N \mu_e = N \alpha_e E$ ; whereN is Number of atoms /$m^3$

$P_e = N (4 \pi \varepsilon_0 R^3 E ) = 4 \pi \varepsilon_0 R^3 N E$; where R is radius of atom

Electric Susceptibility $\chi = P / \varepsilon_0 E$

Therefore $P = \varepsilon_0 E \chi$

$$P = ( 4 \pi R^3 N ) \varepsilon_0 E \qquad \text{where } \chi = 4 \pi R^3 N$$

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

Or $\varepsilon_r - 1 = N \alpha_e / \varepsilon_0$

Hence $\alpha_e = \varepsilon_0 (\varepsilon_r - 1 ) / N$ .

$P = E\,\varepsilon_0(\varepsilon_r - 1)$ ----------------------------2

From eqn. 1 and 2 , we get

$P = E\,\varepsilon_0(\varepsilon_r - 1) = N\,\alpha_e E / [\,1 - N\,\alpha_e / 3\,\varepsilon_0]$ $[\,1 - N\,\alpha_e / 3\,\varepsilon_0] = N\,\alpha_e / \varepsilon_0(\varepsilon_r - 1)$

$1 = N\,\alpha_e / 3\,\varepsilon_0 + N\,\alpha_e / \varepsilon_0(\varepsilon_r - 1)$

$1 = (N\,\alpha_e / 3\,\varepsilon_0)\,(\,1 + 3 / (\varepsilon_r - 1))$

$1 = (N\,\alpha_e / 3\,\varepsilon_0)[\,(\varepsilon_r - 1 + 3) / (\varepsilon_r - 1)\,]$

$1 = (N\,\alpha_e / 3\,\varepsilon_0)[\,(\varepsilon_r + 2) / (\varepsilon_r - 1)\,]$

$(\varepsilon_r + 2) / (\varepsilon_r - 1) = N\,\alpha_e / 3\,\varepsilon_0$, Where N is no of molecules per unit volume.

2.Derive an equation for Ionic polarization.

It is due to the displacement of cations and anions in opposite directions and occurs in an ionic solid.

Consider a NaCl molecule. Suppose an electric field is applied in the positive direction. The positive ion moves by $x_1$ and the negative ion moves by $x_2$

Let M is mass of positive ion, M is mass of negative ion

$x_1$ is displacement of positive ion

$x_2$is displacement of negative ion

Total displacement $x = x_1 + x_2$ --------------(1)

Lorentz force on positive ion = +eE ----------(2) Lorentz force on negative ion = -eE ----------(3) Restoring force on positive ion = $-k_1\ x$--- (2a)

Restoring force on negative ion = $+k_2\ x_2$----------(3 a) where $k_1, k_2$ Restoring force constants

At equilibrium, Lorentz force and restoring force are equal and opposite

For positive ion, $e\,E = k_1 x_1$

For negative ion, $e\,E = k_2\,x_2$ ---------- (4)

Where $k_1 = M\omega_0^2$& $k_2 = m\omega_0$ where $\omega_0$ is angular velocity ofions

Therefore $x = x_1 + x_2 = (\,e\,E / \omega_0^2\,)\ [\,1/M + 1/m\,]$------------(5)

From definition of dipolemoment, μ = charge x distance ofseparation

$$\mu = e\,x = (\,e^2 E / \omega_0^2\,)\ [\,1/M + 1/m]$$ ------------(6)

But $\mu \alpha E$ or $\mu = \alpha_i E$

Therefore $\alpha_i = (e2 / \omega_0\,)\ [1/M + 1/m]$

This is ionic polarizability.

3. What is Internal field or Local field or Lorentz field ?Obtain an expression for it.

Internal field is the total electric field at atomic site.

Internal field $A = E_1 + E_2 + E_3 + E_4$ -------(I)

where $E_1$ is field intensity due to charge density on plates

$E_2$ is charge density induced on two sides ofdielectric

$E_3$ is field intensity due to other atomsin cavityand

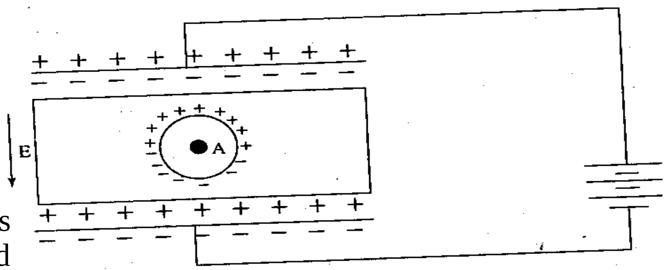
$E_4$ is field intensity due to polarization charges on surface of cavity

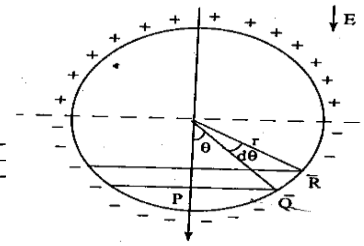
Field $E_1$: $E_1$ is field intensity due to charge density on plates

From the field theory,$E_1 = D / \varepsilon_0$

$$D = P + \varepsilon_0 E$$

Therefore $E_1 = (P + \varepsilon_0 E\,) / \varepsilon_0 = E + P / \varepsilon_0$ ----------(1)






Field $E_2$ : $E_2$ is the field intensity at A due to charge density induced on two sides of dielectric. Therefore $E_2 = -P/\varepsilon_0$ -----------(2)

Field $E_3$ : $E_3$ is field intensity at A due to other atoms contained in the cavity and for a cubic structure,

$E_3=0$ because of symmetry. -----------(3)

Field $E_4$ **:** $E_4$ is field intensity due to polarization charges on surface of cavity and was calculated by Lorentz in the following way:

If 'dA' is the surface area of the sphere of radius $r$ lying between θ and θ + dθwhere θ is the direction with reference to the direction of applied force.

Then $dA = 2\pi (PQ)(QR)$

Butsin$\theta = PQ/r \Longrightarrow PQ = r\sin\theta$

And $d\theta = QR/r \Longrightarrow QR = r\,d\theta$

Hence $dA = 2\pi(r\sin\theta)(rd\theta) = 2\pi r^2 \sin\theta d\theta$

Charge on surface dA isdq = P cosθdA(cosθ isnormalcomponent)$dq = P\cos\theta(2\pi r^2 \sin\theta\, d\theta) = P(2\pi r^2 \sin\theta\cos\theta\, d\theta)$

The field due to the charge dq at A, is denoted by $dE_4$ indirection θ =0

$dE_4 = dq\cos\theta / 4\pi\varepsilon_0 r2 = P(2\pi r^2 \sin\theta\cos\theta\, d\theta)\cos\theta // 4\pi\varepsilon_0 r2$

$dE_4 = P\sin\theta\cos^2\theta\, d\theta / 2\varepsilon_0$

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

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

Let $\cos\theta = x$

$\int dE_4 = P/2\varepsilon_0 \int_0^{\pi} x^2\, dx$

Therefore, $E_4 = P / 2\varepsilon_0 [x^3/3]_0^{\pi}$

$E_4 = -P/2\varepsilon_0[\cos^3\theta/3]_0^{\pi} = -P/6\varepsilon_0[-1-1] = P/3\varepsilon_0$------- (4)

Local field $E_i = E1 + E_2 + E_3 + E_4$

$= E + P/\varepsilon_0 - P/\varepsilon_0 + 0 + P/3\varepsilon_0$

$E_i = E + P/3\varepsilon_0$

3.What are magnetic materials? Classify them.

All matter respond in one way or the other when subjected to the influence of a magnetic field. The response could be strong or weak, but there is none with zero response ie, there is no matter which is non magnetic in the absolute sense. Depending upon the magnitude and sign of response to the applied field, and also on the basis of effect of temperature on the magnetic properties, all materials are classified broadly under 3 categories.

1. Diamagnetic materials 2. Paramagnetic materials, and 3. Ferromagnetic materials

Two more classes of materials have structure very close to ferromagnetic materials but possess quite different magnetic effects. They are i. Anti-ferromagnetic materials and ii . Ferri magneticmaterials.

**Diamagnetic materials**

Diamagnetic materials are those which experience a repelling force when brought near the pole of a strong magnet. In a non-uniform magnetic field they are repelled away from stronger parts of the field.In the absence of an external magnetic field, the net magnetic dipole moment over each atom or molecule of a diamagnetic material is zero.

Ex: Cu, Ag, Au, Bi, Sb, Pb, NaCl, $H_2O$, Zn and rare gases.

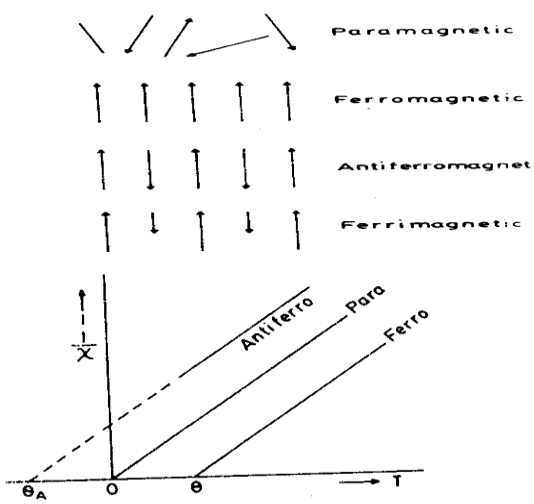
**Paramagnetic materials**

Paramagnetic materials are those which experience a feeble attractive force when brought near the pole of a magnet. They are attracted towards the stronger parts of magnetic field. Due to the spin and orbital motion of the electron, the atoms of paramagnetic material possess a net intrinsic permanent moment.Susceptibility $\chi$ is positive and small for these materials. The susceptibility is inversely proportional to the temperature T.

$\chi \alpha$ 1/T , $\chi$= C/T where C is Curie's constant.

Above the transition temperatures, the materials exhibit the Para magnetism.

Examples: Al, Mn, Pt, Na, $CuCl_2$, $O_2$, crown glass etc.




**FerromagneticMaterials**

Ferromagnetic materials are those which experience a very strong attractive force when brought near the pole of a magnet. These materials, apart from getting magnetized parallel to the direction of the applied field, will continue to retain the magnetic property even after the magnetizing field removed. The atoms of ferromagnetic materials also have a net intrinsic magnetic dipole moment which is due to the spin of the electrons.

Susceptibility is always positive and large and it depends upon temperature.

$\chi$ = C / (T- $\theta$) , $\theta$is Curie's temperature.

Examples: Fe, Ni, Co, MnO.

**Antiferromagnetic materials**

These are the ferromagnetic materials in which equal no of opposite spins with same magnitude such that the orientation of neighboring spins is in antiparallel manner are present.
Susceptibility is small and positive and it is inversely proportional to the temperature.

$$\chi = C/(T+\theta)$$

the temperature at which anti ferromagnetic material converts into paramagnetic material is known as Neel's temperature.
Examples: FeO, $Cr_2O_3$.

**Ferrimagneticmaterials**

These are the ferromagnetic materials in which equal no of opposite spins with different magnitudes such that the orientation of neighboring, spins is in antiparallel manner are present.
Susceptibility positive and large, it is inversely proportional to temperature

$$\chi = C/(T\pm\theta) \qquad T>T_N$$

(Neel'stemperature)Examples : $ZnFe_2O_4$,$CuFe_2O_4$

4.What is Hystersis? Explain in terms of domain theory.

**Hysteresis curve (study of B-H curve):**

The hysteresis of ferromagnetic materials refers to the lag of magnetization behind the magnetization field. when the temperature of the ferromagnetic substance is less than the ferromagnetic Curie temperature ,the substance exhibits hysteresis. The domain concept is well suited to explain the phenomenon of hysteresis. The increase in the value of the resultant magnetic moment of the specimen by the application of the applied field , it attributes to the

1. motion of the domain walls and 2. rotation of domains.

When a weak magnetic field is applied, the domains that are aligned parallel to the field and in the easy direction of magnetization, grow in size at the expense of less favorably oriented ones. This result in Bloch wall movement and when the weak field is removed, the domains reverse back to their original state. This reverse wall displacement is indicated by OA of the magnetization curve. When the field becomes stronger ,the Bloch wall movement continues and it is mostly irreversible movement. This is indicated by the path AB of the graph. The phenomenon of hysteresis is due to this irreversibility.

At the point B all domains have got magnetized along their easy directions. Application of still higher fields rotates the domains into the field direction which may be away from the easy direction. Once the domain rotation is complete the specimen is saturated denoted by C. on removal of the field the specimen tends to attain the original configuration by the movement of Bloch walls. But this movement is hampered by the impurities, lattice imperfections etc, and so more energy must be supplied to overcome the opposing forces. This means that a coercive field is required to reduce the magnetization of the specimen to zero. The amount of energy spent in this regard is a loss. Hysteresis loss is the loss of energy in taking a ferromagnetic body through a complete cycle of magnetization and this loss is represented by the area enclosed by the hysteresisloop.

A hysteresis curve shows the relationship between the magnetic flux density B and applied magnetic field H. It is also referred to as the B-H curve(loop).

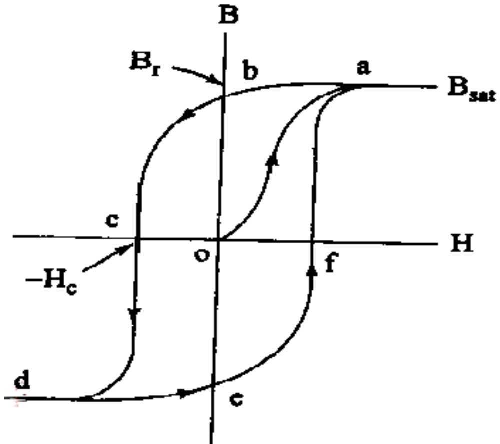
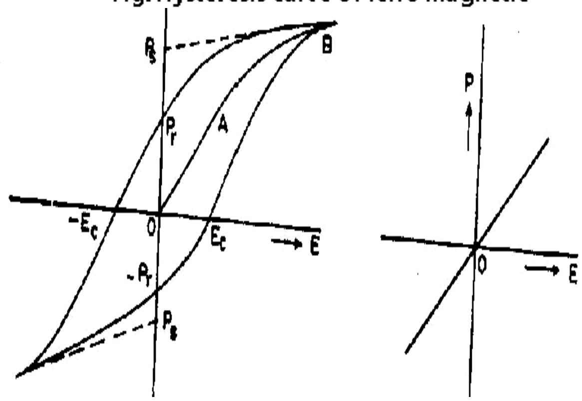


Fig. Hysteresis curve of ferro magnetic

5.What is meant by Ferroelectricity? Explain with an example.

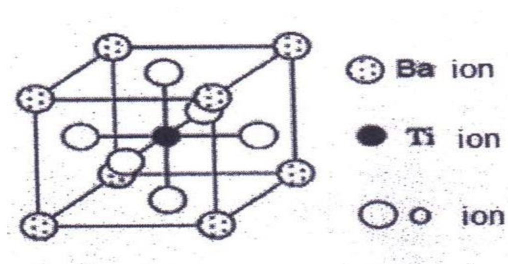
Ferro electric materials are an important group not only because of intrinsic Ferro electric property, but because many possess useful piezo electric, bifringent and electro opticalproperties.

The intrinsic Ferro electric property is the possibility of reversal or change of orientation of the polarization direction by an electric field. This leads to hysteresis in the polarization P, electric field Erelation, similar to magnetic hysteresis. Above a critical temperature, the Curie point $T_c$, the spontaneous polarization is destroyed by thermal disorder. The permittivity shows a characteristic peak at$T_c$..




## $BaTiO_3$Structure

The structural changes in $BaTiO_3$ crystal due to lattice vibration give rise to ferroelectricity. Above curie temperature (approx. $120^0$C), $BaTiO_3$ has a cubic crystal structure with Barium ions are at the corners the titanium ions exactly at the body centre, and Oxygen ions are at the face centers. At those temperatures, there is no spontaneous dipole moment.




When the crystal is cooled below $120^0$C, one axis (axis *c*) stretches and the other axes shrink and turn into a tetragonal crystal structure. In this case, polarization happens as a result of the unit shift of axially elongated Ti-ion crystal. This polarization occurs without applying an external electric field or pressure, and is known as "spontaneous polarization." This characteristic is called ferroelectricity. The displacement of titanium ions create electric dipoles and all the dipoles of the adjacent unit cells get aligned in the same c-direction. Similarly at $5^0$C spontaneous polarization direction corresponds to the face diagonal direction and at -80$^0$C the direction corresponds to a body diagonal. At those temperatures there is an enormous value for dielectric constant.

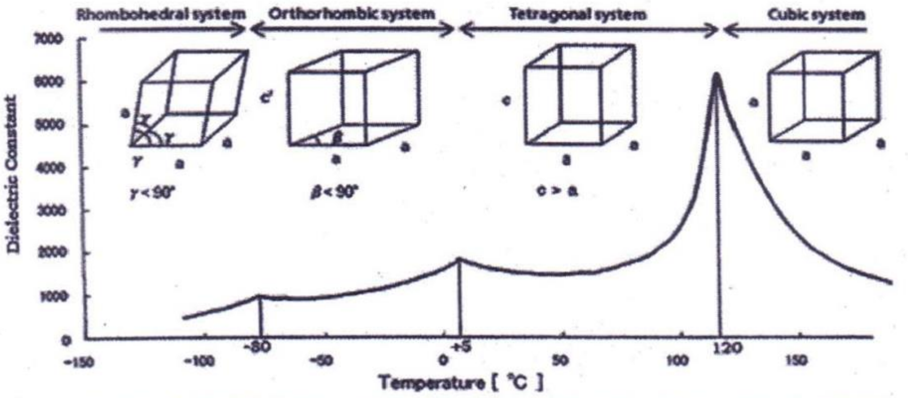



Fig: Crystallographic changes and vatiation of dielctric constant with temperature of $BaTiO_3$