FE Sem-II 2025-26

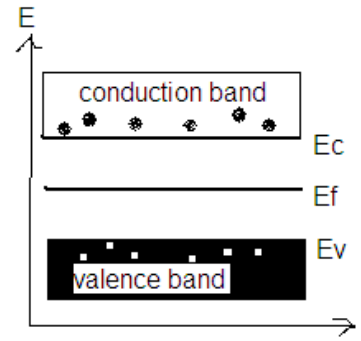
Subject - Semiconductor Physics

Question & Answer for Term Test- 1

1. **Define Fermi level in semiconductor? Show that Fermi level in intrinsic semiconductor always lies at the middle between valence band & conduction band?**

The reference energy level with in energy gap, its position depends depend upon concentration of charge carriers in conduction band and valence band is known as Fermi level in semiconductor.

In intrinsic semiconductor the probability of finding an electron in the conduction band is zero and probability of finding a hole in the valence band is zero at T=0°k. At temperature increases, equal number of electrons and holes get generated. In such a case the Fermi level E_F is given by



Fermi level in intrinsic semiconductor

Proof:

In a pure semiconductor the number of holes and electrons are equal.

That is $n = p = n_i$

$$N_C e^{-(E_C-E_F)/kT} = N_V e^{-(E_F-E_V)/kT}$$

$$\frac{N_C}{N_V} = \frac{e^{-(E_F-E_V)/kT}}{e^{-(E_C-E_F)/kT}} = e^{(-E_F+E_V+E_C-E_F)/kT}$$

$$\frac{N_C}{N_V} = e^{(E_C+E_V-2E_F)/kT}$$

Taking logarithm on both sides

$$\ln\left(\frac{N_C}{N_V}\right) = \frac{E_C+E_V-2E_F}{kT}$$

$$E_C+E_V-2E_F = kT\ln\frac{N_C}{N_V}$$

$$2E_F = E_C+E_V-kT\ln\frac{N_C}{N_V}$$

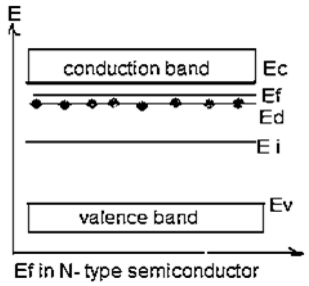
$$E_F = \frac{E_C+E_V}{2} - \frac{kT}{2}\ln\frac{N_C}{N_V}$$

If $N_C = N_V$, $E_C + E_F - 2E_F = 0$

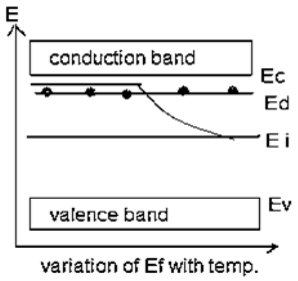
and $$2E_F = E_C + E_V$$

$$E_F = \frac{E_C+E_V}{2}$$

2. Explain the variation of Fermi level with temperature in N-type semiconductor?



Ef in N- type semiconductor



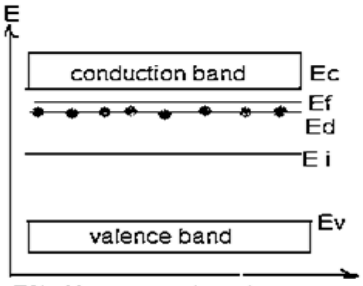
variation of Ef with temp.

In N – type semiconductor, the density of free electrons in the conduction band is greater than density of holes in the valence band. The Fermi level lies at the middle between the bottom level of conduction band Ec and donor level of impurity atoms Ed.

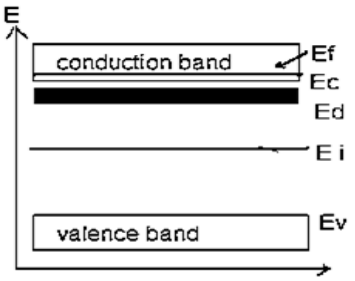
$$\text{Therefore, } Ef = \frac{Ec + Ed}{2}$$

As the temp. Increases, the donor level is depleted by the electrons from the valence band and density of holes in the valence band increases. Therefore Fermi level Ef go on decreasing. At particular temp. the density of free electrons in the conduction band becomes equal to the density of holes in the valence band and Fermi level reaches to intrinsic level Ei. The material loses its extrinsic nature and becomes intrinsic semiconductor. The Fermi level Ef becomes independent of temp.

3. Explain the variation of Fermi level with impurity concentration in N-type semiconductor?



Ef in N- type semiconductor



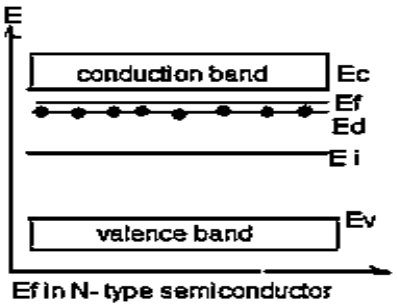
variation of Ef with impurity concentration

In N – type semiconductor at low impurity concentration, the donor atoms are isolated from each other and therefore single donor energy level Ed is formed below the conduction band. The Fermi level lies at the middle between the bottom level of conduction band Ec and donor level of impurity atoms Ed.

$$\text{Therefore, } Ef = \frac{Ec + Ed}{2}$$

As the impurity concentration increases, the number of donor atoms in the donor level increases. These atoms are interacting with each other, therefore donor level splits in to no. of discrete energy levels and donor energy band is formed. The width of donor energy band increases with increase in impurity concentration. The Fermi level Ef shift close to conduction band and at higher concentration Ef may enter in to the conduction band.

4. Derive the expression for Fermi level in N-type semiconductor?



Ef in N- type semiconductor

In N – type semiconductor, donor impurity is just below the conduction band, therefore the density of free electrons in the conduction band is greater than density of holes in the valence band. The Fermi level lies at the middle between the bottom level of conduction band Ec and donor level of impurity atoms Ed.

$$\text{Therefore, } Ef = \frac{Ec + Ed}{2}$$

Consider at temp. T^0K,

n_c – Concentration of free electrons in conduction band.

$$n_c = Nc\ e^{-(Ec - Ef)/KT}$$

$$\text{but } n_c = N_D$$

$$\text{Therefore, } N_D = Nc\ e^{-(Ec - Ef)/KT}$$

$$N_D/N_C = e^{-(Ec - Ef)/KT}$$

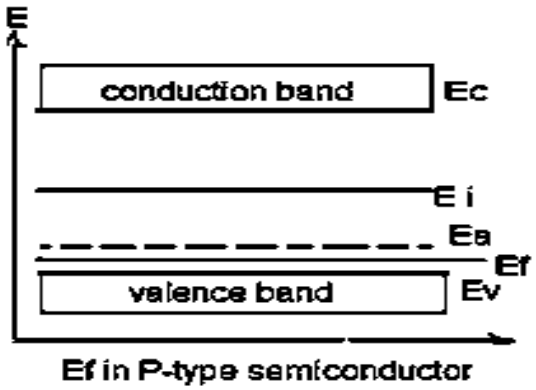
Take logarithm on both side

$$\text{Log } N_D/N_C = -(Ec - Ef)/KT$$

$$KT \log N_D/N_C = -E_C + E_F$$

$$\mathbf{Ef = E_C + KT \log N_D / N_C}$$

5. **Derive the expression for Fermi level in P-type semiconductor?**



Ef in P-type semiconductor

In P – type semiconductor, the Fermi level lies at the middle between the top level of valence band Ev and acceptor level of impurity atoms E_A.

$$\text{Therefore, } Ef = \frac{Ec + EA}{2}$$

Consider at temp. T^0K,

n_v – Concentration of holes in valence band.

$$n_v = Nv\, e^{-(Ef - Ev)/KT}$$

$$\text{but } n_v = N_A$$

$$\text{Therefore, } N_A = Nv\, e^{-(Ef - Ev)/KT}$$

$$N_A/N_V = e^{-(Ef - Ev)/KT}$$

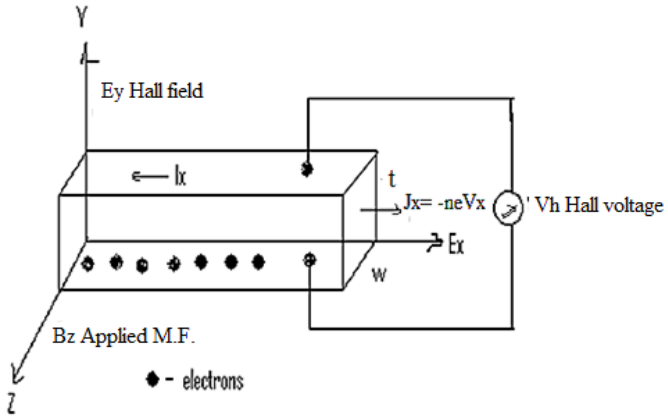
Take logarithm on both side

$$\text{Log } N_A/N_v = -(Ef - Ev)/KT$$

$$KT \log N_A/N_v = -E_f + E_v$$

$$\mathbf{Ef = E_v - KT \log N_A / N_v}$$

6. **What is Hall effect? Derive the expression for Hall voltage?**
7. **What is Hall effect? Explain how it is used to determine density of charge carrier in semiconductor material?**
8. **What is Hall effect? Explain how it is used to determine mobility of charge carrier in semiconductor material?**



"If a conductor (metal or semiconductor) carrying an electric current is kept in magnetic field, then an electric field is produced in the conductor which is perpendicular to both the direction of electric current and applied magnetic field".

Consider a piece of metal carrying an electric current kept in a magnetic field.

If t – thickness and w – width of metal piece.

Ex – applied electric field along X-axis.

Jx – current density along + ve X direction.

Ix - current flowing along X- axis.

Bz – apllied magnetic field along Z – axis.

Vx – drift velocity of electrons along – ve X- axis.

The force acting on the electrons due to magnetic field Bz is

$$\mathbf{F = Bz\ e\ Vx}$$

This force is known as Lorentz force. The direction of this force is along – ve Y- axis.

Due to this force, the free electrons in the metal are collected on the bottom surface of the metal and equal deficiency of electrons will produce on the top surface of the metal piece. Thus an electric field Ey is produced along Y-axis. This field is known as Hall field.

The force acting on the electrons due to Hall field Ey is`

$$\mathbf{F = e\ Ey}$$

The direction of this force is along + ve Y- axis.

At equilibrium, force due to E.F. = force due to M.F.

$$\mathbf{eEy = Bz\ e\ Vx}$$

$$\mathbf{Ey = VxBz} \text{ ---------- (1)}$$

The current density along X- axis is $Jx = - n\ e\ Vx$

$$Vx = - Jx / n\ e$$

Keep this value in equation (1)

$$Ey = (-Jx/ne)\ Bz$$

But $\boxed{\mathbf{R_H = - 1/ne}}$ known as Hall coefficient. The measurement of Hall coefficient gives the sign of the charge carriers and density of charge carriers in the material.

$$\mathbf{Ey = R_H JxBz} \text{ ---------- (2)}$$

If V_h is Hall voltage across the thickness t, then Hall field $Ey = V_h / t$.

If w is width of sample $J_x = I_x / A = I_x / w\ x\ t$

Equation (2) $\Rightarrow V_h / t = R_H\ (I_x / w\ x\ t)\ Bz$

$$\mathbf{V_h = R_H\ (\frac{Ix}{W})\ Bz)}$$

$$= \frac{Rh\ Ix\ Bz}{W}$$

$$= \frac{Ix\ Bz}{neW}$$

The drift velocity per unit electric field is known as mobility of charge carriers.

Therefore $\mu_e = Vx / Ex$

$Vx = \mu_e Ex$

Keep this value in equation (1)

Ey = μe Ex Bz----------(3)

Equating equations (2) and (3)

`

$R_H JxBz = \mu e\ Ex\ Bz$

$\mu_e = R_H Jx / Ex$

$Jx / Ex = \sigma$ conductivity of material.

$$\boxed{\mu_e = R_H \sigma}$$

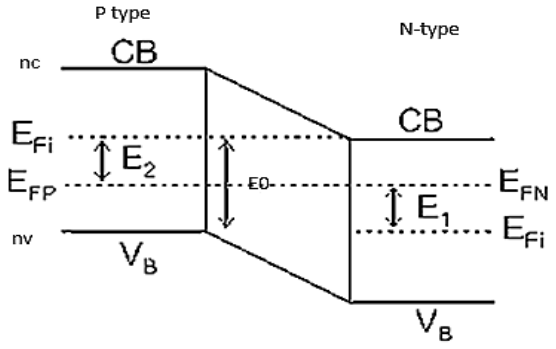
This equation is used to determine the mobility of charge carriers.

Applications of Hall Effect: -

1) To determine the sign of the charge carriers.
2) To determine the electronic structure of the material, whether the material is conductor, insulator or semiconductor.
3) To determine the concentration of the charge carriers.
4) To determine the mobility of the charge carriers.

9. What is PN junction? Derive the expression for barrier potential in PN junction?

1) When P- type and N-type semiconductors are joined together by diffusion method, then it is called P-N junction.
2) A layer of +vely charged ions is formed towards N-type region and layer of –vely charged ions is formed towards P-type region. This region is known as depletion region. Due to charge separation, a small P.D. is developed at the junction, known as barrier potential.



Eo is potential energy of electrons

Eo = E1 + E2

But Eo = eVb where Vb is barrier potential or built-in potential

eVb = E1 + E2

$$Vb = \frac{E1+E2}{e} \quad \text{---------- (1)}$$

From fig. $E1 = E_{FN} - E_{Fi}$ $E2 = E_{Fi} - E_{FP}$

Electrons diffuse from conduction band of N-type to conduction band of P-type region. The concentration of electrons in conduction band of PN junction is

$$n_c = \text{ni}\ e^{\frac{(E_{FN} - E_{Fi})}{KT}}$$

$$Nd = ni\, e^{\frac{(E_{FN} - E_{Fi})}{KT}}$$

$$\frac{Nd}{ni} = e^{\frac{(E_{FN} - E_{Fi})}{KT}}$$

$$\text{Log}\frac{Nd}{ni} = \frac{(E_{FN} - E_{Fi})}{KT}$$

$$E_{FN} - E_{Fi} = KT\ \text{Log}\frac{Nd}{ni}$$

$$E1 = KT\ \text{Log}\frac{Nd}{ni}$$

Holes diffuse from valence band of P type to valance band of N type region.

Concentration of holes in valance band of PN junction is

$$n_v = ni\, e^{\frac{(E_{Fi} - E_{Fp})}{KT}}$$

$$Na = ni\, e^{\frac{(E_{Fi} - E_{Fp})}{KT}}$$

$$\frac{Na}{ni} = e^{\frac{(E_{Fi} - E_{Fp})}{KT}}$$

$$\text{Log}\frac{Na}{ni} = \frac{(E_{Fi} - E_{Fp})}{KT}$$

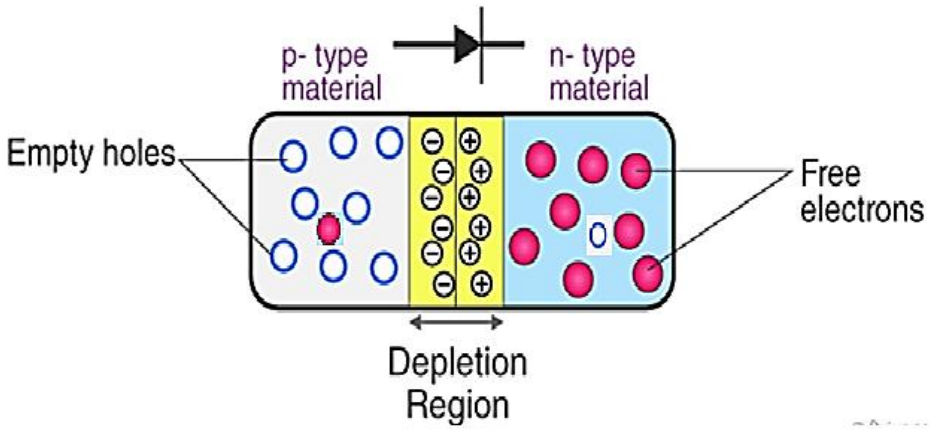
$$E_{Fi} - E_{Fp} = KT\ \text{Log}\frac{Na}{ni}$$

$$E2 = KT\ \text{Log}\frac{Na}{ni}$$

$$\text{Equation (1)} \Rightarrow \boldsymbol{Vb} = \frac{KT \log\frac{Nd}{ni} + KT \log\frac{Na}{ni}}{e}$$

$$\boldsymbol{Vb} = \frac{\boldsymbol{KT}}{\boldsymbol{e}} \boldsymbol{log} \frac{\boldsymbol{Na\, Nd}}{\boldsymbol{ni^2}}$$

10. Explain mechanism of formation barrier potential in PN junction?



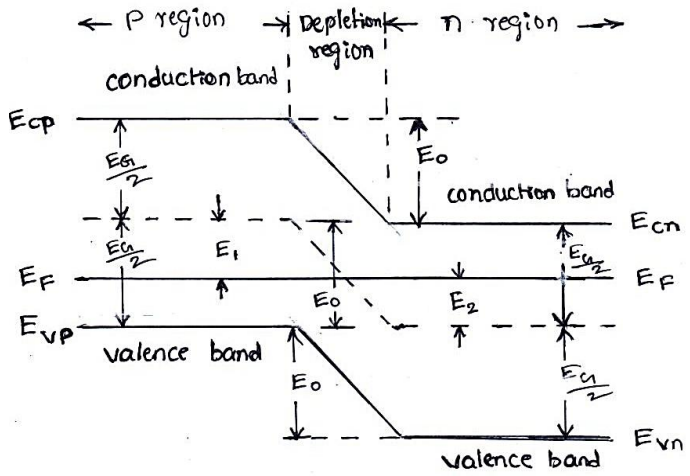


Fig: Energy Band Diagram for p-n Junction under open-circuit Conditions

When P- type and N-type semiconductors are joined together by diffusion method, then it is called P-N junction.

In P-type semiconductor majority charge carriers are holes and in N-type semiconductor majority charge carriers are electrons. Due to thermal excitation during formation of P-N junction some minority charge carriers are produced in the P-type and N-type region.

During formation of P-N junction, the electrons and holes crossover the junction and recombine with each other to become neutral.

The pentavalent impurity atoms donate it valence electron and become + vely charged ions in N-type region, while trivalent atoms gain an extra nuclear electron and become – vely charged ions in P-type region. These ions are immobile and bounded to the crystal lattice.

A layer of +vely charged ions is formed towards N-type region and layer of –vely charged ions is formed towards P-type region. This region is known as depletion region.

Due to charge separation, a small P.D. is developed at the junction, known as barrier potential. The height of the barrier potential continuously increased by the recombination of electrons and holes and after some time further recombination of electrons and holes is not possible. The resultant device is known as diode.

The barrier potential for Ge diode is 0.3 V, while for Si diode it is 0.6 V.

The width of the depletion region depends on the voltage applied to the diode.

The width of depletion region is given by

$$\mathbf{W = 2\,\varepsilon\,(V_b + V_a)\,e\,Na\,Nd}$$

Where:

- W is the width of the depletion region in meters
- ε is the permittivity of the semiconductor material in farads per meter
- V_b is the barrier potential of the PN junction in volts
- V_a is the applied voltage in volts
- e is the electron charge in coulombs

- N_a is the doping concentration of the P-type material in atoms per cubic meter
- N_d is the doping concentration of the N-type material in atoms per cubic meter

The PN junction formula can be used to design PN junctions with specific properties. For example, the doping concentrations can be adjusted to control the width of the depletion region, and the applied voltage can be used to control the current flow through the PN junction

The diode conducts an electric current only in one direction during forward bias condition. PN junction diodes are versatile and important semiconductor devices that are used in a wide variety of applications.

Applications of PN junction Diode

The P-N junction diode has many applications.

- P-N junction diode in the reverse-biased configuration is sensitive to light from a range between 400nm to 1000nm, which includes VISIBLE light. Therefore, it can be used as a photodiode.
- It can also be used as a solar cell.
- P-N junction forward bias condition is used in all LED lighting applications.
- The voltage across the P-N junction biased is used to create Temperature Sensors, and Reference voltages.
- It is used in many circuits' rectifiers, varactors for voltage-controlled oscillators.

11. Write the diode equation and explain the term involve in it & give it significance?

The diode equation is a mathematical model that describes the behavior of a diode. It relates the voltage across the diode (Vd) to the current flowing through it (Id). The ideal diode equation is

$$\mathbf{Id = Io\ e^{\left(\frac{Vd}{\acute{\eta}Vt}-1\right)}}$$

Where:

Id is the diode current

Io is the reverse saturation current (a very small value)

Vd is the voltage across the diode

Vt = KT/q is the thermal voltage (approximately equal to 25.85 mV at room temperature 300 K)

ή is the ideality factor, also known as the quality factor, emission coefficient, or the material constant. (ή =1 for Ge & ή = 2 for SI)

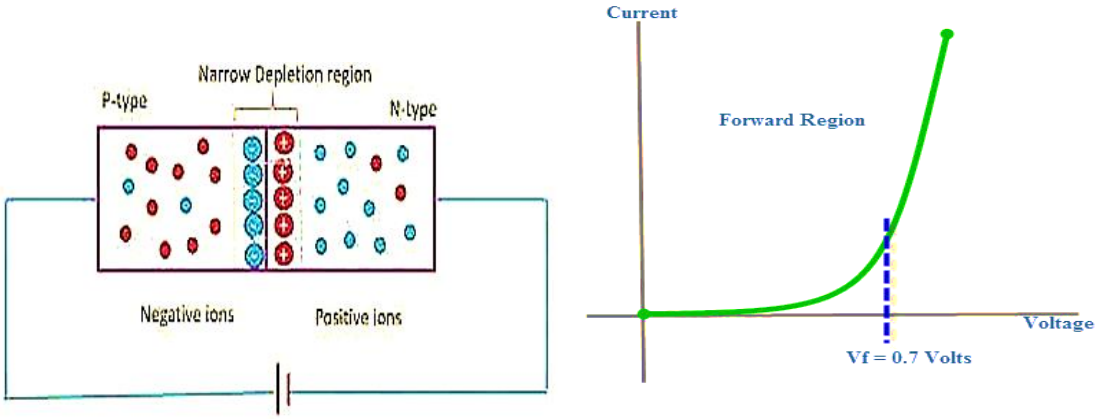
Thermal voltage $Vt = \frac{KT}{q} = \frac{T}{11600}$ volt

Important Points:

1. The diode equation is a non-linear equation, meaning that the current through the diode does not increase linearly with the voltage across it.
2. The thermal voltage (Vt) is a critical parameter in the diode equation, as it affects the shape of the current-voltage curve.
3. The diode equation is widely used in electronic circuit design and analysis, particularly in the study of diode circuits, rectifiers, and power supplies.

12. Explain forward or reverse characteristics of PN junction diode?

Forward Bias:



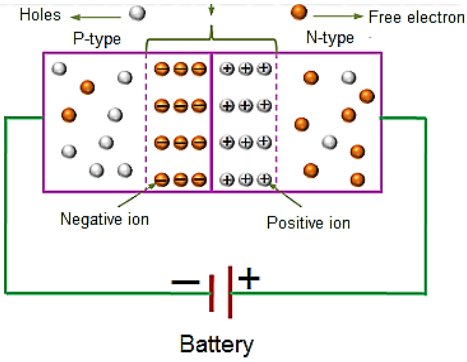
In forward bias, the p-type is connected with the positive terminal and the n-type is connected with the negative terminal. ith a battery connected this way, the holes in the P-type region and the electrons in the N-type region are pushed toward the junction. This reduces the width of the depletion zone.

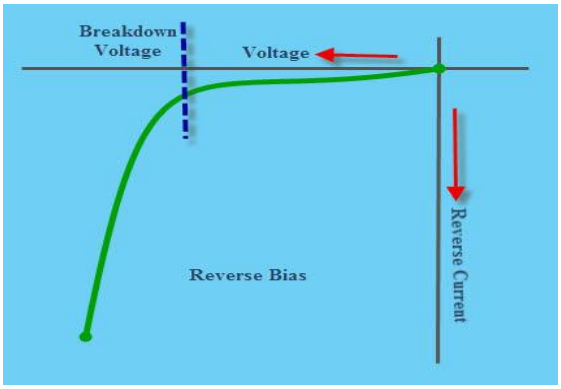
The positive potential applied to the P-type material repels the holes, while the negative potential applied to the N-type material repels the electrons. As electrons and holes are pushed toward the junction, the distance between them decreases. This lowers the barrier in potential. With increasing forward-bias voltage, the depletion zone eventually becomes thin enough that the zone's electric field cannot counteract charge carrier motion across the p–n junction, as a consequence reducing electrical resistance. The electrons that cross the p–n junction into the P-type material (or holes that cross into the N-type material) will diffuse in the near-neutral region. Therefore, the amount of minority diffusion in the near-neutral zones determines the amount of current that may flow through the diode.

The forward V-I characteristic of the P-N junction diode shows that the current grows exceptionally slowly at the beginning. The curve is nonlinear because the external voltage delivered to the p-n junction is used to overcome the potential barrier in this region. The potential

barrier is removed once the external voltage surpasses the possible barrier voltage and the p-n junction functions like an ordinary conductor. As a result, the curve AB climbs significantly as the external voltage rises, which is nearly linear.

Reverse Bias:





Connecting the P-type region to the negative terminal of the battery and the N-type region to the positive terminal corresponds to reverse bias. If a diode is reverse-biased, the voltage at the cathode is comparatively higher than the anode. Therefore, no current will flow until the diode breaks down. Because the p-type material is now connected to the negative terminal of the power supply, the 'holes' in the P-type material are pulled away from the junction, causing the width of the depletion zone to increase. Likewise, because the N-type region is connected to the positive terminal, the electrons will also be pulled away from the junction. Therefore, the depletion region widens, and does so increasingly with increasing reverse-bias voltage. This increases the voltage barrier causing a high resistance to the flow of charge carriers, thus allowing minimal electric current to cross the p–n junction. The increase in resistance of the p–n junction results in the junction behaving as an insulator.