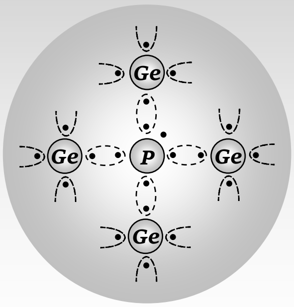
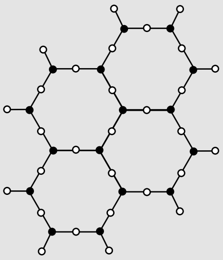
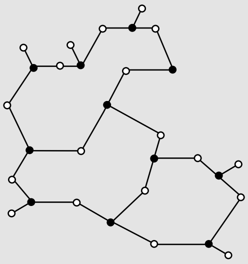


Solids and Semi-conductor Devices

Solids

It is a state of matter which has a definite shape and a definite volume. The characteristic properties of the solid depends upon the nature of forces acting between their constituent particles (*i.e.* ions, atoms or molecules). Solids are divided into two categories.

Crystalline solids	Amorphous or glassy solids
(1) These solids have definite external geometrical form.	These solids have no definite external geometrical form.
(2) Ions, atoms or molecules of these solid are arranged in a definite fashion in all it's three dimensions. 	Ions, atoms or molecules of these solids are not arranged in a definite fashion. 
(3) Examples : Quartz, calacite, mica, diamond etc.	Example : Rubber, plastic, paraffin wax, cement *etc.*
(4) They have well defined facets or faces.	They do not possess definite facets or faces.
(5) They are ordered at short range as well as at long range.	These may be short range order, but there is no long range order.
(6) They are anisotropic, *i.e.* the physical properties like elastic modulii, thermal conductivity, electrical conductivity, refractive index have different values in different direction.	They are isotropic *i.e.* physical properties are similar in all direction.
(7) They have sharp melting point.	They may not have a sharp melting point.
(8) Bond strengths are identical throughout the	Bond strengths vary.

solid.	
(9) These are considered as true solids.	These are considered as pseudo-solids or super cooled liquids.
(10) An important property of crystals is their symmetry.	Amorphous solids do not have any symmetry.

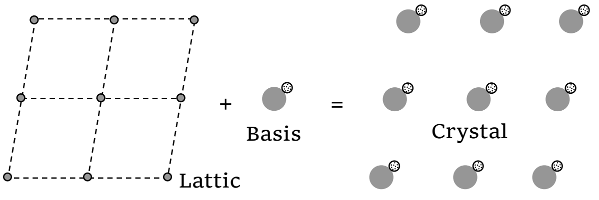
Terms Related With Crystal Structure

(1) **Crystal lattice**

It is a geometrical arrangement of points in space where if atoms or molecules of a solid are placed, we obtain an actual crystal structure of the solid.

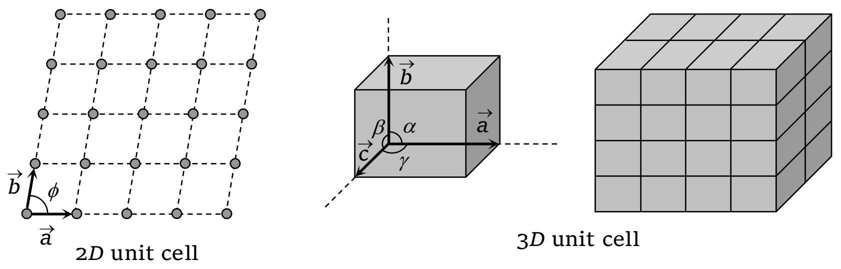
(2) **Basis**

The atoms or molecules attached with every lattice point in a crystal structure is called the basis of crystal structure. Thus,



(3) **Unit cell**

Is defined as that volume of the solid from which the entire crystal structure can be constructed by the translational repetition in three dimensions. The length of three sides of a unit cell (3D) are called primitives or lattice constant they are denoted by a, b, c



2D unit cell

3D unit cell

(4) **Primitive cell**

A primitive cell is a minimum volume unit cell or the simple unit cell with particles only at the corners is a primitive unit cell and other types of unit cells are called non-primitive unit cells. There is only one lattice point per primitive cell.

(5) **Crystallographic axis**

The lines drawn parallel to the lines of intersection of the faces of the unit cell are called crystallographic axis.

Note : ☐ The location of each atom or molecule in a crystal lattice may be marked as a point which is called lattice point.

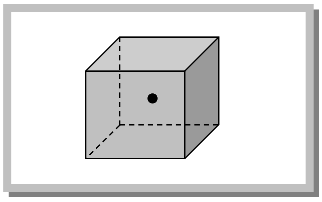
All the crystals on the basis of the shape of their unit cells, have been divided into seven crystal systems as shown in the following table.

S. No.	System	No. of lattices	Lattice constants	Angle between lattice constants	Examples
(i)	Cubic	3	$a = b = c$	$\alpha = \beta = \gamma = 90^o$	Diamond, $NaCl$, Li, Ag, Cu, NH_4Cl, Pb *etc.*
(ii)	Tetragonal	2	$a = b \neq c$	$\alpha = \beta = \gamma = 90^o$	White tin, $NiSO_4$ *etc.*
(iii)	Orthorhombic	4	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^o$	$HgCl_2$, KNO_3, gallium *etc.*
(iv)	Monoclinic	2	$a \neq b \neq c$	$\alpha = \gamma = 90^o$ and $\beta \neq 90^o$	$KclO_3$, $FeSO_4$ *etc.*
(v)	Triclinic	1	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^o$	$K_2Cr_2O_7$, $CuSO_4$ *etc.*
(vi)	Rhombo-hedral or Trigonal	1	$a = b = c$	$\alpha = \beta = \gamma \neq 90^o$	Calcite, As, Sb, Bi *etc.*
(vii)	Hexagonal	1	$a = b \neq c$	$\alpha = \beta = 90^o$ and $\gamma = 120^o$	Zn, Cd, Ni *etc.*

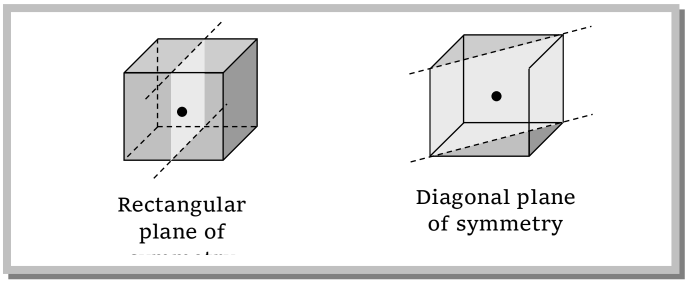
Cubic Lattices

(1) **Different symmetry**

(i) **Centre of symmetry :** An imaginary point within the crystal that any line drawn through it intersects the surface of the crystal at equal distances in both directions.

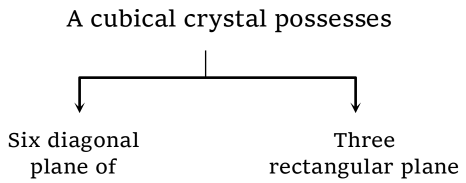


(ii) **Plane of symmetry :** It is an imaginary plane which passes through the centre of a crystal and divides it into two equal portions such that one part is exactly the mirror image of the other.



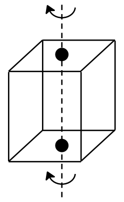
Rectangular plane of

Diagonal plane of symmetry

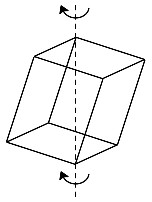


(iii) **Axis of symmetry** : It is an imaginary straight line about which, if the crystal is rotated, it will present the same appearance more than once during the complete revolution.

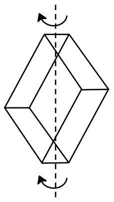
In general, if the same appearance of a crystal is repeated on rotating through an angle $\frac{360^o}{n}$, around an imaginary axis, the axis is called an *n*-fold axis.



Axis of four-fold symmetry (three)



Axis of three-fold symmetry (four)



Axis of two-fold symmetry (six)

A cubical crystal possesses in all 13 axis of symmetry.

(iv) **Elements of symmetry :** The total number of planes, axes and centre of symmetry possessed by a crystal are termed as elements of symmetry. A cubic crystal possesses a total of 23 elements of symmetry.

Planes of symmetry $=(3+6)=9$, Axes of symmetry $=(3+4+6)=13$, Centre of symmetry = 1.

Total number of symmetry elements = 23

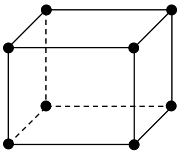
(2) **Different lattice in cubic crystals**

There are three lattice in the cubic system.

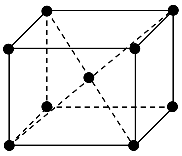
The simple cubic (*sc*) lattice.

The body-centered cubic (*bcc*).

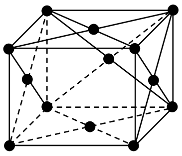
The face-centered cubic (*fcc*).



SC



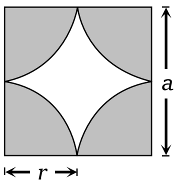
BCC



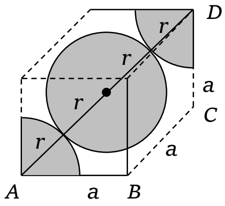
FCC

(3) **Atomic radius**

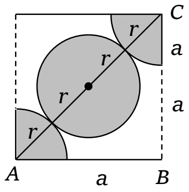
The half of the distance between two atoms in contact is defined as atomic radius.



sc unit cell
$r = a/2$



bcc unit cell
$r = \sqrt{3}\,a/4$



bcc unit cell
$r = a/2\sqrt{2}$

(4) **Atoms per unit cell**

An atom located at the corner of a unit cell of a lattice is shared equally by eight other unit cells in the three dimensional lattice. Therefore, each unit cell has 1/8th share of an atom at its each corner. Similarly, a face of the unit cell is common to the two unit cells in the lattice. Therefore, each unit cell has 1/2 share of an atom at its each face. The atom located at the centre of the unit cell belongs completely to the unit cell.

Let N_c, N_b and N_f be the number of atoms at the corners, centre and face of the unit cell respectively. Therefore the number of atoms per unit cell is given by $N = N_b + \frac{N_f}{2} + \frac{N_c}{8}$

(i) In *sc* lattice : $N_b = 0,\ N_f = 0,\ N_c = 8$ so $N = 1$

(ii) In *bcc* lattice : $N_b = 1,\ N_f = 0,\ N_c = 8$ so $N = 2$

(iii) In *fcc* lattice : $N_b = 0,\ N_f = 6,\ N_c = 8$ so $N = 4$

(5) **Co-ordination number**

It is defined as the number of nearest neighbours that an atom has in a unit cell. It depends upon structure.

(i) Simple cubic structure : Each atom has two neighbours along *X*-axis, two along *Y*-axis and two along *Z*-axis so coordination number = 6.

(ii) Face-centred cubic structure: Every corner atom has four neighbours in each of the three planes *XY*, *YZ*, and *ZX* so coordination number = 12

(iii) Body-centred cubic structure: The atom of the body of the cell has eight neighbours at eight corner of the unit cell so coordination number = 8.

(6) **Atomic packing fraction (or packing factor or relative packing density)**

The atomic packing fraction indicates how close the atoms are packed together in the given crystal structure or the ratio of the volume occupied by atoms in a unit cell in a crystal and the volume of unit cell is defined as APF.

(i) **For *sc* crystal :** Volume occupied by the atom in the unit cell $= \frac{4}{3}\pi r^3 = \frac{\pi a^3}{6}$. Volume of the unit cell $= a^3$

$$\text{Thus P.F.} = \frac{\pi a^3/6}{a^3} = \frac{\pi}{6} = 0.52 = 52\%$$

(ii) **For *bcc* :** P.F. $= \frac{\sqrt{3}\pi}{8} = 68\%$ (iii) **For *fcc* :** P.F. $= \frac{\pi}{3\sqrt{2}} = 74\%$

(7) **Density of unit cell**

$$\text{Density of unit cell} = \frac{\text{Mass of the unit cell}}{\text{Volume of the unit cell}} = \frac{nA}{NV} = \frac{nA}{Na^3}$$

where n = Number of atoms in unit cell (For *sc* lattice n = 1, for *bcc* lattice n = 2, for *fcc* lattice n = 4), A = atomic weight, N = Avogadro's number, V = Volume of the unit cell.

(8) **Bond length**

The distance between two nearest atoms in a unit cell of a crystal is defined as bond length.

(i) In a *sc* lattice : Bond length = a (ii) In a *bcc* lattice : Bond length $= \frac{\sqrt{3}a}{2}$ (iii) In a *fcc* lattice : Bond length $= \frac{a}{\sqrt{2}}$

Note : ☐ Hexagonal closed packed (HCP) lattice –

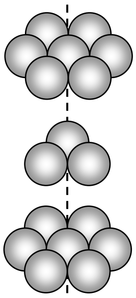
$\Rightarrow a = b \neq c$

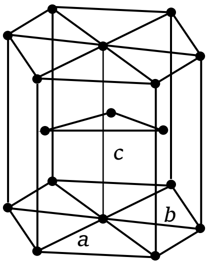
$\Rightarrow$ Coordination number = 12

$\Rightarrow$ P.F. $= \frac{\pi\sqrt{2}}{6}$

$\Rightarrow$ Number of atoms per unit cell = 2

$\Rightarrow$ Magnesium is a special example of HCP lattice structure.





Types of Binding and Crystals

(1) **Binding :** Bindings among the atoms or molecules are mainly of following types.

S. No.	Binding	Cause of binding	M.P.	Electrical conductivity	Examples
(i)	Ionic	Electrostatic force between positive and negative ions	Very high	Very low	*NaCl*, *CsCl*, *LiF* etc.
(ii)	Covalent	Sharing of electrons of opposite spins between two neutral atoms	High	Semi conductor	*Ge*, *Si*, diamond etc.
(iii)	Hydrogen	Mutual electrostatic interaction between molecules of surface of different electron densities	Low	Insulator	H_2O
(iv)	Vander Waal	Non polar molecules or Vander Waal forces or dipole-dipole interaction	Low	Normally insulator	*HF*, NH_3etc.
(v)	Metallic	Mutual interaction between electrons and ion lattice	—	High	Cl_2, I_2, CO_2 *etc.*

(2) **Three kinds of crystals**

(i) **Single crystal :** The crystals in which the periodicity of the pattern extends throughout the piece of the crystal are known as single crystals. Single crystals have anisotropic behaviour *i.e.* their physical properties (like mechanical strength, refractive index, thermal and electrical conductivity) are different along different directions. The small sized single crystals are called mono-crystals.

(ii) **Poly-crystals :** A poly-crystal is the aggregate of the monocrystals whose well developed faces are joined together so that it has isotropic properties. Ceramics are the important illustrations of the poly-crystalline solids.

(iii) **Liquid crystals :** The organic crystalline solid which on heating, to a certain temperature range becomes fluid like but its molecules remain oriented in a particular directions, showing that they retain their anisotropic properties, is called liquid crystal. These crystals are used in a liquid crystal displays (L.C.D.) which are commonly used in electronic watches, clocks and micro-calculators *etc*.

Energy Bands

In isolated atom the valence electrons can exist only in one of the allowed orbitals each of a sharply defined energy called energy levels. But when two atoms are brought nearer to each other, there are alterations in energy levels and they spread in the form of bands.

Energy bands are of following types

(1) **Valence band**

The energy band formed by a series of energy levels containing valence electrons is known as valence band. At 0 *K*, the electrons fills the energy levels in valence band starting from lowest one.

(i) This band is always fulfill by electron.

(ii) This is the band of maximum energy.

(iii) Electrons are not capable of gaining energy from external electric field.

(iv) No flow of current due to such electrons.

(v) The highest energy level which can be occupied by an electron in valence band at 0 *K* is called fermi level.

(2) **Conduction band**

The higher energy level band is called the conduction band.

(i) It is also called empty band of minimum energy.

(ii) This band is partially filled by the electrons.

(iii) In this band the electrons can gain energy from external electric field.

(iv) The electrons in the conduction band are called the free electrons. They are able to move any where within the volume of the solid.

(v) Current flows due to such electrons.

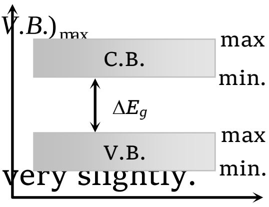
(3) **Forbidden energy gap (ΔE_g)**

Energy gap between conduction band and valence band $\Delta E_g = (C.B.)_{\min} - (V.B.)_{\max}$

(i) No free electron present in forbidden energy gap.

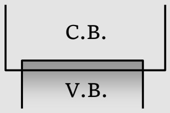
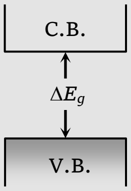
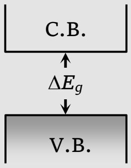
(ii) Width of forbidden energy gap upon the nature of substance.

(iii) As temperature increases (↑), forbidden energy gap decreases (↓) very slightly.



Types of Solids

On the basis of band structure of crystals, solids are divided in three categories.

S.No.	Properties	Conductors	Insulators	Semiconductors
(1)	Electrical conductivity	10^2 to 10^8 $\mho/m$	10^{-8} $\mho/m$	10^{-5} to 10^0 $\mho/m$
(2)	Resistivity	10^{-2} to 10^{-8} Ω-m (negligible)	10^8 Ω-m	10^5 to 10^0 Ω-m
(3)	Band structure			
(4)	Energy gap	Zero or very small	Very large; for diamond it is 6 eV	For Ge E_g = 0.7 eV for Si E_g = 1.1 eV
(5)	Current carries	Free electrons	--	Free electrons and holes
(6)	Condition of V.B. and C.B. at ordinary temperature	V.B. and C.B. are completely filled or C.B. is some what empty	V.B. – completely filled C.B. – completely unfilled	V.B. – somewhat empty C.B. – somewhat filled
(7)	Temperature co-efficient of resistance (α)	Positive	Zero	Negative
(8)	Effect of temperature on conductivity	Decreases	—	Increases
(9)	Effect of temperature on resistance	Increases	—	Decreases
(11)	Examples	Cu, Ag, Au, Na, Pt, Hg etc.	Wood, plastic, mica, diamond, glass etc.	Ge, Si, Ga, As etc.
(12)	Electron density	$10^{29}/m^3$	—	$Ge \sim 10^{19}\ /m^3$ $Si \sim 10^{16}\ /m^3$

Holes in semiconductors

At absolute zero temperature (0 K) conduction band of semiconductor is completely empty and the semiconductor behaves as an insulator.

When temperature increases the valence electrons acquires thermal energy to jump to the conduction band (Due to the braking of covalent bond). If they jumps to C.B. they leaves behind the deficiency of electrons in the valence band. This deficiency of electron is known as ***hole*** or cotter. A hole is considered as a seat of positive charge, having magnitude of charge equal to that of an electron.

(1) Holes acts as virtual charge, although there is no physical charge on it.

(2) Effective mass of hole is more than electron.

(3) Mobility of hole is less than electron.

Types of Semiconductors

(1) **Intrinsic semiconductor**

A pure semiconductor is called intrinsic semiconductor. It has thermally generated current carriers

(i) They have four electrons in the outermost orbit of atom and atoms are held together by covalent bond

(ii) Free electrons and holes both are charge carriers and n_e (in C.B.) $= n_h$ (in V.B.)

(iii) The drift velocity of electrons $(v_e)$is greater than that of holes(v_h)

(iv) For them fermi energy level lies at the centre of the C.B. and V.B.

(v) In pure semiconductor, impurity must be less than 1 in 10^8 parts of semiconductor.

(vi) In intrinsic semiconductor $n_e^{(o)} = n_h^{(o)} = n_i = AT^{3/2}e^{-\Delta E_g/2KT}$; where $n_e^{(o)} =$ Electron density in conduction band, $n_h^{(o)} =$ Hole density in V.B., $n_i =$ Density of intrinsic carriers.

(vii) Because of less number of charge carriers at room temperature, intrinsic semiconductors have low conductivity so they have no practical use.

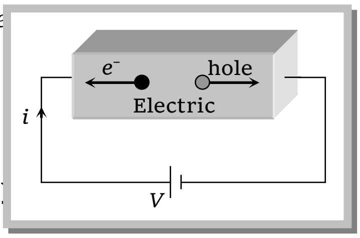
Net current and conductivity

When some potential difference is applied across a piece of intrinsic semiconductor current flows in it due to both electron and holes *i.e.* $i = i_e + i_h \Rightarrow i = n_e eAv_e \quad i = e$

Hence conductivity of semiconductor $\sigma = e[n_e\mu_e + n_h\mu_h]$

where v_e = drift velocity of electron, v_h = drift velocity of holes,

E = Applied electric field $\mu_e = \dfrac{v_e}{E}$ = mobility of e^- and $\mu_n = \dfrac{v_h}{E}$ = mobilit



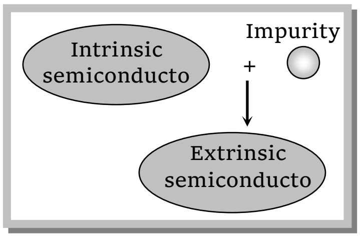
Note : ❑ $(ni)_{Ge} \simeq 2.4\times10^{19}\,/m^3$ and $(ni)_{Si} \simeq 1.5\times10^{16}\,/m^3$

❑ At room temperature $\sigma_{Ge} > \sigma_{Si}$

❑ $\mu_e > \mu_h$

❑ Conductivity of semiconductor increases with temperature because number density of charge carriers increases.

❑ In a doped semiconductor, the number density of electrons and holes is not equal. But it can be established that $\boldsymbol{n_e\,n_h = n_i^2}$; where n_e, n_h are the number density of electrons and holes respectively and n_i is the number density of intrinsic curries (*i.e.* electrons or holes) in a pure semiconductor. This product is independent of donor and acceptor impurity doping.



(2) **Extrinsic semiconductor**

(i) It is also called impure semiconductor.

(ii) The process of adding impurity is called Doping.

(iii) Impurities are of two types :

Pentavalent impurity	Trivalent impurity
The elements whose atom has five valance impurities e.g. As, P, Sb etc. These are also called donor impurities. These impurities are also called donor impurities because they donates extra free electron.	*The elements whose each atom has three valance electrons are called trivalent impurities e.g. In, Ga, Al, B, etc. These impurities are also called acceptor impurities as they accept electron.*

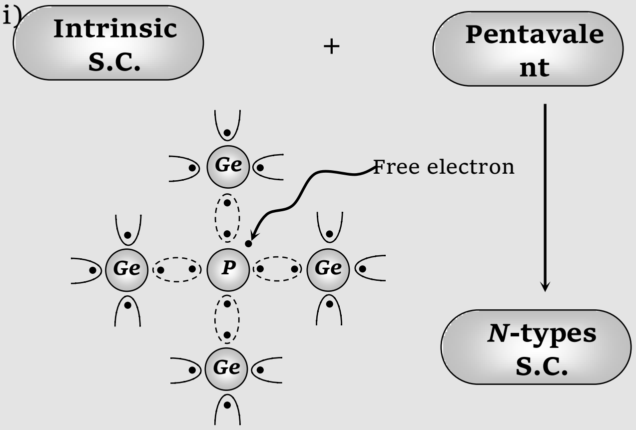
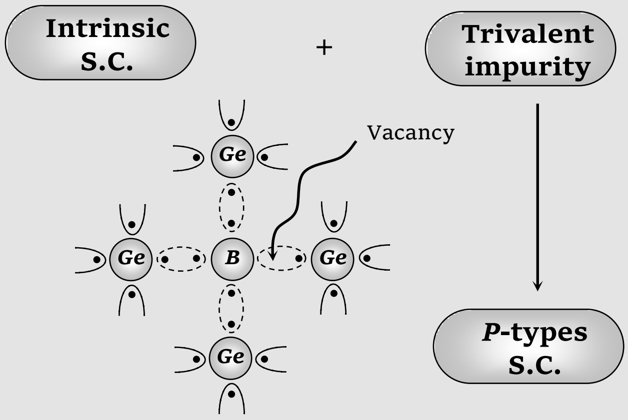
(iv) The number of atoms of impurity element is about 1 in 10^8 atoms of the semiconductor.

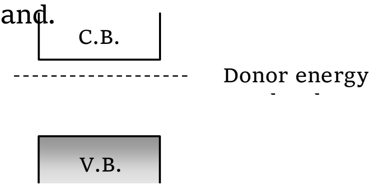
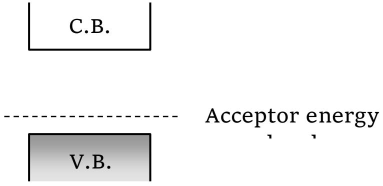
(v) $n_e \neq n_h$

(vi) In these fermi level shifts towards valence or conduction energy bands.

(vii) Their conductivity is high and they are practically used.

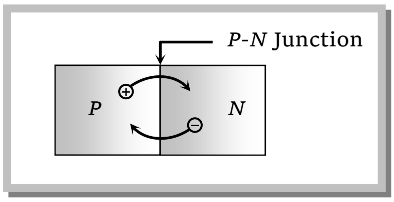
(3) **Types of extrinsic semiconductor**

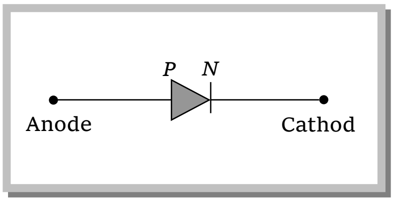
***N*-type semiconductor**	***P*-type semiconductor**
(i) 	
(ii) Majority charge carriers – electrons Minority charge carriers – holes	Majority charge carriers – holes Minority charge carriers – electrons
(iii) $n_e >> n_h$; $i_e >> i_h$	$n_h >> n_e$; $i_h >> i_e$
(iv) Conductivity $\sigma \approx n_e \mu_e e$	Conductivity $\sigma \approx n_h \mu_h e$
(iv) *N*-type semiconductor is electrically neutral (not negatively charged)	*P*-type semiconductor is also electrically neutral (not positively charged)
(v) Impurity is called Donar impurity because one impurity atom generate one e^- .	Impurity is called Acceptor impurity.

(vi) Donor energy level lies just below the conduction band.  	Acceptor energy level lies just above the valence band. 

P-N Junction Diode

When a *P*-type semiconductor is suitably joined to an *N*-type semiconductor, then resulting arrangement is called *P-N* junction or *P-N* junction diode

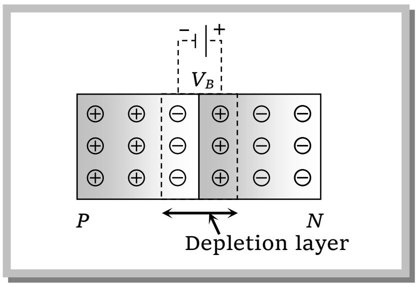




(1) **Depletion region**

On account of difference in concentration of charge carrier in the two sections of *P-N* junction, the electrons from *N*-region diffuse through the junction into *P*-region and the hole from *P* region diffuse into *N*-region.

Due to diffusion, neutrality of both *N* and *P*-type semiconductor is disturbed, a layer of negative charged ions appear near the junction in the *P*-crystal and a layer of positive ions appears near the junction in *N*-crystal. This layer is called depletion layer



(i) The thickness of depletion layer is 1 *micron* = 10^{-6} *m*.

(ii) Width of depletion layer $\propto \frac{1}{\text{Dopping}}$

(iii) Depletion is directly proportional to temperature.

(iv) The *P-N* junction diode is equivalent to capacitor in which the depletion layer acts as a dielectric.

(2) **Potential barrier**

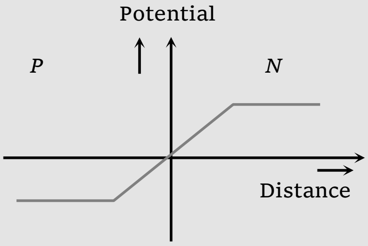
The potential difference created across the *P-N* junction due to the diffusion of electron and holes is called potential barrier.

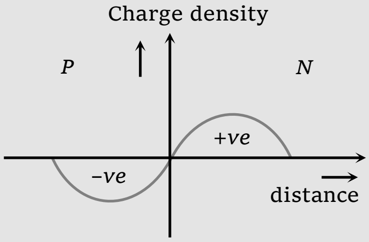
For $Ge \quad V_B = 0.3V$ and for silicon $V_B = 0.7V$

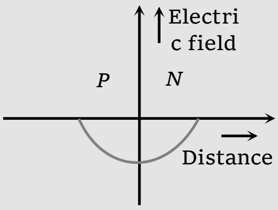
On the average the potential barrier in *P-N* junction is ~ 0.5 *V* and the width of depletion region ~ 10^{-6}.

So the barrier electric field $E = \frac{V}{d} = \frac{0.5}{10^{-6}} = 5 \times 10^{5}\ V/m$

Some important graphs







(3) **Diffusion and drift current**

Because of concentration difference holes/electron try to diffuse from their side to other side. Only these holes/electrons crosses the junction, having high kinetic energy. This diffusion results is an electric current from the *P*-side to the *N*-side known as diffusion current (i_{df})

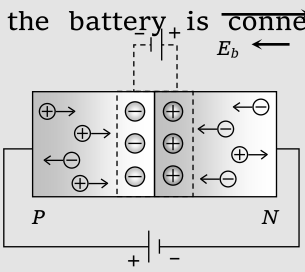
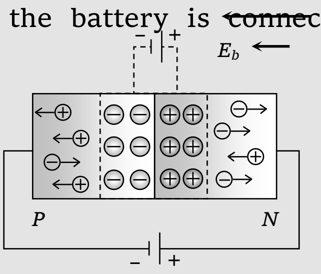
As electron hole pair (because of thermal collisions) are continuously created in the depletion region. These is a regular flow of electrons towards the *N*-side and of holes towards the *P*-side. This makes a current from the *N*-side to the *P*-side. This current is called the drift current (i_{dr}).

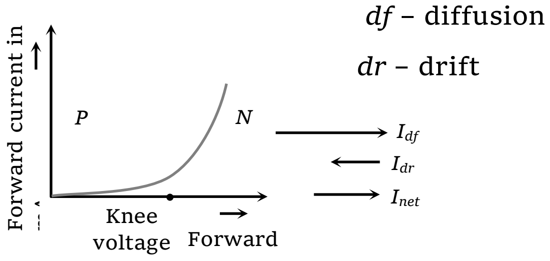
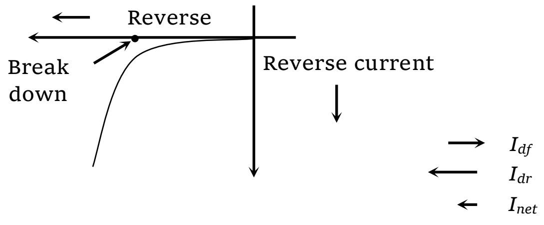
Note : ❑ In steady state $i_{df} = i_{dr}$ so $i_{net} = 0$

❑ When no external source is connected, diode is called unbiased.

(4) **Biasing**

Means the way of connecting *emf* source to *P*-*N* junction diode

Forward biasing	**Reverse biasing**
(i) Positive terminal of the battery is connected to the *P*-crystal and negative terminal of the battery is connected to *N*-crystal 	(i) Positive terminal of the battery is connected to the *N*-crystal and negative terminal of the battery is connected to *P*-crystal 
(ii) Width of depletion layer decreases	(ii) Width of depletion layer increases
(iii) $R_{\text{Forward}} \approx 10\Omega - 25\Omega$	(iii) $R_{\text{Reverse}} \approx 10^5\Omega$
(iv) Forward bias opposes the potential barrier and for $V > V_B$ a forward current is set	(iv) Reverse bias supports the potential barrier and no current flows across the

up across the junction.	junction due to the diffusion of the majority carriers. (A very small reverse currents may exist in the circuit due to the drifting of minority carriers across the junction)
(v) Cut-in (Knee) voltage : The voltage at which the current starts to increase. For *Ge* it is 0.3 *V* and for *Si* it is 0.7 *V*.	(v) Break down voltage : Reverse voltage at which break down of semiconductor occurs. For *Ge* it is 25 *V* and for *Si* it is 35 *V*.
(vi) 	(vi) 

Reverse Breakdown and Special Purpose Diodes

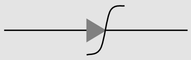
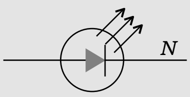
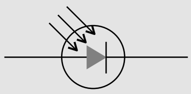
(1) **Zener breakdown**

When reverse bias is increased the electric field at the junction also increases. At some stage the electric field becomes so high that it breaks the covalent bonds creating electron, hole pairs. Thus a large number of carriers are generated. This causes a large current to flow. This mechanism is known as **Zener breakdown.**

(2) **Avalanche breakdown**

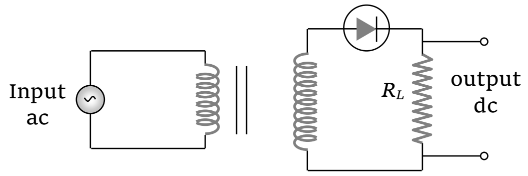
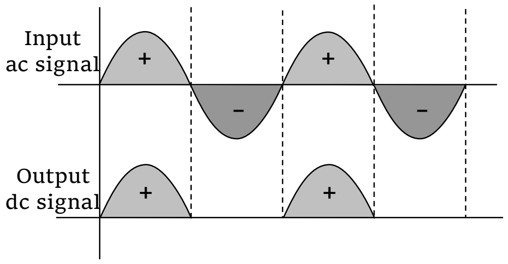
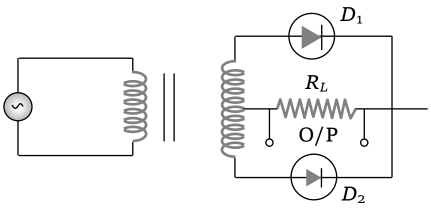
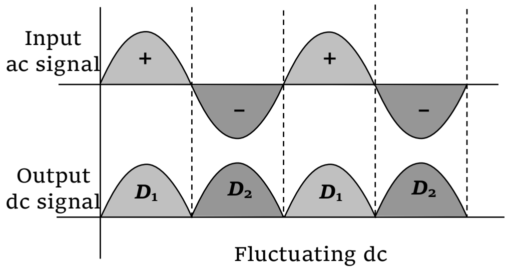
At high reverse voltage, due to high electric field, the miniority charge carriers, while crossing the junction acquires very high velocities. These by collision breaks down the covalent bonds, generating more carriers. A chain reaction is established, giving rise to high current. This mechanism is called **avalanche breakdown.**

(3) **Special purpose diodes**

Zener diode	**Light emitting diode (LED)**	**Photo diode**	**Solar cells**
 It is a highly doped *p-n* junction which is not damaged by high reverse current. The breakdown voltage is made very sharp. In	 Specially designed diodes, which give out light radiations when forward biases. LED'S are made of *GaAsp*, *Gap* etc.	 In these diodes electron and hole pairs are created by junction photoelectric effect. That is the covalent bonds are	It is based on the photovoltaic effect. One of the semiconductor region is made so thin that the light incident on it reaches the *p-n* junction and gets absorbed. It converts

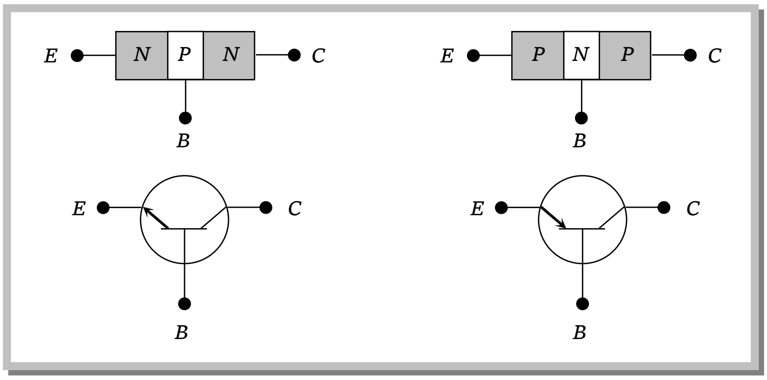
the forward bias, the zener diode acts as ordinary diode. It can be used as voltage regulator		broken by the EM radiations absorbed by the electron in the V.B. These are used for detecting light signals.	solar energy into electrical energy.

P-N Junction Diode as a Rectifier

Half wave rectifier	**Full wave rectifier**
  During positive half cycle Diode → forward biased Output signal → obtained During negative half cycle Diode → reverse biased Output signal → not obtained	  During positive half cycle Diode : D_1 → forward biased D_2 → reverse biased Output signal → obtained due to D_1 only During negative half cycle Diode : D_1 → reverse biased D_2 → forward biased Output signal → Filter tained due to D_2 only *Note* : ❑ Fluctuating dc constant dc.

Transistor

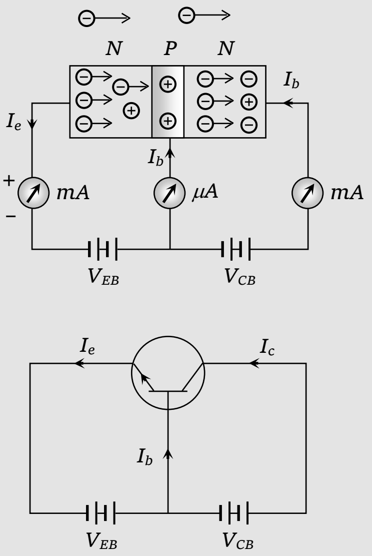
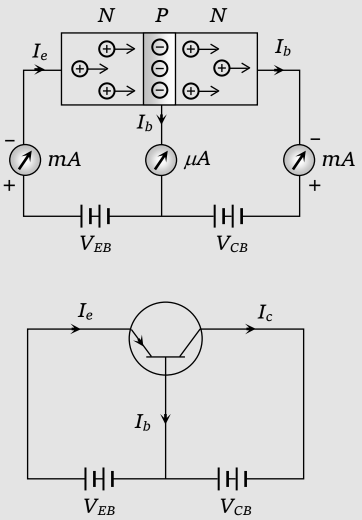
A junction transistor is formed by sandwiching a thin layer of *P*-type semiconductor between two *N*-type semiconductors or by sandwiching a thin layer of *n*-type semiconductor between two *P*-type semiconductor.



E – Emitter (emits majority charge carriers)
C – Collects majority charge carriers
B – Base (provide proper

Note : ❑ In normal operation base-emitter is forward biased and collector base junction is reverse biased.

(1) **Working of Transistor :** In both transistor emitter - base junction is forward biased and collector – base junction is reverse biased.

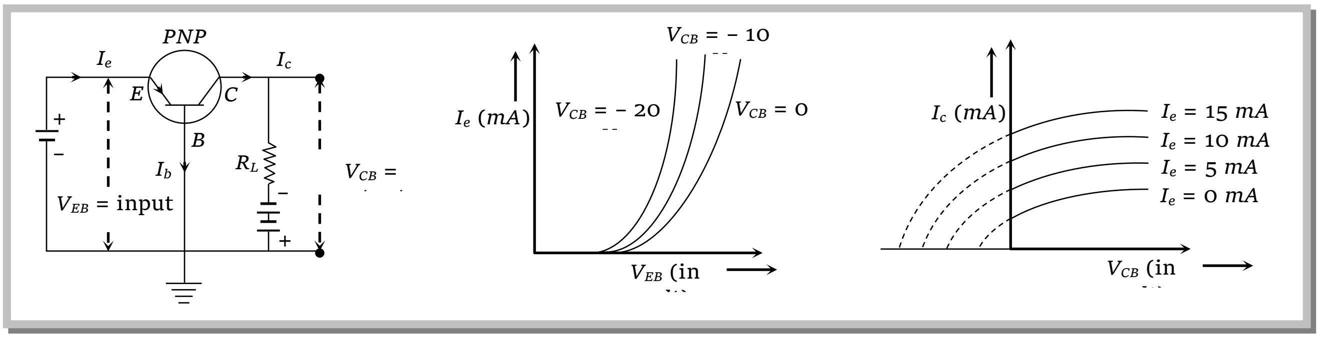
***NPN* – transistor**	***PNP* – transistor**
	
5% emitter electron combine with the holes in the base region resulting in small base current. Remaining 95% electrons enter the collector region.	5% emitter holes combine with the electrons in the base region resulting in small base current. Remaining 95% holes enter the collector region.
$I_e > I_c$, and $I_c = I_b + I_c$	$I_e > I_c$, and $I_c = I_b + I_c$

Note : ❑ In a transistor circuit the reverse bias is high as compared to the forward bias. So that it may exert a large attractive force on the charge carriers to enter the collector region.

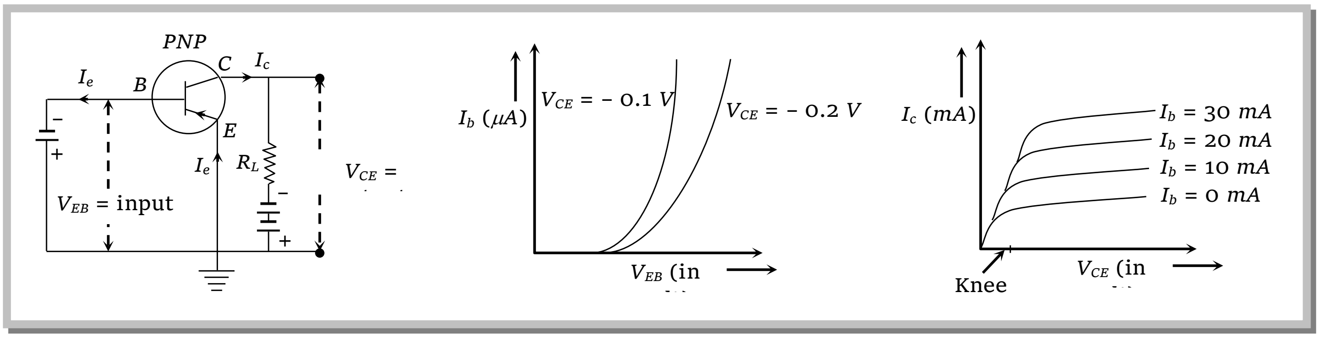
(2) **Characteristics of transistors :** A transistor can be connected in a circuit in the following three different configurations.

(i) Common base (CB) (ii) Common emitter (CE)(iii) Common collector (CC)

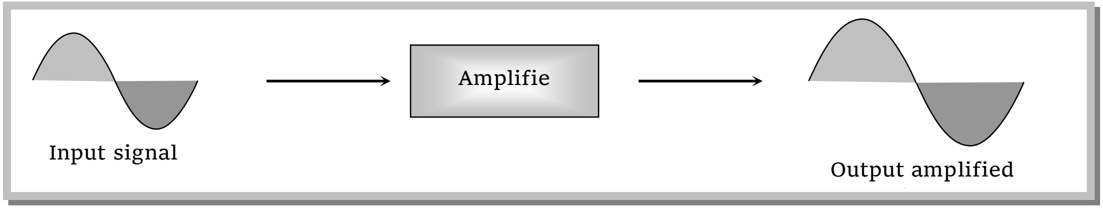
(i) CB characteristics : The graphs between voltages and currents when base of a transistor is common to input and output circuits are known as CB characteristic of a transistor.



(ii) CE characteristics : The graphs between voltages an d currents when emitter of a transistor is common to input and output circuits are known as CE characteristics of a transistor.

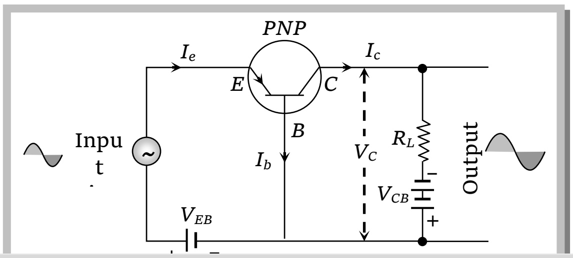


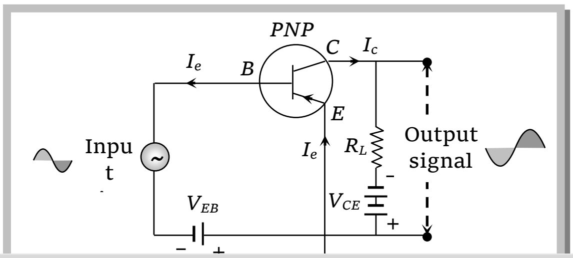
(3) **Transistor as an amplifier :** A device which increases the amplitude of the input signal is called amplifier.



The transistor can be used as an amplifier in the following three configuration

(i) CB amplifier (ii) CE amplifier (iii) CC amplifier





(4) **Parameters of CE/CB amplifiers**

Transistor as C.E. amplifier	**Transistor as C.B. amplifier**
(i) Current gain (α) (a) $\alpha_{ac} = \frac{\text{Small change in collector current }(\Delta i_c)}{\text{Small change in collector current }(\Delta i_e)}$; V_B (constant) (b) $\alpha_{dc}(\text{or }\alpha) = \frac{\text{Collector current}(i_c)}{\text{Emitter current }(i_e)}$ valve of α_{dc} lies between 0.95 to 0.99	(i) Current gain (β) (a) $\beta_{ac} = \left(\frac{\Delta i_c}{\Delta i_b}\right)$ V_{CE} = constant (b) $\beta_{dc} = \frac{i_c}{i_b}$ valve of β_{ac} lies between 15 and 20
(ii) Voltage gain $A_v = \frac{\text{Change in output voltage}(\Delta V_o)}{\text{Change in input voltage }(\Delta V_i)}$ $\Rightarrow A_v = \alpha_{ac} \times$ Resistance gain	(ii) Voltage gain $A_v = \frac{\Delta V_o}{\Delta V_i} = \beta_{ac} \times \text{Resistance gain}$
(iii) Power gain $= \frac{\text{Change in output power}(\Delta P_o)}{\text{Change in input power}(\Delta P_c)}$ $\Rightarrow \text{Power gain} = \alpha_{ac}^2 \times \text{Resistance gain}$	(iii) Power gain $= \frac{\Delta P_o}{\Delta P_i} = \beta_{ac}^2 \times \text{Resistance gain}$ Note : ❑ **Trans conductance (*gm*) :** The ratio of the change in collector current to the change in emitter base voltage is called trans conductance. *i.e.* $g_m = \frac{\Delta i_c}{\Delta V_{EB}}$. Also $g_m = \frac{A_V}{R_L}$; R_L = Load resistance

(5) **Relation between α and β :** $\beta = \frac{\alpha}{1-\alpha}$ or $\alpha = \frac{\beta}{1+\beta}$

(6) **Comparison between *CB*, *CE* and *CC* amplifier**

S.No.	**Characteristic**	**Amplifier**		
		CB	*CE*	*CC*
(i)	Input resistance (R_i)	≈ 50 to 200 Ω low	≈ 1 to 2 kΩ medium	≈ 150 – 800 kΩ high
(ii)	Output resistance (R_o)	≈ 1 – 2 kΩ high	≈ 50 kΩ medium	≈ kΩ low
(iii)	Current gain	0.8 – 0.9 low	20 – 200 high	20 – 200 high

(iv)	Voltage gain	Medium	High	Low
(v)	Power gain	Medium	High	Low
(vi)	Phase difference between input and output voltages	Zero	180°	Zero
(vii)	Used as amplifier for	current	Power	Voltage

Example

Example: 1 What is the coordination number of sodium ions in the case of sodium chloride structure**[CBSE 198**

(a) 6 (b) 8 (c) 4 (d) 12

Solution : (a) In *NaCl* crystal Na^+ ion is surrounded by $6\,Cl^-$ ion, therefore coordination number of Na^+ is 6.

Example: 2 A *Ge* specimen is doped with *Al*. The concentration of acceptor atoms is $\sim 10^{21}$ *atoms*/m^3. Given that the intrinsic concentration of electron hole pairs is $\sim 10^{19}/m^3$, the concentration of electrons in the specimen is

[AIIMS 2004]

(a) $10^{17}/m^3$ (b) $10^{15}/m^3$ (c) $10^4/m^3$ (d) $10^2/m^3$

Solution : (a) $n_i^2 = n_h n_e \Rightarrow (10^{19})^2 = 10^{21} \times n_e \Rightarrow n_e = 10^{17}/m^3$.

Example: 3 A silicon specimen is made into a *P*-type semi-conductor 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} *atoms*/m^3, then the number of acceptor atoms in silicon will be

(a) 2.5×10^{30} *atoms*/cm^3 (b) 1.0×10^{13} *atoms*/cm^3 (c) 1.0×10^{15} *atoms*/cm^3 (d) 2.5×10^{36} *atoms*/cm^3

Solution : (c) Number density of atoms in silicon specimen = 5×10^{28} *atom*/m^3 = 5×10^{22} *atom*/cm^3

Since one atom of indium is doped in 5×10^7 *Si* atom. So number of indium atoms doped per cm^{-3} of silicon.

$$n = \frac{5\times10^{22}}{5\times10^{7}} = 1\times10^{15}\ atom/cm^3.$$

Example: 4 A *P*-type semiconductor has acceptor levels 57 *meV* above the valence band. The maximum wavelength of light required to create a hole is (Planck's constant h = 6.6×10^{-34} *J-s*)

(a) 57 Å (b) 57×10^{-3} Å (c) 217100 Å (d) 11.61×10^{-33} Å

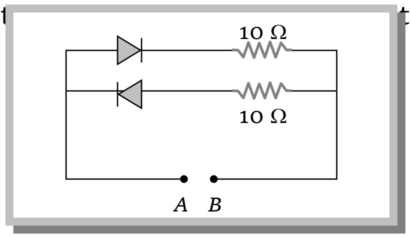
Solution : (c) $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{6.6\times10^{-34}\times3\times10^{8}}{57\times10^{-3}\times1.6\times10^{-19}}$ = 217100 Å.

Example: 5 A potential barrier of 0.50*V* exists across a *P-N* junction. If the depletion region is $5.0\times10^{-7}\,m$ wide, the intensity of the electric field in this region is

(a) $1.0\times10^{6}\ V/m$ (b) $1.0\times10^{5}\ V/m$ (c) $2.0\times10^{5}\ V/m$ (d) $2.0\times10^{6}\ V/m$

Solution : (a) $E=\frac{V}{d}=\frac{0.50}{5\times10^{-7}}=1\times10^{6}\ V/m.$

***Example*: 6** A $2V$ battery is connected across the points A and B as shown in the figure given below. Assuming that the resistance of each diode is zero in forward bias and infinity in reverse bias, the current supplied by the battery when it ted to A is



(a) 0.2 A

(b) 0.4 A

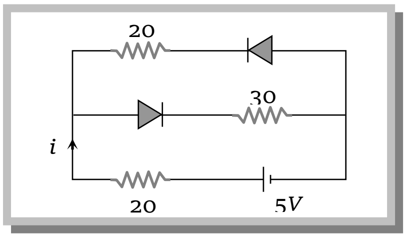
(c) Zero

(d) 0.1 A

Solution : (a) Since diode in upper branch is forward biased and in lower branch is reversed biased. So current through circuit $i=\frac{V}{R+r_d}$; here r_d = diode resistance in forward biasing = 0

So $i=\frac{V}{R}=\frac{2}{10}=0.2A$.

***Example*: 7** Current in the circuit will be



(a) $\frac{5}{40}A$

(b) $\frac{5}{50}A$

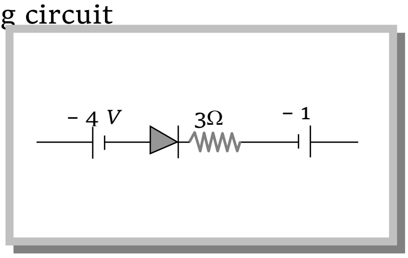
(c) $\frac{5}{10}A$

(d) $\frac{5}{20}A$

Solution : (b) The diode in lower branch is forward biased and diode in upper branch is reverse biased

$\therefore\quad i=\frac{5}{20+30}=\frac{5}{50}A$

***Example*: 8** Find the magnitude of current in the following circuit



(a) 0

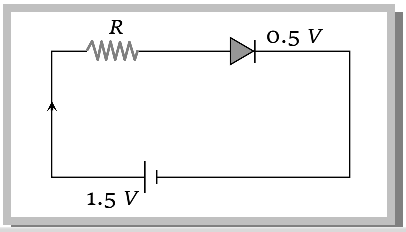
(b) 1 *amp*

(c) 0.1 *amp*

(d) 0.2 *amp*

Solution : (a) Diode is reverse biased. Therefore no current will flow through the circuit.

***Example*: 9** The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 *milliwatts*. What should be the value of the resistor R, connected in series with the diode nt



(a) 1.5 Ω

(b) 5 Ω

(c) 6.67 Ω

(d) 200 Ω

Solution : (b) The current through circuit $i = \frac{P}{V} = \frac{100 \times 10^{-3}}{0.5} = 0.2A$

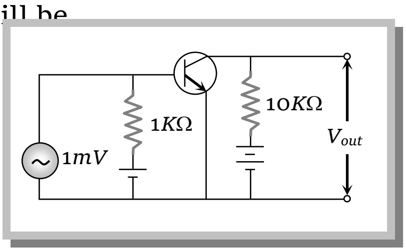
$\therefore$ voltage drop across resistance = 1.5 – 0.5 = 1 V $\Rightarrow R = \frac{1}{0.2} = 5\,\Omega$

***Example*: 10** For a transistor amplifier in common emitter configuration for load impedance of 1 $k\Omega$ (h_{fe} = 50 and h_{oe} = 25) the current gain is

(a) – 5.2 (b) – 15.7 (c) – 24.8 (d) – 48.78

Solution : (d) In common emitter configuration current gain $A_i = \frac{-h_{fe}}{1 + h_{oe} R_L} = \frac{-50}{1 + 25 \times 10^{-6} \times 10^{3}}$ = – 48.78.

***Example*: 11** In the following common emitter configuration an *NPN* transistor with current gain β = 100 is used. The output voltage of the amplifier will be



(a) 10 mV

(b) 0.1 V

(c) 1.0 V

(d) 10 V

Solution : (c) Voltage gain $= \frac{\text{Output voltage}}{\text{Input voltage}}$ $\Rightarrow V_{out} = V_{in} \times$ Voltage gain

$\Rightarrow V_{out} = V_{in} \times$ Current gain $\times$ Resistance gain $= V_{in} \times \beta \times \frac{R_L}{R_{BE}} = 10^{-3} \times 100 \times \frac{10}{1} = 1V.$

***Example*: 12** While a collector to emitter voltage is constant in a transistor, the collector current changes by 8.2 mA when the emitter current changes by 8.3 mA. The value of forward current ratio h_{fe} is **[KCET 2002]**

(a) 82 (b) 83 (c) 8.2 (d) 8.3

Solution : (a) $h_{fe} = \left(\frac{\Delta i_c}{\Delta i_b}\right)_{V_{ce}} = \frac{8.2}{8.3 - 8.2} = 82$

***Example*: 13** The transfer ratio of a transistor is 50. The input resistance of the transistor when used in the common-emitter configuration is 1 $K\Omega$. The peak value for an ac input voltage of 0.01 V peak is **[CBSE PMT 1998]**

(a) 100 μA (b) 0.01 mA (c) 0.25 mA (d) 500 μA

Solution : (d) $i_c = \beta i_b = \beta \times \frac{V_i}{R_i} = 50 \times \frac{0.01}{1000} = 500 \times 10^{-6}\,A = 500\,\mu A$

***Example*: 14** In a common base amplifier circuit, calculate the change in base current if that in the emitter current is 2 mA and α = 0.98

(a) 0.04 mA (b) 1.96 mA (c) 0.98 mA (d) 2 mA

Solution : (a) $\Delta i_c = \alpha \Delta i_e = 0.98 \times 2 = 196\ mA$

$\therefore \quad \Delta i_b = \Delta i_e - \Delta i_c = 2 - 1.96 = 0.04\ mA$.