# PHYSICS

## NEET and JEE Main 2020 : 45 Days Crash Course

# Semiconductor Electronics

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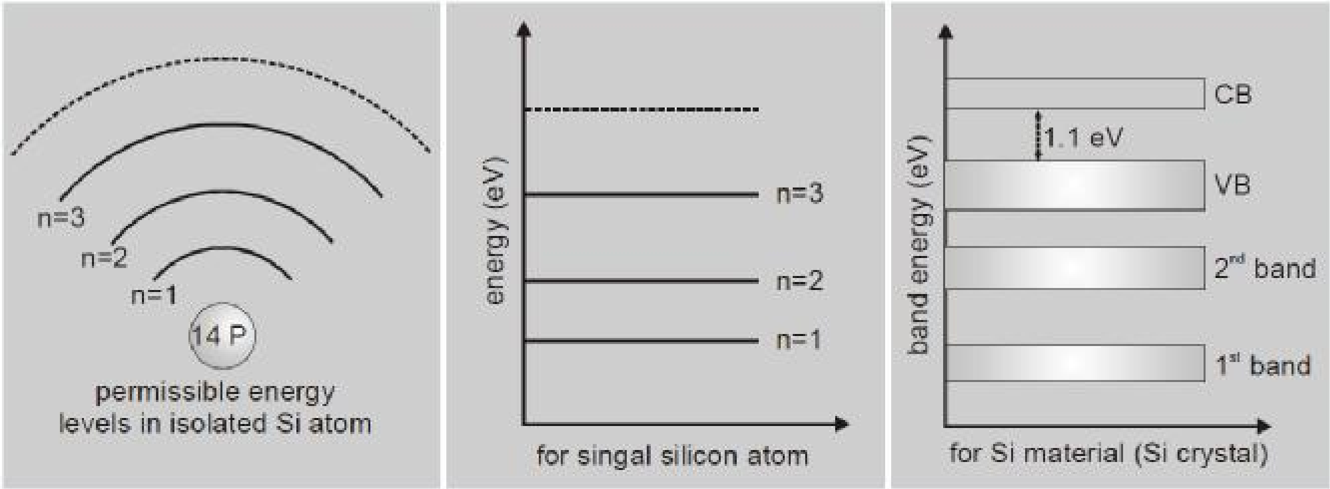
# Energy Bands in Solids




In an isolated atom electrons present in energy level but in solid, atoms are not isolated there is interaction among each other due to this energy level splited into different energy levels.

Quantity of these different energy levels depends on the quantity of interacting atoms.

Splitting of sharp and closely compact energy levels result into energy band.

This is decreate in nature.

Order of energy levels in a band is $10^{23}$ and their energy difference = $10^{-23}$ eV.

# Valence Band, Conduction Band and Forbidden Energy Gap

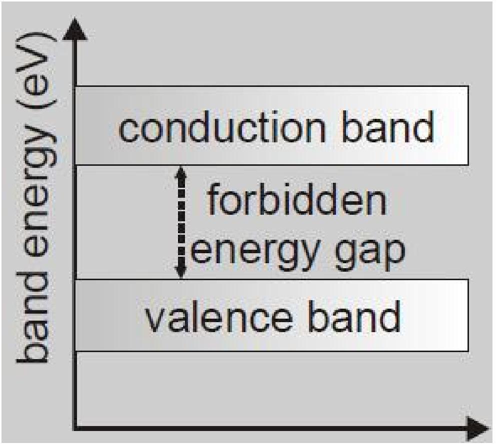
**Valence Band (VB)**

Range of energies possessed by valence electron is known as valence band.

(a) Have bonded electron

(b) No flow of current due to such electron

(c) Always fulfill by electron




**Conduction Band (CB)**

Range of energies possessed by free electron is known as conduction band.

(a) Also called empty band of minimum energy.

(b) In general Partially filled by electron.

(c) If conduction Band is empty, then conduction is not possible.

**Forbidden Energy gap (FEG) ($\Delta$Eg)**

Energy gap between conduction band and valence band, where no free electron can exist.

$$\Delta E_g = (C\ B)_{min} - (V\ B)_{max}$$

- Width of forbidden energy gap depends upon the nature of substance.
- Width is more, then valence electrons are strongly attached with nucleus
- Width of forbidden energy gap is represented in eV.
- As temperature increases forbidden energy gap decreases (very slightly).

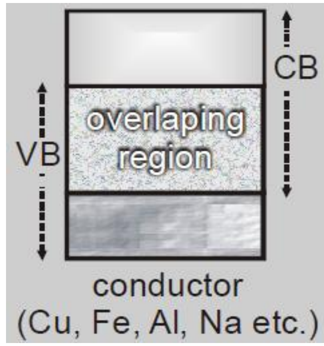
# Explanation of conductor, semiconductor and insulator

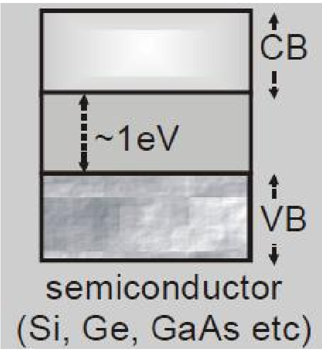
**Conductor**

In some solids conduction band and valence band are overlapping so there is no band gap between them, it means $\Delta E_g = 0$.

Due to this a large number of electrons available for electrical conduction and therefore its resistivity is low ($\rho = 10^{-2} - 10^{-8}\ \Omega m$) and conductivity is high [$\sigma = 10^{2} - 10^{8}\ (\Omega m)^{-1}$]

Such materials are called conductors. For example gold, silver, copper etc.




**Semiconductor**

In some solids a finite but small band gap exists ($E_g < 3eV$).

Due to this small band gap some electrons can be thermally exicited to "conduction band".

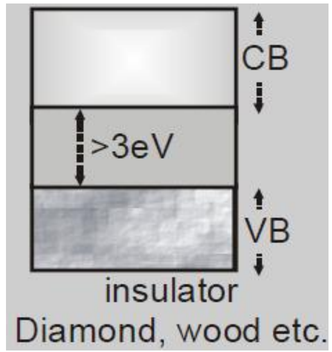
These thermally excited electrons can move in conduction band and can conduct current their resistivity and conductivity both are in medium range, $\rho = 10^{5} - 10^{0}\ \Omega\text{–m}$ and $\sigma = 10^{-5} - 10^{0}\ \Omega\text{–m}^{-1}$

**Insulator**

In some solids energy gap is large ($E_g > 3$ eV).

So in conduction band there are no electrons and so no electrical conduction is possible. Here energy gap is so large that electrons cannot be easily excited from the valence band to conduction band by any external energy (electrical, thermal or optical).

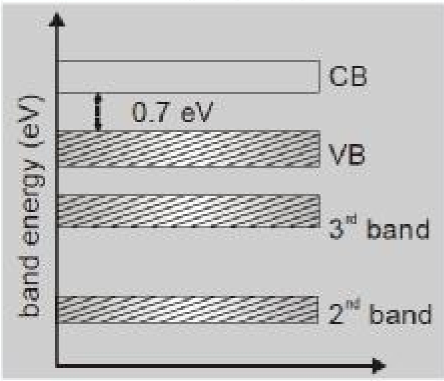
Such materials are called as "insulator". Its $\rho = 10^{8}\ \Omega\text{–m}$ & $\sigma = 10^{-8}\ (\Omega\text{–m})^{-1}$



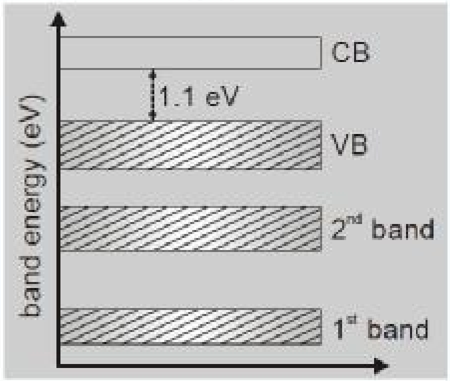
# Properties of Semiconductors

- Negative temperature coefficient ($\alpha$), with increase in temperature resistance decreases
- Crystalline structure with covalent bonding [Face centred cubic (FCC)]
- Conduction properties may change by adding small impurities
- Place in periodic table → IV group (Generally)
- Forbidden energy gap (0.1 to 3 eV)
- Charge carriers : electron and hole
- There are many semiconductors but few of them have practical application in electronics like

$Ge^{32}$ : 2, 8, 18, 4




$Si^{14}$ : 2, 8, 4

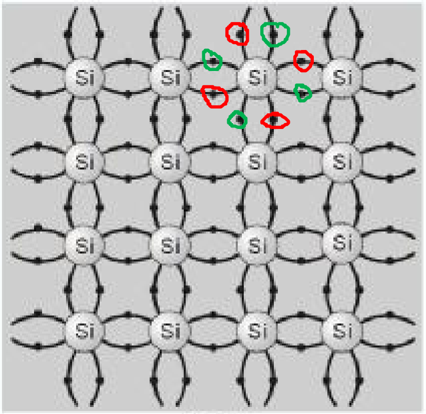



$R = R_0[1 + \alpha\Delta T]$

# Effect of Temperature

**At absolute zero kelvin temperature**

At this temperautre covalent bonds are very strong and there are no free electrons and semiconductor behaves as perfect insulator.

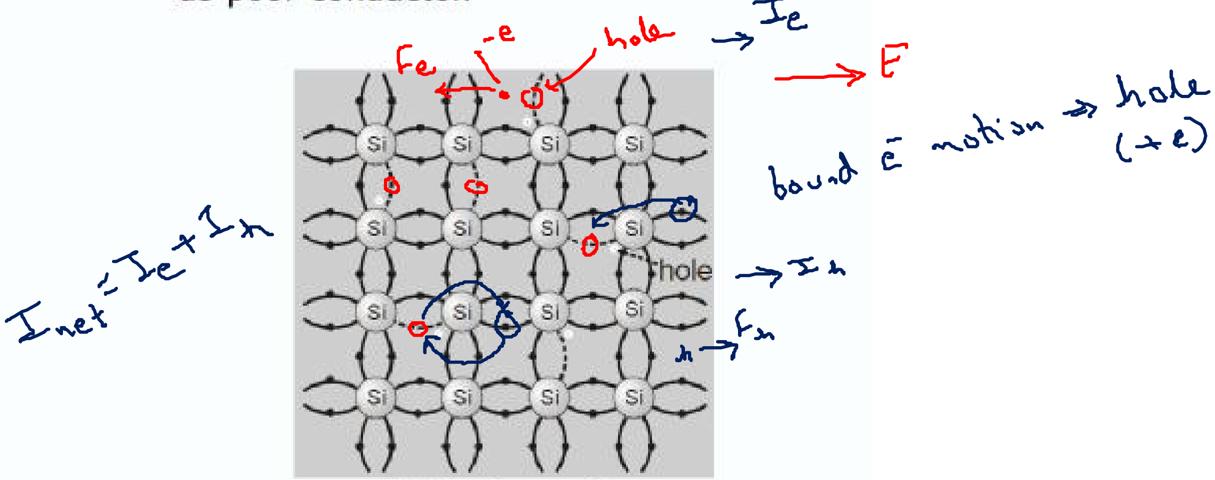



at 0 K

valence band fully filled | conduction band fully empty

**Above absolute temperature**

With increase in temperature some covalent bonds are broken and few valence electrons jump to conduction band and hence it behave as poor conductor.

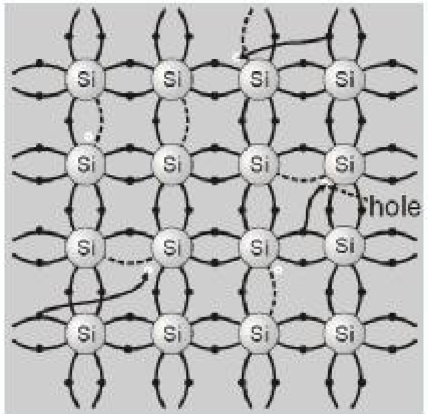


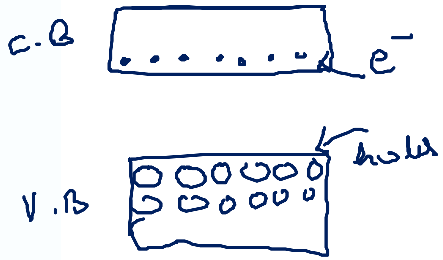

at higher temperature

valence band partially empty | conduction band partially filled

# Concept of holes in semiconductors

Due to external energy (temp. or radiation) when electron goes from valence band to conduction band (i.e. bonded electrons becomes free), vacancy of free $e^-$ create in valence band. This electron vacancy called as"hole"




Which have same charge as electron but positive, this positively charged vacancy moved randomly in semiconductor solid.

**Properties of holes :**

It is missing electron in valence band.

It acts as positive charge.

It is effective mass is more than electron.

It is mobility of hole is less than electron.

Hole acts as virtual charge, although there is no physical charge on it.

**Hole Current**

At room temperature, due to breaking of some Covalant bonds some free electrons are produced. By applying electric field current flow due to free electrons. This current called hole current.

$$\mu = \frac{v}{E}$$

# Effect of Impurity in Semiconductor

Doping is a method of addition of "desirable" impurity atoms to pure semiconductor to increase conductivity of semiconductor.

**GOLDEN KEY POINTS**

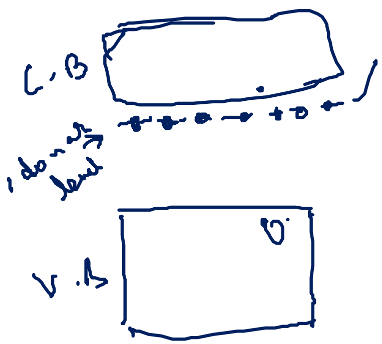
- The concentration of dopant atoms be very low, doping ratio vary from impure : pure :: 1 : $10^6$ to 1 : $10^{10}$ In general it is 1 : $10^8$
- The size of dopant atom (impurity) should be almost the same as that of crystal atom. So that crystalline structure of solid remain unchanged.

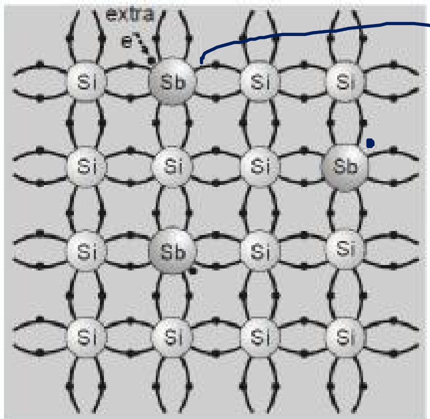
## CLASSIFICATION OF SEMICONDUCTOR

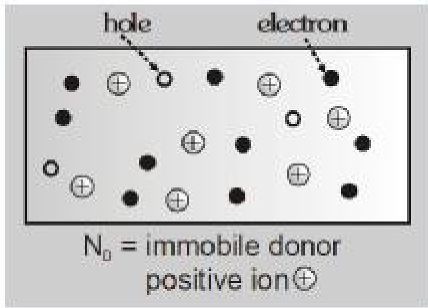
| Intrinsic semiconductor | Extrinsic semiconductor (doped semicondutor) | |
|---|---|---|
| | N-type | P-type |
| (pure form of Ge, Si)<br>$n_e = n_h = n_i$ | pentavalent impurity<br>(P. As, Sb)<br>donor impurity ($N_D$)<br>$n_e >> n_h$<br>$n_e \simeq N_D$ | trivalent impurity<br>(Ga, B, In, Al)<br>acceptor impurity ($N_A$)<br>$n_h >> n_e$<br>$n_h \simeq N_A$ |

# N Type Semiconductor

When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb, Bi) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free $e^-$ for conduction are called as Donor impurity ($N_D$). Here free $e^-$ increases very much so it is called as "N" type semiconductor. Here impurity ions known as "Immobile Donor positive Ion". "Free $e^-$"called as "majority" charge carriers and "holes" called as "minority" charge carriers.

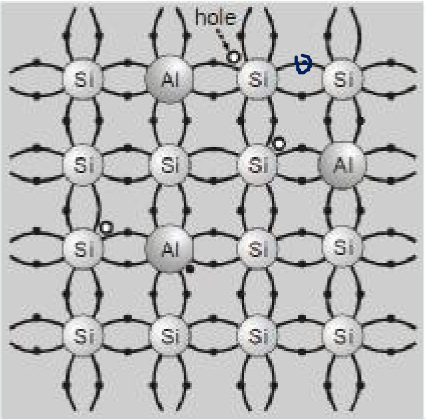


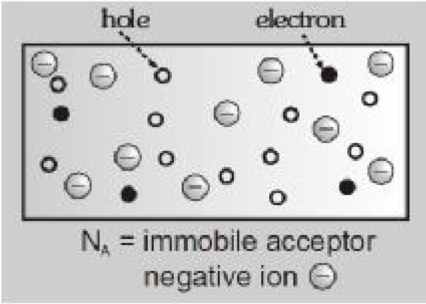



# P Type Semiconductor

When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In, Ga) then outer most three electrons of the valence band of impurity take part in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded $e^-$ from valance band are called as Acceptor impurity ($N_A$). Here holes increases very much so it is called as "P" type semiconductor here impurity ions known as "Immobile Acceptor negative Ion". Free $e^-$ are called as minority charge carries and holes are called as majority charge carriers.

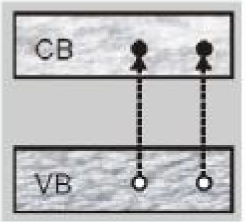


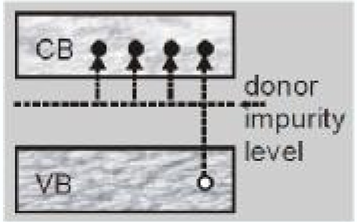



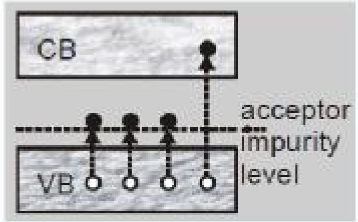

# Comparison Intrinsic & Extrinsic Semiconductor

| | | N-type | P-type |
|---|---|---|---|

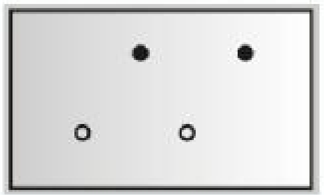
**1.**

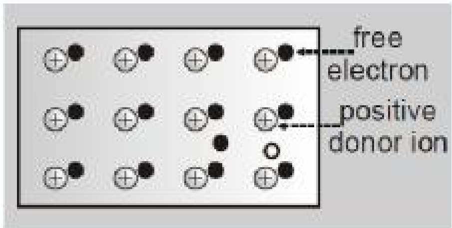


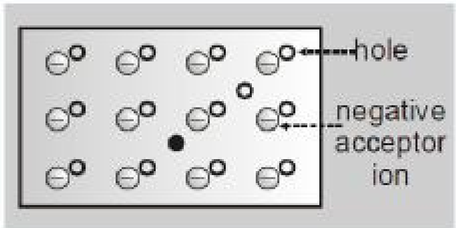




**2.**






| | | | |
|---|---|---|---|
| **3.** | Current due to electron and hole | Mainly due to electrons | Mainly due to holes |
| **4.** | $n_e = n_h = n_i$ ← intrinsic conc. | $n_h << n_e$ ($N_D \simeq n_e$) | $n_h >> n_e$ ($N_A \simeq n_h$) |
| **5.** | $I = I_e + I_h$ | $I \simeq I_e$ | $I \simeq I_h$ |
| **6.** | Entirely neutral | Entirely neutral | Entirely neutral |
| **7.** | Quantity of electrons and holes are equal | Majority - Electrons<br>Minority - Holes | Majority - Holes<br>Minority - Electrons |

# Mass Action Law

In semiconductors due to thermal effect, generation of free $e^-$ and hole takes place.

A part from the process of generation, a process of recombination also occurs simultaneously, in which free $e^-$ further recombine with hole.

At equilibrium rate of generation of charge carries is equal to rate of recombination of charge carrier.

The recombination occurs due to $e^-$ colliding with a hole, larger value of $n_e$ or $n_h$, higher is the probability of their recombination.

For intrinsic semiconductor $n_e = n_h = n_i$

Under thermal equilibrium, the product of the concentration '$n_e$' of free electrons and the concentration $n_h$ of holes is a constant.

Independent of the amount of doping by acceptor and donor impurities.

mass action law $\boxed{n_e \times n_h = n_i^2}$

For any type of semiconductor, in thermal eqlm.

$$\boxed{n_e \times n_h = n_i^2}$$

# Resistivity and Conductivity of Semiconductor

- **Conduction in conductor**

  Relation between current (I) and drift velocity ($v_d$)

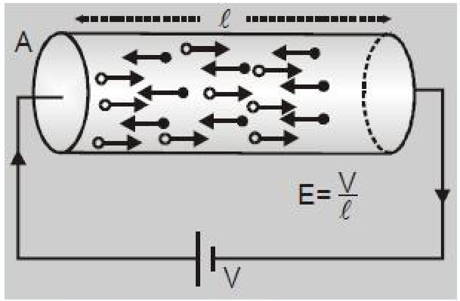
  $I = neAv_d$    n = number of electron in unit volume

  current density $J = \frac{I}{A}$ amp/m$^2$ $= nev_d$

  $\because$ drift velocity of electron $v_d = \mu E$    $\therefore$ $J = ne\mu E = \sigma E$

  Conductivity $\sigma = \mathbf{ne}\mu = 1/\rho$    $\rho$ = Resistivity

  | Mobility | $\mu = \frac{V_d}{E}$ |
  |---|---|




$E = J\rho$

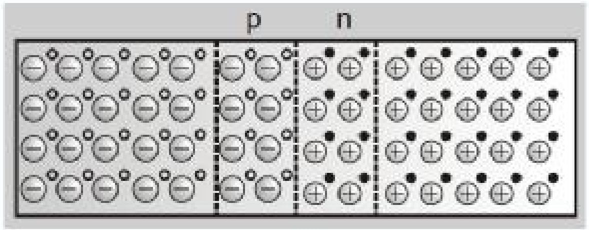
$J = \sigma E$

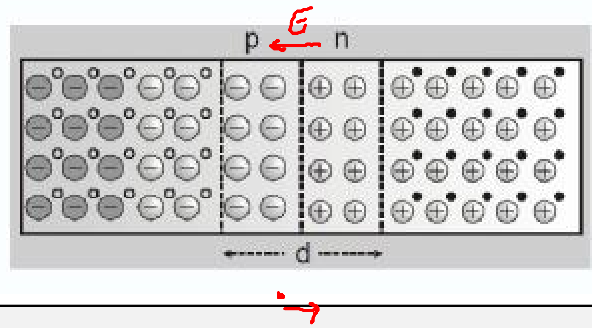
- **Conduction in Semiconductor**

| **Intrinsic semiconductor** | **P - type** | **N - type** |
|---|---|---|
| $n_e = n_h$ | $n_h >> n_e$ | $n_e >> n_h$ |
| $J = ne[v_e + v_h]$ | $J \cong e\,n_h v_h$ | $J \cong e\,n_e v_e$ |
| $\sigma = \frac{1}{\rho} = en[\mu_e + \mu_h]$ | $\sigma = \frac{1}{\rho} \cong e\,n_h \mu_h$ | $\sigma = \frac{1}{\rho} \cong e\,n_e \mu_e$ |

# P-N Junction

Given diagram shows a P–N junction immediately after it is formed. P region has mobile majority holes and immobile negatively charged impurity ions. N region has mobile majority free electrons and immobile positively charged impurity ions. Due to concentration difference diffusion of holes starts from P to N side and diffusion of e⁻ s starts N to P side. Due to this a layer of only positive (in N side) and negative (in P–side) started to form which generate an electric field (N to P side) which oppose diffusion process, during diffusion magnitude of electric field increases due to this diffusion it gradually decreased and ultimately stopes. The layer of immobile positive and negative ions, which have no free electrons and holes called as **depletion layer** as shown in diagram.



# P-N Junction

**GOLDEN KEY POINTS**

◎ **Width of depletion layer ≅ $10^{-6}$ m**

(a) As temperature is increased depletion layer also increases.

(b) P-N junction → unohmic, due to nonlinear relation between I and V.

◎ **Potential Barrier or contact potential**

for Ge → 0.3 V, for Si → 0.7 V

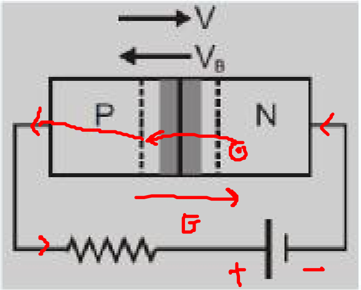
◎ Electric field, produce due to potential barrier $E = \frac{V}{d} = \frac{0.5}{10^{-6}} \Rightarrow E \cong 10^5$ V/m

This field prevents the respective majority carrier from crossing barrier region

# Forward and Reverse biased P-N Junction

**Forward Bias**

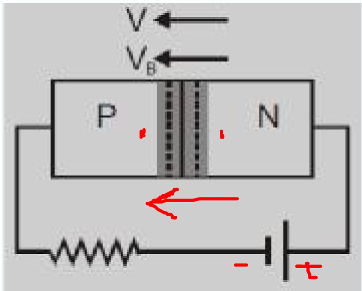
If we apply a voltage "V" such that P–side is positive and N–side is negative as shown in diagram. The applied voltage is opposite to the junction barrier potential. Due to this effective potential barrier decreases, junction width also decreases, so more majority carriers will be allowed to flow across junction. It means the current flow in principally due to majority charge carries and is large (mA) called as forward Bias.




$R_f \approx 10\Omega$

**Reverse Bias**

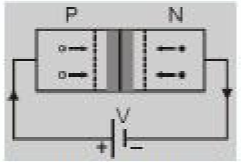
If we apply a voltage "V" such that P–side is negative and N–side is positive as shown in diagram. The applied voltage is same side of to the junction barrier potential. Due to this effective potential barrier increased junction width also increased, so no majority carriers will be allowed to flow across junction. Only minority carriers will drifted. It means the current flow in principally due to minority charge carries and is very small (mA) called as reversed Bias.



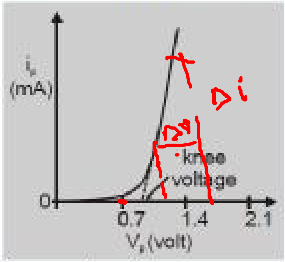
# Comparison of Forward and Reverse bias

**Forward Bias**

P → positive
N → negative




1. Potential Barrier reduces
2. Width of depletion layer decrease
3. P-N Junction Provide very small resistance
4. Forward current flow in circuit
5. Order of forward current in milli amp.
6. Mainly flow majority current flows.
7. Forward characteristic curves.




8. Forward resistance

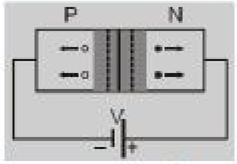
$$R_f = \frac{\Delta V_f}{\Delta I_f} \cong 100\Omega$$

9. Knee or cut in voltage

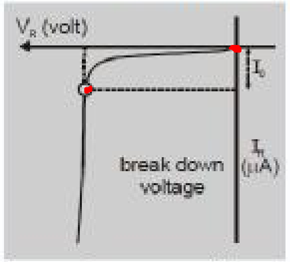
Ge → 0.3 V , Si → 0.7 V

**Reverse Bias**

P → negative
N → positive




1. Potential Barrier increases.
2. Width of depletion layer increases.
3. P-N Junction Provide high resistance
4. Very small current flow.
5. Order of current in micro amp. (Ge) or Nano amp. (Si).
6. Mainly minority current flows
7. Reverse characteristic curve




8. Reverse resistance

$$R_B = \frac{\Delta V_B}{\Delta I_B} \cong 10^6\Omega$$

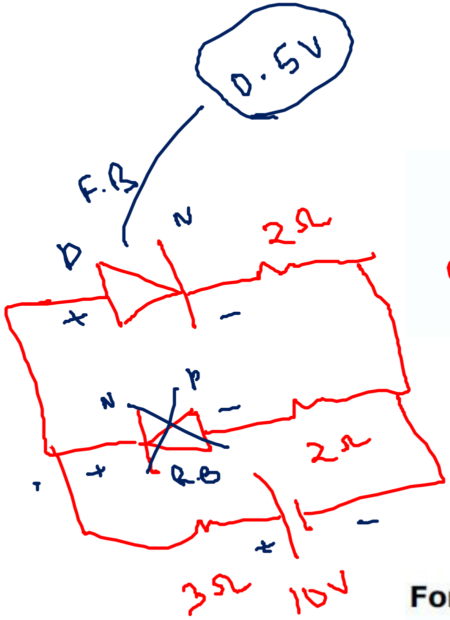
9. Breakdown voltage

Ge → 25 V, Si → 35 V

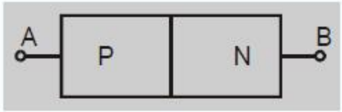
# Zener and Avalanche Break down

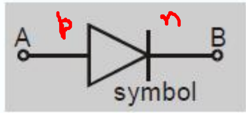
| **Zener Break down** | **Avalanche Break down** |
|---|---|
| Where **covalent bonds** of depletion layer, **its self break,** due to high electric field of very high Reverse bias voltage. | Here covalent bonds of depletion layers are bro ken by **collision of "Minorities"** which aquire high kinetic energy from high electric field of very-very high reverse bias voltage. |
| This phenomena predominant | This phenomena predominant |
| (i) At lower voltage after "break down" | (i) At high voltage after breakdown |
| (ii) In P – N having "High doping" | (ii) In P – N having "Low doping" |
| (iii) P – N Jn. having thin depletion layer | (iii) P – N Jn. having thick depletion layer |
| Here P – N not demage paramanently | Here P – N damage peramanentaly due ot ' |
| "In D.C voltage stablizer zener phenomena is used". | "Heating effect" due to abruptly increament of minorities during repeatative collisoins. |

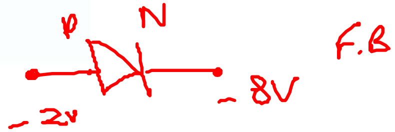
# P-N Junction Diode

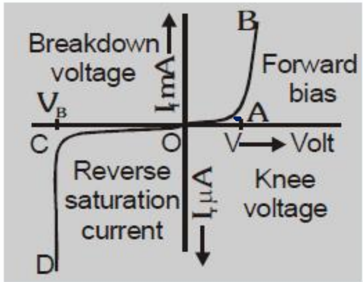



Current through battery

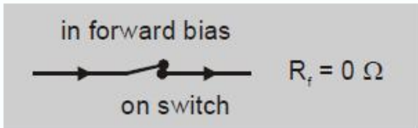


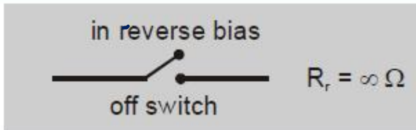



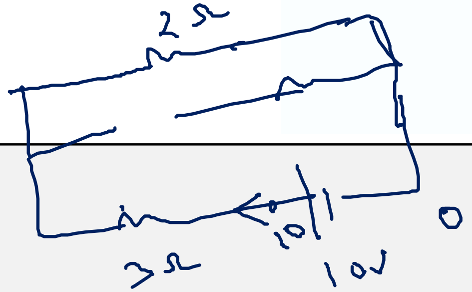




**For Ideal Diode**



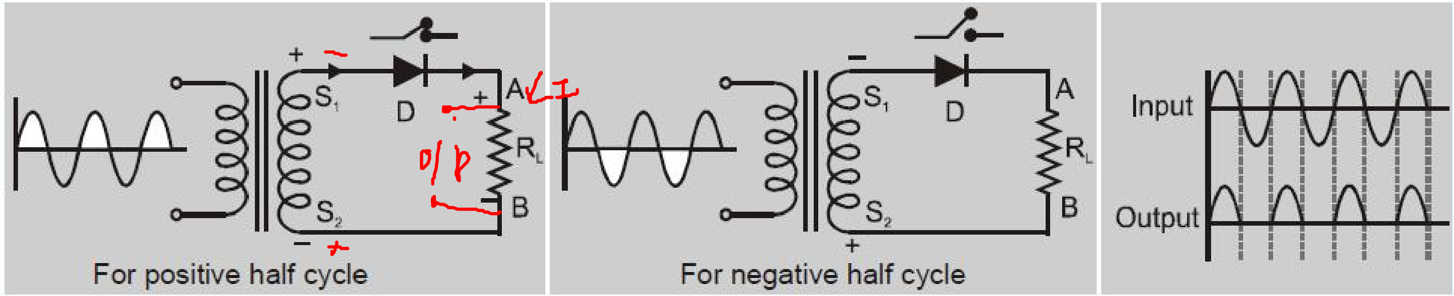

$I = \frac{10}{5} = 2A$

$10 - 0.5 = 9.5V$, $\frac{9.5V}{5}$

# Rectifier

It is device which is used for converting alternating current into direct current.

**Half wave rectifier**

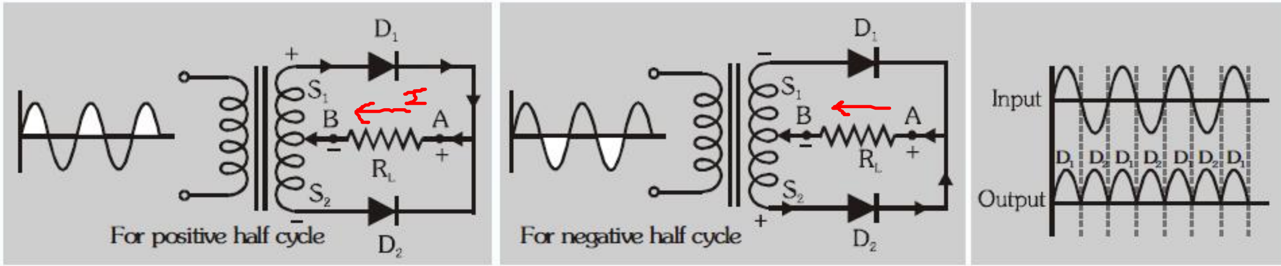



During the first half (positive) of the input signal. Let $S_1$ is at positive and $S_2$ is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance $R_L$ and output voltage is obtained. During the second half (negative) of the input signal, $S_1$ and $S_2$ would be negative and positive respectively. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output voltage. Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output.

# Full Wave Rectifier

**Full wave rectifier**

When the diode rectifies the whole of the AC wave, it is called full wave rectifier. Figure shows the experiemental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary a transformer. The output signal appears across the load resistance $R_L$.




During the positive half of the input signal :

Let $S_1$ positive and $S_2$ negative.

In this case diode $D_1$ is forward biased and $D_2$ is reverse biased. So only $D_1$ conducts and hence the flow of current in the load resistance $R_L$ is from A to B.

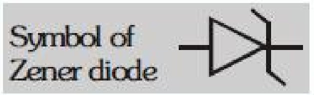
During the negative half of the input signal :

Now $S_1$ is negative and $S_2$ is positive. So $D_1$ is reverse-biased and $D_2$ is forward biased. So only $D_2$ conducts and hence the current flows through the load resistance $R_L$ from A to B.

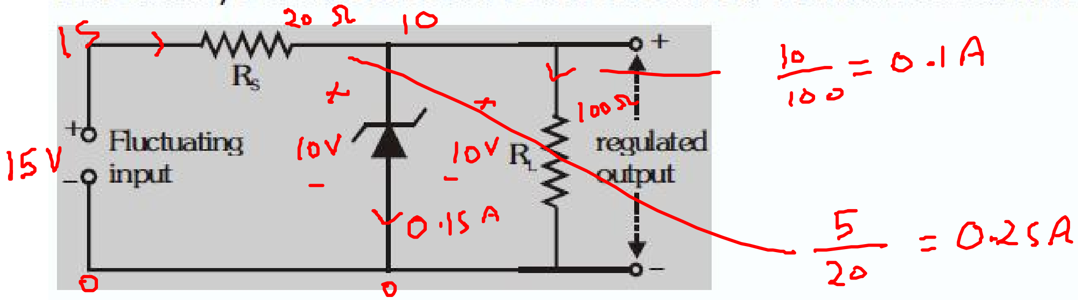
It is clear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and full wave rectification is obtained.

# Zener Diode

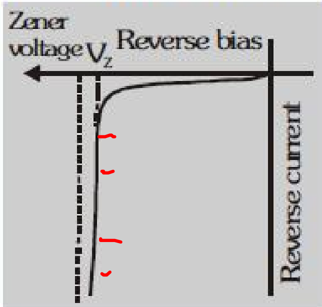
A properly doped crystal diode which has sharp break down voltage is known as Zener diode.




It is always connected in reverse biased condition manner. Used as a voltage regulation




In forward biased it works as a simple diode.



# Special purpose Diodes

- **Photodiode**
  A junction diode made from "light or photo sensitive semiconductor" is called a "photo diode" its symbol . When light of energy "hν" falls on the photodiode (Here hν > energy gap) more electrons move from valence band, to conduction band, due to this current in circuit of photodiode in **"Reverse bias"**, increases. As light intensity is increased, the current goes on increases so photo diode is used, **"to detect light intensity"** for example it is used in "Vedio camera".
- **Light emitting diode (L.E.D)**
  When a junction diode is **"forward biased"** energy is released at junction in the form of light due to recombination of electrons and holes. In case of Si or Ge diodes, the energy released is in infra-red region.
  In the junction diode made of GaAs, InP etc energy is released in visible region such a junction diode is called "light emitting diode" (LED) Its symbol 
- **Solar cell**
  Solar cell is a device for converting solar energy into electrical. A junction diode in which one of the P or N sections is made very thin (So that the light energy falling on diode is not greatly asorbed before reaching the junction) can be used to convert light energy into electric energy such diode called as solar cell. Its symbol 
  (i) It is operated into photo voltaic mode i.e., generation of voltage due to the bombardment of optical photon.
  (ii) **No external bias is applied.**
  (iii) Active junction area is kept large, because we are intrested in more power. Materials most commonly used for solar cell is Si, As, Cds, CdTe, CdSe, etc.