Drift Current : Under the action of an electric field, the carriers in the semiconductor materials drift and produces drift current.

The two types of charge carriers (electrons and holes) produce two drift current components

- The electron drift in the conduction band produces a component J_n given by

$$J_n(\text{drift}) = nq\mu_n E$$

- The hole drift in the valence band causes a component J_p given by.

$$J_p(\text{drift}) = pq\mu_p E$$

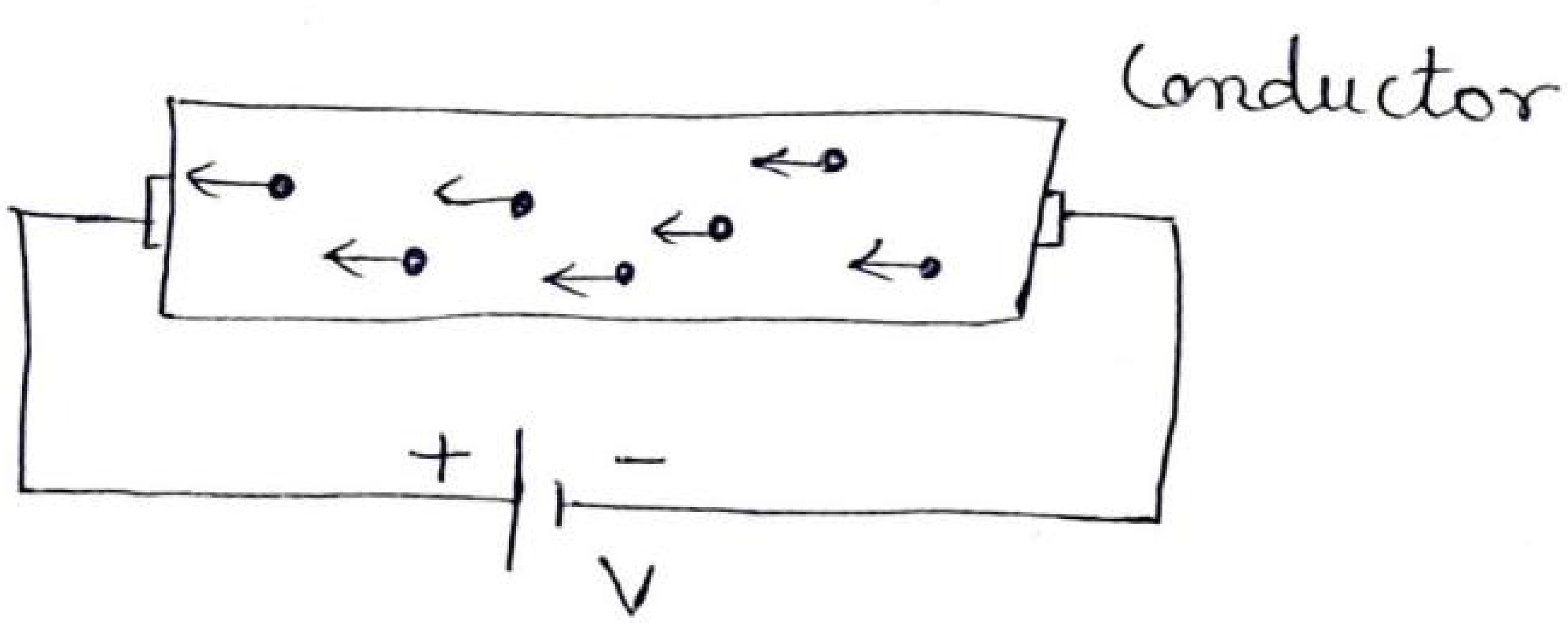
The total drift current density is given by

$$\boxed{J(\text{drift}) = q(n\mu_n + p\mu_p)E}$$

This equation is applicable to both, intrinsic as well as extrinsic semiconductor

Hence drift current depends upon two variables

1) the carrier concentration
2) the electric field.



Diffusion Current : When the concentration of atoms of one element is higher at one point than at ~~other~~. another point, the atom will diffuse from the region of heigher concentration to that of lower concentration

This process of movement of atoms and molecules through matter is known as diffusion.

In case of Semiconductors, the moving species are Charge Carriers. Hence the directional movement of Charge Carriers due to their Concentration gradient produces a Component of Current known as diffusion current.

* This transport of charge Carriers occurs without the assistance of an electric field.
* Diffusion Current is proportional to the rate of change of Carrier concentration per unit length ie concentration gradient.

$$J_n(diff) = q D_n \frac{dn}{dx}$$

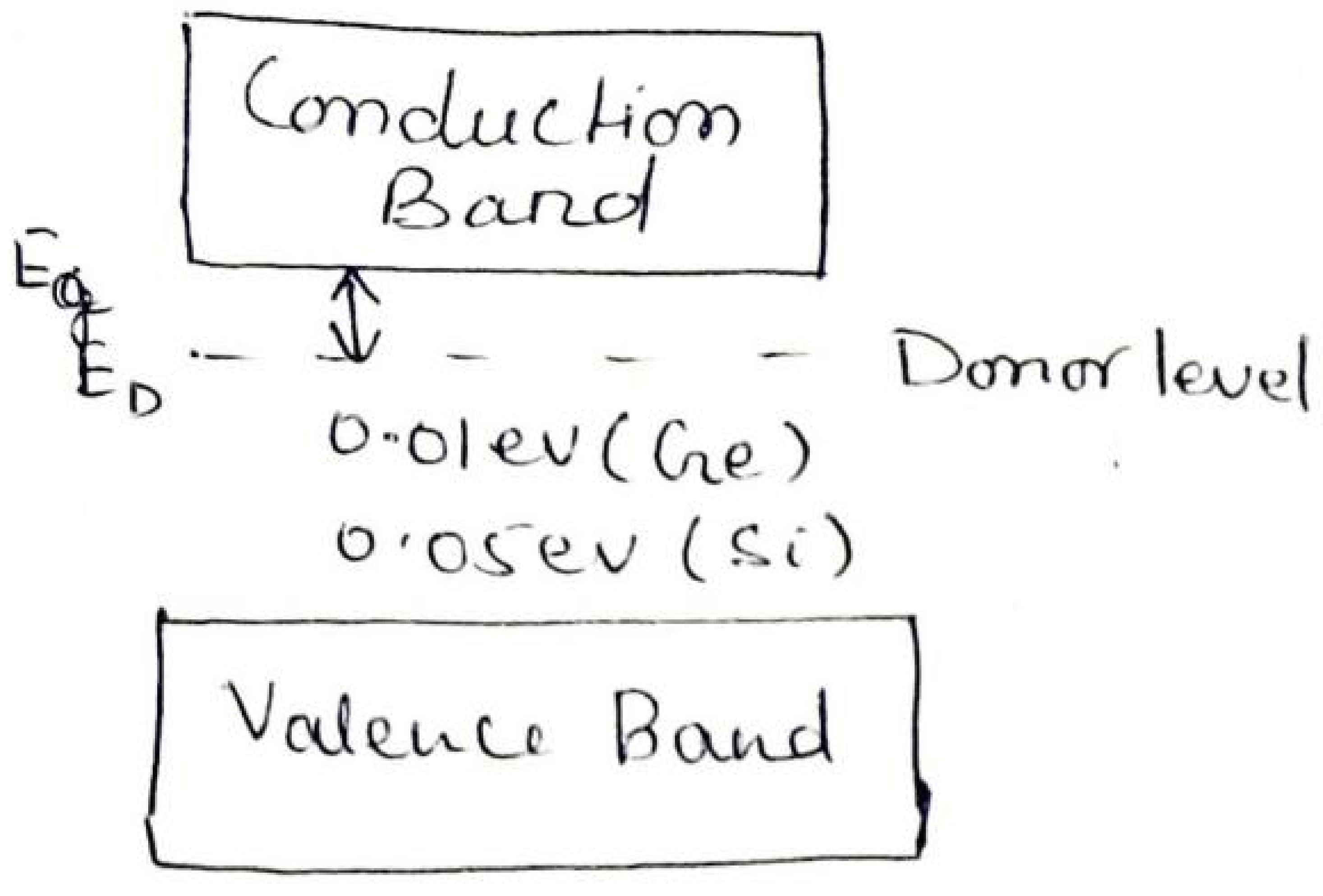
$$J_p(diff) = -q D_p \frac{dP}{dx}$$

D_n and D_p are known as diffusion currents for electrons and holes respectively.

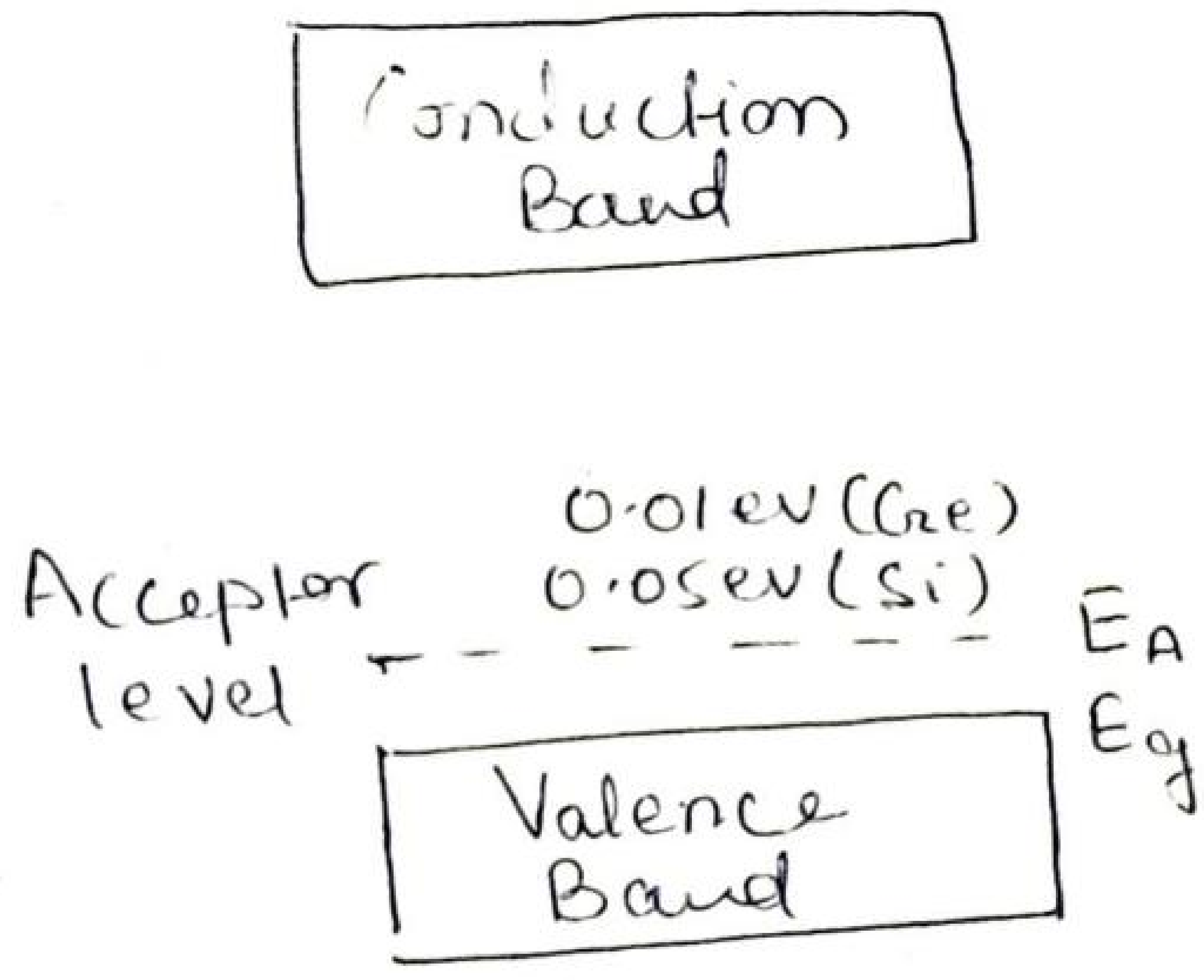
Drift and Diffusion Current exists in Semiconductor

∴ The total current density due to drift and diffusion of electrons may be written as

$$J_n = J_n(drift) + J_n(diff)$$



(N-type)



(P-type)

<u>Fermi level</u>: Electrons in solids obey Fermi-Dirac statistics. This statistics results that the distribution of electrons over a range of allowed energy level at thermal equilibrium is

Fermi-Dirac distribution function

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

k is Boltzmann's Constant ($k = 8.62 \times 10^{-5}$ eV/K)
$= 1.38 \times 10^{-23}$ J/K

"gives the probability that an available energy state of E will be occupied by an electron at absolute temperature T"

E_F is called the fermi level.

Law of <u>Mass action</u> State that the product of majority and minority carrier concentrations in an extrinsic Semiconductor at a particular temperature is equal to the Square of intrinsic Carrier Concentration at that temperature

Thus for an n-type Semiconductor

$$\boxed{n_n p_n = n_i^2}$$

for p-type Semiconductor

$$\boxed{p_p n_p = n_i^2}$$

<u>Law of electrical Neutrality</u>

Since Semiconductor as a whole is electrically neutral, therefore magnitude of total positive charge density is equal to the total negative charge density

$$N_A + n = N_D + p \rightarrow \text{Conc of hole}/m^3$$

N_A : Conc of Acceptor/m^3

n : Conc of e^-/m^3

N_D : Conc of donor/m^3

for <u>n-type</u> $\rightarrow N_A = 0$

$n >> p$

$n \approx N_D$

$$\therefore \; p_n = \frac{n_i^2}{n} = \frac{n_i^2}{N_D}$$

$\rightarrow$ for <u>p-type</u> $N_D = 0$

$p >> n$

$p \approx N_A$

$$n_p = \frac{n_i^2}{p} = \frac{n_i^2}{N_A}$$

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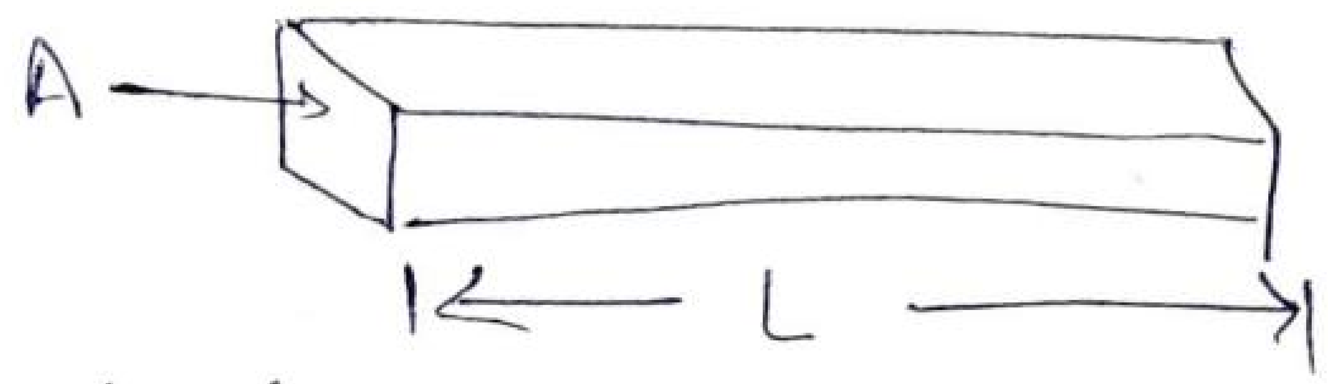
bility : When an electric field 'E' is applied to a Conductor or Semiconductor then electrons (or holes) start flowing in it, in the direction opposite to that of electric field with velocity v_d (drift velocity). The Proportionality constant that relates the drift velocity to the electric field is known as mobility. of Charge Carriers

$$\boxed{\mu = \frac{v_d}{|E|}} \qquad m^2/V\text{-sec}$$

Conductivity :



n - Concentration ∞ (Charge/Volume) of free electrons (known as electron density) available in it.

total Charge Contained in the block

$$Q = Nq$$

$$n = \frac{N}{V} = \frac{N}{A \cdot L}$$

$$Q = nqAL$$

∴ Current $I = \frac{\text{Total Charge}}{\text{Time taken}}$

$$I = \frac{nqAL}{t}$$

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$$\boxed{I = nqAV_d} \qquad \frac{L}{t} = V_d$$

Current density $J = \frac{I}{A}$

$$\boxed{J = nqV_d}$$

Using ohm's law

$$I = \frac{V}{R}$$

$$R = \text{Resistance} = \frac{\text{Resistivity} \times \text{length}}{\text{Area}} = \frac{\rho \times L}{A}$$

$$\therefore \quad I = \frac{VA}{\rho L} = \sigma A E \qquad \frac{1}{\rho} = \sigma \text{ Conductivity}$$

$$\boxed{J = \sigma E}$$

$$\therefore \quad \sigma E = nqV_d$$

$$\sigma = nq\frac{V_d}{E}$$

$$\frac{V_d}{E} = \mu \text{ (mobility of Charge Carrier)}$$

$\therefore$ Conductivity of material

$$\boxed{\sigma = nq\mu}$$

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Conductivity of Semiconductor Material

$J_n = q n v_n$ $\qquad$ $J_p = q p v_p$

$q = 1.602 \times 10^{-19} C$

n = density of free electrons ie.
no. of free electrons/ Volume.

p = density of holes.

v_n = drift velocity of free electrons

v_p = " " " holes.

Conductivity $\sigma_n = \frac{J_n}{E} = \frac{q n v_n}{E} = q n \mu_n$

Conductivity $\sigma_p = \frac{J_p}{E} = \frac{q n v_p}{E} = q n \mu_p$

Where μ_n and μ_p is the mobility of electrons and holes respectively.

Total Conductivity of a Semiconductor.

$$\sigma = \sigma_n + \sigma_p$$

$$= q n \mu_n + q p \mu_p$$

$$\boxed{\sigma = q[n \mu_n + p \mu_p]}$$

Conductivity of Intrinsic Semiconductor

$$n = p = n_i$$

$$\sigma_i = q[n_i \mu_n + n_i \mu_p]$$

$$\boxed{\sigma_i = q n_i (\mu_n + \mu_p)}$$

at 300K $n_i = 1.5 \times 10^{16} m^{-3}$

$n_i = 2.5 \times 10^{19} m^{-3}$

Conductivity of Extrinsic Semiconductor

n-type Semiconductor

$$n >> p$$

$$\boxed{\sigma_n = q n \mu_n}$$

P-type Semiconductor

$$p >> n$$

$$\boxed{\sigma_p = q p \mu_p}$$

Einstein Relationship

The equation which relates the mobility 'μ' (of electrons or holes) and the diffusion co-efficient (of electrons D_n or Holes D_p) is known as Einstein Relationship

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T \quad \left\{ \begin{array}{l} \text{Voltage} \\ \text{equivalent} \\ \text{of temp} \end{array} \right\}$$