Semiconductors

Semiconductors:

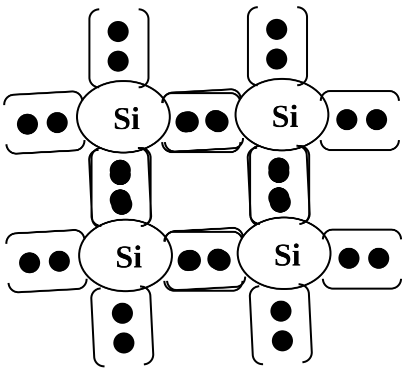
- The substance which conducts **electricity partially** is called semiconductors whose conductivity lies in between conductors and insulators
- Semiconductors are **bipolar and** current transported by two charges (i.e) electrons and holes
- The number of charge carriers are enhanced by **doping** the semiconductor with suitable impurities
- The current transportation in them by both **drift and diffusion**

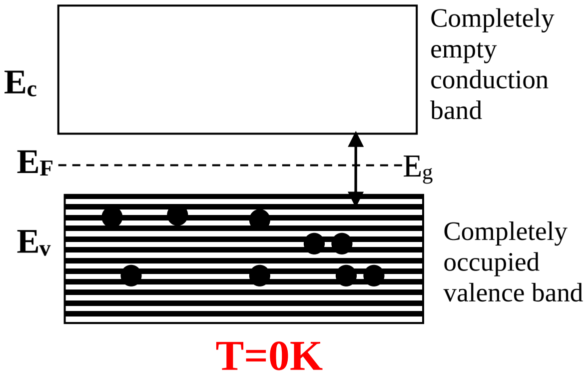
Types of semiconductors

Intrinsic semiconductors (Pure Semiconductors)
Extrinsic semiconductors (Impure Semiconductors)

Intrinsic semiconductors:

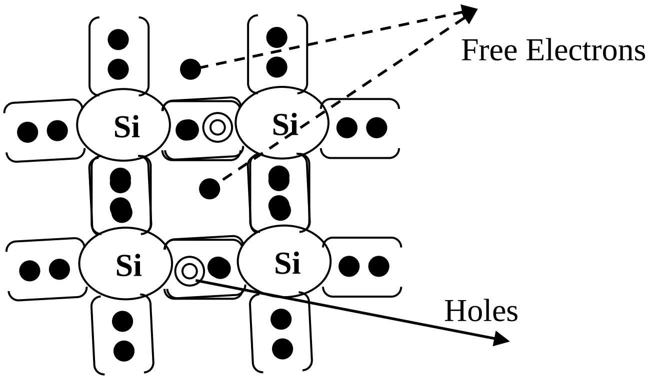
1. **Pure form** of semiconductors is known as intrinsic semiconductors
2. Frequently available semiconductors are **germanium (Ge) and silicon (Si)** belonging to IV group in periodic table.
3. For example the semiconductors like **Si**, has four valence electrons, to get stability each of theses atoms **share the electrons** from the neighboring atoms ,and get **eight electrons in the outermost orbit** , since the electrons are strongly bounded to the atoms at 0K , the semiconductors act as **insulators** since no free electrons are there for conduction.

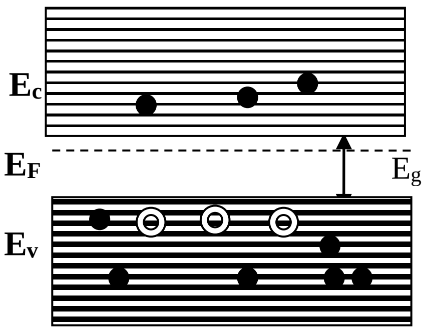




The above energy band diagram shows the conduction and separated by the valence band by the energy gap know E_g , the energy gap is **1.2ev for Si and 0.7ev for Ge.** At 0K the E_F called Fermi level lies in between valence and conduction band, the **valence band is occupied** and **conduction band is empty**

4. As the temperature **increases above 0K**, the **valence electrons acquire sufficient energy**, so they tend to break the covalent bond and become free electrons and goes to the conduction band. Therefore holes will be created in the valence band in the place of the electrons. Therefore the valence band has the holes and the conduction band has free electrons for conduction. **The Fermi level lies between the valence band and conduction band.**





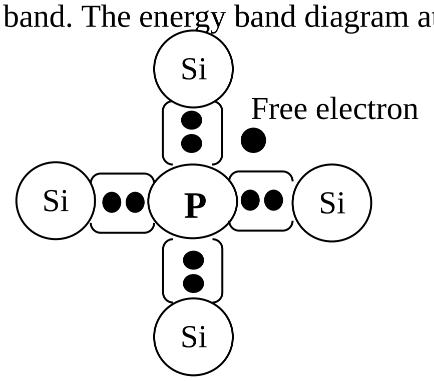
The carrier concentration for the intrinsic semiconductors

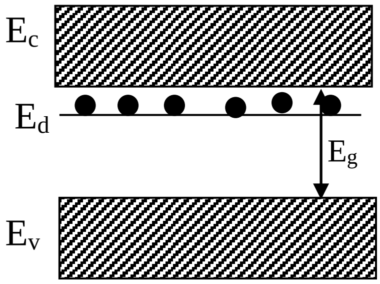
$$n = N_C \; e^{\frac{E_C - E_F}{KT}}$$ no of electrons at a particular temperature

$$p = N_V \; e^{\frac{E_F - E_V}{KT}}$$ no of holes at a particular temperature

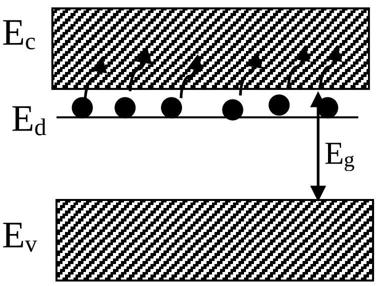
Extrinsic semiconductors:

- **Impure** form of semiconductors is known as extrinsic semiconductors
- If the impurity atoms are added (called doping) to pure semiconductors, they are known as impure or extrinsic semiconductors. Due to the addition of **impurity**, the carrier concentration and hence the conductivity will be improved.
- Depending upon the addition of impurity , they are classified as
  1. **n-type semiconductors**
  2. **p-type semiconductors**

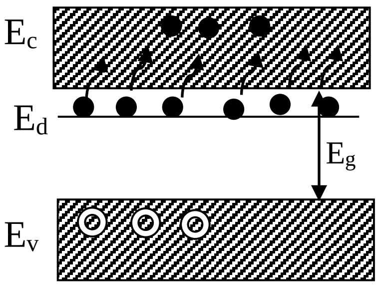
- **n-type semiconductors:**
  1. **Pentavalent impurity** such as **Phosphorus (or) arsenic (or) antimony** is added to the pure form of semiconductor is known as n-type semiconductors
  2. When the pentavalent atom such as Phosphorous is added to the semiconductors like Si or Ge, the impurity atom occupies the silicon atoms position and involve in the **covalent bonding formation**. The four valence electrons of the Phosphorus form covalent bond with the neighboring atoms the **fifth electron is left free**. Since the Phosphorus atom ready to donate one electron it acts as a donor. The donor level formed near to conduction band. The energy band diagram at T=0K is shown below
  3. 



T=0K
  4. When the temperature is increased above 0K (T>0K), the electrons in the donor level goes to the conduction band and involve in conduction.



T>0k



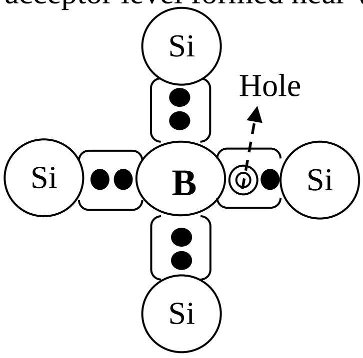
T=300K

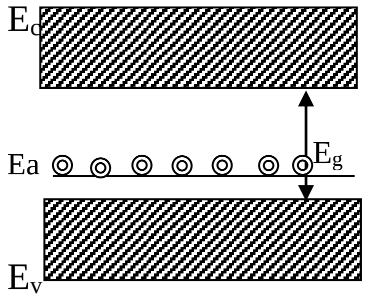
  5. As temperature increases, some electrons which are in covalent bonding breaks the bond and enters into conduction band by leaving some holes in the valence band . So in n-type

materials electrons are more called majority carriers and holes are lea called minority carriers.

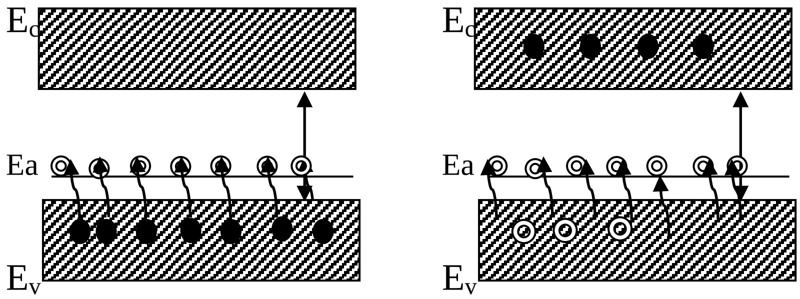
- **P-type semiconductors:**

1. When **trivalent impurity** such as **Boron, indium and aluminum** is added to the pure form of semiconductor is known as p-type semiconductors.
2. If a trivalent impurity is added to the semiconductor like , Si, the three electrons of the boron forms covalent with neighboring Si atoms, and one bond with left over with the deficiency of electron. Since the boron is ready to accept one electron it acts as an acceptor. So the addition of trivalent impurities creates holes so correspondingly the acceptor level formed near valence band.



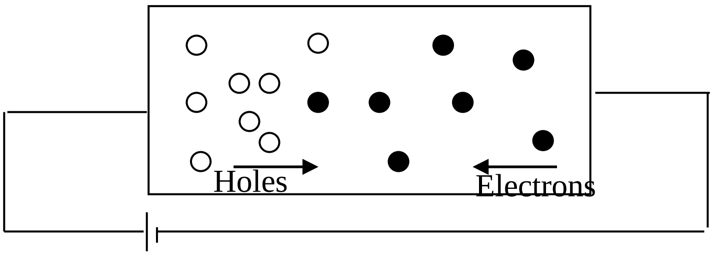


3. As the temperature increases T>0K, the electrons in the valence band goes and occupy the acceptor level leads to carrier movement. As temperature raises , some electrons breaks the covalent bonding and enterers into conduction band by leaving holes in the valence band so number of holes increases , so they are called as majority carriers , the few electrons in conduction band called as minority carriers



Drift and diffusion:

Under the influence of the electric field, the charge carriers are pushed (or) forced to move along a particular direction known as **drift.** Due to the drifting on the charge carriers along a particular direction, the current density which we are getting is



$\mathbf{J = nev_d}$ J=current density is crossing of charge carriers per unit area

Where "n" is the number of electrons in semiconductor, the additional velocity gain by the electrons due to the application of the external field is "v_d",

$\mathbf{J = ne\,\mu E}$ but $V_d \ \alpha\ E$

$V_d = \mu E$ μ is called the mobility of the charge carriers.

Therefore for a n-type material

$\mathbf{J_{n\,(drift)} = ne\,\mu_n E}$ called the **drift current density** for the semiconductor due to the flow of electron.

$\mathbf{J_{p\,(drift)} = pe\,\mu_p E}$ called the **drift current density** for the semiconductor due to the flow of hole

The total current density due to drift is

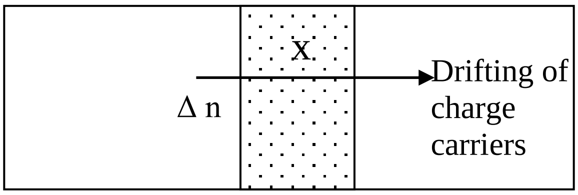
$$\mathbf{J_{p\,(drift)} + J_{n\,(drift)} = pe\,\mu_p E + ne\,\mu_n E}$$

For an intrinsic semiconductor $n=p=n_i$

$$\mathbf{J_{p\,(drift)} + J_{n\,(drift)} = n_i eE\,(\mu_p + \mu_n)}$$

Diffusion:

Due to the non-uniformity in the carrier concentration, the **movement of charge carriers from the higher concentration region to lower concentration region is known as diffusion**.



If "Δn" represents the excess of electron concentration, then according to Fick's law

The rate of diffusion of electrons $\propto \frac{-\partial(\Delta n)}{\partial x}$

or $= D_n \frac{-\partial(\Delta n)}{\partial x}$

The current density (J) = (charge of the electron) x ($D_n \frac{-\partial(\Delta n)}{\partial x}$)

$= (-e) \times (D_n \frac{-\partial(\Delta n)}{\partial x})$

J_n (diffusion) $= e D_n \frac{-\partial(\Delta n)}{\partial x}$

The diffusion current density due to holes J_p (diffusion) $= -e D_p \frac{\partial(\Delta p)}{\partial x}$

The total current density = $J_{drift}+J_{diffusion}$

The total current density = $J_{drift}+J_{diffusion} = -ne\,\mu_n E + e D_n \frac{\partial(\Delta n)}{\partial x}$ (n-type material)

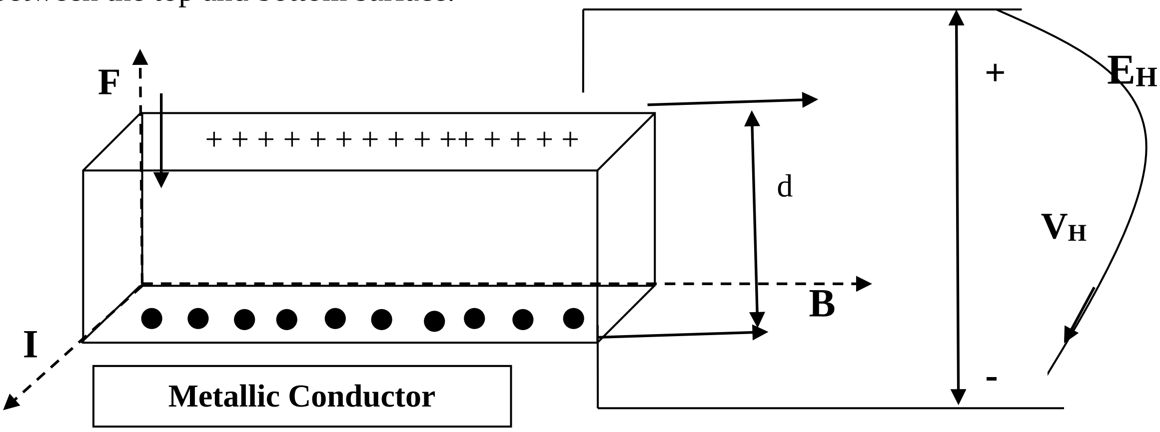
The total current density = $J_{drift}+J_{diffusion} = pe\,\mu_p E - e D_p \frac{\partial(\Delta p)}{\partial x}$ (p-type material)

Hall Effect:

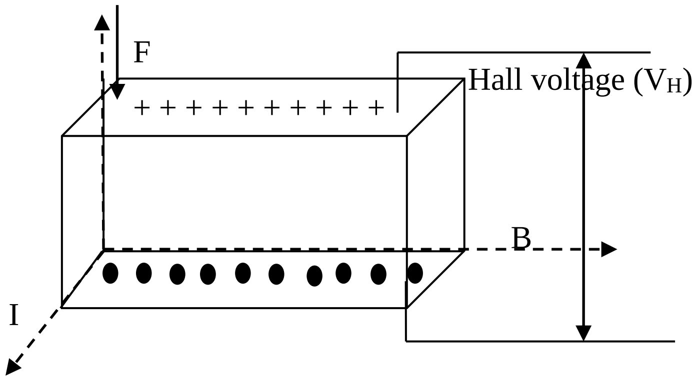
If I_x is the current flowing through a specimen along X-direction and B_y is the magnetic field along the y-direction. An electric field E_z is induced in a direction perpendicular to both the current and magnetic field. This phenomenon is known as **Hall Effect**.

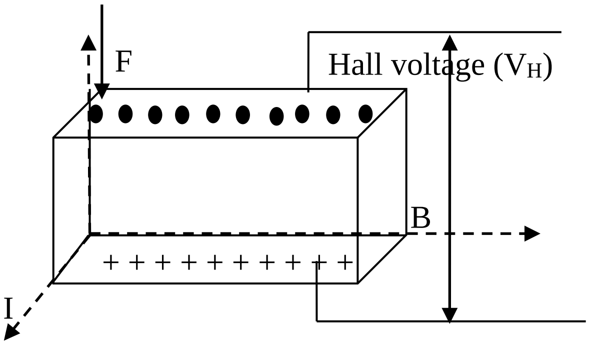
Explanation:

Let us consider a metallic conductor, along which the current is applied along the X-direction and magnetic field is applied along the Y-direction, then a force will be induced along the Z-direction. This force will be acting in the downward, due to this force all the electrons are pushed downwards and they will come and accumulate at the bottom surface, the bottom surface having the excess of electrons will acts as negative and the top surface will positive ion will act as positive in between them a potential difference will be created in between the top and bottom surface.



If our specimen is a semiconductor, (P-type), then due to the force the holes will occupy the bottom surface and become the positive, the upper surface become negative.





If it is n-type semiconductor, the electrons occupy the bottom surface and become negative the upper surface become positive. The voltage developed in between the top and bottom surface of the semiconductor is known as Hall voltage.

Calculation of Hall voltage (V_H)

If the force applied due to the electric field is **"$e\,E_H$"** and the force applied due to the magnetic field is **"Bev",** at equilibrium, the two forces balance each other.

$$e\,E_H = Bev$$

If "V_H"is the Hall voltage between the two faces and "d" is the distance of separation between them,

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

$$e\frac{V_H}{d} = Bev$$

$$V_H = Bvd$$

"v" is the drift velocity,

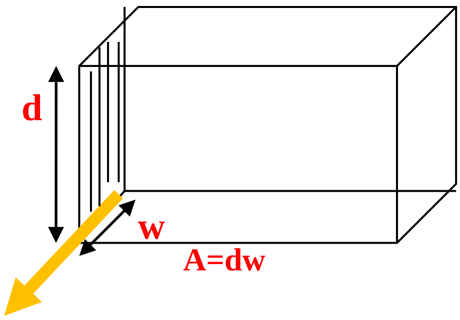
W.K.T $\mathbf{J = n\,e\,v}$

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

$$V_H = B\,d \times \frac{J}{ne}$$

but "current density is charges crossing per unit area"

$$J = \frac{I}{A} = \frac{I}{dw}$$



$$V_H = B\,d \times \left(\frac{I}{dw}\right) \times \left(\frac{1}{ne}\right)$$

$$V_H = B\frac{I}{w} \times \left(\frac{1}{ne}\right) = \frac{BI}{W}\,R_H$$

"R_H" is known as **Hall coefficient**

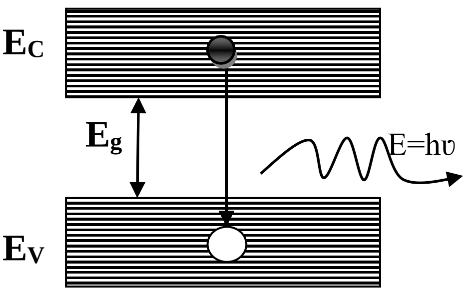
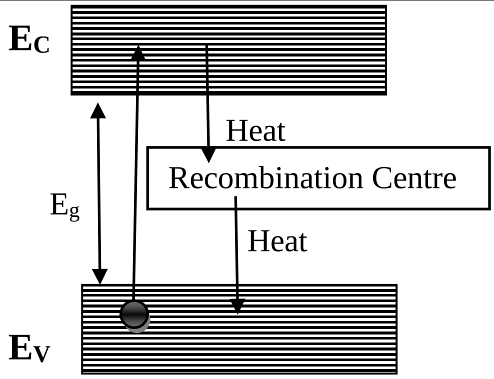
From the value of the Hall coefficient, the concentration of charge carriers and hence the conductivity can be calculated.

Applications of Hall Effect:

- To find the type of the Semiconductor either n-type or p-type
- The carrier concentration and hence the conductivity can be predicted
- It is used to measures the magnetic field accurately
- It is to predict the presence of magnetic field
- It is uses to construct magnetically activated switches

Direct and Indirect band gap Semiconductors:

Direct band gap	Indirect Band gap
The energy gap between the conduction and the valence band is small	The energy gap between the conduction and the valence band is large
During the recombination the electrons directly jump from conduction band to the valence band	During recombination process the electrons takes two steps to come to the valence band , first the electrons jumps from the conduction band to the intermediate energy level called recombination centre , and then from the recombination centre to the valence band

	
During the recombination process light will be emitted	During the recombination process heat will be emitted
The carrier life time is small	The carrier life time is large
Due to the small carrier life time, they are meant for fabrication of **LEDs and Laser diodes**	Due to the large carrier life time, they are meant for fabrication of **junction diodes ,Transistors**
These are mostly **compound** semiconductors	These are mostly **elemental** semiconductors
Ex: InP, GaAs, GaAl As	Ex: Si,Ge……….

Einstein Relations *or* Einstein Equations

It gives the relation between **mobility (μ) and diffusion coefficient (D)**

At equilibrium with no field, the free electron distribution is uniform inside the semiconductor and hence there is no net current flow.

J(drif)= 0

J(Diffusion)= 0

J(Total) =0

If **non-equilibrium** the, free electron distribution occur , then it leads to diffusion current and hence it creates an **internal electrical field**.

This internal electric field creates a drift current

W.K.T

$$J_{n\,(drift)} = \Delta n \, e \, \mu_n E$$

$$J_{n}\,(diffusion) = -e D_n \frac{-\partial(\Delta n)}{\partial x}$$

Under equilibrium conditions,

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

$$\Delta n e \mu_n E = e D_n \frac{-\partial(\Delta n)}{\partial x}$$

The force F on excess carriers due to field

$$F = \Delta n \, e \, E$$

$$F = \frac{e\ Dn}{\mu_n}\frac{\partial n}{\partial x} \qquad \text{------------- (6)}$$

Since electrons behave like gas, According to the kinetic theory of gases,

$$F = K_B T \frac{\partial n}{\partial x} \qquad \text{------------------------ (7)}$$

$$\therefore K_B T \frac{\partial n}{\partial x} = \frac{eD_n}{\mu_n}\frac{\partial n}{\partial x}$$

$$\Rightarrow K_B T = \frac{eD_n}{\mu_n}$$

$$D_n = \frac{K_B T}{e}\mu_n \qquad \text{--------------- (8)}$$

Similarly for holes $D_p = \frac{K_B T}{e}\mu_p$ ---------- (9)

$$\frac{7}{8} \Rightarrow \frac{D_n}{D_p} = \frac{\mu_n}{\mu_p} \qquad \text{------------ (9)}$$

Equations (7), (8) and (9) are called Einstein’s Relations.