Program : **B.Tech**

Subject Name: **Engineering Physics**

Subject Code: **BT-201**

Semester: **2nd**

Notes Introduction to Solids

Q.1 Give the free electron model of solids and explain its limitations. (April10)

Ans: **Free Electron Model of Metals**

1. Loosely bound electrons in a metal are free to roam around
2. These conduction electrons can be treated as a perfect gas obeying FD statistics.
3. We neglect interactions with atomic ions and self-interactions, but the electrons are still bound to the solid

Free electron model successfully predicts temperature dependence of electrical conductivity of metals.

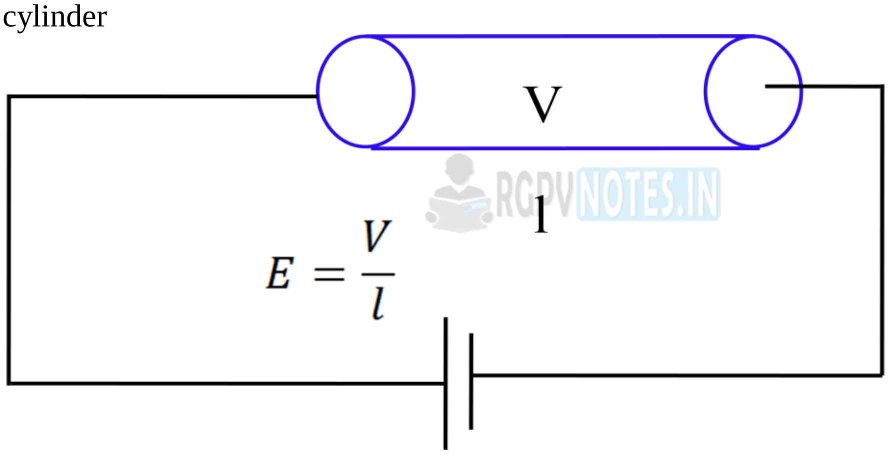
Derivation for Conductivity of Metal: Mean kinetic energy electron gas at temperature T is given as

$$\frac{1}{2}m(\bar{C})^2 = \frac{3}{2}KT$$

$$\text{Hence } \bar{C}^2 = \frac{3KT}{m}$$

$$\text{or } \bar{C} = \sqrt{\frac{3KT}{m}} \qquad (1)$$

Let us consider a metallic cylinder of length l an electric field is applied across the length of cylinder



If 'R' is the resistance of metallic cylinder considered then according to ohms law

$$V = IR \qquad (2)$$

Also

$$R = \rho\frac{l}{A} \qquad (3)$$

Therefore $V = IR$ Or $V = I\rho\frac{l}{A}$

$$\frac{V}{l\rho} = \frac{I}{A}$$

$$J = \sigma E \qquad (4)$$

As the electric field intensity is E, therefore the force experienced by the electron of material

$$F = eE$$

Hence acceleration produced in the electron will be

$$a = \frac{eE}{m}$$

It implies that the drift velocity of electron will be $v_d = a\tau$, where τ is mean free time between two successive collisions when electron is accelerated under the influence of applied filed.

$$v_d = \frac{eE}{m}\tau$$

Mean free time τ can be given as $\tau = \frac{\lambda}{\bar{C}}$

Hence

$$v_d = \frac{eE}{m}\frac{\lambda}{\bar{C}} \qquad (5)$$

As we know that $$J = nev_d \qquad (6)$$

Using equation (1) (4) (5) and (6) we can write

$$\sigma = \frac{ne^2\lambda}{\sqrt{3mKT}}$$

or

$$\rho = \frac{\sqrt{3mKT}}{ne^2\lambda}$$

Q.2 Calculate the density of states in the energy range E and E+dE using free electron model.

Ans: If N is the total number of states between the energy states E and E + dE , then the density of states will be given as

$$D(E) = \frac{dN}{dE}$$

Allowed states of energy according to the solution of Schrodinger equation

$$E = \frac{(\mathrm{n_x}^2 + \mathrm{n_y}^2 + \mathrm{n_z}^2)\pi^2\hbar^2}{2\mathrm{mL}^2}$$

Or

$$\mathrm{n_x}^2 + \mathrm{n_y}^2 + \mathrm{n_z}^2 = \frac{2\mathrm{mL}^2}{\pi^2\hbar^2}E$$

Equation above represents a sphere in n-space with radius

$$\mathrm{R} = \sqrt{\frac{2\mathrm{mL}^2}{\pi^2\hbar^2}E}$$

As $\mathrm{n_x}, \mathrm{n_y}$ and $\mathrm{n_z}$ can have only positive integer non zero values, therefore allowed states of energy will be only one octant of sphere Therefore

$$N = \frac{1}{8} \quad \frac{4}{3}\pi \left(\frac{2\mathrm{m}\mathrm{L}^2}{\pi^2\hbar^2}E\right)^{3/2}$$

Or $$N = \frac{\mathrm{L}^3}{6\pi^2} \quad \left(\frac{2\mathrm{m}}{\hbar^2}\right)^{3/2} E^{3/2}$$

In the equation above $\mathrm{L}^3 = \mathrm{V}$, hence $N = \frac{\mathrm{V}}{6\pi^2} \quad \left(\frac{2\mathrm{m}}{\hbar^2}\right)^{3/2} E^{3/2}$

As each states can accommodate two electrons one with spin up and other with spin down, therefore total number of states will be

$$N = \frac{\mathrm{V}}{3\pi^2} \quad \left(\frac{2\mathrm{m}}{\hbar^2}\right)^{3/2} E^{3/2}$$

The equation above gives the total available states of energy for electron in volume V.

Q.3 Explain the band theory of solids.

Or

Differentiate insulator, conductor and semiconductors on the basis of band theory of solids.

Ans: **Band Theory of Solids**

The material in atomic state possesses discrete energy levels as in gaseous state. In gaseous state the atoms are much far away from each other and they do not influence the energy levels of the other atom. When two atoms are brought closer than their valance electrons interact with each other and significant changes in the energy levels of valance electron is observed. In a solid a large number electrons are very close packed together and the outer most energy level of individual is splitted into various energy levels very closely spaced, these closely spaced energy levels forms a virtual continuum and is called as band of energy. The electrons can occupy these bands obeying Pauli's exclusion principle and as consequence some of energy states cannot be occupied by the electrons resulting in the formation of forbidden energy band. The lower band of energy is called as valance band while the upper energy band is called conduction band.

The formation of bands is illustrated in the following diagrams. In the figure 'a' individual atom is shown. In the figure 'b' the energy levels of the individual atom is shown on graph. The length of horizontal lines parallel to x- axis indicates the circumference of the energy level. While the position of horizontal line on y-axis gives the energy value of an energy level.

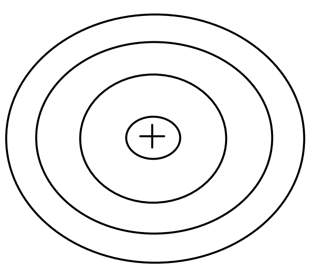


Figure: a

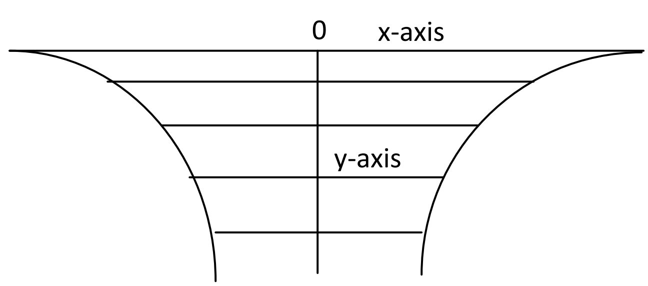


Figure: b

In the figure c two atoms are shown closer and the overlapping of valence energy levels is observed.

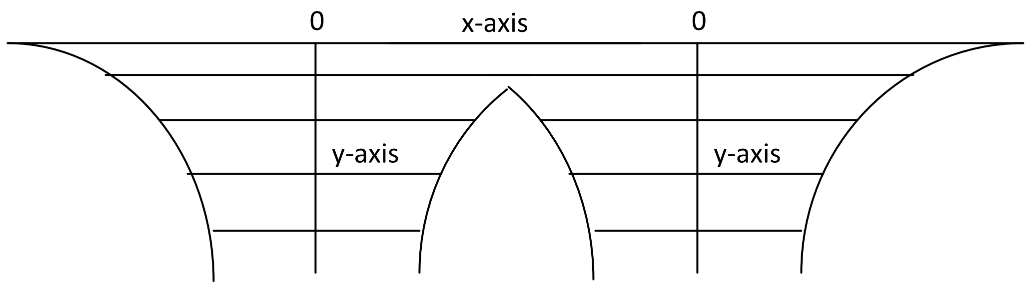


Figure: c

In the last figure n numbers of atoms are shown closer and the formation of bands is also shown

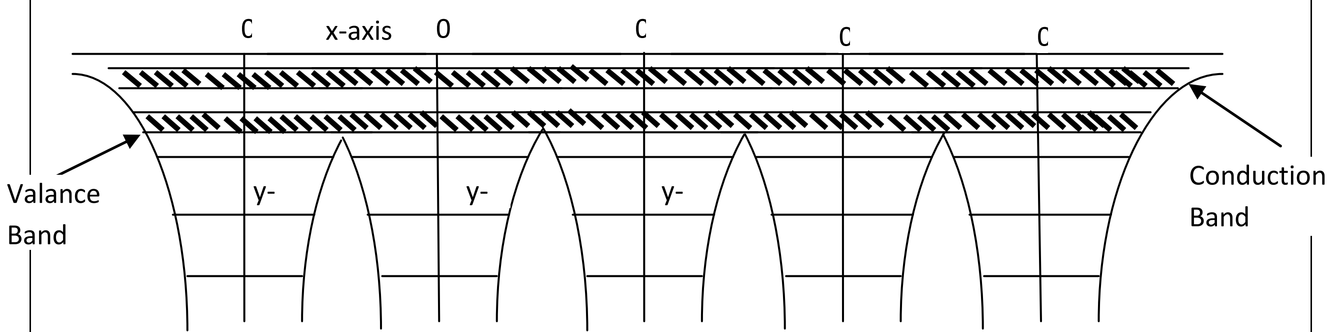
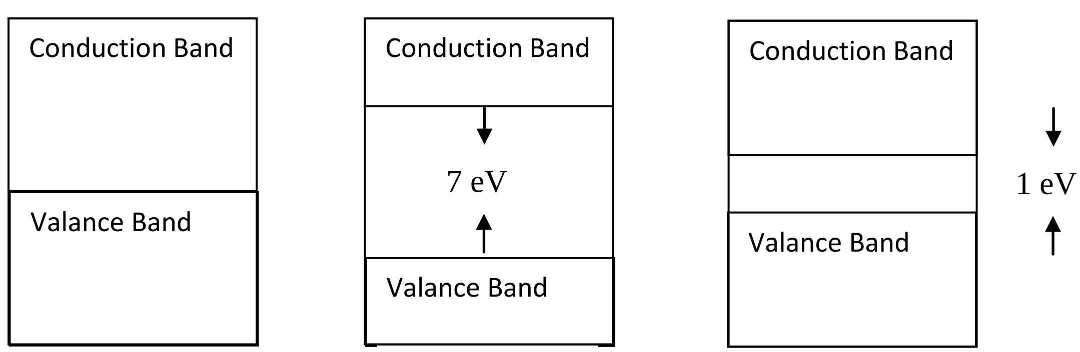


Figure: d

In the figure'd' formation of bands for a solid is depicted. In these bands where electron can freely move is known as **conduction band,** valance electrons attached to the atom forms **valance band,** whereas energy bands which cannot be occupied by electrons is known as **forbidden energy band.**

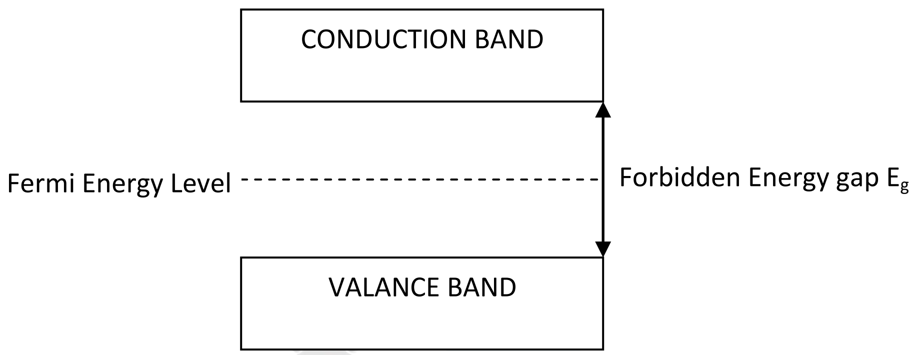
On the basis of band theory **conductors** are the solids in which valance band and conduction bands overlap each other, whereas in **insulators** separation between valance and conduction band is large and is typically of the order of 7 eV. **Semiconductors** are the solids who have a moderate energy gap between valance and conduction band typically of the order of 1 eV.

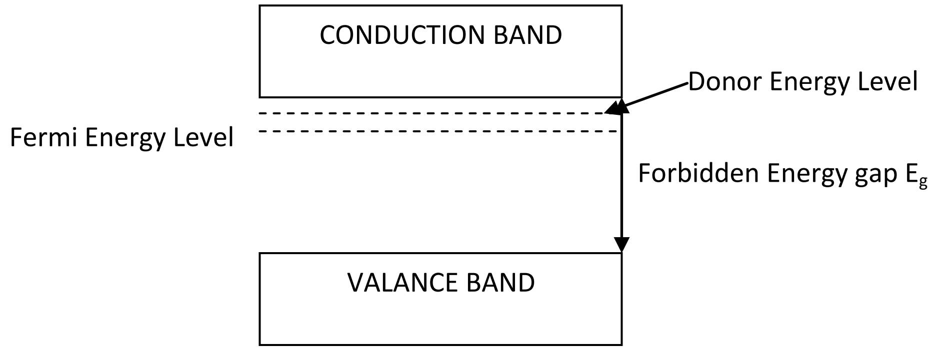
Energy band diagram for conductor, insulator and semiconductor is shown in the figures below.



Conductor Insulator Semiconductor

Q. 4 Define semiconductor. Distinguish between intrinsic and extrinsic semiconductor. **((Feb10)**

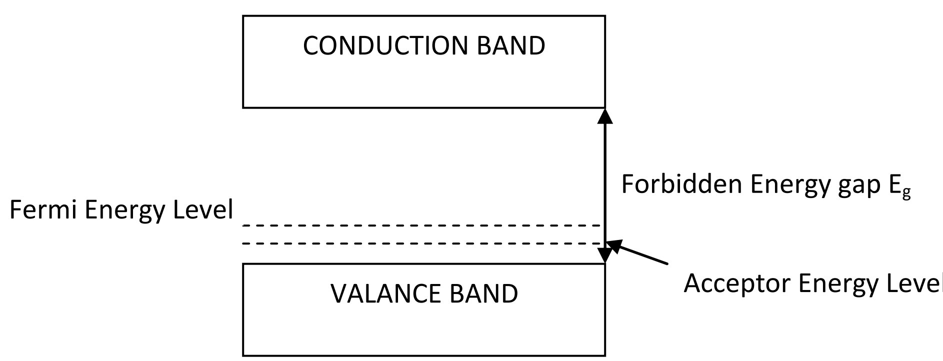
	Or Define n-type and p-type extrinsic semiconductors. **(Jun15)**
Ans:	**Intrinsic Semiconductors** The intrinsic semiconductors are the semiconductors are elemental semiconductors or also called as pure semiconductors. These semiconductors are made up of one kind of atoms only. The examples of intrinsic semiconductors are Silicon (Si) and Germanium (Ge). The intrinsic semiconductors have several limitations when practical applications are considered, because in intrinsic semiconductors the energy gap cannot be changed as per requirement. At T=0 K the intrinsic semiconductor behaves as insulators. Because no electron exists in the conduction band. But at ordinary temperatures due to thermal agitations the covalent bonds are broken and some electrons move to conduction band. The number of electrons and holes are equal inside an intrinsic semiconductor. The Fermi energy level inside an intrinsic semiconductor lies in the middle of energy gap. The energy band diagram for intrinsic semiconductor is shown below.  **Extrinsic Semiconductors** The energy gap and conductivity of intrinsic semiconductors cannot be tailored as per the requirement of application. This problem can be overcome by doping suitable impurity in the intrinsic semiconductors. Thus obtained semiconductors are called as extrinsic semiconductors. Depending upon the type of impurity added the extrinsic semiconductors can be classified as N-type and P-type semiconductors. **N-type Semiconductors** When intrinsic semiconductors either Si or Ge are doped with pentavalent material, then the obtained semiconductor material is called N-type semiconductor. The Si or Ge are tetravalent materials hence the four electrons in the outer shell of these materials forms the covalent bond with another Si or Ge atoms to complete their octet. When a pentavalent impurity Like Arsenic (As) is added to the Si or Ge then the four out of five valance electrons are shared by the host atoms(Si or Ge) while the fifth electrons of the impurity is loosely bound to its parent atom. These loosely bound electrons give rise to new energy levels which exists in the energy gap just below the conduction band and are called as donor levels. At ordinary temperature all the electrons of the donor level move to the conduction band. Thus the electrons become majority charge carriers as compared holes. Since the number of carriers are more in conduction band as compared to holes in valance band the Fermi level in N-type semiconductor shifts towards conduction band. The band diagram for N-type semiconductor is shown in figure below



Band diagram of N-type semiconductor

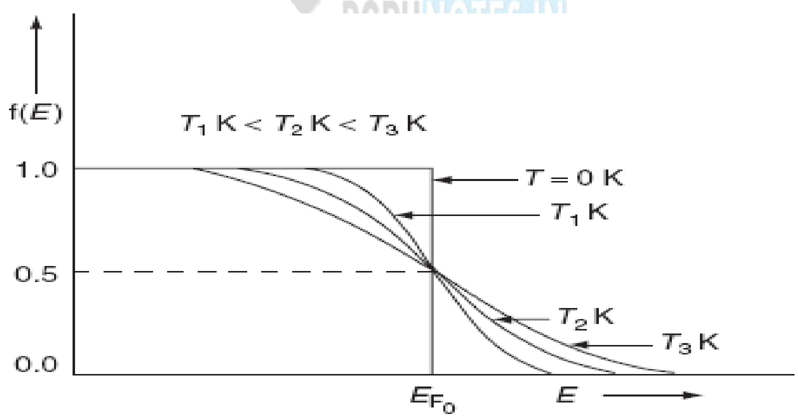
P-type Semiconductors

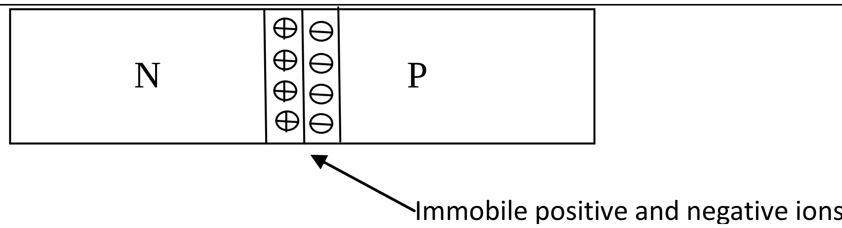
When intrinsic semiconductors either Si or Ge are doped with trivalent material, then the obtained semiconductor material is called P-type semiconductor. The Si or Ge are tetravalent materials hence the four electrons in the outer shell of these materials forms the covalent bond with another Si or Ge atoms to complete their octet. When a trivalent impurity Like Arsenic (Al) is added to the Si or Ge then the three valance electrons of impurity atom is shared by the host atoms (Si or Ge) and one of the electrons of host atom remain unshared. This result in the deficiency of an electron which tries to capture the electron from nearby covalent bond. Thus electron deficiency exists in valance band which give rise to new energy levels which exists in the energy gap just above the conduction band and are called as acceptor levels. Thus the holes become majority charge carriers as compared electrons. Since the numbers of carriers are more in valance band as compared to electrons in conduction band the Fermi level in P-type semiconductor shifts towards valance band. The band diagram for P-type semiconductor is shown in figure below



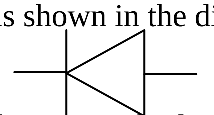
Band diagram of P-type semiconductor

Q.5	What is Fermi energy level? **Or** Explain the effect of temperature on Fermi Dirac distribution function. **(Jun14)**
Ans:	**Fermi Dirac distribution function & Fermi energy level**

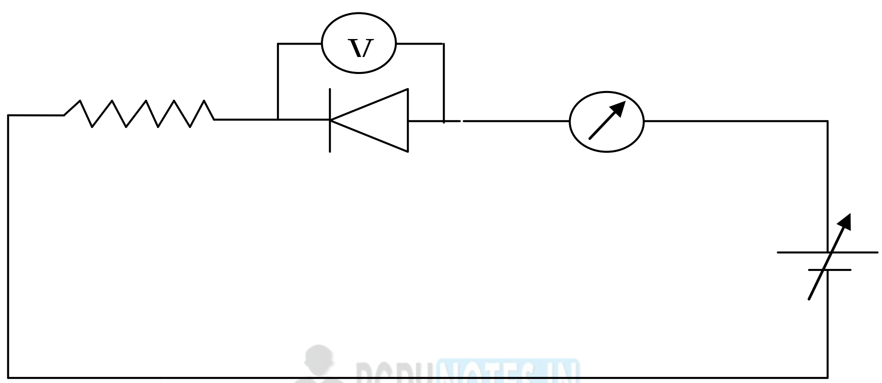
	The Fermi Dirac distribution function gives the probability of finding an electron in energy state E for a given temperature t. mathematically it is expressed as $$F(E) = \frac{1}{e^{\frac{E-E_F}{KT}} + 1}$$ Where E_F is Fermi energy level and K is Boltzmann's constant. Let $T = 0\,Kelvin$ and $E > E_F$ then the value of Fermi Dirac distribution function will be $F(E) = 0$. This implies that all the energy levels above the Fermi energy levels are empty at $T = 0\,Kelvin$. If $T = 0\,Kelvin$ and $E < E_F$ then the value of Fermi Dirac distribution function will be $F(E) = 1$. This implies that all the energy levels below the Fermi energy levels are completely occupied by electrons at $T = 0\,Kelvin$ or we can say that Fermi energy level is the highest possible level of energy for electron at $T = 0\,Kelvin$. For the temperature above 0 $Kelvin$ and $E = E_F$ the value of Fermi Dirac distribution function will be $F(E) = \frac{1}{2}$ i.e. we can say that for the temperatures above 0 $Kelvin$ the Fermi level is the level of energy for which the probability of occupancy of electron is $\frac{1}{2}$. Variation of Fermi Dirac function with temperature is shown in figure below. This figure clearly indicates that conduction band is completely empty at T=0K whereas with the increase in the temperature more energy states in the conduction band is occupied indicated by the increased value of F(E). **Variation of Fermi Function with Temperature** 
Q.6	What is P-N junction diode? Explain the characteristics of P-N junction diode under reverse and forward bias. **(Dec10, 11)**
Ans:	**PN Junction diode** When a slab of intrinsic semiconducting material is doped with trivalent impurity at one end while other end of the slab is doped with pentavalent impurity then a PN junction diode is formed. **PN Junction under no bias** When the junction is formed the flow of electrons starts across the junction due to concentration gradient. As the density of electron is more on N-side as compared to P-side. The electrons and holes recombine across the junction; as a result the ions are uncovered on both P and N-side in a small region around the junction. On N-side +ve ions are uncovered while on P-side –ve ions are uncovered these uncovered ions sets a potential barrier across the junction and prevents the flow of electrons and holes. Hence no current flows across the junction under no bias condition. Figure below represents the diagram of PN junction.



The symbol of PN junction diode is shown in the diagram below.



Forward biased PN junction When a PN diode is connected in a circuit such that its P side is connected to the positive terminal of battery and N side is connected to negative of battery. Then the diode is said to be under forward bias.



The negative potential at the N side forces the electrons to cross the junction. Initially when the value of applied potential is less than the potential barrier no current flows across the junction as the potential applied becomes greater than potential barrier electrons starts to cross the junction further increase in applied potential forces more electrons to cross the junction and a current in the circuit increases rapidly while the voltage across the diode does not change significantly as shown in the curve below.

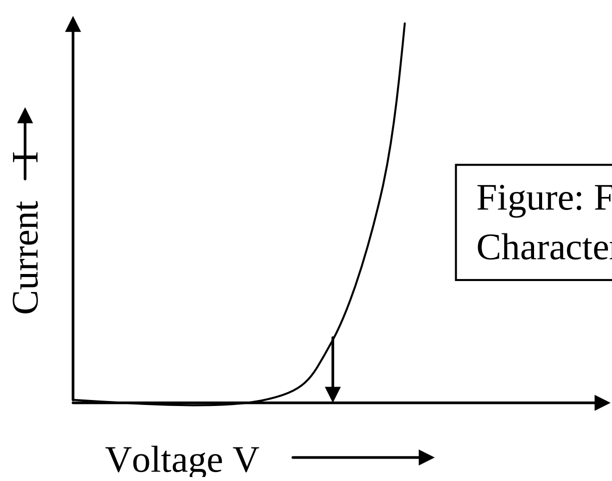
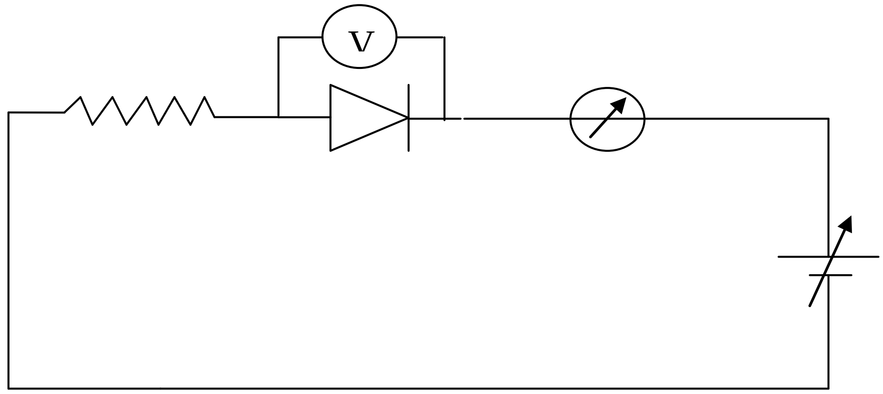


Figure: Forward Biased Diode Characteristics

Reverse biased PN junction When a PN diode is connected in a circuit such that its P side is connected to the negative terminal of battery and N side is connected to positive of battery. Then the diode is said to be under forward bias.



The positive potential at the N side forces the electrons to move away from the junction. Similarly holes also moves away from the junction as consequence majority charge carriers do not contribute to the current in the circuit. But the minority electrons from P side and minority holes from N side moves towards junction and a small current flows across the junction due small number of charge carriers. Further increase in the applied potential does not result in the increase of current. The current is called as reverse saturation current and it depends upon the junction temperature rather than applied potential.

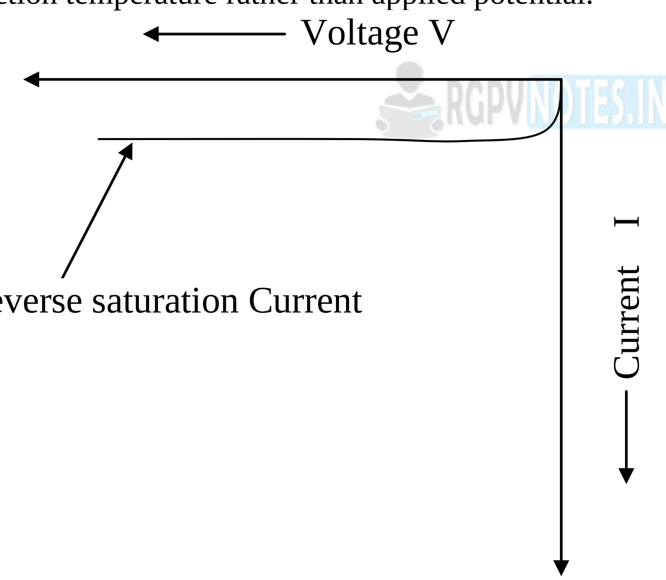
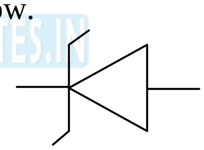
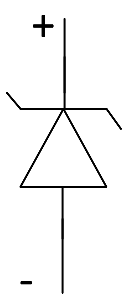
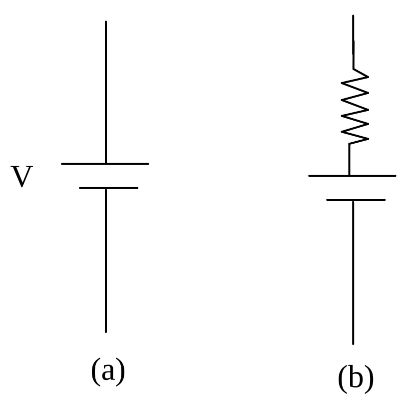
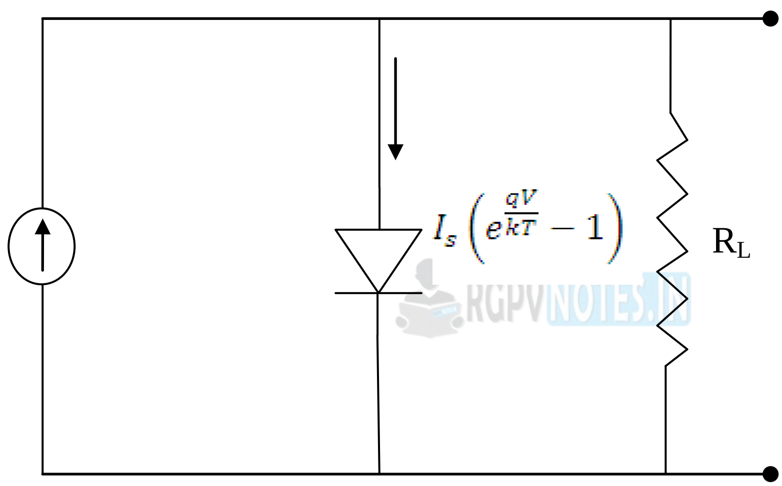
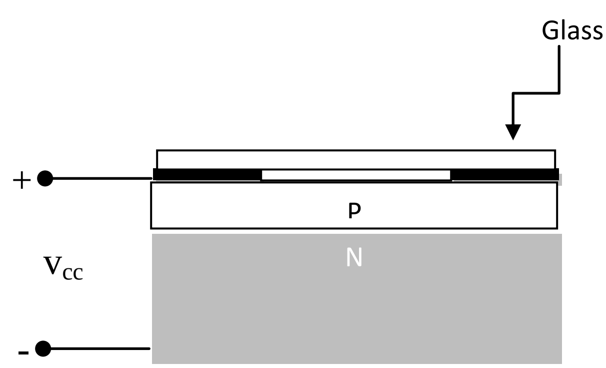


Figure: Reverse Biased Diode Characteristics

Reverse bias and Breakdown When a diode is connected in the reverse bias then the majority charge carriers moves away from the junction and the immobile ions on P and N side gets uncovered resulting in the widening of depletion layer and minority charge carriers contribute to small current. When the applied potential is increased it leads to abrupt increase of reverse current this is called as breakdown. Two kind of mechanism are responsible for the abrupt current change

1. **Avalanche breakdown** This kind of break down occurs when the impurity concentration is lower. The increase in the reverse applied potential does not leads to increase in the current but increase in the potential results in the increase in the kinetic energy of

	electron, when electron acquires the kinetic energy of the order of the strength of covalent bond then this electron breaks the covalent bond of the atom resulting in the electron hole pair. Thus produced electrons get accelerated and break another covalent bond and the process continues in the generation of large number of current carriers and large current starts to flow across the junction. The avalanche breakdown results in the damage of diode. The breakdown curve in this case is gradual near breakdown voltage. 2. **Zener breakdown** This kind of break down occurs when the impurity concentration is higher. The increase in the reverse applied potential does not leads to increase in the current but increase in the potential results in the widening of depletion layer. Thus a large electric field is set across junction, when the strength of internal field is of the order of the strength of covalent bond then this field breaks the covalent bond of the atoms resulting in the generation of large number of electron hole pairs and large current starts to flow across the junction. The zener breakdown does not damage the diode. When reverse potential is removed then the diode acquires its original state. The breakdown curve in this case is sharp near breakdown voltage.
Q.7	What is Zener diode? Draw the equivalent circuit of an ideal and actual Zener diode. What are its uses? **(Jun 12, 14, 15)**
Ans:	**Zener Diode:** Zener diode is made by heavily doped P and N type semiconductors and the surface are of the junction is also increased to avoid the increase in junction temperature in case of break down. When the break down occurs then the zener curve suggests that the voltage becomes constant and increase in the applied potential results in the increase in the reverse current. This property of the zener diode is used for the voltage regulator applications. The symbol of zener diode is shown in the figure below.  **Equivalent circuit for ideal and actual zener diode**  Reverse biased zener diode  Equivalent circuit (a) Ideal (b) Actual For an ideal zener diode in the reverse bias the voltage across the diode will remain constant irrespective of the current through the diode, however for practical applications it is limited by zener impedance. A zener diode can be used as voltage regulator, voltage clipper, wave shaper and rectifier. ***(Note that V-I characteristics of zener diode are similar to P-N junction diode***

	except in the reverse bias where zener breakdown takes place unlike avalanche break down in P-N junction diode)
Q.8	Discuss the basic operation and characteristics of a solar cell with necessary diagram. **(Dec13)** **or** Explain V-I characteristics of a photovoltaic cell. **(Jun16)** **Or** Write a short note on solar cell **(Jun13,10)** **Or** Describe with the diagram the basic operation and characteristics of a solar cell including the short circuit current and open circuit voltage. Derive the expression for the maximum power delivered to the load, fill factor and efficiency of the solar cell.
Ans:	**Solar cell:** A solar cell converts the optical energy into the electrical energy it is a PN junction diode. When the light is incident on the PN junction the flow of electron and hole pair results in the photocurrent. The equivalent circuit for solar cell is given in the diagram below  The construction of solar cell is given in the diagram below  **Working;** when a photon collides with the valance electron either in P-type material or N-type material, it imparts sufficient energy to the electron to leave its parent atom. As a result, free electrons and holes are generated on each side of junction. In P-type material electrons are

minority carriers and similarly holes are minority in N-type materials. These holes and electrons move towards junction without applied bias. The result is increase in minority carriers flow.

Characteristics of solar cell: Let us consider a solar cell with a resistive load R. when the light is incident on the PN junction it produces photocurrent I_L. This current produces a voltage drop across the solar cell and the PN junction becomes effectively forward bias. The current I_F due to forward bias is into opposite direction to photocurrent I_L. Therefore the net current is given by

$$I = I_L - I_F = I_L - I_S\left(e^{\frac{qV}{kT}} - 1\right) \qquad 1$$

Where I_S is reverse saturation current.

Under open circuit condition I=0. Therefore,

$$0 = I_L - I_F = I_L - I_S\left(e^{\frac{qV_{OC}}{kT}} - 1\right)$$

Or

$$\frac{I_L}{I_S} = \left(e^{\frac{qV_{OC}}{kT}} - 1\right)$$

$$\frac{I_L}{I_S} + 1 = \left(e^{\frac{qV_{OC}}{kT}}\right)$$

On taking log $\quad log_e\left(\frac{I_L}{I_S} + 1\right) = \frac{qV_{OC}}{kT}$

Or $\quad V_{OC} = \frac{kT}{q} log_e\left(\frac{I_L}{I_S} + 1\right)$

The power delivered to load will be $P = IV = I_L V - I_S\left(e^{\frac{qV_{OC}}{kT}} - 1\right)V$

For maximum power $\frac{dP}{dV} = 0 = I_L - I_S\left(e^{\frac{qV_m}{kT}} - 1\right) - I_S V_m \frac{q}{kT}\left(e^{\frac{qV_m}{kT}} - 1\right)$

$$\frac{I_L + I_S}{\left[1 + \left(\frac{qV_m}{kT}\right)\right]} = I_S\left(e^{\frac{qV_m}{kT}}\right) \qquad 2$$

Using equation 1 for maximum current I_m we get

$$I_m = I_L - I_S\left(e^{\frac{qV_m}{kT}} - 1\right)$$

Or

$$I_m = (I_L + I_S) - I_S\left(e^{\frac{qV_m}{kT}}\right) \qquad 3$$

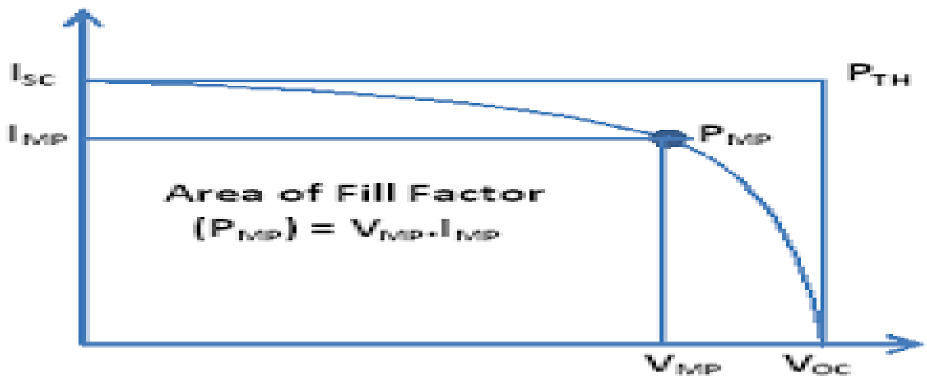
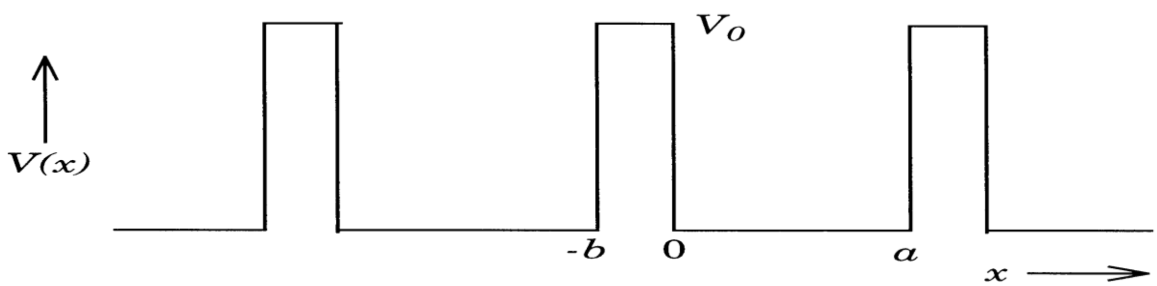
Using equation 2 and 3 we get

$$I_m = (I_L + I_S)\left[\frac{V_m}{V_m + \left(\frac{kT}{q}\right)}\right]$$

Hence the maximum power delivered by solar cell will be

$$P_m = V_m I_m = (I_L + I_S)\left[\frac{V_m^2}{V_m + \left(\frac{kT}{q}\right)}\right]$$

Fill Factor: the ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current

	$$FF = \frac{P_{max}}{I_{sc}V_{oc}}$$ 
Q.9	What is Kronig-Penny model of solids and show that it leads to energy band structure of solids. **(Dec10)** **Or** Discuss the salient features of Kronig-Penny model. **(Jun11)** **Or** Draw periodic potential observed by an electron, moving in one dimensional crystal lattice. Discuss Kronig-Penny model proposed for periodic potential. Write Schrodinger wave equation for such potential and discuss its solution. **(Dec12)** **Or** Describe the behavior of electron in periodic potential using final expression of Kronig-Penny model. **(Dec13)** **Or** Describe the behavior of electron in periodic potential using final expression of Kronig-Penny model and explain the formation of energy bands. **(Jun14)** **Or** Find the effective mass of electron on the basis of Kronig-Penny Model. **(Dec15)**
Ans:	**Kronig Penny Model** The Kronig Peny model considers that electrons inside solid moves in a periodic potential due to rest electrons and ion cores. An approximate picture inside solid is shown in the figure below.  The picture above is one-dimensional periodic potential of electron inside solid. Even though the model is one-dimensional, it is the periodicity of the potential that is the crucial property that yields electronic band structure. The mathematical form of the repeating unit of the potential is $$V(x) = V_0 \; for \; -b < x < 0$$

$$V(x) = 0 \ for \ \ 0 < x < a$$

As shown in figure 1 the potentail has a period of $c = a + b$. The Schrodinger equation for this model will be

$$\frac{d^2\psi}{dx^2} + \frac{2mE}{\hbar^2}\psi = 0 \ for \ \ 0 < x < a \qquad 1$$

$$\frac{d^2\psi}{dx^2} + \frac{2m(E-V_0)}{\hbar^2}\psi = 0 \ for \ \ -b < x < 0 \qquad 2$$

The solution satisfying above equations will be obtained by using Bloch Theorem and will be

$$P\frac{\sin \alpha a}{\alpha a} + \cos \alpha a = \cos Ka \qquad 3$$

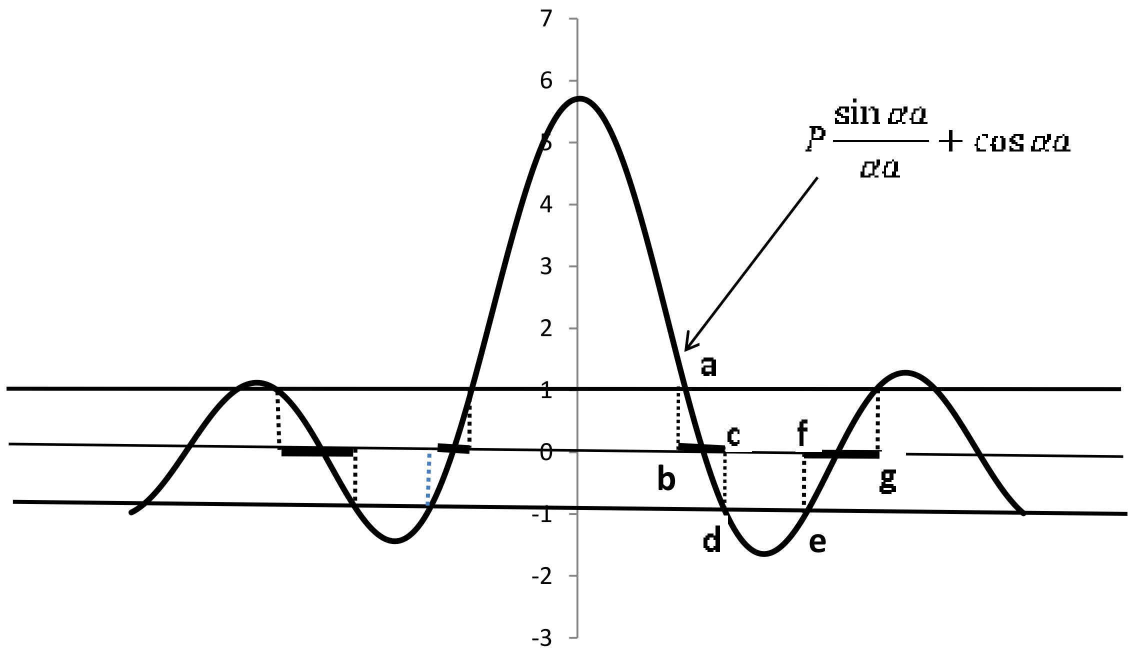
Where

$$P = \frac{maV_0 b}{\hbar^2}$$

and

$$\alpha = \sqrt{\frac{2mE}{\hbar^2}}$$

In equation 3 there are two variables α and K. The right hand side of equation can have values only between +1 and -1. This implies that the equation 3 will be valid only when left hand side of equation will have values between +1 and -1. To find the allowed values of αa we plot left hand side of the equation with respect to αa. In the plot below we have drawn two lines parallel to the x-axis at y-values +1 and -1.



In the above plot the thick line from point 'b' to 'c' shows the allowed values of energy for electrons. Because the term $P\frac{\sin \alpha a}{\alpha a} + \cos \alpha a$ is between +1 to -1, hence the continuous allowed values indicate the formation of band. While the values of αa between points 'c' to 'f' indicates the forbidden band because the term $P\frac{\sin \alpha a}{\alpha a} + \cos \alpha a$ having the values less than -1.

- The solution also suggests that the width of allowed band increases with increase in the value of αa.

- For P=0 the width of forbidden band becomes zero and the electron is a free electro.
- For $P = \infty$ the energy band reduces to the energy levels.
- At $Ka = \pm n\pi$ where *n= 1, 2, 3*.....the energy curve shows the discontinuity.
- The region between $\frac{\pi}{a}$ to $-\frac{\pi}{a}$ is called the first Brillouin zone.

Effective Mass of electron

As $E = \frac{P^2}{2m}$ also $P = \hbar k$ by de-Broglie's hypothesis.

Therefore $E = \frac{\hbar^2 k^2}{2m}$, thus electron energy is parabolic, with wave vector k. the electron mass is inversely related to the curvature (second derivative) of the E-k relationship, since $\frac{d^2E}{dk^2} = \frac{\hbar^2}{m^*}$

$$m^* = \hbar^2 \left(\frac{d^2E}{dk^2}\right)^{-1}$$

From the equation above it is evident that the effective mass m^* is inversely proportional to the $\frac{d^2E}{dk^2}$. Following is concluded for the effective mass

- If the curvature E vs k is large the value of effective mass m^* will be small.
- If the curvature E vs k is small the value of effective mass m^* will be larger.

Q.11 What is Hall effect? Give an elementary theory of Hall effect. **(Dec11, 12, Jun 12, Jan16)**

Or

What are the potential applications of Hall effect? **(Jun11)**

Or

Show that Hall coefficient is independent of the applied magnetic field and is inversely proportional to density of electronic charge. **(Jun12, 14)**

Or

Describe the Hall effect and Hall coefficient in detail. **(Jun10)**

Or

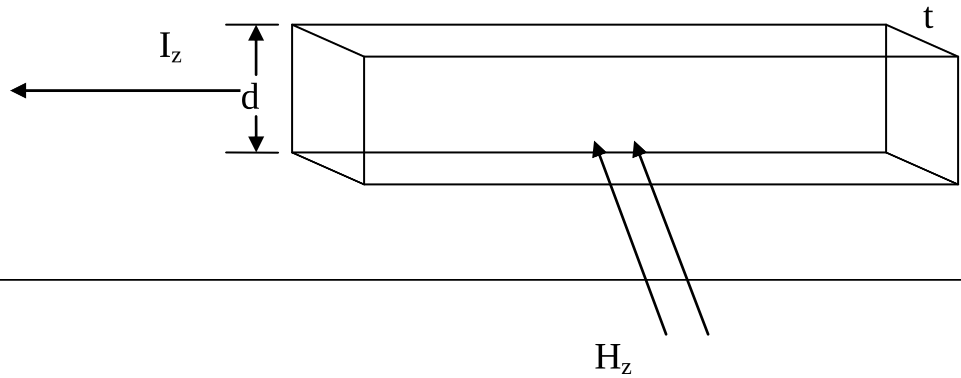
Deduce an expression for Hall effect of a solid and describe a method for its determination experimentally. What important information are obtained from its measurement? **(Dec12)**

Ans: **Hall Effect:**

When a specimen (metal or semiconductor) carrying current I is placed in transverse magnetic field. Then a potential is induced in the specimen in the perpendicular direction to both the current and the magnetic field. This phenomenon is called as Hall Effect.

Derivation

Let us consider an n-type material placed in an electric field in positive x-direction and a magnetic field is applied normal to the field in z-direction. Then the transverse magnetic field will exert Lorentz force on the electrons and electrons will accumulate at one side of specimen giving rise to potential.



When the value of force due to generated field equals the Lorentz force then the induced potential acquires the equilibrium in this condition.

Hall force = Lorentz force

$$F_H = F_L$$

$$-qE_H = v_x B_z q$$

Where v_x is drift velocity of electrons.
Or

$$E_H = -v_x B_z$$

As $j_x = N v_x q$ we get $j_x = -N\frac{E_H}{B_z}q = -N\frac{V_H}{dB_z}q$

Or $V_H = -\frac{j_x d B_z}{Nq} = -\frac{I\,B_z d}{NqA}$

Since t is thickness $V_H = -\frac{I\,B_z}{Nqt}$

The expression above is called as hall voltage. The value of Hall field per unit magnetic field and per unit current density is called as hall coefficient and is denoted by R_H.

$$R_H = -\frac{E_H}{j_x B_z} = -\frac{V_h/d}{j_x B_z}$$

$$R_H = -\frac{1}{Nq}$$

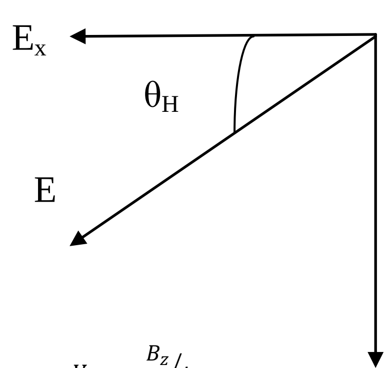
In terms of Hall coefficient the Hall voltage is given by

$$V_H = R_H\frac{I\,B_z}{t}$$

Since the electron mobility is given as $\mu_n = \frac{\sigma}{N|q|}$ therefore

$$\mu_n = |R_H|\sigma$$

The direction of Hall field is the direction the net field in the semiconductor. The net field in the semiconductor is the vector sum of applied field E_x and Hall field E_H as shown in figure below



$\tan\theta_H = \frac{E_H}{E_x}$ as $E_H = \frac{V_H}{d} = \frac{B_z/j_x}{N|q|}$ also $E_x =$

Therefore $\tan\theta_H = \frac{B_z}{N|q|\sigma}$ or $\tan\theta_H = \sigma R_H B_z$

Since $\sigma R_H = \mu_n$ therefore $\tan\theta_H = \mu_n B_z$

Hence $\theta_H = tan^{-1}(\mu_n B_z)$ this is known as direction of Hall field.

	Applications: 1. Hall effect can be used for the measurement of the strength of magnetic field 2. It is used for the determination of carrier concentration of semiconductors 3. The sign of Hall coefficient tells about the predominant charge carriers in a semiconductor 4. Hall effect can be used for the amplification of weak signals