ELECTRONICS

LOGIC GATES

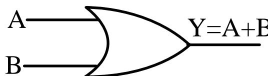
Introduction:

- A logic gate is a digital circuit which is based on certain logical relationship between the input and the output voltages of the circuit.
- The logic gates are built using the semiconductor P-N junction diodes and transistors.
- Each logic gate is represented by its characteristic symbol.
- The operation of a logic gate is indicated in a table, known as truth table. This table contains all possible combinations of inputs and the corresponding outputs.
- A logic gate is also represented by a Boolean algbraic expression. Boolean algebra is a method of writing logical equations showing how an output depends upon the combination of inputs. Boolean algebra was invented by George Boole.

Basic Logic Gates

There are three basic logic gates. They are
(1) OR gate (2) AND gate, and (3) NOT gate

- **The OR gate:-** The output of an OR gate attains the state 1 if one or more inputs attain the state 1.



Logic symbol of OR gate

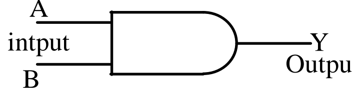
The **Boolen expression** of OR gate is $Y = A + B$, read as Y equals A ORing B.

Truth table of a two input OR gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

- **The AND gate:-** The output of an AND gate attains the sate 1 if and only if all the inputs are in state 1.

Logic symbol of AND gate



The **Boolean expression** of AND gate is $Y = A.B$

It is read as Y equals ANDing B

Truth table of a two-input AND gate

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

- **The NOT gate :** The output of a NOT gate attains the state 1 if and only if the input does not attain the state 1.

Logic symbol of NOT gate A —▷o— Y

The **Boolean expression** is $Y = \overline{A}$, read as Y equals NOT A.

Truth table of NOT gate

A	Y
0	1
1	0

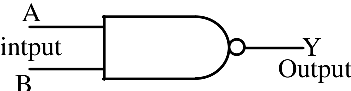
'NOT gate have only one input'

Combination of Gates:

The three basic gates (OR, AND and NOT) when connected in various combinations give us logic gates such as NAND, NOR gates, which are the universal building blocks of digital circuits.

- **The NAND gate:**

Logic symbol of NAND gate



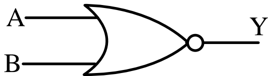
The **Boolean expression** of NAND gate is $Y = \overline{A.B}$

Truth table of a NAND gate

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

- **The NOR gate:**

Logic symbol of NOR gate



The **Boolean expression** of NOR gate is

$$Y = \overline{A + B}$$

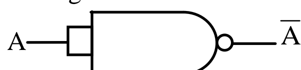
Truth table of a NOR gate

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

Universal gates:

The NAND or NOR gate is the universal building block of all digital circuits. Repeated use of NAND gates (or NOR gates) gives other gates. Therefore, any digital system can be achieved entirely from NAND or NOR gates. We shall show how the repeated use of NAND (and NOR) gates will gives us different gates.

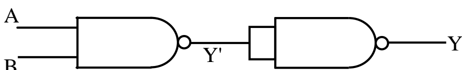
- **The NOT gate from a NAND gate:** When all the inputs of a NAND gate are connected together, as shown in the figure, we obtain a NOT gate



Truth table of a single input NAND gate

A	B = (A)	Y
0	0	1
1	1	0

- **The AND gate from a NAND gates:-** If a NAND gate is followed by a NOT gate (i.e., a single input NAND gate), the resulting circuit is AND gate as shown in figure and truth table given show how an AND gate has been obtained from NAND gates.



Truth table

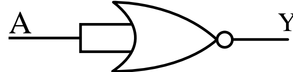
A	B	Y'	Y
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

- **The OR gate from NAND gates:** If we invert the inputs A and B and then apply them to the NAND gate, the resulting circuit is an OR gate.

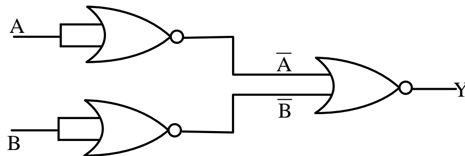
Truth table

A	B	$\overline{A}$	$\overline{B}$	Y
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

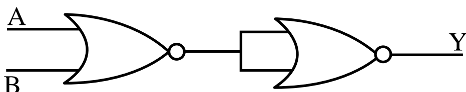
- **The NOT gate from NOR gates:-** When all the inputs of a NOR gate are connected together as shown in the figure, we obtain a NOT gate



- **The AND gate from NOR gates:-** If we invert the inputs A and B and then apply them to the NOR gate, the resulting circuit is an AND gate.



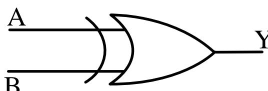
- **The OR gate from NOR gate:** If a NOR gate is followed by a single input NOR gate (NOT gate), the resulting circuit is an OR gate.



XOR and XNOR gates:

- **The Exclusive- OR gate (XOR gate):-** The output of a two-input XOR gate attains the state 1 if one and only one input attains the state 1.

Logic symbol of XOR gate



The **Boolean expression** of XOR gate is

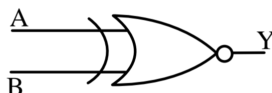
$$Y = A.\overline{B} + \overline{A}.B \text{ or } Y = A \oplus B$$

Truth table of a XOR gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

- **Exclusive – NOR gate (XNOR gate):-** The output is in state 1 when its both inputs are the same that is, both 0 or both 1.

Logic symbol of XNOR gate



The **Boolean expression** of XNOR gate is

$Y = A.B + \bar{A}.\bar{B}$ or $Y = \overline{A \oplus B}$ or $A \odot B$

Truth table of a XNOR gate

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

Laws of Boolean Algebra

Basic OR, AND, and NOT operations are given below:

OR	AND	NOT
A + 0 = A A + 1 = 1 A + A = A	A. 0 = 0 A. 1 = 0 A. A = A	$A + \bar{A} = 1$ $A.\ \bar{A} = 0$ $\bar{\bar{A}}\ . A = A$

Boolean algebra obeys commutative, associative and distributive laws as given below:

- **Commutative laws:**
  A + B = B + A;
  A.B = B.A
- **Associative laws:**
  A + (B + C) = (A + B) + C
  A . (B. C) = (A . B) . C
- **Distributive laws:**
  A . (B + C) = A.B + A.C
- **Some other useful identities:**
  (i) A + AB = A
  (ii) A. (A + B) = A
  (iii) $A + (\bar{A}B) = A + B$
  (iv) $A.(\bar{A} + B) = A.B$
  (v) A + (B.C) = (A + B). (A + C)
  (vi) $(\bar{A} + B).(A + C) = \bar{A}.C + B.A + B.C$
- **De Morgan's theorem:**
  First theorem: $\overline{A + B} = \bar{A}.\bar{B}$
  Second theorem: $\overline{A.B} = \bar{A} + \bar{B}$

SUMMARY OF LOGIC GATES

Names	Symbol	Boolean Expression	Truth table	Electrical analogue	Circuit diagram (Practicval Realisation)
OR		Y = A + B	A B Y 0 0 0 0 1 1 1 0 1 1 1 1		
AND		Y = A.B	A B Y 0 0 0 0 1 0 1 0 0 1 1 1		
NOT or Inverter		$Y = \bar{A}$	A Y 0 1 1 0		
NOR (OR+ NOT)		$Y = \overline{A + B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 0		

Gate	Symbol	Boolean expression	Truth table	Switch circuit	Transistor circuit
NAND (AND + NOT)	A, B, Y	$Y = \overline{A.B}$	A B Y 0 0 1 0 1 1 1 0 1 1 1 0	A, B	A, B, D_1, D_2, R_B, R_1, V_{CC}, Y
XOR (Exclusive OR)	A, B	$Y = A \oplus B$ or $Y = \bar{A}.B + A\bar{B}$	A B Y 0 0 0 0 1 1 1 0 1 1 1 0		
XNOR (Exclusive NOR)	A, B, Y	$Y = A \odot B$ or $Y = A.B + \bar{A}.\bar{B}$ or $Y = \overline{A \oplus B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 1		

NUMBER SYSTEMS

Decimal Number system

The base of this system is 10 and in this system 10 numbers [0, 1, 2, 3, 4, 5, 6, 7, 8, 9] are used.

Ex. 1396, 210.75 are decimal numbers.

Binary Number System

The base of this system is 2 and in this system 2 numbers (0 and 1) are used.

Ex. 1001, 1101.011 are Binary numbers.

Binary to decimal conversion

We can write any decimal number in following from

$2365.75 = 2000 + 300 + 60 + 5 + 0.7 + 0.05$

$= 2 \times 1000 + 3 \times 100 + 6 \times 10 + 5 \times 1 + 7 \times \frac{1}{10} + 5 \times \frac{1}{100}$

$= 2 \times 10^3 + 3 \times 10^2 + 6 \times 10^1 + 5 \times 10^0 + 7 \times 10^{-1} + 5 \times 10^{-2}$

similarly we can write any binary number in following from

$10101.11 = 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2}$

$= 1 \times 16 + 0 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 + 1 \times \frac{1}{2} + 1 \times \frac{1}{4}$

$= 16 + 4 + 1 + \frac{1}{2} + \frac{1}{4} = 21.75$

Ex. Convert binary number 1011.01 into decimal number.

$1011.01 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2}$

$= 8 + 2 + 1 + \frac{1}{4} = 11.25$

Ex. Convert binary number 1000101.101 into decimal number

$1000101.101 = 1 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3}$

$= 64 + 4 + 1 + \frac{1}{2} + \frac{1}{8} = 69 + 0.5 + 0.125 = 69.625$

Ex. Convert the following binary numbers into decimal numbers-

(a) 101 (b) 110.001 (c) 11111 (d) 1011.11

Ans. (a) 5 (b) 6.125 (c) 31 (d) 11.75

DECIMAL TO BINARY CONVERSION

You should remember this table for decimal to binary conversion

2^{-3}	2^{-2}	2^{-1}	2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7	2^8	2^9	2^{10}
0.125	0.25	0.5	1	2	4	8	16	32	64	128	256	512	1024

Ex. Convert the decimal number 25 into its binary equivalent

Sol. $25 = 16 + 8 + 1 \equiv 2^4 + 2^3 + 2^0 = 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 \Rightarrow (25)_{10} = (11001)_2$

Ex. Convert 69 into its binary equivalent

Sol. $69 = 64 + 4 + 1 = 1 \times 2^6 + 1 \times 2^2 + 1 \times 2^0$

$\Rightarrow (69)_{10} \equiv (1000101)_2$

Ex. Convert 13.5 into its binary equivalent

Sol. $13.5 = 8 + 4 + 1 + 0.5 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^1 \Rightarrow (13.5)_{10} = (1101.1)_2$

Ex. Convert the following decimal numbers into binary numbers

(a) 6 (b) 65 (c) 106 (d) 268 (e) 8.125

Ans. (a) 110 (b) 1000001

(c) 1101010 (d)100001100

(e) 1000.001

ELECTRONICS – SEMI CONDUCTOR

INTRODUCTION

The word "electronics' is derived from electron + dynamics which means the study of the behaviour of an electron under different conditions of externally applied fields.

That field of science which deals with electron devices and their utilization. An electronic device is "a device in which conduction takes place by the movement of electron-through a vacuum, a gas or a semiconductor. Some familiar devices are:

(i) Rectifier (ii) Amplifier (iii) Oscillator etc.

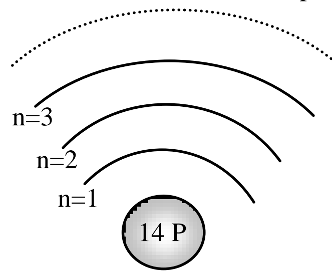
Application of Electronics

Communication	Entertainment	Defence	Medical
Telephone	TV Broadcast	Radar	X-rays
Telegraph	Radio Broadcast	Guided missiles	Electro cardio graph (ECG)
Mobile phone	VCR, VCD		CRO display
FAX			E.E.G. (Electro Engio Graph)
FM mike			

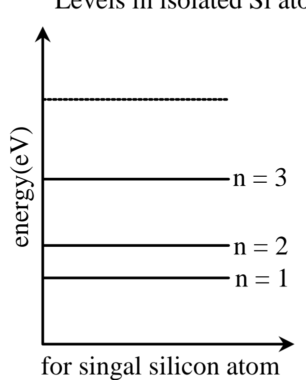
- Main application of electronics is computer which is used in every field.
- All electronics equipments required D.C. supply for operation (not A.C. supply)

ENERGY BANDS IN SOLIDS

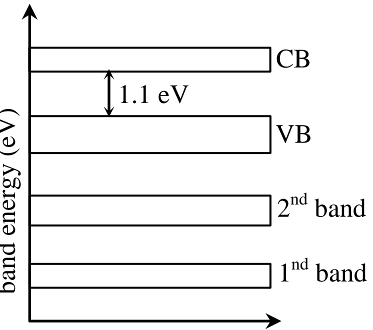
Based on Pauli's exclusion principle



Permissible energy Levels in isolated Si atom



for singal silicon atom



for Si material (Si crystal)

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.

- **Energy Band**

  Range of energy possessed by electron in a solid is known as energy band.

- **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

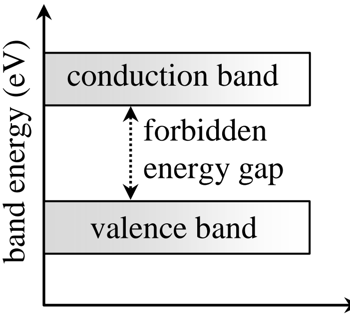
  (b) In general Partially filled by electron.

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

- **Forbidden Energy gap (FEG) (ΔE_g)**

$$\Delta E_g = (CB)_{min} - (VB)_{max}$$

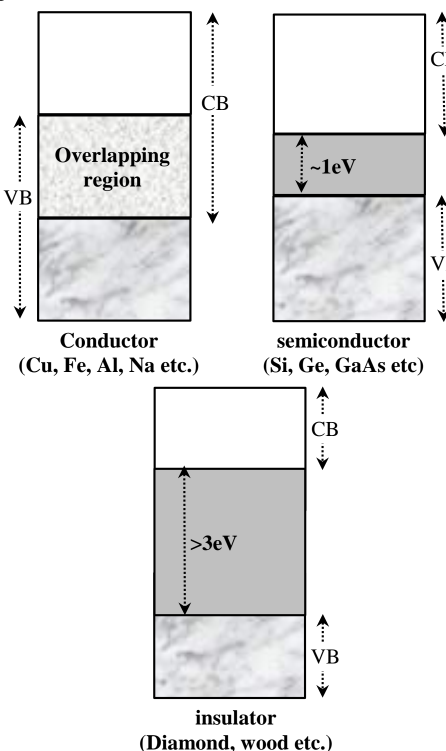
Energy gap between conduction band and valence band, where no free electron can exist.



- 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).

ACCORDING TO ENERGY BAND THEORY

Explanation of conductor, semiconductor and insulator:



Conductor (Cu, Fe, Al, Na etc.)   **semiconductor** (Si, Ge, GaAs etc)

insulator (Diamond, wood etc.)

- **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.

- **Insulator**

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

  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 $\rho = 10^8\ \Omega\text{–m}$ & $\sigma = 10^{-8}\ (\Omega - m)^{-1}$

- **Semiconductor**

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

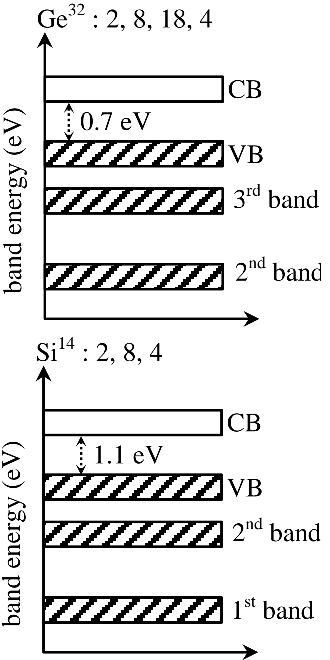
  Due to this small band gap some electrons can be thermally exicited to "conduction band". These thermally excited electrons can move in conduction band and can conduct current their resistivity and conductivity both are in medium range, $\rho = 10^5 - 10^0 \Omega\text{–m}$ and $\sigma = 10^{-5} - 10^0\ \Omega\text{–m}^{-1}$

- **Example of semiconductor material**

Elemental semiconductor	Compound semiconductor	
Si and Ge	Inorganic	CdS, GaAs, CdSe, InP etc.
	Organic	anthracene, doped phalocyanines.
	Organic polymers	Poly pyrrole, Poly aniline polythiophene

PROPERTIES OF SEMICONDUCTORS

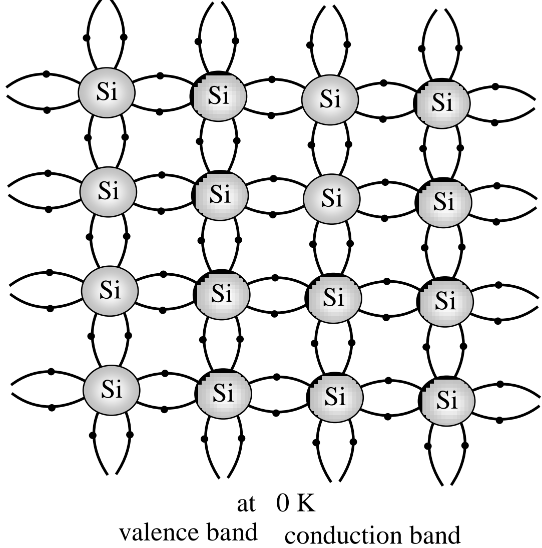
- Negative temperature coefficient (α), with increase in temperature resistance decreases.
- Crystalline structure with covalent bonding [Face centred cubic (FCC)]
- Conduction properties may change by adding small impurities
- Place in periodic table $\rightarrow$ IV group (Generally)
- Forbidden energy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



EFFECT OF TEMPERATURE

At absolute zero kelvin temperature

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

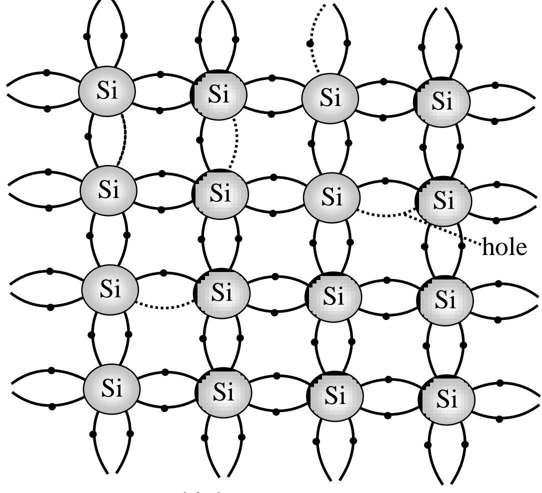


at 0 K

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

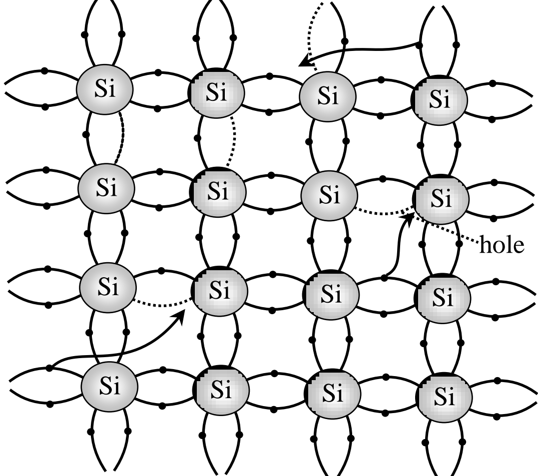
valence band partially empty | conduction band partially filled

- Number of electrons reaching from valence band to conduction band $n = AT^{3/2} e^{-\frac{\Delta E_g}{2kT}}$ where k = Boltzmann constant = 1.38×10^{-23} J/K, T = absolute temperature, A = constant, ΔE_g = energy gap between conduction band and valence band
- In silicon at room temperature out of 10^{12} Si atoms only one electron goes from valence band to conduction band.
- In germanium at room temperature out of 10^{9} Ge atoms only one electron goes from valence band to conduction band.
- In carbon solid Lattice energy very high. So it works as a insulator.

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.

Note:- 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.

EFFECT OF IMPURITY IN SEMICONDUCTOR

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

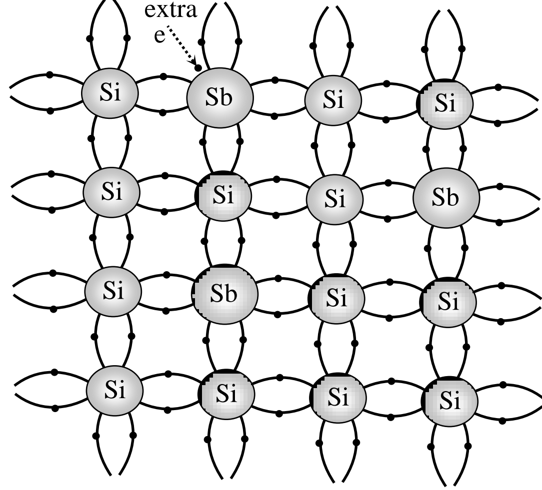
- The concentration of dopant atoms be very low, doping ratio is vary from
  Impure : pure :: 1 : 10^6 to 1 : 10^{10}
  In general it is 1 : 10^8
- There two main method of doping.
  (i) Alloy method
  (ii) Diffusion method (The best)
- The size of dopant atom (impurity) should be almost the same as that of crystal atom. So that crystalline structure of solid remain unchanged.

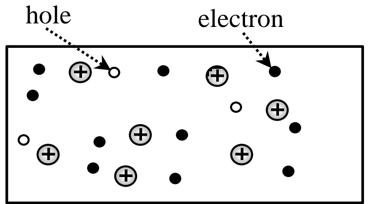
CLASSIFICATION OF SEMICONDUCTOR

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

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.

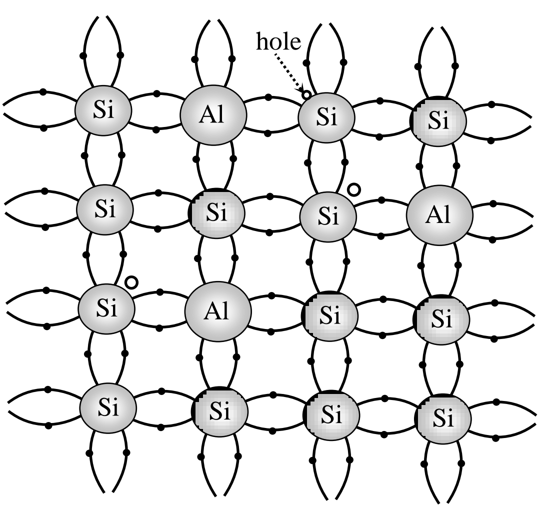


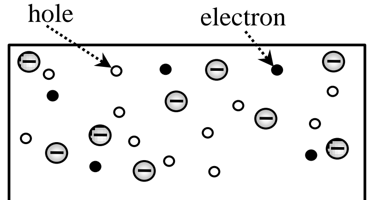


N_D = immobile donor
Positive ion ⊕

P-type semiconductor

When a pure semicronductor (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.





N_A = immobile acceptor
Negative ion ⊖

	Intrinsic Semiconductor	N-type (Pentavalent impurity)	P-type(Trivalent impurity)
1.	CB, VB	CB, donor Impurity level, VB	CB, Acceptor impurity level, VB
2.		free electron, positive donor ion	hole, Negative acceptor ion
3.	Current due to electron and hole	Mainly due to electrons	Mainly due to holes
4.	$n_e = n_h = n_i$	$n_h << n_e$ ($N_D \simeq n_e$)	$n_h >> n_e$ ($N_A \simeq n_h$)
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 Minority-Holes	Majority-Holes 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.

Hence for a given semiconductor rate of recombination $\propto n_e \times n_h$

so rate of recombination = $Rn_e \times n_h$

where R = recombination coefficient,

The value of R remains constant for a solid, according to the law of thermodynamics until crystalline lattice structure remains same.

For intrinsic semiconductor $n_e = n_h = n_i$

so rate of recombination = Rn_i^2

$Rn_e \times n_h = Rn_i^2 \Rightarrow n_i^2 = n_e \times n_h$

> 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 $n_e \times n_h = n_i^2$

Ex. The energy of a photon of sodium light (λ = 589 nm) equals the band gap of a semiconducting material Find : (a) the minimum energy E required to create a hole-electron pair.

(b) the value of $\frac{E}{kT}$ at a temperature of 300 K.

Sol. (a) $E = \frac{hc}{e\lambda}$ (in eV) so $E = \frac{12400}{\lambda}$

(E is in eV and λ is in Å) λ = 5890Å

so $E = \frac{12400}{5890} = 2.1$ eV

(b) $\frac{E}{kT} = \frac{2.1 \times 1.6 \times 10^{-19} J}{1.38 \times 10^{-23} \times 300} = 81$

Ex. A P-type semiconductor has acceptor level 57 meV above the valence band. What is maximum wavelength of light required to create a hole ?

Sol. $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{6.62\times10^{-34}\times3\times10^{8}}{57\times10^{-3}\times1.6\times10^{-19}}$

$= 217100Å$

Ex. A silicon specimen is made into a p-type semiconductor by doping on an average one indium atom per 5×10^7 silicon atoms. If the number density of atoms in the silicon specimen is 5×10^{28} atom/m^3; find the number of acceptor atoms in silicon per cubic centimeter.

Sol. The doping of one indium atom in silicon semiconductor will produce one acceptor atom in p-type semiconductor. Since one indium atom has been dopped per 5×10^7 silicon atoms, so number density of acceptor atoms in silicon

$= \frac{5\times10^{28}}{5\times10^{7}} = 10^{21}$ atom/m^3 = 10^{15} atoms/cm^3

Ex. The concentration of hole-electron pairs in pure silicon at T = 300 K is 7×10^{15} per cubic meter. Antimony is doped into silicon in a proportion of 1 atom in 10^7 Si atoms. Assuming that half of the impurity atoms contribute electron in the conduction band, calculate the factor by which the number of charge carries increases due to doping the number of silicon atoms per cubic meter is 5×10^{28} .

Sol. In pure semiconductor electron-hole pair $= 7 \times 10^{15}$/m^3 total charge carrier $n_{total\ initial} = n_h + n_e = 14 \times 10^{15}$ after doping donor impurity

$N_D = \frac{5\times10^{28}}{10^{7}} = 5\times10^{21}$ and $n_e = \frac{N_D}{2} = 2.5\times10^{21}$

So $n_{final} = n_h + n_e \Rightarrow n_{final} \approx n_e \approx 2.5 \times 10^{21}$

$(\because n_e >> n_h)$

Factor $= \frac{n_{final} - n_{initial}}{n_{initial}} = \frac{2.5\times10^{21} - 14\times10^{15}}{14\times10^{15}}$

$\approx \frac{2.5\times10^{21}}{14\times10^{15}} = 1.8 \times 10^5$

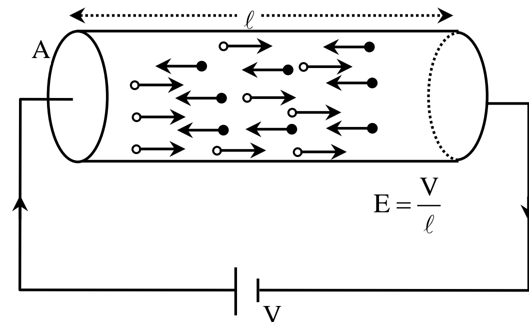
Ex. Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentration of 1.5×10^{16} m^{-3}. Dopping by indium increases n_h to 3×10^{22} m^{-3}. Calculate n_e in the doped Si.

Sol. For a doped semi-conductor in thermal equilibrium $n_e n_h = n_i^2$ (Law of mass action)

$n_e = \frac{n_i^2}{n_h} = \frac{(1.5\times10^{16})^2}{3\times10^{22}} = 7.5 \times 10^9$ m^{-3}

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 = ne v_d

$\because$ drift velocity of electron $v_d = \mu E$

$\therefore$ $J = ne\,\mu E = \sigma E$

Conductivity $\sigma = ne\mu = 1/\rho$

ρ = Resistivity

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

- **Conduction in Semiconductor**

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

- Due to impurity the conductivity increases approximately 10^5 times
- $\sigma_{sc} = \sigma_e + \sigma_h = n_e e\mu_e + n_h e\mu_h$

Ex. What will be conductance of pure silicon crystal at 300K temperature. If electron hole pairs per cm^3 is 1.072×10^{10} at this temperature, $\mu_n = 1350$ cm^2/volt sec & $\mu_P = 480$ cm^2/volt sec

Sol. $\sigma = n_i e\mu_e + n_i e\mu_h = n_i e(\mu_e + \mu_h)$

$= 3.14 \times 10^{-6}$ mho/cm

Ex. Pure Si at 300K has equal electron n_e and hole n_h concentration of 1.5×10^{16} /m^3. Doping by indium increases n_h to 4.5×10^{22}/m^3. Calculate n_e in doped silicon.

Sol. $n_e = \dfrac{n_i^2}{n_h} = \dfrac{(1.5\times10^{16})^2}{(4.5\times10^{22})} = 5 \times 10^9 m^{-3}$

Ex. A semiconductor has equal electron and hole concentration of 6×10^8/m^3. On doping with certain impurity electron concentration increases to 9×10^{12}/m^3.

(i) Identify the new semiconductor obtained after doping.

(ii) Calculate the new hole concentration.

Sol. $n_i = 6 \times 10^8$/m^3 and $n_e = 9 \times 10^{12}$/m^3

(i) $n_e > n_i$ so it is N-type semiconductor

(ii) $\because$ $n_i^2 = n_e n_h \Rightarrow n_h = \dfrac{n_i^2}{n_e} = \dfrac{36\times10^{16}}{9\times10^{12}}$

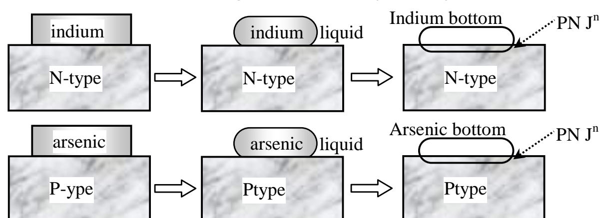
$= 4 \times 10^4$/m^3

P-N JUNCTION

Techniques for making P-N junction

- **Alloy Method**

Here a small piece of III group impurity like indium is placed over n–Ge or n – Si and melted as shown in figure ultimately P–N junction form.

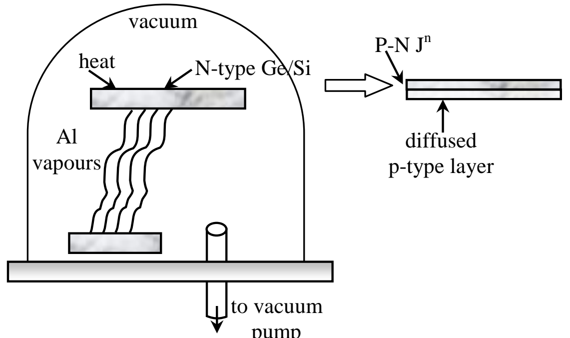


- **Diffusion Junction**

A heated P-type semiconductor is kept in pentavalent impurity vapours which diffuse into P-type semiconductor as shown and make P-N junction.

Vapour deposited junction or epitaxial junction

If we want to grow a layer of n-Si or p-Si then p-Si wafer is kept in an atmosphere of Silane (a silicon compound which dissociates into Si at high temperatures) plus phosphorous vapours.



On craking of silane at high temperature a fresh layer on n-Si grows on p-Si giving the "P-N junction".

Since this junction growth is layer by so it is also referred as layer growth or epitaxial junction formation of P-N junction.

DESCRIPTION OF P-N JUNCTION WITHOUT APPLIED VOLTAGE OR BIAS

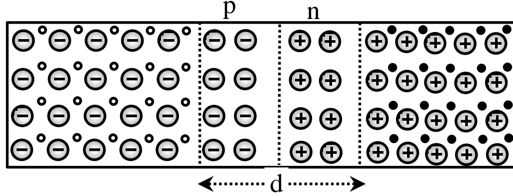
Given diagram shows a P-N junction immediately after it is formed. P region has mobile majority holes and immobile negatively charged impurity ions.

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$^-$ starts N to P side.

p n

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.

- **Width of depletion layer $\cong 10^{-6}$m**

(a) As doping increases depletion layer decreases

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

(c) P-N junction $\rightarrow$ unohmic, due to nonlinear relation between I and V.

- **Potential Barrier or contact potential**

for Ge $\rightarrow$ 0.3 V, for Si $\rightarrow$ 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 respectively majority carrier from crossing barrier region

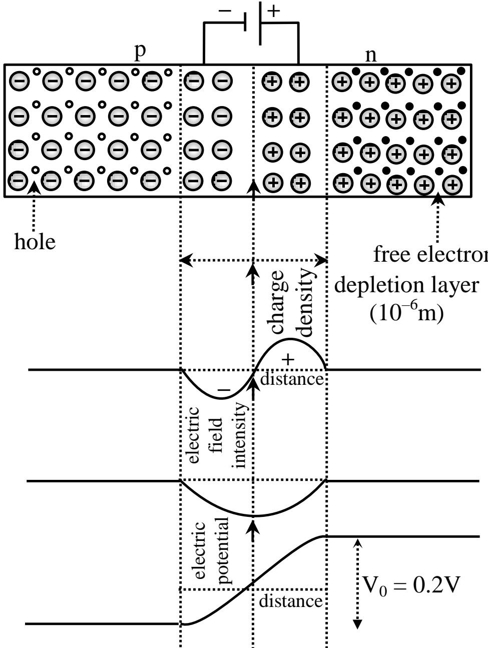
DIFFUSION AND DRIFT CURRENT

(1) Diffusion current: P to N side

(2) Drift current : N to P side

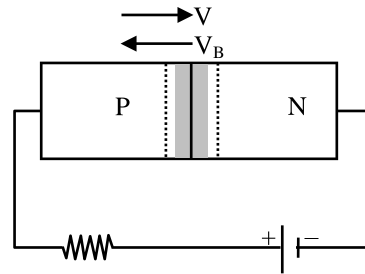
If there is no biasing then diffusion current = drift current

So total current is zero



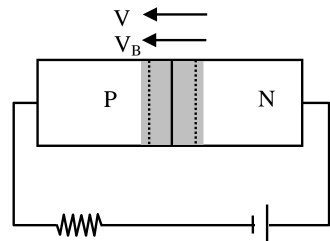
BEHAVIOUR OF P-N JUNCTION WITH AN EXTERNAL VOLTAGE APPLIED OR BIAS

- **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.

- **Reverse Bias**
If we apply a voltage "V" such that P-side is negative and N-side is positive as shown in diagram.

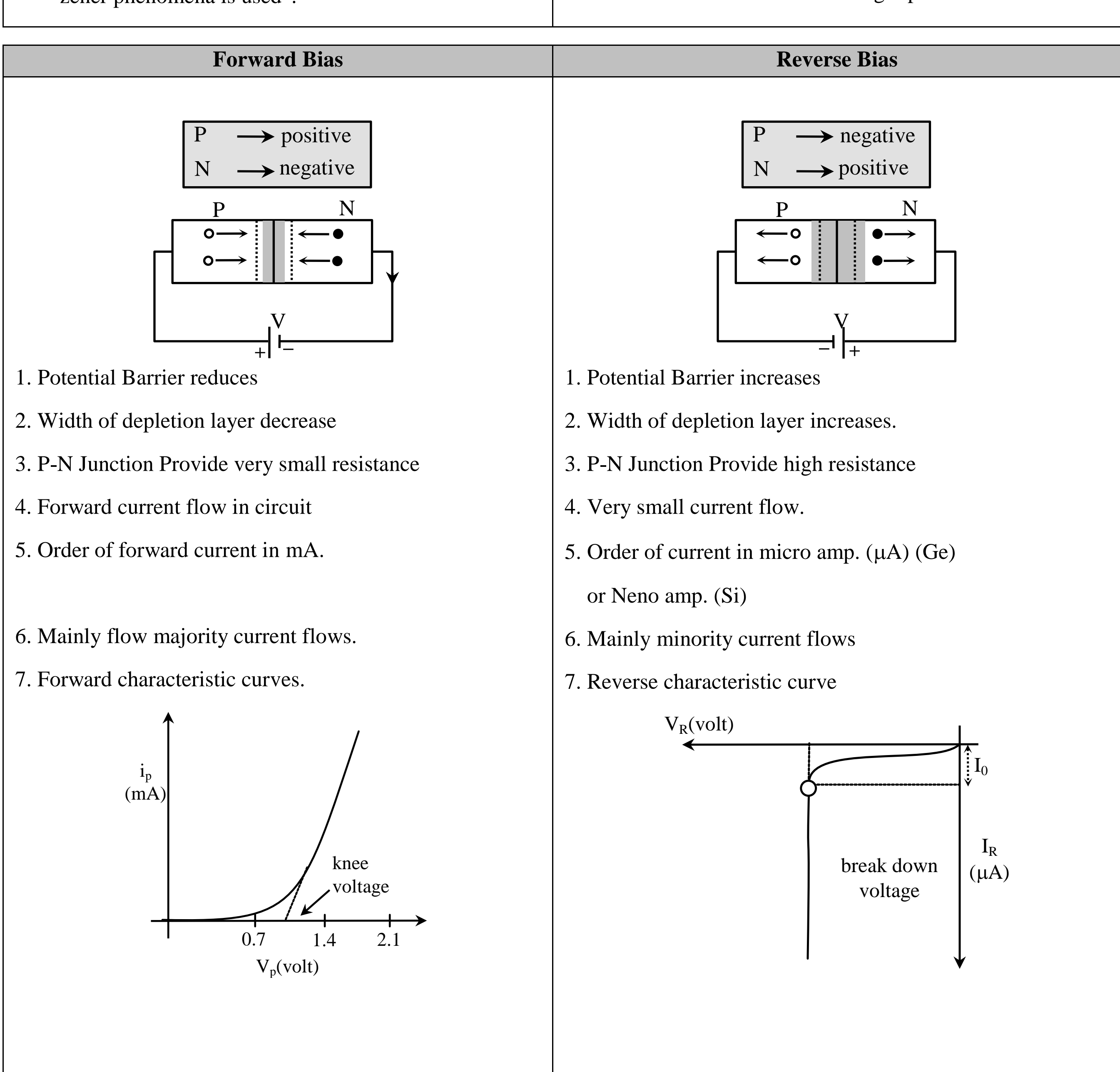


The applied voltage is same side of to the junction barrier potential. Due to this effective potential barrier increased junction width also increased, so no majority carriers will be allowed to flow across junction.

Only minority carriers will drifted. It means the current flow in principally due to minority charge carries and is very small (μA) called as reversed Bias.

- In reverse bias, the current is very small and nearly constant with bias (termed as reverse saturation current). However interesting behaviour results in some special cases if the reverse bias is increased further beyond a certain limit, above particular high voltage breakdown of depletion layer started.
- Breakdown due to covalent breaking of depletion layer termed as Zener breakdown (After the discovery, C Zener) and such a diode is Zener diode.
Zener diodes with different breakdown voltages (for regulations of different voltages) can obtained by changing the doping concentration of its p-and n-sides.
- There is another variant of Zener like breakdown if the doping concentrations of p- and n-side are not as high as for the case of zener diode. Such diodes will have relatively wider junction widths. At very high reverse bias, already existing electrons and holes are accelerated in the junction field and may undergo many collisions (like nuclear chain reaction) with the atoms in the crystal.
These new electron-hole pairs created by impact ionisation also get accelerated in the junction field and collide further with the crystal atoms giving an increasing number of new electrons and holes. These bias beyond a certain critical values. This phenomenon is known as Avalanche breakdown and the device is referred to as Avalanche diode.

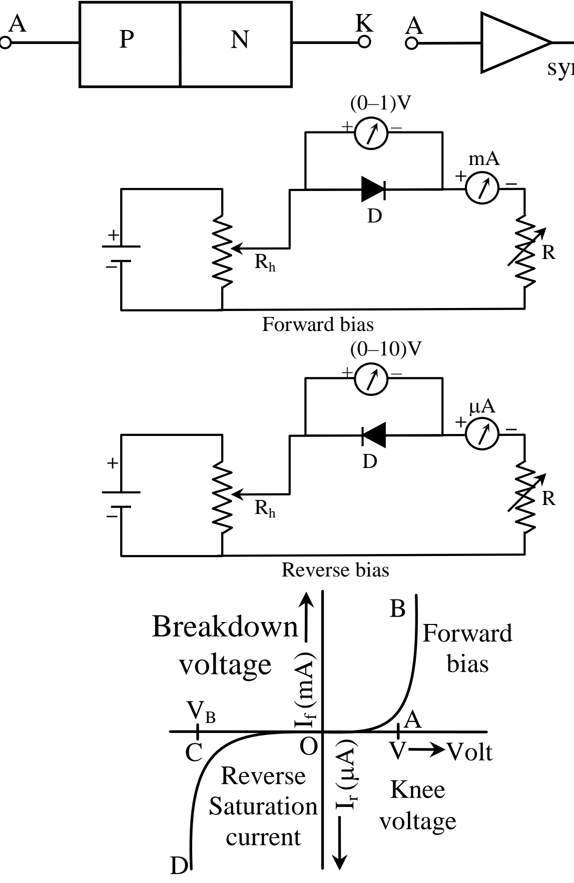
Zener Break down	Avalanche Break down
When covalent bonds of depletion layer, its self break, due to high electric field of very high Reverse bias voltage.	Here covalent bonds of depletion layers are broken by collision of "Minorities" which aquire high kinetic energy from high electric field of very-very 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 dopoing"
(iii) P–N Jn. Having thin depletion layer Here P–N not demage paramanently "In D.C. voltage stabilizer zener phenomena is used".	(iii) P–N Jn. Having thick depletion layer Here P–N damage peramanentaly due to "Heating effect" due to abruptly increament of minorities during repeatative collisions.



Forward Bias	Reverse Bias
1. Potential Barrier reduces	1. Potential Barrier increases
2. Width of depletion layer decrease	2. Width of depletion layer increases.
3. P-N Junction Provide very small resistance	3. P-N Junction Provide high resistance
4. Forward current flow in circuit	4. Very small current flow.
5. Order of forward current in mA.	5. Order of current in micro amp. (μA) (Ge) or Neno amp. (Si)
6. Mainly flow majority current flows.	6. Mainly minority current flows
7. Forward characteristic curves.	7. Reverse characteristic curve

8. Forward resistance	8. Reverse resistance
$R_f = \frac{\Delta V_f}{\Delta I_f} \cong 100\Omega$	$R_B = \frac{\Delta V_B}{\Delta I_B} \cong 10^6\Omega$
9. Knee or cut in voltage	9. Breakdown voltage
$Ge \to 0.3V, \quad Si \to 0.7\ V$	$Ge \to 25V, \quad Si \to 35\ V$
10. Forward current Equation	10. Reverse current equation
$I = I_0\left[e^{+\frac{qv}{kt}} - 1\right]$	$I = I_0\left[e^{-\frac{qv}{kt}} - 1\right]$
$\because e^{\frac{qv}{kt}} >> 1$	$\because e^{-\frac{qv}{kt}} << 1$
$\therefore I \cong I_0\, e^{\frac{qv}{kt}}$ (exp. increament)	$\therefore I \simeq -I_0$
For Ge $\frac{R_B}{R_F} = 10^3 : 1$	For Si $\frac{R_B}{R_F} = 10^4 : 1$

CHARACTERISTIC CURVE OF P-N JUNCTION DIODE

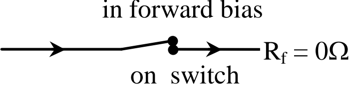


In forward bias when voltage is increased from 0V in steps and corresponding value of current is measured, the curve comes as OB of figure. We may note that current increase very sharply after a certain voltage knee voltage. At this voltage, barrier potential is completely eliminated and diode offers a low resistance.

In reverse bias a microammeter has been used as current is very very small. When reverse voltage is increased from 0V and corresponding values of current measured the plot comes as OCD. We may note that reverse current is almost constant hence called reverse saturation current. It implies that diode resistance is very high. As reverse voltage reaches value V_B, called breakdown voltage, current increases very sharply.

For Ideal Diode

in forward bias



on switch

in reverse bias

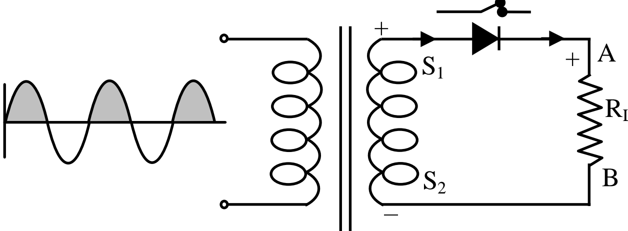
off switch

$R_r = \infty\Omega$

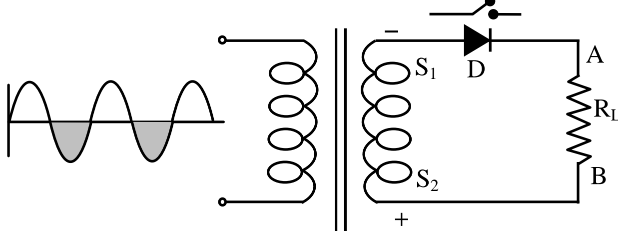
RECTIFIER

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

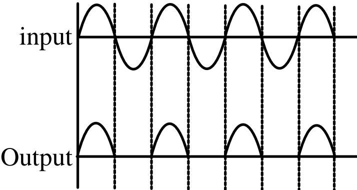
- **Half wave rectifier**



For positive half cycle



For negative half cycle



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.

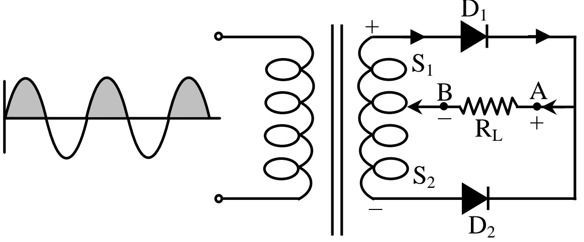
Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output.

Peak inverse voltage (PIV) $V_s = V_{in}$

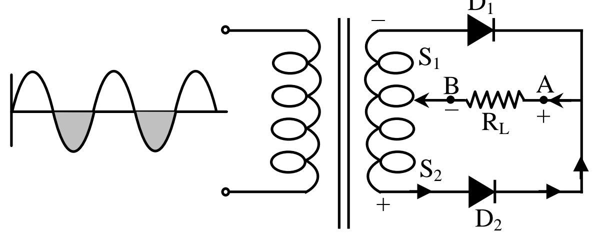
In half wave rectifier PIV = maximum voltage across secondary coil of transformer

- **Full wave rectifier**

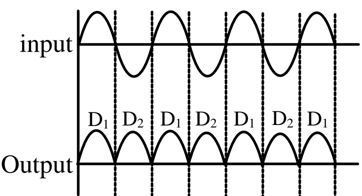
When the diode rectifies the whole of the AC wave, it is called full wave rectifier. Figure shows the experiemental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary a transformer. The output signal appears across the bad resistance R_L.



For positive half cycle



For negative half cycle



During the positive half of the input signal:

Let S_1 positive and S_2 negative.

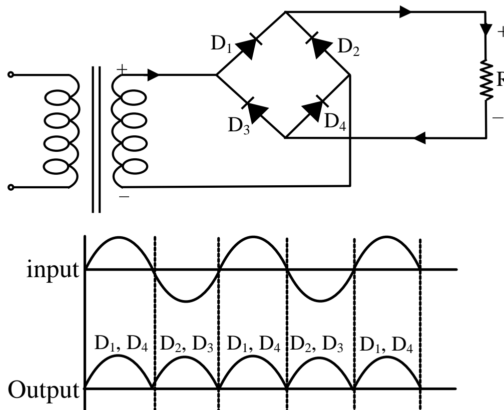
In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.

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 obtained.

- **Bridge Rectifier**



During positive half cycle

D_1 and D_4 are forward biased $\rightarrow$ on switch

D_2 and D_3 are reverse biased $\rightarrow$ off switch

During negative half cycle

D_2 and D_3 are forward biased $\rightarrow$ on switch

D_1 and D_4 are reverse biased $\rightarrow$ off switch

In breadge rectifier peck inverse voltage

$PIV = V_s = V_{in}$

Form Factor

$$F = \frac{I_{rms}}{I_{dc}} \text{ or } \frac{E_{rms}}{E_{dc}}$$

for full wave rectifier $F = \frac{\pi}{2\sqrt{2}}$ for half wave rectifier $F = \frac{\pi}{2}$

Ripple and ripple factor

In the output of rectifier some A.C. components are present. They are called ripple & there measurement is given by a factor so it is called ripple factor. For good rectifier ripple factor must be very low.

Total output current

$I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2}$ I_{ac} = rms value of AC component

Ripple factor $r = \frac{I_{ac}}{I_{dc}} \Rightarrow r = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - I} = \sqrt{F^2 - 1}$

1.For half wave rectifier $I_{rms} = \frac{I_0}{2}$, $I_{dc} = \frac{I_0}{\pi}$, r = 1.21

2. For full wave or bridge wave rectifier

$I_{rms} = \frac{I_0}{\sqrt{2}}$, $I_{dc} = \frac{2I_0}{\pi}$, r = 0.48

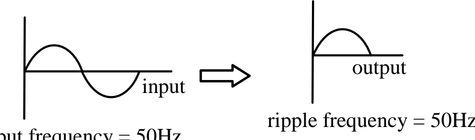
Rectifier efficiency

$$\eta\% = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_F + R_L)} \times 100$$

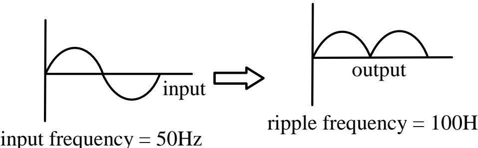
Half wave rectifier	Full wave rectifier or bridge wave rectifier
$\eta = 40.6 \left(\frac{R_L}{R_L + R_f}\right)\%$ if $\frac{R_f}{R_L} << 1$ $\eta = 40.6\%$ Special Note If $R_f = R_L$ $\eta = 20.3\%$	$\eta = 81.2 \times \frac{R_L}{R_L + R_f}\%$ If $\frac{R_f}{R_L} << 1$ $\eta = 81.2\%$ If $R_f = R_L$ $\eta = 40.6\%$ Note: In bridge or full wave rectifier R_f is two times of resistance of P-N in FB

Ripple Frequency

(i) For half wave rectifier

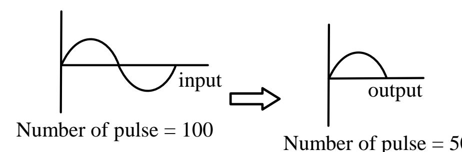


(ii) for full wave rectifier

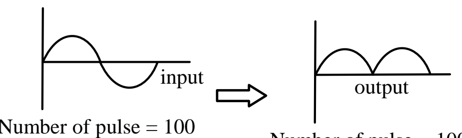


Pulse

(i) For half wave rectifier



(ii) For full wave rectifier



$\bar{I} = \frac{1}{T}\int_0^T Idt$ $\bar{I} = \frac{1}{T}\left[\int_0^{T/2} Idt + \int_{T/2}^T Idt\right]$ $= \frac{1}{T}\int_0^{T/2} I_0 \sin\omega t dt + 0$ $= \frac{I_0}{T}\left[\frac{-\cos\omega t}{\omega}\right]_0^{T/2}$ $= \frac{T_0}{\omega t}\left[-\cos\omega\frac{T}{2} + \cos 0\right]$ $\bar{I} = \frac{I_0}{\pi}$	$\bar{I}^2 = \frac{1}{T}\int_0^T I^2 dt$ $= \frac{1}{T}\int_0^T \frac{2I_0^2 \sin^2\omega t dt}{2}$ $= \frac{I_0^2}{2T}\left[\int_0^T 1 - \cos 2\omega t\right] dt$ $= \frac{I_0^2}{2T}\left[\frac{T}{2} - 0\right] = \sqrt{\frac{I_0^2}{4}} = \frac{I_0}{2}$

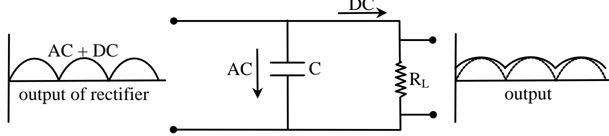
Comparison Between Average Rectifiers

	Half-wave	Full-wave	
		Centre-tap	Bridge
Number of Diodes	1	2	4
Transformer necessary	No	Yes	No
Peak secondary voltage	V_m	V_m	V_m
Peak Inverse Voltage	$V_{in} = V_m$	$2V_{in} = V_m$	$V_{in} = V_m$
Peak load Current, I_m	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{2r_d + R_L}$
RMS Current, I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC current, I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
Ripple factor, r	1.21	0.482	0.482
Rectification efficiency (max)	40.6%	81.2%	81.2%
Lowest ripple frequency, f_r	f_i	$2f_i$	$2f_i$

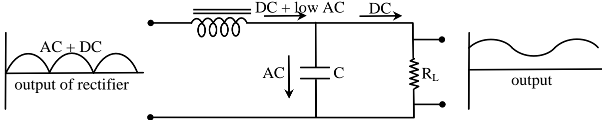
FILTER CIRCUIT

To reduce A.C. Components

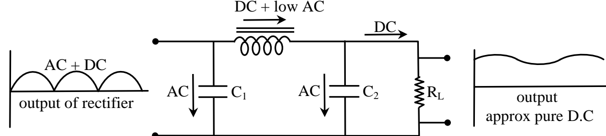
- **Capacitor Filter**



- **L-C Filter**

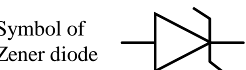


- **π- Filter (Best Filter)**



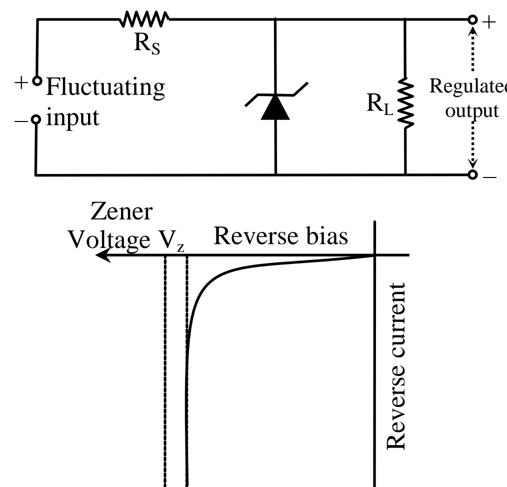
ZENER DIODE

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

Symbol of 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.

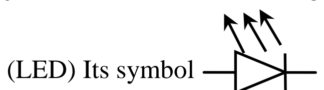
SOME SPECIAL DIODES

- **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 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 made 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 interested in more power. Materials most commonly used for solar cell is Si, As, Cds, CdTe, CdSe, etc.

- **Variable capacitor (Varactor)**

  P-N junction diode can be used as a "Capacitor "here depletion layer acts as "dielectric material" and remaining "P" and "N" part acts as metallic plates.

  P N ≡ P N ,

  its symbol

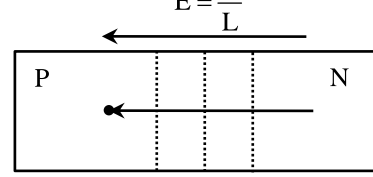
- **Diode laser**

  It is interesting form of LED in which special construction helps to produce stimulated radiation as in laser.

Ex. A potential barrier of 0.5V exists across a p-n junction (i) If the depletion region is 5×10^{-7}m wide. What is the intensity of the electric field in this region ? (ii) An electron with speed 5×10^5 m/s approaches the p-n junction from the n-side with what speed will it enter the p-side.

Sol. (i) Width of depletion layer $\Delta L = 5 \times 10^{-7}$m

$$E = \frac{V}{\Delta L} = \frac{0.5V}{5\times10^{-7}} = 10^6 \text{ volt/m}$$



(ii) Work energy theorem $\frac{1}{2}Mv_i^2 = eV + \frac{1}{2}Mv_f^2$

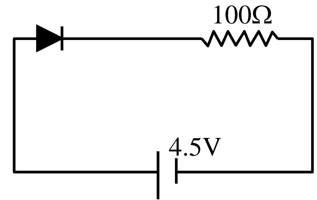
$$v_f = \sqrt{\frac{Mv_i^2 - 2eV}{M}} = 2.7 \times 10^5 \text{ m/s}$$

Ex. Figure shows a diode connected to an external resistance and an e.m.f. Assuming that the barrier potential developed in diode is 0.5 V_1 obtain the value of current in the circuit in milliampere.

Sol. E = 4.5 V, R = 100 Ω,

Voltage drop across p-n junction = 0.5 V

Effective voltage in the circuit V = 4.5 – 0.5 = 4.0V



current in the circuit $I = \frac{V}{R} = \frac{4.0}{100} = 0.04A$

$= 0.04 \times 1000 \text{ mA} = 40\text{mA}$

TRANSISTOR

Inventor William Bradford Shockley, John Bardeen and Walter Houser Brattain.

Transistor is a three terminal device which transfers a single from low resistance circuit to high resistance circuit. It is formed when a thin layer of one type of extrinsic semiconductor (P or N type is sandwitched between two thick layers of other two type extrinsic semiconductor.

Each transistor have three terminals which are:-

(i) Emitter

(ii) Base

(iii) Collector

Emitter

It is the left most part of the transistor. It emit the majority carrier towards base. It is highly doped and medium in size.

Base

It is the middle part of transistor which is sandwitched by emitter (E) and collector (C). It is lightly doped and very thin in size.

Collector

It is right part of the transistor which collect the majority carrier which is emitted by emitter. It have large size and moderately doped.

There are two semiconductor junction in transister

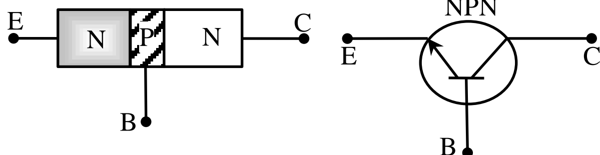
(i) The junction between emitter and base is known as emitter-base junction (**J_{EB}**).

(ii) The junction between base and collecter is known as base-collector junction (**J_{CB}**).

TRANSISTOR ARE OF TWO TYPES

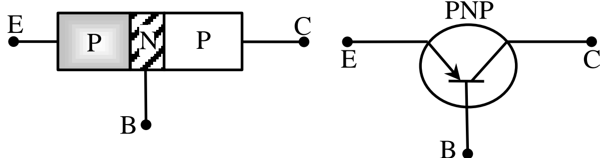
- **N-P-N Transistor**

  If a thin layer of P-type semiconductor is sandwitched between two thick layers of N-type semiconductor is known as NPN transistor.



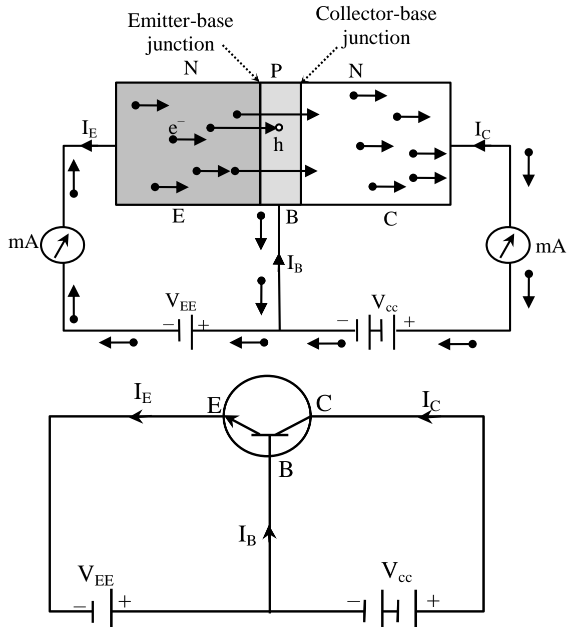
- **P-N-P Transistor**

  If a thin layer of N-type of semiconductor is sandwitched between two thick layer of P-type semiconductor is known as PNP transistor.



WORKING OF NPN TRANSISTOR

The emitter Base junction is forward bias and collector base junction is reversed biased of N-P-N transistor in circuit (A) and symbolic representation is shown in figure.



When emitter base junction is forward bias, electrons (majority carriers) in emitter are repelled toward base. The barrier of emitter base junction is reduced and the electron enter the base, about 5% of these electron recombine with hole in base region result in small current (I_B).

The remaining electron $(\approx 95\%)$ enter the collector region because they are attracted towards the positive terminal of battery results collecter current (I_C)

For each electron entering the positive terminal of the battery is connected with collector base junction an electron from negative terminal of the battery connected with emitter base junction enters the region.

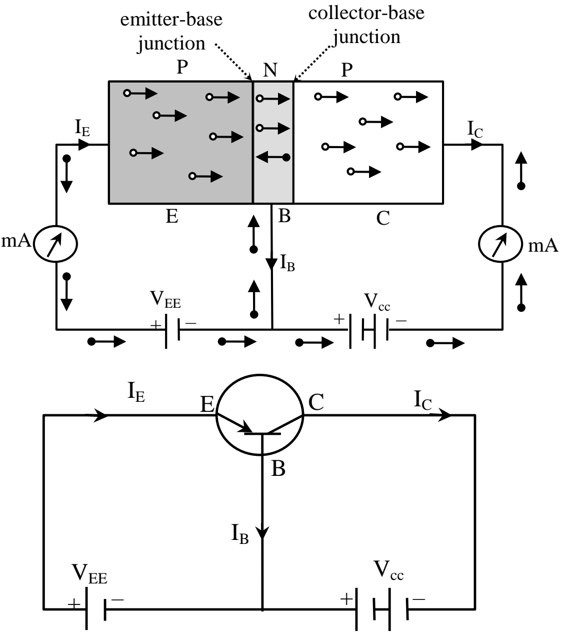
The emitter current (I_E) is more than the collector (I_C).

The base current is the difference between I_E and I_C and proportional to the number of electron hole recombination in the base.

$$I_E = I_B + I_C$$

WORKING OF PNP TRANSISTOR

When emitter-base junction is forward biased holes (majority carriers) in the emitter are repelled towards the base and diffuse through the emitter base junction. The barrier potential of emitter-base junction decreases and hole enter the n-region (i.e. base). A small number of holes $(\approx 5\%)$ combine with electron of base-region resulting small current (I_B). The remaining hole $(\approx 95\%)$ enter into the collector region because they are attracted towards negative terminal of the battery connected with collector-base junction. These hole constitute the collector current (I_C).



As one hole reaches the collector, it is neutralized by the battery. As soon as one electron and a hole is neutralized in collector a covalent bond is broken in emitter region. The electron hole pair is produced. The released electron enter the positive terminal of bettary and hole more towards the collector. So $I_E = I_B + I_C$

CHARACTERISTIC OF TRANSISTOR

To study about the characterstics of transistor we have to make a circuit [i.e. $J_{EB} \rightarrow$ Forward bias and $J_{CB} \rightarrow$ Reverse bias] we need four terminals. But the transistor have three terminals. By keeping one of the terminal of transistor is common in input and output both. So the transistor is connected in three ways in circuit.

(i) Common base connector

(ii) Common emitter

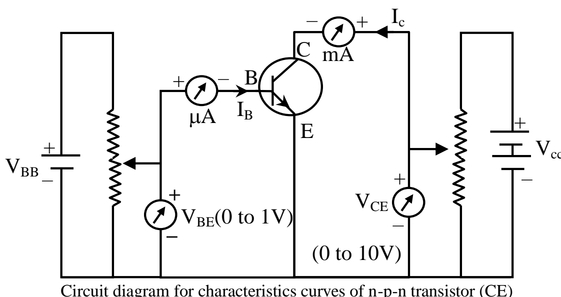
(iii) Common collector

In these three common emitter is widely used and common collector is rarely used.

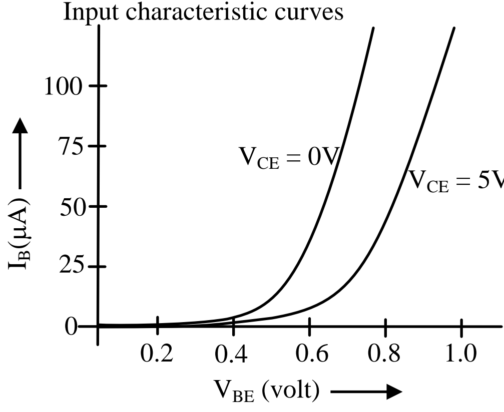
Common emitter characteristics of a transistor

- **Input characteristics**

The variation of base current (I_B) (input) with base emitter voltage (V_{EB}) at constant collector -emitter voltage (V_{CE}) is called input characteristic.



Circuit diagram for characteristics curves of n-p-n transistor (CE)



(i) Keep the collector-emitter voltage (V_{CE}) constant (say $V_{CE} = 1V$)

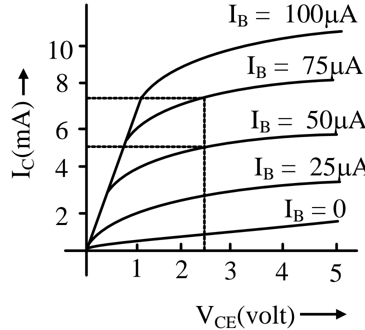
(ii) Now change emitter base voltage by R_1 and not the corresponding value of base current (I_B).

(iii) Plot the graph between V_{EB} and I_B.

(iv) A set of such curves can be plotted at different V_{CE}(say $V_{CE} = 2V$)

- **Output characteristics**

The variation of collector current I_C (output) with collector-emitter voltage (V_{CE}) at constant base current (I_B) is called output characteristic.



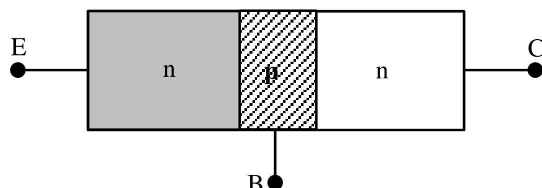
(i) Keep the base current (I_B) constant (say $I_B = 10\mu A$)

(ii) Now change the collector-emitter voltage (V_{CE}) using variable resistance R_2 and not the corresponding values of collector current (I_C).

(iii) Plot the graph between (V_{CE} versus I_C)

(iv) A set such curves can be plotted at different fixed values of base current (say 0, 20 μA, 30 μA etc.)

- Transistor have two P-N Junction J_{EB} and J_{CB}. On the bases of junction condition transistor work in four regions



Emitter-Base	Collector-Base	Region of working
Forward biased	Reverse biased	Active
Reverse biased	Forward biased	Inverse Active
Reverse biased	Reverse biased	Cut off
Forward biased	Forward biased	Saturation

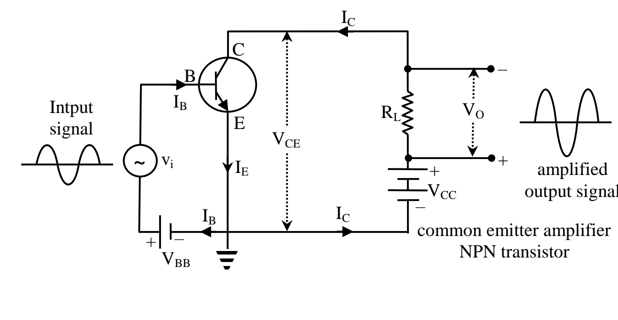
Emitter	Medium size	High dopping
Base	Smallest size	Low dopping
Collector	Largest size	Medium dopping

- The collector region is made physically larger than the emitter. Because collector has to dissipiate much greater power.
- Transistor all mostly work in active region in electronic devices & transistor work as amplifier in Active region only.
- Transistor i.e. It is a short form of two words ''Transfer resistors''. Signal is introduced at low resistance circuit and out put is taken at high resistance circuit.
- Base is lightly doped. Otherwise the most of the charge carrier from the emitter recombine in base region and not reaches at collector.
- Transistor is a current operated device i.e. the action of transistor is controlled by the motion of charge carriers. i.e. current

TRANSISTOR AS AN AMPLIFIER

The process of increasing the amplitude of input signal without distorting its wave shape and without change its frequency is known as amplification.

A device which increases the amplitude of the input signal is called amplifier.

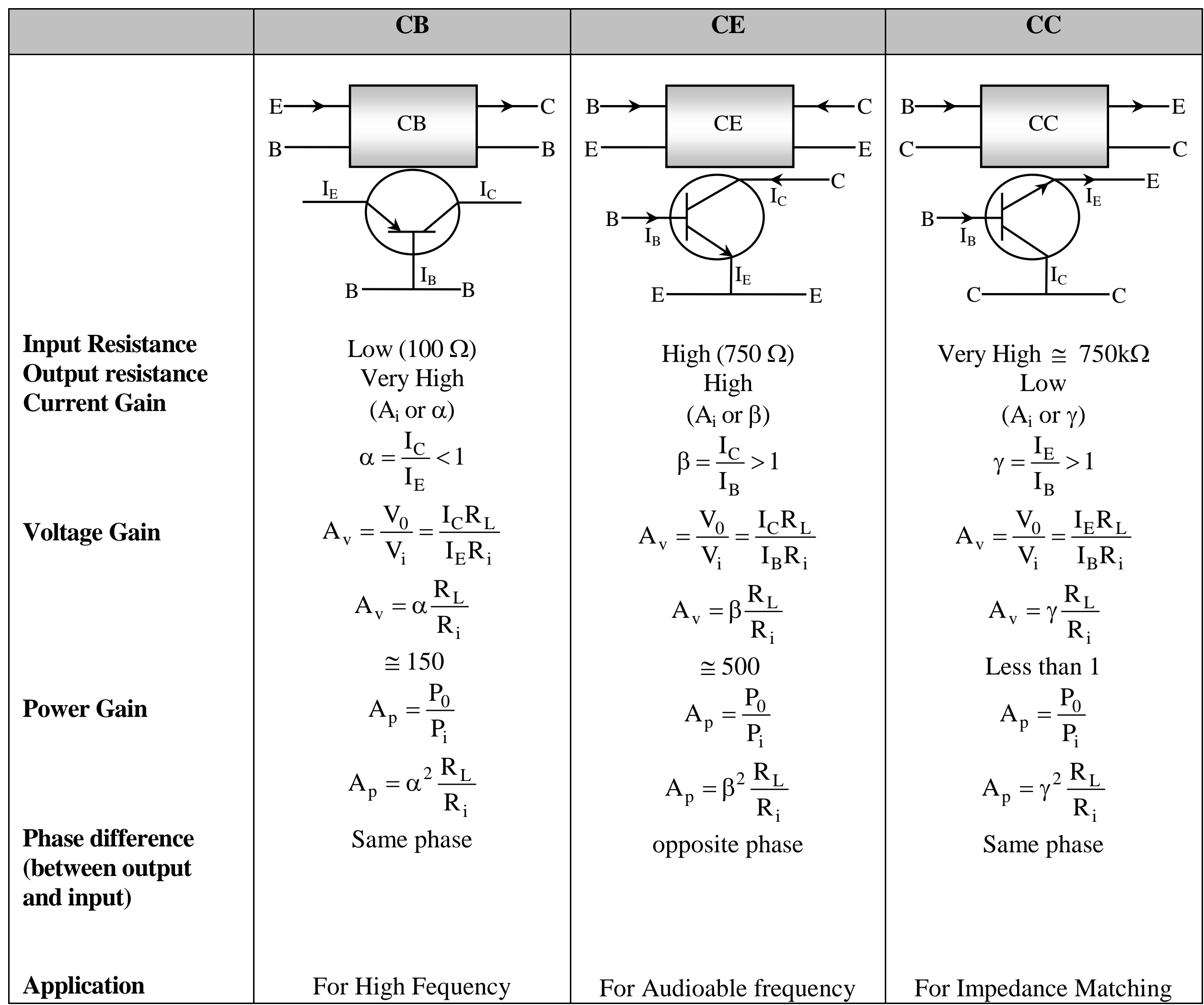


common emitter amplifier NPN transistor

amplifier

Comparative study of transistor configuration

1. Common Base (CB) 2. Common Emittor (CE) 3. Common Collector (CC)



	CB	CE	CC
Input Resistance	Low (100 Ω)	High (750 Ω)	Very High ≅ 750kΩ
Output resistance	Very High	High	Low
Current Gain	(A_i or α) $\alpha = \frac{I_C}{I_E} < 1$	(A_i or β) $\beta = \frac{I_C}{I_B} > 1$	(A_i or γ) $\gamma = \frac{I_E}{I_B} > 1$
Voltage Gain	$A_v = \frac{V_0}{V_i} = \frac{I_C R_L}{I_E R_i}$ $A_v = \alpha \frac{R_L}{R_i}$ ≅ 150	$A_v = \frac{V_0}{V_i} = \frac{I_C R_L}{I_B R_i}$ $A_v = \beta \frac{R_L}{R_i}$ ≅ 500	$A_v = \frac{V_0}{V_i} = \frac{I_E R_L}{I_B R_i}$ $A_v = \gamma \frac{R_L}{R_i}$ Less than 1
Power Gain	$A_p = \frac{P_0}{P_i}$ $A_p = \alpha^2 \frac{R_L}{R_i}$	$A_p = \frac{P_0}{P_i}$ $A_p = \beta^2 \frac{R_L}{R_i}$	$A_p = \frac{P_0}{P_i}$ $A_p = \gamma^2 \frac{R_L}{R_i}$
Phase difference (between output and input)	Same phase	opposite phase	Same phase
Application	For High Fequency	For Audioable frequency	For Impedance Matching

Relation between α, β and γ

α,β	β,γ	α,γ
$I_E = I_B + I_C$	$I_E = I_B + I_C$	$I_E = I_B + I_C$
divide by I_C	divide by I_B	$\gamma = 1 + \frac{\alpha}{1-\alpha}$
$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$	$\frac{I_E}{I_B} = 1 + \frac{I_C}{I_B}$	$\gamma = \frac{1}{1-\alpha}$
$\frac{1}{\alpha} = \frac{1}{\beta} + 1$	γ = 1 + β	
$\beta = \frac{\alpha}{1-\alpha}$		

- In transistor charge carriers move from emitter to collector. Emitter send the charge carriers and collector collect them this happen only when emitter-base junction is forward bias and collector-base junction is reverse bias (base of amplifier
- In transistor reverse bias is high as compared to forward bias so that the charge carriers move from emitter to base exert a large attractive force to enter in collector region so base current is very less.
- CE configuration is widely used because it have large voltage and power gain as compared to other amplifiers.
- In amplifier negative feed back is used to stabilized the gain.
- CC is used for impudence matching for connecting two transistors in cascade.

Q.1 A transistor is a current operated device. Explain why ?

Ans. The action of a transistor is controlled by the charge carriers (electrons or holes). That is why a transistor is a current operated device.

Q.2 In a transistor, reverse bias is quite high as compared to the forward bias. Why ?

Ans. In a transistor, charge carriers (electrons or holes) move from emitter to collector through the base. The reverse bias on collector is made quite high so that it may exert a large attractive force on the charge carriers to enter the collector region. These moving carriers in the collector constitute a collector current.

Q.3 A transistor is a temperature sensitive device. Explain.

Ans. In a transistor, conduction is due to the movement of current carriers electrons and holes. When temperature of the transistor increases, many covalent bonds may break up, resulting in the formation of more electrons and holes. Thus, the current will increase in the transistor. This current gives rise to the production of more heat energy. The excess heat causes complete breakdown of the transistor.

Q.4 The use of a transistor in common-emitter configuration is preferred over the common-base configuration. Explain whey ?

Ans. The current gain and hence voltage gain in the common-emitter configuration is much more than i of common-base configuration. Hence the former is preferred over the later.

Q.5 Why to we prefer transistor over the vacuum tubes in the portable radio receivers ?

Ans. This is because of two reasons:

(i) Transistor is compact and small in size than the vacuum tube.

(ii)Transistor can operate even at low voltage which can be supplied with two or three dry cells.

Q.6 Why a transistor cannot be used as a rectifier ?

Ans. If transistor is to be used as rectifier the either emitter-base or base-collector has to used as diode. For equated working of the said set of diodes, the number density of charge carriers in emitter and base or base and collector must be approximately same. As base is lightly doped and comparatively thin, so emitter cannot work as a rectifier.

Ex. In a transistor, the value of β is 50. Calculate the value of α.

Sol. $\beta = \frac{\alpha}{1-\alpha} \Rightarrow 50 = \frac{\alpha}{1-\alpha} \Rightarrow 50 - 50\alpha = \alpha \Rightarrow$

$\alpha = \frac{50}{51} = 0.98$

Ex. Calculate the emitter current for which

$I_B = 20\mu A, \beta = 100$

Sol. $I_C = \beta I_B = 100 \times 20 \times 10^{-6} = 2000\ \mu A$

$I_E = I_B + I_C = 20 + 2000 = 2020\mu A$

$= 2.02 \times 10^{-3}\ A = 2.02\ mA$

Ex. For a common emitter amplifier, current gain = 50. If the emitter current is 6.6 mA, calculate the collector and base current. Also calcualte current gain, When emitter is working as common base amplifier.

Sol. $\because\ \beta = \frac{I_C}{I_B} \qquad \therefore I_C = \beta I_B = 50 I_B \qquad ...(i)$

$I_E = I_C + I_B$ using equation (i) we get

$6.6 = 50\ I_B + I_B = 51\ I_B$

$\Rightarrow I_B = \frac{6.6}{51} = 0.129\ mA$

Hence $I_C = 50 \times \frac{6.6}{51} = 6.47\ mA$

And $\alpha = \frac{\beta}{1+\beta} = \frac{50}{51} = 0.98$

Ex. Transistor with β = 75 is connected to common-base configuration. What will be the maximum collector current for an emitter current of 5 mA ?

Sol. $\beta = 75, I_e = 5\ mA$

$\alpha = \frac{\beta}{1+\beta} = \frac{75}{1+75} = \frac{75}{76}$

$\because\ \alpha = \frac{I_C}{I_E} \qquad \therefore I_C = \alpha I_E = \frac{75}{76} \times 5 = 4.93\ mA$

Ex. The base current is 100μA and collector current is 3mA.

(a) Calculate the value of β, I_E and α

(b) A change of 20 μA in the base current produces a change of 0.5 mA in the collector current. Calculate $\beta_{a.c.}$

Sol. (a) $\beta = \frac{I_C}{I_B} = \frac{3}{0.100} = 30,$

$\alpha = \frac{\beta}{1+\beta}$

$= \frac{30}{1+30} = \frac{30}{31} = 0.97$ and

$I_E = \frac{I_C}{\alpha} = \frac{3 \times 31}{30} = 3.1\ mA$

(b) $\Delta I_B = 20\ \mu A = 0.02\ mA, \Delta I_C = 0.5\ mA$

$$\therefore \beta_{ac} = \frac{\Delta I_C}{\Delta I_B} = \frac{0.5}{0.02} = 25$$

Ex. In npn transistor circuit, the collector current is 10 mA. If 95% of the electrons emitted reach the collector, what is the base current ?

Sol. $I_C = 95\%\ I_E = 0.95\ I_E$

$$\Rightarrow I_E = \frac{I_C}{0.95} = \frac{100}{95} \times 10\text{mA} = 10.53 \text{ mA}$$

Now $I_E = I_C + I_B$

$\therefore I_B = I_E - I_C = 10.53 - 10 = 0.53$ mA

Ex. In an NPN transistor 10^{10} electrons enter the emitter in 10^{-6} s and 2% electrons recombine with holes in base, then current gain α and β are :

Sol. Emitter current

$$I_E = \frac{Ne}{t} = \frac{10^{10} \times 1.6 \times 10^{-19}}{10^{-6}} = 1.6 \text{ mA}$$

Base current $I_B = \frac{2}{100} \times 1.6 = 0.032$ mA

but $I_E = I_C + I_B$

$\therefore I_C = I_E - I_B = 1.6 - 0.032 = 1.568$ mA

$$\therefore \alpha = \frac{I_C}{I_E} = \frac{1.568}{1.6} = 0.98$$

$$\text{and } \beta = \frac{I_C}{I_B} = \frac{1.568}{0.032} = 49$$

Second method

$I_E = 100$ (let)

$I_C = 98$, $I_B = 2$

So $\alpha = \frac{I_C}{I_E} = 0.98$

$$\beta = \frac{I_C}{I_E} = 49$$

FEEDBACK

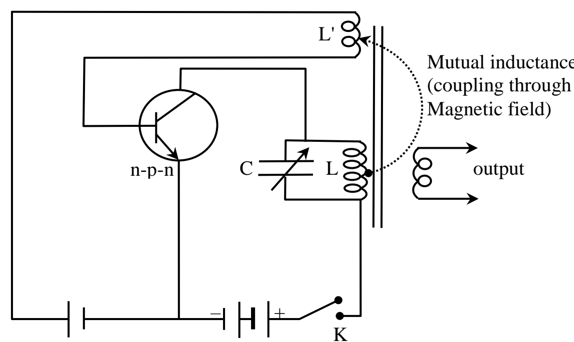
Feedback are two types:

- **Positive feedback**
  When input and output are in the same phase then positive feedback is there. It is used in oscillators.

- **Negative feedback**
  In input and output are out of phase and some part of that is feedback to input is known as negative feedback. It is used to get constant gain amplifier.

TRANSISTOR IN AN OSCILLATOR

Oscillator is device which delivers a.c. output wave form of desired frequency form d.c. power even without input singal excitation.



The electric oscillations are produced by L–C circuit (i.e. tank circuit containing inductor and capacitor). These oscillations are damped one i.e. their amplitude decrease with the passage of time due to the small resistance of the inductor. In other words, the energy of the L-C oscillations decreases. If this loss of energy is compensated from outside, then undamped oscillations (of constant amplitude) can be obtained. This can be done by using feeback arrangement and a transistor in the circuit.

L-C circuit producing L-C oscillations consists of an inductor of inductance L and capacitor of variable capacitance C inductor of inductance L' is connected in the collector-emitter circuit through a battery and a tapping key (K). Inductors L and L' are inductively coupled (Figure)

Working

When key K is closed, collector current begins to flow through the coil L. As this current grows, magnetic flux linked with coil L increases (i.e. changes).

Since coil L is inductively coupled with L' so magnetic flux linked with coil L' also changes. Due to change in magnetic flux, induced e.m.f. is set up across the coil L'.

The direction of induced e.m.f. is such that the emitter-base junction is forward biased. As a result of this biasing, emitter current I_E increases which in turn increases the collector current I_C [$\therefore I_E = I_B + I_C$].

With the increase in collector current, magnetic flux linked with coil L also increases. This increases the e.m.f. induced in the coil L'.

The increased induced e.m.f. increases the forward bias of emitter-base junction. Hence emitter current is further increased which in turn increases the collector current. The process of increasing the collector current continues till the magnetic flux linked with coil L' becomes maximum (i.e.

constant). At this stage, the induced e.m.f. in coil L' becomes zero.

The upper plate of the capacitor C gets positively charged during this process.

The when induced e.m.f. becomes zero, the capacitor C states discharging through the inductor? When emitter current starts decreasing resulting in the collector current. With decreasing collector current which flow through L', e.m.f. is again induced in the coil L' but in the opposite direction. It opposes the emitter current and hence collector current ultimately decreases to zero.

The change in magnetic flux linked with coil L' stops and hence induced e.m.f. in the coil L becomes zero. At this stage, the capacitor gets discharged through coil L but now in the opposite direction. Now the emitter current and hence collector current increase but now in the opposite direction.

This process repeats and the collector current oscillates between maximum and minimum values. Oscillating frequency $f = \frac{1}{2\pi\sqrt{LC}}$

ADVANTAGES OF SEMICONDUCTOR DEVICES OVER VACUUM TUBES

Advantages

- Semiconductor devices are very small in size as compared to the vacuum tubes. Hence the circuits using semiconductor devices are more compact.
- In vacuum tubes, current flow when the filament is heated and starts emitting electrons. So, we have to wait for some time for the operation of the circuit. On the other hand, in semiconductor devices no heating is required and the circuit begins to operate as soon as it switched on.
- Semiconductor devices require low voltage for their operation as compared to the vacuum tube. So a lot of electrical power is saved.
- Semiconductor devices do not produce any humming noise which is large in case of vacuum tube.
- Semiconductor devices have longer life than the vacuum tube. Vacuum tube gets damaged when its filament is burnt.
- Semiconductor devices are shock proof.
- The cost of production of semiconductor devices is very small as compared to the vacuum tubes.
- Semiconductor devices can be easily transported as compared to vacuum tube.

Disadvantages

- Semiconductor devices are heat sensitive. They get damaged due to overheating and high voltages. So they have to be housed in a controlled temperature room.
- The noise level in semiconductor devices is very high.
- Semiconductor devices have poor response in high frequency range.

Q.1 Why is a transistor so called ?

Ans. The word Transistor can be treated as short form of two words 'transfer resistor'. In a transistor, a signal is introduced in the low resistance circuit and output is taken across the high resistance circuit. Thus, a transistor helps to transfer the current from low resistance part to the high resistance part.

Q.2 The base region of a transistor is lightly doped. Explain why ?

or

In a transistor, the base is lightly doped. Explain why ?

Ans. In a transistor, the majority carriers (holes or electrons) from emitter region move towards the collector region through base. If base is made thick and highly doped, then majority of carriers from emitter will combine with the carriers in the base and only small number of carriers will reach the collector. Thus the output or collector current will be considerably small. To get large output or collector current, base is made thin and lightly doped so that only few electron-hole combination may take place in the base region.

Q.3 Explain why the emitter is forward biased and the collector is reverse biased in a transistor ?

Ans. IN a transistor, the charge carriers move from emitter to collector. The emitter sends the charge carriers and collector collects them. This can happen only if emitter is forward biased and the collector is reverse biased so that it may attract the carriers.