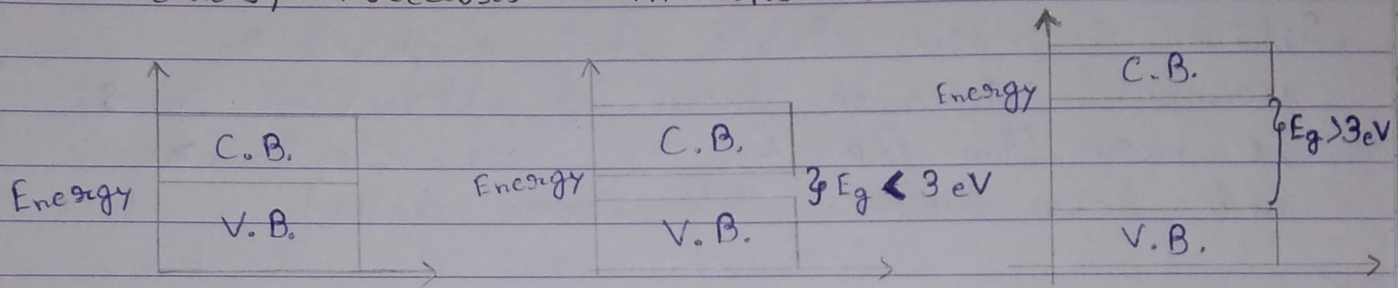
22/12/21

Unit-1

*) Classification on the basis of energy bands

Classification of metals, non-metals and semi-conductors on the basis of energy bands.

Metals/Conductors Semi-Conductors Non-metals/Insulator



$E_g = 0$

$E_g = kt$ t → temperature
k → Boltzman Constant

Conductivity (σ)

(i) For metals
$\sigma \cong 10^2 - 10^3\ Sm^{-1}$

(ii) For insulators
$\sigma = 10^{-11} - 10^{-19}\ Sm^{-1}$

(iii) For semi-conductors
$\sigma = 10^5 - 10^{-6}\ Sm^{-1}$

→ First LED bulb was built with Ga, As

$E_g = 1.21 - 3.6 \times 10^{-4}\,T$ eV (For Si) T → Temp. in Kelvin

$E_g = 0.785 - 2.23 \times 10^{-4}\,T$ eV (For Ge)

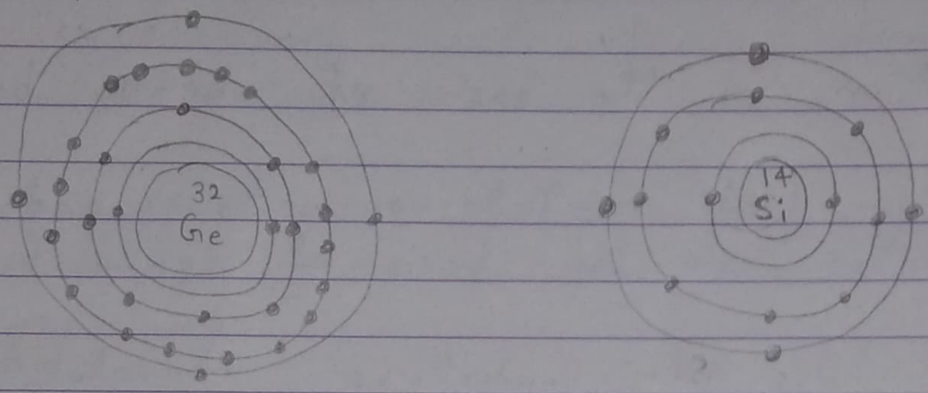
At room temp. i.e. 27°C (300 K)

$E_g = 1.12$ eV (For Si)

$E_g = 0.785$ eV (For Ge)

Q) Why silicon is used in abundance?

A)

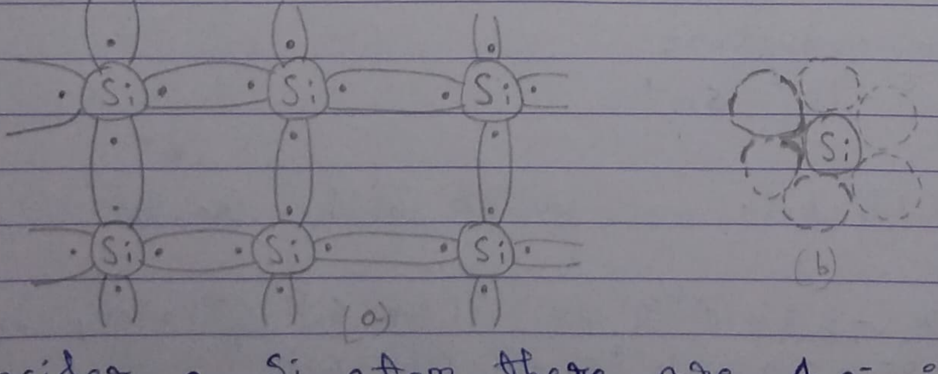


Silicon is more stable when compared to germanium because force of attraction in Si is more than Ge (due to less electrons and less distance b/w inner shells)

*) Intrinsic Semiconductors

Semiconductors in their pure form without doping $\frac{1}{100}$ million part of impurities which is very less.

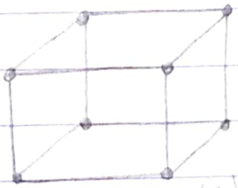
*) Crystal Structure of intrinsic semiconductors



(a) Consider a Si atom, there are 4 e^- in its outer shell thus each forms a covalent bond ~~forms~~ with neighbouring atoms. This sharing of e^- from a bond with neighbouring atom.

(b) The atom align themselves to form a 3D pattern called crystal which consists of a repetitive occurence in 3D unit cell.

(c) This unit cell is in the form of tetrahedron with atom at each vertex.

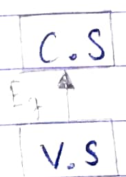


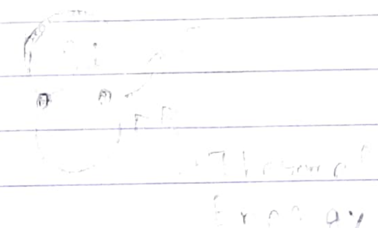
(c)

→ An intrinsic semiconductor behave as a perfect insulator at room temperature.

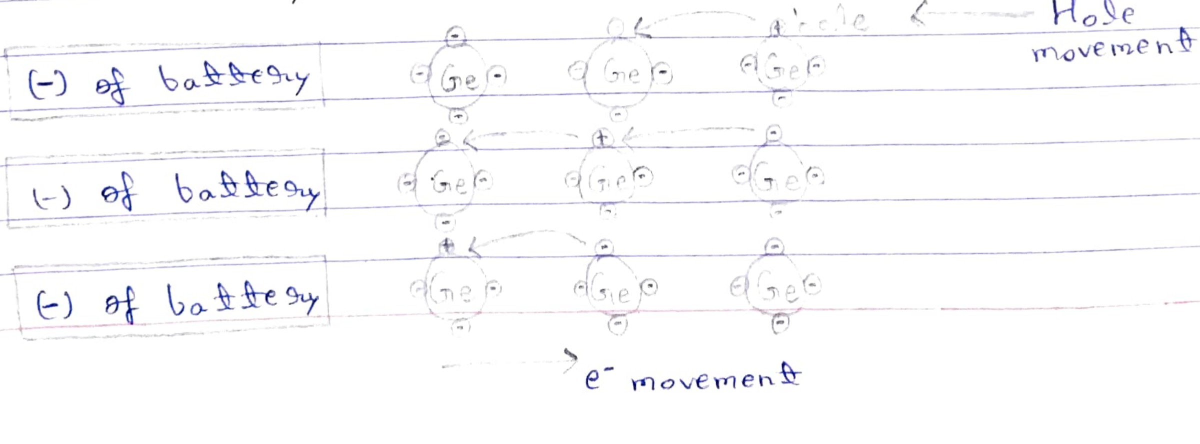
*) Charge carriers in intrinsic semiconductor

① At room temp., no. of valence e^- absorb the thermal energy due to which they break the covalent bond and become free e^-.





*) Conduction by e^- and holes in intrinsic semiconductors



Due to thermal agitation, e^- and holes are generated and move randomly therefore it does not constitute any current.
Consider a battery is connected under the influence of applied voltage, they have a motion of e^- and holes in one particular direction causing flow of current.

Total Current = Electron current + Hole Current

*) Extrinsic Semiconductors

- The process of adding other materials to the crystals of intrinsic semiconductor in order to improve its conductivity is called doping.
- The impurity added is called dopant.
- Doped semi-conductor material is called extrinsic semiconductor.

*) Types of impurities

① Pentavalent atom

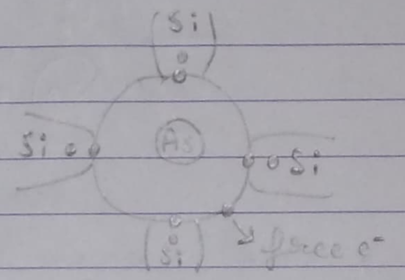
[having 5 valence e^- & when this]

These are impurity material added to intrinsic semiconductor, when they are added it is called donor doping as each donates one free e^- to an intrinsic material such an impurity is called donor impurity. E.g., Arsenic, Bismuth, Antimony & Phosphorus.
This creates an extrinsic semiconductor with large no. of free e^- called as n-type.

② Trivalent Atom

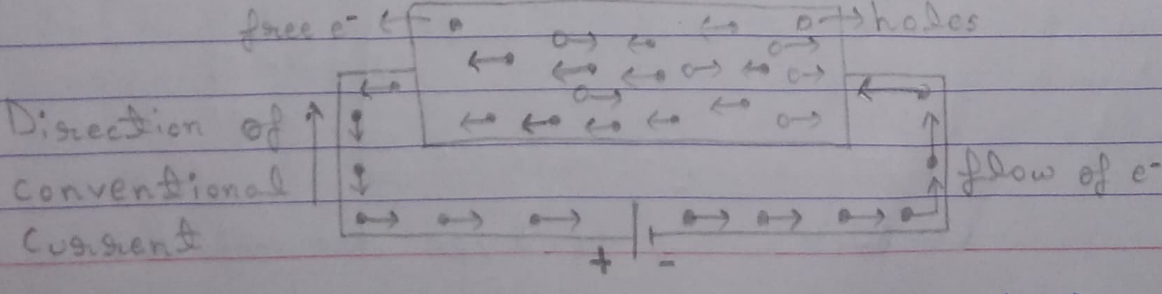
These are impurity material having three valence e^-, the impurity is called acceptor impurity. When added to intrinsic semiconductor, it creates more holes and ready to accept an e^-. Hence, doping is called ~~of~~ acceptor doping.
E.g. ⇒ Al, Ga, In, B, etc.
This creates an extrinsic semiconductor, with large no. of holes called as p-type.

*) n-type semiconductor



Pentavalent atom added to pure semi-conductor result in a free e^- and hence called n-type semiconductor.

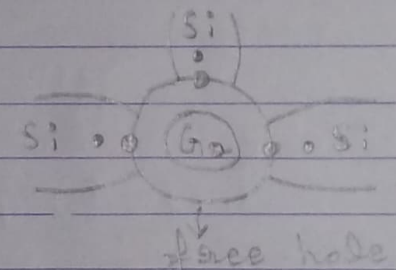
Working :- Consider the working of semi-conductor material by adding As. Four of the valence e^- of As atom are ~~called also~~ able to form covalent bonds with neighbouring Si atoms.
The fifth e^- is free, this enters conduction band. Such n-type material is shown in the diagram.



Conduction in n-type semiconductor

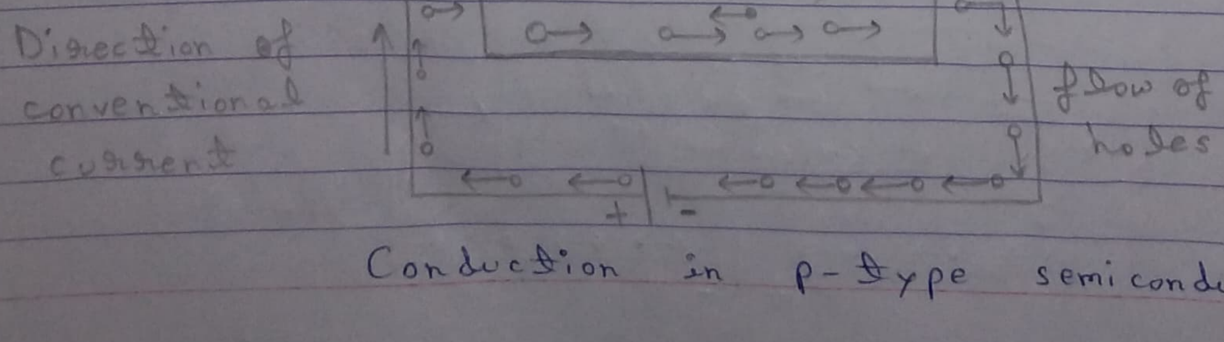
When voltage is applied to n-type semiconductor, the free e^- due to added impurity move in the direction of (+) terminal of voltage applied.
This constitute a current which is predominantly due to free e^-.
Thus,
in n-type semiconductor, majority carrier → free e^-
minority carrier → free holes

*) p-type semiconductor



When a small amount of trivalent impurity is added to pure semi-conductor, it is called p-type semiconductor.

Working :- Consider the formation of a p-type semi-conductor by adding Ga, three valence e^- are able to form covalent bond with neighbouring Si atoms, leaving one free hole.
This p-type material is shown in the diagram-



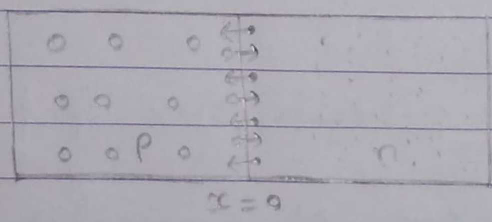
Conduction in p-type semiconductor

When voltage is applied to p-type semi-conductor, the holes due to the added impurity move in the direction of (-) terminal of voltage applied.
This constitute a current which is predominantly due to holes.
Thus,
in p-type semiconductor, majority carriers → free holes
minority carriers → free e^-

*) p-n junction

Two materials p-type and n-type chemically combined with a fabrication technique to form a p-n junction.
E.g.: Diode, transistors, etc.

*) Unbiased p-n diode

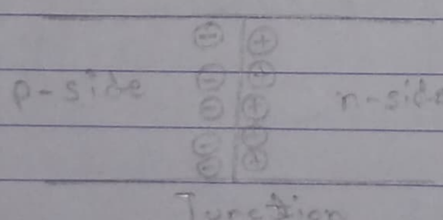


If in a given material, doping is not uniform, then at one place large no. of charge carrier exist, while at other place, small no. of charge carrier exist.
In a high charge carrier conc. area, all charge carriers start moving from high conc. area in order to achieve uniform conc. all over the material.
This process is known as diffusion.

Rate of diffusion depend on:-
① Type of material
② Conc. of material

*) Formation of a depletion region

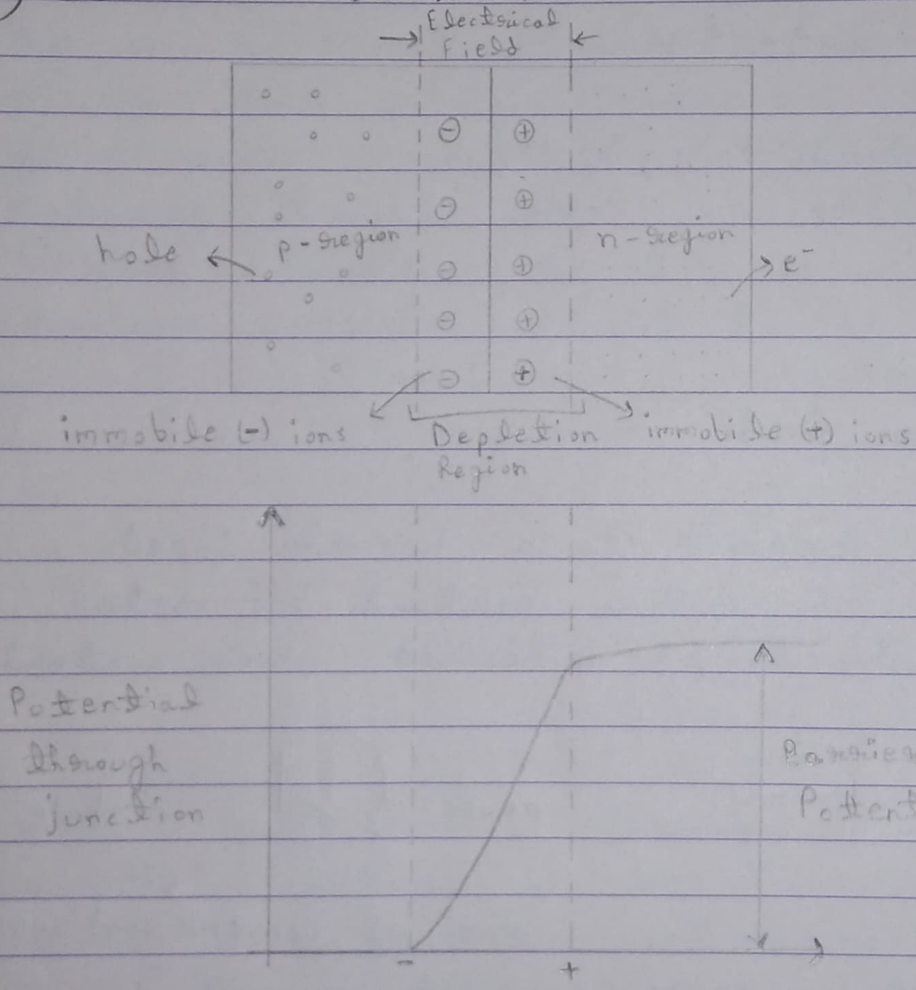
① As hole enters the n-region, they find number of donor atoms.
② The holes recombine with donor atoms.
③ As donor atoms accept additional holes, they become (+) charged immobile ions.
④ This happens immidiately when holes cross the junction and hence no. of (+) charged immobile ions get formed near the junction of n-type.



① As e^- enters the p-region, they find no. of acceptor atoms.
② The e^- recombine with the acceptor atom.
③ As acceptor atom donate additional e^-, they form (-) charged immobile ions.
④ This happens immediately when e^- cross the junction.

Thus, in thermal equilibrium condition, in the region near the junction, there exist a wall of (-) immobile charge on p-side & (+) immobile charge on n-side. As there is no mobile charge carrier, such a region is depleted of free charge carrier and hence called depletion region or depletion layer. This is also called as space charge region. The depletion region is very thin, upto one micron (1×10^{-6} m).

*) Barrier Potential



- Due to immobile (+) charge on n-side and (-) charge on p-side, there exist an electric field across the junction.
- This creates potential difference across the junction known as barrier potential, junction potential, cut-in potential and built-in potential.

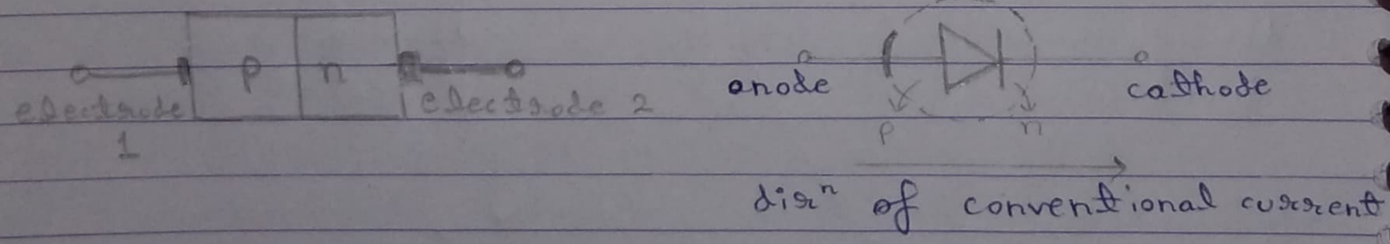
Barrier potential depend upon :-

1. Type of S.C.
2. Donor impurity added
3. Acceptor impurity added
4. Temperature
5. Intrinsic Concentration

Barrier potential → V_j, V_o, V_r
expressed in volts
For Si → 0.6 V
For Ge → 0.2 V

*) p-n junction diode

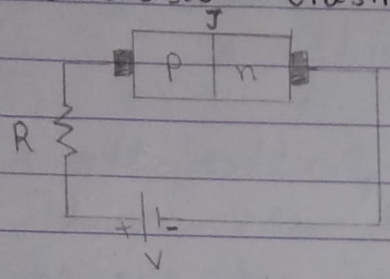
A metal is applied to a heavely doped n & p type S.C. such a contact b/w metal and heavely doped S.C. is called ohmic contact.

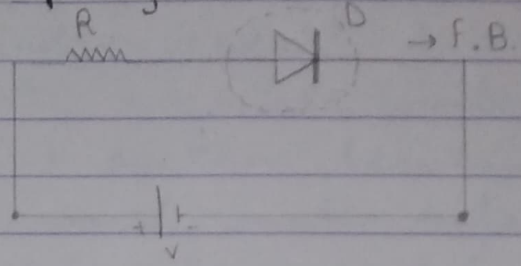


Properties :- ① It conducts current equally in both the directions.
② The drop across the contact is very small which does not affect the performance of device.

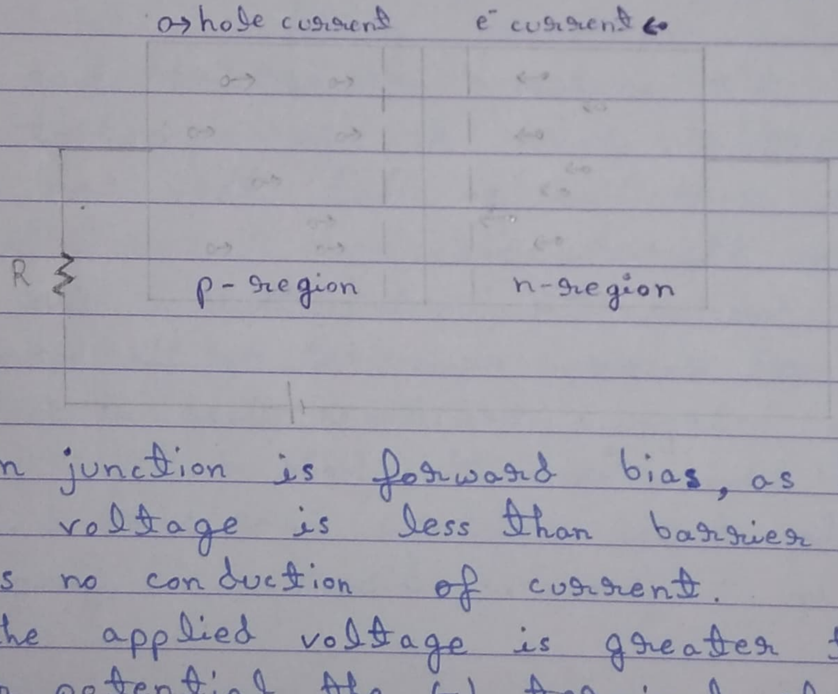
Two types of biasing of a p-n junction diode:-
1. Forward biasing
2. Reverse biasing

① Forward biasing of a p-n junction diode





If an external DC Voltage is connected in such a way that p-region connected to (+) terminal & n-region connected to (−) terminal of the voltage, then it is called forward biasing.
Current limiting resistor is used to limit the maximum possible current to the p-n junction diode.



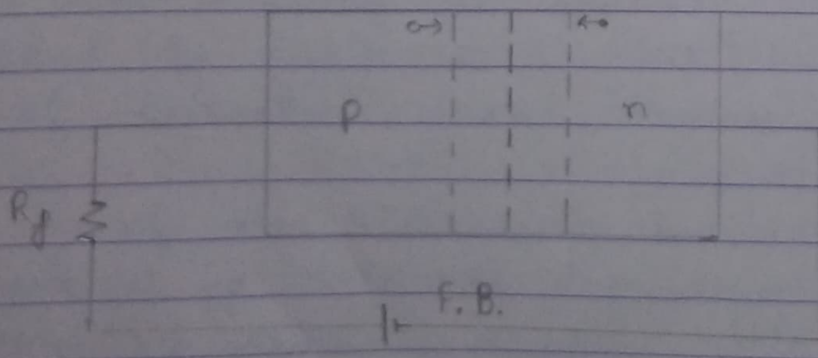
When p-n junction is forward bias, as long as applied voltage is less than barrier potential, there is no conduction of current.
When the applied voltage is greater than barrier potential, the (−) terminal of battery pushes the e^- against barrier potential from n-region to p-region.
Similarly, (+) terminal pushes the hole from p-region to n-region i.e. holes get repelled by (+) terminal and cross junction against barrier potential.

Thus, the applied voltage overcome the barrier potential thereby reducing the width of depletion region.
As forward voltage is increased further, the depletion region become very much narrow such that large no. of majority charge carriers can cross the junction.
This constitute a current known as forward current.

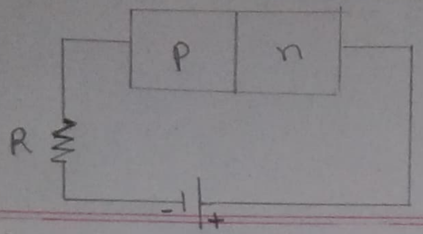
Affect on depletion region → become narrow.

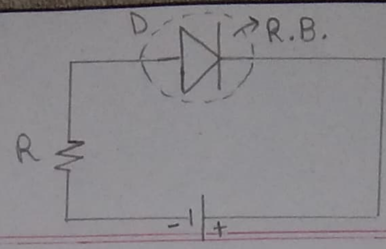
Effect of barrier potential

Under the infuence of applied bias voltage, the free e^- gets energy equivalent to the barrier potential so that they can easily overcome the barrier.
While crossing the junction, these e^- give up the amount of energy equivalent to the barrier potential.
Due to internal resistance, there is an additional voltage drop across the diode.
Thus, the total voltage drop access a p-n junction diode in a forward direction is given by-



$$V_{F.B.} = V_{r} + I_f R_f$$



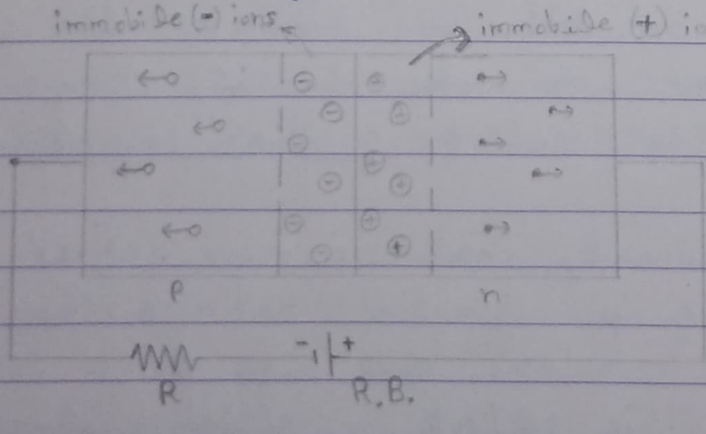


(2) * Reverse biasing of a p-n junction diode

- The (-) terminal attracts hole in the region away from the junction.
- The (+) terminal attracts e^- in the region away from the junction.

- No charge carrier is able to cross the junction.
- The depletion region widens creating more (+) ion in n-region and more (-) ion in the p-region.
- Reverse bias increases.
- Barrier potential also increases.
- Reverse current flows due to minority charge carrier which are small in number hence reverse bias current is very small.

The generation of minority charge carrier depends on temperature and not on applied reverse bias. Thus, reverse current depends upon the thermal generation.



For constant temp. reverse current is almost constant and reaches a saturation value I_o.

*) Breakdown in reverse bias

Though the reverse saturation current (I_o) is not dependent on applied reverse voltage, yet if reverse voltage if increased above particular value, large reverse current can flow damaging the diode.

These contribute to two effects-

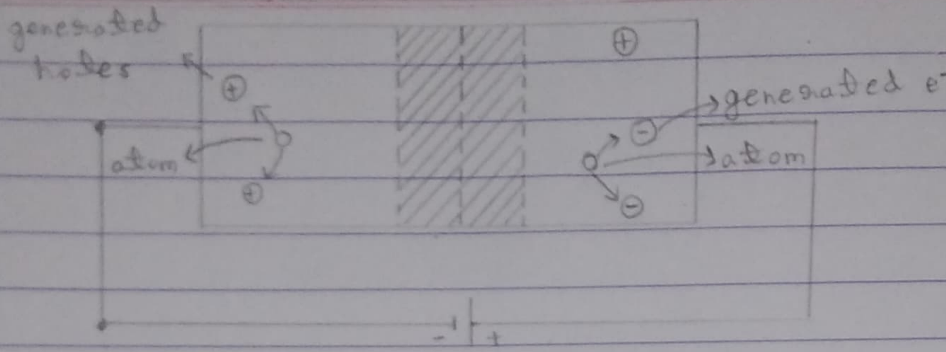
① Avalanche's breakdown effect

② Zener breakdown effect

*) Avalanche's Breakdown effect

Though reverse current is not dependent on reverse voltage, if reverse voltage increases, velocity of minority charge carriers also increase. Due to the K.E. associated with the minority carriers, more minority charge carriers are created on the collision with the atoms. This allows e^- to break the covalent bond thereby generating more e^- which get accelerated on reverse voltage generating more and more minority charge carriers. This effect is called carrier multiplication.

Large no. of minority carriers move across the junction breaking p-n junction barrier. These large no. of minority carriers give rise to a very high reverse current. This effect is called avalanche's effect and voltage is called reverse breakdown voltage.



*) Zener breakdown effect

The breakdown of p-n junction may occur because of one more effect. When a p-n junction is heavily doped, depletion region is very narraw. Under the reverse bias, the electric field across the depletion region is very intense.

$$E = \frac{V}{d}$$

- $E \rightarrow$ very intense
- $V \rightarrow$ Reverse voltage (very high)
- $d \rightarrow$ Width of depletion region (very narrow)

Such an intense electric field is enough to pull e^- out of valence bond of the stable atom. Such creation of e^- is due to the zener effect and the mechanism is called zener breakdown mechanism.