☆ Intrinsic (or) Pure Semiconductors:

→ Most of the electronic devices are made up of either silicon (si) (or) Germenium (Ge) with the following Configuration:

$Si (14) \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^2.$

$Ge (32) \rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2.$

⇒ If two silicon atoms 1 & 2 are brought very closed to each other then atom - 1 expects valance shell $4e^-$ of atom - 2 to be given atom - 1. so that incomming $4e^-$ and existing $4e^-$ make atom - 1 to have $8e^-$ in valance shell thus gets Saturation and stability.

⇒ $Na(11)^+ \xrightarrow{\quad 1e^- \quad} Cl^- (17)$

$1s^2 2s^2 2p^6 3s^1$ $\quad$ $1s^2 2s^2 2p^6 3s^2 3p^6 + 1e^-$

→ If Sodium and Clorine atom are brought close to each other then Sodium will give away $3s^1$ electrone to Clorine become +ve ion and gets Stability with $8e^-$ in valance shell

(2nd orbit). Clorine by accepting 1 electron becomes -ve ion and gets stability with 8e⁻ in valance shell (3rd orbit). These two ions attract each other and ionic bond forms.

-> Clorine gets stability by loosing 1e⁻ (or) by gaining 7e⁻. Hence, loosing versus gaining ratio is 1:7.

-> Silicon atom can gets stability by loosing 4e⁻ (or) by gaining 4e⁻. Hence loosing versus gaining ratio is 4:4 (or) 1:1. In the case of sodium and Clorine since ratio is non-uniform exchange will occur. In the case silicon since ratio is uniform sharing of electron will occur. After sharing gets completed a 3-D crystal lattice gets created.

=> Fig. (1) shows a 2-D view of crystal lattice of silicon.

⇒

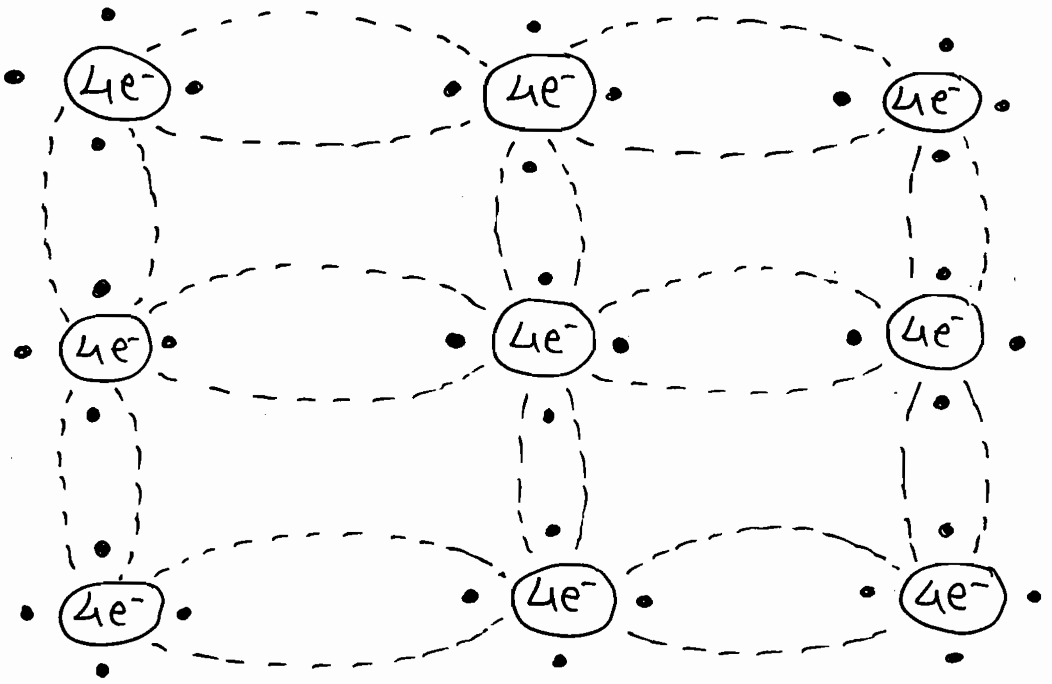


Fig - ① Crystal lattice

⇒ Fig - ② Shows normal atomic model of a silicon atom.

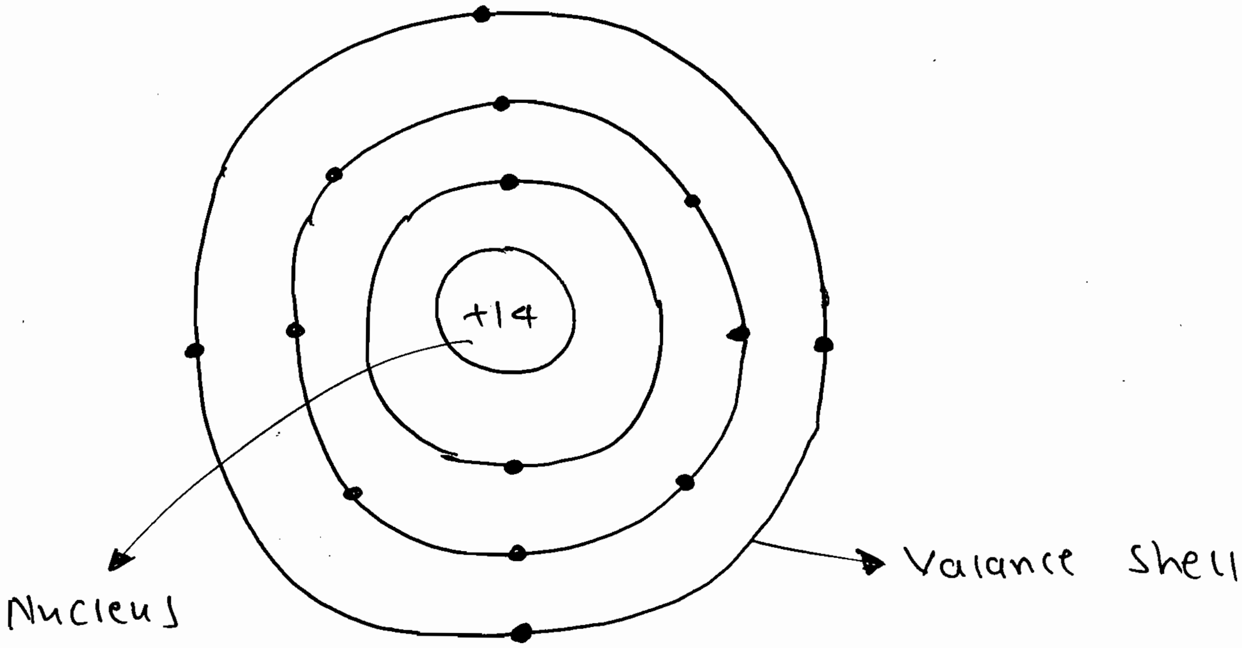


Fig - ② - Atomic model of silicon atom.

⇒ All atoms are electrically nutral.

(No. of proton = no. of electron).

⇒ If a charge carrier moves through a

unit cross sectional area then per unit it can produce current i.e.

$$I = \frac{dq}{dt}.$$

⇒ All the -vely charge electron bound to +vely charge nuclues. Such bound are immobile electron can not support current.

⇒ If an external force is applied to electron more than electric force applied by nucleus then electron comes out of force of attraction of nucleus becomes free. Such free electrons are mobbile electron can support current.

⇒ As we move from the nucleus force of attraction decreases. hence to comment on conductivity only valance shell electrons only to be considered as they can made free easly.

⇒ FIG - ③ Shows modified atomic model representation of silicon atom.

⇒

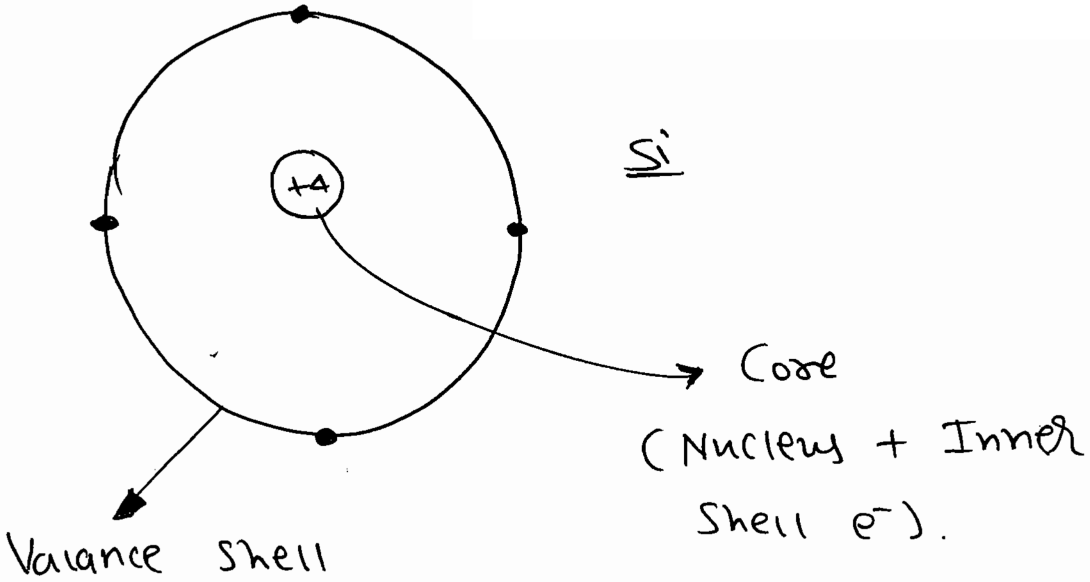


Fig-3 - Modified atomic model of si.

→ Fig-③ is valid representation to comment on Conductivity of Silicon (or) Germenium (or) any atom of group 4 of periodic table. Using this a set of 5 atoms (or) Superimpose as in fig-④.

⇒

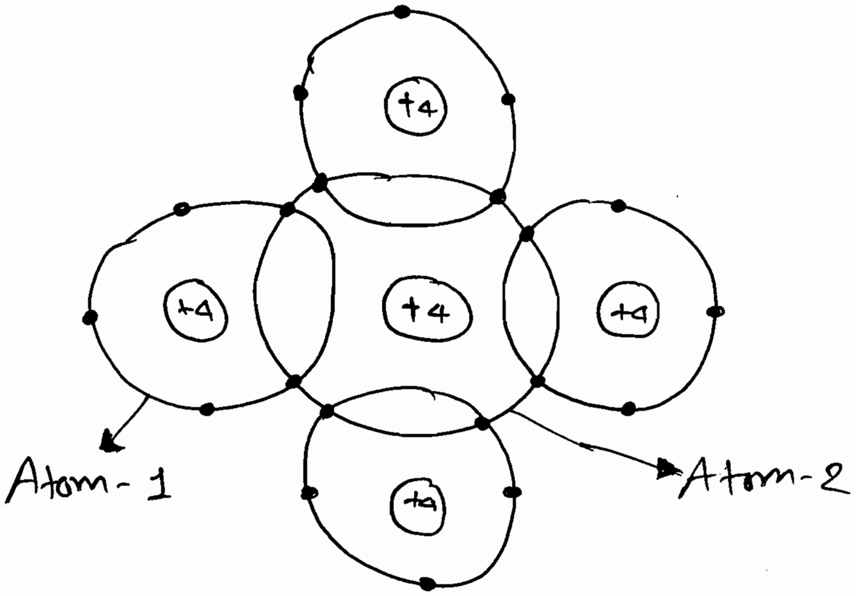


Fig-4

* Energy Band Diagram:

⇒ Collection of closedy spaced discrete energy level is called energy band diagram.

⇒

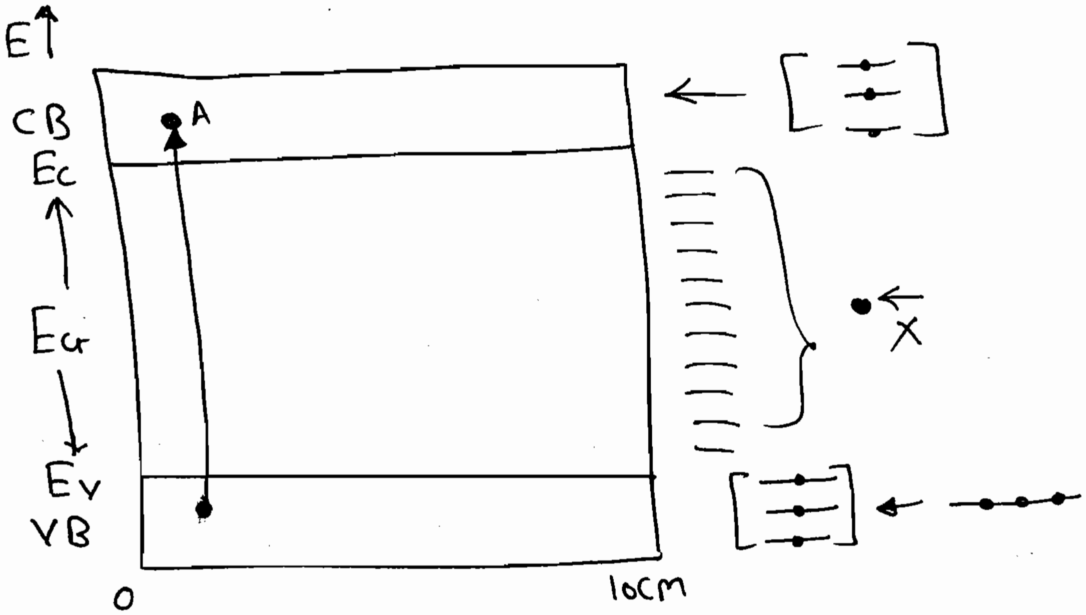


Fig- 5 - Energy Band diagram.

⇒ If all the atoms of a crystal are pulled seperately and kept at larger distance from each other then all the atom's Valance shell electrons will occupy the same energy level.

⇒ If atoms are broughten very closed to each other to form a crystal then so many electrons sitting at the same energy violates Paulli's exclusion principle which states that no two electrons belonging to the same interacting

System can have the same value for the quantum numbers n, l, m & s.

⇒ To satisfy Paulli's principle electron diverges and form valance Band (VB). An electron in VB (lower energy level) belongs to valance shell and it is bound hence can not support current.

⇒ If an externa energy is applied to an e^- more than the ~~electric~~ energy with which the nucleus pulls the electron, the electrons becomes free and gets aexicted move to higher energy and found Conduction band (CB). an electrons in CB (higher energy level) is of ~~xxxe~~ type free and can support the current.

⇒ E_c : Lowest Energy Level (or) Edged of Conduction band.

⇒ E_v : Highest Energy Level (or) Edged of Valanced band.

⇒ Between E_c & E_V, energy level exist but in them electrons do not exist and it is called forbidden band (or) Energy band gap. i.e. E_g

⇒ $$\boxed{E_{g\,(ev)} = E_c - E_V.}$$

⇒ As E_g increases material becomes insulator, As E_g decreases material becomes Conductor.

⇒ E_g approximately zero for Conductor.

⇒ At 0°K, all valance shell electrons are bound in covelent bond (i.e. bound to parent nuclie). Hence, material acts as insullator.

⇒ Covelent bonds are force, existing but not visible. Hence shown by dotted line.

⇒ At 300 K, an electron breaks a covelent bond (i.e. comes out of force of attraction of nucleus) becames free and can be drifted to produce electron drift current In and make material conductor.

* e^- Current (I_n)	Hole current (I_p).
① A free electron is moving.	① An electron is moving from one bound state to other.
② An electron is moving in conduction band.	② An electron is moving in Valance band.
③ An electron is moving at higher energy level.	③ An electron is moving at ~~higher~~ Lower energy level.
④ An electron is moving through interatomic gap.	④ An electron is moving from one covelent bond to other.

⇒ Non-existance of electron in a covelent bond is defined as space.

⇒ To Under-stand, the current given by space a set of 8 atoms (or) superimpose as shown in fig-6.

⇒ Using atomic model representation of fig-③, ABCDE are covelent bonds. Each dots is a valance shell electrons sitting in a covelent bond.

⇒ Fig-⑥ is atomic model representation of crystal lattice at 0°K.

⇒

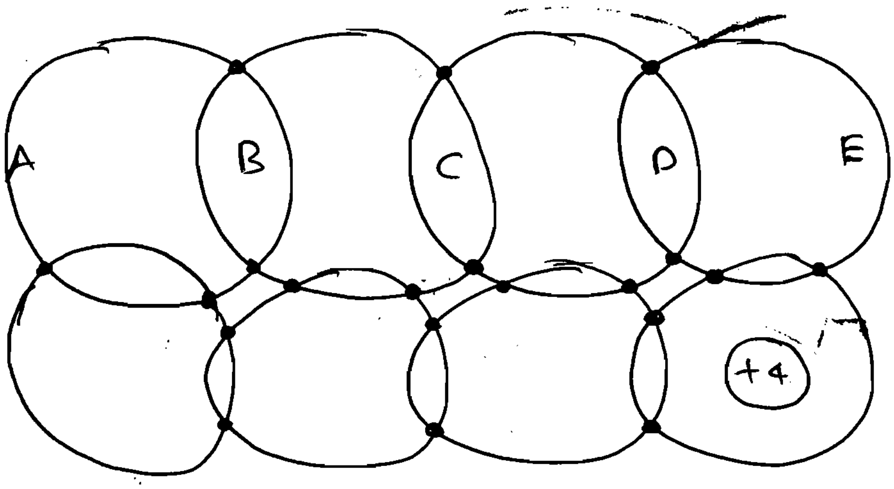


Fig- 6

⇒ At 300°K an electron breaks a covelent bond becomes free and creates space as shown in fig- 7.

⇒

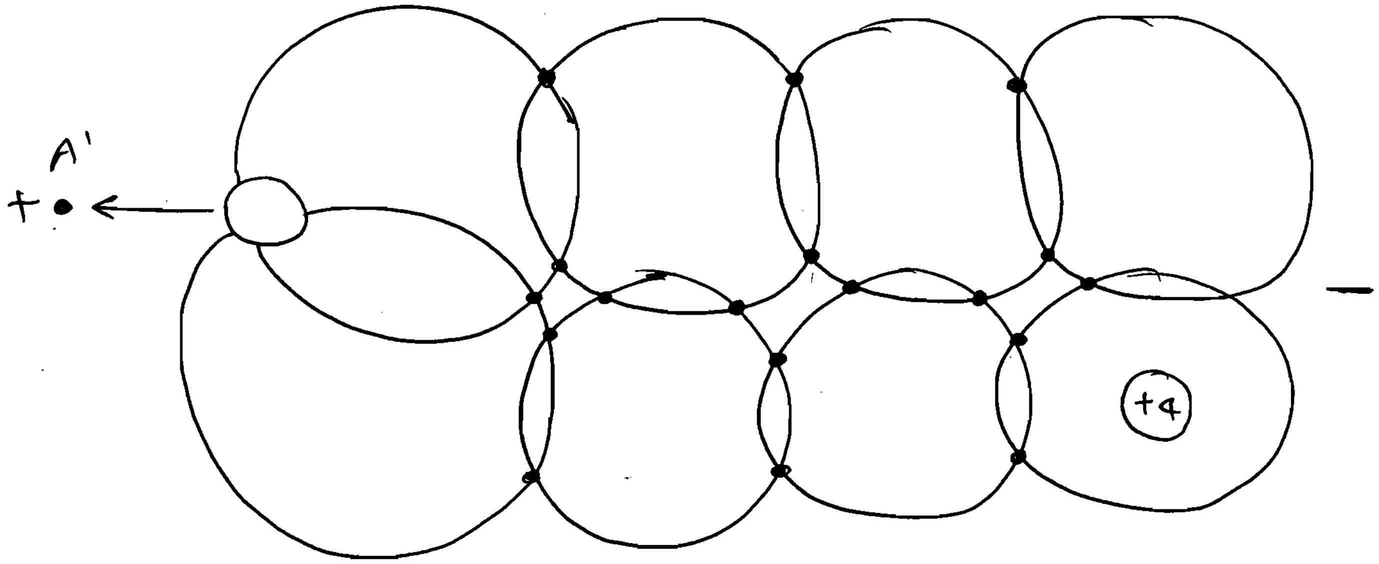


Fig - 7

→ An electron is driftting from E to A (Right to left) through EDCBA path. from EDCBA and producting current to right side as in Fig-8.

⇒

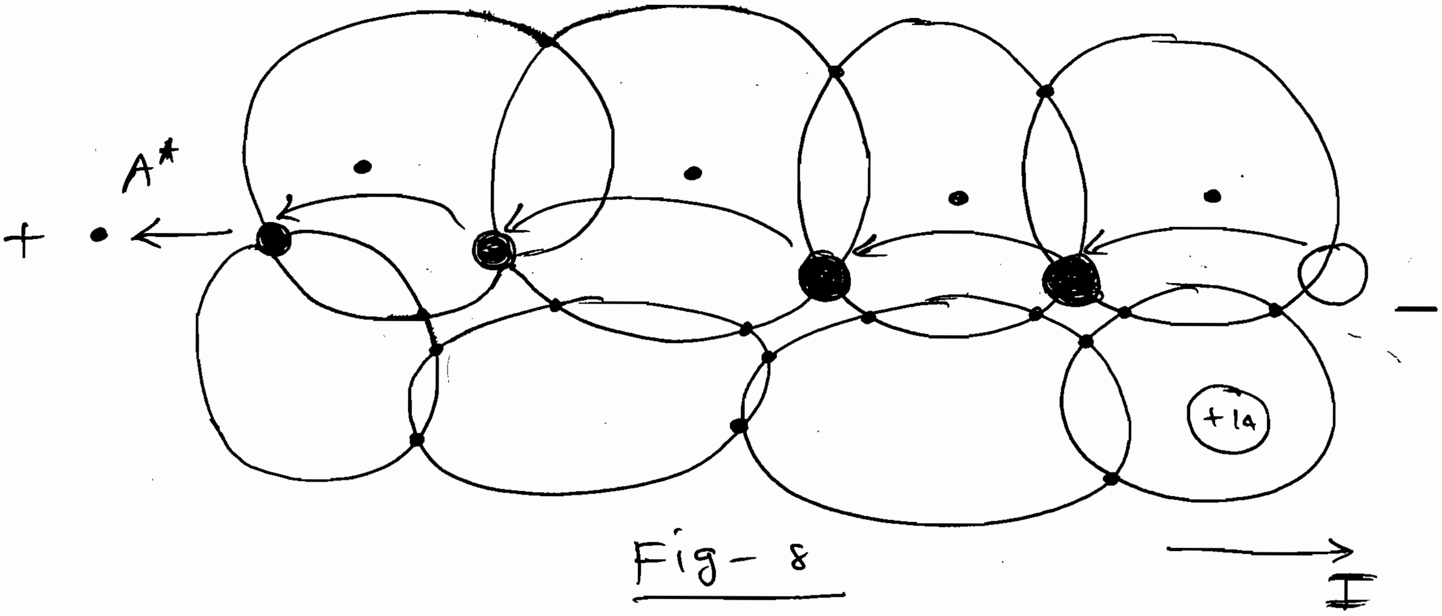


Fig-8

⇒ The electron transition shown in atomic model of fig-8 are transfer to energy diagram as in fig-⑨.

⇒

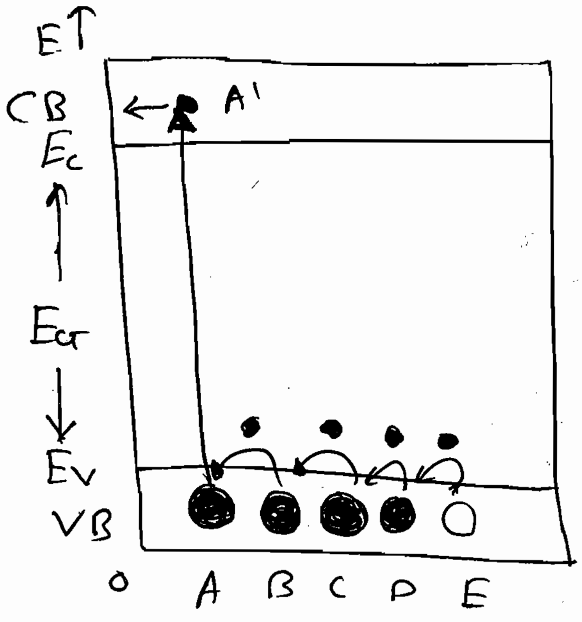


Fig-9

⇒ Space motion from A to E through ABCDE path is producing current to right side. Hence space is defined as a +vely Charged mobille partical called Hole.

⇒ If one electron goes to conduction band it leaves one hole in valance band hence called electron- hole pair (EHP) generation.

⇒ In n- intrinsic conduction,

$\boxed{\Rightarrow \text{Free electron Concentration } n = \text{Hole consentration } p}$

⇒ But electron current $\boxed{I_n > I_p}$ because mobility of electron μ_n is greater than mobility of hole μ_p (i.e $\boxed{\mu_n > \mu_p}$) and net current is sum of electron and hole currents.

i.e. $\boxed{I = I_n + I_p.}$

⇒ Drift current,

$$\boxed{I = \underbrace{nq\mu_n EA}_{I_n} + \underbrace{pq\mu_p EA}_{I_p}.}$$

$$\therefore \quad I = I_n + I_p.$$

$$\therefore \quad \boxed{I = nqEA[\mu_n + \mu_p].}$$

⇒ Electrons and holes are moving opposite direction but current given by them will be in the same direction.

Note:

→ For IES exam (or) Engineering college teaching don't use fig - ③, ④, ⑥, ⑧.

☆ Extrinsic (or) Impure Semiconductors:

⇒ $\sigma = nq\mu_n + pq\mu_p$.

$R = \left[\frac{L}{\sigma A}\right]$.

$I = V/R$.

⇒ α INT : 1mA (300°K) ⟶ 10mA (400°K) 127°C.

✓ INT : $\xrightarrow{\text{Impurities}}$ EXT.

1mA : ⟵ 300°K : ⟶ 10mA.

⇒ Without extrinsic semiconductor it is not possible to produce required current at room temp. and it is not possible to design an electronic device.

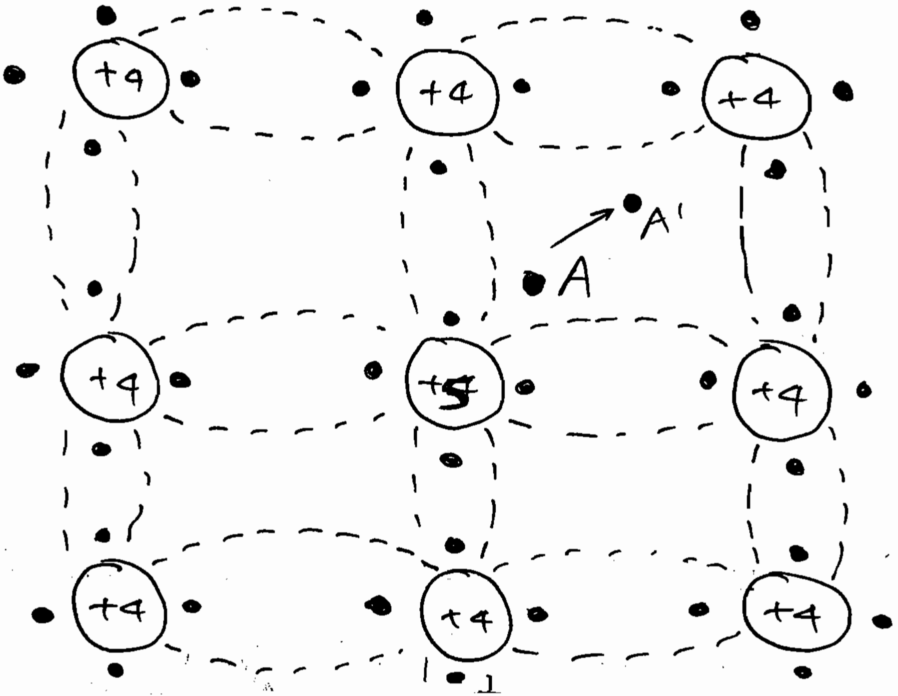
* Extrinsic Negative type (or) Extrinsic n-Type. Semiconductor

⇒ Penta Valent impurities (Fig - 2) like Phosphrus , Arcenic , Antimony (or) Bismath are added to an intrinsic semiconductor.

⇒ When a pentavalent atom replaces, a tetravalent silicon (or) Germenium atom then outof five Valance electron four electrons are supplied to four Covelent bonds and one electron is excess as in crystal lattice (Fig- 1).

⇒ All such excess electron occupy a new energy level E_d at 0°k sightly below Conduction band at 0.01ev for Germenium and 0.05 ev for silicon as in energy diagram (fig- 3).

⇒ Fig- 1 Fig-



⇒

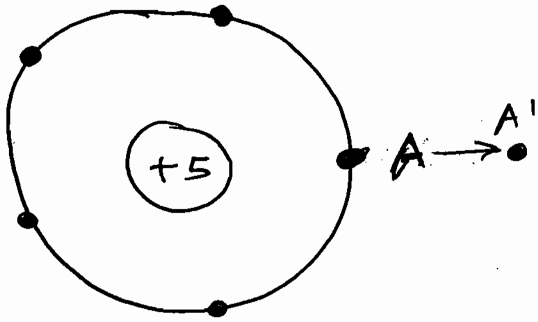


FIG - 2

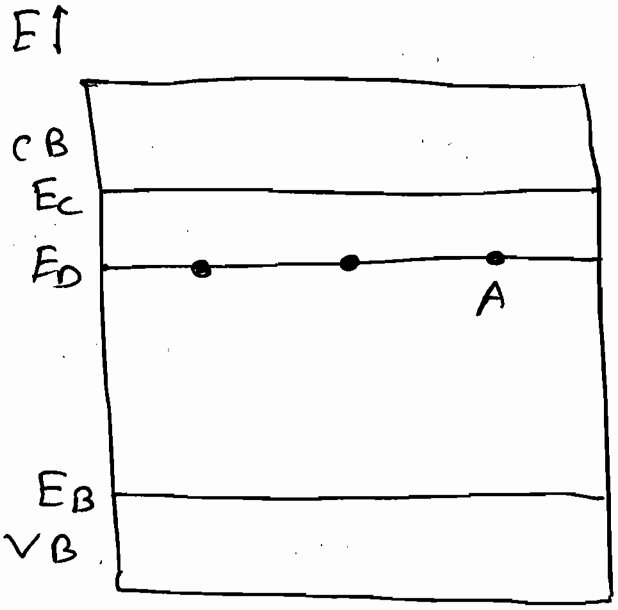


FIG - ③

⇒ At 0° K all intrinsic and extrinsic Semiconductors act as insulators.

⇒ At 0°K from Fig-3, $n=0$ & $p=0$ hence $\sigma=0$, $R=\infty$ & $I=0$. i.e. Insulator.

⇒

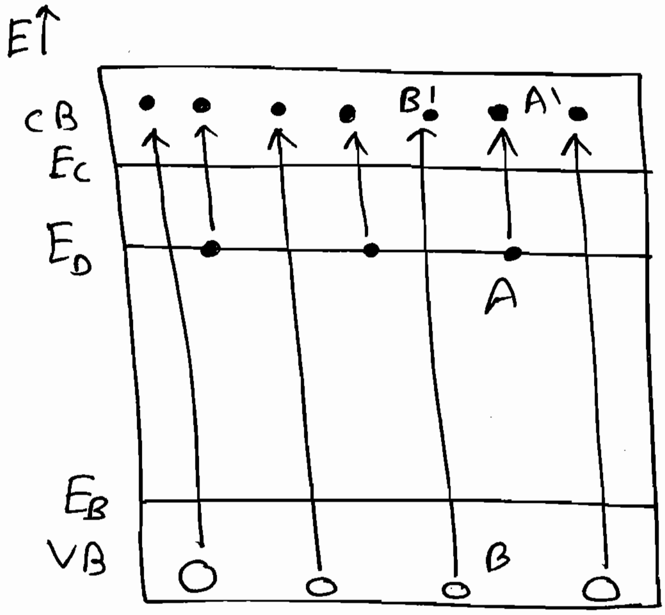


FIG - 4

⇒ At 50°K for Ge and 100°K for silicon Pentavalent impurities loose excess electrons becomes +ve ion called impurity ionization (I.I). Hence $n > 0$ and $P \cong 0$ $P=0$. Hence, $\sigma > 0$, $R < \infty$ and $I > 0$ i.e conductor.

⇒ Pentavalent atom is giving 1 e^- for support of current hence called donor atom.

⇒ E_D : donor energy Level.

⇒ At 300° K electron hole pair (EHP) generation (OR) Band to Band (B.B) transition occurs. hence, n increases and p increases. Hence, σ increases, R decreases and I increases. i.e. more current is possible in extrinsic than intrinsic due to I.I. (Impurity Ionizatio

⇒

$$\boxed{I = \underbrace{I_n(I.I) + I_n(B.B)}_{I_n} + \underbrace{I_p(B.B)}_{I_p} = I_n + I_p.}$$

→ $\underset{\downarrow A'}{I_n(I.I)}$: Current due to electrons given by I.I.

→ $\underset{\downarrow B'}{I_n(B.B)}$: current due to electrons given by B.B

→ $\underset{\downarrow B}{I_p(B.B)}$: Current due to holes given by B.B

⇒ Lightly bond electron becoming free can not create hole. A hole is created when electron breaks a covelent bonds.

⇒ To comment on the type of semiconductor never compare currents always compare concentration i.e.

$n = p$ → INT.
$n \neq p$ → EXT.
$n > p$ → N - TYPE.
$n < p$ → P - TYPE.

✓

⇒ All intrinsic and extrinsic semiconductor are electrically nutral. ✓

⇒ Charge carriers which are more in no. ~~or~~ are called majority carriers and current given by them is called majority current i.e.

Majority carriers → e^-
Minority carriers → Hole
Majority currents → I_n
Minority currents → I_p

=> Negetively Charge electrons are majority Carriers. Hence, called extrinsic negative type Semiconductor.

* Extrinsic Positive type (or) Extrinsic p-type (or) P-type Semiconductor:

=> Trivalent impurities (Fig- ⑥) like Boron, Alluminium, Gallium (or) Indium are added to an intrinsic semiconductor.

=> When a trivalent atom replaces a tetravalent silicon (or) Ge atom then to four covelent bond only 3 valence e^- are supplied hence one excess hole created as in crystal lattice (fig-5). All such excees holes occupie a new energy level E_A at 0°K above valence band at 0.01eV for Ge and 0.05 eV for si. as shown in Energy diagram (Fig-7).

=>

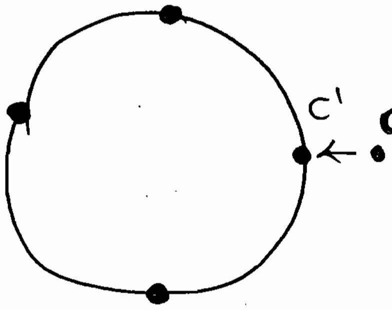


FIG- ⑥

⇒

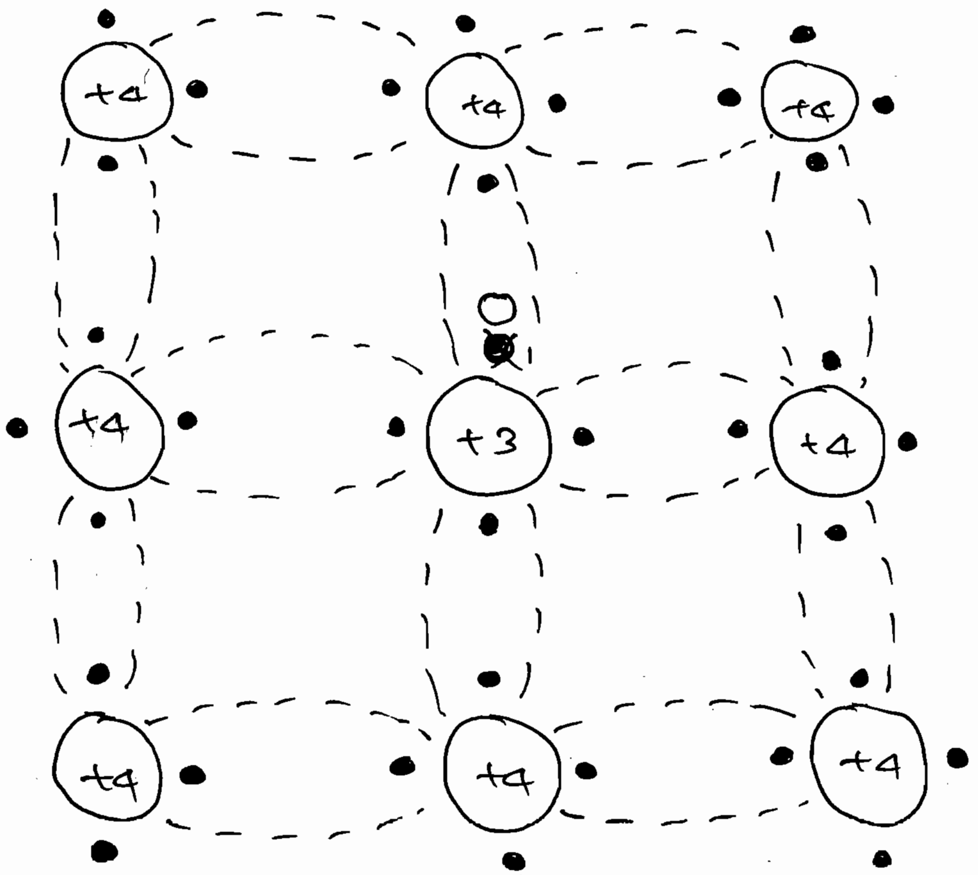


FIG - 5

⇒

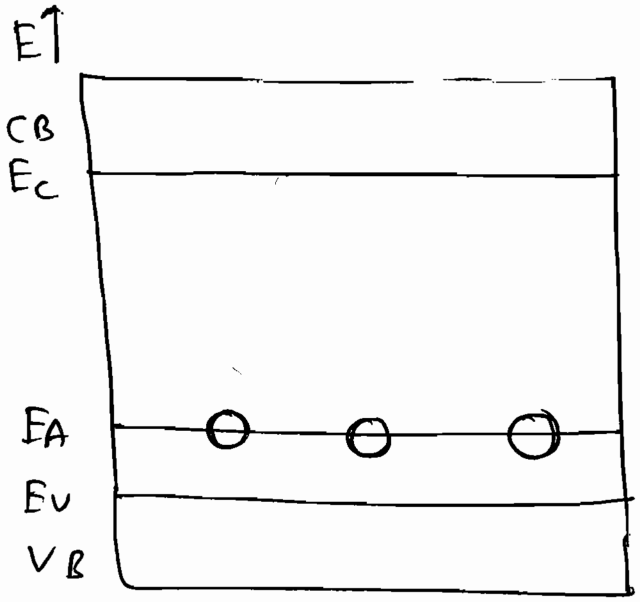


FIG - 7

⇒ At 0°K from fig-7 n=0 & p=0. Hence σ=0, R=∞ & I=0. i.e. Insulator.

⇒ At 50°K for Ge (or) 100°K for Si electrons gain energy and move to holes at E_A level than all the

⇒

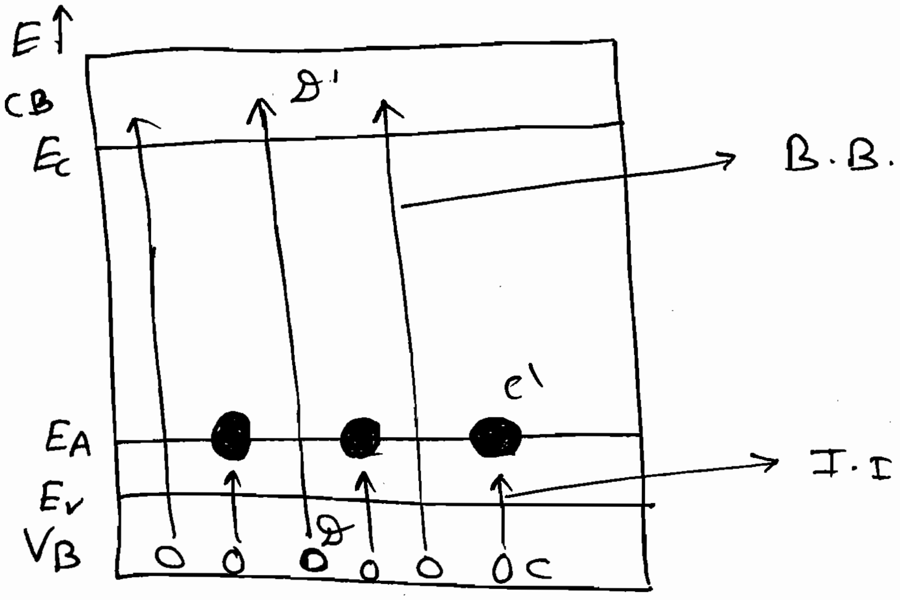


FIG- ⑧

holes at E_A level disappear and equal no. of holes get created in valance Band. Hence, $n=0$ & $p>0$. Hence $\sigma > 0$ $R < \infty$ & $I > 0$. i.e. Conductor.

⇒ Trivalent impurity by accepting electron becomes negative ion called impurity ionization (I.I). Trivalent atom by accepting e^- creates hole and supports current hence called acceptor atom.

→ E_A : Acceptor Energy Level.

⇒ At 300 K EHP Generation (or) Band to Band (B.B) transition occurs. Hence n increases and p increases hence σ increases R decreases and I increases.

⇒

Majority Carriers → HOLE

Minority Carriers → e^-

Majority currents → I_p

Minority Currents → I_n.

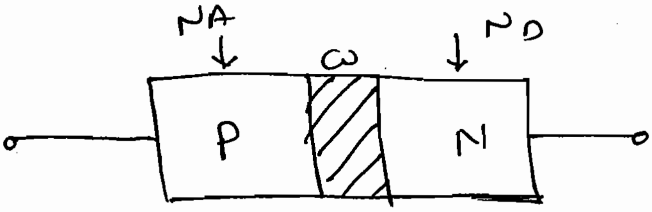
Note:

→ At very high temp. all extrinsic Semiconductors become intrinsic because band to band transition dominates (or) over through impurities ionization and at this temp. Usefullness of all electronic devices will get terminated.

⇒ **n-Type:**

	e^- (I.I)	e^- (B.B)	hole (B.B)	
300°k:	10^2	10^2	10^2	: n ≠ p ⇒ EXT.
400°k:	10^2	10^3	10^3	: n ≠ p ⇒ EXT.
700°k:	10^2	10^5	10^5	: n ≃ p ⇒ INT.

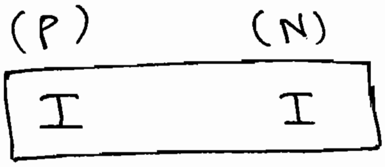
⇒



300°k: FB : + − : W↓ → I↑ : ON

RB : − + : W↑ → I↓ : OFF.

⇒ $\boxed{700\text{ K}}$

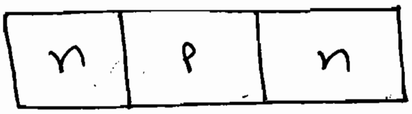


~~Switch~~

FB : + − : $\overrightarrow{IA}$

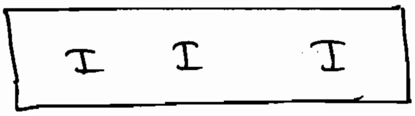
RB : − + : $\overleftarrow{IA}$

⇒ $\boxed{300\text{ K}}$:



: Amplifier.

$\boxed{700\text{ K}}$:



: Attenuator.

* Mass Action Law:

⇒ The Product of free electron and hole Concentration in an intrinsic (or) Extrinsic Semiconductor at a given temp. is a constant given by

$$\boxed{np = n_i^2} \quad \text{———} \quad ①$$

Where; n_i : intrinsic Concentration given by

$$\boxed{n_i^2 = A_o T^3 . e^{-E_{Go}/KT}} \quad \text{———} \quad ②$$

where A_o is a constant dependent on

semiconductor and independent on temp.

T : Temp in °K.

E_{GO} : Energy Band gap at 0°K.

k : Boltzman Constant in eV/°K.

⇒ $\boxed{300°K}$: INT : $np = n_i^2$

$\downarrow$

N-type : $(n\uparrow)(P\downarrow) = n_i^2$

⇒ Consider an intrinsic Semiconductor at 300°K with $n.P = n_i^2$ say it is Converted to n-type without changing temperature then n_i^2 is constant. Due to donors e^- concentration n increases hence prob. of hole recombine with electron increases. Increase to n and decreases to P counter make $n.p = n_i^2$ constant.

⇒ $\boxed{INT}$:

300°K : $n_1 P_1 = n_{i_1}^2$

400°K : $n_2 P_2 = n_{i_2}^2$.

⇒ Consider an intrinsic semiconductor at 300°k with $n_1 \cdot P_1 = n_{i_1}^2$ say temp.

increases to 400°K and $n_{i_1}^2$ to $n_{i_2}^2$. Due to increase in temp. EHP generation increases hence n_1, P_1 increases to n_2, P_2 such that $n_2 \cdot P_2 = n_{i_2}^2$.

→ $n \cdot P = n_i^2$ is valid at a given temp.

If temp changes again valid but for different value. i.e.

$$\boxed{\begin{array}{l} n_1 \cdot P_1 \neq n_2 \cdot P_2 \\ \Rightarrow \; n_{i_1}^2 \neq n_{i_2}^2 \end{array}}$$

⇒ Based on electrical nutrality

$$\boxed{N_D + P = N_A + n} \quad \text{———} \quad ③$$

⇒ LHS gives total +ve ~~ions~~ charges per cubic volume given by donor ions and holes.

⇒ RHS gives total -ve charges per cubic volume given by acceptor ions and electrons.

* Case - I :- Intrinsic ($N_D = N_A = 0$).

$$\Rightarrow \underset{0}{\cancel{N_D}} + p = \underset{0}{\cancel{N_A}} + n.$$

$$\Rightarrow \boxed{n = P} \; ✓ \quad \text{———} \quad ④$$

From eqn ① & ④

$$\boxed{n = p = n_i} \quad \text{———} \quad ⑤.$$

Case - II : N - Type ($N_D > 0$, $N_A = 0$).

$\Rightarrow$ From eqn - ③

$$N_D + \underset{\text{Neglect}}{\cancel{P_n}} = \overset{0}{\cancel{N_A}} + n_n .$$

When, P_n, n_n is hole, free electron Concentration in N-Type.

$$\rightarrow \quad \boxed{n_n \simeq N_D} \quad \text{———} \quad ⑥.$$

Note: $n.P = n_i^2$ is valid for only one Semiconductor which Can be intrinsic (or) n-type (or) p-type. It is not applicable across multiple Semiconductors.

$$\rightarrow \quad n_n P_n = n_i^2$$

$$\rightarrow \quad \boxed{P_n = \frac{n_i^2}{n_n} \simeq \frac{n_i^2}{N_D}} \quad \text{———} \quad ⑦$$

Case- III : P - Type ($N_D = 0, \quad N_A > 0$).

$$\Rightarrow \quad \cancel{N_D}^{0} + P_p = N_A + \cancel{n_p}$$

neglect.

$$\Rightarrow \quad \boxed{P_p \simeq N_A} \quad \text{———} \quad ⑧ .$$

$$\rightarrow \quad n_p P_p = n_i^2$$

$$\therefore \quad \boxed{n_p = \frac{n_i^2}{P_p} = \frac{n_i^2}{N_A}} \quad \text{———} \quad ⑨ .$$

* Diffussion

⇒

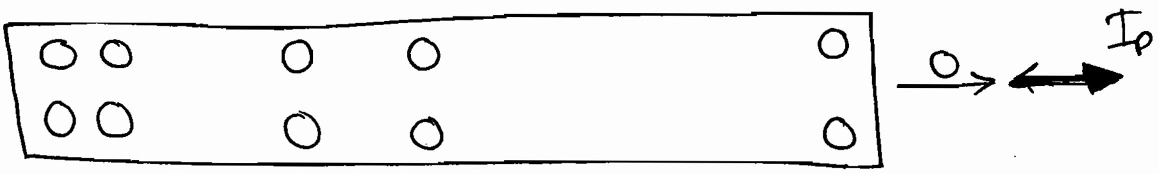


FIG - 1

⇒ Consider a P - type semiconductor as in Fig - 1. Due to difference in Concentration, holes diffusse from higher to Lower (Left to right) Concentrated area untill uniform Carrier concentration ($\frac{dP}{dx} = 0$) is achieved and produced hole diffussion current I_p where hole diffussion

Current density $J_p(x)$ is given by

$$\boxed{J_p(x) = \frac{I_p}{A} = -qD_p \frac{dP}{dx}.}$$

⇒

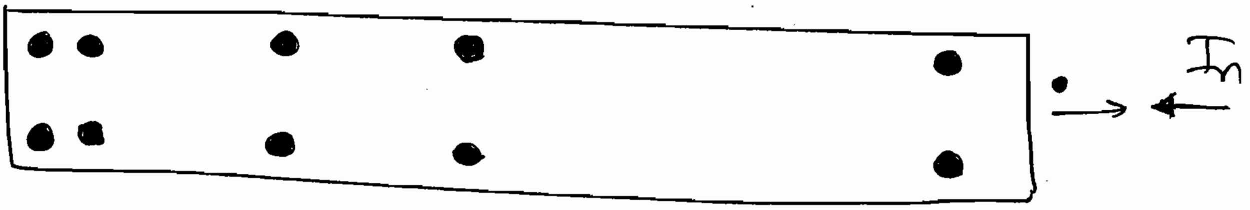


FIG - 2

⇒ Consider an n-type Semiconductor (fig-2) with a non-zero value of concentration gradient ($\frac{dn}{dx} \neq 0$). Due to difference in concentration electrons ~~holes~~ diffuse from higher to lower (Left to right) concentrated area until uniform concentration ($\frac{dn}{dx} = 0$) is achieved. and produced electron diffussed current. where electron diffussion current density. $J_n(x)$ is given by.

$$\boxed{J_n(x) = \frac{I_n}{A} = +qD_n \frac{dn}{dx}.}$$

⇒ If a Charge Carrier moves due to difference in concentration it is said to be diffussing where as if a Charge Carrier moves due to attraction (or) repulsion of a voltage it is said to be drifting. Diffussion current is proportional Concentration gradient of Charge Carriers where as drift current is proportional to concentration of charge Carriers and electric field where drift current density J is given by

$$\Rightarrow \boxed{J = \frac{I}{A} = \sigma E = (nq\mu_n + pq\mu_p) E.}$$

⇒ D_p, D_n : Diffussion Constants for hole, electron given by

$$\boxed{\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T = KT = \frac{\bar{K}T}{q} = \frac{T°K}{11,600} = 0.026V \quad (\text{AT } 300°K)}$$

↑

Einsten's Relationship.

$K = eV/K$

$\bar{K} = J/°K$

→ V_T : thermal Voltage

k: Boltzman's constant in eV/°K.

$\bar{K}$ = Boltzmann constant in J/°K.

T : temp. in °K.

* Hall Effect:

⇒ If a semiconductor carrying a current I_x is placed in transverse magnetic field B_z then an electric field E_y gets induced in a direction perpendicular to I_x & B_z.

⇒

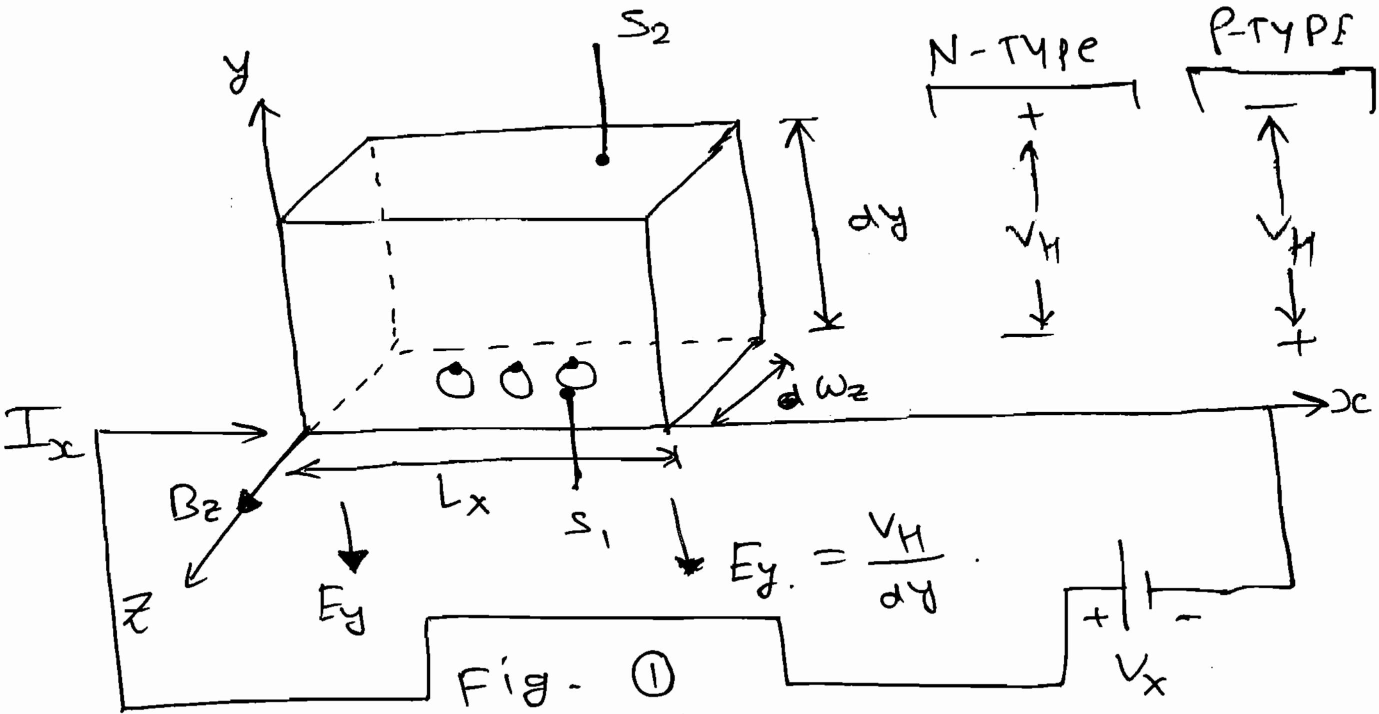


Fig- ①

$E_x = \frac{V_x}{L_x}$

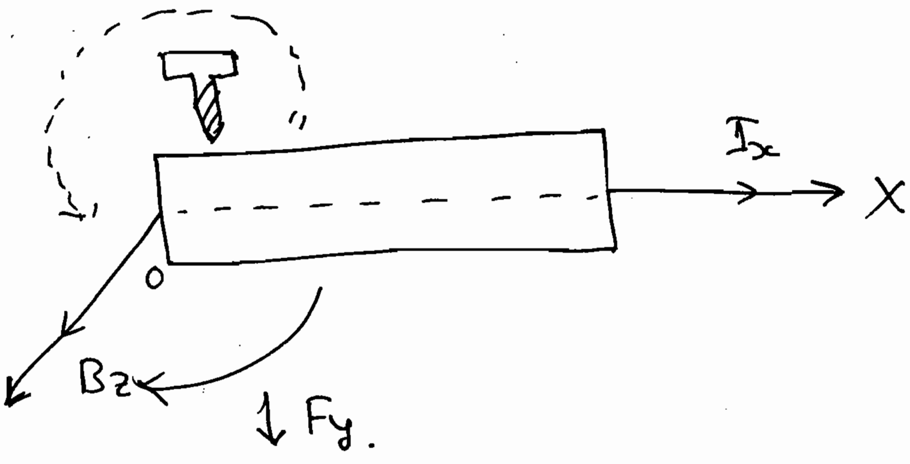
S_1, S_2: Surface-1, Surface-2.

→ If a semiconductor carrying a current I_x is placed in a transverse magnetic field B_z then according a motor

Law a force gets induced in a direction perpendicular to I_x & B_z in the direction of forward motion of a right handed screw wound from I_x to B_z.

$$\boxed{V_H = \frac{B_z \cdot I_x}{e\, \omega_z} (V).}$$

e = Charge density

⇒ 

⇒ Due to the induced force all the charge carriers are pulled towards a surface hence that surface becomes negatively (or) positively charged w.r.t. other surface. Hence, the potential ~~[illegible]~~ (or) voltage called Hall voltage V_H gets induced along y-dimension of sample. Hence an electric field E_y gets induced along y- direction. It was proved in 1879 by Edwin Hall.

* Applications:

⇒ ① It can be used to find the type of semiconductor. (N or p type). by looking at V_H polarities.

⇒ ② It can be used to find charge density and hence carrier concentration (electron (OR) Hole concentration).

$$\overset{\checkmark}{V}_H = \frac{\overset{\checkmark}{B_z} \cdot \overset{\checkmark}{I_x}}{\text{ⓔ} \cdot \underset{\checkmark}{W_z}} \rightarrow \rho = \checkmark$$

N - Type : $\overset{\checkmark}{e_n} = \text{ⓝ}\overset{\checkmark}{q} \rightarrow n = \checkmark$

P- Type : $\overset{\checkmark}{e_p} = \text{ⓟ}\overset{\checkmark}{q} \rightarrow p = \checkmark$

⇒ ③ Given mobility, conductivity can be calculate (OR) viceversa.

⇒ Hall constant (OR) Hall coefficient

$$\boxed{\text{Ⓡ}_H = \frac{1}{e} = \frac{\checkmark V_H \cdot W_z \checkmark}{\checkmark B_z \cdot I_x \checkmark} \ m^3/C} \longrightarrow R_H = \checkmark$$

$\rightarrow \quad \sigma = \rho\mu \quad \longrightarrow \quad \mu = \frac{\sigma}{e}$

σ : conductivity

e : charge density

μ : mobility.

$$\Rightarrow \boxed{\text{ⓜ} = \text{Ⓣ} R_H}$$

④

=> It can be used to multipiy two signals. (Hall effect multipiier).

$\boxed{a}$ Calculate μ_p for a p-type Germenium bar Connected as in figure - 1 and is exibitting Hall effect given

$B_z = 0.1$ Wb/m²

$d_y = W_z = 3$ mm.

$V_H = 50$ mV.

$I_x = 10\ \mu A$.

$\rho = 200,000\ \Omega$-cm.

Solⁿ:

$$R_H = \frac{V_H . W_z}{B_z . I_x}.$$

$$\therefore R_H = \frac{50 \times 10^{-3} \times 3 \times 10^{-3}}{0.1 \times 10 \times 10^{-6}}$$

$$\therefore R_H = 150 \ m^3/C.$$

$$\therefore \mu = \sigma . R_H.$$

$$\therefore \mu = \frac{1}{\rho} . R_H.$$

$\rho \rightarrow$ Resistivity.

$$\therefore \mu = \frac{1}{2 \times 10^3} \times 150.$$

$$\therefore \boxed{\mu = 75 \times 10^{-3} \ m^2/V\text{-}s.}$$

Note: In $R_H = 1/\rho$ eqn ρ is charge density where as ρ given in problem statement is Resistivity.

$\boxed{Q}$ Find the magnitude of Hall Voltage V_H in an N-Type ge bar connected as in fig-① and is exibutting Hall effect given.

$N_0 = 10^{17}$ cm^{-3}

$B_z = 0.1$ Wb/m^2.

$d_y = 3$mm

$E_x = 5$ v/cm.

$\mu_n = 3800$ cm^2/v-sec.

Soln:

$$V_H = \frac{B_z \cdot I_x}{e \cdot W_z}.$$

Note: E_x, V_x, I_x, B_z are applied quantities F_y, V_H & E_y are induced quantities.

$$J_x = \frac{I_x}{A}.$$

Note In drift and diffussion current density eqns ($J = I/A$) cross sectional area A is defined as perpendicular area for current.

→ $$\boxed{J_x = \frac{I_x}{\omega_z \cdot d_y} = \rho v = \rho \mu_n E_x}$$ ✓

ρ = charge density.

v = drift velocity.

→ μ : mobility

E : electric field.

$$\boxed{\frac{I_x}{W_z} = \rho \mu_n E_x d_y}$$ — ②. ✓

Sub. eq ② into ①.

$$V_H = \frac{B_z}{\cancel{\rho}} \cdot \cancel{\rho} \mu_n E_x d_y.$$

$$\therefore \boxed{V_H = B_z \cdot \mu_n \cdot E_x \cdot d_y.}$$ ✓

$$\therefore V_H = 0.1 \times 3800 \times 10^{-4} \times 5 \times 10^{2} \times 3 \times 10^{-3}.$$

$$\therefore V_H = 5700 \times 10^{-5}$$

$$\therefore \boxed{V_H = 57\,mV.}$$

Q A p-type silicon speciman is exibitting Hall effect and is connected as in fig-① calculate induced Voltage given

$B_z = 0.1$ wb/m².

$E_y = 750$ V/m.

$d_y = 0.009$ m.

Soln:
$\Rightarrow$

$$V_H = E_y \cdot dy$$

$$= 750 \times 0.009$$

$$\therefore \boxed{V_H = 6.75V}$$