UNIT-1

QUANTUM PHYSICS & SOLIDS

FAILURES OF CLASSICAL MECHANICS:-

It doesn't explain

- The stability of atoms
- Origin of discrete spectra of atoms
- Spectrum of black body radiations
- Photo electric effect, Compton Effect, Zeeman Effect, Raman Effect.

Newton corpuscular theory:

Light consists of minute fast moving elastic particles known as corpuscles.

But it fails to explain interference, diffraction, and polarisation.

Huygens wave theory and Maxwell's electromagnetic theory:

Light travels in the form of waves in hypothetical medium ether.

Successfully explained the phenomenon of interference, diffraction polarisation.

Quantum theory of light by max Planck:

Matter is composed of a large no. of oscillating particles which vibrate with different frequencies.

Energy of oscillating particle is quantised.

$$E = nh\vartheta$$

When they move from one state to another state It emits or absorbs energy.

$$\Delta E = h\vartheta$$

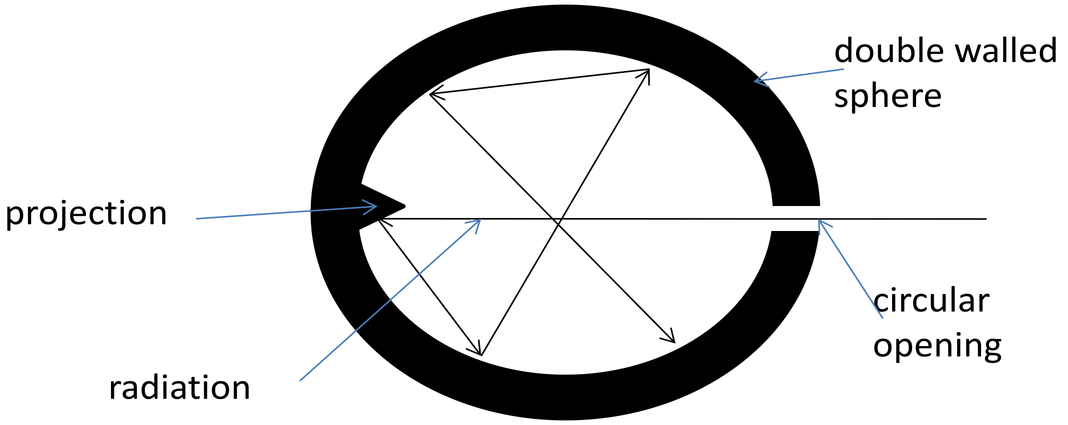
This emission and absorption of energy is not continuous but it takes place in discrete amounts of $h\vartheta$.

Exchange of energy between light and matter is not continuous, but it is small bundles or packets or quanta of definite energy proportional to frequency of light. These small packets of energy are called photons, which propagate with light speed.

BLACK BODY RADIATIONS:

A black body is a body which absorbs the radiations of all wavelengths incident up on it. It neither reflects nor transmits any of the incident radiations and therefore appears black whatever be the colour of radiation. When a black body is heated, it emits radiations which are known as black body radiations. No actual body is a perfect black body. A black body can artificially constructed

Construction: According to Ferry, a black body consists of a hollow thick double walled sphere, painted lamp black internally and provided a small circular opening to enter the radiations. A projection is placed in front of the opening to prevent the direct reflection. When a radiation enters, it suffers many reflections inside the sphere and is finally absorbed.



Stefan's law:

According to Stefan, when a black body is heated to some temperature T, the total energy emitted by it is directly proportional to fourth power of the temperature.

$$E \propto T^4$$

$$E = \sigma T^4$$

Where σ is called stefan's constant.

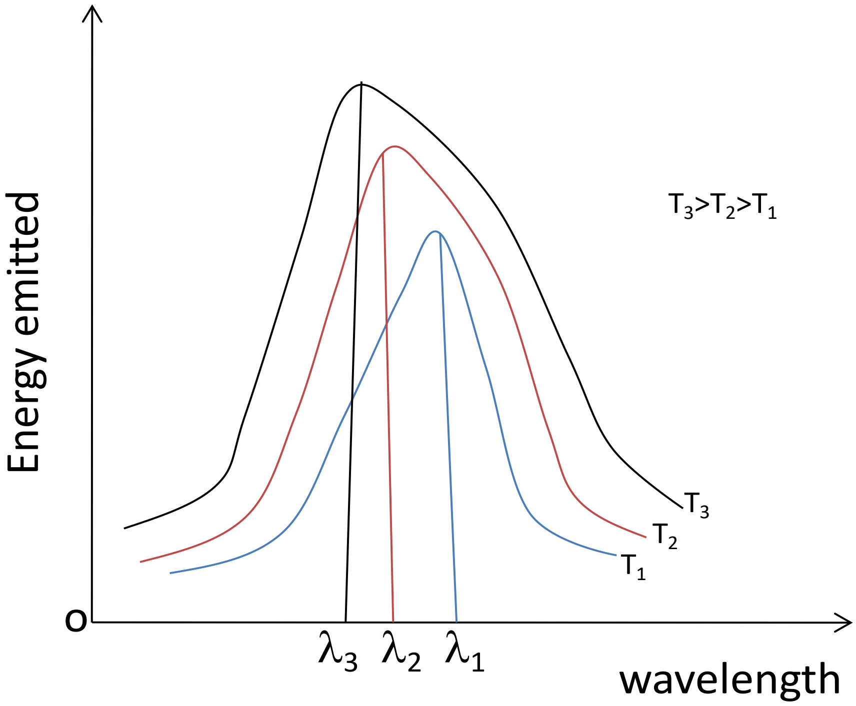
Energy Distribution Curves:

- The distribution of energy in a black body for different wavelengths at different temperatures was experimentally determined by Lumer and Pringshen in 1899. so, according to them,
- The emission from a black body at any temperature is composed of radiation of all wavelengths

- The total energy of radiation at any temperature is given by the area under the curve.
- As the temperature of the black body increases, the intensity of energy of the radiation for each wave length increases.

- The wave length corresponding to the maximum energy shift towards shorter wavelength as the temperature increases. This is called Weins-Displacement Law.

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



PLANCK'S LAW:

Statement:

According to this law, the energy emitted by a black body with in a wavelength range λ to $\lambda+d\lambda$ is given by

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

Proof: According to Planck's hypothesis,

A black body consists of number of oscillators inside the cavity of the black body.

Each oscillator can have discrete set of energies given by,

$$E_n = nh\nu \qquad n = 0,1,2,3, \dots\dots\dots$$

If N is the number of oscillators inside the cavity and E is the total energy. Then, the average energy per oscillator is

$$\bar{E} = \frac{E}{N}$$

Let N_o, N_1 , N_2, N_3, N_4, ……. be the oscillators inside the cavity with energy 0, $h\upsilon$, $2h\upsilon$, $3h\upsilon$, $4h\upsilon$, …… respectively.

Therefore,

$N= N_o+ N_1+N_2+N_3+ N_4+ \dots\dots.$

$E= (0)N_o+(h\upsilon)N_1+(2h\upsilon)N_2+(3h\upsilon)N_3+ (4h\upsilon)N_4+ \dots\dots.$

$E= (h\upsilon)N_1+(2h\upsilon)N_2+(3h\upsilon)N_3+ (4h\upsilon)N_4+ \dots\dots.$

According to Maxwell-Boltzmann distribution law, the number of oscillators having ($rh\upsilon$) energy is given by,

$$N_r = N_0\ exp\left[\frac{-rh\nu}{KT}\right]$$

The total number of oscillators,

$N= N_o+ N_1+N_2+N_3+ N_4+ \dots\dots.$

$$N = N_0\, exp\left[\frac{-0h\nu}{KT}\right] + N_0\, exp\left[\frac{-1h\nu}{KT}\right] + N_0\, exp\left[\frac{-2h\nu}{KT}\right] + N_0\, exp\left[\frac{-3h\nu}{KT}\right] + \ldots\ldots\ldots$$

$$N = N_0 + N_0\, exp\left[\frac{-h\nu}{KT}\right] + N_0\, exp\left[\frac{-2h\nu}{KT}\right] + N_0\, exp\left[\frac{-3h\nu}{KT}\right] + \ldots\ldots\ldots$$

$$N = N_0\left[1 + exp\left[\frac{-h\nu}{KT}\right] + exp\left[\frac{-2h\nu}{KT}\right] + exp\left[\frac{-3h\nu}{KT}\right] + \ldots\ldots\ldots\right]$$

$$N = N_0\left[1 + exp\left[\frac{-h\nu}{KT}\right] + \left[exp\left[\frac{-h\nu}{KT}\right]\right]^2 + \left[exp\left[\frac{-h\nu}{KT}\right]\right]^3 + \ldots\ldots\ldots\right]$$

$$let\ x = exp\left[\frac{-h\nu}{KT}\right]$$

$$N = N_0\,[1 + x + [x]^2 + [x]^3 + \ldots\ldots\ldots]$$

$$N = N_0\,[1 - x]^{-1}$$

$$N = \frac{N_0}{[1 - x]} = \frac{N_0}{\left[1 - exp\left[\frac{-h\nu}{KT}\right]\right]}$$

The total energy is given by

$E= (h\upsilon)N_1+(2h\upsilon)N_2+(3h\upsilon)N_3+ (4h\upsilon)N_4+ \ldots\ldots.$

$$E = \left\{(h\nu)N_0\, exp\left[\frac{-1h\nu}{KT}\right]\right\} + \left\{(2h\nu)N_0\, exp\left[\frac{-2h\nu}{KT}\right]\right\} + \left\{(3h\nu)N_0\, exp\left[\frac{-3h\nu}{KT}\right]\right\} + \cdots\ldots\ldots\ldots..$$

$$E = \left\{(h\nu)N_0\, exp\left[\frac{-1h\nu}{KT}\right]\right\} \times \left[1 + \left\{(2)\, exp\left[\frac{-h\nu}{KT}\right]\right\} + \left\{(3)\, exp\left[\frac{-2h\nu}{KT}\right]\right\} + \cdots\ldots\ldots\ldots..\right]$$

$$let\ x = exp\left[\frac{-h\nu}{KT}\right]$$

$$E = \{(h\nu)N_0\, x\} \times [1 + \{(2)\, x\} + \{(3)\, x^2\} + \{(4)\, x^3\} + \cdots\ldots\ldots\ldots..]$$

$$E = \{(h\nu)N_0\, x\} \times [1 - x]^{-2}$$

$$E = \frac{\{(h\nu)N_0\, x\}}{[1 - x]^2}$$

$$E = \frac{\left\{(h\nu)N_0\, exp\left[\frac{-h\nu}{KT}\right]\right\}}{\left[1 - exp\left[\frac{-h\nu}{KT}\right]\right]^2}$$

Average energy of the oscillator,

$$\bar{E} = \frac{E}{N}$$

$$\bar{E} = \frac{\dfrac{\left\{(h\nu)N_0\, exp\left[\frac{-h\nu}{KT}\right]\right\}}{\left[1 - exp\left[\frac{-h\nu}{KT}\right]\right]^2}}{\dfrac{N_0}{\left[1 - exp\left[\frac{-h\nu}{KT}\right]\right]}}$$

$$\bar{E} = \frac{\left\{(h\nu)\ exp\left[\frac{-h\nu}{KT}\right]\right\}}{\left[1 - exp\left[\frac{-h\nu}{KT}\right]\right]^1}$$

$$\bar{E} = \frac{(h\nu)}{\left[\dfrac{1 - exp\left[\frac{-h\nu}{KT}\right]}{exp\left[\frac{-h\nu}{KT}\right]}\right]^1}$$

$$\bar{E} = \frac{(h\nu)}{\left[\dfrac{1}{exp\left[\frac{-h\nu}{KT}\right]} - \dfrac{exp\left[\frac{-h\nu}{KT}\right]}{exp\left[\frac{-h\nu}{KT}\right]}\right]^1}$$

$$\bar{E} = \frac{(h\nu)}{\left[exp\left[\frac{h\nu}{KT}\right] - 1\right]^1}$$

The number of oscillators per unit volume in a frequency range υ to υ+dυ is,

$$N = \frac{8\pi\vartheta^2}{c^3}\ d\vartheta$$

Therefore the energy per unit volume with in the frequency range υ to υ+dυ is,

$$E_\vartheta d\vartheta = N\bar{E}$$

$$E_\vartheta d\vartheta = \frac{8\pi\vartheta^2}{c^3}\ d\vartheta\ \times \frac{(h\nu)}{\left[exp\left[\frac{h\nu}{KT}\right] - 1\right]^1}$$

$$E_\vartheta d\vartheta = \frac{8\pi h\vartheta^3}{c^3}\ \times \frac{1}{\left[exp\left[\frac{h\nu}{KT}\right] - 1\right]^1}\ d\vartheta$$

This is Planck's law in terms of frequency

We know that

$$\vartheta = \frac{c}{\lambda}\ \&\ E_\vartheta d\vartheta = -E_\lambda d\lambda$$

On differentiation

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

On substitution,

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

$$E_\lambda d\lambda = \left[\frac{8\pi hc}{\lambda^5} \times \frac{1}{\left[exp\left[\frac{hc}{\lambda KT}\right]-1\right]^1}\, d\lambda\right]$$

This is Planck’s law in terms of wavelength

WIEN'S FORMULA:

This formula is applicable on shorter wavelength side of the Planck's law

$$E_\lambda d\lambda = \left[\frac{8\pi hc}{\lambda^5} \times \frac{1}{\left[exp\left[\frac{hc}{\lambda KT}\right]-1\right]^1}\, d\lambda\right]$$

So, when λ is small, $1/\lambda$ is very large

Therefore

$$exp\left[\frac{hc}{\lambda KT}\right] \gg 1$$

Hence 1 can be neglected from the denominator of the Planck's law

$$E_\lambda d\lambda = \left[\frac{8\pi hc}{\lambda^5} \times \frac{1}{exp\left[\frac{hc}{\lambda KT}\right]}\, d\lambda\right]$$

This is called Wien's formula.

RAYLEIGH JEANS FORMULA:

This formula is applicable on longer wavelength side of the Planck's law

$$E_\lambda d\lambda = \left[\frac{8\pi hc}{\lambda^5} \times \frac{1}{\left[exp\left[\frac{hc}{\lambda KT}\right]-1\right]^1}\, d\lambda\right]$$

So, when λ is large, $1/\lambda$ is very small

Then,

$$exp\left[\frac{hc}{\lambda KT}\right] = 1 + \frac{hc}{\lambda KT} + \left[\frac{hc}{\lambda KT}\right]^2 + \left[\frac{hc}{\lambda KT}\right]^3 + \ldots\ldots\ldots$$

$since, \frac{hc}{\lambda KT}$ *is small, higher order terms can be neglected in the above expression*

Hence,

$$exp\left[\frac{hc}{\lambda KT}\right] = 1 + \frac{hc}{\lambda KT}$$

On substitution,

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \times \frac{1}{\left[1 + \frac{hc}{\lambda KT} - 1\right]^1} d\lambda$$

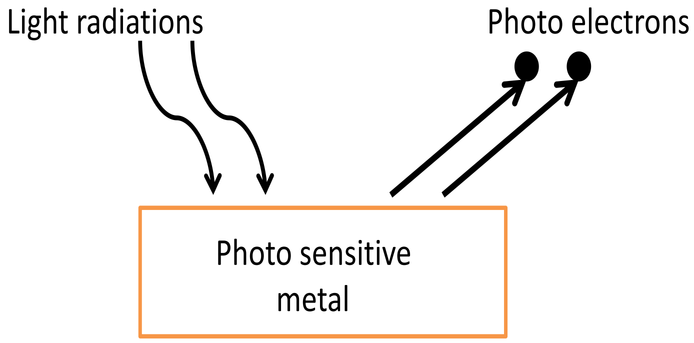
$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \times \frac{1}{\left[\frac{hc}{\lambda KT}\right]^1} d\lambda$$

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

This is called Rayleigh jeans formula

PHOTO ELECTRIC EFFECT:

When a light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface. These photo generated electrons are called photo electrons.

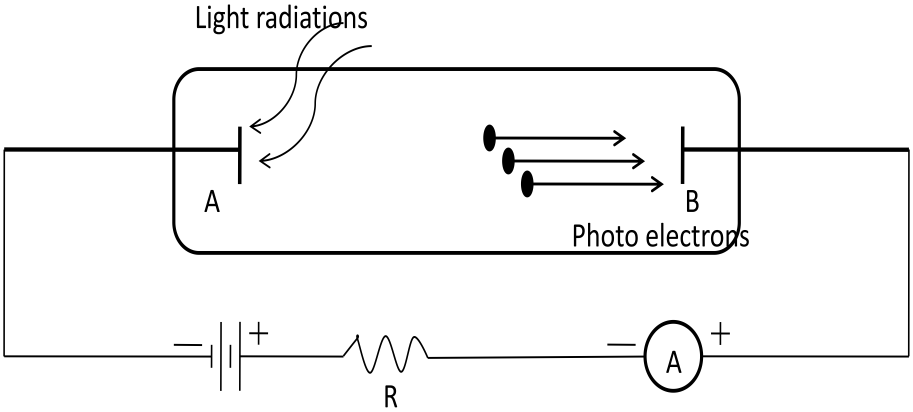


Experimental Verification:

Arrangement consists of

- Two photo sensitive plates A and B enclosed in a quartz bulb. Plate A is connected to negative terminal of battery and plate B is connected to positive terminal of battery through a ammeter and a resistor. Hence, plate A acts like a cathode and plate B acts like a anode.

- When light radiations are made to fall on plate A, the photo electrons are emitted by it and are attracted by the anode (plate B). Hence there is a flow of current in the circuit called as photo electric current.

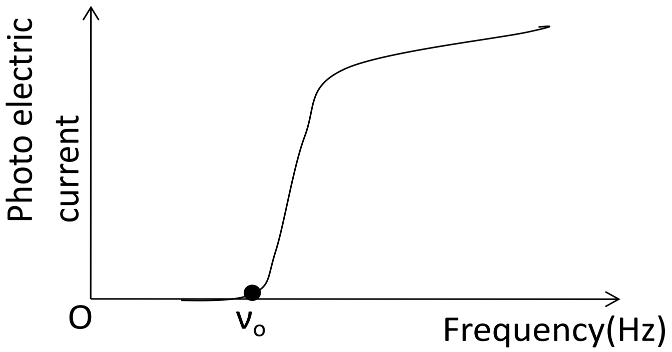


- This photo electric current is a function of
  - Incident light radiation frequency
  - Intensity of incident light radiation
  - Voltage potential across the plates
- Plate A is the metallic surface in which electrons requires a minimum energy to escape out from the metal surface. This minimum energy is called as work function.

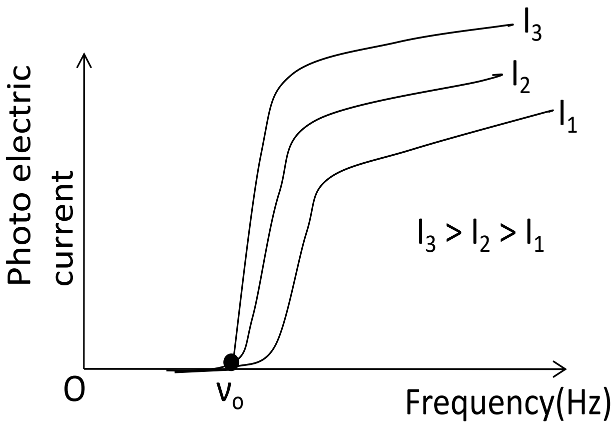
$$\Phi = h\,\nu_o$$

VARIATION OF PHOTO ELECTRIC CURRENT

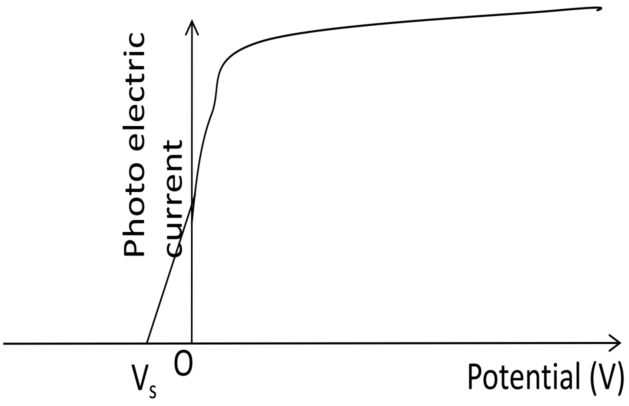
With frequency of incident radiation: Keeping intensity of incident radiation and applied potential as constant, if the frequency of the incident radiation increases, then up to certain frequency called threshold frequency (ν_o), the photo current is zero and after that varies as shown



With intensity of incident radiation: Keeping applied potential as constant, if the intensity of the incident radiation increases, then the photo current also increases. But the threshold frequency remains constant for a given material even the intensity increases



- With applied potential: Keeping intensity and frequency of radiation as constant, if the applied potential increases, then the photo current also increases and becomes steady. Even if the applied potential is zero, there will be certain current in the circuit due to constant incident radiations. To make this current as zero if the reverse potential is increased, current decreases and becomes zero at a potential called as stopping potential



Einstein photo electric equation:

According to Einstein, when light of energy (hν) is incident on a metal surface, a part of incident energy ($h\nu_o$) is utilized to remove electron from the material and remaining energy ($h\nu-h\nu_o$) is appeared as kinetic energy of the electron. There fore

$$(h\nu-h\nu_o)=K.E$$

$$(h\nu-h\nu_o)=1/2\ m\ v^2$$

The above equation is called as Einstein photo electric equation. Where $\varphi=h\nu_o$ is called as work function.

WAVES AND PARTICLES:

Wave is a disturbance that propagates through space and time, usually with transference of energy. Wave's travel and transfer energy from one point to another, often with little or no permanent displacement of the particles of the medium. it is specified by its frequency, wave length, phase or wave velocity, amplitude and intensity.

A particle has mass and it is located at some definite point. The particle is specified by its mass, velocity, momentum, energy. A subatomic particle is an elementary or composite particle smaller than an atom. Particle physics and nuclear physics are concerned with the study of these particles.

MATTER WAVES:-

In 1924, Louis de- Broglie suggested that matter has dual nature. Matter might exhibit wave like properties under approximate conditions.

Louis debroglie led to the concept of matter waves by considering the following.

- Since radiations has been shown to possess dual nature. Matter must also possess dual nature.
- Radiation is supplemented with particle characteristics to explain optical phenomenon, such as photo electric effect.

On similar lines material particles have to be supplemented with a wave aspect for understanding their behaviour. Based on the above concepts, debroglie made a bold suggestion in his doctorate thesis and presented the new idea of matter waves. For this he was honoured with the award of noble prize in 1929.

DE-BROGLIE HYPOTHESIS:

In 1924, de-Broglie extended dual nature to material particles or micro particles like electrons, protons, neutrons etc. according to his hypothesis, when particles are accelerated then they will spread like a wave with a certain wave length.

He gave simple mathematical equations to support his hypothesis as follows:

The dual nature of matter was explained by combining Planck's equation for energy of a photon,

$$E= h\vartheta$$

And Einstein's mass and energy relation $E = mc^2$

$$mc^2 = h\vartheta$$

We know that velocity of light, $c = \vartheta\lambda$

Therefore, $h\frac{c}{\lambda} = mc^2$

$$\lambda = \frac{h}{mc} = \frac{h}{P}$$

The above equation indicates that a photon is associated with a momentum 'P'.

Consider a particle of mass m, moving with a velocity v is associated with a wave called matter wave of wavelengthλ, given by

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

This is known as de-Broglie wave length.

If E is the kinetic energy of the material particle, then

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

$$= \frac{(mv)^2}{2m}$$

$$= \frac{(P)^2}{2m}$$

Therefore, $P = \sqrt{2mE}$

Hence, de-Broglie wavelength,

$$\lambda = \frac{h}{P} = \frac{h}{\sqrt{2mE}}$$

deBroglie wavelength associated with electrons:

Let us consider the case of electrons of rest mass m_0 and charge ‘e’ being accelerated by potential ‘V’ volts.

$$\frac{1}{2}m_0v^2 = eV$$

$$v = \sqrt{\frac{2eV}{m_0}}$$

Therefore, debroglie wavelength

$$\lambda = \frac{h}{m_0 v} = \frac{h}{m_0\sqrt{\frac{2eV}{m_0}}}$$

$$\lambda = \frac{h}{\sqrt{2em_0V}} = \frac{12.26}{\sqrt{V}}A^0$$

CHARACTERISTICS OF MATTER WAVES:

Since,

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

- Lighter the particle, greater is the wavelength associated with it.

- Lesser the velocity of particle, longer the wavelength associated with it.
- For υ=0,λ =∝. This means that only with moving particles matter waves are associated.
- Whether the particle is charged or not, matter wave is associated with it.
- Matter waves can travel faster than light.

$$w = \frac{c^2}{v} = \left(\frac{1}{v}\right)c^2$$

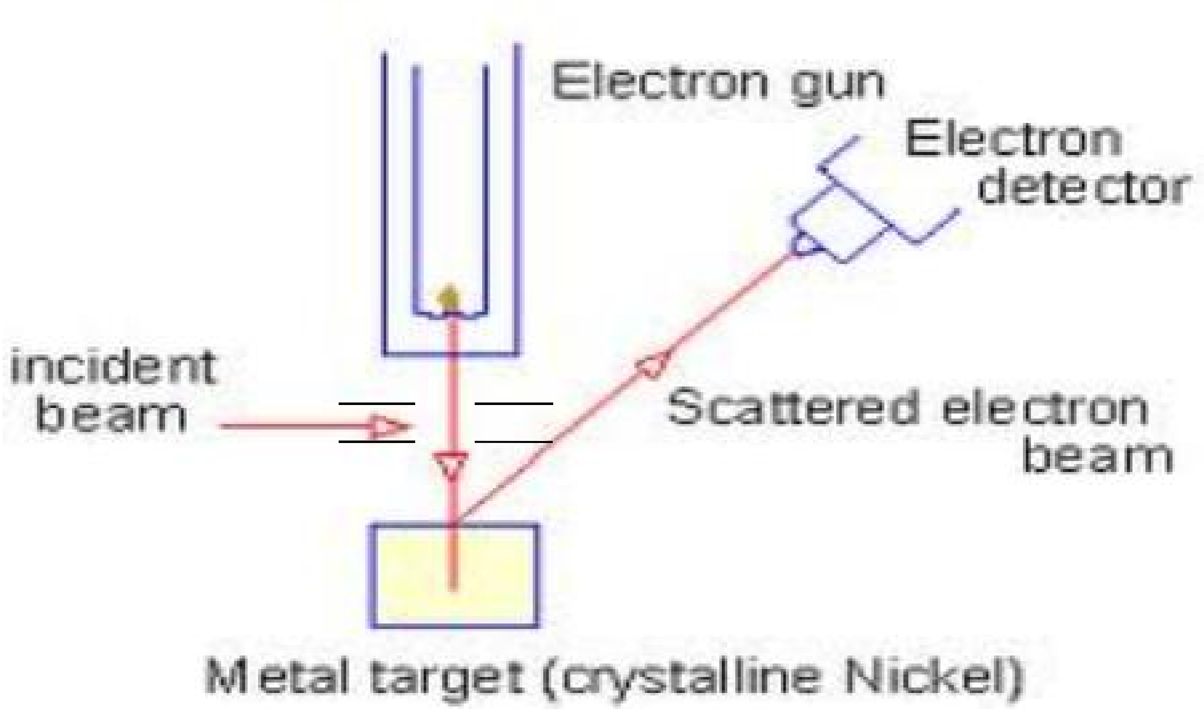
- Particle and wave nature cannot be exhibited simultaneously.

EXPERIMENTAL STUDY OF MATTER WAVES:-

In 1927, Davisson and germer in the United States and in 1928 Thomson proved experimentally the existence of matter waves. They demonstrated that streams of electrons are diffracted when they are scattered from crystals. Also, stern and others showed the existence of matter waves in connection with molecular and atomic beams.

GERMER-DAVISSON EXPERIMENT:

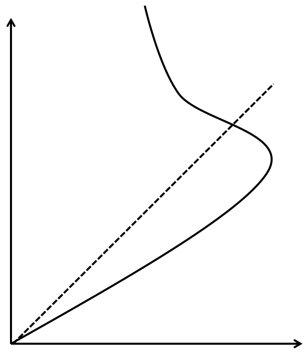
Experimental arrangement:



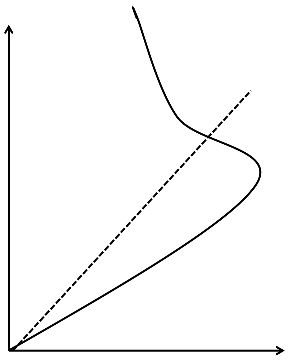
The experimental arrangement consists of an electron gun G where the electrons are produced and obtained in a fine beam by passing them through slits $s_1$and s_2. The beam of electrons is directed to fall on a large single crystal nickel, known as target T. the electrons acting the waves, are diffracted in different directions. The angular distribution is measured by an ionisation chamber ‘c’ which is connected to galvanometer. The chamber can moves on a circular graduated scale ‘s’ between 29 to 90 degrees to receive the reflected electrons. A retarding potential is maintained in the chamber so that only fast moving electrons coming from electron gun may enter inside it.

The secondary electrons (slow electrons) produced by collisions with atoms from nickel target are reflected by ionisation chamber. In this way the galvanometer deflection is only due to electrons coming from electron gun.

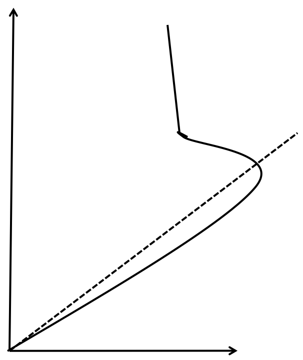
For a particular accelerating potential ‘V’, the ionisation chamber is moved to various positions on the scale s and galvanometer current is noted for each position. A graph is then plotted between galvanometer current against angle Ɵ between incident beam and beam entering the cylinder. The observations are repeated for different accelerating potentials.



44V



54V



60V

It is observed that a bump begins to appear in the curve for 44 V electrons.

- ✓ With increasing potential, the bump moves upwards.
- ✓ The bump becomes most prominent in the curve for 54 V electrons at Ɵ=50
- ✓ At higher potentials, the bumps gradually disappear.

According to de-Broglie, the wavelength associated with electron accelerated through a potential V is given by

$$\lambda = \frac{12.26}{\sqrt{V}} A^0$$

For V=54 V,

$$\lambda = \frac{12.26}{\sqrt{54}} A^0$$

$$\lambda = 1.67\ A^0$$

From X-ray analysis, for nickel crystal d=$0.1A^0$. According to experiment, θ=50. Corresponding angle of incidence relative to the Bragg plane is

$$\theta' = \frac{180-50}{2} = 65^0$$

Therefore, for n=1$\lambda = 2d\ \sin\theta = 1.69\ A^0$

This is the good agreement with the wavelength from de-Broglie hypothesis. Since two values are coincided, hence confirms the de-Broglie concept of matter waves.

SCHRODINGER WAVE EQUATION:

Schrodinger in 1926 developed a wave equation for the moving particles. If a particle of mass 'm' moving with a velocity v is associated with a group of waves.

Let φ be the wave function of the particle

$$\varphi = \varphi_o \sin(\omega t - Kx) \ldots\ldots.(1)$$

where K=$\frac{2\pi}{\lambda}$

Differentiating twice the eq. (1)

$$\frac{\partial^2\varphi}{\partial x^2} = -K^2\varphi_o \sin(\omega t - Kx) = -K^2\varphi \ldots\ldots\ldots\ldots\ldots(2)$$

$$\frac{\partial^2\varphi}{\partial x^2} + K^2\varphi = 0$$

$$\frac{\partial^2\varphi}{\partial x^2} + \frac{4\pi^2}{\lambda^2}\varphi = 0 \ldots\ldots\ldots.(3)$$

From de-Broglie wavelength, $\lambda = \frac{h}{mv} \ldots\ldots\ldots.(4)$

From (3) & (4),

$$\frac{\partial^2\varphi}{\partial x^2} + \frac{4\pi^2 m^2 v^2}{h^2}\varphi = 0 \ldots\ldots\ldots(5)$$

If E is total energy and K & V are kinetic and potential energies then

$$E = K + V$$

$$K = E - V$$

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

$$m^2v^2 = 2m(E - V)\text{……….}(6)$$

From (5) & (6)

$$\frac{\partial^2\varphi}{\partial x^2} + \frac{4\pi^2}{h^2}2m(E - V)\varphi = 0$$

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

Since, $\hbar = \frac{h}{2\pi}$. The above equation becomes,

$$\frac{\partial^2\varphi}{\partial x^2} + \frac{2}{\hbar^2}m(E - V)\varphi = 0\text{………}(7)$$

This is the Schrodinger wave equation in 1-D.

For 3-D,

$$\frac{\partial^2\varphi}{\partial x^2} + \frac{\partial^2\varphi}{\partial y^2} + \frac{\partial^2\varphi}{\partial z^2} + \frac{8\pi^2}{h^2}m(E - V)\varphi = 0\text{……….}(8)$$

Using laplacian operator, $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$

From (8)

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

This is the Schrodinger wave equation.

Since time factor doesn't appear in the above equation this is called Schrodinger time independent equation.

PHYSICAL SIGNIFICANCE OFφ:-

The wave function φ has no direct physical meaning. To explain the relation of particle to wave packet Max Born proposed the physical significance of φ. According to Born $\varphi\varphi^* = |\varphi|^2$ gives the probability of finding the particle in the stateφ. That is φ^2 is a measure of probability density. For the total probability of finding the particle somewhere is

$$\iiint |\varphi|^2 dx\, dy\, dz = 1.$$

φ Satisfying above requirements is said to be normalised.

Besides normalisation, the wave function φ must fulfil the following requirements.

- It must be finite everywhere.

  If it is infinite at a particular point, then pbb. of finding the particle at that point is infinitely large. This is not possible. Hence, φ must be finite or zero value at any point.

- It must be single valued:
  If it is multi valued then finding a particle at a point will have more value. It is not possible.

- It must be continuous:
  For Schrodinger equation $\frac{\partial^2\varphi}{\partial x^2}$ must be finite everywhere. This is possible only when $\frac{\partial\varphi}{\partial x}$ is continuous. Which means that φ is continuous.

PARTICLE IN ONE DIMENSIONAL POTENTIAL BOX:-

Consider a particle of mass 'm' moving along X-axis between the two rigid walls A and B at x=0 and x=a. the particle is free to move between the walls. The potential energy is constant between the walls because no force is acting on the particle.

Since the particle strikes the walls and get reflected back. So, the force acting on the particle abruptly changes from zero to a finite value F with in a distance of zero at the wall. We know that $|F| = \frac{\partial V}{\partial x}$. Therefore, $\Delta V \rightarrow 0 \; as \; \Delta x \rightarrow \propto \; such \; that \; \frac{\partial V}{\partial x}$ has a finite value.

So, potential energy of particle becomes infinite at the walls. Therefore,

$$V(x) = \propto \qquad for\; x < 0 \;\; and\; x > a$$

$$V(x) = 0 \qquad for\; 0 \leq x \leq a$$

The Schrodinger wave equation for particle is given by

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

As V=0 between the walls,

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{8\pi^2}{h^2}m(E)\varphi=0$$

Let $\frac{8\pi^2}{h^2}m(E)=K^2$. Therefore,

$$\frac{\partial^2\varphi}{\partial x^2}+K^2\varphi=0$$

The solution of above equation is

$$\varphi(x)=A\sin Kx+B\cos Kx$$

Where A & B are constants, which are obtained by applying the boundary conditions.

$$\varphi=0\ at\ x=0,x=a$$

- $\varphi=0\ at\ x=0$

$$0=A\sin 0+B\cos 0$$
$$\rightarrow B=0$$
$$\varphi(x)=A\sin Kx$$

- $\varphi=0\ at\ x=a$

$$0=A\sin Ka$$

Either A=0 or $\sin Ka=0\ but\ A\neq 0$

Because if A=0, the entire function will be zero as B=0.

Therefore, $\sin Ka=0$

Ka=nπ

K=$\frac{\mathrm{n}\pi}{a}$

Therefore wave function becomes,

$$\varphi(x)=A\sin\frac{\mathrm{n}\pi}{a}x$$

We know that

$$K^2=\left(\frac{\mathrm{n}\pi}{a}\right)^2\ \&\ \frac{8\pi^2}{h^2}m(E)=K^2.$$

Therefore,

$$\left(\frac{\mathrm{n}\pi}{a}\right)^2=\frac{8\pi^2}{h^2}m(E)$$

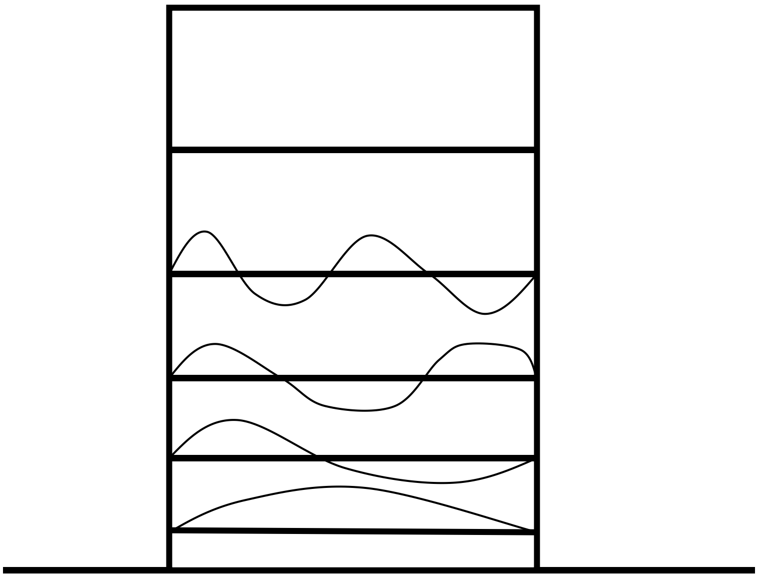
$$E_n=\frac{n^2h^2}{8ma^2}$$

From the above equation it is clear that the particle can have only discrete set of values of energy. That is energy is quantised.

$$E_1 = \frac{h^2}{8ma^2}, for\, n = 1$$

$$E_2 = \frac{4h^2}{8ma^2}, for\, n = 2$$

The energy levels are shown below



The value of A can be obtained by applying normalisation condition given in below equation

$$\iiint |\varphi|^2 dx\, dy\, dz = 1.$$

Since the particle is inside the box of length ‘a’, the pbb. of finding the particle inside the box is unity.

$$\int_0^a |\varphi|^2 dx = 1$$

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

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

$$\frac{A^2}{2}\left[x - \frac{a}{2n\pi}\sin\frac{2n\pi x}{a}\right] = 1$$

$$\frac{A^2a}{2} - 0 = 1$$

$$A = \sqrt{\frac{2}{a}}$$

The normalised wave function is

$$\varphi_n(x) = \sqrt{\frac{2}{a}} \sin\frac{\mathrm{n}\pi}{a}x$$

The wave function φ_n and corresponding energiesE_n, which are often called eigen function and Eigen values respectively.

The Eigen function in 3-d potential well is

$$\varphi_n = \left(\frac{8}{L^3}\right)^{1/2} \sin K_1x \ \sin K_2y \ \sin K_3z$$

$$\text{Where} K_1 = \frac{n_1\pi}{a}, K_2 = \frac{n_2\pi}{a}, K_3 = \frac{n_3\pi}{a}$$

And Eigen value is

$$E_n = \frac{n^2h^2}{8ma^2}$$

Where, $n^2 = {n_1}^2 + {n_2}^2 + {n_3}^2$

Where three integers n_1, n_2, n_3 are called quantum numbers. $n_1, n_2, n_3$are never be zero, since φ is not zero.

HEISENBERG UNCERTAINTY PRINCIPLE:

Heisenberg proposed this principle in the year 1927, which is a direct consequence of dual nature of matter.

In classical mechanics, moving particle at any instant has fixed position in space and a definite momentum which can be determined if the initial values are known.

In wave mechanics, particle is described in terms of wave packets. If wave packet is small, position of particle is fixed but particle will spread rapidly. If wave packet is large, the velocity can be fixed but there is large indefiniteness in position. In this way the certainty in position involves uncertainty in momentum or vice versa. Hence we can measure either the position or the momentum of a particle with any desired degree of accuracy.

According to Heisenberg uncertainty principle, “it is impossible to measure both the position and momentum of a particle simultaneously to any desired degree of accuracy”.

$$\Delta p \,.\, \Delta x \approx h$$

Where, Δp is uncertainty in momentum

Δx Is uncertainty in position.

Similarly,

$$\Delta E \,.\, \Delta t \approx h$$

$$\Delta j \,.\, \Delta \theta \approx h$$

Principle: the product of uncertainties in determining the position and momentum of the particle can never be smaller than the order of $\frac{\hbar}{2}$

So, $$\Delta x . \Delta p \geq \frac{\hbar}{2}$$

$$\Delta E \,.\, \Delta t \geq \frac{\hbar}{2}$$

$$\Delta j \,.\, \Delta \theta \geq \hbar/2$$

Consequences:

1. Non- existence of electrons in nucleus:
2. Proof for existence of protons and neutrons in nuclei:
3. Uncertainty in the frequency of light emitted by an atom:

SOLIDS

FREE ELECTRON THEORY

In solids, electrons in outer most orbits of atoms determine its electrical properties. Electron theory is applicable to all solids, both metals and non metals. In addition, it explains the electrical, thermal and magnetic properties of solids. The structure and properties of solids are explained employing their electronic structure by the electron theory of solids.

It has been developed in three main stages:

1. Classical free
electron theory 2.
Quantum Free Electron
Theory.

3. Zone Theory.

Classical free electron theory: The first theory was developed by Drude & Lorentz in 1900. According to this theory, metal contains free electrons which are responsible for the electrical conductivity and metals obey the laws of classical mechanics.

Quantum Free Electron Theory: In 1928 Sommerfield developed the quantum free electron theory. According to Sommerfield, the free electrons move with a constant potential. This theory obeys quantum laws.

Zone Theory: Bloch introduced the band theory in 1928. According to this theory, free electrons move in a periodic potential provided by the lattice. This theory is also called “Band Theory of Solids”. It gives complete informational study of electrons.

Classical free electron theory:

Even though the classical free electron theory is the first theory developed to explain the electrical conduction of metals, it has many practical applications. The advantages and disadvantages of the classical free electron theory are as follows:

Advantages:

1. It explains the electrical conductivity and thermal conductivity of metals.
2. It verifies ohm’s law.

3. It is used to explain the optical properties of metals.
4. Metal composed of atoms in which electrons revolve around the nucleus are many states available for occupation. If the density of states is zero, no states can be occupied at that energy level.
5. The valence electrons are freely moving about the whole volume of the metals like the molecules of perfect gas in a container
6. The free electrons moves in random directions and collide with either positive ions or other free electrons. Collision is independent of charges and is elastic in nature 7. The movements of free electrons obey the laws of classical kinetic theory of gases
8. Potential field remains constant throughout the lattice.
9. In metals, there are large numbers of free electrons moving freely within the metal i.e. the free electrons or valence electrons are free to move in the metal like gaseous molecules, because nuclei occupy only 15% metal space and the remaining 85% space is available for the electrons to move

Drawbacks:

1. It fails to explain the electric specific heat and the specific heat capacity of metals.
2. It fails to explain superconducting properties of metals.
3. It fails to explain new phenomena like photoelectric effect, Compton effect, black – Body radiation, etc.
4. It fails to explain Electrical conductivity (perfectly) of semiconductors or insulators.
5. The classical free electron model predicts the incorrect temperature dependence of
6. It fails to give a correct mathematical expression for thermal conductivity.
7. Ferromagnetism couldn’t be explained by this theory.
8. Susceptibility has greater theoretical value than the experimental value.

Quantum free electron theory:

Advantages:

1. All the electrons are not present in the ground state at 0 K, but the distribution obeys Pauli's exclusion principle. At 0 K, the highest energy level filled is called Fermi- level. 2. The potential remains constant throughout the lattice.

3. Collision of electrons with positive ion cores or other free electrons is independent of charges and is elastic in nature. Energy levels are discrete.
4. It was successful to explain not only conductivity, but also thermionic emission paramagnetism, specific heat.

Drawbacks:

1. It fails to explain classification of solids as conductors, semiconductors and insulators.

Fermi – Dirac Statistics:

1) The particles which obey F –D statistics are called fermions.
2) Fermions are identical and indistinguishable
3) There cannot be more than one particle in a single cell in phase space i.e they obey Pauli's exclusion principle.
4) Fermions have integral spin
5) Wave function representing fermions are antisymmetric ie $\varphi(1,2) = -\varphi(2,1)$
6) Weak interaction exists between particles
7) Uncertainity principle is applicable.
8) Energy states are discrete.
9) The Fermi Dirac distribution function f(D), is the probability that a fermions occupies a state of energy E and is given by

$$f_{FD} \quad \frac{1}{\exp \quad \frac{E-}{kt} \quad 1}$$

α is constant and is dependent on temperature α = -EF/kT

PERIODIC POTENTIAL AND BLOCH THEOREM:

According to free electron model, a conduction electron in metal experiences constant potential. But in real crystal, there exists a periodic arrangement of positively charged ions through which the electrons move. As a consequence, the potential experienced by electrons is not constant but it varies with the periodicity of the lattice. In zone theory, as per Bloch, potential energy of electrons considered as varying potential with respect to lattice ‘a’.

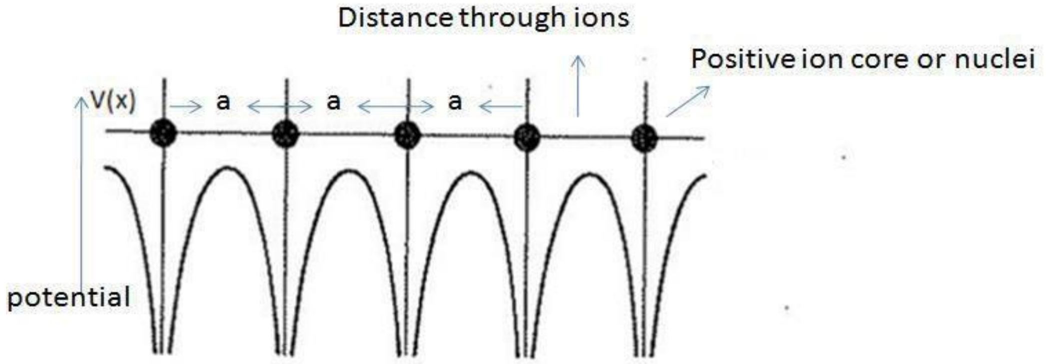
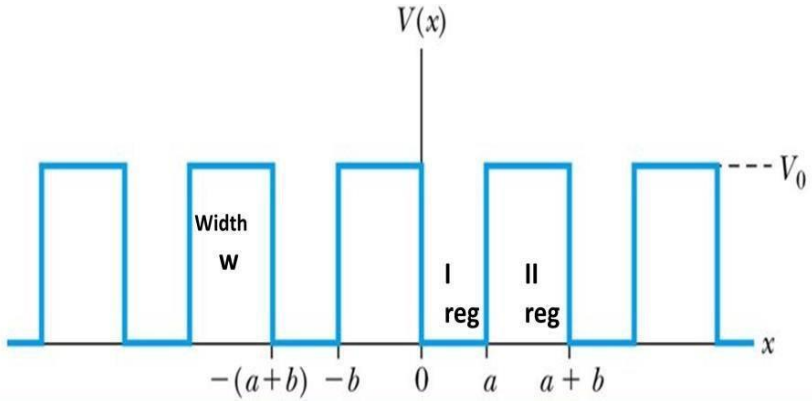


Fig: Variation of potential energy in a periodic lattice

KRONIG -PENNEY MODEL:

According to this theory, the electrons move in a periodic potential produced by the positive ion cores. The potential of electron varies periodically with periodicity of ion core and potential energy of the electrons is zero near nucleus of the positive ion core. It is maximum when it is lying between the adjacent nuclei which are separated by inter-atomic spacing. The variation of potential of electrons while it is moving through ion core is shown fig.



V (x) = { 0 , for the region $0 < x < a$

{ V_0 for the region $-b < x < a$ ---------------------(1)

Applying the time independent Schrödinger's wave equation for above two regions

$d^2\Psi / dx^2 + 2 m E \Psi / \hbar^2 = 0$ for region $0 < x < a$

-----------(2) and $d^2\Psi / dx^2 + 2 m (E - V) \Psi / \hbar^2 = 0$

for region $-b < x < a$ -----------(3)

Substituting $\alpha^2 = 2 m E / \hbar^2$ ---------------(4)

$\beta^2 = 2 m (E - V) / \hbar^2$ -----------(5) $d^2\Psi /$

$dx^2 + \alpha^2 \Psi = 0$ for region $0 < x < a$ -----------(6)

$d^2\Psi / dx^2 + \beta^2 \Psi = 0$ for region $-b < x < a$ ------

-----(7)

The solution for the eqn.s (6) and (7) can be written as

$\Psi(x) = U_k(x) e^{ikx}$ ------------------(8)

The above solution consists of a plane wave e^{ikx} modulated by the periodic function.

$U_k(x)$, where this $U_k(x)$ has the periodicity of the

ion such that $U_k(x) = U_k(x+a)$ ---------

---------(9)

and where k is propagating vector along x-direction and is given by $k = 2 \Pi / \lambda$. This k is also known as wave vector.

Differentiating equation (8) twice with respect to x, and substituting in equation (6) and (7), two independent second order linear differential equations can be obtained for the regions $0 < x < a$ and $-b < x < 0$.

Applying the boundary conditions to the solution of above equations, for linear equations in terms of A,B,C and D it can be obtained (where A,B,C,D are constants) the solution for these equations can be determined only if the determinant of the coefficients of A , B , C , and D vanishes, on solving the determinant.

$(\beta^2 - \alpha^2 / 2 \alpha \beta)\sin h\beta b \sin \alpha a + \cos h\beta b \cos \alpha a = \cos k (a + b)$ ---------- ---- (10)

The above equation is complicated and Kronig and Penney could conclude with the equation. Hence they tried to modify this equation as follows

Let V_o is tending to infinite and b is approaching to zero. Such that $V_o b$ remains finite. Therefore $\sin h\beta b \rightarrow \beta b$ and $\cos h\beta b \rightarrow 1$

$$\beta^2 - \alpha^2 = (2m/\hbar^2)(V_o - E) - (2mE/\hbar^2)$$

$$= (2m/\hbar^2)(V_o - E - E) = (2m/\hbar^2)(V_o - 2E)$$

$$= 2mV_o/\hbar^2 \quad (\text{since } V_o >> E)$$

Substituting all these values in equation (10) it verities as

$$(2mV_o / 2\hbar^2 \alpha\beta)\,\beta b \,.\, \sin \alpha a + \cos \alpha a == \cos ka$$

$$(m V_o b a/\hbar^2)\,(\sin \alpha a / \alpha a) + \cos \alpha a == \cos ka$$

$$(P/\alpha a) \sin \alpha a + \cos \alpha a == \cos ka \quad \text{-------------------(11)}$$

Where $P = [\, m V_o b a / \hbar^2 \,]$ ------------------(12) and is a measure of potential

barrier strength.

The left hand side of the equation (11) is plotted as a function of α for the value of P = 3 Π / 2 which is shown in fig, the right hand side one takes values between -1 to +1 as indicated by the horizontal lines in fig. Therefore the equation (11) is satisfied only for those values of ka for which left hand side between ± 1.

From fig , the following conclusions are drawn.

1) The energy spectrum of the electron consists of a number of allowed and forbidden energy bands.

2) The width of the allowed energy band increases with increase of energy values ie increasing the values of αa. This is because the first term of equation(11) decreases with increase of αa.

$$(P/\alpha a) \sin \alpha a + \cos \alpha a ==$$

3 Π / 2

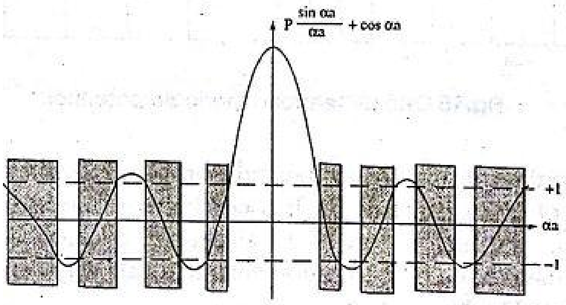


Fig. 16 Plot of $P\frac{\sin \alpha a}{\alpha a} + \cos \alpha a$ versus αa.

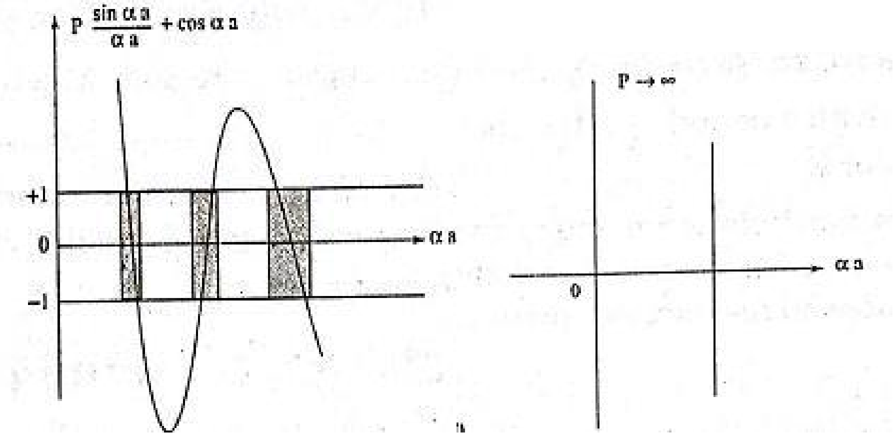


Fig. p--> infinity and p--> 0

3) With increasing P, ie with increasing potential barrier, the width of an allowed band decreases. As $P \rightarrow \infty$, the allowed energy becomes infinitely narrow and the energy spectrum is a line spectrum as shown in fig.

If $P \rightarrow \infty$, then the equation (11) has solution ie $\sin \alpha a = 0$

$$\alpha a = \pm n \Pi$$

$$\alpha = \pm n$$

$$\Pi / a$$

$$\alpha^2 = n^2$$

$$\Pi^2 / a^2$$

But $\alpha^2 = 2 m E / \hbar^2$

Therefore $2 m E / \hbar^2 = n^2 \Pi^2 / a^2$

$$E = [\hbar^2 \Pi^2 / 2 m a^2] n^2$$

$E = n h^2 / 8 m a^2$ (since $\hbar = h / 2 \Pi$)

This expression shows that the energy spectrum of the electron contains discrete energy levels separated by forbidden regions.

4) When $P \to 0$ then $\cos \alpha a = \cos ka$

$$\alpha = k , \quad \alpha^2 =$$

$$k^2 \text{ but } \quad \alpha^2$$

$$= 2\,m\,E / \hbar^2$$

$$k^2 = (h^2 / 2\,m)(1/\lambda^2) = (h^2 / 2\,m)(P^2 / h^2)$$

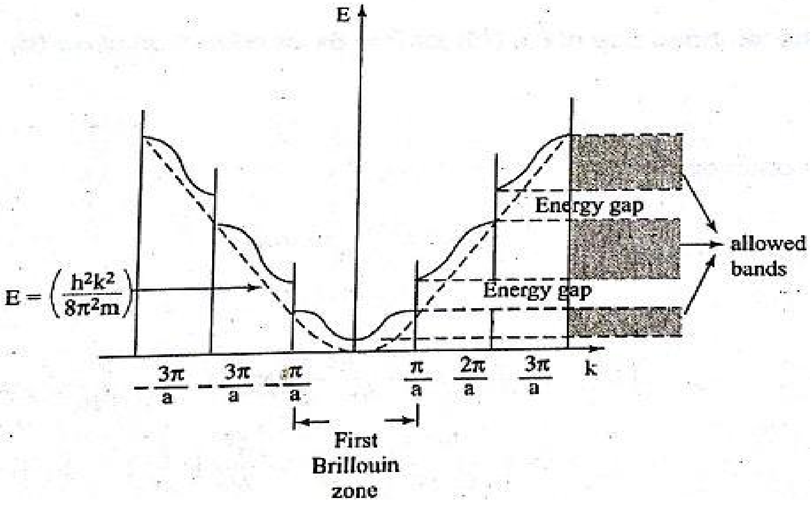
$$E = P^2 / 2\,m$$

$$E = 1/2mv^2 \text{ ----------------(14)}$$

The equation (11) shows all the electrons are completely free to move in the crystal without any constraints. Hence , no energy level exists ie all the energies are allowed to the electrons and shown in fig(5). This case supports the classical free electrons theory.

$$[\,(P/\alpha a)\sin \alpha a + \cos \alpha a\,] , P \to 0$$

BRILLOUIN ZONE OR E-K DIAGRAM:



The Brillouin zone are the boundaries that are marked by the values of wave vector k,in which electrons can have allowed energy values. These represent the allowed values of k of the electrons in 1D, 2D, &3D.

It is the energy spectrum of an electron moving in presence of a periodic potential field and is divided into allowed energy regions (allowed zones) or forbidden energy gaps (forbidden zones).

Allowed energy values lie in the region k=-π/a to =+π/a. This zone is called the first Brillouin zone. After a break in the energy values, called forbidden energy band, we have another allowed zone spread from k=-π/a to -2π/a and +π/a to +2π/a. This zone is called the second Brillouin zone. Similarly, higher Brillouin zones are formed.

CONCEPT OF EFFECTIVE MASS OF ELECTRON:

When an electron in a periodic potential of lattice is accelerated by an known electric field or magnetic field, then the mass of the electron is called effective mass and is represented by m*

To explain, let us consider an electron of charge 'e' and mass 'm' moving inside a crystal lattice of electric field E.

acceleration $a = eE / m$ is not a constant in the periodic lattice of the crystal. It can be considered that its variation is caused by the variation of electron's mass when it moves in the crystal lattice.

Therefore Acceleration $a = eE / m^*$

Electrical force on the electron $F = m^* a$ --------------(1)

Considering the free electron as a wave packet, the group velocity v_g

corresponding to the particle's velocity can be written as

$v_g = dw / dk = 2 \Pi\, dv/ dk = (2 \Pi / h)\, dE / dk$ ------------------(2) where the

energy $E = h \upsilon$ and $\hbar = h / 2 \Pi$.

Acceleration $a = d v_g / dt = (1 / \hbar)\, d^2E / dk\, dt = (1 / \hbar)(d^2E / dk^2)$ dk / dt

Since $\hbar k = p$ and

$dp / dt = F$,

$dk / dt = F / \hbar$

Therefore $a = (1 / \hbar^2)(d^2E / dk^2) F$

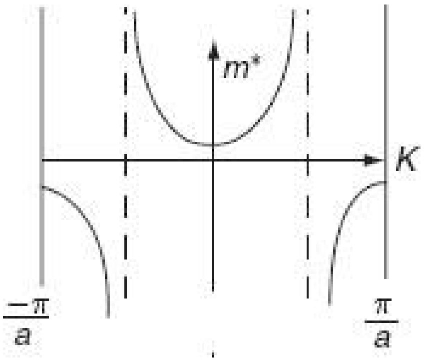
Or $F = (\hbar^2 / (d^2E / dk^2))\, a$ --------------------

---(3) Comparing eqns . (1) and (3) we get

$$m^* = \hbar^2 / (d^2E / dk^2) \quad \text{---------------(4)}$$

This eqn indicates that the effective mass is determined by **d^2E / dk^2**

Variation of effective mass m* with k: The graph shows variation of m* with k. Near k=0,effective mass approaches m. As the k value increases ***m***m* increases, reaching its maximum value known as infinite effective mass. Above the point of inflection, m* is negative and as k tends to$^{\pi/a}$, it decreases to a small negative value called negative effective mass in the lower region. The positively charged particle which can be located in the lower region called negative



ORIGIN OF ENERGY BAND FORMATION IN SOLIDS:

The band theory of solids explains the formation of energy bands and determines whether a solid is a conductor, semiconductor or insulator.

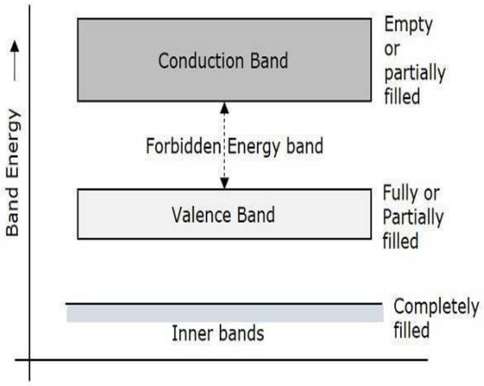
The existence of continuous bands of allowed energies can be understood starting with the atomic scale. The electrons of a single isolated atom occupy atomic orbitals, which form a discrete set of energy levels.

When two identical atoms are brought closer, the outermost orbits of these atoms overlap and interact. When the wave functions of the electrons of different atoms begin to overlap considerably, the energy levels corresponding to those wave functions split.

If more atoms are brought together more levels are formed and for a solid of N atoms, each of the energy levels of an atom splits into N energy levels. These energy levels are so close that they form an almost continuous band. The width of the band depends upon the degree of overlap of electrons of adjacent atoms and is largest for the outermost atomic electrons.

As a result of the finite width of the energy bands, gaps are essentially leftover between the bands called forbidden energy gap.

The electrons first occupy the lower energy levels (and are of no importance) then the electrons in the higher energy levels are of important to explain electrical properties of solids and these are called valence band and conduction band.



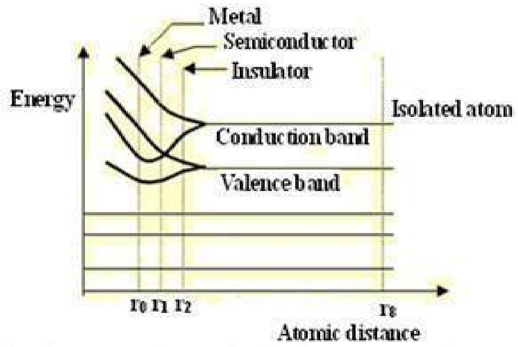
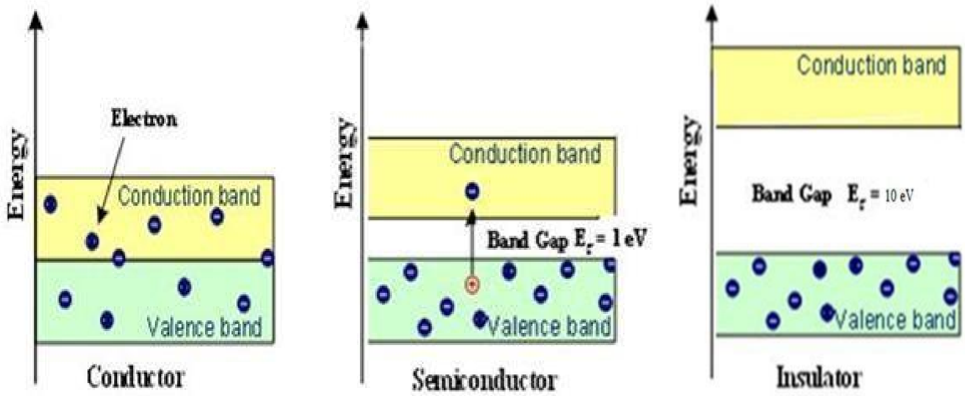


Fig: Formation of energy bands when atoms are closer

Valence band: A band occupied by valence electrons and is responsible for electrical, thermal and optical properties of solids and it is filled at 0K.
Conduction band: A band corresponding to outer most orbit is called conduction band and is the highest energy band and it is completely empty at 0K.
The **forbidden energy gap** between valence band conduction band is known as the energy band gap. By this solids are classified in to conductors, semiconductors and insulators.

CLASSIFICATION OF SOLIDS INTO CONDUCTORS , SEMICONDUCTORS & INSULATORS:

Based on the energy band diagram materials or solids are classified as follows:



Conductors: In this kind of materials, there is no forbidden gap between the valence band and conduction band. It is observed that the valence band overlaps with the conduction band in metals as shown in figure. There are sufficient numbers of free electrons, available for electrical conduction and due to the overlapping of the two bands there is an easy

transition of electrons from one band to another band takes place, and there no chance for the presence of holes.
Resistivity of conductors is very small and it is very few milli ohm meters.(Ω m).

Examples: All metals (Na, Mg, Al, Cu, Ni Cu, Ag, Li, Ar etc)

Semiconductors: In semiconductors, there is a band gap exists between the valence band and conduction band and it is very less and it is the order of -1 to 2 eV are known as semiconductors. It will conduct electricity partially at normal conditions. The electrical resistivity values are 0.5 to 10^3 ohm meter. Due to thermal vibrations within the solid, some electrons gain enough energy to overcome the band gap (or barrier) and behave as conduction electrons. Conductivity exists here due to electronics and holes.

Examples: Silicon, Germanium, Ga As.

Insulators: In insulators, the width of forbidden energy gap between the valence band and conduction band is very large. Due to large energy gap, electrons cannot jump from V.B to C.B.Energy gap is of the order of ~10 eV and higher than semiconductors. Resistivity values of insulators are 10^7 to 10^{12} ohm-m. Electrons are tightly bound to the nucleus, no valence electrons are available.

Examples: Wood, rubber, glass.

UNIT-2

SEMICONDUCTORS & DEVICES

SEMICONDUCTORS:-

A semiconductor is a solid having a fully filled valence band which is separated from an empty conduction band by a forbidden gap at absolute zero. This gap is usually quite narrow in semiconductors so that at finite temperatures some of the electrons of the filled valence band are always excited across this gap in to the conduction band where they become free. Further as the temperature increases, more and more electrons are free in this manner. Hence, in these materials, it is possible to control the carrier concentration.

On the other hand, in metals and insulators such a control is not possible by any means. The mechanism that provide and control the free charge carrier concentration in semiconductors will be classified into two broad categories.

1. Thermal effects: at a finite temperature there is a certain no. of electrons that is excited from the filled valence band to the empty conduction band, and as the temperature is increased this number is also increased.

   An electron so exited leaves holes behind in the valence band. Both, the electrons in the conduction band and the holes in the valence band can act as charge carriers.

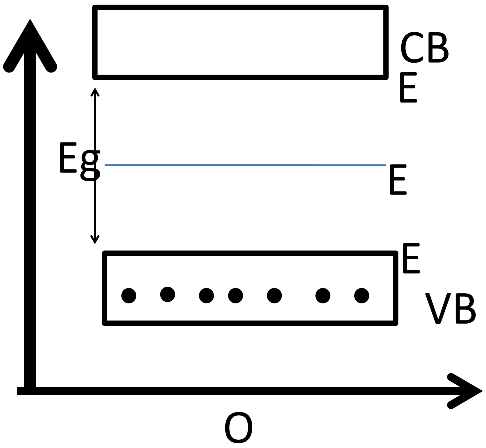
2. Introduction of certain impurities in to the pure semiconductors: a suitable highly doped semiconductor at low temperatures will bring about a change in the charge carrier concentration. The properties of such semiconductors are therefore controllable by the nature and amount of impurities added. Such semiconductors are classified as the extrinsic semiconductors.

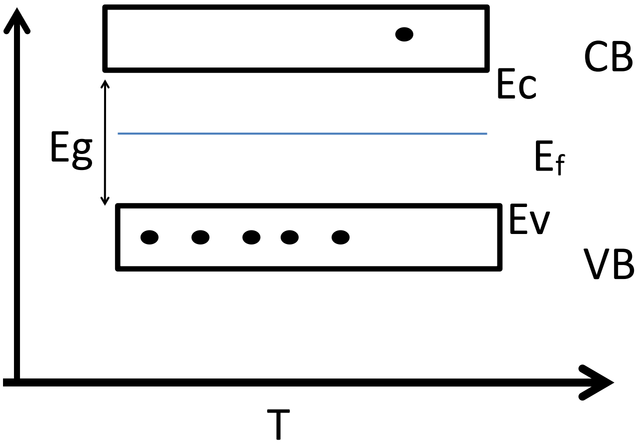
   In pure semiconductors, the primary mechanism that brings a change in charge carrier concentration arises from the valence band to conduction band. Obviously their properties are determined by the inherent nature of the elements themselves. Such semiconductors are classified as the pure or intrinsic semiconductors.

INTRINSIC SEMICONDUCTORS:

The band structure of intrinsic semiconductors at 0 K is not unlike to that of insulators. There is a vacant conduction band separated by an energy gap E_g from a filled valence band.

At absolute zero, the electric conduction is not possible. But as the temperature is increased, the electrons are thermally excited from the valence band to the conduction band. Where they become free and the conduction is possible. Hence, the electron-hole pairs are created. The no. of electrons in the conduction band will be equal to the no. of holes in the valence band. Energy band diagram of intrinsic semiconductor at 0 and T kelvin temperature:





EXTRINSIC SEMICONDUCTOR:-

A semiconducting material in which the charge carrier originates from impurity atoms added to the material is called impurity semiconductor or extrinsic semiconductor.

The electrical properties of pure semiconductors are drastically modified by addition of certain impurities.

Eg: - addition of boron to silicon in the proportion of 1 boron atom to 10^5 silicon atoms increases the conductivity of pure silicon by a factor 10^3at room temperature.

There are two types of impurities possible.

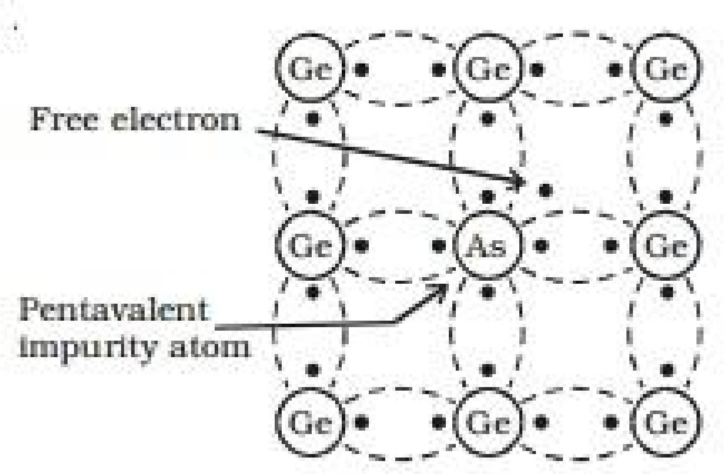
n- Type semiconductor:

Pentavalent elements which are having 5 electrons in its outermost orbit are added to an intrinsic semiconductor in small trace, then the semiconductor formed is called n- type semiconductor.

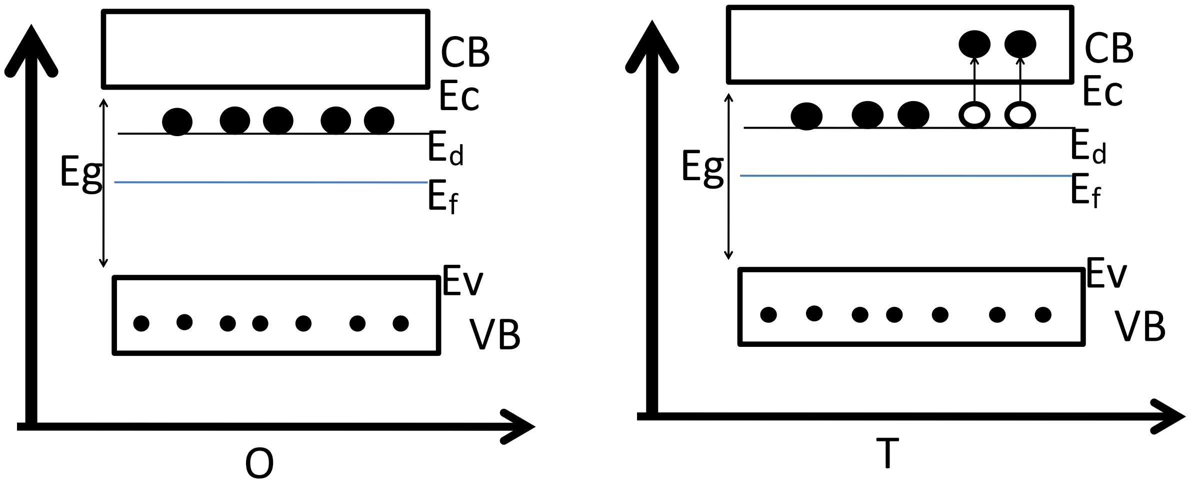
Out of 5 electrons of the impurity 4 electrons are bounded to the germanium atoms and 1 electron is left free which is weakly bonded to the atom.

Even for lesser thermal energy, this fifth electron is released leaving the parent atom positively ionised. In the energy level diagram, the energy level of the fifth electron is called donor level which is very close to the conduction band. The electron in donor level gets excited to conduction band at room temperature only.

Hence, majority charge carriers in n-type semiconductor are electrons and holes are minority charge carriers.



Energy band diagram of n-type extrinsic semiconductor at 0 and T kelvin temperature:



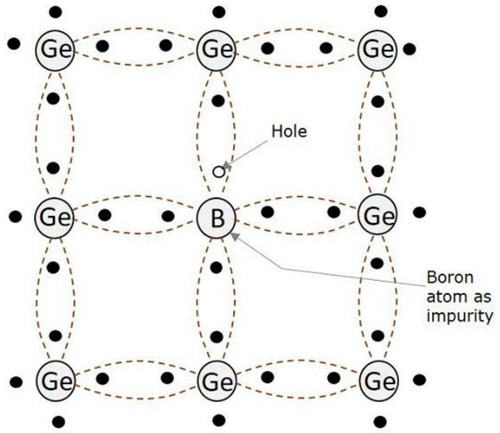
P-type semiconductor:

Trivalent elements which are having 3 electrons in its outer most orbits are added to an intrinsic semiconductor in small trace, then the semiconductor formed is called p-type semiconductor.

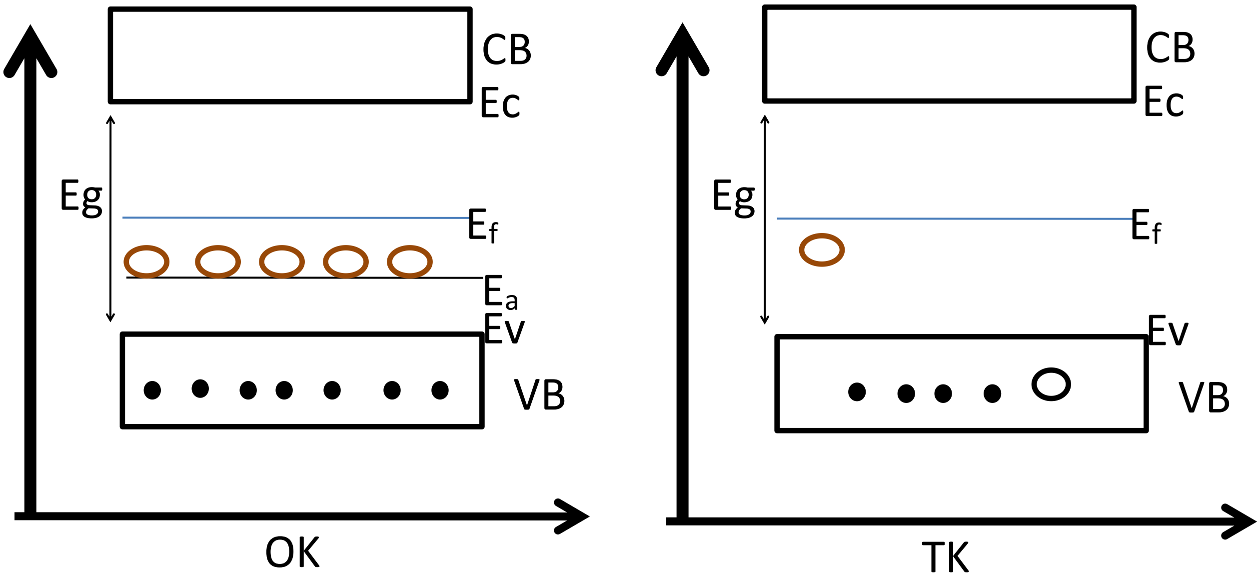
All the three electrons in In (indium) are engaged in covalent bonding with three neighbouring Ge atoms. In needs one more electron to complete its bond. Since In accepts one extra electron to complete the bond, the energy level of this impurity atom is called acceptor level.

This acceptor level lies just above the valence band. Even at relatively low temperatures, the acceptor atoms get ionised taking electron from valence band and thus giving rise to the holes in valence band for conduction.

Hence, majority charge carriers in p-type semiconductor are holes in valence band and minority charge carriers are electrons.

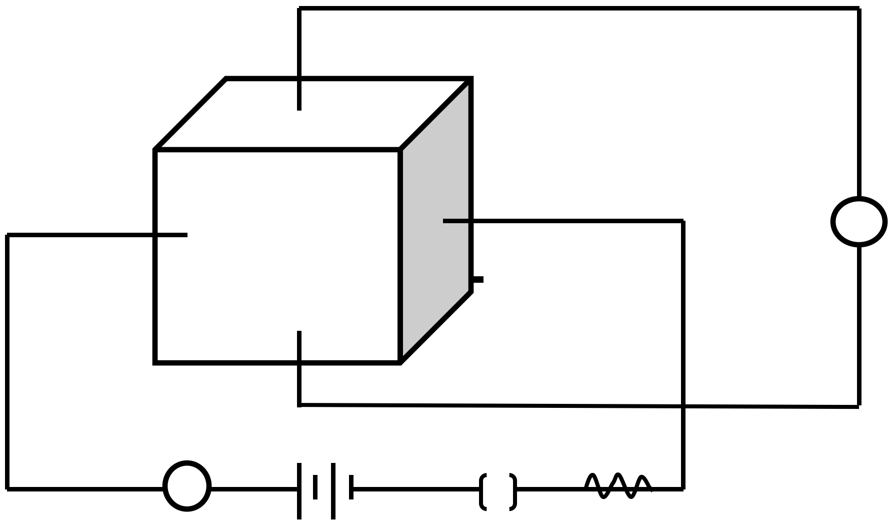


Energy band diagram of P-Type semiconductor at 0 and T kelvin temperature:



HALL EFFECT:

Suppose a material carrying an electric current is placed in a magnetic field. Then an electric field is produced inside the material in a direction which is at right angles to both the current and the magnetic field. This effect was discovered by Edwin H Hall in the year 1879. This phenomenon is known as the Hall Effect and the generated voltage is known as hall voltage.



Let us consider a n-type semiconductor. Let v be the velocity of the electron flowing right to left just opposite to the conventional flow of current and magnetic field is applied perpendicular to the flow of current. Then, the electron experiences a force of ‘Bev’ due to magnetic field which is perpendicular to both ‘B’ and flow of current.

Thus electron is deflected causing a negative charge to accumulate on one face of the slab. A potential difference is therefore established between faces and gives rise to a force eE_H on electron in opposite direction. At equilibrium,

$$eE_H = Be\vartheta$$

$$E_H = B\vartheta$$

If J is current density, then

$$J = ne\vartheta$$

$$\vartheta = \frac{J}{ne}$$

Therefore,

$$E_H = \mathrm{B}\frac{J}{ne}$$

$$E_H = \mathrm{BJ}R_H$$

Where, $R_H = \frac{1}{ne}$ is called hall coefficient. Since all quantities E_H, J, B are measurable, the hall coefficient R_H and hence the carrier density 'n' can be found out.

Determination of type of semi conductor:

For, n-type field is developed in negative direction compared to p-type. Therefore,

For n-type, $R_H = -\frac{1}{ne}$

For p-type, $R_H = \frac{1}{pe}$

Determination of hall cooefficient:

If 'b' is width of sample across which hall voltage V_H is measured. Then

$$E_H = \frac{V_H}{b}$$

$$R_H = \frac{E_H}{BJ}$$

$$R_H = \frac{V_H}{BbJ}$$

$$V_H = R_H\, BbJ$$

If't' is thickness of sample, then current density, $J = \frac{I}{A} = \frac{I}{bt}$

$$V_H = R_H\, Bb \times \frac{I}{bt}$$

$$R_H = \frac{V_H t}{BI}$$

Determination of mobility:

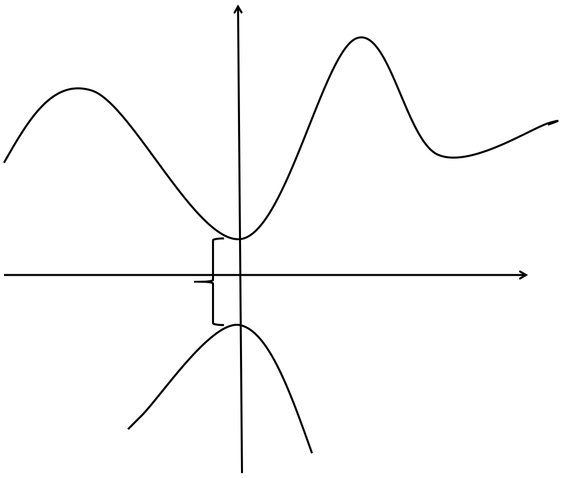
For n-type material, $\sigma_n = ne\mu_e$

$$\mu_e = \frac{\sigma_n}{-1/R_H}$$

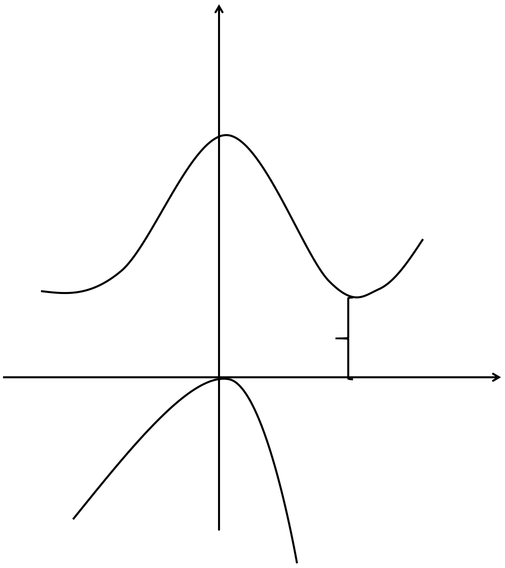
For p-type material, $\mu_h = \frac{\sigma_p}{1/R_H}$

DIRECT AND INDIRECT BAND GAPS OF SEMICONDUCTORS:

In semiconductors E-K relationship is shown below.



(a) Direct band gap



(b) indirect band gap

Hence, energy band formation depends on the orientation of electron wave vector to the crystallographic axes. In some crystals, the maximum of valence band occurs at the same of K as the minimum of conduction band. This is called direct band gap semiconductor.

Eg: gallium arsenide.

In few semiconductors, the maximum of valence band does not always occur at the same K value as the minimum of conduction band. This is called indirect band gap semiconductor.

Eg: silicon.

In direct band gap semiconductors, the direction of motion of an electron during the transition across energy gap, remains unchanged. Hence, transition of charge carriers across the band gap is more in direct band gap than in indirect band gap semiconductors.

P-N JUNCTION:

Fabrication:-

When a layer of p-type semiconductor material is placed on the layer of n-type semiconductor material insuch a way that the atoms of p-type combine with the atoms of n-type across the surface contact. Such a surface junction where combination has occurred is known as P-N junction. In practice, a PN junction is obtained in three ways.

1. Grown junction type
2. Fused or alloyed junction type
3. Diffused junction type

Grown junction type:

Grown junctions are formed when donor impurities are introduced into one side and acceptor impurities in to the other side of a single crystal at the time of crystal growing from a melt of silicon or germanium.

First germanium or silicon are melt is doped with a small amount of p-type impurity. Then after sufficient time during the growth process an n-type impurity is added in sufficient quantity to overcome the effect of p-type impurity so that subsequently n type material is formed.

Advantages: locating the junction and also attaching leads to narrow grown junction regions is difficult.

Alloy junction type:

In this type, p-type and n-type materials are kept in contact and fused together properly by heat treatment to form junction.

Eg: an indium is pressed on a wafer of n-type germanium. During few minutes of heat treatment, indium atom’s fuse into the surface of germanium and produce p-type region. Hence, P-N junction is formed.

Diffused junction type:

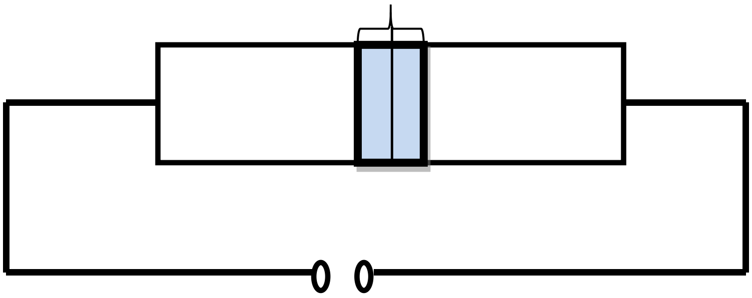
In this process, a p-type impurity is painted into n-type substrate and both are heated. Now impurity atoms diffuse into n-type substrate for a short distance and from p-n junction.

The formation of p-n junction is shown below. When the p-type and n-type are joined, in the region of contact the free electrons diffuse from n-region and combine with holes in p-region. This leaves n-region near the boundary positively charged and p-region negatively.

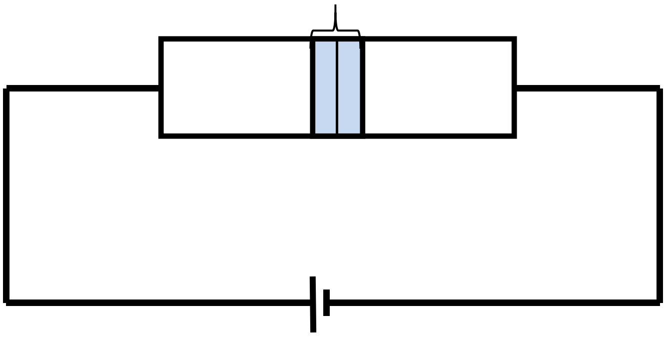
As a result, electric field E_B appears in small region w on either side of junction. This region is called depletion region. Due to this electric field E_B, potential difference appears across the region and this potential V_B is called contact potential or barrier potential or junction barrier.

BIASING OF PN JUNCTION:

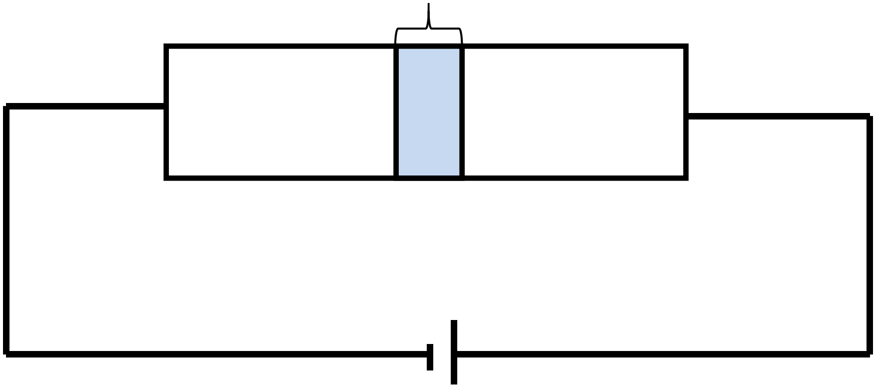
When the PN junction is **unbiased**, it is in equilibrium and contact potential $V_B$appears across the region.



When the positive of the source is connected to the p-side and negative of the source is connected to the n-side, then the junction is said to be **forward biased**. This voltage appears across the depletion region. Since, V_B acts from n to p, the electrostatic potential barrier is lowered and is given by $V_B - V_f$. The electric field in the transition region reduces. Since, the width of the transition region is proportional to the $\sqrt{V}$, the width of transition region decreases.



When the positive of the source is connected to the n-side and negative of the source is connected to the p-side, then the junction is said to be **reverse biased**. Since this potential acts along V_B, the electrostatic potential barrier increases by $V_B + V_r$. The electric field in the transition region increases. Since the width of the transition region is proportional to the square root of the electrostatic potential barrier, the width of the transition region increases.



V-I CHARACTERISTICS OF JUNCTION DIODE:

Unbiased circuit:-

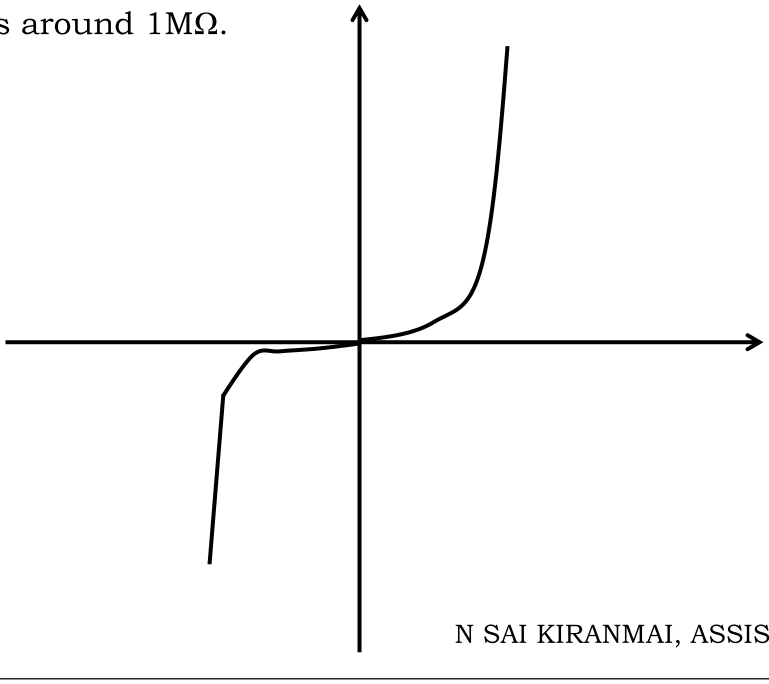
When the junction is not connected to any voltage source, it is said to be unbiased and due to barrier potential across the junction, there is no flow of charge carriers and hence no current flow through the junction.

Forward biased circuit:-

Since the potential barrier height is very small, when the applied voltage exceeds that value, the junction becomes almost zero. Hence, for small increase of applied voltage, large increase in circuit current is observed. The current is called forward current. Under forward bias, the D.C resistance is around 100Ω for Ge diode.

Reverse biased circuit:-

When the diode is reverse biased, a slight reverse current (in µA) flows in the circuit. Even for a large increase in bias voltage, there is a negligible increase in current. When the applied reverse voltage is high enough to break the covalent bonds of the crystal, the current rises suddenly. This voltage is called breakdown voltage or reverse voltage. For Ge diode reverse resistance is around 1MΩ.



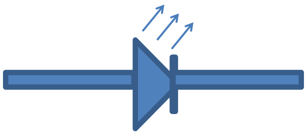
LIGHT EMITTING DIODE:[LED]

Construction:- the typical construction of LED is as shown in figure.

LED has to be constructed in such a way that most of the radiative recombination's takes place from the side of the junction nearest to the surface so that loss due to reabsorption is minimised.

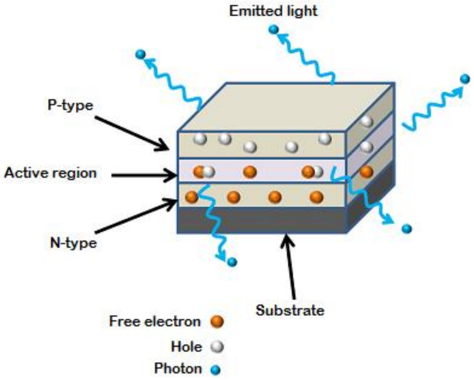
The LED is constructed on a GaP n-doped substrate. A thin epitaxial p-doped GaP layer is grown on the top of this substrate.

Electrical contacts can be made leaving as much of the upper surface of the p-type material uncovered. The recombination takes place and radiation is generated between p and n layers i.e., PN junction. Since GaP layer is transparent, the radiation escapes through the top layer. To the bottom electrode a reflective layer is added to improve efficiency.



Requirements:-

LED material must have energy gap of appropriate width, both p and n types must exist with low resistivity's, efficient radiative paths must be present.



Working:-

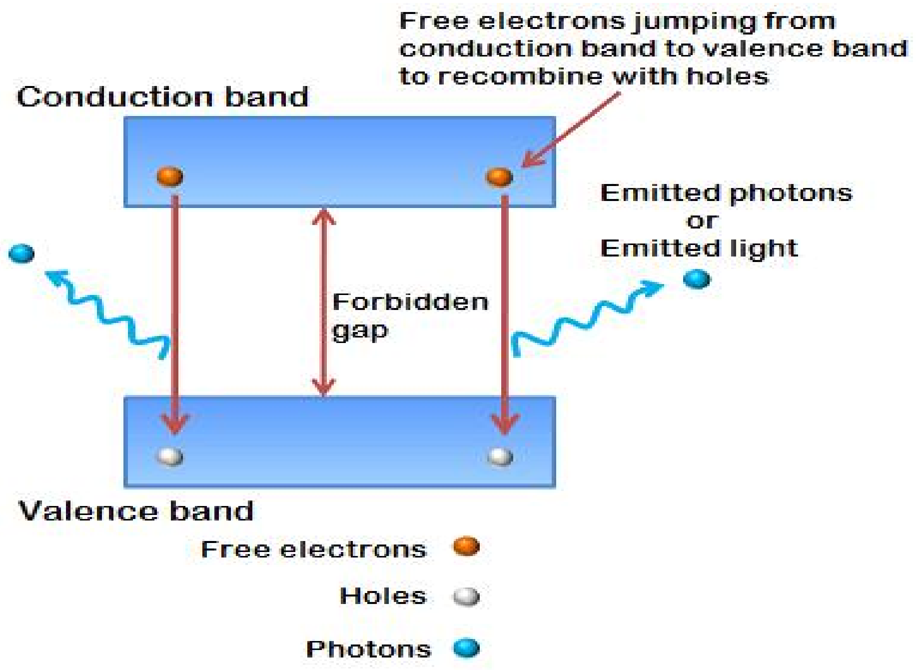
PN junction diode operated under forward bias gives rise to injection luminescence.

Under forward bias, majority carriers from both sides of the junction cross the internal potential barrier and enter the other side of the junction.

Where they are minority charge carriers. This process is called minority carrier injection.

These excess minority carriers while diffusing away from the junction undergo radiative recombination with majority carriers, emitting photons.

The no. of radiative recombination's is proportional to the carrier injection rate.



Process of light emission in LED

Advantages:-

- o/p is bright
- they can be operated in a wide range of temperature 0 to 70
- Available in different colours.
- Very small in size
- Has long life and high degree of reliability
- Viewing angle is not limited.

Disadvantages:-

- LEDs need more power to operate than normal p-n junction diodes.
- Luminous efficiency of LEDs is low.

Applications:-

The various applications of LEDs are as follows

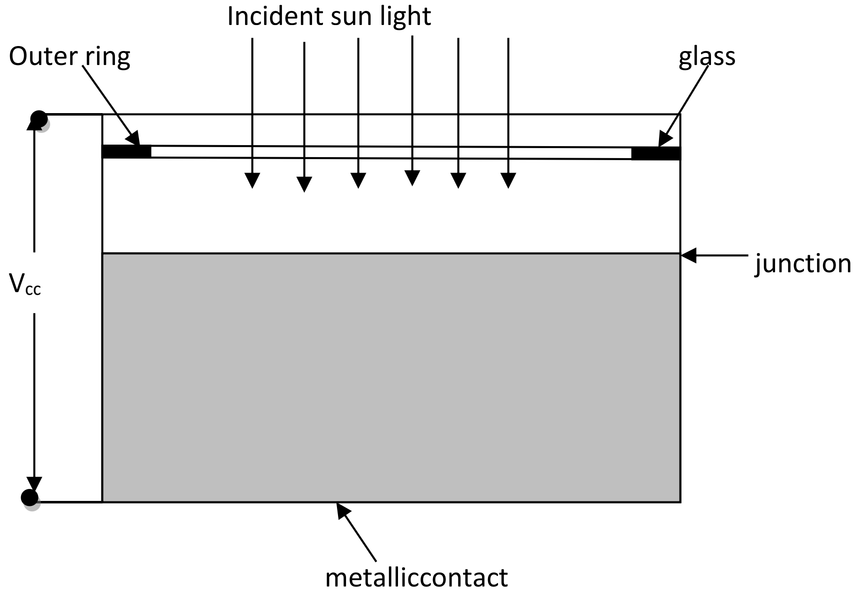
- Burglar alarms systems

- Calculators
- Picture phones
- Traffic signals
- Digital computers
- Multimeters
- Microprocessors
- Digital watches
- Automotive heat lamps
- Camera flashes
- Aviation lighting

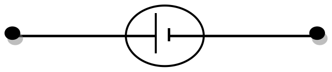
SOLAR CELL:

The solar cells are semiuconductor junction devices which are used for converting optical radiation in to electrical energy. The generated electric voltage is proportional to the intensity of incident light. Due to their capability of generating voltage, they are called as photovoltaic cells. A solar cell converts photon power into electric power and delivers this power to load.

Construction: figure shows the construction of solar cell.



Symbol: the circuit symbolfor solar cell is



The cell is a P- N junction diode with appropriately doped semiconductors. The top p-type layer is made very thin so that the light radiation may penetrate to fall on junction. The doping level of p-doped semiconductor is very high. Every effort is made to ensure that the surface area perpendicular to sun is maximum. P- Type material is surrounded by a nickel plated ring which serves as the positive terminal of the cell. A metallic contact at the bottom of the cell acts as a negative terminal.

Working: when a photon of light energy collides with the valence electron either in p-type or n-type material, it imparts sufficient energy to the electron to leave its parent atoms. As a result, free electrons and holes are generated on each side of the junction.

In p-type material, the newly generated electrons are minority carriers which are free to move across the junction with no applied bias. In n-type material, the newly generated holes are minority carriers which are free to move across the junction with no applied bias. The result is an increase in minority carriers flow. In this way depletion region potential causes the photo current to flow through the external load.

Advantages:

1. It is a self generating device.
2. Pollution free energy conservation system.
3. It can be operated over a wide range of temperatures
4. These are extensively used in space satellites for long period of time for source of power.

Limitations:

1. Low efficiency
2. Doesn’t convert all solar rays in to electrical energy.
3. More effective in outer space applications than terrestrial applications.

Applications:

1. In portable exposure meters
2. In space satellites
3. In low resistance relays for ON and OFF operations.
4. Used in detectors.

ZENER DIODE:

A Zener diode is a silicon semiconductor device that permits current to flow in either a forward or reverse direction. The diode consists of a special, heavily doped p-n junction, designed to conduct in the reverse direction when a certain specified voltage is reached.

Zener Effect:-

When the voltage across the terminals of a Zener diode is reversed and the potential reaches the Zener Voltage (knee voltage), the junction breaks down and the current flows in the reverse direction. This effect is known as the Zener Effect.

Working:

A Zener diode operates just like a normal diode when it is forward-biased. However, a small leakage current flows through the diode when connected in reverse biased mode. As the reverse voltage increases to the predetermined breakdown voltage (Vz), current starts flowing through the diode.The current increases to a maximum, which is determined by the series resistor, after which it stabilizes and remains constant over a wide range of applied voltage.There are two types of breakdowns for a Zener Diode:

- Avalanche Breakdown
- Zener Breakdown

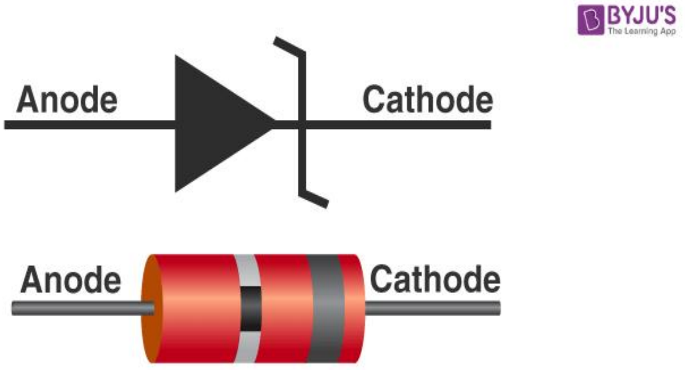
Avalanche Breakdown in Zener Diode:-

Avalanche breakdown occurs in normal diode and Zener Diode at high reverse voltage. When a high value of reverse voltage is applied to the PN junction, the free electrons gain sufficient energy and accelerate at high velocities. These free electrons moving at high velocity collide with other atoms and knock off more electrons.Due to this continuous collision, a large number of free electrons are generated as a result of electric current in the diode rapidly increases.This sudden increase in electric current may permanently destroy the normal diode. However, a Zener diode is designed to operate under avalanche breakdown and can sustain the sudden spike of current. Avalanche breakdown occurs in Zener diodes with Zener voltage (Vz) greater than 6V.

Zener Breakdown in Zener Diode:-

When the applied reverse bias voltage reaches closer to the Zener voltage, the electric field in the depletion region gets strong enough to pull electrons from their valence band. The valence electrons that gain sufficient energy from the strong electric field of the depletion region break free from the parent atom. At the Zener breakdown region, a small increase in the voltage results in the rapid increase of the electric current.

Circuit Symbol:-



(Zener diode)

V-I Characteristics of Zener Diode:-

The V-I characteristics of a Zener diode can be divided into two parts as follows:

(i) Forward Characteristics

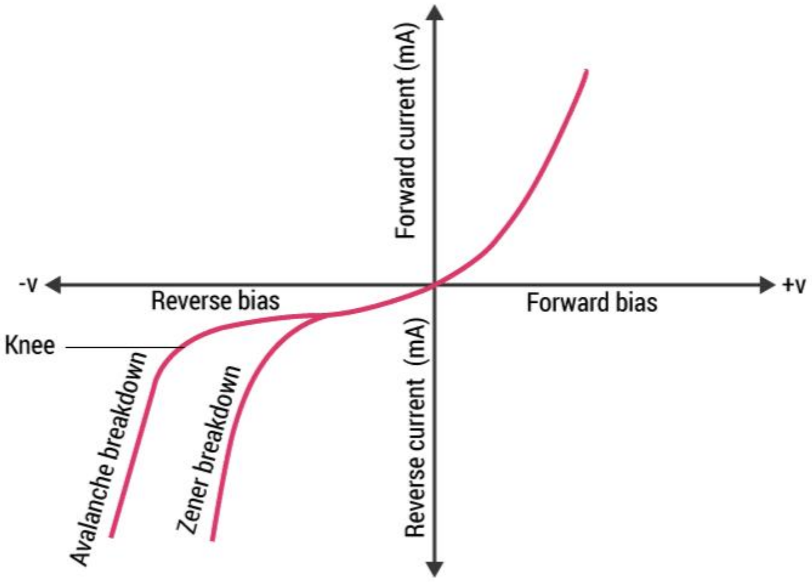
(ii) Reverse Characteristics

Forward Characteristics of Zener Diode

The first quadrant in the graph represents the forward characteristics of a Zener diode. From the graph, we understand that it is almost identical to the forward characteristics of any other P-N junction diode.

Reverse Characteristics of Zener Diode

When a reverse voltage is applied to a Zener voltage, a small reverse saturation current Io flows across the diode. This current is due to thermally generated minority carriers. As the reverse voltage increases, at a certain value of reverse voltage, the reverse current increases drastically and sharply. This is an indication that the breakdown has occurred. We call this voltage breakdown voltage or Zener voltage, and Vz denotes it.



Applications:

1. Zener diode as a voltage regulator:

Zener diode is used as a Shunt voltage regulator for regulating voltage across small loads. The Zener diode is connected parallel to the load to make it reverse bias, and once the Zener diode exceeds knee voltage, the voltage across the load will become constant. The breakdown voltage of Zener diodes will be constant for a wide range of currents.

2. Zener diode in over-voltage protection:

When the input voltage is higher than the Zener breakage voltage, the voltage across the resistor drops resulting in a short circuit, this can be avoided by using the Zener diode.

3. Zener diode in clipping circuits:

Zener diode is used for modifying AC waveform clipping circuits by limiting the parts of either one or both the half cycles of an AC waveform.

PHOTO DIODE:-

Construction: the typical silicon photodiode structure for photo-conductive operation is as shown below.

A junction is formed between heavily doped p-type material (P^+) and fairly lightly doped n-type material so that the depletion region extends well in to the n-material.

Metallic contacts can be made directly to the P^+ material but to obtain an ohmic contact to the n- material an intermediate n^+ layer is formed.

Working:- the function of the photodiode junction is the opposite of an LED junction.

In a PN junction diode, the depletion region is formed on the either side of the junction when there are no free carriers.

Only ionised atoms of opposite polarity remain. When an electron-hole pair is generated by photon absorption within this region, the internal fields causes the electron and hole to separate.

This charge separation can be detected in two different methods.

If the device is left on open circuit an externally measurable potential appears between p and n regions. This is known as photo voltaic mode of operation.

If we short circuit the device externally, the external current flows between the p and n regions. This is known as photo conductive mode of operation.

PIN DIODE:

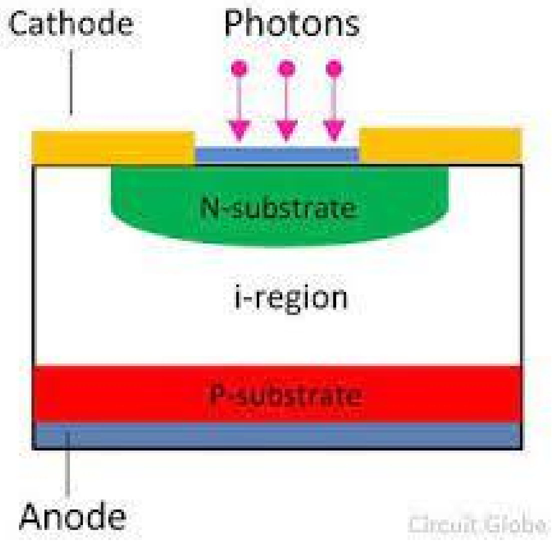
Construction:

The PIN diode has three layers such as

- P-type layer

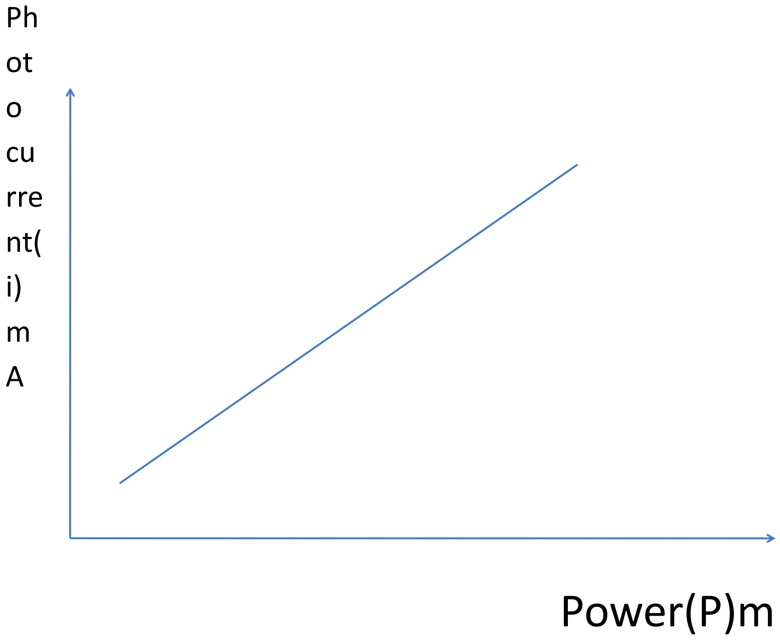
- Intrinsic layer
- N-type layer

PIN diode is formed by sandwiching intrinsic layer between p-type and n-type semiconductor to create an electric field between them.The P and N regions are there and the region between them consists of the intrinsic material and the doping level is said to be very low in this region.The thickness of the intrinsic layer is very narrow, which ranges from 10 – 200 microns. The P region and the N-type regions are known to be heavily doped.The changes in the properties of the diode are known from the intrinsic material. These diodes are made of silicon. The intrinsic region of the PIN diode acts like an inferior rectifier which is used in various devices such as attenuators, photodetectors, fast switches, high voltage power circuits, etc.



Working:

The PIN diode is operated in photo conductive mode, where a reverse bias is applied. When light falls on the detector, photons with proper energy create electron-hole pairs in this region by raising an electron from valence band to conduction band, leaving a hole behind. These carriers drift quickly away from junction creating current which is proportional to intensity of incident light.



Advantages:

- Low noise
- Low dark current
- Low bias voltage
- Higher reverse voltages to be tolerated
- High-speed response
- Low junction capacitance
- Large depletion region

Disadvantages:-

- Less sensitivity.
- No internal gain.
- Small area.
- Slow response time.

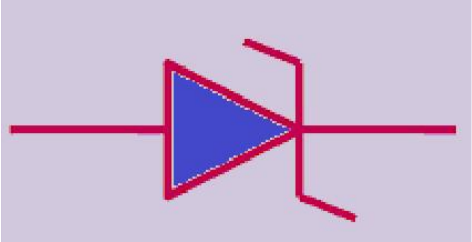
- High reverse recovery time due to power loss are significant.

Applications:

1. These diodes are used in the RF and also for microwave switches and microwave variable attenuators since they are said to have low capacitance.
2. They are used in Photodetectors and photovoltaic cell and the PIN photodiodes are used for fibre optic network cards and also switches.
3. These diodes are effectively used for RF protection circuits and it can also be utilized as an RF switch.
4. The PIN photodiode is also used to detect X-rays and gamma rays photons.

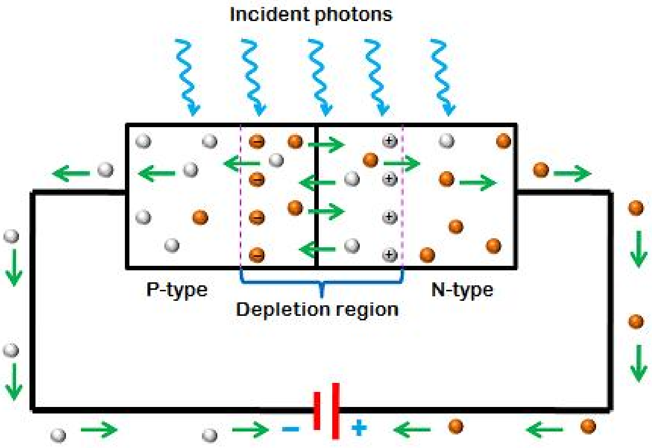
AVALANCHE PHOTO DIODE:

An avalanche photodiode (APD) is a highly sensitive semiconductor photodiode that exploits the photoelectric effect to convert light into electricity. 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.



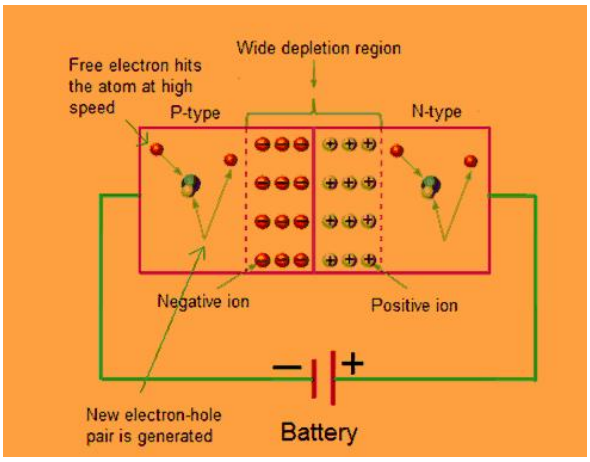
Construction:-

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. 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.

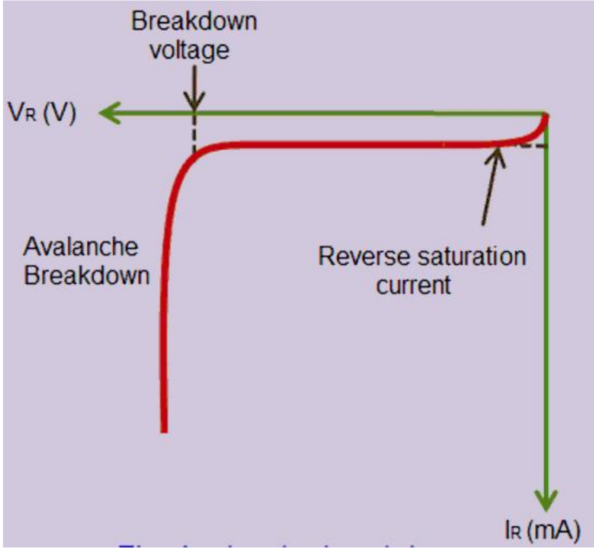


Working :-

The main difference of the avalanche photodiode to other forms of photodiode is that it operates under a high reverse bias condition. This enables avalanche multiplication of the holes and electrons created by the photon / light impact. As a photon enters the depletion region and creates a hole electron pair, these charge carriers will be pulled by the very high electric field away from one another. Their velocity will increase to such an extent that when they collide with the lattice, they will create further hole electron pairs and the process will repeat.



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



Advantages:-

High level of sensitivity as a result of avalanche gain is the advantage of this diode

Disadvantages:-

- Much higher operating voltage may be required.
- Avalanche photodiode produces a much higher level of noise than a PN photodiode
- Avalanche process means that the output is not linear

Applications:-

1. Typical applications for APDs are
2. laser rangefinders,
3. long-range fiber-optic telecommunication, and
4. quantum sensing for control algorithms.
5. New applications include positron emission tomography and particle physics.
6. APD arrays are becoming commercially available, also lightning detection and optical SETI may be future applications.

3-DIELECTRIC & MAGNETIC MATERIALS

Introduction:

Dielectrics are the substances which do not contain free electrons or the number of such electrons is too low to constitute the electric current. So, the dielectric is insulating materials. Dielectrics are non metallic materials of high specific resistance and have negative temperature coefficient of resistance.

Comparable to conductors, the dielectrics are

1. Insulators
2. Doesn't conduct electricity
3. Charge given to them remains localized
4. For particular field strength, they lose their insulating character.

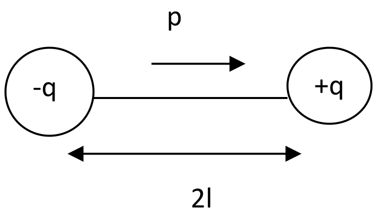
The molecules in which the centre of gravity due to positive and negative charges coincides are called non polar molecules otherwise polar molecules. For non polar molecules (H_2, N_2, O_2, CO_2, BENZENE), the dipole moment is zero and they have symmetrical structure. For polar molecules (H2O, HCl, CO, N2O, NH3), the dipole moment is permanent and they have unsymmetrical structure.

When non polar dielectrics are placed in a electric field, they get polarized. This means that the induced surface charges appear which tend to weaken the original field within the dielectric.

When polar molecules are placed in an electric field their dipole moment increases with increase in electric field or decrease in temperature.

Electric dipole:

The arrangement of two equal and opposite point charges at a fixed distance is called an electric dipole.



Dipole moment:

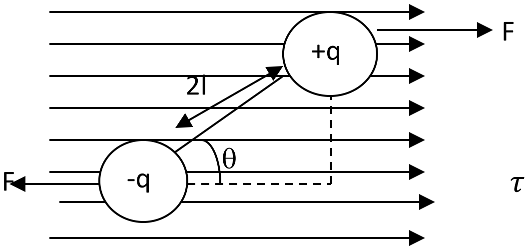
The product of the magnitude of either charge and the distance between the charges is called as electric dipole moment.

$$p = q \times 2l = 2ql$$

It is a vector quantity and units are “coulomb- meter.

When the dipole is placed in a uniform electric field the couple acting on it is

$$\tau = pE\ \sin\theta$$



$$\sin\theta = \frac{x}{2l}$$

$$x = 2l\ \sin\theta$$

$$\tau = F \times x = qEx$$

$$\tau = qE(2l\ \sin\theta) = pE\ \sin\theta$$

If θ=90 and E=1N/c then τ=p. Thus, dipole moment may be defined as the moment of the couple acting on the dipole place perpendicular to the direction of uniform electric field of unit intensity.

Dielectric constant:

It is defined as the ratio of capacitance of the condenser with dielectric to the capacitance of the same condenser without dielectric.

$$K = \frac{C}{C_o}$$

It is also defined as the ratio of permittivity of the medium to the permittivity of the free space.

$$K = \varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$$

K has no units and K=1 for vacuum and k is infinity for metals.

Polarizability:

When the strength of the electric field is increased, the induced dipole moment is also increased. So,

$$p \propto E$$

$$p = \alpha E$$

Where αis called polarisability.

So, polarisability is defined as induced dipole moment per unit electric field. Electric dipole moment per unit volume is called dielectric polarization.

$$\vec{P} = \frac{q^{'}(2l)}{A(2l)} = \frac{q^{'}}{A}$$

Where P is called polarization vector.

Electric susceptibility:

When a dielectric is placed in electric field, it is polarized. So,

$$\vec{P} \propto \vec{E}$$

$$\vec{P} = \chi \vec{E}$$

Where χ is called electric susceptibility. So, it is defined as the ratio of polarization vector to the electric field intensity in the dielectric.

Displacement vector:

when a dielectric is placed in between the plates of a condenser then

$$E = E_o - E^{'}$$

$$\frac{q}{\varepsilon_o KA} = \frac{q}{\varepsilon_o A} - \frac{q^{'}}{\varepsilon_o A}$$

$$\frac{q^{'}}{\varepsilon_o A} + \frac{q}{\varepsilon_o KA} = \frac{q}{\varepsilon_o A}$$

$$\frac{q^{'}}{A} + \frac{q}{\varepsilon_o KA}\varepsilon_o = \frac{q}{A}$$

$$\vec{P} + \varepsilon_o E = \frac{q}{A}$$

$$\vec{P} + \varepsilon_o E = \vec{D}$$

Where D is called displacement vector.

Note: since $D=q/A$ & $E=q/(\varepsilon_o KA)$. Then $D=\varepsilon_o KE$

$$\vec{D} = \vec{P} + \varepsilon_o E$$

$$\varepsilon_0 KE = \varepsilon_0 E + P$$

$$\varepsilon_0 E(K-1) = P = \chi\vec{E}$$

$$\varepsilon_0 E(K-1) = \chi\vec{E}$$

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

Types of polarization:

There are three mechanisms by which electric polarization can occur in dielectric materials when they are subjected to an external electric field. They are

1. Electronic polarization
2. Ionic polarization
3. Orientation polarization.

Electronic polarization:

On the application of electric field, the displacement of positively charged nucleus and negatively charged electrons of the atom in opposite directions, results in electronic polarization.

Since the nucleus and centre of electron cloud are separated, dipole moment is created in each atom. So, induced dipole moment (p_e) and dielectric polarization is proportional to field strength (E).

$$P_e \propto E$$

If there are N no. of atoms then,

$$P_e \propto NE$$

$$P_e = \alpha_e NE \ldots\ldots\ldots\ldots\ldots(1)$$

Where α_e is called electronic polarisability.

Where $\alpha_e = 4\pi\varepsilon_0 R^3$ is called electronic polarisability.

Ionic polarization:

This type of polarization occurs only in those dielectric materials which posses ionic bonds such as NaCl. When such material is subjected to an external electric field, the adjacent ions of opposite signs undergo displacement. Therefore, ionic polarization is due to displacement of cations and anions in opposite direction.

$$P_i = \alpha_i E$$

Where

$$\alpha_i = \frac{e^2}{{\omega_o}^2}\left(\frac{1}{m} + \frac{1}{M}\right) \textit{ is called ionic polarisability.}$$

Orientation polarizasbility:

Polar dielectrics exhibit orientation or dipolar polarizability.

When an external field is applied to polar dielectrics, they tend to align themselves in the direction of external applied field. The polarization due to such alignment is called orientation polarization. This is dependent on temperature and decreases with increase in temperature.

With increase of temperature, the thermal energy tends to randomize the alignment. So,

$$P_o = N\vec{\mu} = \frac{N\mu^2 E}{3KT}$$

$$P_o = N\alpha_o E$$

Where $\alpha_o = \frac{\mu^2}{3KT}$ is called orientation polarizability.

Total Electric polarization: -

The Total Electric polarization is the sum of electronic polarization, ionic polarization, orientation polarization, and space charge polarization. Among these, the space charge polarization is very small compared to others. So it can be neglected.

Therefore the total polarizability is given by

$$\alpha = \alpha_e + \alpha_i + \alpha_0$$

Where, $\alpha_e = 4\pi\varepsilon_o R^3$

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

$$\alpha_o = \frac{\mu^2}{3KT}$$

Therefore,

$$\alpha = \alpha_e + \alpha_i + \alpha_0$$

$$\alpha = 4\pi\varepsilon_o r^3 + \left(\frac{e^2}{{\omega_0}^2}\left(\frac{1}{m} + \frac{1}{M}\right)\right) + \frac{\mu^2}{3KT}$$

We know that the total polarization is

$$P = N\alpha E$$

$$P = N\left(4\pi\varepsilon_o r^3 + \left(\frac{e^2}{{\omega_0}^2}\left(\frac{1}{m} + \frac{1}{M}\right)\right) + \frac{\mu^2}{3KT}\right)E$$

This equation is called **Langevin- Debye equation**

Internal fields in solids:

In solids, the atoms are very close to each other and interact considerably. When an electric field is applied, the atoms are polarized. Each of the atoms develops a dipole moment. i.e., each atom acts as dipole. Therefore, electric field at any given atom is the sum of applied electric field plus the electric field due to surrounding dipoles. This resultant local field is called as internal field.

Expression:

Consider a solid dielectric be placed between the plates of a parallel plate capacitor and let there be an imaginary spherical cavity around the atom a inside the dielectric. It is also assumed that the radius of the cavity is large compared to the radius of the atom. The internal field at the atom site A is given by

I. E_1 field:

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

$$E_1 = \frac{D}{\varepsilon_o}$$

$$D = P + \varepsilon_o E$$

Therefore,

$$E_1 = \frac{P + \varepsilon_o E}{\varepsilon_o}$$

$$E_1 = \frac{P}{\varepsilon_o} + E$$

II. E_2 field:

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

$$E_2 = -\frac{P}{\varepsilon_o}$$

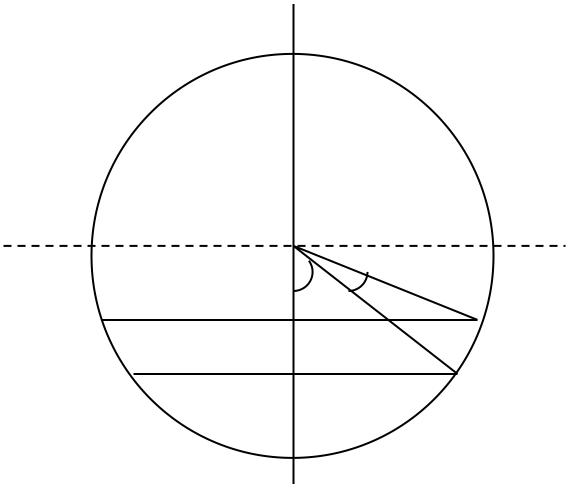
$$E_1 = \frac{P}{\varepsilon_o} + E$$

III. E_3 field:

It is the field due to other atoms contained in the cavity. Since it is a cubic structure, due to symmetry E_3=0.

IV. E_4 field:

It is the field due to polarization charges on the surface of the cavity and was calculated by Lorentz.



If dA is the surface area of the sphere of radius r lying between θ and θ+dθ. then,

$$dA=2\Pi(PQ)(QR)$$

$$PQ=r\sin\theta$$

$$QR=r\,d\theta$$

Therefore, $dA=2\Pi r^2\sin\theta\,d\theta$

The charge on the surface dA is

$$dq=P\cos\theta\,dA$$

$$=P2\Pi r^2\sin\theta\cos\theta\,d\theta$$

$$=P\Pi r^2\sin 2\theta\;\;d\theta$$

Therefore,

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

$$=\frac{P}{4\varepsilon_o}\cos\theta\sin 2\theta\;\;d\theta$$

So,

$$E_4=\int d\,E_4$$

$$=\frac{P}{4\varepsilon_o}\int\cos\theta\sin 2\theta\;\;d\theta$$

$$=\frac{P}{2\varepsilon_o}\int\cos^2\theta\sin\theta\;\;d\theta$$

$$=\frac{P}{2\varepsilon_o}\int\cos^2\theta\;\;d(-\cos\theta)$$

$$=-\frac{P}{6\varepsilon_o}[-1-1]$$

$$= \frac{P}{3\varepsilon_o}$$

Therefore internal field,

$$E_i = E + \frac{P}{\varepsilon_o} - \frac{P}{\varepsilon_o} + 0 + \frac{P}{3\varepsilon_o}$$

$$E_i = E + \frac{P}{3\varepsilon_o}$$

Classius-mosotti relation:

Consider a dielectric having cubic structure. Since for these materials, there are no ions and permanent dipoles, $\alpha_i = \alpha_o = 0$

Hence,

$$P = \alpha_e N E_i = \alpha_e N \left[E + \frac{P}{3\varepsilon_o}\right]$$

$$P\left[1 - \frac{\alpha_e N}{3\varepsilon_o}\right] = [\alpha_e N E]$$

$$P = \frac{[\alpha_e N E]}{\left[1 - \frac{\alpha_e N}{3\varepsilon_o}\right]}$$

we know that

$$\varepsilon_o E(K - 1) = P$$

So,

$$\varepsilon_o E(\varepsilon_r - 1) = \frac{[\alpha_e N E]}{\left[1 - \frac{\alpha_e N}{3\varepsilon_o}\right]}$$

$$1 - \frac{\alpha_e N}{3\varepsilon_o} = \frac{[\alpha_e N]}{[\varepsilon_o(\varepsilon_r - 1)]}$$

$$1 = \frac{\alpha_e N}{3\varepsilon_o}\left[1 - \frac{3}{[(\varepsilon_r - 1)]}\right]$$

$$\frac{\alpha_e N}{3\varepsilon_o} = \frac{1}{1 + \frac{3}{[(\varepsilon_r - 1)]}} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}$$

This is called classius-mosotti relation.

Piezo electricity:

Piezo electric phenomenon was discovered by curie brothers in 1880. Some of the materials when compressed or stretched in a certain direction become polarized and polarization charges appear on its surface.

Polarization of a dielectric as a result of mechanical deformation is called as piezo electric effect. The crystals that exhibit this effect are called piezo electrics.

These materials exhibit inverse piezo electric effect. When electric stress is applied to materials they become strained. Strain is proportional to applied field. This piezoelectric effect is utilized in conversion of mechanical energy in to electrical energy and vice versa.

Example: quartz crystal, ceramic.

Applications:

1. Quartz is used for filter, resonator.
2. Rochelle salt used as transducer in gramophones, ear phones.
3. Ceramics are used as high voltage generators, accelerometers.
4. Semiconductors used as amplifier of ultrasonic waves.

Pyro electricity:

Pyro electric effect is the change in the spontaneous polarization when the temperature of the specimen is changed.

The pyro electric coefficient λ is defined as the change in polarization per unit temperature change of specimen.

$$\lambda = \frac{dP}{dT}$$

Applications: the pyro electric materials such as $BaTiO_3$, $LiNiBO_3$ etc are used to make very good infra red detectors which can operate at room temperature.

Ferro electricity:

There are some classes of dielectrics which posses a

i. Non linear relation between P & E.
ii. Dielectric constant that changes with temperature.
iii. Electrical hysteresis.
i.e., variation of polarization with applied field.

Therefore, Ferro electric materials are that class of dielectric materials which popsses electrical properties which are analogues to the magnetic properties of a ferro magnetic materials.

Example: $BaTiO_3$, KH_2PO_4, $NaKC_4H_4O_6.4H_20$, Rochelle salt.

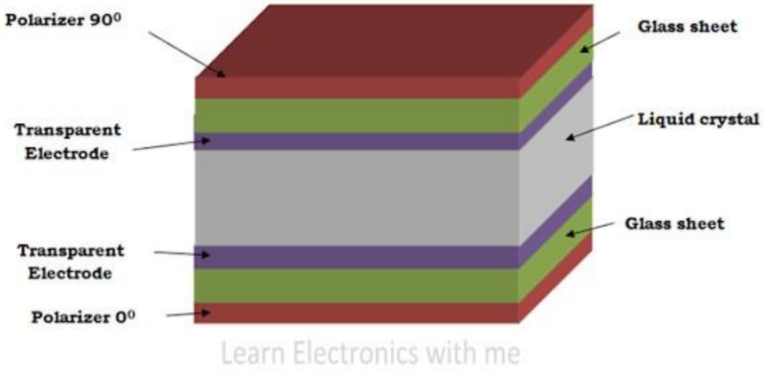
Applications:

1. Used to manufacture small sized capacitors of large capacitance
2. Used as memory devices in computers
3. Used to detect infrared solutions
4. Used in electromechanical filters.

LIQUID CRYSTAL DISPLAY:-

Liquid Crystal Display (LCD) is an flat display screen used in electronic devices such as laptop, computer, TV, cellphones and portable video games. As the name says liquid crystal is a material which flows like a liquid and shows some properties of solid. These LCD are vey thin displays and it consumes less power than LEDs.

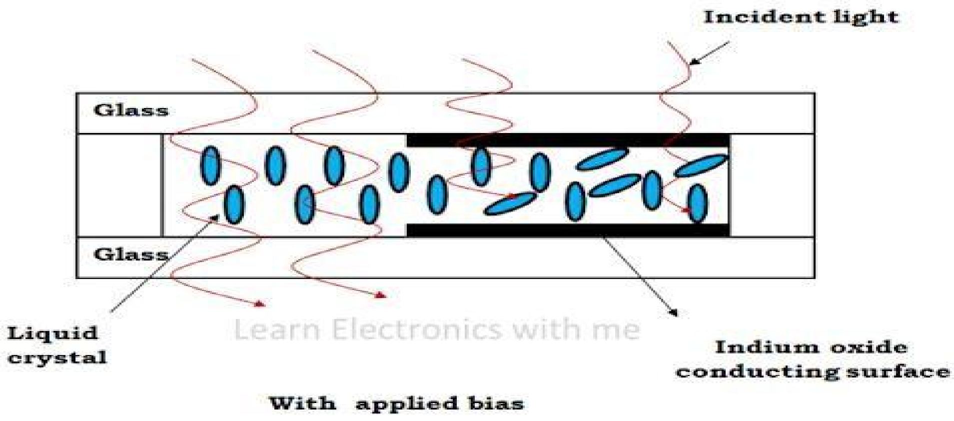
Construction of Liquid Crystal Display:



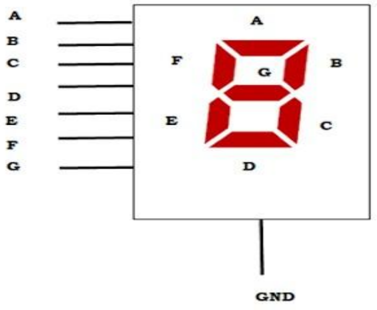
Construction of LCD consists of two polarized glass pieces. Two electrodes are used, one is positive and the other one is negative. External potential is applied to LCD through this electrodes and it is made up of indium-tin-oxide. Liquid crystal layer of about 10μm- 20μm is placed between two glass sheets. The light is passed or blocked by changing the polarization.

Working of Liquid Crystal Display

The basic working principle of LCD is blocking of light. It does not produce light on its own. So external light source is used. When the external light passes from one polarizer to the next polarizer, external supply is given to the liquid crystal ,the polarized light aligns itself so that the image is produced in the screen.



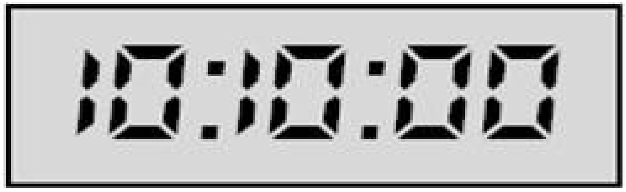
The indium oxide conducting surface is a transparent layer which is placed on both the sides of the sealed thick layer of liquid crystal . When no external bias is applied the molecular arrangement is not disturbed.

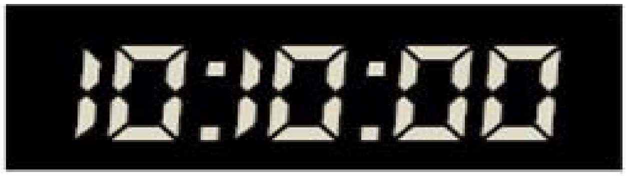


When the external bias is applied the molecular arrangement is disturbed and it and that area looks dark and the other area looks clear.

In the segment arrangement, the conducting segment looks dark and the other segment looks clear. To display number 2 , the segments A,B,G,E,D are energized.

Positive and Negative LCDs:





In positive LCD display the segments are dark and the background is white and the polarizers are placed perpendicular to each other. In the negative LCD display the segments are white in the dark background and the polarizers are aligned to each other.

Advantages:

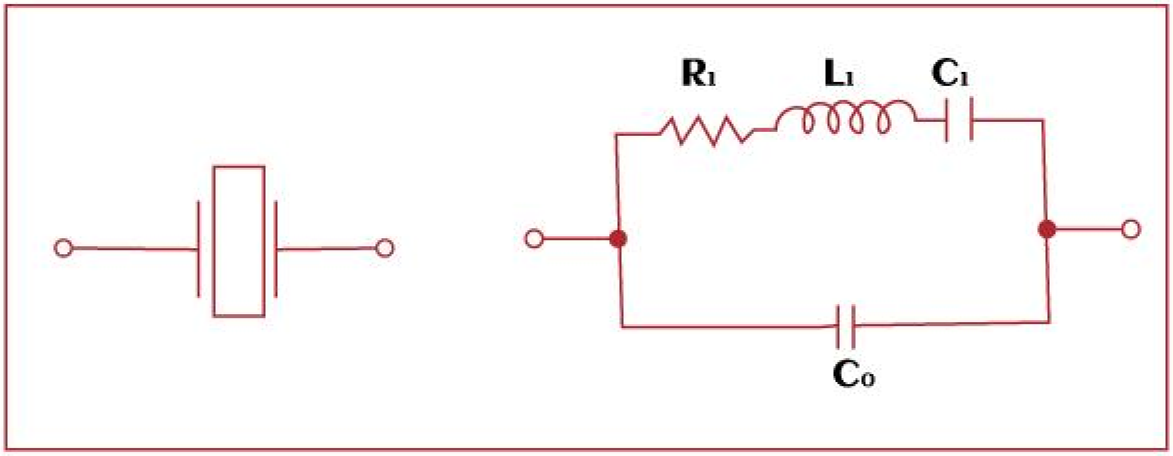
- It is thin and compact
- Low power consumption
- Less heat is emitted during operation
- Low cost **Disadvantages:**
- Speed of operation is low
- Lifespan is less
- Restricted viewing angles **Applications:**
- Used in digital wrist watch
- Display images in digital cameras
- Used in numerical counters
- Display screen in calculators

- Mainly used in television
- Used in mobile screens
- Used in video players
- Used in image sensing circuits

CRYSTAL OSCILLATOR:

The crystal oscillator is a quartz crystal used as a frequency selective element. The quartz crystal is also known as piezoelectric crystal. Hence the oscillator circuit containing piezoelectric crystal is called a crystal oscillator. It has two electrodes that supply signals to the crystal. Crystal oscillators have high-frequency stability and a high Quality factor compared to RC and LC tuned circuit oscillators. It is considered one of the highly stable oscillators suitable for high-frequency applications.

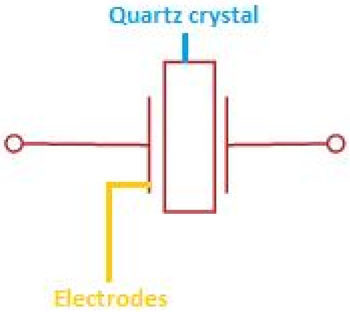
The circuit of a crystal oscillator is shown below



The quartz crystal is attached in parallel with the resonant circuit of the oscillator. The resonant circuit includes a resistor, capacitor, and an inductor connected in series. Co is the static capacitance associated with the quartz crystal

Working :-

The input signal is applied to crystal oscillator circuit. It consists of a **crystal** and the **resonance circuit,** as shown above. The signal first passes through the electrodes of the quartz crystal. It changes its shape due to the applied voltage. When the voltage is removed, the crystal returns to its original shape. The crystal generates a small voltage before returning to its original position. The piezoelectric crystal uses the electrical signal to produce vibrations. It means that the crystal converts electrical energy into mechanical energy. The vibrations get converted into oscillations of constant frequency. The other terminal converts the mechanical energy back to electrical energy. The produced oscillations of constant frequency act like an RLC circuit. Once a crystal is adjusted to a specific frequency and other environmental factors, it starts maintaining a high frequency or high-Quality factor. The crystal oscillators cover frequencies below 1000 Hz and above 200M Hz.



MAGNETIC PROPERTIES

INTRODUCTION:

Magnetic materials are those substances which get magnetized when placed in a magnetic field. So, the substance develop magnetization which may be parallel or antiparallel to the applied field. Depending upon the magnitude and sign of response to the applid field, and also on the basis of temperature on the magnetic properties, all materials are classified as follows.

1. Diamagnetic materials
2. paramagnetic materials
3. ferromagnetic materials
4. antiferromagnetic materials
5. ferrimagnetic materials

PERMEABILITY:

The magnetic permeability (μ) of any material is the ratio of magnetic induction in the sample to the applied magnetic field intensity.

$$\mu = \frac{B}{H}$$

Units are H/m.

FIELD INTENSITY:

The magnetic field intensity (H) at any point in the magnetic field is the force experienced by an unit north pole placed at that point.

Units are A/m

MAGNETIC FIELD INDUCTION:

The magnetic field induction (B) or magnetic flux density in any material is the no.of lines of magnetic force passing through unit area perpendicularly.

Units are Wb/m^2 or Tesla

The magnetic induction B and intensity H are related by

$$B = \mu_0 H$$

Where μ_0 is permeability of free space=$4\pi\times10^{-7}$ H/m

In the medium, B= μH.

The ratio of μ/ μ0 is called relative permeability.so, $\mu_r = \frac{\mu}{\mu_0}$.

MAGNETIZATION:

When a magnetic substance is placed in a magnetic field, the substance acquires magnetic moment (M). The magnetic moment per unit volume of the substance is called as intensity of magnetization (I).

$$I = \frac{M}{v}$$

Units are A/m

MAGNETIC SUSCEPTIBILITY:

It is defined as the ratio of intensity of magnetization I to magnetic intensity H. Therefore,

$$\chi = \frac{I}{H}$$

It has no units.

ORIGIN OF MAGNETIC MOMENT:

An electron revolving in an orbit about the nucleus of an atom is a minute current loop and produces a magnetic field. It thus behaves like a magnetic dipole. Let us calculate its magnetic moment.

Let us consider an electron of mass 'm' and charge 'e' moving with speed 'v' in a circular bohr orbit of radius r. it constitutes a current of magnitude,

$$i = \frac{e}{T}$$

Where T is the orbital period of the electron.

Now,

$$T = \frac{2\pi r}{v}$$

So,

$$i = \frac{ev}{2\pi r}$$

From electromagnetic theory, the orbital magnetic dipole moment magnitude for a current I in loop of area A is

$$\mu_L = iA = \frac{ev}{2\pi r}\pi r^2 = \frac{evr}{2}$$

The orbital angular momentum is given by

$$l = mvr$$

$$\frac{\mu_L}{L} = \frac{e}{2m}$$

The (e/2m) ratio is called **gyro magnetic ratio.**

In vector form,$\vec{\mu_L} = -\left(\frac{e}{2m}\right)\vec{L}$

Where minus indicates they are in opposite direction. Units of magnetic dipole moment is amp-m^2 or J/T.

BOHR MAGNETON:

From wave mechanics, the permitted values of L are

$$L = \sqrt{L(L+1)}\frac{h}{2\pi}$$

Where l is orbital quantum number.

So, orbital magnetic moment is

$$\mu_L = L\frac{e}{2m}$$

$$= \sqrt{L(L+1)}\frac{eh}{4\pi m}$$

The quantity [eh/4πm] is called the 'Bohr magneton' denoted by μ_B. where μ_B =9.28*10^{-24} A-m^2.

Thus $\mu_L = \sqrt{L(L+1)}\mu_B$

CLASSIFICATION OF MAGNETIC MATERIALS:

The distinction of magnetic materials depends upon whether the atoms carry permanent magnetic dipoles or not.

Materials which are lack of permanent dipoles are called diamagnetic.

If the atoms of the material carry permanent magnetic dipoles, such materials may be

Paramagnetic- permanent dipoles do not interact among themselves.

Ferromagnetic- if they interact and line up themselves in parallel.

Anti Ferro & ferri magnetic: if they interact and line up themselves anti parallel

In anti ferromagnetic materials, the magnitude of permanent dipoles aligned anti parallel are equal and hence magnetization vanishes.

In ferri magnetic materials, the magnitude of permanent dipoles aligned anti parallel are not equal and hence exhibiting magnetization

Diamagnetic:

The substance which when placed in the magnetic field acquire feeble magnetism opposite to the direction of the field are known as dia magnetic substances.

Eg: bismuth (Bi), zinc (Zn), copper (Cu), silver (Ag), gold (Au)

Properties:

1. when a bar of dia-magnetic material is suspended freely between two magnetic poles, then the axis of the bar becomes perpendicular to magnetic field.
2. $\mu<1$ and x is negative.
3. When U-tube containing diamagnetic liquid is placed in magnetic field then it shows depression.
4. When a dia magnetic substance is placed in non uniform magnetic field then it tends to move from stronger part to the weaker part of the field.

Paramagnetic:

The substance which when placed in a magnetic field, acquire feeble magnetism in the direction of magnetic field are known as paramagnetic substance.

Eg: aluminum (Al), platinum (Pt), manganese (Mn), oxygen (O_2).

Properties:

1. When a bar of paramagnetic substance is placed in a magnetic field, it tries to concentrate the lines of force in to it.
2. $\mu>1$ and x is small & positive.
3. When a bar of paramagnetic substance is suspended freely between two magnetic poles, its axis becomes parallel to magnetic field.
4. When U-tube containing paramagnetic liquid is placed in magnetic field then it shows a rise.
5. When a dia magnetic substance is placed in non uniform magnetic field then it tends to move from weaker part to the stronger part of the field.

Ferro magnetic substances:

The substance which when placed in a magnetic field, becomes strongly magnetized in the direction of field are known as Ferro magnetic substances.

Eg: iron (Fe), nickel (Ni), cobalt (Co), magnate (Fe_3O_4).

Properties:

1. When a Ferro magnetic material is subjected to the influence of a magnetic field, there will be a crowding of flux lines in the body.
2. They are attracted by magnets.
3. Obeys curies law
$$\chi \propto \frac{1}{T}$$
4. Above curies temperature, Ferro magnetic substance changes to paramagnetic substance.
5. These all materials posses the propertie3s of paramagnetic substances.

DOMAIN THEORY OF FERROMAGNETISM ON THE BASIS OF HYSTERESIS CURVE:

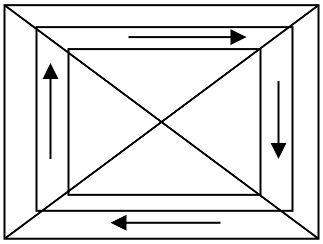
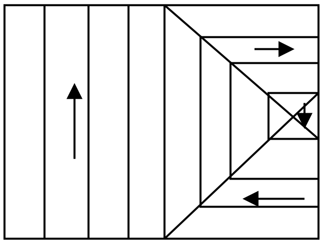
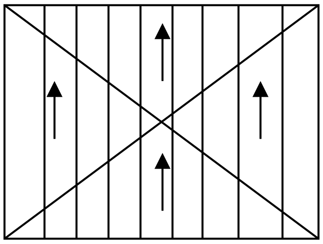
In Ferro magnetic substances, the atoms due to certain mutual interaction, form innumerable small effective regions called **domains**. Each domain contains 1017 to 1021 atoms whose magnetic axes are aligned in the same direction even in the absence of any external field. Each domain is strong magnet.

When a ferromagnetic substance is placed in an external magnetic field, the magnetic moment increase in two different ways:

1. ***By the displacement of the boundaries of the domains:***
   When the substance is placed in magnetic field, the domains which are oriented favorable with respect to the external field increases in size while those oriented opposite to the external field are reduced.
2. ***By the rotation of domains:***
   The domains rotate until their magnetic moment aligned more or less in the direction of external magnetic field.

   When external field is weak, the substance is magnetized mostly by the boundary displacement. On the other hand, in strong magnetic fields, the magnetization takes place mostly by the rotation of domains.

   On the removal of external field, the boundaries do not move completely back to their original position and hence the substance is not completely demagnetized. At high temperatures, the domains break up and ferromagnetic substance becomes paramagnetic.

Hysteresis curve:

Consider an unmagnetised ferromagnetic substances in a magnetizing field. The substance shows a relation between intensity of magnetization and strength of magnetic field. Thios property is called hysteresis.

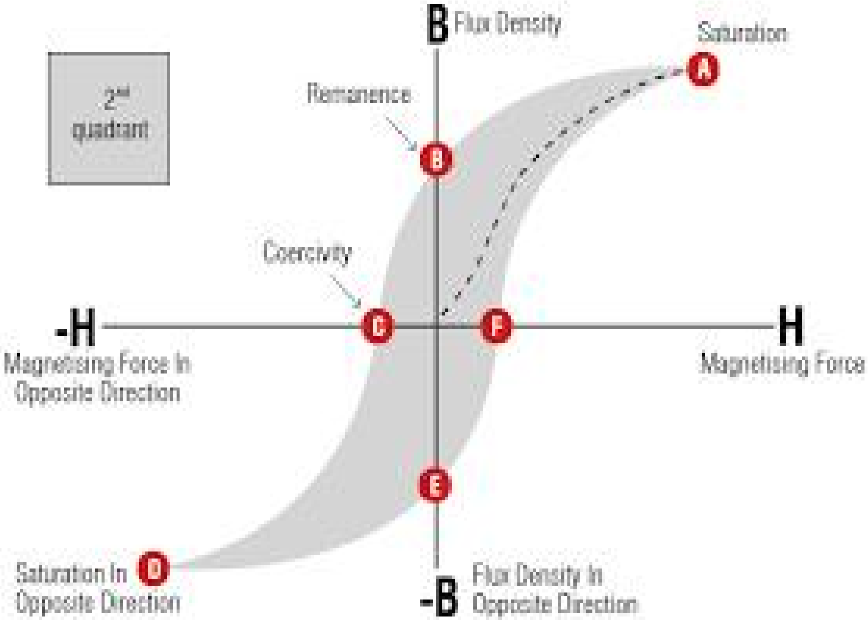
i. When a substances is slowly magnetized, the intensity of magnetization I increases with field H. As part OA.

   At point A, the intensity of magnetization I becomes constant. That is the state of magnetic saturation.

ii. Now, consider that magnetizing field H is decreased it is onvious from figure that intensity of magnetization also decreases but it doesn't follows the path AO. It follows the path AB. At B, I has some value even H=0. The value of intensity of magnetization for which H=o is called retentivity or residual magnetism.

iii. Further consider the direction of H is reversed. As H increases in reverse direction, I decreases and becomes zero. The value of magnetizing field for which residual magnetism is destroyed is called coercivity. Further increase of H in reverse direction gives saturation point D.

iv. If now the field is increased in steps, a curve DEFA is obtained. In throughout the cycle, I lags behind H. thus, lagging of intensity of magnetization behind the magnetic field is called hysteresis and path ABCDEFA is called hysteresis loop.

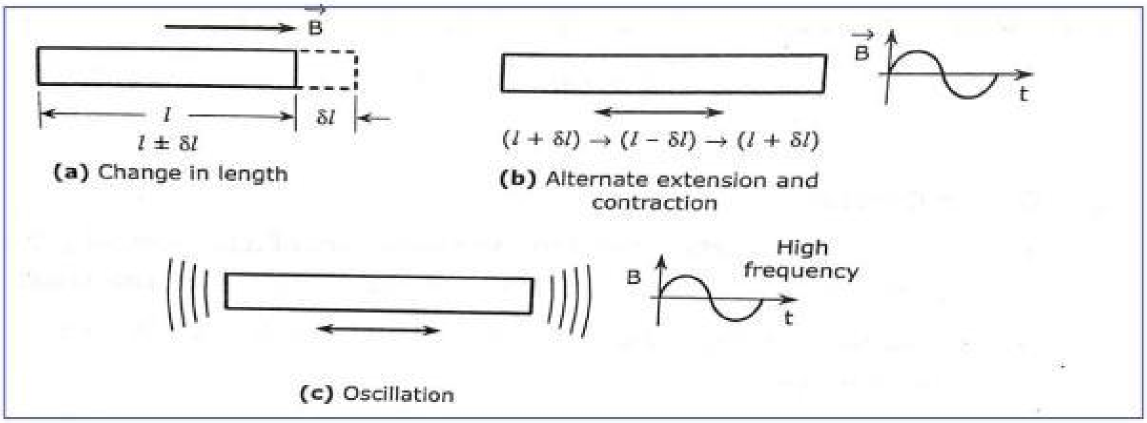


SOFT AND HARD MAGNETIC MATERIALS:

Hard magnetic materials	Soft magnetic materials
1. These materials have large hysteresis loss due to large hysteresis loop area.	1. These materials have less hysteresis loss due small hysteresis loop area.
2. In these materials domain wall movement is difficult.	2. In these domain walls movement is relatively easier.
3. Coercivity and retentivity are large. Hence magnetization and demagnetization of these materials is difficult.	3. Coercivity and retentivity are small. Hence magnetization and demagnetization of these materials is easy.

MAGNETOSTRICTION

When a ferromagnetic rod like iron, nickel is kept in the strong magnetic field parallel to it length, it is subjected to a change in dimensions. This is called magnetostriction effect. If the rod is placed in a rapidly varying magnetic field alternately expands and contracts with twice the frequency of the applied magnetic field. This change in length of the ferromagnetic material is independent of the polarity of applied magnetic field. The longitudinal expansion and contraction in ferromagnetic rod produces ultrasonic sound waves in the medium surrounding the nickel rod. The frequency range of the waves depend on the mode of vibration of the ferromagnetic material and may vary from few hundred to 3,00,000 Hz. Since, the rod vibrates longitudinally; the frequency of the fundamental mode of vibration can be used as



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

where Y is the Young's modulus of the material and ρ its density and m is mode of vibration. m=1 fundamental frequency, m=2 first over tone Similarly the frequency of LC oscillatory

circuit is

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

MAGNETORESISTANCE :-

It was discovered by William Thomson in 1856

The change in the electrical resistance of certain materials under the application of external magnetic field is known as magneroresistance. The materials which exhibit this nature are known as the magnetoresistors. The resistance of the magnetoresistors are directly proportional to the magnetic field.

Working Principle: In the absence of the magnetic field, the charge carriers of the magneto resistor move in the straight path. But when the field is applied, the electrons will experience a force, which will increases the path length and the collisions of electrons. This will result in increase in the resistance of the material. These magnetoresistors are classified into three categories.

1.Giant magnetoresistors (GMR): In these magnetoresistors, the resistance will becomes small when their ferromagnetic layers are parallel to each other and vice versa.

2. Extraordinary magnetoresistors: In these magnetoresistors, the resistance of the material is high in the absence of magnetic field and low in the presence of a field.

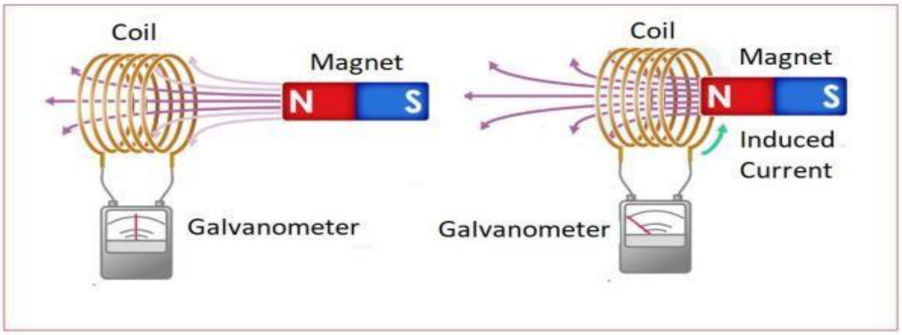
3. Tunnel magnetoresistors: In these magnetoresistors, the heavy current flows if the magnetisation of the electrodes is parallel to each other. The antiparallel arrangement increases the resistance between the layer.

MAGNETIC FIELD SENSORS:-

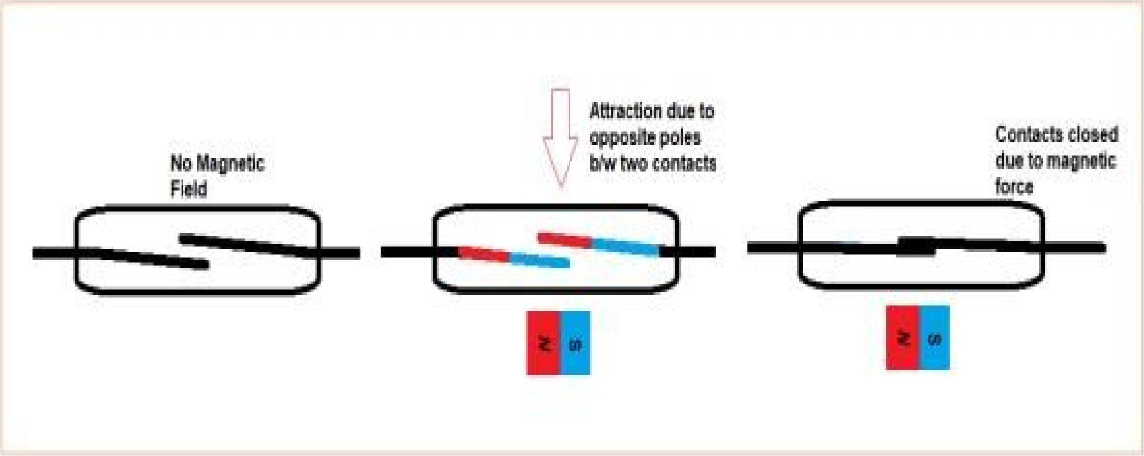
Magnetic field sensors are the devices that detect and measure magnetic fields around permanent magnets, current conductors, and electrical devices. These devices are very accurate, space efficient and operate with little power. These magnetic sensor works by converting the variations of a magnetic field and its magnitude into electric signals.

Typical magnetic sensors and their application

a) Coils: The coil is used detect the variations in a magnetic field. when a magnet is moved towards a coil , the magnetic flux density in the coil will increases. This increase in magnetic flux density in the coil result in the induced electromotive force and induced current. The measurement of the induced electromotive force and current will allow you to detect the ratio of change in magnetic flux density and its direction. These coils will become a highly sensitive magnetic sensors when combined with other coils or magnetic materials. The typical examples for the coil sensors are search coils, rotation angle sensors (resolvers), fluxgate sensors.



b) **Reed switches:** The device consist of a glass tube filled with inert gas to prevent the activation (deterioration) of the contacts.



These glass tube consist two reeds (contacts), made of nickel or other magnetic material and come from the right and left ends of the tube. The role of the inert gas is to prevent the deterioration of the contacts. In the absence of the field, the reed switch is open. But under the application of magnetic field, the magnetic material is magnetized and the contacts are attracted to each other closing the circuit (conduction state).

Unlike semiconductor sensors such as MR sensor elements or Hall elements, the reed switch operates without a power supply and is therefore often used in automobiles or other locations where power is difficult to supply.

c) **MR (Magnetoresistance) sensor elements:** These sensors works on the principle of magnetoresistance effect. There are a number of MR sensor types using different operating principles.

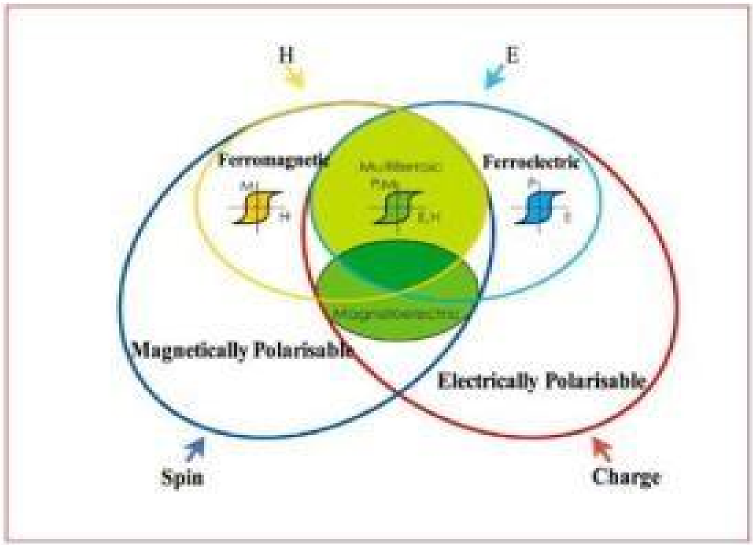
d) **Anisotropic Magneto-Resistance (AMR) sensor elements**: It is discovered by William Thomson in 1956. Anisotropic Magneto-Resistance effect is exhibited by the ferromagnetic material when placed in an external magnetic field. When the direction of magnetization in a ferromagnetic material is parallel to the current, the electron orbital becomes perpendicular to the current. This will increases the spin-dependent scattering of electrons and the resistance of the material will increases.

Similarly when the direction of magnetization is perpendicular to the current, the electron orbital becomes horizontal to the current. This will reducing the spin-dependent scattering and the resistance of the material will decreases. The rate of change in resistance caused by the state of the magnetic field is called magnetoresistive ratio (MR ratio). The MR ratio for an AMR sensor element is about 5%. The AMR sensor element is often used in magnetic switches and rotation sensors because of its simple structure.

MULTIFERROICS (MFS)

There three fundamental ferroic behaviours in nature, namely

- Ferromagnetism
- Ferroelectricity
- Ferroelasiticity



Multiferroics are those materials which will exhibit more than one ferroic behaviour simultaneously. However the multiferroics which will exhibit ferromagnetism and ferroelectricity are more popular and have vast applications. In these materials the intensity of magnetization can be controlled by the electric field intensity and polarization can be controlled by the magnetic field. These multiferroics are classified in two categories i.e. type-I multiferroics and type-II multiferroics

Type-I multiferroics: These materials show a linear magnetoelectric response, as well as changes in dielectric susceptibility at the magnetic phase transition. In these materials the ferroelectricity and ferromagnetism will occur at different temperatures. The ferroelectricity (which requires the structural distortion) occurs at high temperature but the magnetic ordering (usually anti ferromagnetic) occurs at low temperature.

Ex: BeFO3 (Beryllium Fluorate)

Type-II multiferroics: These are the materials in which the magnetic ordering breaks the inversion symmetry and directly causes the ferroelectricity. In these materials the ferroelectricity and ferromagnetism will occur at same temperatures.

Ex: $TbMn2O5$ (Terbium Manganese Pentoxolane)

Applications : Multiferroics have potential for applications as actuators, switches, magnetic field sensors and new types of electronic memory devices.

4-NANOTECHNOLOGY

INTRODUCTION:

In recent years nanotechnology has become one of the most important and exciting forefront field in physics, chemistry, and biology and engineering and technology. Nano means 10^{-9}. Atoms are extremely small. For example,

One carbon atom-0.15nm in diameter

Water molecule-0.3nm

Red blood cells-7000nm

Human hair-80000nm

NANOMATERIALS:

Those materials which have structured components with size less than 100nm at least in one dimension are called as nanomaterial's. Materials that are Nano scale in 1-D are layers, such as thin films or surface coatings. Materials that are Nano scale in 2-D includes nanowires and nanotubes. Materials that are Nano scale in 3-D are particles. For example precipitates, collides and quantum dots (tiny particles of semiconductor materials) and Nano crystals.

CLASSIFICATION OF NANO MATERIALS:

There are two categories

- Fullerenes
- Inorganic compounds or nanoparticles

Fullerenes: class of allotropes of carbon which are grapheme sheets rolled into tubes or hollow spheres.

Spherical fullerence-bucky balls

Cylindrical fullerence-bucky tubes or Nano tubes

Discovered by Bucky inster fullereneC_{60} in 1950.Carbon nanotubes [CNTs] are allotropes of carbon with cylindrical nanostructures. CNTs are categorised as single walled nanotubes [SWNTs] and multiwallnanotubes. They are applicable in nanotechnology, electronics, optic and material science. They exhibit extraordinary strength and unique electrical properties. They are efficient conductors of heat.

NANOPARTICLES:

These particles are sized between 1 to 100nm. Some of them are

- Nano clusters have dimension between 1 to 100nm.
- Nano powders are fragments of nanoparticles or Nano clusters
- Nanometre sized single crystals are called Nano crystals.
- When nanoparticles are in suspended form in liquid phase, it is called Nano collides.
- Quantum dots are tiny particles of semiconducting materials.

PROPERTIES OF NANOPARTICLES ARE DIFFERENT:

Two principle factors cause the properties of nanomaterial's to differ significantly from other materials

1. Increase in surface area to volume ratio:

   First, Nano materials have a relatively larger surface area when compared to the other material of same volume. Consider a sphere of radius "r". Its surface area, A=$4\pi r^2$. And its volume is V=$\frac{4}{3}\pi r^3$. So,

$$\frac{A}{V}=\frac{3}{r}$$

Hence, when radius decreases, its surface area to volume ratio increases.

Consider a cubic volume

Surface area=$6m^2$. When it is divided into eight pieces, surface area= $6 \times \left(\frac{1}{2}\right)^2 \times 8 = 12\, m^2$.

When the same volume divided in to 27 pieces, surface area= $6 \times \left(\frac{1}{3}\right)^2 \times 27 = 18\, m^2$.

Hence nanoparticles have a much greater surface area per given volume. Therefore it makes particles more chemically reactive. In some cases materials that are inert in larger form are reactive when produced in their Nano scale form. This affects their strength and electrical properties.

QUANTUM CONFINEMENT EFFECTS:

When atoms are isolated the energy levels are discrete. When very large no. of atoms are closely packed to form a solid, the energy levels split and form bands. When dimension of wells or box are of the order of de-Broglie wavelength of electrons or mean free path of electrons then energy levels of electrons changed. This effect is called quantum confinement. Due to this, the optical, electrical and magnetic behaviour of materials can affect.

PROPERTIES OF NANOMATERIALS:

- Mechanical properties: most metals used for different purposes are made up of small crystalline grains. The boundaries between the grains arrest the propagation of defects when the material is stressed, thus giving it strength. If these grains can be made very small, the interface area within the material increases, which enhances its strength.
  Eg: Nano crystalline nickel is as strong as hardened steel.
- Chemical properties: as the particle size decreases, the inter particle spacing decreases in metals and the surface area increases. As a result
  - Melting point decreases
  - Enhanced activity applications such as catalyst.
- Magnetic properties: as the particle size decreases, the formation of domain wall becomes energetically unfavourable and the particles are called single domain particles with a critical diameter. Hence, the magnetisation requires the coherent rotation of spins resulting in large coercivities.

FABRICATION OF NANOMATERIALS:

In general there are two approaches to produce nanoparticles

- Top-down technique
- Bottom-up technique

TOP DOWN TECHNIQUE:

It involves starting with a block of individual material and then milling it down to the desired size. Nano material particles can be made through this method. For example turmeric powder. This method includes

- ✓ Chemical vapour deposition

- ✓ Physical vapour deposition
- ✓ Ball milling method

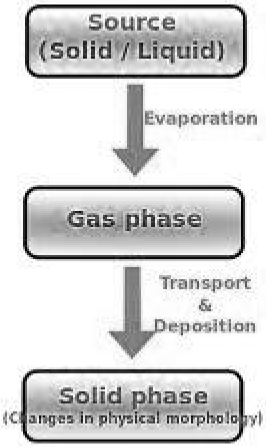
1. Chemical vapour deposition: [CVD]

In this, the synthesis is achieved by putting a carbon source in the gas phase and using an energy source, such as plasma or a resistively heated coil to transfer energy to a gaseous carbon molecule. Commonly used gaseous carbon sources include methane, carbon monoxide and acetylene. The energy source is used to crack the molecule into reactive atomic carbon. Then, the carbon diffuses towards the substrates, which is heated and coated with a catalyst where it binds. Carbon nanotubes are formed if the proper parameters are maintained.

By CVD carbon nanotube synthesis is essentially a two-step process consisting of a catalyst preparation step followed by the actual synthesis of the nanotubes. The temperature for the synthesis of nanotubes by CVD is generally within the 650-900 C range. If the energy source is plasma then it is plasma enhanced CVD or if the energy source is heating coil then it is thermally enhanced CVD. The carbon nanotubes formed are multiwall. The diameter range of the carbon nanotubes depends on the thickness of the catalytic film. Excellent alignment as well as positional control on nanometre scale, control over the diameter, as well as the growth rate of the nanotubes can also be achieved by using CVD.

2. Physical vapour deposition:[PVD]

This is one of the methods of preparation of nanoparticles and is used to describe any of a variety of methods to deposit thin films by the condensation of a vaporised form of the material onto various surfaces. The coating method involves purely physical processes such as high temperature vacuum evaporation and hence the name physical vapour deposition. Methods of PVD are:



- Evaporative deposition: in which the material to be deposited is heated to a high vapour pressure by electrically resistive heating in low vacuum.
- Electron beam physical vapour deposition: in which the material to be deposited is heated to high vapour pressure by electron bombardment in high vacuum.
- Sputter deposition: in which a glow plasma discharge bombards the material sputtering some away as a vapour.
- Cathode arc deposition: in which a high power arc directed at the target material blasts away some into a vapour.
- Pulsed laser deposition: in which a high power laser ablates material from the target into a vapour.

3.BALL MILLING METHOD :-

In ball milling, also called mechanical crushing, small balls are allowed to rotate around the inside of a drum and then fall on a solid with gravity force and crush the solid into nano crystallites. Ball milling can be used to prepare a wide range of elemental and oxide powders.

For example iron with grain sizes of 10-30 nm can be formed. Other crystallites such as iron nitriles can be made using ammonia gas. A variety of intermetallic compounds based on nickel and aluminum can be formed. Ball milling is the preferred method for preparing metal oxides.

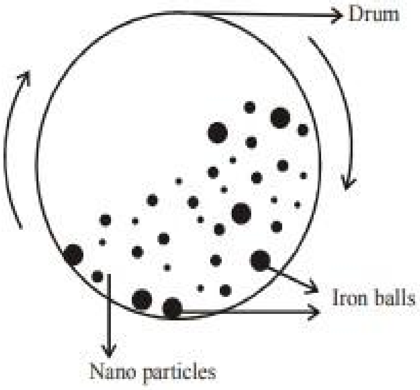


Fig. Ball Moulding

BOTTOM UP TECHNIQUE:

It involves the assembly of smaller sub unit to make larger structure. For example honey behaves made in nature by honey bees. The process involves the building of desired structures, atom by atom or molecule by molecule. This method includes

- ✓ Sol-Gel process
- ✓ Precipitation method
- ✓ Combustion method.

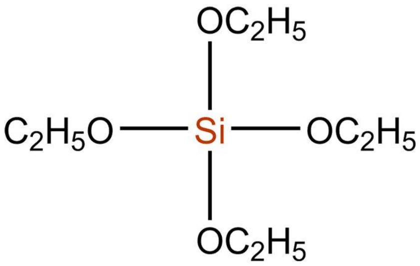
1. Sol-Gel method:

Initially a homogeneous solution [Sol] of a material is prepared and used as a precursor for nanofabrication. The Sol is deposited on a suitable substrate by spraying, dipping or spinning. It is kept for a while for gelation [Gel]. During this 'gelation time' the material gradually losses its fluidity and undergoes transition from viscous liquid state to elastic solid state.

The desired nanomaterial is finally fabricated from the Gel by further processing of heat treatment etc.

Eg: material processed by this method is TEOS-$(C_2H_5O)_3 - Si - OC_2H_5$

TEOS is a molecule which displays 4 functional arms $(O - C_2H_5)$. In the presence of water, the arms $(O - C_2H_5)$ are transformed into new and very reactive $(O - H)$ arms, via hydrolysis.



$$(C_2H_5O)_3 - Si - OC_2H_5 + H_2O \rightarrow (C_2H_5O)_3 - Si - OH + C_2H_5OH$$

The resulting compounds will interact together to form a Si-O-Si bridge, which will link them together. The reaction is called polycondensation.

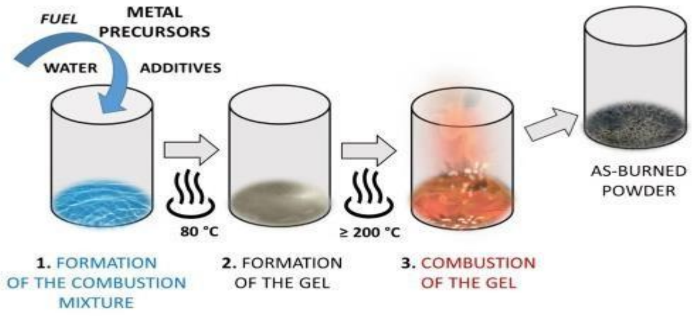
$$\begin{aligned}(C_2H_5O)_3 - Si - OH + OH - Si - (C_2H_5O)_3 \\ \rightarrow (C_2H_5O)_3 - Si - O - Si - (C_2H_5O)_3\end{aligned}$$

This forms a polymeric tri-dimensional network. This is a Gel.

2. Combustion method

Combustion reaction: when a substance reacts with oxygen, forming light and heat in the form of fire. Combustion is a high-temperature exothermic (heat releasing) redox (oxygen adding) chemical reaction between a fuel and an oxidant. For example, when methane burns in oxygen, it releases carbon dioxide and water. The formation of carbon dioxide shows the carbon present in the methane has undergone oxidation.

For the combustion process, fuel and oxidizer are required; metal nitrate acts as an oxidizing reactant and urea acts as a reducing reactant. The synthesis process involves weighing solid precursors, then grinding and mixing generally in an aqueous solution of distilled water in which the ingredients are dissolved.



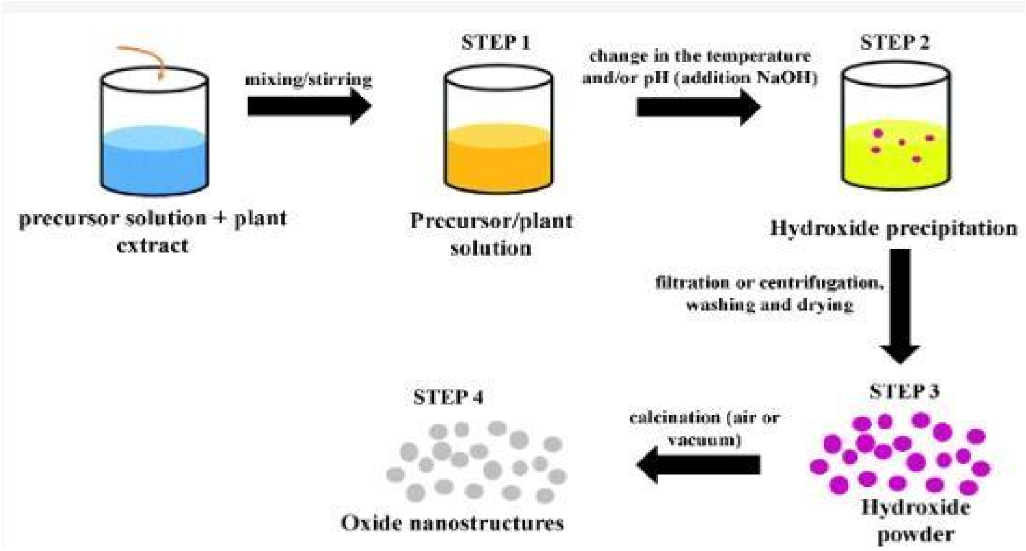
3. Chemical Precipitation and Co-precipitation

A chemical precipitation process consists of three main steps:

- chemical reaction
- nucleation
- crystal growth

Chemical precipitation is generally not a controlled process in terms of reaction kinetics and the solid phase nucleation and growth processes. Therefore, solids obtained by chemical precipitation have a wide particle size distribution plus uncontrolled particle morphology, along with agglomeration. To obtain nanoparticles with a narrow size distribution, the necessary requirements are (i) a high degree of supersaturation, (ii) a uniform spatial concentration distribution inside a reactor and (iii) a uniform growth time for all particles or crystals.

The other commonly used solution method for the synthesis of multi component oxide ceramics is co-precipitation method, which produces a "mixed" precipitate comprising two or more insoluble species that are simultaneously removed from solution. The precursors used in this method are mostly inorganic salts (nitrate, chloride, sulfate, etc.) that are dissolved in water or any other suitable medium to form a homogeneous solution with clusters of ions. The solution is then subjected to pH adjustment or evaporation to force those salts to precipitate as hydroxides, hydrous oxides, or oxalates. The crystal growth and their aggregation are influenced by the concentration of salt, temperature, the actual pH and the rate of pH change. After precipitation, the solid mass is collected, washed and gradually dried by heating to the boiling point of the medium.

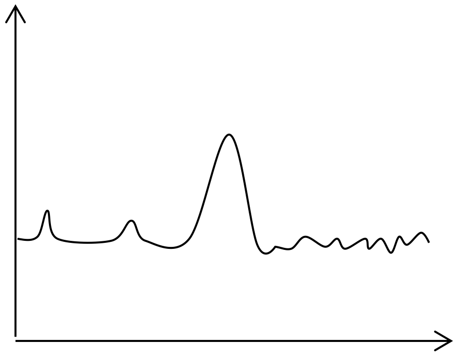


CHARACTERISATION OF NANOMATERIALS:

For characterisation of nanoparticles both X-ray diffraction [XRD] and transmission electron microscope [TEM] are the most widely used techniques.

XRD analysis:

Typical XRD pattern of silver particles prepared by chemical method is as shown



From this study considering the peak of diffraction angle at 45 degrees, average particle size has been estimated by using DebyeScherer formula particle diameter is given by

$$D = \frac{0.9\lambda}{W\cos\theta}$$

Where, $\lambda -$ wavelength of X-ray

W- FWHM

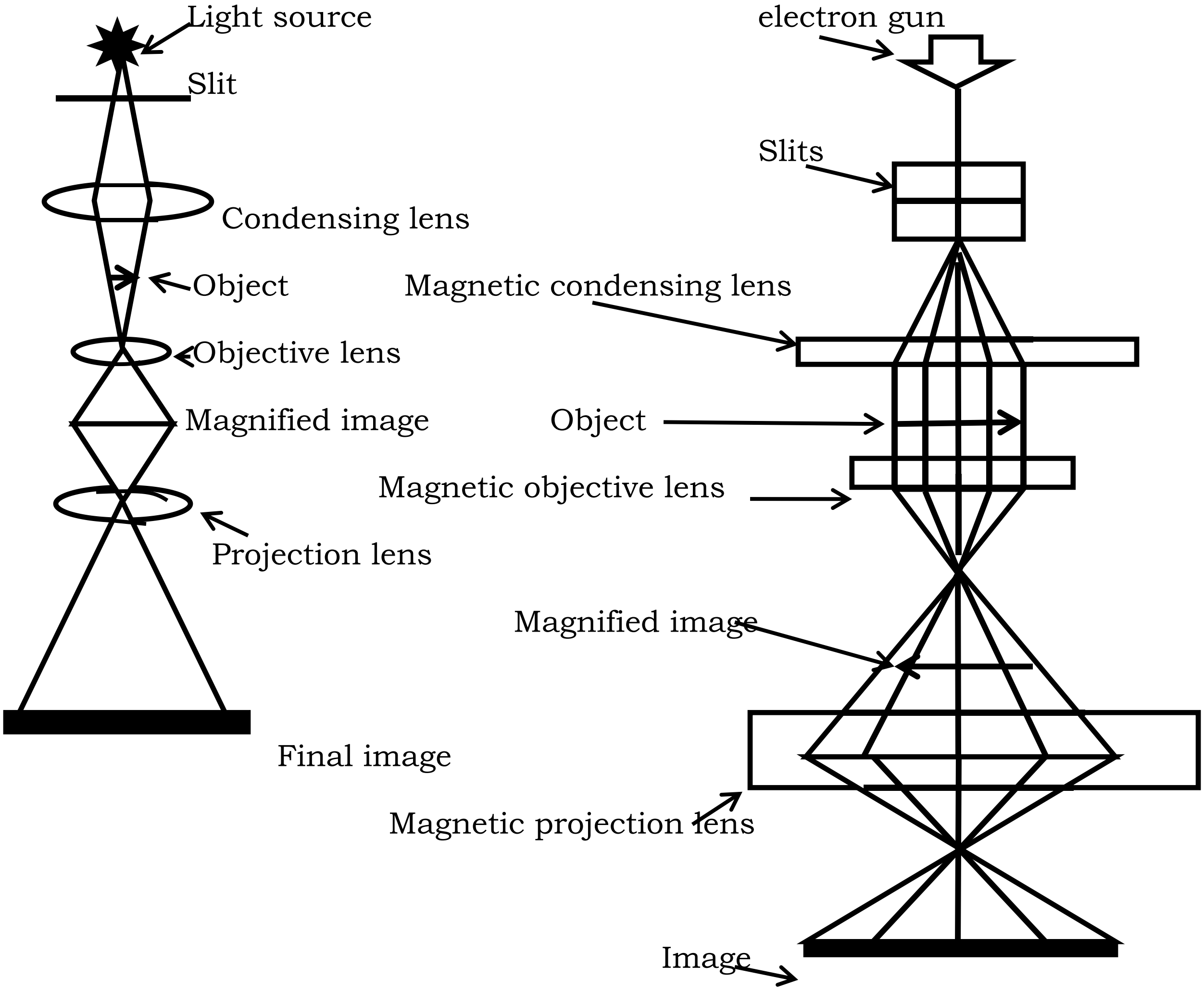
$\theta -$ Diffraction angle.

The average size of particle is 14 nm

ELECTRON MICROSCOPE:

Immediate application of wave nature of matter is electron microscope. Resolving power of microscope is inversely proportional to wavelength of radiation. An electron microscope is similar in principle to optical microscope.

The electrons from the filament are accelerating by a large potential applied to the electrodes in electron gun. These accelerated electrons passes through a electromagnet which acts as condensing lens. Parallel beam of electrons from this falls on the object to be magnified. Transparent regions of object transmit more electrons while denser regions transmit less. Thus, the electron beam transmitted by the object carries the image. The next electromagnet called magnetic objective lens forms an enlarged image of the object on its other side. The projection lens further magnifies this image on the fluorescent screen producing a final image.



TEM: transmission electron microscope

TEMs are patterened after the transmission light microscope. And will yield similar information.

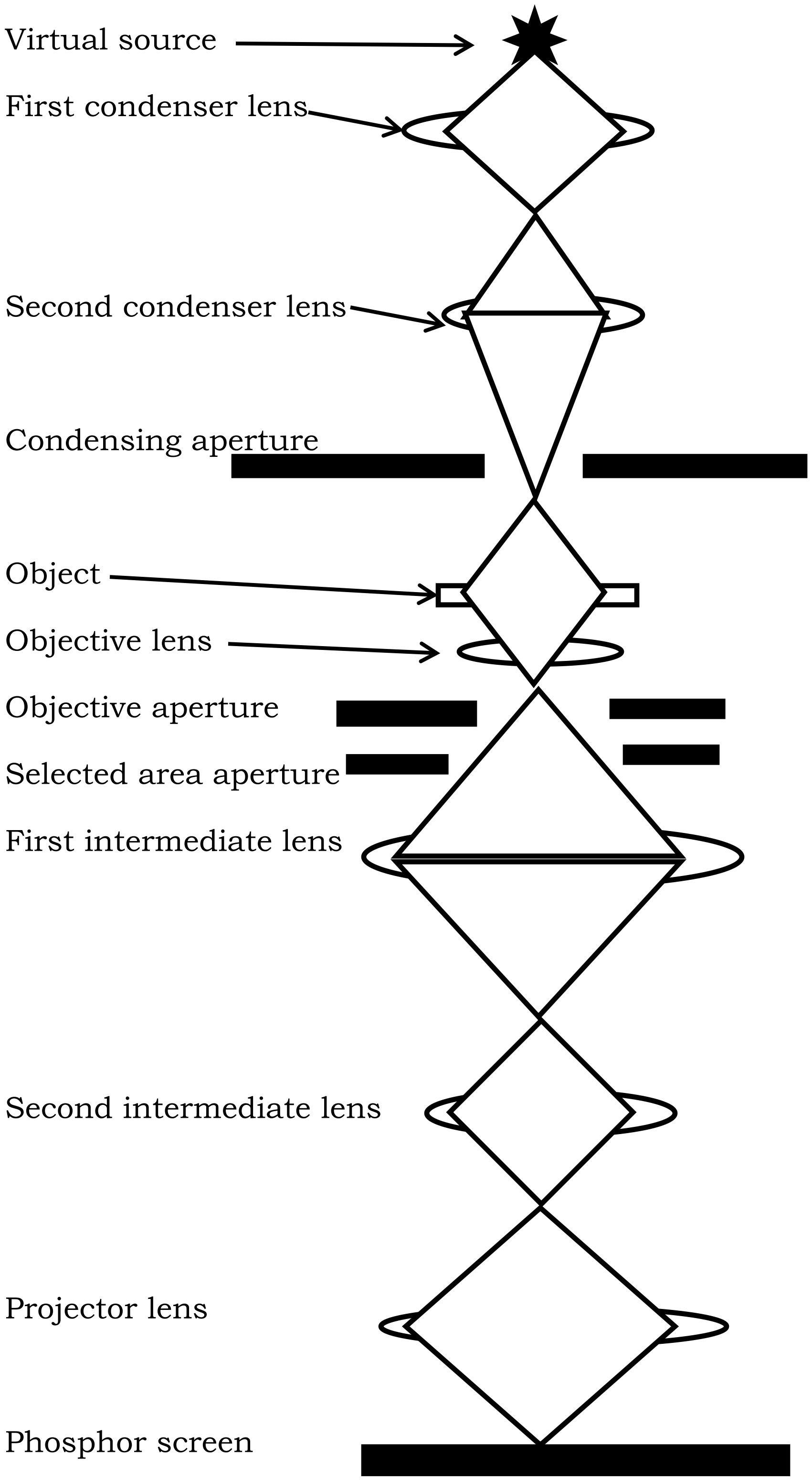
Morphology: the shape, size and arrangement of particles which make up the specimen as well as their relationship between each other on the scale of atomic diameters.

Crystallographic information: the arrangement of atoms in the specimen and their degree of order, detection of atomic-scale defects in areas a few nanometre's in diameter.

Compositional information: the elements and compounds of the sample is composed of and their relative ratios in areas a few nanometre's in diameter.

Working of TEM is as follows:

- The "virtual source" at the top represents the gun, producing a stream of monochromatic electrons.This stream is focussed to a small, thin, coherent beam by the use of condenser lens 1 and 2.
- The beam is restricted by the condenser aperture knocking out high angle electrons.
- Beam strikes the specimen and parts of it are transmitted.The transmitted portion is focused by the lens into an image.
- The objective and selected area apertures can restrict the beam.The image is passed through the intermediate and projector lenses being enlarged all the way.
- The image strikes the phosphor screen and light is generated, allowing the user to see.


Virtual source
First condenser lens
Second condenser lens
Condensing aperture
Object
Objective lens
Objective aperture
Selected area aperture
First intermediate lens
Second intermediate lens
Projector lens
Phosphor screen

APPLICATIONS OF NANOTECHNOLOGY:

- In dispersed state nanoparticlesare used as filters, paints, magnetic recording media, Ferro fluids, drugs, phosphors, rocket propellant, fuel additives etc.
- Material technology:
  - Cutting tools made of Nano crystalline materials find applications in the drills used to bore holes in circuit boards.
  - Wear and scratch resistant hard coatings which are placed between hard outer layer and substrate material to improve adhesion.
  - Synthesis of harder metals having hardness 5 times higher than normal metals
  - Useful in magneto resistance spin valves.
  - Useful in higher catalytic activity.
  - A carbon nanoparticle act as filters in a matrix. For example, they are used as a filler to reinforce car tyres
  - Nano coating of highly activated titanium dioxide is highly hydrophobic and antibacterial.
  - These are used in motors, analytic instruments like magnetic resonance imaging [MRI] due to their high coercivity.
  - Nano sized iron oxide is present in some lip sticks as a pigment.
- Information technology:
  - Nano scale fabricated magnetic materials also have applications in data storage. The area required to record one piece of information can be shrunk in the Nano scale, the storage capacity of the disk can be improved dramatically.
  - Coatings with thickness controlled at the Nano scale have been used in optic electronic devices, catalytically active and chemically functionalised surface.
  - Nanoparticles are used for information storage
  - Quantum electronic devices have started replacing bulky conventional devices.
  - Nano dimensional photonic crystals are used in chemical/ optical computers.
- Bio-medical:
  - Nano crystalline zirconium oxide is hard, wear resistant, bio-corrosion resistant and bio-compatible. It

therefore presents an attractive alternative material for implants.

- Nano crystalline silicon carbide is a candidate material for artificial heart valves primarily because of its low weight, high strength and inertness.
- Bio sensitive nanoparticles are used for tagging of DNA and DNA chips.
- Controlled drug delivery is possible using nanotechnology
- Nanostructured ceramics readily interact with bone cells and hence find applications as an implant material.

- Energy storage:

- Addition of Nano particulate cerium oxide to diesel fuel improves fuel economy.
- The hydrogen used as the immediate fuel in cells is generated from hydrocarbons by catalytic reforming.
- Nano-crystalline materials synthesized by Sol-Gel techniques are candidates for separator plates in batteries.
- Since the hydrogen absorbing capacity increases with decrease in size of nanoparticles, nanoparticles of Ni, Pd and Pt are useful in hydrogen storage devices.

UNIT-5

LASERS & FIBRE OPTICS

INTRODUCTION:

The light emitted from a conventional light source said to be incoherent because the radiation emitted from different atoms do not bear any definite phase relationship with each other.

LASER-light amplification by stimulated emission of radiation.

LASER is also a light source having high monochromacity, high intensity, high directionality and high degree of coherence. Lasing has been extended up to γ −rays. γ −Ray Lasers are called as Grasers. The Laser is the outgrowth of Maser which means microwave amplification by stimulated emission of radiation. If the stimulated radiation lies in optical region, then the device is called as optical MASER or LASER.

CHARACTERISTICS OF LASER:

The important characteristics of a LASER radiation are

Monochromatic: The Laser light is highly monochromatic. The spread is of the order of few angstroms only. That is less than 10A. and Laser emit continuous waves of very long duration.

Directional: The emitted lights from LASER are only in one direction as the photons travelling along the optical axis of the system.

Coherent: the waves emitted by a laser source will be in phase and are of same frequency. Whereas convention light source [incandescent lamp] emits random wavelength light waves with no common phase relationship.

Intensity: a LASER beam emits light in the form of a narrow beam which propagates in the form of plane waves. As the energy is concentrated in a very narrow region, its intensity is tremendously high. It is estimated that light from a typical 1mW LASER is 10000 times brighter than the light from the source at the earth’s surface.

Divergence:the divergence or angular speed of the LASER beam is extremely small. The angular speed is given by

$$\Delta\theta = \frac{1.22\lambda}{d}$$

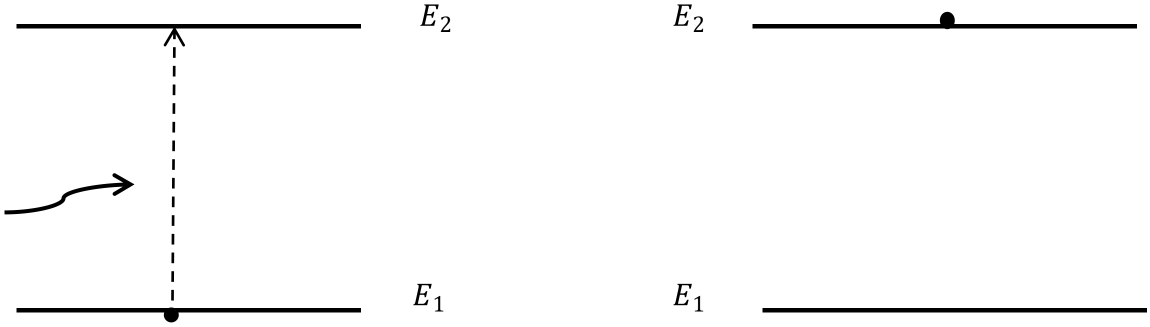
Where ‘d’ is diameter of the front mirror. In case of gas lasers $\Delta\theta$ is small as 10^{-5} to 10^{-6} radians.

SPONTANEOUS AND STIMULATED EMISSION OF RADIATION:

Consider a radiation interacts with matter. for interaction to occur, first of all the energy of the interacting photon $h\vartheta$ must match with energy difference between the two states of the atoms involved in the interaction.

Stimulated absorption:

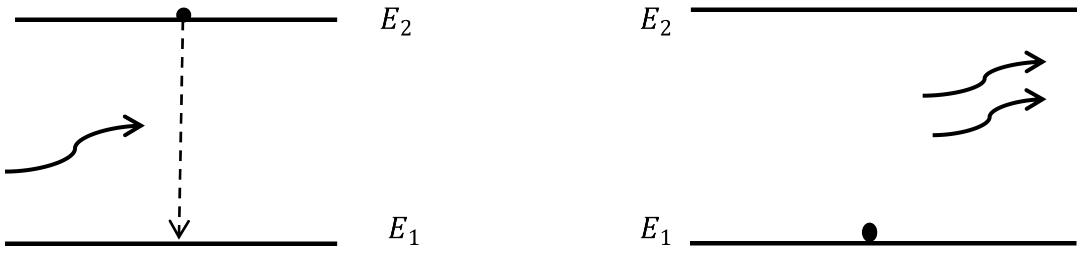
If the radiation interacts with atoms in the lower energy state say E_1, the atoms absorb the energy and get excited to higher energy state E_2. This process is called stimulated absorption.



Initial state final state

Stimulated emission:

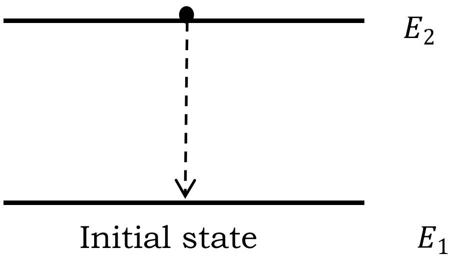
If the radiation interacts with atoms which are already in the exicted state E_2, then the atom comes to the lower energy state E_1 occurs with the emission of photons of energy $h\vartheta$. This process is called stimulated emission.

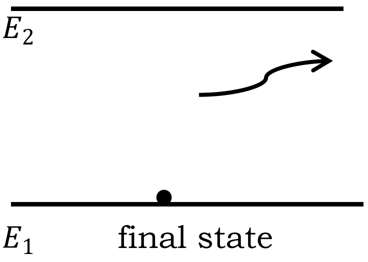


Initial state final state

Spontaneous emission:

In this process, the atoms in the exited state drop to the lower energy state after they have stayed in excited state for some time called life time. During this process, photon of energy $h\vartheta$ has been emitted. The life time of the particle in the excited state is of the order 10^{-8} sec. There exist some excited states in which life time is much greater than 10^{-8} sec. these states are called metastable states. The life time of the atom in meta stable state is of the order 10^{-3}sec.





EINSTEIN COEFFICIENTS AND THEIR RELATIONS:

Consider a substance, in which the process of stimulated absorption, spontaneous emission and stimulated emission occur simultaneously. Let N_1 be the no. of atoms per unit volume with energy E_1 and N_2 be the no. of atoms per unit volume with energy E_2. Let 'n' be the no. of photons per unit volume with a frequency ϑ such that $h\vartheta = E_2 - E_1$. Then, energy density of interacting photon is given by

$$\rho(\vartheta) = nh\vartheta \text{..................}(1)$$

Stimulated absorption rate depends on the no. of atoms available in E_1 as well as the energy density interacting radiation. Therefore, stimulated absorption rate is

$$\propto N_1$$

$$\propto \rho(\vartheta)$$

$$= \rho(\vartheta) N_1 B_{12} \text{............}(2)$$

Where B_{12} is Einstein coefficient of stimulated absorption.

Once they are excited to higher states, after their life time they move to their lower energy level spontaneously emitting photons. This spontaneous emission rate depends on the no. of atoms in the excited energy state. Therefore, spontaneous emission rate is

$$\propto N_2$$

$$= N_2A_{21}\text{............}(3)$$

WhereA_{21} is Einstein coefficient of spontaneous emission.

Before de-excitation to lower energy level, they may interact with photons resulting in stimulated emission of photon. That stimulated emission rate depends on

$$\propto N_2$$

$$\propto \rho(\vartheta)$$

$$= \rho(\vartheta)N_2B_{21}\text{............}(4)$$

Where B_{21} is Einstein coefficient of stimulated emission.

At equilibrium, the upward transition rate must be equal to downward transition rate.

$$\rho(\vartheta)N_1B_{12} = \rho(\vartheta)N_2B_{21} + N_2A_{21}$$

$$\rho(\vartheta) = \frac{A_{21}N_2}{N_1B_{12} - N_2B_{21}}$$

$$\rho(\vartheta) = \frac{{A_{21}}/{B_{21}}}{\frac{N_1}{N_2}\frac{B_{12}}{B_{21}} - 1}\text{..........}(5)$$

According to Maxwell Boltzmann statistics, the population of various levels is

$$N_i = N_0g_i\exp\frac{-E_i}{KT}\text{..................}(6)$$

Hence,

$$N_1 = N_0g_1\exp\frac{-E_1}{KT}$$

$$N_2 = N_0g_2\exp\frac{-E_2}{KT}$$

$$\frac{N_1}{N_2} = \frac{g_1}{g_2}\exp\frac{E_2 - E_1}{KT}\text{............}(7)$$

Substituting (7) in (5)

$$\rho(\vartheta)=\frac{A_{21}/B_{21}}{\left(\frac{g_1}{g_2}\frac{B_{12}}{B_{21}}\exp\frac{E_2-E_1}{KT}\right)-1}\,\ldots\ldots.(8)$$

From Planks law of black body radiation, the radiation density

$$\rho(\vartheta)=\frac{8\pi h\,\vartheta^3/c^3}{exp\left(\frac{E}{KT}\right)-1}\,\ldots\ldots\ldots(9)$$

Comparing equations (8) & (9)

$$\frac{g_1}{g_2}=\frac{B_{12}}{B_{21}}=1\ldots\ldots\ldots(10)$$

$$\text{And}\,{}^{A_{21}}/_{B_{21}}=8\pi h\,{}^{\vartheta^3}/_{c^3}\,\ldots\ldots\ldots.(11)$$

Equations (10) & (11) are called as Einstein relations.

Case-1:

The ratio of spontaneous emission rate to the stimulated emission rate is given by

$$R=\frac{N_2A_{21}}{N_2B_{21}\rho(\vartheta)}=\frac{A_{21}}{B_{21}\rho(\vartheta)}=\;exp\left(\frac{h\vartheta}{KT}\right)-1$$

Therefore, spontaneous emission rate predominates. To make R smaller,$\rho(\vartheta)$ has to be made large.

Case-2:

The ratio of stimulated emission rate to the stimulated absorption rate is given by

$$Q=\frac{N_2B_{21}\rho(\vartheta)}{\rho(\vartheta)N_1B_{12}}=\frac{N_2}{N_1}$$

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

Instead of this, if we create $N_2>N_1$, stimulated emission will predominant. If stimulated emission predominates the photon density increases and LASER occur.

To achieve more stimulated emission, population of excited state (N_2) should be made larger than the population of the lower state (N_1). This condition is called population inversion.

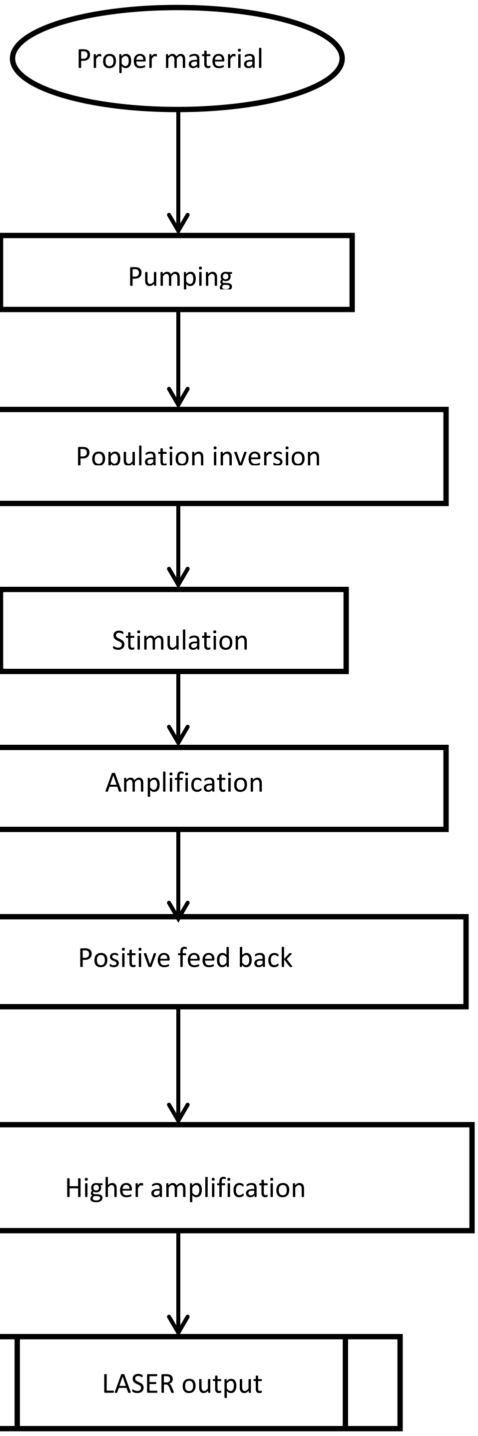
To have LASER,

- Create population inversion.
- Increase the energy density of interacting radiation.

LASER ACTION:

Using pumping process, the no. of atoms in the excited state (N_2) is greater than the no.of atoms in the ground state (N_1). i.e., $N_2 > N_1$. It is called as population inversion state.

In the presence of external photon, we can induce the atoms in the excited state to undergo transition to lower energy state. This is the process of stimulated emission. The avalanche effect takes place and hence there is an amplification of light. By resonator cavity proper feedback is given and there is enormous amplification. The output is LASER radiation.



POPULATION INVERSION:

The no. of particles (N) at any given energy level (E) is given by Boltzmann distribution function. I.e.,

$$N = N_0 \exp\left(\frac{-E}{KT}\right)$$

Therefore, as the energy of the level increases, the no. of particles in that level decreases and its dependence is an exponential function.

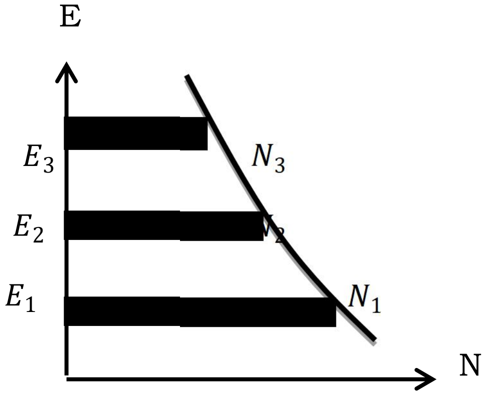
Consider a three level system of energies $E_1, E_2, and\ E_3$ ($E_3 > E_2 > E_1$), the no. of particles in each energy level represented by $N_1, N_2, and\ N_3$ respectively. For a temperature T are given by

$$N_1 = N_0 \exp\left(\frac{-E_1}{KT}\right)$$

$$N_2 = N_0 \exp\left(\frac{-E_2}{KT}\right)$$

$$N_3 = N_0 \exp\left(\frac{-E_3}{KT}\right)$$

Usually, $N_1 > N_2 > N_3$



The ratio of population can be given by

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

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

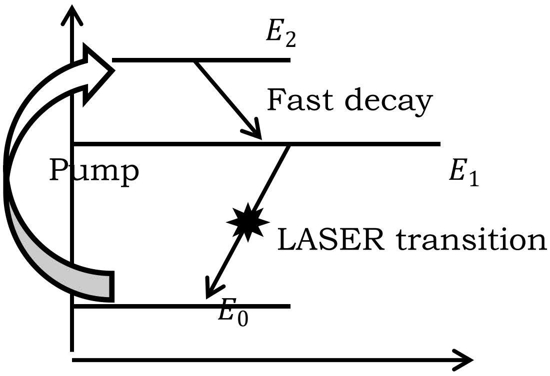
Similarly,

$$N_3 = N_1 \exp\frac{-(E_3 - E_1)}{KT}$$

It means $N_1 > N_2 > N_3$ as the energy levels $E_3 > E_2 > E_1$. By making $N_2 > N_1$, population inversion has been achieved. The states of system in which the population of higher energy state is more in comparison with the population of lower energy state are called negative temperature states. Population inversion can be achieved by

- Three level scheme
- Four level scheme

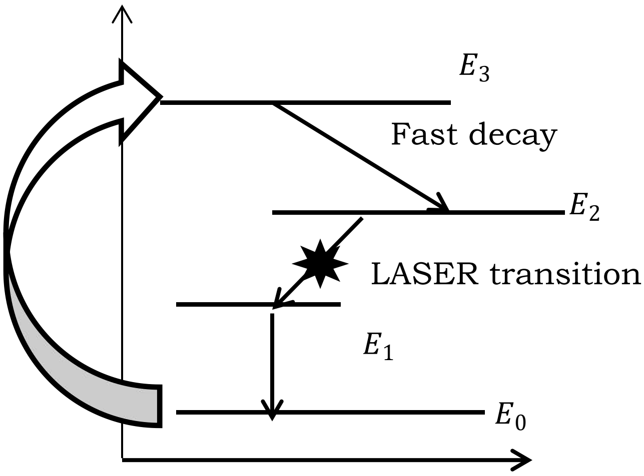
Three level scheme:



If the collection of atoms is intensely pumped, a large no. of atoms are excited through stimulated absorption to the highest energy levelE_2. If the level E_2 has very short life time, the atoms decay fast to levelE_1. If the level E_1has relatively longer life time [a state known as metastable state] atoms tend to accumulate at E_1. With intense pumping, E_1 is more populated than E_0. And LASER transition takes place between level E_1 and levelE_0.

Hence population inversion is achieved between E_1andE_0. If the pumping continues when the condition $N_1 > N_0$ is reached, stimulated emission rate exceeds stimulated absorption rate. This scheme can be worked in pulsed mode only. For example ruby laser.

Four level scheme:



On pumping, the atoms are lifted from the ground state to the highest of the four levels involved in the process. From this level, the atoms decay to the metastable stateE_2, and the population of this state grows rapidly. Hence, population inversion exist between E_2andE_1. Therefore, laser transition takes place between higher energy level E_2 and lower energy levelE_1. Hence, continuous o/p is obtained. For this to happen $E_1$to E_0 transition should be fast. If this transition ($E_1 \rightarrow E_0$) is slow, even four level lasers will work in pulsed mode only.

Eg: He-Ne laser for continuous o/p and N_2 laser for pulsed o/p.

MECHANISM FOR PUMPING SCHEMES:

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

- Optical pumping
- Electric discharge
- Chemical reaction
- Injection current

Optical pumping: solid lasers are optically pumped using Xenon flash lamps. Since these materials have very broad band absorption, sufficient amount of energy is absorbed from the emission band of flash lamp and population inversion is created. For example Ruby LASER, Nd:YAG, Nd:glass, dye etc.

Electric discharge: population inversion can also be achieved by direct excitation as it occurs in an electric discharge. The best example for this method is argon ion laser.

In some lasers one type of atoms are excited by electric discharge. These atoms collide in elastically with another type of atoms. The latter atoms provide population inversion needed for laser emission. The best example is He-Ne laser.

Chemical reaction: in this the energy is supplied directly from a chemical reaction not from any other source. For example carbon dioxide laser.

Injection current: in some semiconductors, lasing action is produced by the conversion of electrical energy into light energy in which recombination of electrons and holes occurs. For example gallium arsenide laser.

ELEMENTS OF LASER:

Active medium: the active medium is a collection of atoms or molecules that can be excited to a state of inverted population. The two states chosen for the lasing transition must possess certain characteristics.

First, atoms must remain in the upper lasing level for a relatively long time to provide more emitted photons by stimulated emission than by spontaneous emission.

Second, there must be an effective method of “pumping” atoms from the highly populated ground state into the upper lasing state in order to increase the population of the higher energy level over the population in the lower energy level.

The active medium may be a gas, a liquid, a solid material or a junction between two slabs of semiconductor materials.

Pumping mechanism: the excitation mechanism is a source of energy that excites, or pumps, the atoms in the active medium from a lower to a higher energy state in order to create a population inversion.

In gas and semiconductor lasers, the excitation mechanism usually consists of an electric current flow through the active medium. Solid and liquid lasers most often employ optical pumps.

Resonant cavity: the feedback mechanism returns a portion of the coherent light originally produced in the active medium back to the active medium for further amplification by stimulated emission

The feedback mechanism usually consists of two mirrors. Each one at end of the active medium aligned in such a way that they reflect the coherent light back and forth through the active medium.

Laser action: when the excitation mechanism of a laser is activated, energy flows in to the active medium, causing atoms to move from the ground state to certain excited state. In this population inversion is created.

Some of the atoms in the upper lasing level spontaneously emitting incoherent photons. When these photons travel along axis of the active medium produce stimulated emission.

RUBY LASER:

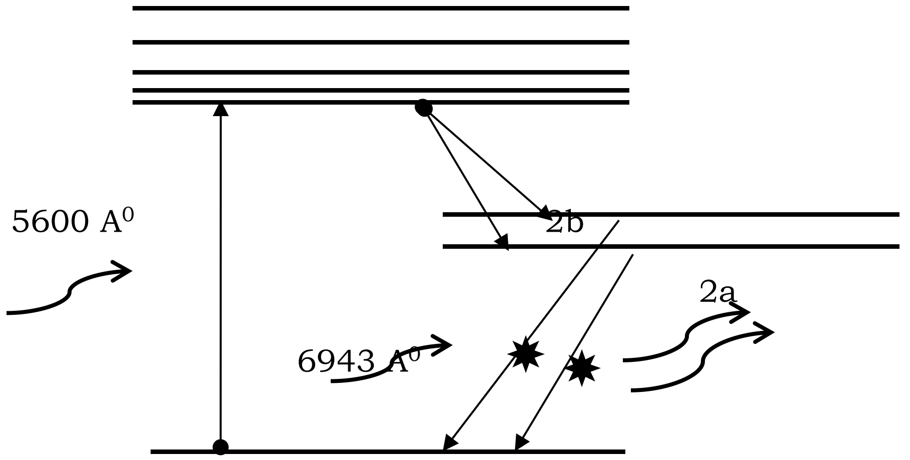
Ruby laser is a three level solid state laser and was constructed by malman in the year 1960. It is a pulsed laser having very high power of hundreds of megawatt in single pulse with about 10 ns duration. Ruby rods are prepared from Al_2O_3 doped with 0.05% chromium by weight. So, that some of the Al^{3+}ions are replaced by Cr^{3+} ions. The ruby laser systems consist of mainly three parts:

Active medium: ruby crystal in the form of a rod of nearly 10 cm in length and 0.8 cm in diameter.

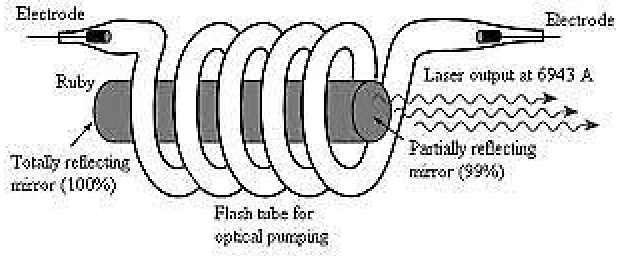
Resonant cavity: flat end faces A and B of the rod are made strictly parallel, plane and silvered so that the end faces A becomes fully reflecting and the end face B partially reflecting. The rod is surrounded by a cylindrical glass tube through which water circulates to keep the rod cool.

Pumping system: the ruby rod is arranged along the axis of a helical xenon flash tube so that the coils of the tube surround the rod. The flash tube is provided with a suitable power supply to flash for several milliseconds.

Construction: the ruby rod is surrounded by a xenon flash lamp tube which provides the optical pumping to raise the Cr^{3+} ions to upper energy level. The energy level diagram of ruby laser is



Where R=692.7 A^0 and R'=694.7 A^0.



Working: when light from the flash tube is made to fall upon the ruby rod, the chromium atom absorb the green component 560 nm and get excited from level 1 to energy level 3. Chromium ions stay here for a very short time of the order of 10^{-3} seconds. The transition from $E_3$to E_2 is non radiative in nature but produces heat. Hence cooling system is essential. As the life time of E_2 is much longer, the no. of ions in this state goes on increasing while in the ground state goes on decreasing. In this way population inversion exist between $E_2$and E_1. When an ion passes spontaneously from the metastable state E_2 to the ground state E_1, it emits a photon of wave length 694.3nm. This photon travels through the ruby rod and if it is moving parallel to the axis of the crystal, is reflected back and forth by the silvered ends until it stimulates an excited ion in E_2 and causes it to emit fresh photon in phase with the earlier photon. This stimulated transition triggers the laser transition. The process is repeated again and again and the photons thus get multiplied. When the photon beam become sufficiently intense, such that the part of it energies through the partially silver end of the crystal. O/p is pulsed.

Applications:

1. Holography
2. For drilling high quality holes
3. In military as target designators and range finders.

He-Ne LASER:

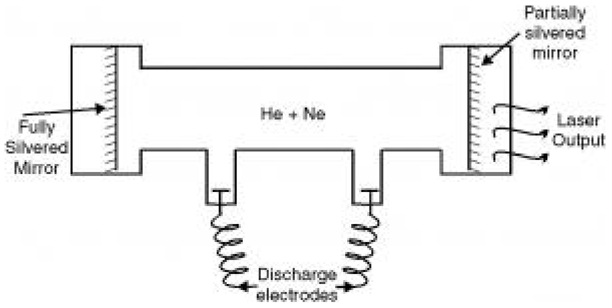
For the continuous laser beam, He-Ne laser is used. The o/p laser is highly mono chromatic, coherent and directional but o/p is generally few mill watts. He-Ne gas lasers are used in holograms and in medicine. The He-Ne laser mainly consists of

Active medium: this laser consists of a gas discharge tube of length 80cm and diameter 1cm. The tube is made up of quartz and is filled with a mixture of neon under pressure of 0.1 mm of Hg and helium under a pressure of 1mm of Hg. The ratio of He-Ne mixture is 10:1.

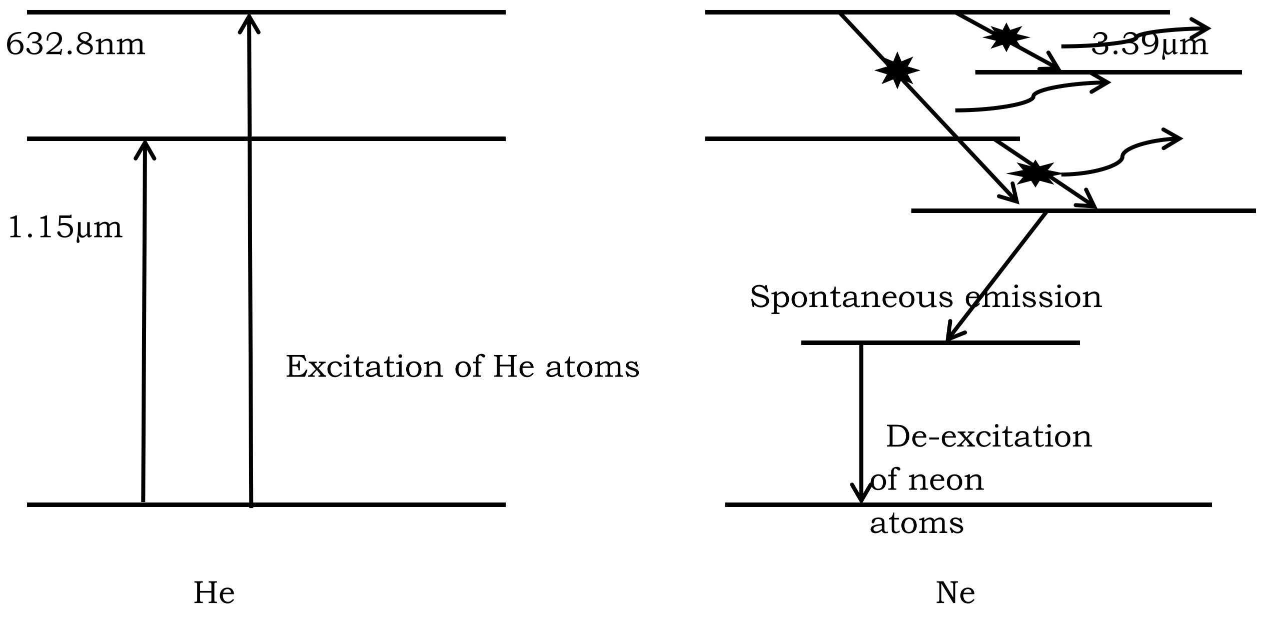
Resonant cavity: the mixture is enclosed between a set parallel mirrors forming a resonating cavity. One of the mirrors is completely reflecting and the other is partially reflecting.

Pumping scheme: the electric discharge is efficient method of producing population inversion in these gas lasers.

Construction: the construction of this laser is as shown below



The different energy levels of helium atoms and neon atoms is



Working:

The levels E_2 and E_3 of helium have nearly the same energy as the $E_4^{'}$ and $E_6^{'}$ of neon. Where E_2 and E_3 are metastable states. When discharge is passed through the mixture of gas, the electrons collide with helium atoms and excite them to the metastable states $E_2$and E_3. This is called pumping. The He atoms continue in these states in long time.

The He atoms collide with unexcited neon atoms raising them to the levels $E_4^{'}$and$E_6^{'}$. Hence population inversion occurs w.r.t the levels $E_3^{'}$and $E_5^{'}$. Therefor the transitions occur are

1. $E_6^{'} \rightarrow E_5^{'}$ producing laser of 3.39 μm
2. $E_6^{'} \rightarrow E_3^{'}$ producing laser of 632.8nm
3. $E_4^{'} \rightarrow E_3^{'}$ producing laser of 1.15 μm

From the level $E_3^{'}$ the Ne atoms drop to level $E_2^{'}$ by spontaneous emission and de-excited to ground level by collisions. Thus, they are again ready to go through the cycle.

SEMICONDUCTOR LASER:

The semiconductor laser is also called as diode laser. It has very important application in fibre optic communication. There are two types' semiconductors that is direct band gap semiconductors and indirect band gap semiconductors.

In case of direct band gap semiconductors, there is a large possibility for direct recombination of holes and electrons which emit photon than in an indirect band gap semiconductorsA well-known example of a direct band gap semiconductor is Ga As and hence it is widely used to prepare LED and LASERS. The wave length of the emitted light depends up on the band gap of the material.

$$\lambda = \frac{hc}{E_g} = \frac{1.24}{E_g}\ \mu m$$

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 hetro junction semiconductor laser source.

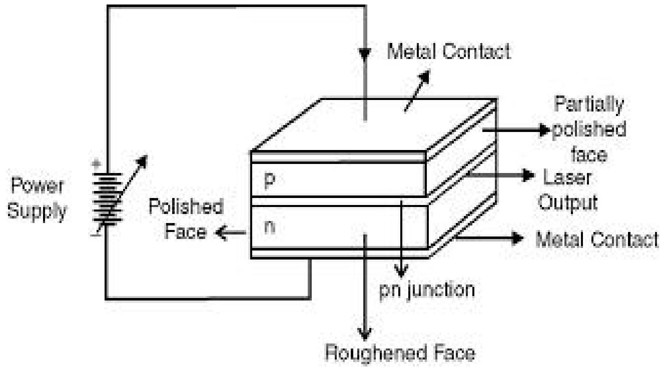
Construction:

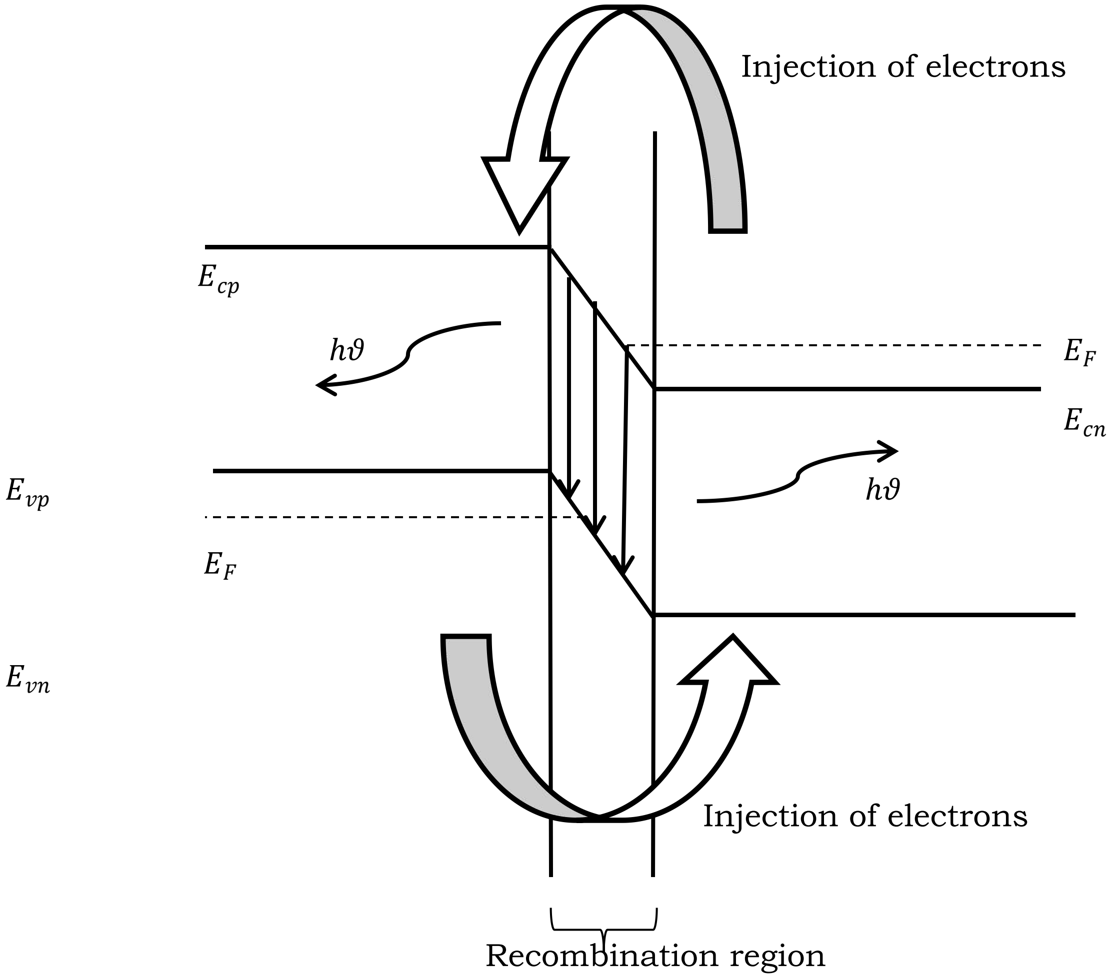
The basic mechanism responsible for light emission from a semiconductor is the recombination of electrons and holes at p-n junction when a current is passed through the diode.

Active medium: GaAs crystal which is heavily doped with suitable dopants to form a p-n junction.

Pumping scheme: injection current method

Resonant cavity: at the junction the sides through which emitted light is coming out are well polished and parallel to each other.





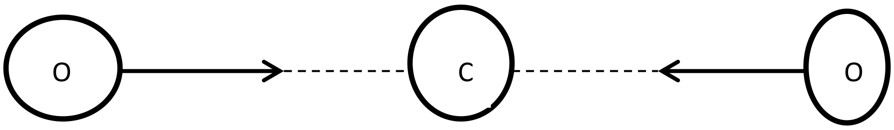
The electrons are minority charge carriers in p-side and holes are minority charge carriers in n-side. The continuous injection of charge When a current is passed through a p-n junction, holes are injected from p-region into n-region and electrons are injected from n-region into p-region as junction is forward biased. carriers creates the population inversion of minority charge carriers. The excess minority charge carriers recombine with majority charge carriers of n and p material, resulting in the release of photons. Further emitted photons increase the recombination rate. Thus, stimulated emission takes place more efficiently. Only pulsed output is obtained. This drawback is overcome in hetro junction laser structure. For example Ga Al As.

CO_2 LASER:

This laser was invented by C. Kumar N. Patel in the year 1963. This laser is a mixture of CO_2, N_2 and He gases in the ratio 1:4:5. The lasing action is from CO_2 molecules due to transition between vibrational- rotational levels. The CO_2molecules possess three different types of vibrational modes which possessno. of rotational modes.

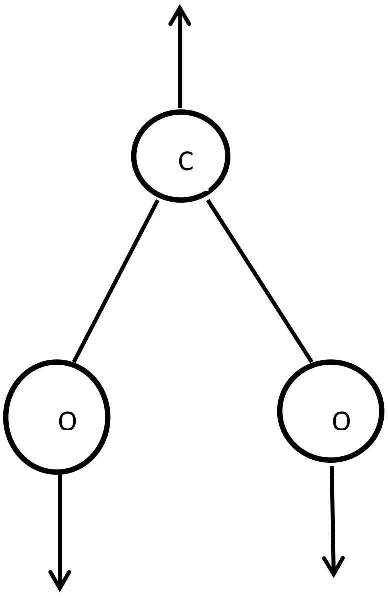
In symmetric stretching mode, the carbon atom is stationary and the oxygen atoms symmetrically move away or approach the carbon atom.

[ϑ, 0, 0]



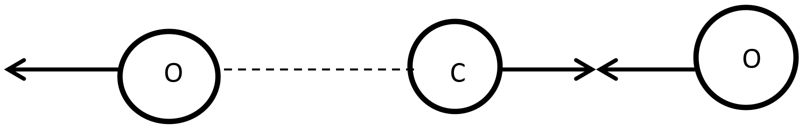
In bending mode, some atoms [not all] move perpendicular to the molecular axis.

[0, ϑ, 0]



In asymmetric stretching mode, both the oxygen's move in one direction along the molecular axis and carbon move in opposite direction.

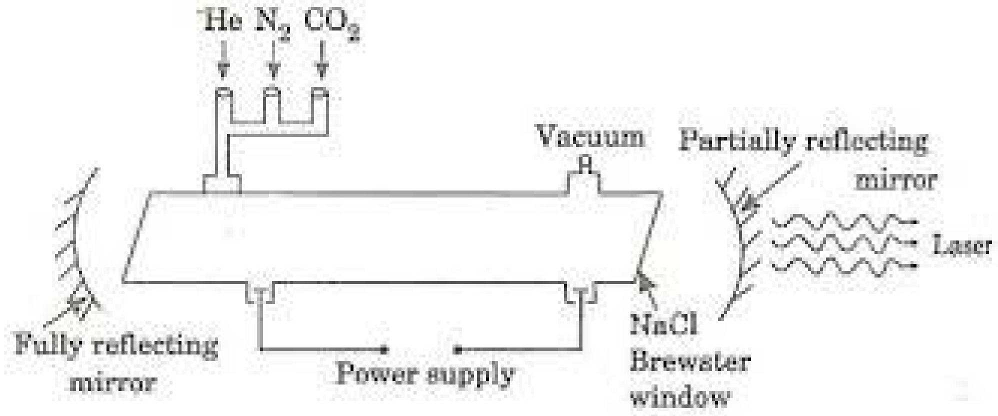
[0, ϑ, 0]



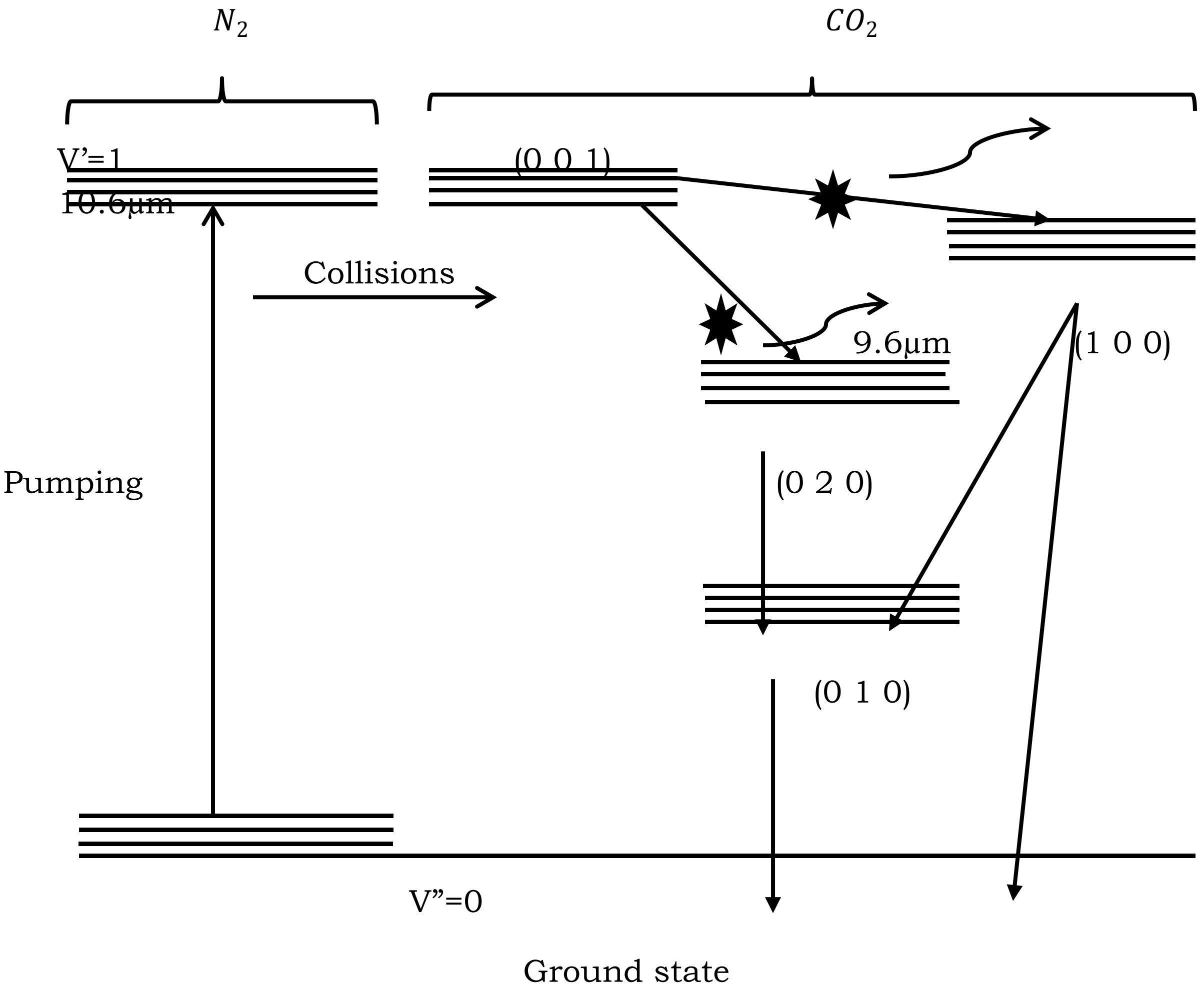
Construction:

CO_2Laser consists of a long tube of about 5 m long and 25 cm diameter. The ends of the tube are closed with Alkali halide [NaCl] Brewster windows. Then it is placed between confocal silicon mirrors coated with aluminium with aluminium are arranged. This forms the resonant cavity. Inside the tube, the gases combine and continuously pass through it.

The pressure inside the tube will be 33 torr mm. the purpose of N_2 is to increase the population inversion of upper level and He helps to depopulate the lower level. The emission of laser from CO_2 molecules is given by



Working:



The electric discharge in CO_2 laser may excite CO_2 and N_2 molecules to higher vibrational – rotational levels by electron impacts. The collision of N_2 molecules present in v"=1 level collide with CO_2molecules lead to resonance transfer of energy. Because v"=1 level of N_2 molecules and (0 0 1) level of CO_2 are nearly at the same energy. Population inversion exist between (0 0 1) and (1 0 0), (0 2 0) levels. Two laser transitions takes place between these levels:

1. (0 0 1) to (1 0 0) gives a wavelength of 10.6 μm.
2. (0 0 1) to (0 2 0) gives a wavelength of 9.6 μm.

Of these 10.6 μm wave is intensified and its power o/p is of 10KW, efficiency being 30%, whereas 9.6μm waves are weak. The lower levels are very close. The CO_2 molecules present in (1 0 0), (0 2 0) and (0 1 0) levels may make non-radiative transition to the ground state quickly by colliding with He atoms.

APPLICATIONS OF LASER:

- IN COMMUNICATION:
    - Open space communication: the angular speed of laser beam is very narrow which recommends the laser beam can be used for the communication between earth and moon or to other satellite.
    - Fibre optic communication: in optical fibre communications, lasers are used as light source to transmit audio, video signals and data to long distances without attenuation and distortion.
    - Under water communication: as laser radiation is not absorbed by water, so, laser beam is used for inside sea communications
- Industrial communication:
    - Metal cutting: using laser techniques, cutting materials such as metal sheets and clothes is easy. In mass production of stitched clothes, the cutting in the desired dimension is done by stock filling a large no. of cloth material and cutting them all at once by exposing a laser beam.
    - Welding: a laser beam is exposed to the place where welding has to be done, at that place the material melts due to the heat produced by the beam and on cooling the material makes a stronger joint.
    - Drilling: when a larger beam is focused on a very small area, the laser light energy is converted into heat energy. So, the material may be heated, melted and evaporated. Using these techniques holes can be drilled in steel, ceramic, diamond and alloys.
    - Dissimilar metals can be welded and micro welded is done with great ease.
    - Lasers are widely used in electronic industry in trimming the components of ICs.
- Medical applications:
    - Lasers are used in eye surgery by opthal mologists, especially in detached retina. The retina can be attached to the choroid by heating it over a no. of spots. The heating can be achieved by focussing a laser beam of predetermined intensity on the retina. This can be done by using Argon ion lasers

  - Laser angioplasty: lasers are used for treatment such as plastic surgery, skin injuries etc., this can be done by using Nd:YAG lasers.
  - Dermatologists use lasers for the treatment to remove moles and tumours developed in skin tissue and also to remove tattoos.
  - Lasers are used in stomatology- the study of mouth and its diseases. Mouth ulcers can be cured by exposing it to a laser beam.
  - Lasers are used to destroy kidney stones and gall stones. The laser pulses break the stones into small pieces.
  - Lasers are used in cancer diagnosis and therapy.
  - Lasers are used in blood loss less surgery
  - Lasers are used to control haemorrhage
  - Using organ and CO_2 lasers, liver and lung treatment can be carried out.
  - Lasers are used in endoscopes to detect hidden parts.
- <u>Military applications</u>:
  - Death rays: by focusing high energetic laser beam for few seconds to aircraft, missile etc. can be destroyed. So, they are called death rays or war weapons.
  - Laser gun: the vital part of enemy body can be evaporated at short range by focussing a highly convergent laser beam from a laser gun.
  - LIDAR: [light detecting and ranging]This is used to estimate the size and shape of distant objects or war weapons.
  - To guide the missiles also LASERS are used.
- <u>In computers</u>:
  - By using lasers, a large amount of information or data can be stored in CD-ROM or their storage capacity can be increased.
  - Lasers are used in computer printers.
- <u>In thermo nuclear fusion</u>:
  - Since it need high temperatures that can be given by the lasers.
- <u>In scientific research</u>:
  - Lasers are used to study the nature of chemical bonds.
  - Used for isotope separation.
  - Used to estimate the size and shape of biological cells.
  - Used to find the size of dust particles.
  - Used for recording and reconstruction of holograms.

- Lasers are used to develop hidden finger prints and to clean delicate pieces of art.

FIBRE OPTICS

INTRODUCTION:

The improvement in the communication process would mean motivation to improve the transmission fidelity and at the same time to improve the data rate of transmission.

With the development of lasers, reliable and powerful coherent radiation became available. So, it was natural to use this light for communication process. There are two reasons for this

- Higher frequency
- More information carrying capacity compared to conventional radio and microwave carriers.

Light waves cannot travel far in open atmosphere as the energy gets very rapidly dissipated. Hence, some kind of guiding channel is needed just like for guiding electric current in a metal wire. Optical fibre provide necessary wave guide for light.

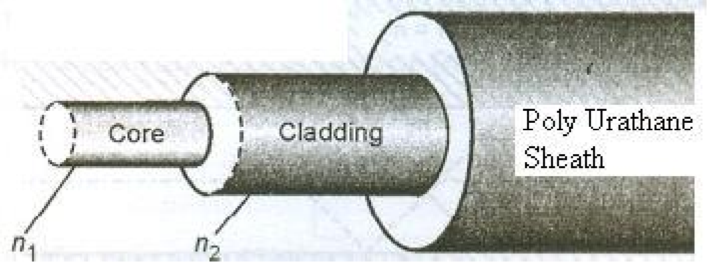
Fibre optics technology is increasingly replacing wire transmission lines in communication systems and is expected to be as electrical wiring even in our vehicles and houses very shortly.

PRINCIPLE OF OPTICAL FIBER:

The optical fibres are based on the principle of total internal reflection. An optical fibre is a hair thin cylindrical fibre of glass. It is a flexible medium having a cylindrical shape consisting of three sections.

1. The core
2. The cladding and
3. The outer jacket.

The structure of optical fibre is

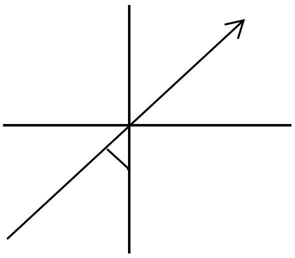


The fibre has a core surrounded with a cladding with refractive index slightly less than that of the core to satisfy the condition for total internal reflection. To give protection to the fibre, a outer jacket is used.

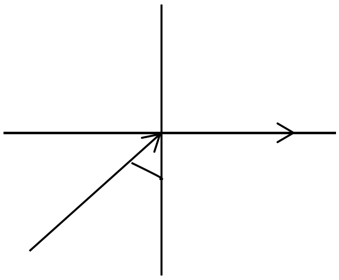
The light launched inside the core through its one end propagates to the outer end due to total internal reflection at the core cladding interface. This is the principle of optical fibre.

The condition for total internal reflection is

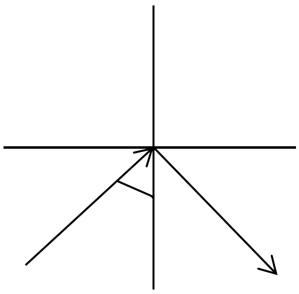
- $\mu_{core} > \mu_{cladding.}$
- $angle\ of\ incidence > critical\ angle$



$\theta < \theta_c$



$\theta = \theta_c$



$\theta > \theta_c$

When the ray travels from denser medium to rarer medium angle of reflection (θ_R) is greater than angle of incidence (θ_i). With increase of θ_i the θ_R also increases. For a particular θ_i, the refracted ray grazes the interface between core and cladding. This angle of incidence is known as critical angle.

When θ_i is further increased, the ray is reflected back into the core at the interface obeying law of reflection. This phenomenon is called as total internal reflection.

ACCEPTANCE ANGLE AND ACCEPTANCE CONE:-

When we launch a light beam into a fibre at its one end, the rays which make the angle of incidence greater than the critical angle at core cladding interface undergo total internal reflection and propagate through the core. Other rays are lost.

So, we have to launch the beam at its end to enable the entire light to pass through the core. This maximum angle of launch is called acceptance angle.

Consider a cylindrical fibre wire which consists of an inner core of refractive index $n_1$and cladding of refractive index n_2 where $n_1 > n_2$.

Let n_0 be the refractive index of medium from which the light ray enters the fibre. This end is called launching end.

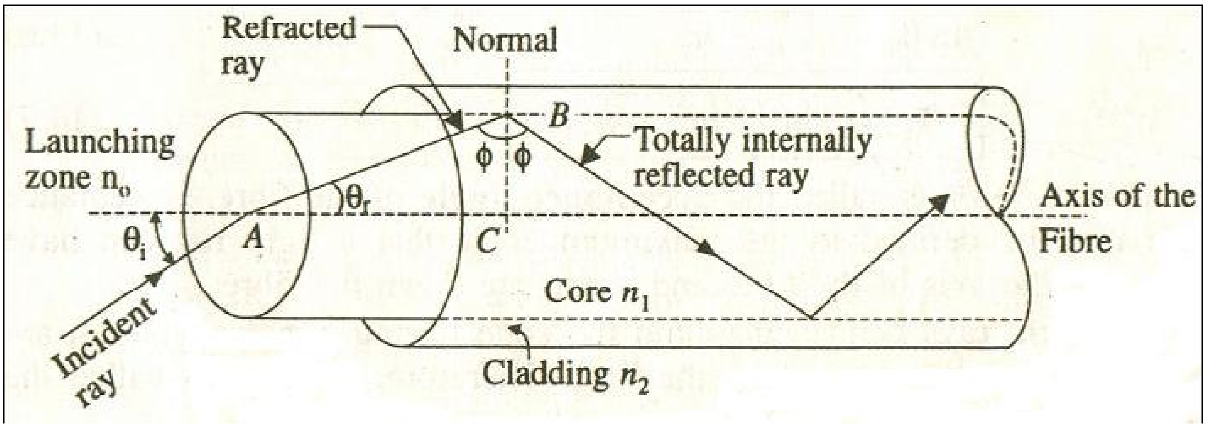
Let the light ray enter the fibre at an angle θ_i (acceptance angle) for which$\theta \geq \theta_c$, so that light stay within the fibre.

Applying snells law of refraction at point of ray OA in to the core, we have

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0} \ldots\ldots\ldots\ldots (1)$$

From triangle BCA,

$$\theta_r = 90 - \emptyset \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$



Therefore,

$$\sin\theta_r = \sin(90 - \emptyset) = \cos\emptyset \ldots\ldots\ldots (3)$$

From (1) & (3)

$$\sin\theta_i = \frac{n_1}{n_0}\cos\emptyset \ldots\ldots\ldots\ldots(4)$$

Let $(\theta_i)_{max}$ occurs when $\emptyset = \theta_c$

$$\sin(\theta_i)_{max} = \frac{n_1}{n_0}\cos\theta_c \text{ ....(5)}$$

We know that

$$\sin\theta_c = \frac{n_2}{n_1} \text{ .... (6)}$$

Therefore,

$$\cos\theta_c = \sqrt{1-(\sin\theta_c)^2}$$

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

$$\cos\theta_c = \sqrt{\frac{n_1^2-n_2^2}{n_1^2}} \text{ .... (7)}$$

From (5) & (7)

$$\sin(\theta_i)_{max} = \frac{n_1}{n_0}\sqrt{\frac{n_1^2-n_2^2}{n_1^2}}$$

$$\sin(\theta_i)_{max} = \frac{\sqrt{n_1^2-n_2^2}}{n_0} \text{ ....(8)}$$

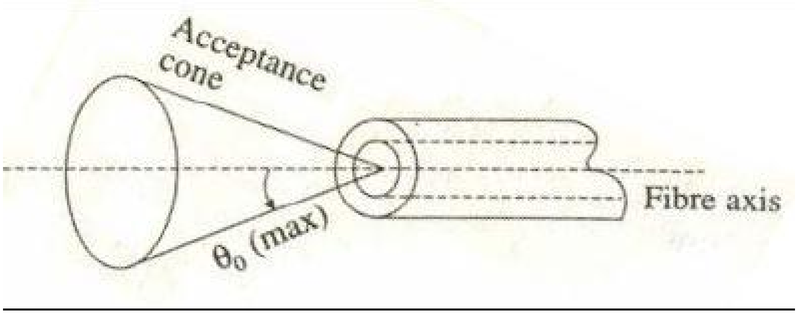
If launching medium is air, then $n_0 = 1, (\theta_i)_{max} = \theta_0$. Then,

$$\sin\theta_0 = \sqrt{n_1^2-n_2^2}$$

Here θ_0 is called acceptance angle.

$$\theta_0 = \sin^{-1}\sqrt{n_1^2-n_2^2}$$

If the ray OA is rotated around the fibre axis keeping θ_0 same, then it describes a conical surface. Now, only those rays which are funnelled into the fibre within this cone having a half angle θ_0 are propagated. Therefore, the cone is called as acceptance cone.



NUMERICAL APERTURE:-

Light gathering ability of a fibre is determined by using numerical aperture. This is defined as the sine of acceptance angle.

$$\text{NA}=\sin\theta_0=\sin\left(\sin^{-1}\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right)$$

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

Consider, $\Delta=\frac{n_1^2-n_2^2}{2n_1^2} \rightarrow n_1^2-n_2^2=2n_1^2\Delta$

$$NA=\frac{n_1\sqrt{2\Delta}}{n_0}$$

For launch medium, $n_0=1$

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

Therefore, light collecting capacity is effectively dependent on refractive indices core and cladding and not on fibre dimensions.

TYPES OF OPTICAL FIBERS:-

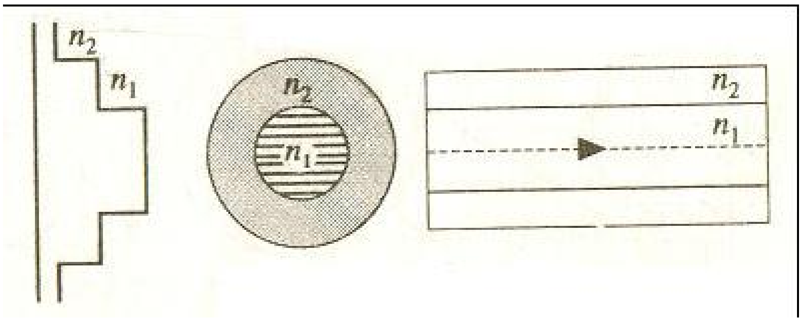
1. Step index fibre
2. Graded index fibre.

Step index fibre:

These are the fibers in which the refractive index of core is maximum and constant throughout the core as

$$n(r)=n_1\, for\, r<a\,[core]$$

$$n(r) = n_2 for\, r > a\, [cladding]$$



There is a step-wise decrease of refractive index from the core (n_1) to the cladding (n_2) at r=a. the refractive index of cladding material (n_2) is given as

$$n_2 = n_1(1 - \Delta)$$

Where n_1 → refractive index of core

Δ→fractional difference.

There are two types of step index fibres

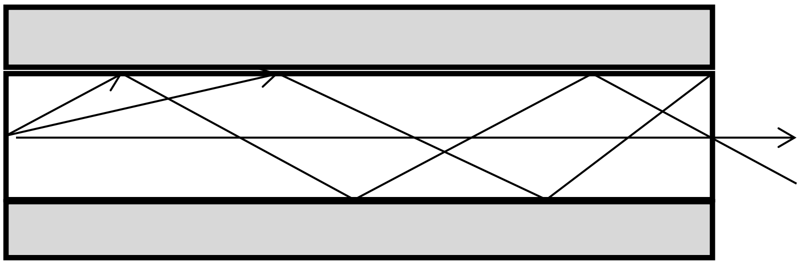
- Step index single mode fibre
- Step index multi-mode fibre.

In step index multimode fibre, the difference between μ of cladding and core is more. Further its core diameter is large. Generally, these are used in short distant communication because of its attenuation.

In step index single mode fibre, the difference between μ of core and cladding is very small and its core diameter is also very small. It has low attenuation and very high band width. It has low numerical aperture. These are used in long distant communication.

Transmission of signal:-

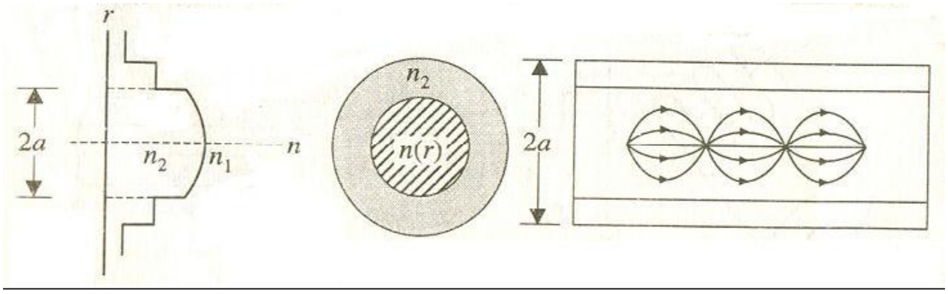
Generally the signal sent through the fibre is in digital form. Let us consider the propagation of one such pulse through the multimode step index fibre. The same pulsed signal travels in different paths.



Hence, three rays reach the received end at different times. The signal received at the end gets broadened. This is called intermodal dispersion. Due to this, the transmission rate and capacity is reduced. This difficulty is overcome in graded index fibres.

Graded index fibre:-

A graded index fibre is a multimode fibre with a care consisting of concentric layers of different refractive indices. That is the refractive index of the core decreases with distance from the fibre axis. It has a maximum value at centre and decreases with ‘r’.



These fibres have several modes of transmission through the core. Because of the continuously varying refractive index across the core, the light rays are bent smoothly and converge repeatedly at points along the cable.

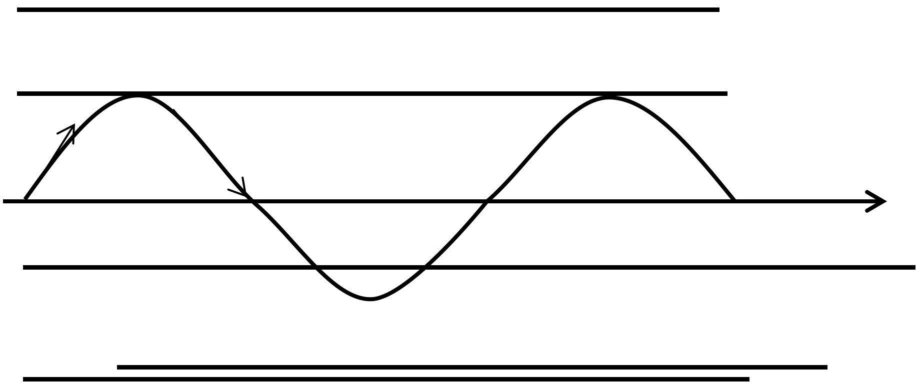
The light ray near the edge of the core take a longer path but travel faster since μ is lower. The variation of refractive index of core is

$n(r) = n_1\left[1 - \Delta\left(\frac{r}{a}\right)^{\infty}\right]$ for r<a

$= n_1[1 - \Delta]$ for r≥ a

Transmission of signal :-

Let us consider a signal pulse travelling through graded index fibre in two differentpaths represented by (1) & (2)



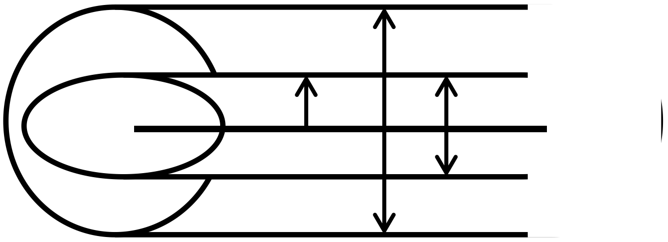
(1) Travels through higher refractive index

(2) Travels through lower refractive index.

Hence, both pulses reach the other end simultaneously. Then, the problem of intermodal dispersion can be reduced to minimum in using graded index fibre.

SINGLE MODE AND MULTI-MODE FIBRE:-

Consider a fibre with core diameter of 2a, and cladding diameter of 2b represented in figures.



Let r be a distance of core position from the axis when a light is launched at one end, the light progresses through the fibre core in different trajectories. Each trajectory is called as a mode.The no. of modes that a fibre allows through it depends upon the diameter of core. If the core diameter is small it allows only one mode to travel through it. Then, the fibre is called single mode or monomode fibre.

In single mode fibre only HE_{11} mode is allowed to travel through it. HE_{11}[the ray along fibre axis]. The monomode fibres has very small core diameter less than 10μm. if fibre allows more no. of modes then it is called multimode fibre. The core diameter of a multimode fibre is of the order of 50μm.

V-number of a fibre:-

This indicates the no. of possible propagation modes in the core.

$$V = \frac{2\pi}{\lambda}\alpha(NA)$$

Where, λ is the wavelength of the propagating waves.

α is the radius of the core

NA is the numerical aperture.

- The no. of modes propagating through the step-index fibre.

$$N_{SI} = \frac{V^2}{2}$$

- For the SI two possible polarizations are there.

$$N_{SI} = 2\left(\frac{V^2}{2}\right) = V^2$$

Therefore no. of modes in SI fibre=V^2

- The no. of modes propagating in graded index fibre

$$N_{GI} = \left[\frac{\alpha}{\alpha + 2}\right]\left[\frac{V^2}{2}\right]$$

For parabolic profile,

$$\alpha = 2$$

$$N_{GI} = \frac{V^2}{4}$$

For GI two possible polarizations are there.

$$N_{GI} = 2\left(\frac{V^2}{4}\right)$$

$$N_{GI} = \frac{V^2}{2}$$

$$N_{GI} = \frac{N_{SI}}{2}.$$

ATTENUATION IN OPTICAL FIBERS:-

The main specification of a fibre optic cable is its attenuation. The power of the light at the o/p end is found to be always less than the power launched at the i/p end. The attenuation is found to be a function of fibre material, wavelength of light and length of the fibre.

Losses intrinsic to fibres result in attenuation. These losses are

- Scattering losses
- Absorption losses
- Bending losses

Scattering losses:

By its nature, glass is a disordered structure in which there are macroscopic variations around the average density and local microscopic variation in composition.

Each of these give rise to fluctuations of refractive index on a scale. Due to this light is scattered in the manner known as Rayleigh 's scattering. This scattering light is then lost from the fibre.

The loss caused by this mechanism can be minimised by selecting proper fibre fabrication method. The loss is higher in multicomponent glasses because of compositional variations.

Rayleigh scattering loss coefficient $\alpha_R = \frac{A}{\lambda^4}$, A-constant for given material.

Absorption losses:-

Three different mechanisms contribute to absorption losses in glass fibres. There are

- UV absorption
- IR absorption
- Ion resonance absorption

In pure fused silica, absorption of UV radiation around 0.14 µm results in ionisation. Thus, there is a loss.

Absorption of IR photons by atoms with in glass molecules results in increase of random mechanical vibrations.

OH^-ions are present in the material due to trapping of minute quantities of water molecules during manufacturing.

Bending losses:-

The distortion of the fibre from the ideal straight line configuration may also result in losses in fibre. Tight bends cause some of the light not to be internally reflected but to propagate in to the cladding and be lost. The loss coefficient is

$$\alpha_B = C \exp\left(-\frac{R}{R_c}\right)$$

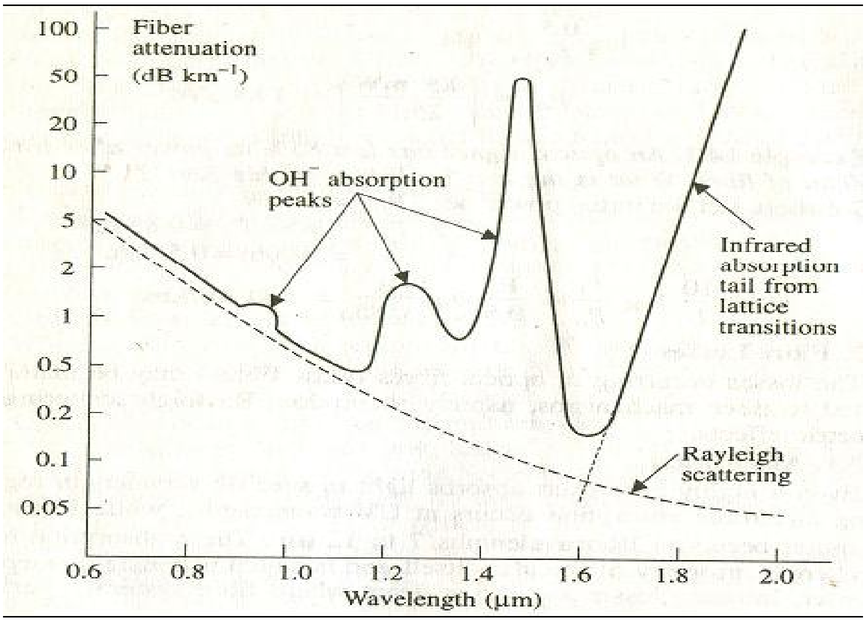
Where c - constant

R - bend radius

$R_c = \frac{a}{(NA)^2}$

a- radius of the fibre

NA - numerical aperture.



Loss in decibels:

Attenuation is generally measured in terms of the decibels (dB) which is a logarithmic unit. The decibel loss of optical power in a fibre is

$$\text{Loss in optical power} = -10\log\left(\frac{P_{out}}{P_{in}}\right)\ dB.$$

Attenuation loss is given by the number of decibles per kilometre of fibre.

$$\frac{\text{Loss}}{Km} = -\frac{10}{L}\log\left(\frac{P_{out}}{P_{in}}\right)\ dB/Km.$$

APPLICATIONS OF OPTICAL FIBERS:-

- In medical field:
  1. Endoscopic applications
  2. Bundles of optical fibers from part of gastroscapes and other medical instruments.
  3. Fibre optic endoscopes are of two types depending upon usage
     - Gastroscopes- used to examine the stomach.

        - Anthoscope- used to study the small spaces with in the joints

- Telecommunication/telephone applications:
  The various applications of fibre optics in telecommunication area include the voice telephones, video phones, telegraph services, various new services and data networks all transmitted over common carrier links.
- Military applications:
  It includes the airborne systems, naval systems, undersea systems, space applications.
- Sensor applications:
  Various kinds of sensors have been developed. They are temperature sensors, pressure sensor, acoustic sensor, current sensor, flow meter, strain detector, chemical sensor, humidity sensor etc.

OPTICAL FIBER IN COMMUNICATIONS:

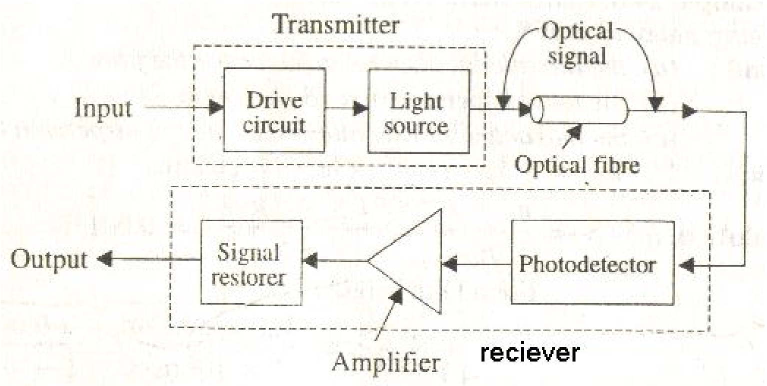


Fig.14.18: Illustration of a typical fibre optic communication link.

The important application of the optical fiber in the field of communication as transmission medium. The block diagram of the basic communication system is shown in figure. It consists of transmitter, receiver and an information channel.In general the information to be communicated is non electrical form which must be converted into electrical form. A drive circuit converts the audio or video signal into electrical signal. This drive circuit is connected to light source. Here the signal is converted into corresponding light signal.This light is fed to optical fiber. The optical signal traveling through the fiber will be attenuated gradually because of losses and dispersion of signal in fiber. Therefore repeaters are used in the transmission line to amplify and reshape the signal. At the receiver end light emerging from the fiber channel is detected by photo detector. The detector converts the light wave into electrical current. In the next step the detector output current is filtered and is amplified. The amplifier does this task. The amplifier output is fed to the signal restorer which restores the signal. Finally this electrical signal is fed to transducer which converts signal into audio or video form.

Transducer: it is a device which converts one form of energy into another form.