JAYA COLLEGE OF ENGINEERING AND TECHNOLOGY ,POONAMALLEE, CHENNAI 600056
Department of Science and Humanities Twisted Questions & Answers
PHYSICS FOR INFORMATION SCIENCE. (PH3256) (Common to CSE branches) R-2021

Unit - 1; Electrical properties of Materials.

1. Obtain Wiedemann-Franz law using the expression for Inverse resistivity and Heat conductivity and find the related number.
2. Arrive the expression for the quantum free electron theory based law and explain for the electrons in metal.
3. Derive the formation of the electron mass varying and show it varies with the wave vector.
4. Find the expression for the energy states which are available for the occupation of the electrons.
5. Based on finite potential well, derive an expression for electron moves in any direction in space.

Unit - 2; Semiconductor Physics.

6.Attain the statement for the number of charge carriers per unit volume of material in an pure form of semiconductor.
7.Find the formation for the acceptor concentration of electron absence in valence band doped semiconductor.
8.Describe the types of Metal-Semiconductor junctions which are important role in the present day Integrated circuits(IC) technology.
9.Derive the coefficient expression and determination of charge carriers based on Hall effect

Unit - 3; Magnetic properties of Materials.

10. Compare the magnetic materials based on the response to an external electric field and existence of dipole moment.
11. Describe the working of the device used in magnetic hard disc for high density data storage based on spin valve.
12. Distinguish between the magnetic materials based on magnetization.
13. Explain quantum mechanical concept spin interaction.
14. Explain lagging behind behaviour of Ferromagnetism and describe domain theory based on M vs H behavior

Unit - 4; Optical properties of Materials.

15. Explain the interaction of light in meals, insulator and semiconductor.

16. Explain electron-hole creation & annihilation processes in semiconductor.

17. Describe the construction and working of p-n junction diode which converts light energy into electrical energy

18. Explain the solid state device made in thin films of organic materials produce light by the presence of electric field.

Unit - 5; Nano devices and Quantum computing

19. Outline the One-Qubit quantum gates.
20. Describe the two-qubit quantum gates (CNOT Gate)
21. Explain the device can control the motion of electron and consists of quantum dots which have the tunnel junctions.
22.Explain the difference between the types of computing and give the comments of superior type of computing.
23.Discuss the quantum confined structures in 0,1 and 2-dimension.
24.Describe the density of quantum confined structures in 0,1 and 2-dimension.

Unit -1; ELECTRICAL AND THERMAL CONDUCTIVITY.

1. Obtain Wiedemann-Franz law using the expression for Inverse resistivity and Heat conductivity and find the related number.

Expression for the Electrical Conductivity:

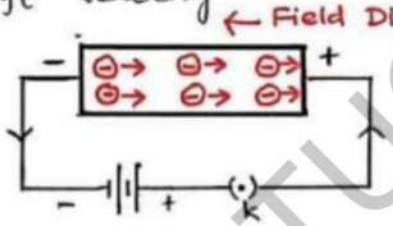
Definition:-

It is the quantity of Electric charges flowing per unit time (t) per unit area (A) maintained at a unit potential gradient (E).

$$\sigma = \frac{Q}{tAE} = \frac{ne^2\tau}{m^*} \quad \Omega^{-1}m^{-1}$$

Derivation:

When an electrical field applied to an electron of charge 'e', It moves in a opposite direction with the applied field with a constant velocity (v_d) known as "drift velocity"



Here the force experienced by the electron by external field

$$F = eE \quad -(1)$$

and the accaleration gained by the electron 'a' is given by

$$\text{acceleration } a = \frac{\text{velocity}}{\text{Time}} = \frac{v_d}{\tau}$$

$$\therefore a = \frac{v_d}{\tau}$$

$$v_d = a\tau \quad -(2)$$

We know that from Newton's II law

$$F = ma \quad -(3)$$

By comparing eqns (1) & (3)

$$eE = ma$$

$$a = \frac{eE}{m} \quad -(4)$$

Substituting eqn (4) in eqn (2)

$$v_d = \frac{eE\tau}{m} \quad -(5)$$

If $n \rightarrow$ no. of free electron
$e \rightarrow$ charge of an electron

Then current density interms of 'v_d' is given by

$$J = nev_d \quad -(6)$$

Substitute eqn (5) in eqn (6)

$$J = ne\frac{eE\tau}{m}$$

$$J = \frac{ne^2E\tau}{m} \quad -(7)$$

From the definition of Charge density is directly proportional to applied electric field.

$$J \propto E$$

$$J = \sigma E \quad -(8)$$

Comparing eqns (7) & (8) we get

$$\sigma E = \frac{ne^2\tau E}{m}$$

$$\sigma = \frac{ne^2\tau}{m} \quad -(9)$$

Eqn (9) is the expression for the electrical conductivity.

Thermal Conductivity:

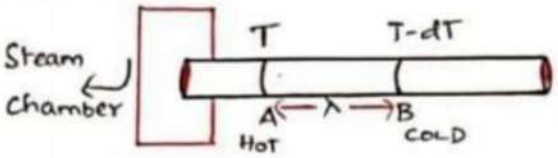
Definition:

It is the amount of heat Conducted per unit area (A), per unit time (t) maintained at unit temperature gradient.

$$K = \frac{Q}{dT/dx} = \frac{n v^2 K_B \tau}{2}$$

Derivation:-

Consider a unifor metallic rod contain free electron.



Here A & B → Cross-sectional area near hot & cold end

T, T-dT → Temp at A & B

λ → Mean free path

The average K.E of electrons Crossing A

$$E_1 = \frac{1}{2} m v^2 = \frac{3}{2} K_B T \quad -(1)$$

III'y K.E of free electron at 'B'

$$E_2 = \frac{3}{2} K_B (T - dT) \quad -(2)$$

Excess energy carried out by electrons from A to B

$$K.E = \frac{3}{2} K_B T - \frac{3}{2} K_B (T - dT)$$

$$= \frac{3}{2} K_B T - \frac{3}{2} K_B T + \frac{3}{2} K_B dT$$

$$K.E = \frac{3}{2} K_B dT \quad -(3)$$

Assume, the electron can move in all possible direction, then the no. of electron crossing per unit area, per unit time from 'A' to 'B'.

$$n = \frac{1}{6} n v \quad -(4)$$

∴ The excess average energy carried from A to B is given by

$$E = \frac{1}{6} n v \times \frac{3}{2} K_B dT$$

$$E = \frac{1}{4} n v K_B dT \quad -(5)$$

Hence the net amount of heat transformed from 'A' to 'B'.

$$Q = \frac{1}{4} n v K_B dT - \left[-\frac{1}{4} n v K_B dT\right]$$

$$Q = \frac{1}{2} n v K_B dT \quad -(6)$$

from the definition, we know that

$$Q = K \cdot \frac{dT}{dx}$$

$$Q = K \cdot \frac{dT}{\lambda} \quad -(7)$$

By comparing eqn (7) & (6)

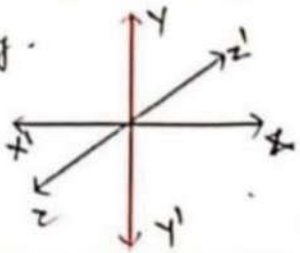
$$K \frac{dT}{\lambda} = \frac{1}{2} n v K_B dT$$

$$K = \frac{1}{2} n v K_B \lambda \quad -(8)$$

Wkt $\lambda = \tau v$

$$\therefore \boxed{K = \frac{1}{2} n v^2 K_B \tau} \quad -(9)$$

Eqn (9) is the expression for thermal conductivity.



Wiedemann - Franz Law

The ratio of thermal to electrical conductivity is directly proportional to the absolute temperature.

$$\frac{K}{\sigma} \propto T \quad (\text{or}) \quad \frac{K}{\sigma} = L \cdot T$$

Where L is Lorentz number.

$$\therefore \frac{\frac{1}{2} m v^2 k}{\frac{n e^2}{m}} = LT$$

$$\frac{\frac{1}{2} m v^2 k}{e^2} = LT$$

But $\frac{1}{2} m v^2 = \frac{3}{2} kT$

$$\therefore \frac{\frac{3}{2} kT \cdot k}{e^2} = LT$$

$$\frac{3}{2} \frac{k^2}{e^2} \cdot T = LT$$

$$\therefore L = \frac{3}{2} \left(\frac{k^2}{e^2} \right)$$

$$\boxed{L = \frac{3}{2} \left(\frac{k}{e} \right)^2}$$

$$\therefore L = \frac{3}{2} \left(\frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} \right)^2$$

$$\boxed{L = 1.12 \times 10^{-8} \, W \Omega K^{-2}}$$

2. Arrive the expression for the quantum free electron theory based law and explain for the electrons in metal.

FERMI DISTRIBUTION FUNCTION **Unit-1**

Fermi Distribution function:-

Definition:

It is the probability of occupation of electrons among different energy levels at absolute temperature.

It is given by

$$F(E) = \frac{1}{1 + e^{(E-E_F)/K_BT}}$$

Where E → Energy level to be considered.

E_F → Fermi energy level.

K_B → Boltzmann Constant

T → Absolute Temperature.

If F(E)=1, the energy level is occupied by an electron.

If F(E)=0, the energy level is vaccant

If F(E) = 0.5, then there is 50% chance for the electron to occupy.

Case (i):-

If $E < E_f$ at T=0K

Then $$F(E) = \frac{1}{1 + e^{(E-E_F)/K_BT}}$$

$$= \frac{1}{1 + e^{(E-E_F)/0}}$$

$$= \frac{1}{1 + e^{-\infty}} = \frac{1}{1+0} = 1$$

$$F(E) = 1$$

Thus at T=0K, 100% chance for the electrons to occupy the energy levels.

Case (ii)

If T=0K at $E > E_F$

Then $$F(E) = \frac{1}{1 + e^{(E-E_F)/K_BT}}$$

$$= \frac{1}{1 + e^{\infty}} = \frac{1}{1+\infty}$$

$$F(E) = 0$$

Thus 0% chance for the electron to occupy the energy levels

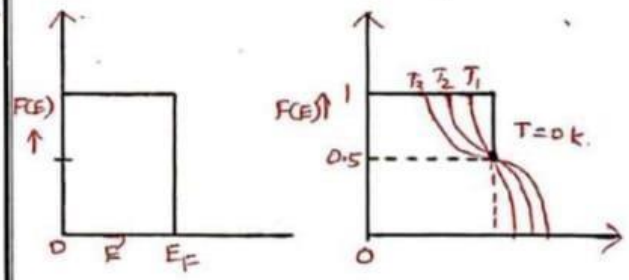
Case (iii)

If T>0K at $E = E_F$

$$F(E) = \frac{1}{1 + e^{0}} = \frac{1}{1+1}$$

$$F(E) = \frac{1}{2} \quad \text{or} \quad F(E) = 0.5$$

There is 50% chance for the electrons to occupy the fermi energy level



Variation of E_F with respect to temperature.

When T=0K, occupation is upto E_F

When T>0K valence electrons got breakdown in its bond and exited to conduction band.

3. Derive the formation of the electron mass varying and show it varies with the wave vector.

Effective Mass of Electron:-

Definition:-

The mass acquired by an electron, when it is accelerated in a periodic potential is called effective mass (m^*)

Derivation:-

Consider a crystal subjected to electric field (E). Then the velocity gained by the electrons(v) It is described by the wave vector (k) & it is equivalent to the wave packet moving with a group velocity (v_g).

$$v_g = \frac{d\omega}{dk} \quad -(1)$$

where $\omega \rightarrow$ angular velocity ($2\pi\nu$)

$k \rightarrow$ wave vector.

we know that

$$E = h\nu \quad (or)\ \omega = 2\pi\nu$$

$$\nu = \frac{\omega}{2\pi}$$

$$E = \frac{h\omega}{2\pi}$$

$$\hbar = \frac{h}{2\pi}$$

$$E = \hbar\omega$$

$$\omega = \frac{E}{\hbar} \quad -(2)$$

$\therefore$ Eqn (1) can be written as

$$v_g = \frac{d}{dk}\left[\frac{E}{\hbar}\right]$$

$$v_g = \frac{1}{\hbar}\left[\frac{dE}{dk}\right] \quad -(3)$$

Under this condition the acceleration 'a' of an electron

$$a = \frac{dv_g}{dt}$$

$$= \frac{d}{dt}\left[\frac{1}{\hbar}\left(\frac{dE}{dk}\right)\right]$$

$$a = \frac{1}{\hbar}\frac{d^2E}{dk^2}\cdot\frac{dk}{dt} \quad -(4)$$

The momentum of an electron from de-Broglie wave length

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

$$p = \frac{h}{2\pi}\cdot\frac{2\pi}{\lambda}$$

$$p = \hbar\frac{2\pi}{\lambda}$$

$$p = \hbar k \quad -(5)$$

Differentiate eqn (5) w.r.t. 't'

$$\frac{dp}{dt} = \hbar\frac{dk}{dt} \quad (or)\ \frac{dk}{dt} = \frac{F}{\hbar} \quad -(6)$$

[Force acting on the electron $F = \frac{dp}{dt}$]

Hence eqn (4) can be written as

$$a = \frac{1}{\hbar}\cdot\frac{d^2E}{dk^2}\cdot\frac{F}{\hbar}$$

$$a = \frac{F}{\hbar^2}\frac{d^2E}{dk^2}$$

$$F = \left[\frac{\hbar^2}{\left(\frac{d^2E}{dk^2}\right)}\right]a \quad -(7)$$

When an electric field is applied, acceleration of the electron due to field.

$$a = \frac{eE}{m^*} = \frac{F}{m^*}$$

$$F = m^*a \quad -(8)$$

Comparing eqns (7) & (8)

$$m^*a = \left[\frac{\hbar^2}{\left(\frac{d^2E}{dk^2}\right)}\right]a$$

$$m^* = \frac{\hbar^2}{\left(\frac{d^2E}{dk^2}\right)} \quad \text{— (9)}$$

Eqn (9) → Effective mass of an electron is not constant, but depends on the value $\frac{d^2E}{dk^2}$

Case(i): $\frac{d^2E}{dk^2}$ = +ve, m^* = +ve

Case(ii) $\frac{d^2E}{dk^2}$ = -ve, m^* = -ve

Case(iii) $\frac{d^2E}{dk^2}$ → more, m^* is ~~higher~~ lesser

Case(iii) $\frac{d^2E}{dk^2}$ → less m^* is ~~less~~ large

4. Find the expression for the energy states which are available for the occupation of the electrons.

UNIT-1

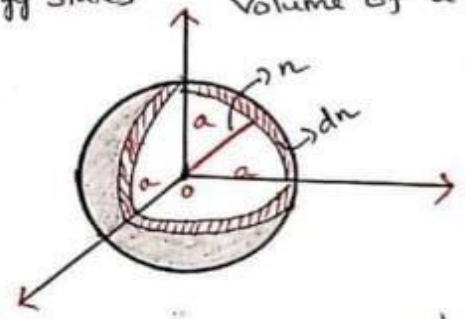
Density of Energy States:-

Definition:

It is defined as the no. of available energy states presented per unit volume of a metal piece

$$Z(E)dE = \frac{N(E)dE}{V}$$

Density of Energy States = $\frac{\text{No. of avaliable energy state between E \& E+dE}}{\text{Volume of a metal.}}$



Let us consider a sphere inside a cubical metal piece of side 'a'.

* Here n_x, n_y, n_z are the coordinate axes.
* n → inner radius of the sphere.
* E and E+dE are the energy of the inner and outer shell of the sphere.
* The sphere consists of no. of shells, between inner and outer shell each represents a energy level.

The no of available energy states within the thickness of the sphere of radius 'n'

$$n = \frac{1}{8}\left[\frac{4}{3}\pi n^3\right] \quad -(1)$$

III'ly the energy states within the sphere of radius (n+dn)

$$n+dn = \frac{1}{8}\left[\frac{4}{3}\pi(n+dn)^3\right] \quad -(2)$$

Hence, the no. of avaliable energy states between (n & n+dn) the energy interval E and E+dE.

$$N(E)dE = \frac{1}{8}\left[\frac{4}{3}\pi(n+dn)^3 - \frac{4}{3}\pi n^3\right]$$

$$= \frac{1}{8}\left[\frac{4}{3}\pi(n^3 + 3n^2dn + 3ndn^2 + dn^3 - n^3)\right]$$

$$N(E)dE = \frac{1}{8}\left[\frac{4}{3}\pi(3n^2dn + 3ndn^2 + dn^3)\right]$$

∵ dn very small, neglecting the higher orders,

$$N(E)dE = \frac{1}{8}\left[\frac{4}{3}\pi(3n^2dn)\right]$$

$$N(E)dE = \frac{\pi}{2}n^2dn \quad -(3)$$

We know that

the energy of an electron in a cubical metal piece of side 'a' is

$$E = \frac{n^2h^2}{8ma^2} \quad -(4)$$

Differentiating eqn (4) we have

$$dE = \frac{2n\,dn\cdot h^2}{8ma^2}$$

(ii) $$ndn = \frac{8ma^2}{2h^2}\cdot dE \quad -(5)$$

From eqn (4)

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

$$n = \left[\frac{8ma^2E}{h^2}\right]^{1/2} \quad -(6)$$

Hence eqn ③ can be written as

$$N(E)dE = \frac{\pi}{2} n.ndn \quad \text{—⑦}$$

By substituting eqn ⑤ & ⑥ in ⑦

$$N(E)dE = \frac{\pi}{2}\left[\frac{(8m)^{1/2}aE^{1/2}}{h}\right]\left[\frac{8ma^2dE}{2h^2}\right]$$

$$\therefore N(E)dE = \frac{\pi}{2}\frac{(8m)^{3/2}a^3E^{1/2}dE}{2h^3} \quad \text{—⑧}$$

Here $a^3 = V \rightarrow$ Volume

∴ Density of energy states

$$Z(E)dE = \frac{N(E)dE}{V}$$

$$Z(E)dE = \frac{\pi(8m)^{3/2}VE^{1/2}dE}{4h^3.V}$$

$$Z(E)dE = \frac{\pi}{4h^3}(8m)^{3/2}E^{1/2}dE \quad \text{—⑨}$$

According to Pauli's exclusion principle in each state 2 electrons can be accomodated.

$$\therefore Z(E)dE = 2 \times N(E)dE$$

$$\therefore Z(E)dE = 2 \times \frac{\pi}{4h^3}(8m)^{3/2}E^{1/2}dE$$

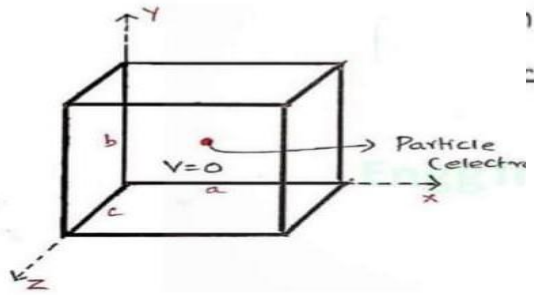
$$\boxed{Z(E)dE = \frac{\pi}{2h^3}(8m)^{3/2}E^{1/2}dE} \quad \text{—⑩}$$

5. Based on finite potential well, derive an expression for electron moves in any direction in space.

Unit-1

Particle in 3D Potential Well:

Consider a particle of mass 'm' moving three dimensionally in a box of lengths a, b &c as shown in the figure.



The potential function is given by

$V(x,y,z) = 0$ for $0 < x < a$, $0 < y < b$, $0 < z < c$

$V(x,y,z) = \infty$ for $0 \geq x \geq a$, $0 \geq y \geq b$, $0 \geq z \geq c$

The solution of one dimensional potential well is extended for a three dimensional potential well.

In 3D potential well, instead of one quantum number 'n', we have to use three quantum numbers n_x, n_y and n_z corresponding to the three coordinate axes namely x, y and z respectively.

The Eigen function and eigen value of a particle moving in a one dimensional potential well can be derived as follows.

One dimensional schroedinger's time independent wave equation of a free particle is given by

$$\frac{d^2\psi}{dx^2} + \frac{2mE}{\hbar^2}\psi = 0 \quad \text{—(1)}$$

Substituting $\frac{2mE}{\hbar^2} = k^2$ in eqn (1)

$$\frac{d^2\psi}{dx^2} + k^2\psi = 0 \quad \text{—(2)}$$

The general solution of equation (2) is given by

$$\psi(x) = A\sin kx + B\cos kx \quad \text{—(3)}$$

Where A and B are two constants A & B can be determined by boundary conditions.

Condition-1

$\psi = 0$ at $x = 0$

③ $\Rightarrow 0 = A \sin 0 + B \cos 0$

$0 = 0 + B \times 1$

Hence $B = 0$

Condition-2

$\psi = 0$ at $x = a$

③ $\Rightarrow 0 = A \sin ka + 0$

$A \sin ka = 0$

It is found that either $A = 0$ or $\sin ka = 0$

Since $B = 0$, 'A' cannot be zero.

$\therefore \sin ka = 0$

i.e. $ka = n\pi$

$$k = \frac{n\pi}{a}$$

$$k^2 = \frac{n^2\pi^2}{a^2} \quad \text{—④}$$

We know that

$$k^2 = \frac{2mE}{\hbar^2} = 2mE \cdot \frac{4\pi^2}{h^2}$$

$$k^2 = \frac{8\pi^2 mE}{h^2} \quad \text{—⑤}$$

Comparing eqn ⑤ & ④ we get

$$\frac{n^2\pi^2}{a^2} = \frac{8\pi^2 mE}{h^2}$$

$$E_n = \frac{n^2 h^2}{8ma^2} \quad \text{—⑥}$$

Substituting $k = \frac{n\pi}{a}$ in eqn ③, ③

$$\psi_n(x) = A \sin \frac{n\pi x}{a} \quad \text{—⑦}$$

The constant 'A' can be determined by normalisation of wave function.

The value of 'A' is given by

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

$\therefore$ Eqn ⑦ $\Rightarrow \psi_n(x) = \sqrt{\frac{2}{a}} \sin \frac{n\pi x}{a}$ —⑧

The eqn ⑥ and eqn ⑧ give eigen value and eigen function of a particle moving in an one dimensional potential well.

These two equations can be extended to three dimensional potential well as follows.

Energy of the particle

$$E_{n_x n_y n_z} = E_{n_x} + E_{n_y} + E_{n_z}$$

$$E_{n_x n_y n_z} = \frac{n_x^2 h^2}{8ma^2} + \frac{n_y^2 h^2}{8mb^2} + \frac{n_z^2 h^2}{8mc^2}$$

$$\boxed{E_{n_x n_y n_z} = \frac{h^2}{8m}\left[\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2} + \frac{n_z^2}{c^2}\right]} \quad \text{—⑨}$$

The corresponding normalised wave function of the particle in the three dimensional well is given by

$$\psi_{n_x n_y n_z} = \sqrt{\frac{2}{a}}\sin\left(\frac{n_x\pi x}{a}\right)\sqrt{\frac{2}{b}}\sin\left(\frac{n_y\pi y}{b}\right)\sqrt{\frac{2}{c}}\sin\left(\frac{n_z\pi z}{c}\right)$$

$$\psi_{n_x n_y n_z} = \sqrt{\frac{2}{a}}\sqrt{\frac{2}{b}}\sqrt{\frac{2}{c}}\sin\left(\frac{n_x\pi x}{a}\right)\sin\left(\frac{n_y\pi y}{b}\right)\sin\left(\frac{n_z\pi z}{c}\right)$$

$$\boxed{\psi_{n_x n_y n_z} = \sqrt{\frac{8}{abc}}\sin\left[\frac{n_x\pi x}{a}\right]\sin\left[\frac{n_y\pi y}{b}\right]\sin\left[\frac{n_z\pi z}{c}\right]} \quad \text{—⑩}$$

6. Attain the statement for the number of charge carriers per unit volume of material in an pure form of semiconductor. **Unit-2**

Carrier Concentration - Intrinsic Semiconductor:-

The no. of charge carriers per unit volume of the material is called carrier concentration also known as density of charge carriers.

Derivation:

In intrinsic semi conductor the no. of electrons in the conduction band (n) and holes in the valence band (p) is equal to each other at T>0k.

$$n = p = n_i$$

The density of electrons in the conduction band (n) is given by

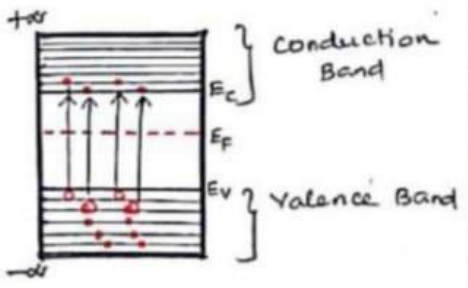
$$\int dn = n = \int_{E_c}^{\infty} Z(E)\, F(E)\, dE \quad \text{—(1)}$$

We know that, Density of energy States

$$Z(E)dE = \frac{4\pi}{h^3}(2m_e^*)^{3/2} E^{1/2}\, dE \quad \text{—(2)}$$

Probability of Electron occupation

$$F(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{k_B T}}} \quad \text{—(3)}$$



$$\therefore n = \int_{E_c}^{+\infty} \frac{4\pi}{h^3}(2m_e^*)^{3/2} E^{1/2} \frac{1}{1 + e^{\frac{(E-E_f)}{k_B T}}} dE \quad \text{—(4)}$$

Here

m_e^* – Effective mass of Electron.

E – kE of conduction electron

$E = E - E_c$

E_c – Lower conduction Energy level.

Eqn (4) can be written

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} \int_{E_c}^{+\infty} \frac{(E-E_c)^{1/2}}{1 + e^{\left(\frac{E-E_f}{k_B T}\right)}} dE \quad \text{—(5)}$$

We know that at T>0K

$$E - E_f >> k_B T$$

$$\frac{E-E_f}{k_B T} >> 1 \quad (\text{or}) \quad e^{\left(\frac{E-E_f}{k_B T}\right)} >> 1$$

$$\therefore 1 + e^{\frac{(E-E_f)}{k_B T}} \simeq e^{\frac{(E-E_f)}{k_B T}}$$

Hence eqn (5) can be written as

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} \int_{E_c}^{\infty} \frac{(E-E_c)^{1/2}}{e^{\left(\frac{E-E_f}{k_B T}\right)}} dE$$

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} \int_{E_c}^{\infty} (E-E_c)^{1/2} e^{E_f - E/k_B T}\, dE$$

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} e^{E_f/k_B T} \int_{E_c}^{\infty} (E-E_c)^{1/2} e^{-E/k_B T}\, dE \quad \text{—(6)}$$

To calculate eqn (6)

Let	when	
$E - E_c = x$	$E = E_c$	$E = \infty$
$E = x + E_c$	$E_c - E_c = x$	$\infty - E_c = x$
$dE = dx$	$x = 0$	$x = \infty$

∴ Eqn ⑥ can be written as

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} e^{E_f/k_BT} \int_0^\infty x^{1/2} e^{-(E_c+x)/k_BT} dx$$

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} e^{(E_f-E_c)/k_BT} \int_0^\infty x^{1/2} e^{-x/k_BT} dx$$

Using gamma function

$$\int_0^\infty x^{1/2} e^{-x/k_BT} dx = \frac{\sqrt{\pi}}{2}(k_BT)^{3/2}$$

Hence

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2} e^{(E_f-E_c)/k_BT} \frac{\sqrt{\pi}}{2}(k_BT)^{3/2}$$

$$n = 2\left[\frac{2\pi m_e^* k_BT}{h^2}\right]^{3/2} e^{\frac{(E_f-E_c)}{k_BT}} \quad \text{—⑧}$$

Eqn ⑧ is the expression for the density of electrons in a Conduction band.

Density of Holes (P):

It is given by

$$\int_{E_1}^{E_2} dP = P = \int_{E_1}^{E_2} Z(E)\, dE\, [1 - F(E)] \quad \text{—⑨}$$

Here

$$Z(E)\, dE = \frac{4\pi}{h^3}(2m_h^*)^{3/2} E^{1/2} dE$$

here

$m = m_h^*$

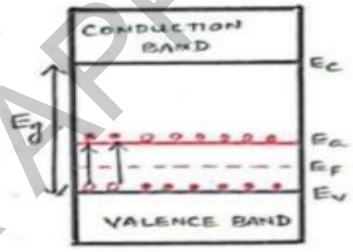
$E = E_v - E$.

$$1 - F(E) = 1 - \frac{1}{1 + e^{(E-E_F)/k_BT}}$$

P-Type Semiconductor:

* The Energy level diagram is shown in the figure

* Here the excess no. of holes from a new energy level (E_a) acceptor level just below the Conduction Band.



We know that the density of Holes in the valence band.

$$P = 2\left[\frac{2\pi m_h^* k_BT}{h^2}\right]^{3/2} e^{(E_v-E_F)/k_BT} \quad \text{—①}$$

E_v → Top energy level of valence Band

E_a → Acceptor Energy level

E_f → Fermi Energy level.

Density of Electrons in the acceptor energy level is given by

$$n_e = N_a[F(E_a)]$$

$$n_e = N_a \frac{1}{1 + e^{\frac{(E_a-E_f)}{k_BT}}} \quad \text{—②}$$

Since $E_a - E_f \gg k_BT$ (or) $\frac{E_a - E_F}{k_BT} \gg 1$

$$\therefore 1 + e^{(E_a-E_f)/k_BT} \approx e^{(E_a-E_f)/k_BT}$$

$$\therefore n_e = N_a e^{\frac{(E_f-E_a)}{k_BT}} \quad \text{—③}$$

At equilibrium,

No. electrons in the acceptor energy level (p) = No of holes in valence band (n_e)

$$2\left[\frac{2\pi m_h^* k_BT}{h^2}\right]^{3/2} e^{\frac{(E_v-E_f)}{k_BT}} = N_a e^{\frac{(E_f-E_a)}{k_BT}} \quad \text{—④}$$

By substituting and simplyfying the density of Holes

$$P = 2\left[\frac{2\pi m_h^* k_BT}{h^2}\right] e^{\frac{(E_v-E_f)}{k_BT}} \quad \text{—⑩}$$

$$\frac{e^{\left(\frac{E_v - E_f}{K_B T}\right)}}{e^{\left(\frac{E_f - E_a}{K_B T}\right)}} = \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}$$

$$e^{\left[\frac{E_v - E_f - E_f + E_a}{K_B T}\right]} = \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}$$

$$e^{\left[\frac{-2E_f + E_v + E_a}{K_B T}\right]} = \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}$$

Taking log on bothsides,

$$\frac{-2E_f + E_v + E_a}{K_B T} = \log \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}$$

Rearranging Equation,

$$E_f = \frac{E_a + E_v}{2} - \frac{K_B T}{2} \log \left[\frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}\right] \quad \text{---(6)}$$

The density of holes in the p type can be written by substituting equation (6) in eqn (1)

$$p = 2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2} e^{\left[\frac{E_v - E_f}{K_B T}\right]}$$

Here $e^{\left[\frac{E_v - E_f}{K_B T}\right]}$ can be rearranged as follows,

$$= \exp\left[\frac{E_v - \left[\left(\frac{E_a + E_v}{2}\right) - \frac{K_B T}{2} \log \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}\right]}{K_B T}\right]$$

$$= \exp\left[\frac{2E_v - E_a - E_v}{2K_B T} + \frac{1}{2} \log \left[\frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}\right]\right]$$

$$= \exp\left[\frac{E_v - E_a}{2K_B T} + \frac{1}{2} \log \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}\right]$$

∴ Eqn (1) can be written as

$$p = 2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2} \exp\left[\frac{E_v - E_a}{2K_B T} + \frac{1}{2} \log \frac{N_a}{2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}}\right]$$

$$p = 2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2} e^{\frac{E_v - E_a}{2K_B T}} \cdot \frac{(N_a)^{1/2}}{\left[2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/2}\right]^{1/2}}$$

$$p = (2N_a)^{1/2}\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{3/4} e^{(E_v - E_a)/K_B T} \quad \text{---(7)}$$

Eqn (7) is the expression for the carrier concentration of 'p'-type semiconductor.

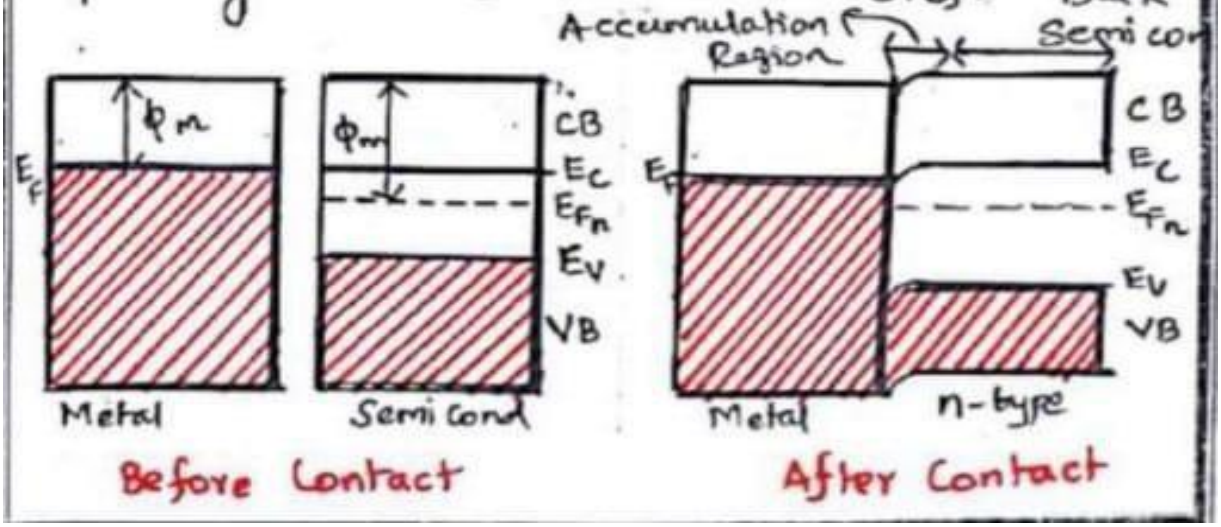
Ohmic Contacts:

Definition:-

An ohmic contact is a type of metal Semiconductor function. It is formed by a contact of a metal with a heavily doped Semiconductor.

When the Semiconductor has a higher work function than that of metal, then the function formed is called the ohmic function.

Here the current is conducted equally in both directions.



Working:

Fermi levels of the metal and Semiconductor are at different positions before contact. [Fig (i)]

After contact, at equilibrium the electrons move from the metal to the empty states in the conduction band of Semiconductor.

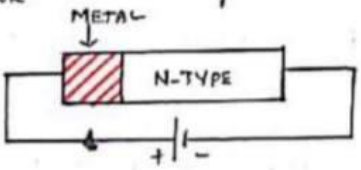
∴ An accumulation region near the interface is appeared. (Semi-conductor side)

Fermi levels after contact are shown in [fig(ii)].

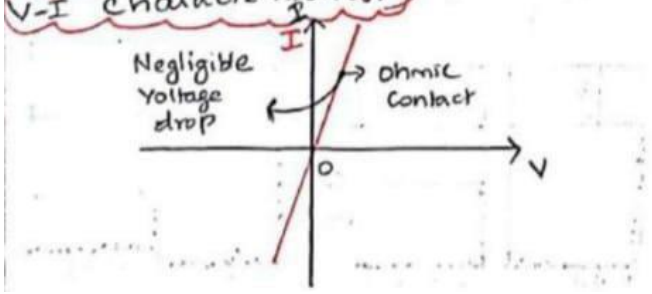
Accumulation region has a higher conductivity than the bulk Semiconductor due to higher concentration.

Ohmic contact behaves as a resistor conducting in both forward and reverse biase. (Fig. (ii)).

The resitivity is determined by the bulk resistivity of the Semiconductor.



V-I characteristics:



The current density is proportional to the potential across the junction.

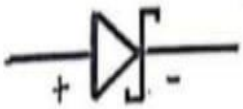
Ohmic contacts are non-rectifying and show negligible voltage drop and resistance irrespective of the direction and magnitude of current.

Applications:

The use of ohmic contact is to connect one semiconductor device to another, an IC or to connect an IC to its external terminals

Schottky Diode:-

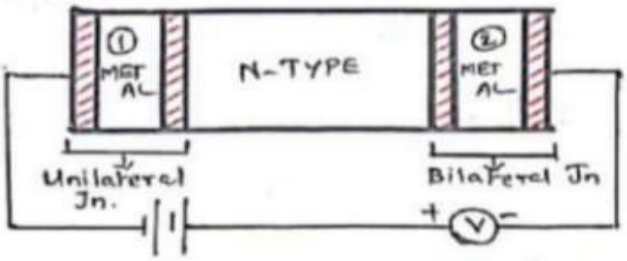
Schottky diode is a unilateral device, in which current flow from metal to semiconductor in one direction.



Construction:

A Schottky diode also called as Schottky barrier diode. It is made up of 2 junctions.

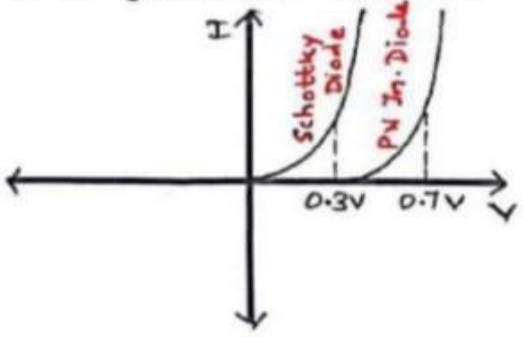
(i) Unilateral [Metal-Semiconductor
(ii) Bilateral [Metal-Semiconductor



The Schottky diode act as a terminal device in which metal 1 and Semiconductor formed at one end act as anode with unilateral junction, metal 2 and Semiconductor formed at other end act as cathode with bilateral junction.

Working:

Applying forward bias, the voltage applied to diode and their corresponding current is measured. The V-I curve is drawn for Schottky diode as compared with P-N Junction diode.



As per V-I curve, during forward bias for a Schottky diode I increase enormously even for

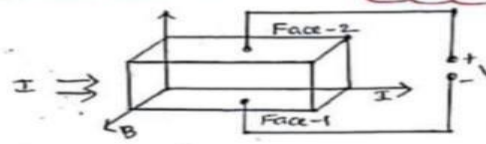
9. HALL Derive the coefficient expression and determination of charge carriers based on Hall effect. **Unit -2**

Hall Effect:

When a conductor carrying a current (I) is placed perpendicular to a magnetic field (B) a potential difference is produced inside the conductor in a direction perpendicular to current and magnetic field.

This phenomenon is known as "Hall effect" and generated voltage is called Hall "voltage"

Hall Effect in n-type Semiconductor & P-type



Consider n-type semiconductor in the form of rectangular slab. Current (I) flow in x-direction magnetic field (B) is applied in z-direction, Due to Hall effect Voltage developed along y-direction (in fig). current flow due to electron flow.

Electrons moving with velocity 'v', experience downward force.

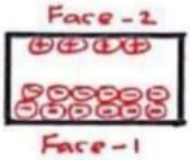
Force due to magnetic field (Downward) $= Bev$ — (1)

Force due to potential difference $= eE_H$ — (2)

At equilibrium (1) = (2)

$Bev = eE_H$

$E_H = Bv$ — (3)



we know that

Current density

$J_x = -nev$

$v = \frac{-J_x}{ne}$ — (4)

Substitute eqn (4) in eqn (3)

$E_H = B\left(\frac{-J_x}{ne}\right)$

$E_H = R_H J_x B$ — (5)

where $R_H = \frac{-1}{ne}$

-ve sign indicate Elec. field in -ve Y axis

∴ Hall coefficient

$R_H = \frac{E_H}{J_x B}$

III'ly in P-type Semiconductor Current flow due to flow of holes (+ve charge)

Compare with n-type semiconductor current density $J_x = pev$

$v = \frac{J_x}{pe}$ — (6)

Substitute eqn (6) in (3)

$E_H = R_H J_x B$ — (7)

$R_H = \frac{1}{pe}$

Hall coefficient interms of Hall voltage

Hall voltage $V_H = E_H t$ — (8)

where $E_H \rightarrow$ Hall field.

Substitute eqn (7) in eqn (8).

$V_H = R_H J_x B t$ — (9)

Area of the sample A = thickness x Breadth

$A = bt$

Current density $J_x = \frac{I_x}{A}$

$J_x = \frac{I_x}{bt}$ — (10)

Substitute eqn (10) in eqn (9)

$V_H = \frac{R_H I_x B t}{bt}$

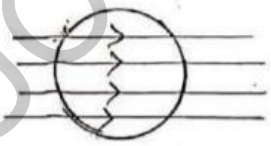
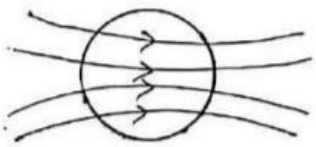
$V_H = \frac{R_H I_x B}{b}$ — (11)

$R_H = \frac{V_H b}{R_H B}$ — (12)

Eqn (12) gives Hall coefficient in interms of hall voltage.

10.TYPES OF MAGNETIC EFFECTS: **Unit-3**

Dia, Para, Ferro Magnetic Effects:

Dia	Para	Ferro
(i) It is non-magnetic material consits of no-permanent dipoles	Temporary magnetic material. consits of permanent dipole.	Permanent magnetic material. consits of large no. of permanent dipoles.
(ii) Dipoles are opposite to each other in the absence of external field. Net dipole moment is zero	Dipoles are randomly oriented in the absence of external field. Net dipole moment is minimum	Dipole are oriented parallel to each other, in the absence of external field. net dipole moment is large.
(iii) In the presence of external field dipole allign opposite to the external field.	In the presence of external field dipoles allign parallel to the external field.	Here also, dipoles allign parallel to the external field.
(iv) Magnetic flux lines are repelled out of the material.	Magnetic flux lines are attracted by the material	Magnetic flux lines are attracted maximum by the material.
Bin << Bout	Bin >> Bout	Bin >>> Bout
(v) 		
(v) Permiability (μ) is less than 1 and susceptibility is -ve $\mu << 1$, χ = -ve	Permiability (μ) is greater than 1 & susceptibility is +ve. $\mu > 1$, χ = +ve	Permiability (μ) is very much greater than 1, susceptibility is +ve, $\mu >> 1$, χ = +ve
(vi) Independent on temperature	Dependent on temperature	Dependent on temperature
(vii) At very low temp. it will be in diamagnetic	Temp above maximum para mag. converted into Dia mag. is known as curie Temp.	Above curie temperature it is converted in to para materials
Ex: Bismuth, Gold.	Ex: Al, Pt.	Ex: Fe, Ni, Co.

magnetic moment in a thin mag-layer and GMR effect is used as the principle to read the data in HDD.

Here Zero(0) represents missing transition and one(1) represents transition in the medium.

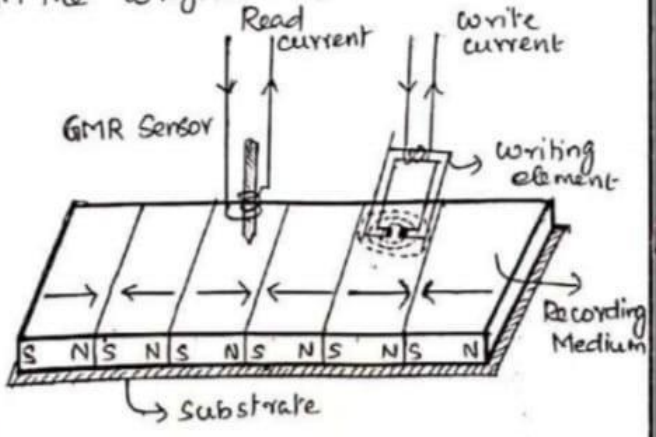
Construction:-

* The HDD consists of recording medium made up of thin layer of magnetic garnets grown over the substrate the GMR Sensor.

* The substrate is made up of ferrites and anti ferromagnetic materials. This is used as reading element

* The writing element is made up of inductive magnetic transducer.

* The writing element and the GMR sensor shall be made to slide over the recording media in the longitudinal direction.



Working:- (Writing)

1. Initially the current is passed through the writing element and a magnetic field is induced in between the gap of the inductive magnetic transducer.

2. During writing, the amplitude of current is kept constant, and the direction of current is reversed.

3. Due to reversal of current the reversal of current, the magnetization orientation is reversed in the recording medium (ie) from south → North

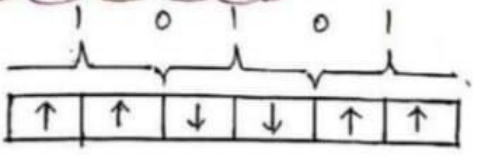
4. When the induced magnetic field is greater than the Coercivity of the recording media, then data is recorded in the form of 1.

5. Thus one(1) is stored as data in the recording medium as a magnetic transition.

6. When there is no magnetic transition, then it is referred as zero.

7. In this way 0's & 1's are stored in the recording medium

Reading / Retrieving:



GMR Devices – Magnetic Hard Disk Drive with GMR Sensor:

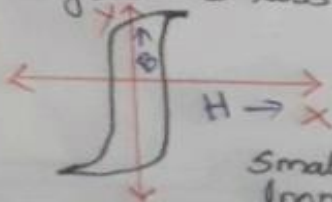
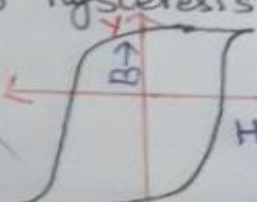
GMR sensors, which has a very high magnetic sensitivity are used to read the data at greater speed.

Principle:

In Hard Disk drives, the binary data in terms of zero's (0) and one's (1) are stored by inducing.

12. Differences between Soft & Hard Magnetic Materials.

Differences between Soft & Hard magnetic Materials.

S.No	Soft magnetic materials	Hard magnetic materials
1	It can be magnetised and demagnetised easily	It can't be magnetised and demagnetised easily.
2	It have high Permeability	low Permeability.
3	magnetic energy stored is low	High magnetic energy Storage.
4	Low Coercivity and retentivity	high Coercivity & Retentivity.
5	High resistivity, low eddy current loss	low resistivity, high eddy current loss.
6	Domain walls are easy to move	Domain walls are hard to move.
7	Uses: Temporary magnets in electric motor, generators, transformers, radar	Permanent magnets loud speakers and electrical measuring instruments.
8	Ex: Fe – Si alloy, ferrites Ni – fe alloy Si – steels	Tungston steel, Cobalt steel, Alini, Alnico.
9	Strongly attract the magnetic field	Strongly repel the magnetic field.
10	The value of B-H Product (energy Product) low	B-H Product value high.
11	Low hysteresis loss	High hysteresis loss
12	 Small loop area	 large loop area.

Exchange Interaction:-

The Weiss theory of ferro-magnetism explains about the molecular field but it is not possible to explain large value of internal field.

To explain the large internal field, Heisenberg gave an explanation which is based on the non magnetic interaction called exchange interaction between electron.

These force appears in the form of spin-spin interaction and strength of the interaction depends upon the interatomic separation. If the interatomic distance is decreased, the electron spin are decreased and the exchange force decreases and become anti parallel spins.

According to Heisenberg theory, the change interaction between electrons in different quantum states lead to a lower energy provided the spin quantum number of the both states are parallel.

∴ The exchange interaction between the electrons is given by

$$E_{ex} = -2 J_{ij} S_i S_j$$

Where J_{ij} → The exchange integral for the two atoms.

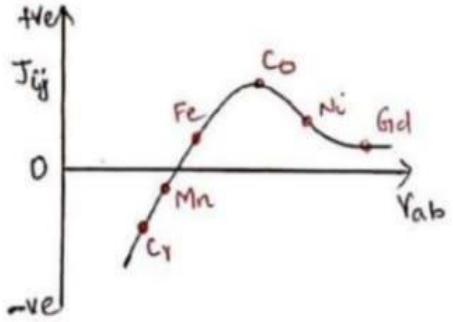
S_i → Spin angular moments associated with i^{th} state.

S_j → Spin angular moments associated with j^{th} state.

A plot of exchange Integral value (J_{ij}) and the interatomic distance (r_{ab})

r_{ab} → interatomic distance.

r_0 → the orbital radius of electron



From graph,

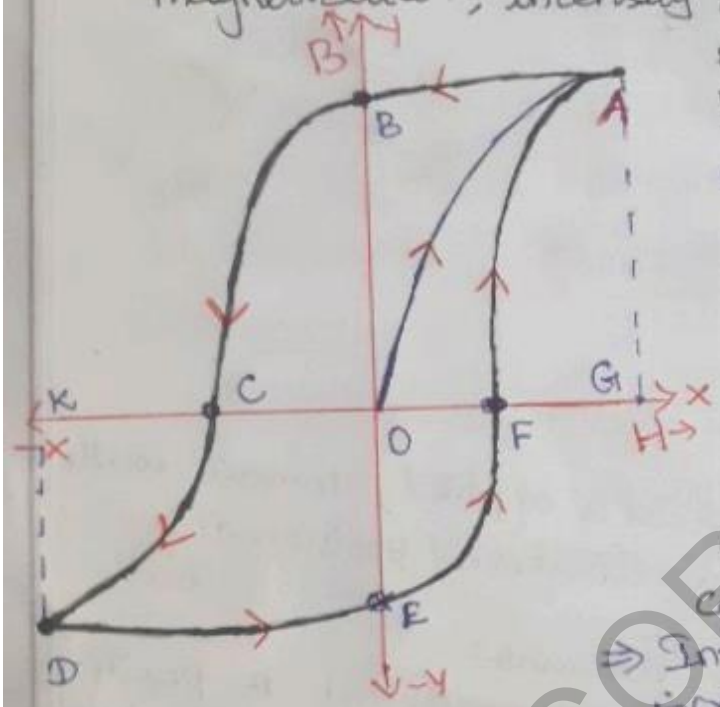
1. The value of J_{ij} is +ve when $\frac{r_{ab}}{r_0} > 3$ (ie) the exchange energy is -ve and hence the parallel orientation is high. Due to this atom possess ferromagnetic properties [Ex: Fe, Co, Ni, Gd]

2. The value of J_{ij} is -ve when $\frac{r_{ab}}{r_0} < 0$ (ie) the exchange energy is +ve and hence the atoms coming under this criteria possess anti-ferromagnetic properties [Ex: Cr, Mn]

(a) Hysteresis – M Vs H behaviour

⇒ Hysteresis means lagging behind.

" when a ferromagnetic material taken a cycle of magnetisation, intensity of magnetisation (M) and magnetic induction (B) lag behind the magnetic field (H)



⇒ $H = 0$; M and $B \neq 0$

⇒ The lagging of M and B behind H is called Hysteresis.

⇒ The variation of 'B' with respect to H represented by a closed loop (or) curve is called Hysteresis loop (or) curve.

⇒ Intensity of magnetisation (B) increases with magnetic field (H) Position 'OA'.

⇒ When $H = 0$; $B \neq 0$; is called retentivity (position 'OB')

⇒ The applied m.f (H) is reversed, the intensity of magnetisation is zero is called coercivity (position C)

⇒ The m.f is reversed, the intensity of magnetisation curve DEFA. (complete cycle of magnetisation)

⇒ The loop ABCDEFA is called hysteresis loop.

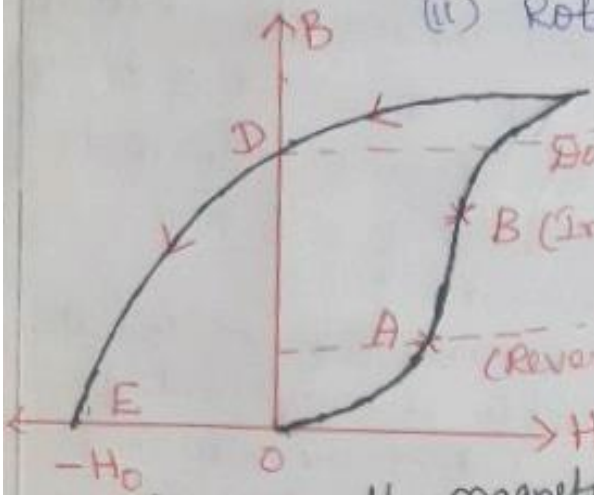
⇒ Intensity of magnetisation ($B \neq 0$), when magnetic field strength ($H = 0$)

⇒ The lagging of intensity of magnetisation behind the applied field strength is called magnetic hysteresis.

⇒ The amount of intensity magnetisation retained in the material after removing the magnetic field is called Retentivity (or) Residual magnetism.

(b) Hysteresis on the basis of Domain theory.

⇒ When a ferromagnetic materials subjected to an external magnetic field, resultant is increase in magnetic moment of the materials,
It's due to: (i) motion of domain walls
(ii) Rotation of domain walls.



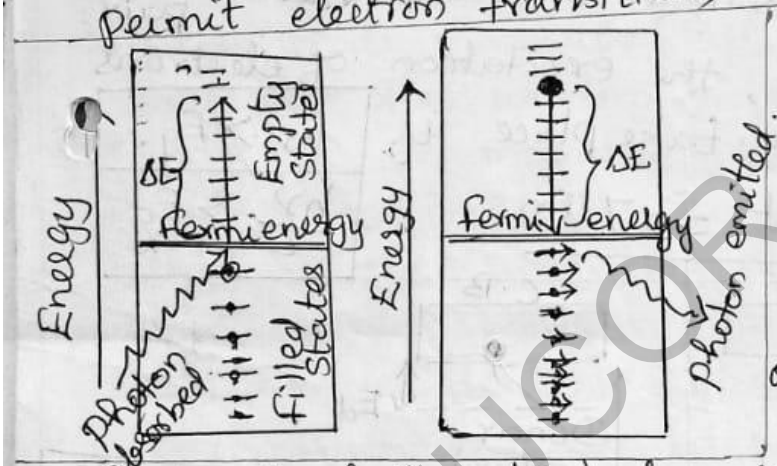
⇒ When small magnetic field is applied, domain walls along the direction of magnetisation (Position-A)
⇒ Applied m.f is removed the domain walls return to its original position (reversible domains)
⇒ magnetic field increases, domain walls at 'B' position, even removed m.f, domain walls donot come back their original position (Irreversible domains)
⇒ further increase in m.f, domains are start rotating along field direction, and anisotropic energy stored in hard direction (BC - represented)
⇒ Now materials attained the maximum magnetisation.
⇒ The removal of m.f, materials has maximum magnetisation is called residual magnetisation (or) retentivity
⇒ On the removal of m.f, the specimen attain the original configuration, but its stopped due to the presence of impurities
⇒ Overcome this, a large amount of reverse m.f is applied. "The amount of energy spend to reduce magnetisation is zero is called Coercivity."

Unit-IV Optical Properties of Materials: (1)

2nd: Describe absorption and emission of light in metal, Insulator and Semiconductor:

(a) In metals:

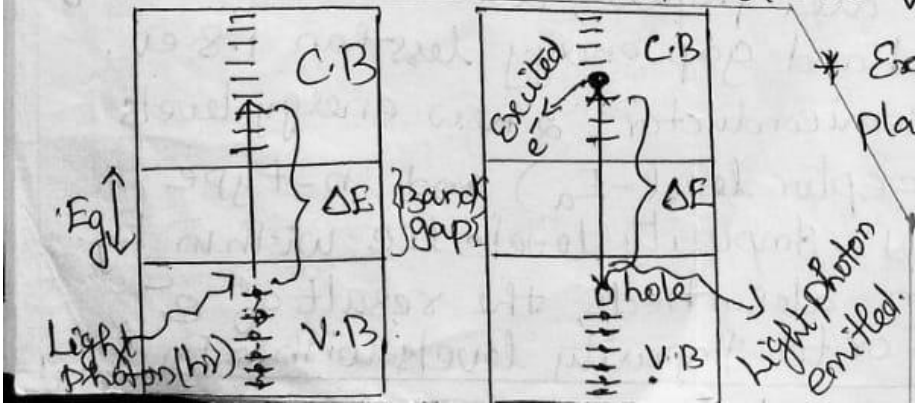
* metals are opaque, the incident radiation is observed. Total absorption is less than 0.1 μm
* metallic film thicker than 0.1 μm are capable of transmitting visible light.
* All the frequencies of visible light are absorbed by metals (ie available empty electron states which permit electron transitions)



* metals are opaque to all Electromagnetic radiation. lower end from Radio waves, IR, visible and the middle of ultraviolet radiations
* metals are transparent of high frequency (X & γ rays) Radiation.
* most of the absorbed radiation, re-emitted in visible light, (ie reflected light)
* The reflectivity of emission is small, (0.90 to 0.95) in the form of heat
* metals exposed white light show bright silvery. It denotes highly reflects all parts of visible spectrum.

(b) In Insulators:

* Absorption of a light photon may occur in Insulator.
* free e^- in C.B and hole in V.B are created.



* Excitation e^- takes place only light photon energy

$$\Delta E = h\nu$$

h → planck's Constant
ν → frequency

light photon absorption takes place

$h\nu > E_g$

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

c → velocity of light

λ → wavelength of light. [$\lambda_{min} = 0.4\mu m$, Visible li

$$E_g(max) = \frac{hc}{\lambda_{min}} = \frac{6.62\times10^{-34}\times3\times10^{8}}{0.4\times10^{-6}} = 4.96\times10^{-19}\ J$$

$$E_g(max) = \frac{4.96\times10^{-19}}{1.6\times10^{-19}} = 3.1\ eV$$; $E_g(max) = 3.1\ eV$

* No visible light is absorbed, $E_g > 3.1$ ev, These materials appear transparent and colourless.

(c) In Semiconductors:

* Light photon is absorbed to Create electron-hole pair.

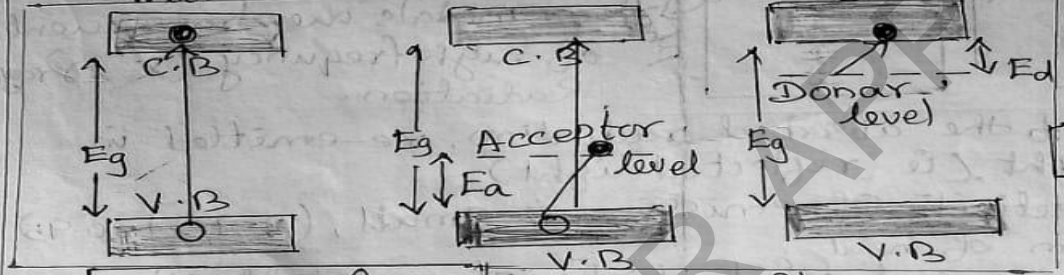
Ex: Si & Ge.

* Transition occurs, the excitation of electrons due to absorption can take place if

$h\nu > E_g$.

$\frac{h\nu}{c} > E_g$.

λ_{max} for Visible light $= 0.7\mu m$.



$1\ eV = 1.6\times10^{-19}\ J$

$$E_g(min) = \frac{hc}{\lambda_{max}} = \frac{6.62\times10^{-34}\times3\times10^{8}}{0.7\times10^{-6}} = 2.84\times10^{-19}\ J$$

$$E_g(min) = \frac{2.84\times10^{-19}}{1.6\times10^{-19}} = 1.8\ eV$$

$E_g(min) = 1.8$ ev

* Semiconductors are opaque, due to absorbed of visible light band gap energy lessthan 1.8 ev.

* for Extrinsic Semiconductor, 2 new energy levels for P-type (acceptor level - E_a) and n-type (Donar level - E_d). Impurity levels lie with in E_g

* Light radiation absorbed, the result of e^- transition from or to Impurity levels with in E_g.

16.Carrier generation and recombination processes **unit-4**

(8) CARRIER GENERATION AND RECOMBINATION PROCESSES

CARRIER GENERATION:

* The Process whereby electrons and holes are created.

* There are 3 types:

(a) Photo generation (b) Phonon generation

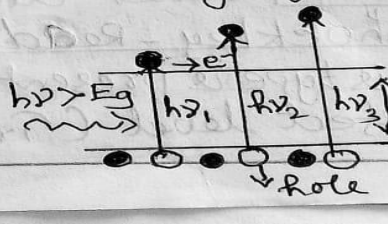
(c) Impact generation.

(a) Photo generation:

(i) Light frequency falls greater than E_g of Semiconductor

(ii) Absorption of light photon

One electron from valence band to Conduction band to form electron-hole pair.

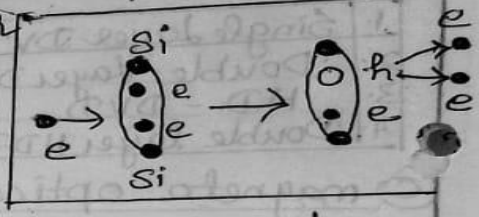


(b) Phonon generation:

* It's due to thermal excitation.
* Temperature increases, lattice vibration increases, due to this break covalent bond electron-hole pair generated.

(c) Impact Ionization:

* One energetic charge carrier (e) create another charge carrier under electric field.
* Bond breaks out generating more carriers.
* High field, avalanche breakdown



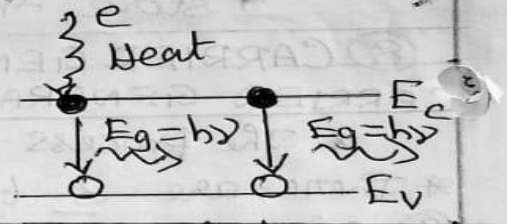
Recombination:

* The process whereby electrons and holes are annihilated.
* There are 3 types.

(a) Radiative Recombination (b) Shockley-Read-Hall Recombination (c) Augar Recombination.

(a) Radiative Recombination:

* In direct band semiconductor, e^- from C.B (min) falls to V.B (max); momentum no change.
* e^- are excited to higher energy state in C.B to C.B (min) by releasing heat energy.
* from C.B (min) to V.B (max) emitting energy $E_g = h\nu$ called direct recombination.



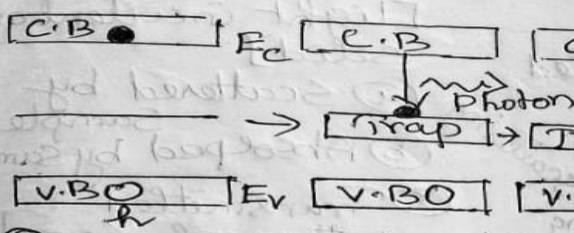
e – electron
C.B → conduction band

(b) Shockley-Read-Hall Recombination:

* This type is present in impure semiconductor.
* Defect level (Trap) is present.

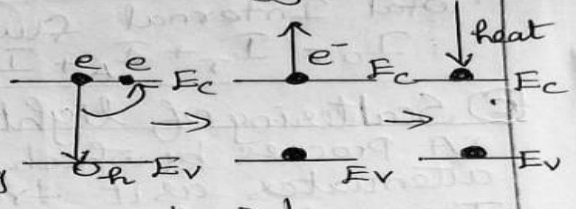
Trap:- Intermediate energy level present in the energy gap between conduction band & valence band.

* which arises due to presence of impurity atoms
* e from C.B to Trap radiating energy, $h\nu$.
* from C.B to V.B, radiate energy, $h\nu$.



(c) Auger Recombination:

* Three carriers are involved e-h recombine, this energy is given to 3rd e^- in C.B.
* 3rd e^- comes to C.B emitting energy as heat.
* It's occur in heavily doped material.

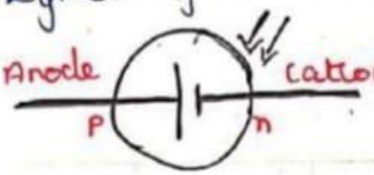


Solar Cell:

* Principle:

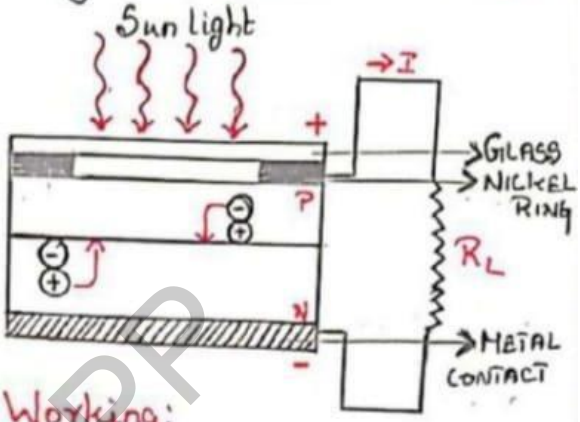
A solar cell is basically a P-N junction photo diode, which converts solar energy (light energy) into electrical energy. With larger efficiency of photon absorption.

* The symbol of the solar cell



* Construction:

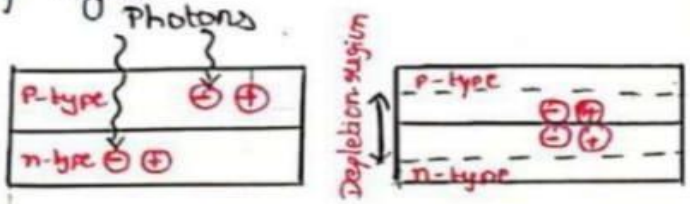
- A solar cell is made up of a heavily doped 'p' and 'n' type material
- The P-N diode is packed in a can with glass window on top such that light may fall upon P and N type material.
- The thickness of the p-region and n-region is very small Therefore charge carriers generated in this region can easily diffuse to the junction.
- Nickel ring at the top and metal at bottom act as terminals.
- The two terminals connected to the load resistance R_L through the ohmic contacts.



* Working:

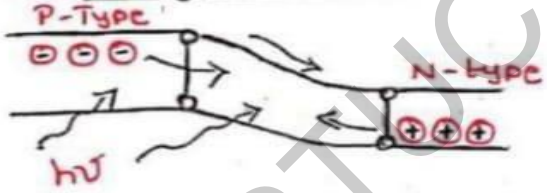
- Light radiation is allowed to fall on P-N junction diode, without load resistance (R_L).
- The photon energy is sufficient to break the covalent bond and produce electron-hole pairs.
- There electrons and holes quickly diffuses and reaches the depletion region.
- Therefore the strong barrier electric field existing in the junction
- The minority carries electrons in the p-side cross the barrier potential to reach N-side and the holes in N-side move to the p-side.

- The minority current is directly proportional to the illumination of light.



- The electrons and holes accumulate on either side of the junction, which gives rise to open-circuit voltage (V_o).
- Load Resistance R_L is connected across the diode, reverse current I_R flows through the circuit.

Energy level Diagram



* Merits:
- ⓞ Utilize renewable energy.
- ⓞ Eco-friendly
- ⓞ pollution free
- ⓞ Life time durability high.

* Demerits:
- ⓞ Cost is very high.
- ⓞ seasonal energy
- ⓞ Occupies more energy.

* Uses:
- ⓞ power production.
- ⓞ used in artifical satellite and space probes.

OLED - Organic LED:

* Definition:

ⓞ OLED are solid state devices made up of thin films of organic molecules that produce light with the application of electricity

ⓞ It is also known as light emitting polymers (LEP) or Organic electro luminescence

ⓞ Thickness of these layers is around 100 - 500 nm thick.

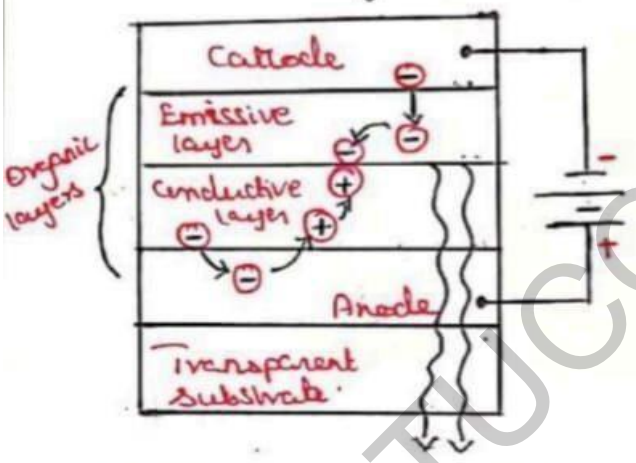
* Principle:

. An electron moves from the cathode to the emissive layer

and hole moves from the anode to the conductive layer and they recombine to produce otons.

* Construction:

- It is constructed with different layers of polymers coated with Organic compound.



- It consist of an emissive layer made up of poly-fluorine and a conductive layer made up of poly-aniline kept between cathode and anode substrate.
- This hole layers placed over transparent electrode layers.

* Working:

- Forward bias voltage is applied across the OLED
- Due to this cathode diffuse electron into emissive layer
- Anode gets an electron from Conductive layer & produces a hole in conductive layer.
- Thus, emissive layer becomes rich in negative charged particles & conductive layer becomes rich in positive charged particles.
- Due to the electrostatic force, electrons and holes, come closer & recombine with each other.
- In organic sc, holes move faster than electrons.
- This recombination produces light and it is emitted through the transparent substrate.

* Merits:
  - It is thin & flexible.
  - Light weight
  - Larger field view
  - Emission is brighter than normal light (LED's).

* Demerits:
  - Manufacturing cost is high
  - Easily damaged.
  - Maintainence is high.

* Application:
  - Used in cell phones, Car radios, digital camers.
  - Used in TV screens, Computers displays, adverti-sing
  - Automative dash boards
  - Used in flexible display boards.

One Qubit quantum gates

A one qubit gate transform an input qubit

$|\psi\rangle = \alpha_0 |0\rangle + \alpha_1 |1\rangle$ into an output qubit

$$|\psi\rangle = \alpha_0 |0\rangle + \alpha_1 |1\rangle$$

Mathematically, a gate G is represented by a 2×2 transfer matrix with complex entries

$$G = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix}$$

The normalization conditions are

$|\alpha_0|^2 + |\alpha_1|^2 = 1$ and $|\alpha_0'|^2 + |\alpha_1'|^2 = 1$.

Therefore to meet these conditions G must be a unitary matrix.

The transfer matrix of a quantum gate is G. The input and output qubits represented as column vectors are $|\psi\rangle$ and $|\phi\rangle$ respectively. The transformation performed by the gate is given by

For single quit gate, the equation can be written as

$$\begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix} = \begin{pmatrix} \alpha_0' \\ \alpha_1' \end{pmatrix}$$

The output vectors of these gates $|\varphi\rangle$ for a given input $|\psi\rangle = \alpha_0|0\rangle$ are given below.

$$I|\psi\rangle = |\varphi\rangle \quad : \quad \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix} = \begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix}$$

$$|\varphi\rangle = \alpha_0|0\rangle + \alpha_1|1\rangle$$

$$|\varphi\rangle = \sigma_x|\psi\rangle = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_0 \end{pmatrix}$$

(or) $$|\varphi\rangle = \alpha_1|0\rangle + \alpha_0|1\rangle$$

$$|\varphi\rangle = \sigma_y|\psi\rangle = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix} = i\begin{pmatrix} -\alpha_1 \\ \alpha_0 \end{pmatrix}$$

(or) $$|\varphi\rangle = -i\alpha_1|0\rangle + i\alpha_0|1\rangle$$

$$|\varphi\rangle = \sigma_z|\psi\rangle = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix} = \begin{pmatrix} \alpha_0 \\ -\alpha_1 \end{pmatrix}$$

(or) $$|\varphi\rangle = \alpha_0|0\rangle - \alpha_1|1\rangle$$

$$|\varphi\rangle = H|\psi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix}$$

(or) $$|\varphi\rangle = \frac{\alpha_0}{\sqrt{2}}(|0\rangle + |1\rangle) + \frac{\alpha_1}{\sqrt{2}}(|0\rangle - |1\rangle)$$

The Hadamad gate H, when applied to a purse state $|0\rangle$ or $|1\rangle$, creates a superposition state,

$$H|0\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

Thus.

$\alpha_0' = g_{11}\alpha_0 + g_{12}\alpha_1$ and

$\alpha_1' = g_{21}\alpha_0 + g_{22}\alpha_1$

A few important one qubit gates and their transfer matrices are given as

1. $I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ the I identity gate - It leaves a qubit unchanged.

2. $X = \sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$ is the X or NOT gate - it transpose the components of a qubit.

3. $Y = \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$ the Y gate - it multiplies the input qubit by i and flips the two components.

4. $Z = \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ the Z gate - it changes the phase

5. $H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$ the hadamard gate H - It creates a super position state from pure input states.

Where I is identity matrix.

$X = \sigma_x$, $Y = \sigma_y$ and $Z = \sigma_z$ are pauli matrices.

and

$$H|1\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$$

In general, the transformation of a qubit $|x\rangle$ with $x = 0$ (or) $x = 1$, carried out by a hadamard gate can be expressed as

$$|x\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle + (-1)^x |1\rangle).$$

Two - Qubit Quantum gates - CNOT gate.

* A gate with two inputs and two outputs is called CNOT. One input is called the control input and the other is the target input. The first output is called the control and the second is called the target.

* The classical equivalent of a quantum CNOT gate is the XOR gate. For a classical CNOT gate the target output is equal to the target input if the control input is 0 and flipped (complemented) if the control input is 1.

* The two qubits applied to the input of the CNOT gate in figure 5.18 are a control qubit $|\psi\rangle$ and a target qubit $|\phi\rangle$

$$|\psi\rangle = \alpha_0 |0\rangle + \alpha_1 |1\rangle, \quad |\phi\rangle = \beta_0 |0\rangle + \beta_1 |1\rangle$$

the input vector of the Quantum CNOT gate is:

$$|V_{CNOT}\rangle = |\psi\rangle \otimes |\phi\rangle = \begin{pmatrix} \alpha_0 \\ \alpha_1 \end{pmatrix} \otimes \begin{pmatrix} \beta_0 \\ \beta_1 \end{pmatrix} = \begin{pmatrix} \alpha_0 \beta_0 \\ \alpha_0 \beta_1 \\ \alpha_1 \beta_0 \\ \alpha_1 \beta_1 \end{pmatrix}$$

It is easy to determine the output state vector $|W_{CNOT}\rangle$ given the input state vector $|V_{CNOT}\rangle$ and the transfer matrix of a CNOT gate:

$$|W_{CNOT}\rangle = G_{CNOT} |V_{CNOT}\rangle$$

$$|W_{CNOT}\rangle = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} \alpha_0 \beta_0 \\ \alpha_0 \beta_1 \\ \alpha_1 \beta_0 \\ \alpha_1 \beta_1 \end{pmatrix} = \begin{pmatrix} \alpha_0 \beta_0 \\ \alpha_0 \beta_1 \\ \alpha_1 \beta_1 \\ \alpha_1 \beta_0 \end{pmatrix}$$

this result can be written as

$$|W_{CNOT}\rangle = \alpha_0 \beta_0 |00\rangle + \alpha_0 \beta_1 |01\rangle + \alpha_1 \beta_1 |10\rangle + \alpha_1 \beta_0 |11\rangle.$$

the output can also be written as

$$|W_{CNOT}\rangle = \alpha_0 |0\rangle [\beta_0 |0\rangle + \beta_1 |1\rangle] + \alpha_1 |1\rangle [\beta_1 |0\rangle + \beta_0 |1\rangle]$$

The CNOT gate is reversible. Indeed, the product $G_{CNOT} G_{CNOT} = I$;

of $|10\rangle$ with $|11\rangle$ and $|11\rangle$ and $|10\rangle$ are :

$$|00\rangle\langle 00| = \begin{pmatrix}1\\0\\0\\0\end{pmatrix}(1000) = \begin{pmatrix}1&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&0&0\end{pmatrix}$$

$$|01\rangle\langle 01| = \begin{pmatrix}0\\1\\0\\0\end{pmatrix}(0100) = \begin{pmatrix}0&0&0&0\\0&1&0&0\\0&0&0&0\\0&0&0&0\end{pmatrix}$$

$$|10\rangle\langle 11| = \begin{pmatrix}0\\0\\1\\0\end{pmatrix}(0001) = \begin{pmatrix}0&0&0&0\\0&0&0&0\\0&0&0&1\\0&0&0&0\end{pmatrix}$$

$$|11\rangle\langle 10| = \begin{pmatrix}0\\0\\0\\1\end{pmatrix}(0010) = \begin{pmatrix}0&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&1&0\end{pmatrix}$$

therefore, the transition matrix of the circuit is,

$$G_{CNOT} = \begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{pmatrix}$$

$$\begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{pmatrix}\begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{pmatrix} = \begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}$$

The CNOT quantum gate can be used to realise a universal gate. Further, any multiple qubit gate can be constructed from single qubit and CNOT gates.

SINGLE ELECTRON TRANSISTOR:(SET)

⊗ SET is three-terminal switching device which can transfer electron from source to drain one by one.

⊗ SET is individually control the tunneling of electron into and out of the quantum dot.

Construction & Working:-

⊗ Apply voltage bias to the gate voltage; Voltage difference occurs between source & Drain. That the current and electron flow in the same direction, from which the electron are orginate.

⊗ Gate voltage creat an electric field that alter the conductivity of the semiconducting channel below it, enabling current to flow from Source to Drain

⊗ Due to electric field, change in potential energy in dot w.r.t to Source and Drain

⊗ Gate Voltage-Controlled potential difference make electron in the source attracted to the dot, Simultaneously electron in the dot attracted to the drain.

Energy need to move a charge Q, across the potential difference 'V'

$$E = VQ$$

$$V = \frac{E}{Q} = \frac{E}{e} = \frac{W_c}{e}$$

$\because$ Q => Charge of Electron, 'e'

W_c => Charging Energy.

$$V = \frac{e}{2C}$$

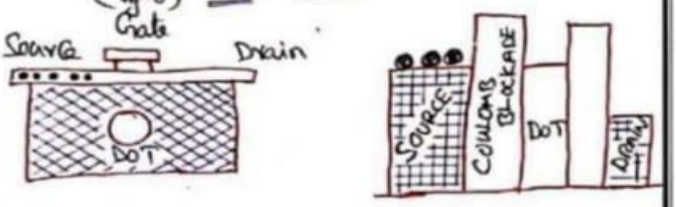
$$\therefore W_c = e^2/2C$$

This much of voltage require to electron tunnel through Coulomb blockade of Quantum dot.

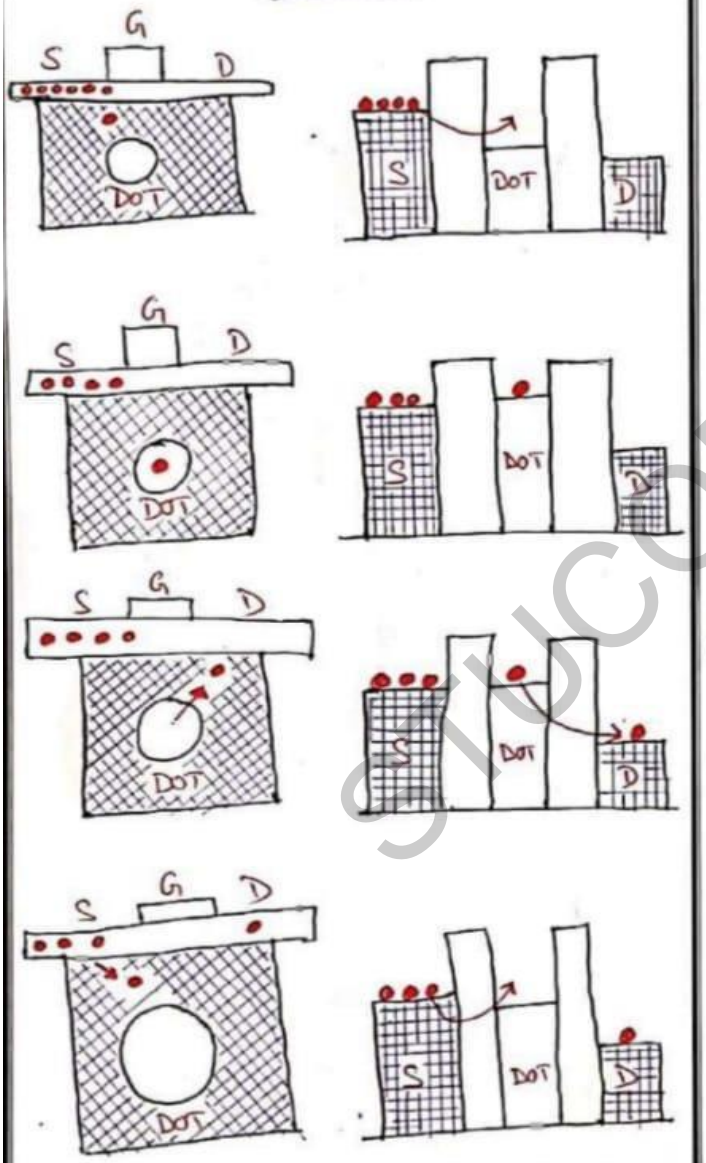
Working:

The SET has an electrically isolated quantum dot located between the source & drain.

OFF MODE



ON MODE



⊛ SET in "OFF" Mode, it is not energetically favorable for electron Source to dot via tunnel.

⊛ SET in "ON" Mode, electron tunnel one at a time via the dot from source to drain.

⊛ Apply proper gate voltage, the potential energy of dot is low to encourage electron to tunnel through energy barrier.

⊛ The electron is on it, the dot potential energy rises as in fig.

⊛ Electron then tunnel through the Coulomb blockade on the other side to reach the lower potential energy at the drain.

⊛ The dot empty and the potential lower again, the process repeats.

Application :-

→ SET is used in sensor technology and digital electronic circuits

⇒ It is used for mass data storage.

⇒ It is used in highly sensitive electrometer

⇒ SET is suitable measurement set-up for single electron spectroscopy.

22..Explain the difference between the types of computing and give the comments of superior type of computing.

The quantum computers can solve the complex mathematical problems. Traditional computers find impossible to solve in a practical time frame.

The computing power is sufficient to process excessively large amounts of data (2.5 Exabyte daily i.e. equal to 5 million laptops)

Due to the teleportation phenomenon known as 'quantum tunneling,' it can work in parallel. It uses less amount of electricity, hence, reducing the power consumption upto 100 to 1000 times.

A computer is "thousands of times" faster than any classical computer.

It can work without being overheated. (since for its stability it kept cold upto 0.2 Kelvin inside the quantum system).

It can easily solve optimization problems such as finding the best route and scheduling trains and flights.

The quantum effect is made to reduce the size of electronic devices.

The simulation efficiency is high in quantum computers than in classical computers.

Disadvantages of quantum computing.

Due to advancements in quantum computers, the security of the existing Internet of Things (IoT) would fall down. Cryptographic techniques, Databases of defense systems can be hacked. Considering these facts, government and private large organizations, banks, and quantum computers can be terrible for our future.

The Quantum Computers will work as a different Since, classical computers are better at some places device and cannot replace classical computers entirely. than quantum computers like email, excel, etc.

It has not been invented completely yet as only parts are being implemented and people are still imaging how it would look.

It is very delicate and error-prone. Any kind of vibrations affects subatomic particles like atoms and electrons. Due to which noise, faults, and even failures are possible. It leads to "*Decoherence*" which is a loss of coherence in quantum.

Quantum processors are very unstable and are very hard to test even. For the stability of the quantum computer, it is kept at 0.2 Kelvin (absolute Kelvin) which is nearly below the inverse temperature.

23. QUANTUM CONFINEMENT

QUANTUM CONFINEMENT :-

It is a process of reducing the size of a cubic solid, so that the energy level inside become discrete.

- It is observed when the size of the particle is too small compare to the wavelength of the electron.
- In which only small percent of electron free to move during confinement.
- By bottom up or Top down process the dimension reduced.

QUANTUM STRUCTURE :-

When a bulk material reduced in its size. If the reduced dimension is in the order of few nanomaterials, then the structure is known as "Quantum Structure".

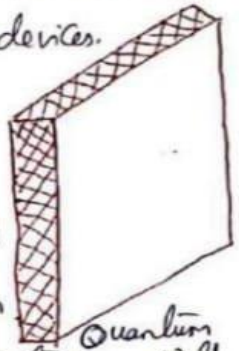
It is classified into 3 types based on direction.

i) Quantum well
ii) Quantum wire.
iii) Quantum Dot.

i) Quantum Well :-

If one direction is reduced to nano range while the other two dimension remain large, then we get a structure known as "Quantum Well".

- Quantum well are made from alternative layer of different semiconductor or by deposition of very thin metal film.
- It is a large structure in which the carrier particle are free to move in 2D.
- The particle are confined in one Dimension, they are considered as Quantum Confinement.
- Confinement of carriers, the quantum well structure has important application to making devices.


Quantum well.

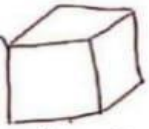
ii) Quantum Wire :-

- If 2D are reduced and one dimention remain large, the resulting structure, "Quantum Wire".
- The carrier are free to move its trajectory along the wire.
- Quantum wire structure are nanowire, nanorod and nanotube.


Quantum wire

iii) Quantum Dots :-

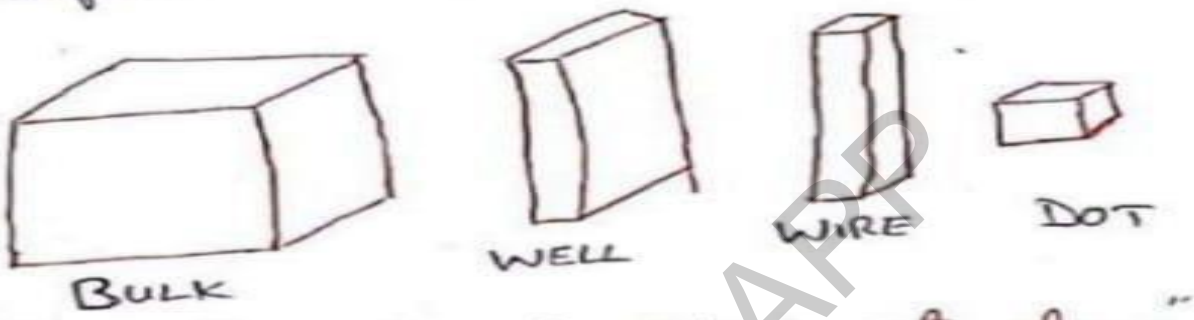
- All three dimention are minimized, the resulting structure is known as "Quantum Dot".



⊗ The Carriers has only confined state is not freely moving.

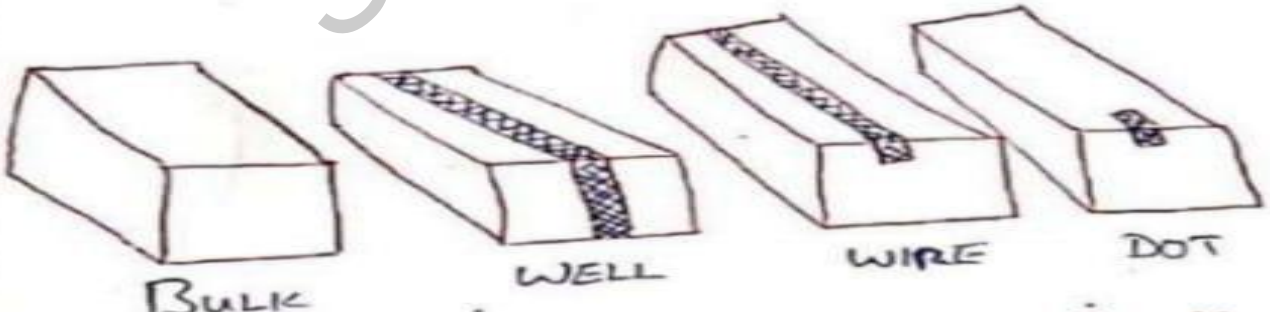
⊗ It has many thousand of atom, Carrier are considered a single atom due to its peculiar properties.

⊗ It is used in a quantum computer and quantum dot laser etc



"Rectangular Nano structure"

"Curvilinear Nano Structure"



"Three Quantum Structure"

UNIT - V NANOELECTRONIC DEVICES:

Qn1: Electron density in Bulk materials:

⇒ Electron density → "No. of e⁻s per unit volume"

Density of States: "The total no. of e⁻ energy state N with energies upto 'E' determined by

$$N = \left(\frac{8\pi}{3}\right)(2mE)^{3/2}(a^3/h^3) \quad \text{— (1)}$$

E → Maximum Energy level
m → mass of electron
h → planck's constant.

Number of energy states per unit volume (n)

$$n = \frac{N}{a^3} = \left(\frac{8\pi}{3}\right)\frac{(2mE)^{3/2}}{h^3} \quad \text{— (2)}$$

$m = 9.11\times10^{-31}$ kg
$h = 6.62\times10^{-34}$ Js

Density of energy states (Z) $= \frac{dn}{dE}$

$$Z(E) = \frac{8\pi}{3}\frac{(2m)^{3/2}}{h^3}\frac{d(E)^{3/2}}{dE}$$

$$= \frac{8\pi}{3} \times \frac{2^1 \times 2^{1/2} \times m^{3/2}}{h^3} \times \left(\frac{3}{2}E^{1/2}\right)$$

$$Z(E) = \frac{8\pi\sqrt{2}\, m^{3/2}}{h^3}\sqrt{E}$$

$2^{3/2} = 2^1 \times 2^{1/2}$

Electron density in bulk material at 0K is

$$n_c = \frac{8\pi}{3}\left[\frac{(2mE_F)^{3/2}}{h^3}\right] \quad \text{— (3)}$$

Size dependence of fermi energy:

Fermi energy: "The highest energy level occupied by the e⁻ at 0K"

The rearranging of eqn (3) $\Rightarrow E_F = \frac{h^2}{2m}\left(\frac{3n_c}{8\pi}\right)^{2/3}$

(i) $E_F \propto n_c^{2/3}$

(ii) Fermi energy only deponds on electron density. (h, m & π are Constants)

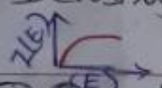
(a) Bulk structure : (3-Dimension)

⇒ The density of state of a bulk material is

$$Z(E) = \frac{8\pi\sqrt{2}\, m^{*3/2}(E-E_c)^{1/2}}{h^3}$$

where
E_c – bottom of Conduction Band energy
m^* – Effective mass of e^-

* Density state curve is "Parabolic"

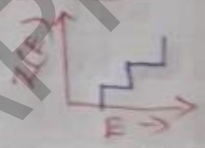


(b) Quantum well structure (2-Dimension)

⇒ The e^- can move freely in 2-D and Confined in 1-D.
⇒ The density of state of the quantum well structure

$$Z(E) = \frac{4\pi m^*}{h^2}; \quad E_0 > E_i; \quad i = 1,2,3$$

* Density of state function is Constant and it gives step like function with energy.



(c) Quantum wire structure (1-D)

⇒ Carrier move freely one Direction and 2-D Confined
⇒ The density of state is

$$Z(E) = \frac{2\sqrt{2}\, m^* (E-E_i)^{-1/2}}{h}; \quad i = 1,2,3$$

(i) Density of states of quantum wire is Proportional to $1/\sqrt{E}$"

* The density states function with energy as "M"

(d) Quantum dot structure (0-Dimension)

⇒ Carrier move in all directions are Confined and no direction. (e^- movement is free)
⇒ The density of state is

$$Z(E) = \delta(E-E_i); \quad i = 1,2,3$$

⇒ quantum dot (or) nano particle

* The density of energy levels appear as "discrete line"