SOLIDS AND SEMICONDUCTOR DEVICES

Electronic instruments are being utilized in various fields like telecommunication, entertainment, computers, nuclear physics and many more. Although the history started with the advent of vacuum tubes, however the rapid advancement in electronics which we see today is due to the valuable contributions of semiconductor devices.

Semiconductor devices are not only small in size, consumes less power, have long life times and are more efficient than vacuum tubes but also are of low cost. That is why these have replaced vacuum tubes nearly in all applications. As an example we can consider the case of a computer. In early days, the vacuum tube based computers were as big as the size of a room and were capable of performing simple calculations only. At present the personal computer (PC) that you see in laboratory or at your home is much smaller in size and capable of performing many operations. Needless to say this is possible because of the advances in semiconductor technology.

We will learn the basic concept of semiconductors. This will enable us to understand the operation of many semiconductor devices and then we will be discussing few semiconductor devices like diode, transistor along with their applications.

CLASSIFICATION OF METALS, CONDUCTORS AND SEMICONDUCTORS

On the basis of conductivity

On the basis of the relative values of electrical conductivity (σ) or resistivity ($\rho = 1/\sigma$), the solids are broadly classified as:

(i) Metals: They possess very low resistivity (or high conductivity).

$\rho \sim 10^{-2} - 10^{-8}\ \Omega$ m

$\sigma \sim 10^{2} - 10^{8}$ S m^{-1}

(ii) Semiconductors: They have resistivity or conductivity intermediate to metals and insulators.

$\rho \sim 10^{-5} - 10^{6}\ \Omega$ m

$\sigma \sim 10^{5} - 10^{-6}$ S m^{-1}

(iii) Insulators: They have high resistivity (or low conductivity).

$\rho \sim 10^{11} - 10^{19}\ \Omega$ m

$\sigma \sim 10^{-11} - 10^{-19}$ S m^{-1}

The values of ρ and σ given above are indicative of magnitude and could well go outside the ranges as well. Relative values of the resistivity are not the only criteria for distinguishing metals, insulators and semiconductors from each other. There are some other differences, which will become clear as we go along in this chapter. Our interest in this chapter is in the study of semiconductors which could be:

(i) Elemental semiconductors: Si and Ge

(ii) Compound semiconductors: Examples are:

- Inorganic: CdS, GaAs, CdSe, InP, etc.
- Organic: anthracene, doped pthalocyanines, etc.
- Organic polymers: polypyrrole, polyaniline, polythiophene, etc.

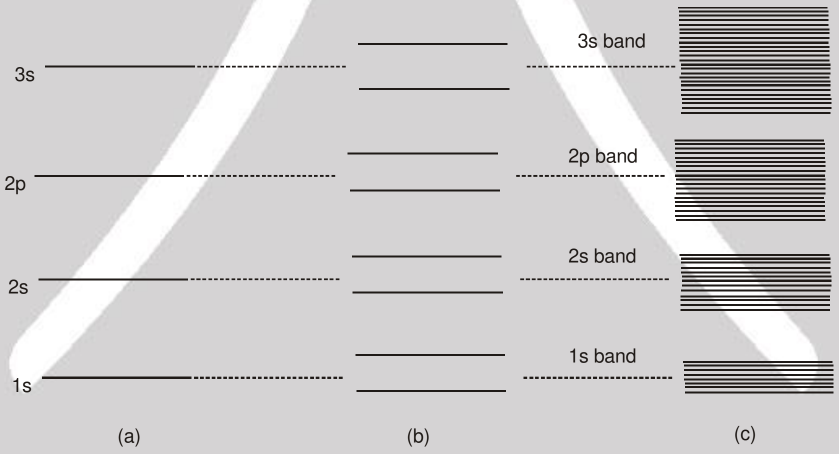
Most of the currently available semiconductor devices are based on elemental semiconductors Si or Ge and compound inorganic semiconductors. However, after 1990, a few semiconductor devices using organic semiconductors and semiconducting polymers have been developed signalling the birth of a futuristic technology of polymerelectronics and molecular-electronics. In this chapter, we will restrict ourselves to the study of inorganic semiconductors, particularly elemental semiconductors Si and Ge. The general concepts introduced here for discussing the elemental semiconductors, by-and-large, apply to most of the compound semiconductors as well.

1. ENERGY LEVELS AND ENERGY BANDS IN SOLIDS

The electrons of an isolated atom are restricted to well defined energy levels. The maximum number of electrons which can be accommodated in any level is determined by the Pauli exclusion principle. The electrons belonging to the outermost energy level are called valence electrons. For example, the electronic configuration of sodium (atomic number 11) is $-1s^2\ 2s^2\ 2p^6\ 3s^1$, here the electron belonging to the 3s level is the valence electron. Most of the solids including metals with which we are familiar occur in crystalline form. As we know a crystal is a regular periodic arrangement of atoms separated from each other by very small distance called lattice constant. The value of lattice constant is different for different crystalline solids, however it is of the order of linear dimension of atoms {~Å}. Obviously at such a short separation between various neighbouring atoms, electrons in an atom cannot only be subjected to the Coulombic force of the nucleus of this atom but also oby Coulombic forces due to nuclei and electrons of the neighbouring atoms. In fact it is this interaction which results in the bonding between various atoms which leads to the formation of crystals.

When atoms are interacting (such as in crystal) then the energy level scheme for the individual atoms as shown in figure(a) does not quite hold. The interaction between atoms affect the electron energy levels, as a result there occurs a splitting of energy levels belonging to various atoms. To understand this phenomenon in more clear terms, let us first consider the simplest case of two interacting identical atoms. Let us assume that initially they are far apart i.e. the forces of interaction between them can be neglected.

[If the distance between two atoms is much larger (~50Å) compared to their linear dimensions (~ 10Å) this assumption is reasonably correct] .In such a case we may treat them as isolated with energy levels like that for the case of an isolated atom as shown in figure(a).

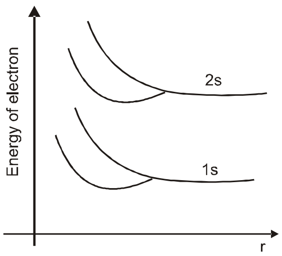


In crystals the number of atoms, N is very large of the order of 10^{22} to 10^{23} per cubic centimetre, so each energy band contains as many levels as the number of atoms. The spacing between various levels within a band is therefore very small. If for example we assume the total width of a band of energies as 1 eV and 10^{22} levels are to be accommodated with in this band, then the average spacing between the adjacent levels is about 10^{-22} eV. For all practical purposes, therefore, energy within a band can be assumed to vary continuously. The formation of bands in a solid is shown schematically in figure (c).

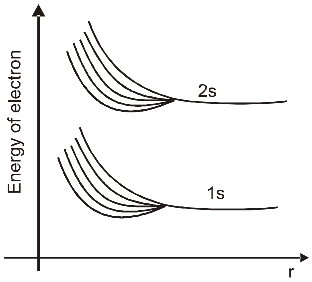
Energy Bands :

This theory is based on the Pauli exclusion principle.

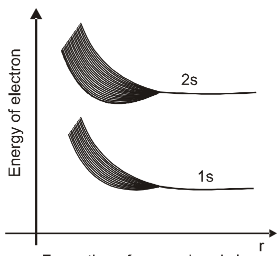
In isolated atom the valence electrons can exist only in one of the allowed orbitals each of a sharply defined energy called energy levels. But when two atoms are brought nearer to each other, there are alterations in energy levels and they spread in the form of bands.



Splitting of 1s and 2s levels when two sodium atoms are brought together



Splitting of 1s and 2s levels when five sodium atoms are brought together



Formation of energy bands large no. of sodium atoms are assembled to form solid

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 filled with electrons.
(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 electron present in this band.
(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 electron 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

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

2. ENERGY BAND DESCRIPTION OF CONDUCTOR, INSULATOR AND SEMICONDUCTOR

The electrical conductivity of materials is a physical quantity which varies over a large span. On one hand we know about metals having very large values of electrical conductivity and on the other hand we have insulators like quartz and mica having negligible conductivity. Beside these there are materials having conductivity (at room temperature) much smaller, than that of metals but much larger than that of insulators these materials are called semiconductors e.g. Silicon and Germanium. Not only that the conductivity of a semiconductor is intermediate, to that of metals and insulators the conductivity of semiconductor varies substantially with temperature. For very low temperature (around 0K) semiconductor behaves like insulator, however, its conductivity increases with increase in temperature.

(a) Conductors :

These are solids in which either the energy band containing valence band is partially filled or the energy band containing valence electrons overlaps with next higher band to give a new band which is partially filled too. For both these situations there are enough free levels available for electrons to which they can be excited by receiving energy from an applied electric field.

Conduction band and valence band in monovalent metal

Let us consider an example of sodium which is a monovalent metal. Its band structure is such that 1s, 2s and 2p bands are filled with electrons to their capacity however, the 3s band is only half filled. The reason for such a band structure is that for an isolated sodium atom in its electronic structure.

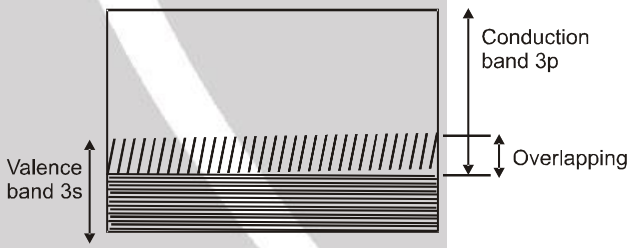
$1s^2$, $2s^2$, $2p^6$, $3s^1$ the energy levels 1s, 2s and 2p are filled while 3s contains only one electron against its capacity of accommodating two electrons. The completely filled 1s, 2s and 2p bands do not contribute to electrical conduction because an applied electric field cannot bring about intra band transitions in them. Electrons can also not make band to band transitions from 1s to 2s or from 2s to 2p band as for both these situations unfilled energy levels are not available. However, electrons belonging to 3s band can take part in intra band transitions as half of the energy levels present in this band are available. An applied electric field can impart them an amount of energy sufficient for the transition to free energy levels, and take part in the process of conduction.

(a)

Thus the conduction properties of sodium are due to this partially filled band which is shown in figure (a). The lower half portion of this band is called valence band and upper half portion is called conduction band as it is in this part when electron reach after receiving energy from electric field the process of conduction starts. All monovalent metals have a half filled conduction band like sodium.

Conduction band and valence band in bivalent metal

The bivalent elements belonging to the second group of the periodic table e.g magnesium, zinc etc are also metallic. In the solid state of these materials there is an overlapping between the highest filled band and next higher unfilled band. For example magnesium atom (atomic number = 12) has electronic structure -$1s^2$ $2s^2$ $2p^6$ $3s^2$ and in atomic state there is some energy gap between completely filled 3s level and next higher but unfilled 3p level. However, during the process of crystal formation, the splitting of energy levels take place in such a manner that the 3p band overlaps with 3s band. In the 'hybrid' band' so formed now electrons have sufficient number of unfilled levels for transition. In such situation if 3s band is called valence band then 3p band is conduction band and the two bands overlap as shown in figure (B).



(b)

We can conclude that for both the above metals there is no energy gap between maximum energy of valence band and the minimum energy of the conduction band.

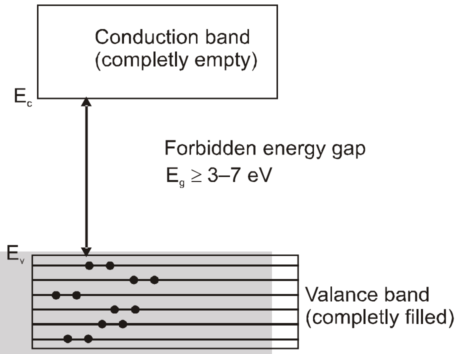
The energy that an electron gains from an ordinary current source usually is 10^{-4} to 10^{-8} eV which is sufficient to cause transition between levels inside a partially filled band. As the difference between the adjacent levels is infinitesimal, for such bands the electron can absorb infinitesimal energy in a manner like free electron. Such electrons when reach unfilled higher levels contribute to the process of electric conduction. In metals both the number of free electrons and the vacant energy levels for transitions are very large that is why metals are good conductors of electricity and heat. For metals at ordinary temperature the electrical conductivities are in range 10^6 mho/metre to 10^8 mho/metre indicating this fact.

(b) Insulator :

It is a solid in which the energy band formation takes place in such a manner, that the valence band is completely filled while the conduction band is completely empty. In addition to this, these two bands are separated by a large energy gap called forbidden energy gap or band gap. If E_c and E_v respectively denotes the minimum energy in conduction band and the maximum energy in valence band then band gap E_g is defined as

$$E_g = E_c - E_v.$$

For insulators E_g ~ 3 to 7 eV. As in an empty band no electron is there to take part in the process of electric conduction, such a band does not contribute in conduction. In a completely filled band very large number of electrons are present but no vacant levels to which these electrons make transition are available and hence again there will not be any conduction.



As explained earlier ordinary current sources provide only a very small energy to an electron in a solid and so electrons cannot be excited from valence band to conduction band. Also not only at ordinary temperatures but at elevated temperatures too, the thermal energy is much smaller than the band gap energy E_g so electrons cannot be excited from valence band to conduction band by thermal means. Consequently solids with such large band gaps are insulators.

For diamond, $E_g \approx 6$ eV hence it is insulator.

In general electrical conductivities of insulators are in the range 10^{-12} mho/metre to 10^{-18} mho/metre (resitivity in the range 10^{12} ohm-metre to 10^{18} ohm metre.]

(c) Semiconductors :

In case of semiconductors, the band structure is essentially of the same type as that for insulators with the only difference that of a relatively smaller forbidden gap. In case of a semiconductor this is typically of the order of 1eV. At absolute zero temperature, the valence band is completely filled and the conduction band is completely empty and consequently no electrical conduction can result. This is the same behaviour as observed in insulators. i.e, at absolute zero a semiconductor behaves like an insulator.

At finite temperatures (room temperature and above) some of the electrons from near the top of valence band acquire enough thermal energy to move into the otherwise empty conduction band. These electrons contribute to the conduction of electricity in a semiconductor.

Also the above said transitions create some unfilled levels in the valence band and the electrons of this band can move into these levels again resulting in conduction. Thus the electrical conductivity of a semiconductor is larger than that of an insulator at room temperature. However since the number of electrons made available to conduction band via this process of thermal excitation is very small as compared to what available for conduction in metals, the conductivity of semiconductors is much smaller than that of metals at a given temperature. Thus the conductivity of semiconductor lies between that of metals and insulators, that is why these are named so. The conductivity of semiconductor increases with temperature.

Note : Free electron and Hole in semiconductors.

(1) When an electron is removed from a covalent bond, it leaves a vacancy behind. An electron from a neighbouring atom can move into this vacancy, leaving the neighbour with a vacancy. In this way the vacancy formed is called hole (or cotter), and can travel through the material and serve as an additional current carriers.
(2) A hole is considered as a seat of positive charge, having magnitude of charge equal to that of an electron.
(3) Holes acts as virtual charge, although there is no physical charge on it.
(4) Effective mass of hole is more than electron.
(5) Mobility of hole is less than electron.
(6) Free electron move in CB, while hole in VB in opposite direction.
(7) Immobile ions are at rest.

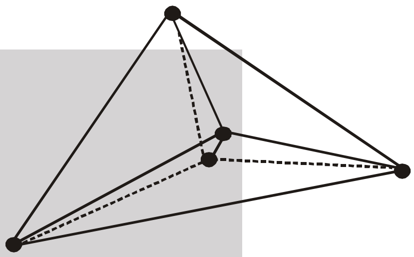
3. INTRINSIC SEMICONDUCTORS :

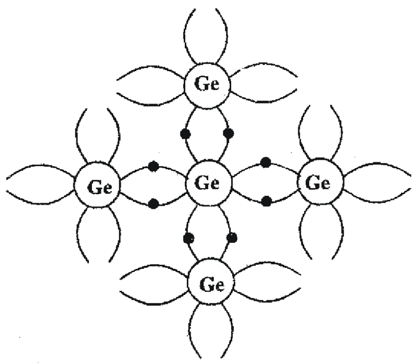
A semiconductor free from impurities is called an intrinsic semiconductor. Ideally an intrinsic semiconductor crystal should contain atoms of this semiconductor only but it is not possible in practice to obtain crystals with such purities. However if the impurity is less than 1 in 10^8 part of semiconductor it can be treated as intrinsic. For describing the properties of intrinsic semiconductor we are taking examples of silicon and germanium. Both silicon and germanium are members of the group IV of periodic table of elements and are tetravalent. Their electronic configuration is as follows:

Si(14)=$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

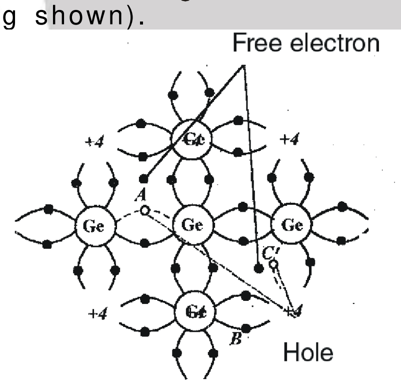
Ge(32)= $Is^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^2$

Both elements crystallize in such a way that each atom in the crystal is inside a tetrahedron formed by the four atoms which are closest to it. Figure shows one of these tetrahedral units. Each atom shares its four valence electrons with its immediate neighbours on a one to one basis, so that each atom is involved in four covalent bonds. For convenience, a two dimensional representation of the crystal structure for germanium is shown in figure, which can also be used for silicon (as only covalent bands are being shown).





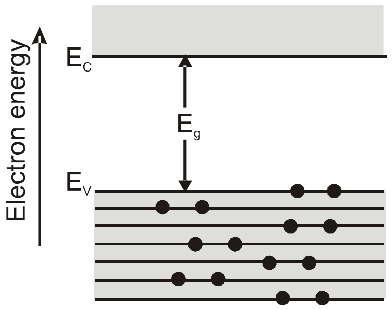
Two dimensional representation of the crystal structure of germanium at 0 K



Formation of electron hole pair

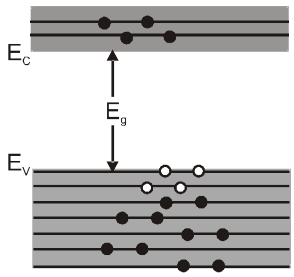
At 0K, all the valence electrons are involved in the bonding and so the crystal is a perfect insulator as there are no free electrons available for conduction. At higher temperatures, however, some of the valence electrons have sufficient energy to break away from the bond and move in the crystal in random manner. Under an applied electric field these electrons drift and conduct electricity.

When an electron escapes from a band it leaves behind a vacancy in the lattice. This vacancy is termed as a "hole". The absence of electron amounts to the presence of a positive charge of same magnitude. As explained later, holes also take part in conduction in semiconductors. When a covalent bond is broken, all electron- hole pair is contributed. At room temperature (300K) many electron - hole pairs are present in the crystal. The process of electron - hole generation is explained in figure. Let due to thermal energy an electron is set free from the covalent bond at site A whereby a hole is created at this site. An electron from the covalent bond of a neighbouring atom site B may jump to vacant site A then bond is completed at A but a hole is created at B. In this process a very small energy is involved compared to what is required for an electron - hole pair generation. It is because the electron is jumping from one bond to the other and all electrons in bonding are on an average of same energy. As shown in the figure when an electron jumps from C to B a hole is created at C and so on. In effect then such a vacancy or hole can be considered as mobile. Thus in a semiconductor both electrons and holes act as charge carriers and contribute in electric conduction.



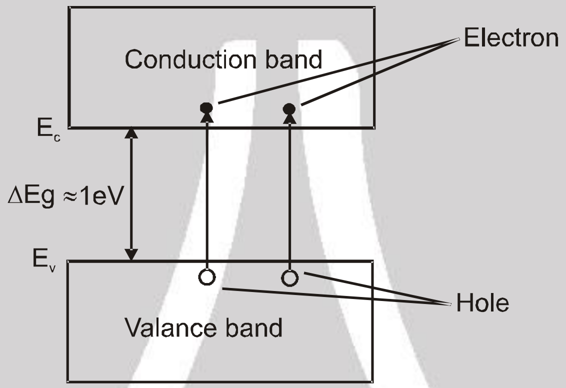
An intrinsic semiconductor at T = 0 K behaves like insulator.

(a)



At T > 0 K four thermally generated electron-hole pairs. The filled circles (.) represent electrons and empty fields (O) represent holes.

(b)



The number of electrons and holes generated by thermal means is equal for an intrinsic semiconductor. If n_e and n_h represents the electron and hole concentrations respectively then

$$n_i = n_e = n_h$$

$$n_e n_h = n_i^2$$

Here n_i is intrinsic charge carriers concentration.

Note :

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

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

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

(4) The drift velocity of electrons (v_e) is greater than that of holes (v_h).

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

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

(7) In intrinsic semiconductor $n_e^{(0)} = n_h^{(0)} = n_i$; where $n_e^{(0)}$ = Electron density in conduction band, $n_h^{(0)}$ = Hole density in V.B., n_i = Density of intrinsic carriers.

(8) The fraction of electron of valance band present in conduction band is given by $f \propto e^{-Eg/kT}$; where E_g = Fermi energy, k = Boltzmann's constant and T = Absolute temperature.

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

(10) Number of electrons reaching from valence band to conduction band $n = AT^{3/2}e^{-Eg/2kT}$ where A is positive constant.

(11) Net charge of a pure semiconductor is zero.

(a) Electrical conductivity of intrinsic semiconductor:

A semiconductor, at room temperature, contains electrons in the conduction band and holes in the valence band. When an external electric field is applied, the electrons move opposite to the field and the holes move in the direction of the field, thus constituting current in the same direction. The total current is the sum of the electron and hole currents.

$i = i_e + i_h$

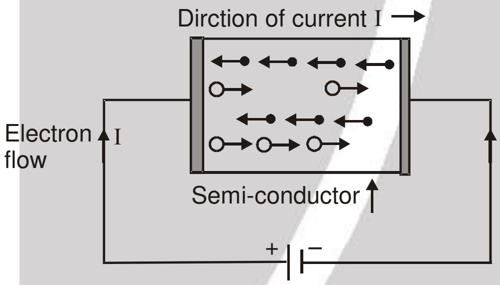
Hole Current (i_h):

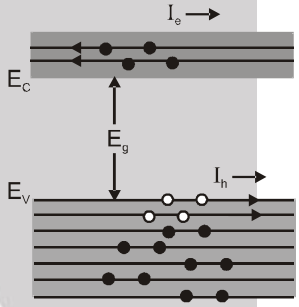
Electrons of covalent bond site jump from one position to another position in valency band so hole moves opposite to the jumping of electrons in valence band. Electron originally set free is not involved in the process of hole motion. Motion of hole is only a convenient way of describing the actual motion of bonded electrons of valence band.

Electron Current (i_e)

Free electron moves completely independently as conduction electron and give electron current under the effect of electric field.

It may be noted that apart from the process of generation of conduction electrons and holes, a simultaneous process of recombination occurs in which the electrons recombine with the holes. At equilibrium, the rate of generation is equal to the rate of recombination of charge carriers. The recombination occurs due to an electron colliding with a hole.





Let us consider a semiconductor block of length ℓ, area of cross-section A and having electron concentration n_e and hole concentration is n_h, across the ends of the semiconductor creates an electric field E given by

$$E = \frac{V}{\ell} \qquad \text{.........(i)}$$

Under the field E, the electrons and the holes both drift in opposite directions and constitute currents i_e and i_h respectively in the direction of the field. The total current flowing through the semiconductor is

$i = i_e + i_h$

If v_e be the drift velocity of the electrons in the conduction band and v_h the drift velocity of the holes in the valence band, then we have

$i_e = n_e e A v_e$ and $i_h = n_h e A v_h$

Where e is the magnitude of electron charge

$$\therefore \quad i = i_e + i_h = eA (n_e v_e + n_h v_h) \quad \text{or} \quad \frac{i}{A} = e (n_e v_e + n_h v_h). \qquad \text{.......(ii)}$$

Let R be the resistance of the semiconductor block and ρ the resistivity of the block material. Then

$$\rho = RA/\ell. \qquad \text{.......(iii)}$$

Dividing equation (i) by equation (iii), we have

$$\frac{E}{\rho} = \frac{V}{RA} = \frac{i}{A}, \quad \text{(Since V = iR by Ohm's law).}$$

Substituting in it the value of i/A from equation (ii), we get

$$\frac{E}{\rho} = e (n_e v_e + n_h v_h) \quad \text{or} \quad \frac{1}{\rho} = e\left(n_e \frac{v_e}{E} + n_h \frac{v_h}{E}\right) \qquad \text{........(iv)}$$

Let us now introduce a quantity μ, called mobility which is defined as the drift velocity per unit field and is expressed in meter^2/(volt-second). Thus, the mobilities of electron and hole are given by

$$\mu_e = \frac{v_e}{E} \quad \text{and} \quad \mu_h = \frac{v_h}{E}$$

Introducing μ_e and μ_h in equation (iv), we get

$$\frac{1}{\rho} = e\,(n_e\,\mu_e + n_h\,\mu_h)$$

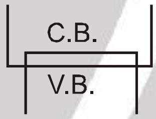
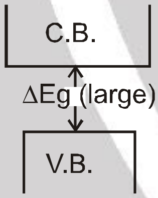
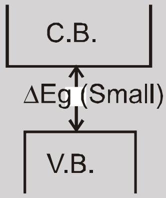
The electrical conductivity σ is the reciprocal of the resistivity ρ . Thus, the electrical conductivity of the semiconductor is given by

$$\sigma = e\,(n_e\,\mu_e + n_h\,\mu_h) \qquad \text{.........(v)}$$

So $\sigma = en_i\,(\mu_e + \mu_h)$ $\therefore$ $n_e = n_h = n_i$

This is the required expression. It shows that the electrical conductivity of a semiconductor depends upon the electron and hole concentrations (number densities) and their mobilities. The electron mobility is higher than the hole mobility.

As temperature rises, both the concentrations n_e and n_h increase due to breakage of more covalent bonds. The mobilities μ_e and μ_h, however, slightly decrease with rise in temperature but this decrease is offset by the much greater increase in n_e and n_h. Hence, the conductivity of a semiconductor increases (or the resistivity decreases) with rise in temperature.

Properties	**Conductors**	**Insulators**	**Semiconductors**
Electrical conductivity	10^2 to 10^8 ℧/m	10^{-8} ℧/m	10^{-5} to 10^0 ℧/m
Resistivity	10^{-2} to 10^{-8} Ω-m (negligible)	10^8 Ω-m	10^5 to 10^o Ω-m
Band Structure			
Energy gap (E_g)	Zero or very small	Very large : for diamond it is 6 eV	Ge → 0.7 eV Si → 1.1 eV GaAs → 1.3 eV GaF_2 → 2.8 eV
Current carriers	Free electrons	—	Free electrons and holes
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 .field C.B.–Completely unfilled	V.B– some what empty C.B.- some what filled
Temperature co-efficient of resistance	Positive	Zero	Negative
Effect of temperature on conductivity	Decreases	—	Increases
Effect of temperature on resistance	Increases	—	Decreases
Examples	Cu, Ag, Au, Na, Pt, Hg etc.	Wood, plastic, mica diamond, glass etc.	Ge, Si GaAs etc,
Electron density	10^{29}/m^3	—	Ge ~ 10^{19}/m^3 Si ~ 10^{16} / m^3

4. EXTRINSIC SEMICONDUCTORS :

The conductivity of an intrinsic semiconductor depends on its temperature, but at room temperature its conductivity is very low. As such, no important electronic devices can be developed using these semiconductors. Hence there is a necessity of improving their conductivity. This can be done by making use of impurities. When a small amount, say, a few parts per million (ppm), of a suitable impurity is added to the pure semiconductor, the conductivity of the semiconductor is increased manifold. Such materials are known as *extrinsic semiconductors* or *impurity semiconductors*. The deliberate addition of a desirable impurity is called *doping* and the impurity atoms are called *dopants*. Such a material is also called a *doped semiconductor*. The dopant has to be such that it does not distort the original pure semiconductor lattice. It occupies only a very few of the original semiconductor atom sites in the crystal. A necessary condition to attain this is that the sizes of the dopant and the semiconductor atoms should be nearly the same. There are two types of dopants used in doping the tetravalent Si or Ge:

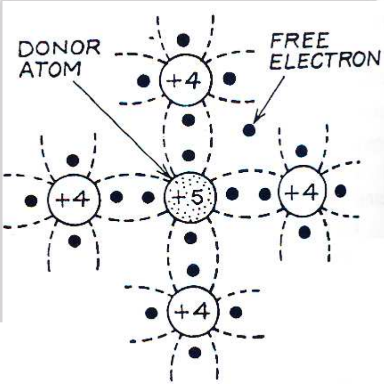
(i) Pentavalent (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.

(ii) Trivalent (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.

We shall now discuss how the doping changes the number of charge carriers (and hence the conductivity) of semiconductors. Si or Ge belongs to the fourth group in the Periodic table and, therefore, we choose the dopant element from nearby fifth or third group, expecting and taking care that the size of the dopant atom is nearly the same as that of Si or Ge. Interestingly, the pentavalent and trivalent dopants in Si or Ge give two entirely different types of semiconductors as discussed below.

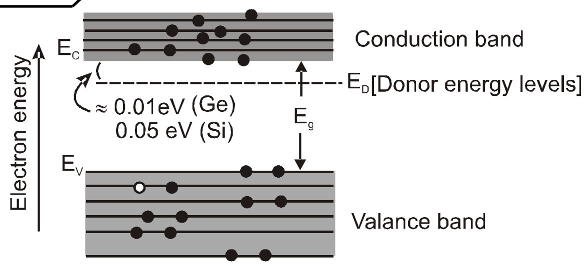
Extrinsic semiconductor are of two types : n–type and p–type.

(a) n–type semiconductor : When a pentavalent impurity atom (antimony, phosphorus or arsenic) is added to a Ge(or Si) crystal, it replaces a Ge (or Si) atom in the crystal lattice. Four of the five valence electrons of the impurity atom form covalent bonds with one with each valence electron of four Ge (or Si) atoms surrounding. Thus, by adding pentavalent impurity to pure Ge (or Si), the number of free electrons increases, that is, the conductivity of the crystal increases. The impure Ge (or Si) crystal is called an 'n–type' semiconductor because it has an excess of 'negative' charge–carrier (electrons). The impurity atoms are called 'donor' atoms because they donate the conducting electrons to the crystal.



The fifth valence electrons of the impurity atoms occupy some discrete energy levels just below the conduction band. These are called 'donor levels' and are only 0.01 eV below the conduction band in case of Ge, and 0.05 eV below in case of Si. Therefore, at room temperature, the "fifth" electrons of almost all the donor atoms are thermally excited from the donor levels into the conduction band where they move as charge–carriers when an external electric field is applied.

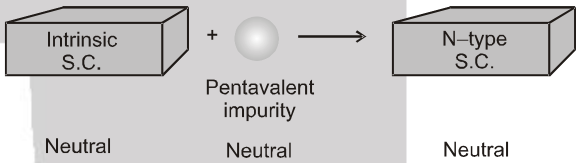
At ordinary temperature, almost all the electrons in the conduction band come from the donor levels, only a few come from the valence band. Therefore, the main charge–carriers responsible for conduction are the electrons contributed by the donors. Since the excitation from the valence band is small, there are very few holes in this band.



The current contribution of the holes is therefore small. Thus, in an n–type semiconductor the electrons are the 'majority carriers' and the holes are the 'minority carriers.'
The adjecent figure shows n-type semiconductor at T > 0 K. Its conduction band has One thermally generated electron-hole pair and 9 conduction electrons from donor atoms.

Some important facts about N-Type Semiconductor

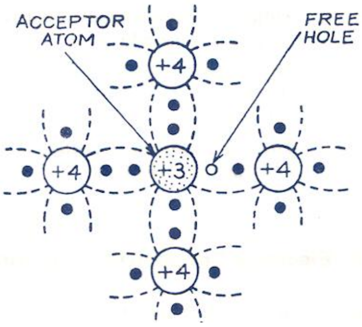
These are obtained by adding a small amount of pentavalent impurity to a pure sample of semiconductor (Ge).



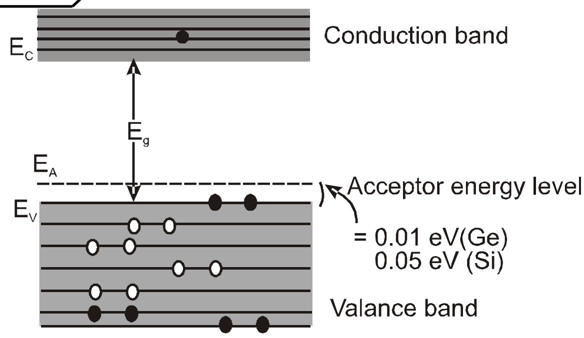
(1) Majority charge carriers – electrons
Minority charge carriers – hole
(2) $n_e >> n_h$; $i_e >> i_h$
(3) Conductivity $\sigma = n_e \mu_e e$
(4) Donor energy level lies just below the conduction band.
(5) **Electrons and hole concentration :** In a doped semiconductor, the electron concentration n_e and the hole concentration n_h are not equal (as they are in an instrinsic semiconductor). It can be shown that $n_e n_h = n_i^2$
where n_i is the intrinsic concentration.
In an n–type semiconductor, the concentration of electrons in conduction band is nearly equal to the concentration of donor atoms (N_d) and very large compared to the concentration of holes in valence band. That is :
$n_e \; N_d >> n_h$
(6) Impurity atom called donar atom which is elements of V group of periodic table.
(7) Net charge on N type crystal is zero.
(8) Immobile charge is positive charge

(b) p–type semiconductor :

When a trivalent impurity atom (boron, aluminium, gallium or indium) is added to a Ge (or Si) crystal, it also replaces one of the Ge (or Si) atoms in the crystal lattice. Its three valence electrons form covalent bonds with one each valence electron of these Ge (or Si) atoms surrounding it. Thus, there remains an empty space, called a 'p–type' semiconductor because it has an excess of positive 'acceptor' atoms because they create holes which accept electrons.

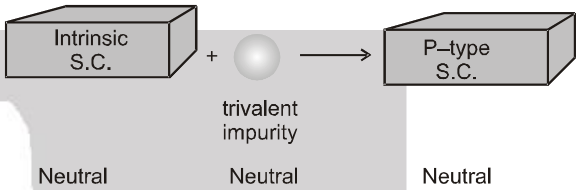


The impurity atoms occupy vacant discrete energy levels just above the top of the valence band. These are called 'acceptor levels'. At room temperature, electrons are easily excited from the valence band into the acceptor levels. The corresponding holes created in the valence band are the main charge–carries in the crystal when an electric field is applied.
Thus, in a p–type semiconductor the holes are the 'majority carriers' and the few electrons, thermally excited from the valence band into the conduction band, are 'minority carriers'.
The adjecent figure shows Electron and hole concentration for p-type semiconductor at T > 0 K.
One thermally generated electron-hole pair + seven holes due to acceptor atoms.



Some important facts about P-Type Semiconductor

There are obtained by adding a small amount of trivalent impurity to a pure sample of semiconductor (Ge).



(1) Majority charge carries – holes
Minority charge carries – electrons

(2) $n_h >> n_e$; $i_h >> i_e$

(3) Conductivity $\sigma \approx n_h \mu_h e$

(4) P–type semiconductor is also electrically neutral (not positively charged)

(5) Impurity is called Acceptor impurity which is element of III group of the periodic table.

(6) Acceptor energy level lies just above the valency band.

(7) **Electron and hole concentration :** In a p–type semiconductor, the concentration of holes in valence band is nearly equal to the concentration of acceptor atoms (N_a) and very large compared to the concentration of electron in conduction band. That is

$$n_h = N_a >> n_e$$

(8) Net charge on p-type crystal is zero.

(9) Imobile charge is negative charge.

Distinction between intrinsic and extrinsic semiconductors :

	Instrinsic Semiconductor		Extrinsic Semiconductor
1	It is a pure, natural semiconductor, such as pure Ge and pure Si.	1	It is prepared by adding a small quantity of impurity to a pure semiconductor, such as n-and p-type semiconductors.
2	In it the concentration of electrons and holes are equal.	2	In it the two concentrations are unequal. There is an excess of electrons in n-type semiconductors and an excess of holes in p-type semiconductors.
3	Its electrical conducitivity is very low.	3	Its electrical conductivity is siginifcantly high.
4	Its conductivity cannot be controlled.	4	Its conductivity can be controlled by adjusting the quantity of the impurity added.
5	Its conductivity increases exponentially with temperature.	5	Its conductivity also increases with temperature, but not exponentially.

Distinction between n–type and p–type semiconductor :

	n-type semiconductor		p-type semiconductor
1	It is an extrinsic semiconductor obtained by adding a pentavalent impurity to a pure intrinsic semiconductor.	1	It is also an extrinsic semiconductor obtained by adding a trivalent impurity to a pure intrinsic semiconductor.
2	The impurity atoms added provides extra free electrons to the crystal lattice and are called donor atoms.	2	The impurity atoms added create holes in the crystal lattice and are called acceptor atoms because the created holes accept electrons.
3	The electrons are majority carriers and the holes are minority carriers.	3	The holes are majority carriers and the electrons are minority carriers.
4	The electrons concentration is much more than the hole concentration ($n_e >> n_h$).	4	The hole concentration is much more than the electron concentration ($n_h >> n_e$).

Solved Examples

Example 1. 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} atoms/m^3 ; find the number of acceptor atoms in silicon per cubic centimeter.

Solution : The doping of one indium atoms in silicon semiconductor will produce one acceptor atom in p-type semiconductor. Since one indium atom has been dropped 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.

Example 2. Pure Si at 300K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium increases n_h to 3×10^{22} m^{-3}. Calculate n_e in the doped Si.

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

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

Example 3. Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium increases n_h to 4.5×10^{22} m^{-3}. Calculate n_e in the doped Si-

Solution : $n_e n_h = n_i^2$

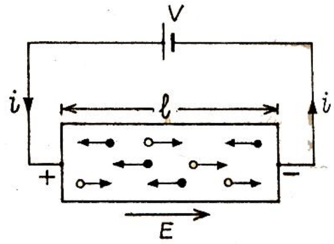
$n_h = 4.5 \times 10^{22}$ m^{-3}

so, $n_e = 5.0 \times 10^9$ m^{-3}

(c) Electrical conductivity of extrinsic semiconductors :

A semiconductor, at room temperature, contains electrons in the conduction band and holes in the valence band. When an external electric field is applied, the electrons move opposite to the field and the hole move in the direction of the field, thus constituting current in the same direction. The total current is the sum of the electron and hole currents.

Let us consider semiconductor block of length l, area of cross–section A and having electrons concentration n_e and hole concentration n_h.



A potential difference V applied across the ends of the semiconductor creates an electric field E given by :

$E = \frac{V}{\ell}$ ....(i)

Under the field E, the electrons and the holes both drift in opposite directions and constitute currents i_e and i_h respectively in the direction of the field. The total current flowing through the semiconductor is,

$i = i_e + i_h$

If v_e, be the drift velocity of the electrons in the conduction band and v_h the drift velocity of the holes in the valence band, then we have

$i_e = n_e e A v_e$ and $i_h = n_h e A v_h$

where e is the magnitude of electron charge

$\therefore \quad i = i_e + i_h = eA(n_e v_e + n_h v_h)$

or $\frac{i}{A} = e(n_e v_e + n_h v_h)$ ....(ii)

Let R be the resistance of the semiconductor block and ρ the resistivity of the block material. Then

$\rho = R A / l$ ....(iii)

Dividing eq.(i) by eq.(ii) we have

$\frac{E}{\rho} = \frac{V}{RA} = \frac{i}{A}$,

Because, V = iR (Ohm's law). Substituting in it the value of i/A from eq.(ii), we get

$\frac{E}{\rho} = e(n_e v_e + n_h v_h)$ or $\frac{1}{\rho} = e\left(n_e \frac{v_e}{E} + n_h \frac{v_h}{E}\right)$ ....(iv)

Let us introduce a quantity μ, called mobility which is defined as the drift velocity per unit field and is expressed in metre^2 / (volt/second). Thus, the mobilities of electrons and hole are given by :

$\mu_e = \frac{v_e}{E}$ and $\mu_h = \frac{v_h}{E}$

Introducing μ_e and μ_h in eq. (iv), we get

$\frac{1}{\rho} = e(n_e\mu_e + n_h\mu_h)$

The electrical conductivity ρ is the reciprocal of the resitivity ρ. Thus, the electrical conductivity of the semiconductor is given by

$\sigma = e(n_e \mu_e + n_h \mu_h)$

This is the required expression. It shows that the electrical conductivity of a semiconductor depends upon the electron and hole concentrations (number densities) and their mobilities. The electrons is higher than the hole mobility.

As temperature rises, both the concentration n_e and n_h increases due to breakage of more convalent bonds. The mobilities μ_e and μ_h , however, slightly decrease with rise in temperature but this decrease is offset by the much greater increase in n_e and n_h. Hence, the conductivity of a semiconductor increases (or the resistivity decreases) with rise in temperature.

Solved Examples

Example 4. The majority charge carriers in P-type semiconductor are

(1) Electrons (2) Protons (3) Holes (4) Neutrons

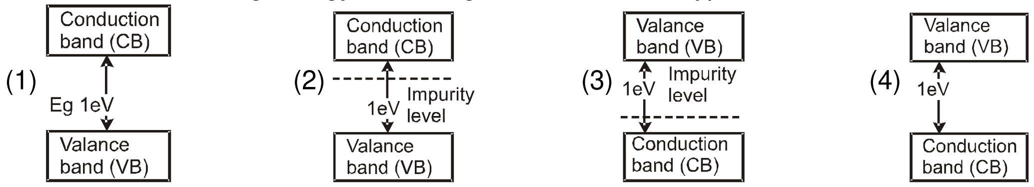
Solution : (3) In P-type semiconductors, holes are the majority charge carriers

Example 5. When a semiconductor is heated, its resistance

(1) Decreases (2) Increases (3) Remains unchanged (4) Nothing is definite

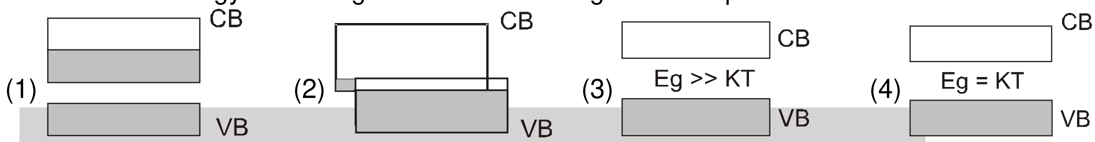
Answer : (1)

Example 6. Which of the following energy band diagram shows the N-type semiconductor



Solution : (2) In N-type semiconductor impurity energy level lies just below the conduction band.

Example 7. Which of the energy band diagram shown in the figure corresponds to that of a semiconductor



Solution : (4) In semiconductors, the forbidden energy gap between the valence band and conduction band is very small, almost equal to kT. Moreover, valence band is completely filled where as conduction band is empty.

Example 8. The P-N junction is-

(1) an ohmic resistance (2) non ohmic resistance

(3) a positive resistance (4) a negative resistance

Answer : (2)

Example 9. The mean free path of conduction electrons in copper is about 4×10^{-8} m. For a copper block, find the electric field which can give, on an average, 1eV energy to a conduction electron.

Solution : Let the electric field be E. The force on an electron is eE. As the electron moves through a distance d, the work done on it is eEd. This is equal to the energy transferred to the electron. As the electron travels an average distance of 4×10^{-8} m before a collision, the energy transferred is $eE(4 \times 10^{-8}\text{ m})$. To get 1 eV energy from the electric field,

$eE(4 \times 10^{-8}\text{ m}) = 1\text{ eV}$ or $E = 2.5 \times 10^{7}$ V/m.

Example 10. The band gap in germanium is $\Delta E = 0.68$ eV. Assuming that the number of hole–electron pairs is proportional to $e^{-\Delta E/2kT}$, find the percentage increase in the number of charge carries in pure germanium as the temperature is increased from 300 K to 320 K.

Solution : The number of charge carries in an intrinsic semiconductor is double the number of hole–electron pairs. If N_1 be the number of charge carries at temperature T_1 and N_2 at T_2, we have $N_1 = N_0 e^{-\Delta E/2kT_1}$

and $N_2 = N_0 e^{-\Delta E/2kT_2}$

The percentage increase as the temperature is raised from T_1 to T_2 is

$$f = \frac{N_2 - N_1}{N_1} \times 100 = \left(\frac{N_2}{N_1} - 1\right) \times 100 = 100\left[e^{\frac{\Delta E}{2k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} - 1\right]$$

Now $$\frac{\Delta E}{2k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = \frac{0.68\text{eV}}{2 \times 8.62 \times 10^{-5} \quad \text{eV/K}}\left(\frac{1}{300 \quad K} - \frac{1}{320 \quad K}\right) = 0.82$$

Thus $f = 100 \times [e^{0.82} - 1]$ 127.

Thus, the number of charge carries increase by about 127%.

Example 11. The energy of a photon of sodium light (λ = 589 nm) equals the band gap of a semiconducting material. (a) Find the minimum energy E required to create a hole-electron pair. (b) Find the value of E/kT at a temperature of 300 K.

Solution : (a) The energy of the photon is $E = \frac{hc}{\lambda} = \frac{1242 \quad eV - nm}{589 \quad nm} = 2.1$ eV.

Thus the band gap is 2.1 eV. This is also the minimum energy E required to push an electron from the valence band into the conduction band. Hence, the minimum energy required to create a hole–electron pair is 2.1 eV.

So it is difficult for the thermal energy to create the hole–electron pair but a photon of light can do it easily.

(b) At T = 300 K,

$kT = (8.62 \times 10^{-5}$ eV/K) (300 K) $= 25.86 \times 10^{-3}$ eV.

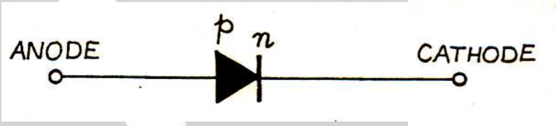
Thus, $\frac{E}{kT} = \frac{2.1 \quad eV}{25.86 \times 10^{-3} eV} = 81$

5. Junction Diode

A junction diode is a basic semiconductor device. It is a semiconductor crystal having acceptor impurities in one region (P – type crystal) and donor impurities in the other region (n–type crystal). The boundary between the two regions is called 'p–n junction'.

Circuit Symbol for a p-n Junction Diode:

In electronic circuits, the semiconductor devices are represented by their symbols. The symbol for the basic device, the p-n junction diode, is shown in Fig. The arrow-head represents the p -region and the bar represents the n -region of the diode.



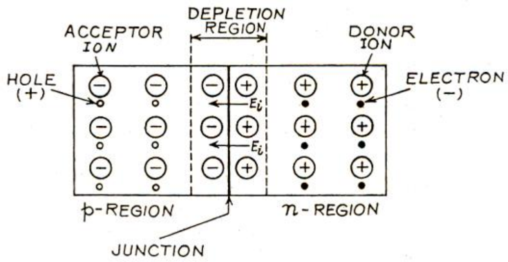
The direction of the arrow is from p to n and indicates the direction of conventional current flow under forward bias. The p -side is called 'anode' and the n -side is called 'cathode'.

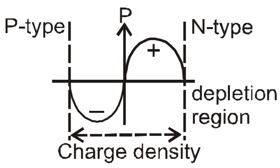
(a) Formation of p-n Junction :

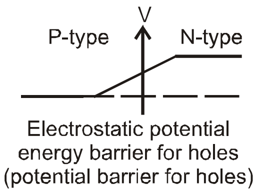
A p-n junction is not the interface between p -type and n – type semiconductor crystals pressed together. It is a single piece of semiconductor crystal having an excess of acceptor impurities into one side and of donor impurities into the other.

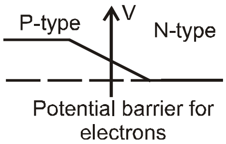
(b) Potential Barrier at the Junction: Formation of Depletion Region:

A p-n junction is shown in Fig. The p -type region has (positive) holes as majority charge-carriers, and an equal number of fixed negatively-charged acceptor ions. (The material as a whole is thus neutral). Similarly, the n -type region has (negative) electrons as majority charge-carriers, and an equal number of fixed positively-charged donor ions.









The region on either of the junction which becomes depleted (free) of the mobile charge-carriers is called the 'depletion region'. The width of the depletion region is of the order of 10^{-6} m. The potential difference developed across the depletion region is called the 'potential barrier'. It is about 0.3 volt for Ge, p-n junction and about 0·7 volt for silicon p-n junction. It, however, depends upon the dopant concentration in the semiconductor.

The magnitude of the barrier electric field for a silicon junction is $E_i \approx \frac{V}{d} \approx \frac{0.7}{10^{-6}} = 7 \times 10^5\ Vm^{-1}$

Diffusion & Drift Current : Due to concentration difference hole try to diffuse from p side to n side but due to depletion layer only those hole are able to diffuse from p to n side which have high kinetic energy. Similarly electron of high kinetic energy also diffuse from n to p so diffusion current flow from p to n side.
Due to thermal collision or increase in temperature some valence electron comes in conduction band. If this occurs in depletion region then hole move towards p side & electron move towards n side so a current produce from n to p side. It is called drift current, in steady state both diffusion & drift current are equal & opposite.

Solved Examples

Example 12. In a p-n junction with open ends,
(1) there is no systematic motion of charge carriers
(2) holes and conductor electrons systematically go from the p-side and from the n-side to the p-side respectively
(3) there is no net charge transfer between the two sides
(4) there is a constant electric field near the junction

Answer : (3,4)

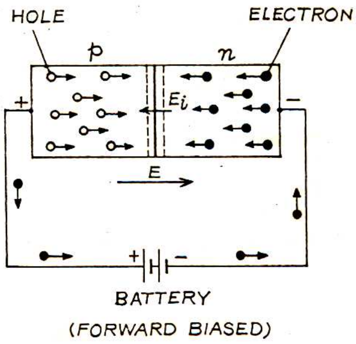
Example 13. A potential barrier of 0.50 V exists across a P-N junction. If the depletion region is 5.0×10^{-7} m wide, the intensity of the electric field in this region is
(1) 1.0×10^6 V/m (2) 1.0×10^5 V/m (3) 2.0×10^5 V/m (4) 2.0×10^6 V/m

Solution : (1) $E = \frac{V}{d} = \frac{0.5}{5 \times 10^{-7}} = 10^6$ V/m

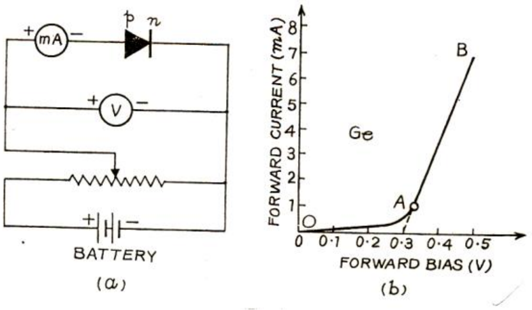
(c) Forward and Reverse Biasing of Junction Diode

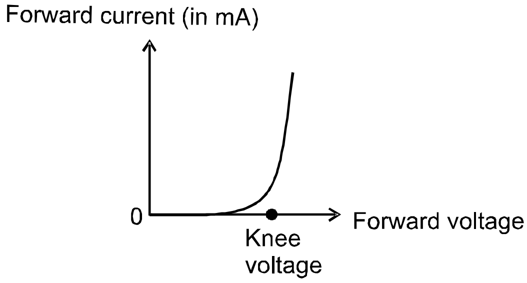
The junction diode can be connected to an external battery in two ways, called 'forward biasing' and 'reverse biasing' of the diode. It means the way of connecting emf source to P-N junction diode. It is of following two types

(i) Forward Biasing :
A junction diode is said to be forward-biased when the positive terminal of the external battery is connected to the p -region and the negative terminal to the n-region of the diode.



Forward-Biased Characteristics : The circuit connections are shown in Fig. The positive terminal of the battery is connected to the p -region and the negative terminal to the n -region of the





junction diode through a potential-divider arrangement which enables to change the applied voltage. The voltage is read by a voltmeter V and the current by a millimetre mA. Starting with a low value, the forward bias voltage is increased step by step and the corresponding forward current is noted. A graph is then plotted between voltage and current. The resulting curve OAB (Fig. b) is the forward characteristic of the diode.

In the beginning, when the applied voltage is low, the current through the junction diode is almost zero. It is because of the potential barrier (about 0·3 V for Ge p-n junction and about 0·7 V for Si junction) which opposes the applied voltage. With increase in applied voltage, the current increases very slowly and non-linearly until the applied voltage exceeds the potential barrier. This is represented by the portion OA of the characteristic curve. With further increase in applied voltage, the current increases very rapidly and almost linearly Now the diode behaves as an ordinary conductor. This is represented by the straight-line part AB of the characteristic. If this straight line is projected back. it intersects the voltage-axis at the barrier potential voltage.

Note :

(i) In forward biasing width of depletion layer decreases

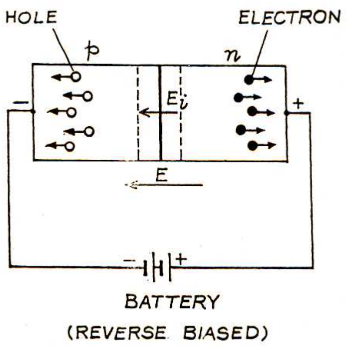
(ii) In forward biasing resistance offered $R_{Forward} \approx 10\Omega - 25\Omega$

(iii) Forward bias opposes the potential barrier and for $V > V_B$ a forward current is set up across the junction.

(iv) Cut-in (Knee) voltage : The voltage at which the current starts to in crease rapidily. For Ge it is 0.3 V and for Si it is 0.7V.

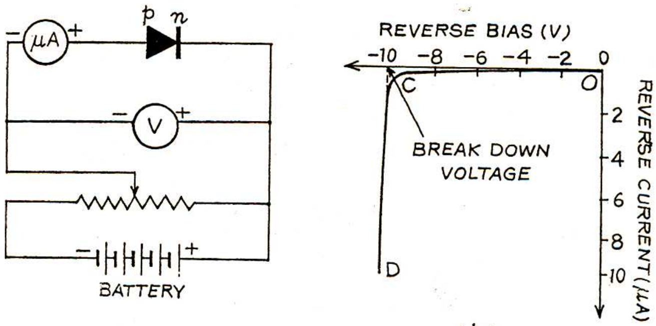
(ii) Reverse Biasing: A junction diode is said to be reverse-biased when the positive terminal of the external battery is connected to the n -region and the negative terminal to the p -region of the diode (Fig.)

In this condition, the external field E is directed from n toward p and thus aids the internal barrier field E_i Hence holes in the p -region and electrons in the n -region are both pushed away from the junction, that is, they cannot combine at the junction. Thus, there is almost no current due to flow of majority carriers.



Reverse-Biased Characteristic:

The circuit connections are shown in Fig. (a) in which the positive terminal of the battery is connected to the n -region and the negative terminal to the p -region of the junction diode. In reverse-biased diode, a very small current (of the order of μA) flows across the junction due to the motion of the few thermally-generated minority-carriers (electrons in p -region and holes in n-region) whose motion is aided by the applied voltage. The small reverse current remains almost constant over a sufficiently long range of reverse bias (applied voltage),increasing very little with increasing bias. This is represented by the part OC of the reverse characteristic curve (Fig b).



(a) (b)

Note:

(i) In reverse biasing width of depletion layer increases

(ii) In reverse biasing resistance offered $R_{Reverse} \approx 10^5\Omega$

(iii) Reverse bias supports the potential barrier and no current flows across the 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)

(iv) Break down voltage : Reverse voltage at which break down of semiconductor occurs. For Ge it is 25V and for Si it is 35 V.

(d) Avalanche Breakdown :

The avalanche breakdown occurs in lightly doped junction. If the reverse bias is made very high, the minority-carriers acquire kinetic energy enough to break the covalent bonds near the junction, thus liberating electron-hole pairs. These charge-carriers are accelerated and produce, in the same way, other electron-hole pairs. The process is cumulative and an avalanche of electron-hole pairs is produced. The reverse current then increases abruptly to a relatively large value (part CD of the characteristic). This is known as 'avalanche breakdown' and may damage the junction by the excessive heat generated. The reverse bias voltage at which the reverse current increase abruptly is called the 'breakdown voltage' .

Zener Breakdown : Zener breakdown occurs in heavily doped junctions. Under a high reverse - bias voltage, the p-n junction's depletion region expands, leading to a high strength electric field across the junction. A sufficiently strong electric field manages to break the covalent bonds of the semiconductor atoms, which liberates a large number of free minority carries. The sudden generation of carries rapidly increases the reverse current and gives rise to high slope resistance of Zener diode.

The reverse bias voltage at which the reverse current increase abruptly is called the 'ZENER breakdown voltage' or 'Zener voltage'. The numerical value of the breakdown voltage varies from tens of volts to several hundred volts depending on the number density of the impurity atoms doped into the diode.

(e) Dynamic Resistance of a Junction Diode

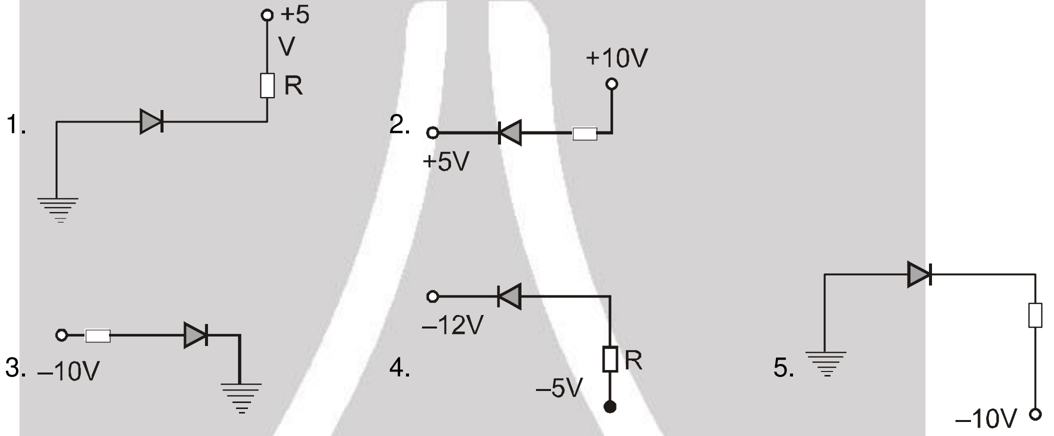
The current-voltage curve of junction diode shows that the current does not vary linearly with the voltage, that is, Ohm's law is not obeyed. In such situation, a quantity known as 'dynamic resistance' (or a.c. resistance) is defined.

The dynamic resistance of a junction diode is defined as the ratio of a small change in applied voltage (ΔV) to the corresponding small change in current (Δi), that is $R_d = \frac{\Delta V}{\Delta I}$

In the forward characteristic of p-n junction diode, beyond the turning point (knee), however, the current varies almost linearly with voltage. In this region, R_d is almost independent of V and Ohm's law is obeyed.

Solved Examples

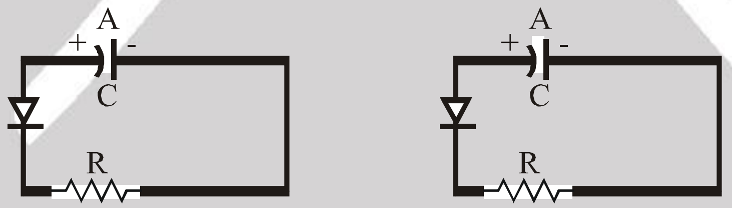
Example 14. In the given figure, which of the diodes are forward biased ?



(1) 1, 2, 3 (2) 2, 4, 5 (3) 1, 3, 4 (4) 2, 3, 4

Solution : (2) In figure 2,4 and 5. P-crystals are more positive as compared to N-crystals.

Example 15. Two identical capacitors A and B are charged to the same potential V and are connected in two circuits at t = 0 as shown in fig. The charges on the capacitor at a time t = CR are, respectively,

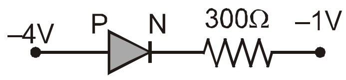


(A) (B)

(1) VC, VC (2) VC/e, VC (3) VC, VC/e (4) VC/e, VC/e

Answer : 2

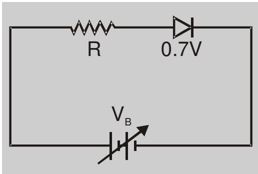
Example 16. What is the current in the circuit shown below



(1) 0 amp (2) 10^{-2} amp (3) 1 amp (4) 0.10 amp

Solution : (1) The potential fof P-side is more negative that of N-side, hence diode is in reverse biasing. In reverse biasing it acts as open circuit, hence no current flows.

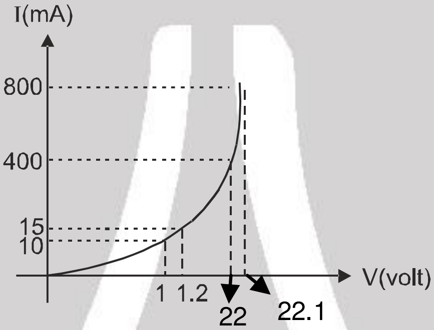
Example 17. Assume that the junction diode in the following circuit requires a minimum current of 1 mA to be above the knee point (0.7V) of its I-V characteristic curve. Also assume that the voltage across the diode is independent of current above the knee point. If V_B = 5V, what should be the maximum value of R so that the voltage is above the knee point-



(1) 4.3 kΩ (2) 860 kΩ (3) 4.3 Ω (4) 860 Ω

Answer : (1)

Example 18. The i-V characteristic of a p-n junction diode is shown in figure. Find the approximate dynamic resistance of the p-n junction when (a) a forward bias of 1 volt is applied, (b) a forward bias of 2 volt is applied



(a) The current at 1 volt is 10 mA and at 1.2 volt it is 15 mA. The dynamic resistance in this region is $R = \frac{\Delta V}{\Delta i} = \frac{0.2 \ \text{volt}}{5 \ \text{mA}} = 40\ \Omega$

(b) The current at 2 volt is 400 mA and at 2.1 volt it is 800 mA. The dynamic resistance in the region is $R = \frac{\Delta V}{\Delta i} = \frac{0.1 \ \text{volt}}{400 \ \text{mA}} = 0.25\ \Omega$.

6. p-n Junction Diode as a Rectifier

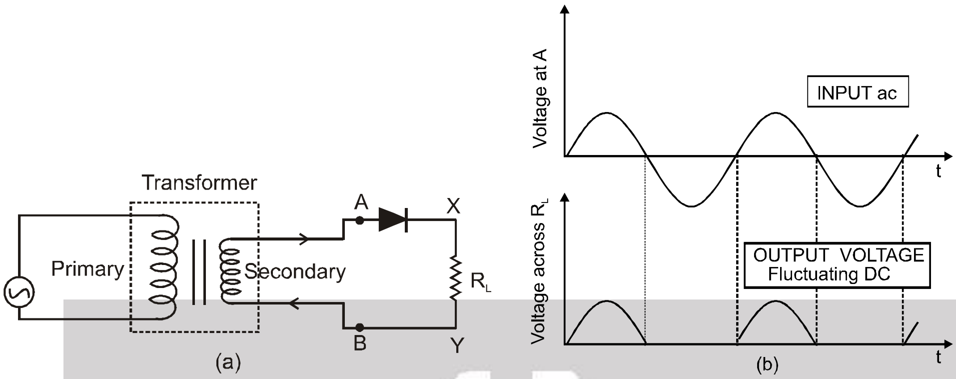
An electronic device which converts alternating current / voltage into direct current / voltage is called 'rectifier'.

A p-n junction diode offers a low resistance for the current to flow, when forward-biased, but a very high resistance, when reverse-biased. It thus passes current only in one direction and acts as a rectifier. The junction diode can be used either as an half-wave rectifier, when it allows current only during the positive half-cycles of the input a.c. supply; or as a full-wave rectifier when it allows current in the same direction for both half-cycles of the input alternating current .

(a) p-n Junction Diode as Half·wave Rectifier:

The half-wave rectifier circuit is shown in Fig. (a) and the input and output wave forms in Fig. (b). The alternating input voltage is applied across the primary P_1P_2 of a transformer. S_1S_2 is the secondary coil of the same transformer. S_1 is connected to the p -type crystal of the junction diode and S_2 is connected to the n -type crystal through a load resistance R_L.

During the first half-cycle of the a.c. input, when the terminal S_1 of the secondary is positive and S_2 is negative, the junction diode is forward-biased. Hence it conducts and current flows through the load R_L in the direction shown by arrows. The current produces across the load an output voltage of the same shape as the half-cycle of the input voltage. During the second half-cycle of the a.c. input, the terminal S_1 is negative and S_2 is positive. The diode is now reverse-biased. Hence there is almost zero current and zero output voltage across R_L. The process is repeated. Thus, the output current is unidirectional, but pulsating, as shown in lower part of Fig. (b).



Since the output- current corresponds to one half of the input voltage wave, the other half being missing, the process is called half-wave rectification.

The purpose of the transformer is to supply the necessary voltage to the rectifier. If direct current at high voltage is to be obtained from the rectifier, as is necessary for power supply, then a step-up transformer is used, as shown in Fig. (a). In many solid-state equipments, however, direct current of low voltage is required. In that case, a step-down transformer is used in the rectifier.

Note :

(i) During positive half cycle
Diode ⟶ forward biased
Output signal ⟶ obtained

(ii) During negative half cycle
Diode ⟶ reverse biased
Output signal ⟶ not obtained

(iii) Output voltage is obtained across the load resistance R_L. It is not constant but pulsating (mixture of ac and dc) in nature.

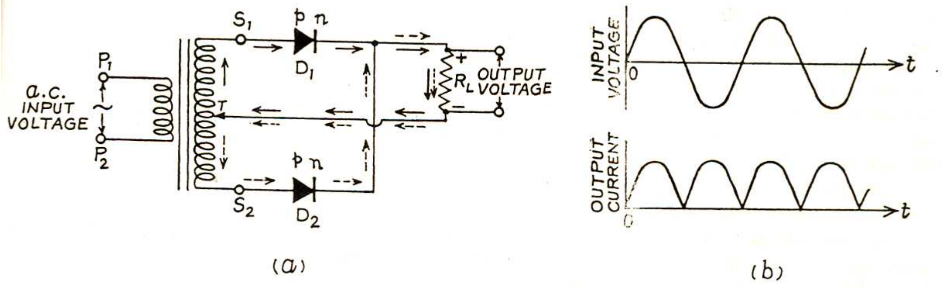
(iv) r.m.s. output : $I_{rms} = \frac{I_0}{2}$, $V_{rms} = \frac{V_0}{2}$

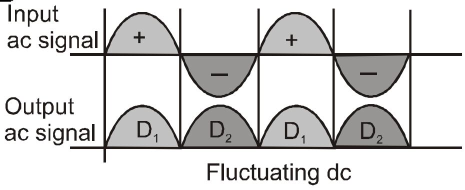
(v) Efficiency is 40.6%

(vi) The ripple frequency (ω) for half wave rectifier is same as that of ac.

(b) p-n Junction Diode as Full-wave Rectifier: In a full-wave rectifier, a unidirectional, pulsating output current is obtained for both halves of the alternating input voltage. Essentially, it requires two junction diodes so connected that one diode rectifies one half and the second diode rectifies the second half of the input.

The circuit for a full-wave rectifier is shown in Fig. (a) and the input and output wave forms in Fig. (b). The alternating input voltage is applied across the primary P_1P_2 of a transformer. The terminals S_1 and S_2 of the secondary are connected to the p-type crystals of the junction diodes D_1 and D_2 whose n -type crystals are connected to each other. A load resistance R_L is connected across the n -type crystals and the central-tap T of the secondary S_1S_2.





During the first half-cycle of the a.c. input voltage, the terminal S_1 is suppose positive relative to T and S_2 is negative. In this situation, the junction diode D_1 is forward-biased and D_2 is reverse-biased. Therefore, D_1 conducts while D_2 does not. The conventional current flows through diode D_1 load R_L and the upper half of the secondary winding, as shown by solid arrows. During the second half-cycle of the input voltage, S_1 is negative relative to T and S_2 is positive. Now, D_1 is reverse-biased and does not conduct while D_2 is forward-biased and conducts. The current now flows through D_2, load R_L and the lower half of the secondary, as shown by dotted arrows. It may be seen that the current in the load R_L flows in the same direction for both half-cycles of the alternating input voltage. Thus, the output current is a continuous series of unidirectional pulses. However, it can be made fairly steady by means of smoothing filters.

Filter : The rectified voltage is in the form of pulses of the shape of half sinusoids. Though it is unidirectional it does not have a steady value. To get steady dc output from the pulsating voltage normally a capacitor is connected across the output terminals (parallel to the load R_L). One can also use an inductor in series with R_L for the same purpose. Since these additional circuits appear to filter out the ac ripple and give a pure dc voltage, so they are called filters.
Now we shall discuss the role of capacitor in filtering. When the voltage across the capacitor is rising, it gets charged. If there is no external load, it remains charged to the peak voltage of the rectified output. When there is a load, it gets discharged through the load and the voltage across it begins to fall. In the next half-cycle of rectified output it again gets charged to the peak value. The rate of fall of the voltage across the capacitor depends upon the inverse product of capacitor C and the effective resistance R_L used in the circuit and is called the time constant. To make the time constant large value of C should be large. So capacitor input filters use large capacitors. The output voltage obtained by using capacitor input filter is nearer to the peak voltage of the rectified voltage. This type of filter is most widely used in power supplies.

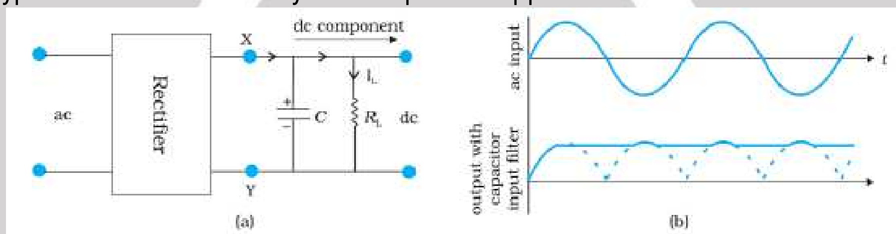


FIGURE (a) A full-wave rectifier with capacitor filter, (b) Input and output voltage of rectifier in(a).

NOTE :

(i) During positive half cycle
Diode : $D_1 \longrightarrow$ forward biased $D_2 \longrightarrow$ reverse biased
Output signal $\longrightarrow$ obtained due to D_1 only

(ii) During negative half cycle
Diode : $D_1 \longrightarrow$ reverse biased $D_2 \longrightarrow$ forward biased
Output signal $\longrightarrow$ obtained due to D_2 only

(iii) Fluctuating dc $\longrightarrow$ Filter $\longrightarrow$ constant dc.

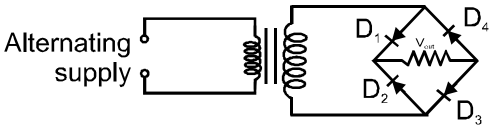
(iv) Output voltage is obtained across the load resistance R_L. It is not constant but pulsating in nature.

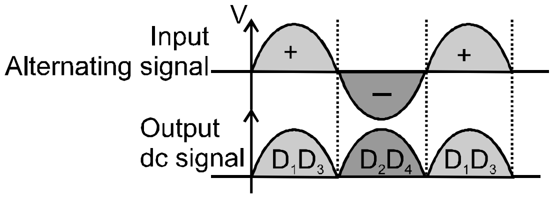
(v) Average output : $V_{av} = \dfrac{2V_0}{\pi}$, $I_{av} = \dfrac{2I_0}{\pi}$

(vi) Ripple frequency :The ripple frequency of full wave rectifier = 2×(Frequency of input ac)

(vii) Efficiency = 81.2%

Full wave bridge rectifier : Four diodes D_1, D_2, D_3 and D_4 are used in the circuit. During positive half cycle D_1 and D_3 are forward biased and D_2 and D_4 are reverse biased. During negative half cycle D_2 and D_4 are forward biased and D_1 and D_3 are reverse biased.





(c) Different Types of Junction Diode

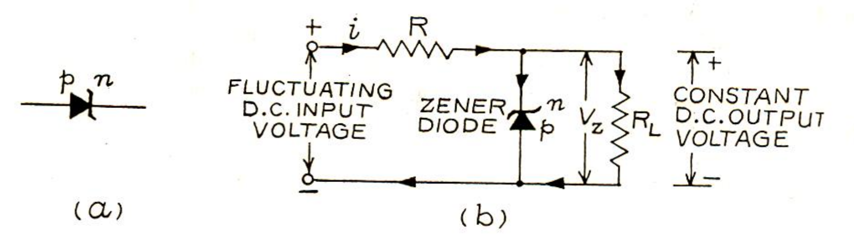
The junction diodes are of many types. The important types are Zener diode, photodiode, light-emitting diode (LED) and solar cell.

(i) Zener Diode: It is a voltage-regulating device based upon the phenomenon of avalanche breakdown in a junction diode.

When the reverse-bias applied to a junction diode is increased, there is an abrupt rise in the (reverse) current when the bias reverse reaches a certain value, known as 'breakdown voltage' or 'Zener voltage'.

Thus, in this region of the reverse characteristic curve, the voltage across the diode remains almost constant for a large range of currents. Hence the diode may be used to stabilize voltage at a pre-determined value. It is then known as 'Zener diode'. It can be designed, by properly controlled doping of the diode, to stabilize voltage at any desired value between 4 –100 volt.

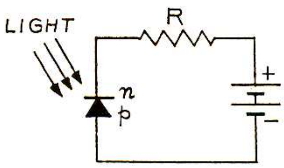
Fig. (a) shows the symbol of a Zener diode and Fig. (b) shows a simple circuit for stabilizing voltage across a load R_L. The circuit consists of a series voltage-dropping resistance R and a Zener diode in



parallel with the load R_L. The Zener diode is selected with a Zener voltage V_Z equal to the voltage desired across the load. The fluctuating d.c. input voltage may be the d.c. output of a rectifier. Whenever the input voltage increases, the excess voltage is dropped across the resistance R . This causes an increase in the input current i. This increase is conducted by the Zener diode, while the current through the load and hence the voltage across it remains constant at V_Z. Likewise, a decrease in the input voltage causes a decrease in the input current i. The current through the diode decreases correspondingly, again maintaining the current through the load constant.

Since the resistance R absorbs the input voltage fluctuations to give a constant output voltage V_Z, the circuit cannot work if the input voltage falls below V_Z. .

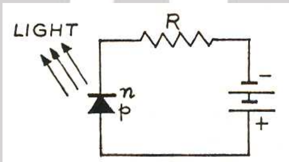
(ii) Photodiode : A photodiode is a reverse-biased p-n junction made from a photosensitive semiconductor. The junction is embedded in clear plastic. The upper surface across the junction is open to light, while the remaining sides of the plastic are painted black or enclosed in a metallic case. The entire unit is extremely small, of the order of a 0·1 inch size.



When no light is falling on the junction and the reverse-bias is of the order of a few tenths of a volt, an almost constant small current (μA) is obtained. This "dark" current is the reverse saturation current due to the thermally-generated minority-carriers (electrons in p -region and holes in n -region). When light of appropriate frequency is made incident on the junction, additional electron-hole pairs are created near the junction (due to breaking of covalent bonds). These light-generated minority-carriers cross the· (reverse-biased) junction and contribute to the (reverse) current due to thermally-generated carriers. Therefore, the current in the circuit increases (a fraction of a mA). This, so-called 'photoconductive' current varies almost linearly with the incident light flux.

The p--n photodiodes can operate at frequencies of the order of 1 MHz. Hence they are used in high-speed reading of computer punched cards, light-detection systems, light-operated switches, electronic counters etc.

(iii) Light-Emitting Diode (LED) : When a p-n junction diode is forward-biased. Both the electron and the holes move towards the junction. As they cross the junction, the electrons fall into the holes (recombine). Hence, energy is released at the junction (because the electrons fall from a higher to a lower energy level). In case of Ge and Si diodes, the energy released is infra-red radiation. If, however,



the diode is made of gallium arsenide or indium phosphide, the energy released is visible light. The diode is then called a 'light-emitting diode' (LED).

LEDs have replaced incandescent lamps in many applications because of their low input power, long life and fast on-off switching.

They are extensively used in fancy electronic devices like calculators, etc.

Solved Examples

Example 19. A zener diode of voltage V_Z (= 6 Volt) is used to maintain a constant voltage across a load resistance R_L (=1000Ω) by using a series resistance R_S (=100Ω). If the e.m.f. or source is E (= 9V), calculate the value of current through series resistance, Zener diode and load resistance. What is the power being dissipated in Zener diode.

Solution : Here, E = 9V; V_Z = 6; R_L = 1000Ω and R_s = 100Ω,

Potential drop across series resistor $V = E - V_Z = 9 - 6 = 3$ V

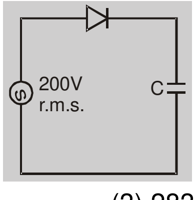
Current through series resistance R_S is $I = \frac{V}{R} = \frac{3}{100} = 0.03$A

Current through load resistance R_L is $I_L = \frac{V_Z}{R_L} = \frac{6}{1000} = 0.006$A

Current through Zener diode is $I_Z = I - I_L = 0.03 - 0.006 = 0.024$ A

Power dissipated in Zener diode is $P_Z = V_Z I_Z = 6 \times 0.024 = 0.144$ Watt

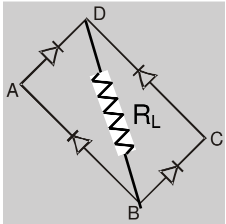
Example 20. In the figure, an A.C. of rms voltage 200 volt is applied to the circuit containing diode and the capacitor and it is being rectified. The maximum potential across the capacitor C in volt will be-



(1) 500 (2) 200 (3) 283 (4*) 141

Answer : (4)

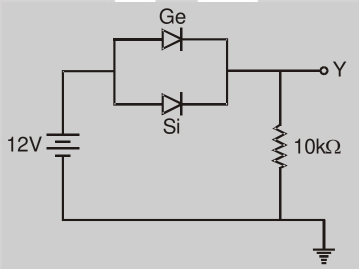
Example 21. In the figure, input is applied across A and C and output is taken across B and D, then the output is-



(1) Zero (2) Same as input (3) Full wave rectified (4) Half wave rectified

Answer : (3)

Example 22. Two junction diodes one of germanium (Ge) and other of silicon (Si) are connected as shown in figure to a battery of emf 12 V and a load resistance 10 kΩ. The germanium diode conducts at 0.3 V and silicon diode at 0.7 V. When a current flows in the circuit, the potential of terminal Y will be-



(1) 12 V (2) 11 V (3) 11.3 V (4) 11.7 V

Answer : (4)

Example 23. Potential barrier developed in a junction diode opposes-

(1) Minority carriers in both regions only (2) Majority carriers
(3) Electrons in N-region (4) Holes in P-region

Answer : (2)

Example 24. Avalanche breakdown in a semiconductor diode occurs when-

(1) Forward current exceeds a certain value (2) Reverse bias exceeds a certain value
(3) Forward bias exceeds a certain value (4) The potential barrier is reduced to zero

Answer : (2)

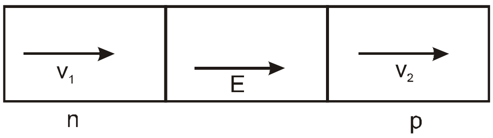
Example 25. A potential barrier of 0.50 V exists across a p-n junction.

(a) If the depletion region is 5.0×10^{-7} m wide, what is the intensity of the electric field in this region ?

(b) An electron with speed 5.0×10^{5} m/s approaches the p-n junction from the n-side. With what speed will it enter the p-side ?

Solution : (a) The electric field is E = V/d $= \frac{0.50 \text{ V}}{5.0 \times 10^{-7} \text{m}} = 1.0 \times 10^{6} \text{V/m}.$

(b) Suppose the electron has a speed v_1 when it enters the depletion layer and v_2 when it comes out of it (figure). As the potential energy increases by e × 0.50 V, from the principle of conservation of energy,



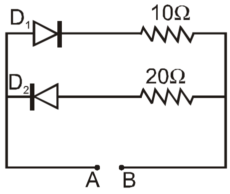
$$\frac{1}{2}mv_1^2 = e \times 0.50 \text{ V} + \frac{1}{2}mv_2^2$$

or $\frac{1}{2} \times (9.1 \times 10^{-31} \text{ kg}) \times (5.0 \times 10^{5} \text{ m/s})^2 = 1.6 \times 10^{-19} \times 0.5 \text{ J} + \frac{1}{2} (9.1 \times 10^{-31} \text{ kg})\, v_2^2$

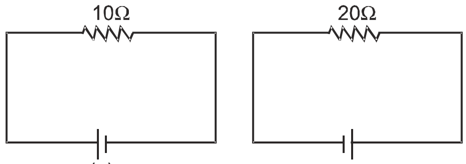
or, 1.13×10^{-19} J $= 0.8 \times 10^{-19}$ J $+ (4.55 \times 10^{-31}\text{kg})\, v_2^2$.

Solving this, $v_2 = 2.7 \times 10^{5}$ m/s

Example 26. A 2V battery may be connected across the points A and B as shown in figure. Assume that the resistance of each diode is zero in forward bias and infinity in reverse bias. Find the current supplied by the battery if the positive terminal of the battery is connected to (a) the point A (B) the point B.



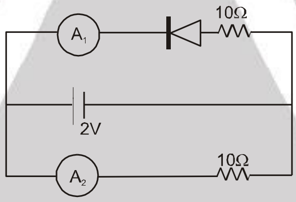
Solution : (a) When the positive terminal of the battery is connected to the point A, the diode D_1 is forward-biased and D_2 is reverse-biased. The resistance of the diode D_1 is zero, and it can be replaced by a resistanceless wire. Similarly, the resistance of the diode D_2 is infinity, and it can be replaced by a broken wire. The equivalent circuit is shown in figure. The current supplied by the battery is 2 V/10 Ω = 0.2 A.



(a) (b)

(b) When the positive terminal of the battery is connected to the point B, the diode D_2 is forward-biased and D_1 is reverse biased. The equivalent circuit is shown in figure (b). The current through the battery is 2 V/20 Ω = 0.1 A.

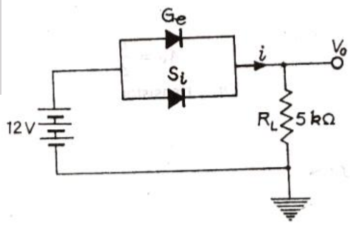
Example 27. What are the reading of the ammeters A_1 and A_2 shown in figure. Neglect the resistance of the meters.



Answer. Reading of A_1 is zero, Reading of A_2 is 0.2 A

Example 28. Calculate the value of V_0, if the Si diode and the Ge diode start conducting at 0.7 V and 0.3 V respectively, in the given circuit. If the Ge diode connection be reversed, what will be the new values of V_0 and I ?

Solution : The effective forward voltage across Ge diode is 12 V – 0.3 = 11.7. This will appear as the output voltage across the load, that is, V_0 = 11.7 V



The current in the load is $i = \frac{V_0}{R_L} = \frac{11.7}{5\ \text{K}\Omega}$ = 2.34 mA.

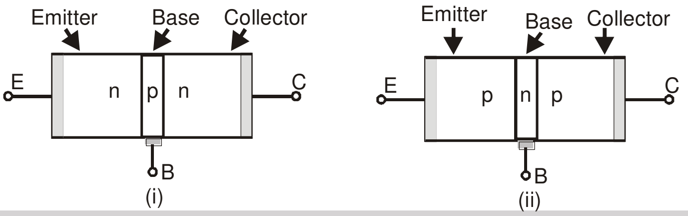
On reversing the connections of Ge diode, it will be reverse-biased and conduct no current. Only Si diode will conduct. The effective forward voltage across Si diode is 12 V – 0.7 V = 11.3 V. This will appear as output, that is V_0 = 11.3 V

The current in the load is $i = \frac{V_0}{R_L} = \frac{11.3}{5\ \text{k}\Omega}$ = 2.26 mA.

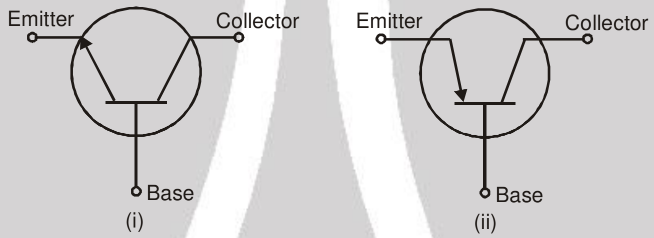
7. Junction Transistor :

Transistor structure and action :

A transistor has three doped regions forming two p–n junctions between them. There are two types of transistors, as shown in figure.



(a) Schematic representations of a n–p–n transistor and p–n–p transistor



(b) Symbols for n–p–n and p–n–p transistors.

(i) n–p–n transistor : Here two segments of n–type semiconductor (emitter and collector) are separated by a segment of p–type semiconductor (base).

(ii) p–n–p transistor : Here two segments of p–type semiconductor (termed as emitter and collector) are separated by a segment of n–type semiconductor (termed as base).

The schematic representations of an n–p–n and a p–n–p configuration are shown in figure. All the three segments of a transistor have different thickness and their doping levels are also different. In the schematic symbols used for representing p–n–p and n–p–n transistors (figure b) the arrowhead shows the direction of conventional current in the transistor. A brief description of the three segments of a transistors is given below:

Emitter : This is the segment on one side of the transistor shown in fig.(a). It is of moderate size and heavily doped. It supplies a large number of majority carriers for the current flow through the transistor.

Base : This is the central segment. It is very thin and lightly doped.

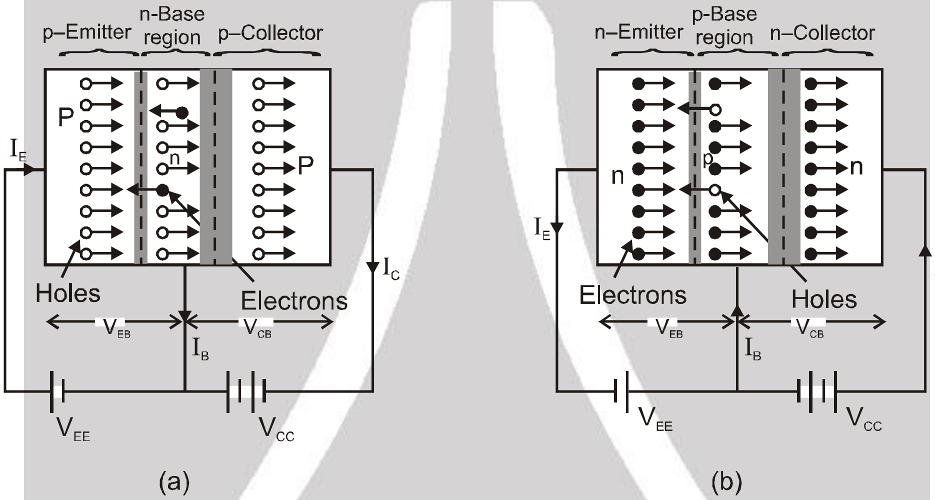
Collector : This segment collects a major portion of the majority carriers supplied by the emitter. The collector side is moderately doped and larger in size as compared to the emitter, so that heat generated during the collection of charge carriers may be easily dissipated into atmosphere

In case of a p–n junction, there is a formation of depletion region across the junction. In case of a transistor, there are two depletion regions are formed respectively at the emitter base–junction and the base collector junction.

The transistor works as an amplifier, with its emitter–base junction forward biased and the base–collector junction reverse biased. This situation is shown in figure, where V_{CC} and V_{EE} are used for creating the respective biasing. When the transistor is biased in this way it is said to be in active state. We represent the voltage between emitter and base as V_{EB} and that between the collector and base as V_{CB} . In figure, base is a common terminal for the two power supplies whose other terminals are connected to emitter and collector, respectively. So, the two power supplies are represented as V_{EE}, and $V_{CC'}$ respectively. In circuits, where emitter is the common terminal, the power supply between the base and emitter is represented as V_{BB} and that between collector and emitter as $V_{CC'}$.

The heavily doped emitter has a high concentration of majority carriers, which will be holes in a p–n–p transistor and electrons in an n–p–n transistor. These majority carriers enter the base region in large numbers. The base is thin and lightly doped. So, the majority carriers there would be few. In a p–n–p transistor the majority carries in the base are electrons since base is of n–type semiconductor. The large number of holes entering the base from the emitter swamps the small number of electrons there.

As the base collector–junction is reverse biased, these holes, which appear as minority carriers at the junction, can easily cross the junction and enter the collector. The holes in the base could move either towards the base terminal to combine with the electrons entering from outside or cross the junction to enter into the collector and reach the collector terminal. The base is made thin so that most of the holes find themselves near the reverse-biased base-collector junction and so cross the junction instead of moving to the base terminal.



Bias Voltage applied on : (a) p–n–p transistor and (b) n–p–n transistor

Note : Due to forward bias a large current enters the emitter–base junction, but most of it is diverted to adjacent reverse–biased base–collector junction and the current coming out of the base becomes a very small fraction of the current that entered the junction. If we represent the hole current and the electron current crossing the forward biased junction by the sum $I_h + I_e$. We see that the emitter current $I_E = I_h + I_e$ but the base current $I_B << I_h + I_e$, because a major part of I_E goes to collector instead of coming out of the base terminal. The base current is thus a small fraction of the emitter current.

It is obvious from the above description and also from a straight forward application of Kirchoff's law to figure(a) that the emitter current is the sum of collector current and base current : $I_E = I_C + I_B$

We also see that $I_C \approx I_{E'}$

Our description of the direction of motion of the holes is identical with the direction of the conventional current. But the direction of motion of electrons is just opposite to that of the current. Thus in a p–n–p transistor the current enters from emitter into base whereas in a n–p–n transistor it enters from the base into the emitter. The arrowhead in the emitter shows the direction of the conventional current.

We can conclude that in the active state of the transistor the emitter–base junction acts as a low resistance while the base collector acts as a high resistance.

In a transistor, only three terminals are available viz emitter (E), base (B) and collector (C). Therefore in a circuit the input/output connections have to be such that one of these (E,B or C) is common to both the input and the output. Accordingly, the transistor can be connected in either of the following three configurations :

Common Emitter (CE), Common Base (CB), Common Collector (CC).

Working of Transistor

(1) There are four possible ways of biasing the two P-N junctions (emitter junction and collector junction) of transistor.
  (i) Active mode : Also known as linear mode operation.
  (ii) Saturation mode : Maximum collector current flows and transistor acts as a closed switch from collector to emitter terminals.
  (iii) Cut-off mode : Denotes operation like an open switch where only leakage current flows.
  (iv) Inverse mode : The emitter and collector are inter changed.

Different modes of operation of a transistor

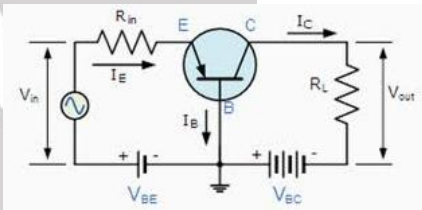
Operating mode	**Emitter base bias**	**Collector base bias**
Active	Forward	Reverse
Saturation	Forward	Forward
Cut off	Reverse	Reverse
Inverse	Reverse	Forward

(2) A transistor is mostly used in the active region of operation i.e., emitter base junction is forward biased and collector base junction is reverse biased.
(3) From the operation of junction transistor it is found that when the current in emitter circuit changes. There is corresponding change in collector current.
(4) In each state of the transistor there is an input port and an output port. In general each electrical quantity (V or I) obtained at the output is controlled by the input.

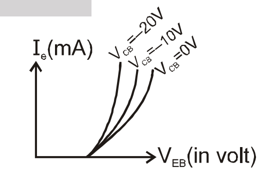
Transistor Configurations

A transistor can be connected in a circuit in the following three different configurations.
Common base (CB), Common emitter (CE) and Common collector (CC) configuration.

(1) CB configurations : Base is common to both emitter and collector.

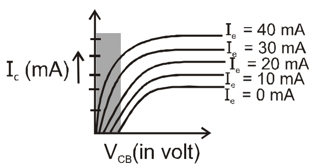


  (i) Input current = I_e
  (ii) Input voltage = V_{EB}
  (iii) Output voltage = V_{CB}
  (iv) Output current = I_C
  With small increase in emitter-base voltage V_{EB}, the emitter current I_e increases rapidly due to small input resistance.
  (v) **Input characteristics :** If V_{CB} = constant, curve between I_e and V_{EB} is known as input charactersistics. It is also known as emitter charactersistics :
  Input characteristics of NPN transistor are also similar to the above figure but I_e and V_{EB} both are negative and V_{CB} is positive. Dynamic input resistance of a transistor is given by



$$R_i = \left(\frac{\Delta V_{EB}}{\Delta I_e}\right)_{V_{CB=constant}} \quad \{R_i \text{ is of the order of } 100\Omega\}$$

  (vi) **Output characteristics :** Taking the emitter current i_e constant, the curve drawn between I_C and V_{CB} are known as output charactersistics of CB configuration.



$$\text{Dynamics output resistance } R_0 = \left(\frac{\Delta V_{CB}}{\Delta i_C}\right)_{i_e=constant}$$

Note: Transistor as CB amplifier

(i) ac current gain $\alpha_c = \dfrac{\text{Small change in collector current } (\Delta i_c)}{\text{Small change in collector current } (\Delta i_e)}$

(ii) dc current gain α_{dc} (or α) = $\dfrac{\text{Collector current } (i_c)}{\text{Emitter current } (i_e)}$ value of α_{dc} lies between 0.95 to 0.99

(iii) Voltage gain $A_v = \dfrac{\text{Change in output voltage } (\Delta V_0)}{\text{Change in input voltage } (\Delta V_i)}$

$\Rightarrow A_v = \alpha_{ac} \times$ Resistance gain

(iv) Power gain = $\dfrac{\text{Change in output power } (\Delta P_0)}{\text{Change in input power } (\Delta P_C)}$ $\Rightarrow$ Power gain = $\alpha^2_{ac} \times$ Resistance gain

(v) Phase difference (between output and input) : same phase

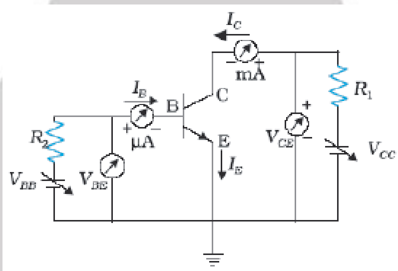
(vi) Application : For High frequency

COMMON EMITTER(CE) : The transistor is most widely used in the CE configuration.

When a transistor is used in CE configuration, the input is between the base and the emitter and the output is between the collector and the emitter. The variation of the base current I_B with the base–emitter voltage V_{BE} is called the input characteristic. The output characteristics are controlled by the input characteristics. This implies that the collector current changes with the base current.

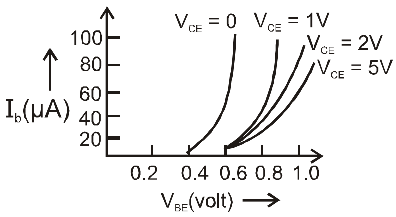
CE configurations : Emitter is common to both base and collector.

The graphs between voltages and currents when emitter of a transistor is common to input and output circuits are known as CE charactersistics of a transistor.



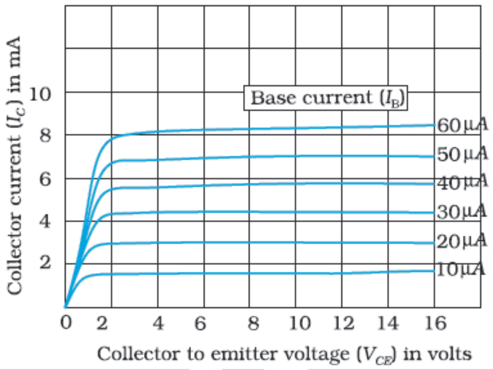
Input charactersistics : Input charactersistics curve is drawn between base current I_b and emitter base voltage V_{EB}, at constant collector emitter voltage V_{CE}.

Dynamic input resistance $R_i = \left(\dfrac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE} \to \text{constant}}$



Output characteristics : Variation of collector current I_C with V_{CE} can be noticed for V_{CE} between 0 to 1 V only. The value of V_{CE} up to which the I_C changes with V_{CE} is called knee voltage. The transistor are operated in the region above knee voltage.

Dynamic output resistance $R_0 = \left(\dfrac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B \to \text{constant}}$



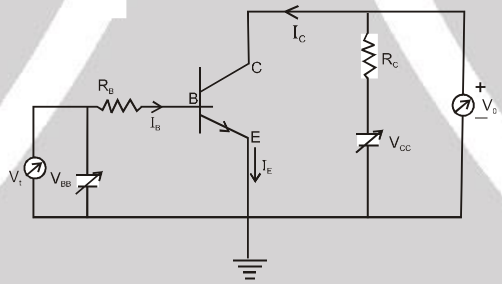
(b) Transistor as a device :

The transistor can be used as a device application depending on the configuration used (namely CB, CC and CE), the biasing of the E-B and B-C junction and the operation region namely cutoff, active region and saturation.

When the transistor is used in the cutoff or saturation state it acts as a switch. On the other hand for using the transistor as an amplifier, it has to operate in the active region.

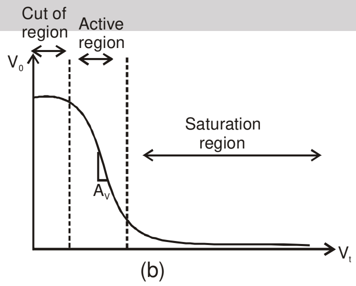
(i) Transistor as a switch :

We shall try to understand the operation of the transistor as a switch by analysing the behaviour of the base-biased transistor in CE configuration as shown in fig. (a). Applying Kirchhoff's voltage rule to the input and output sides of this circuit, we get $V_{BB} = I_BR_B + V_{BE}$ and $V_{CE} = V_{CC} - I_CR_C$.



(a)

We shall treat V_{BB} as the dc input voltage V_i and V_{CE} as the dc output voltage V_o.So, we have $V_i = I_BR_B + V_{BE}$ and $V_0 = V_{CC} - I_CR_C$.



(b)

Let us see how V_0 changes as V_i increases from zero onwards. In the case of Si transistor, as long as input V_i is less than 0.6 V, the transistor will be in cut off state and current I_C will be zero. Hence $V_O = V_{CC}$.

When V_i becomes greater than 0.6 V the transistor is in active state with some current I_C in the output path and the output V_0 decrease as the term I_CR_C increases. With increase of V_i, I_C increases almost linearly and so V_0 decreases linearly till its value becomes less than about 1.0 V.

Beyond this, the change becomes non linear and transistor goes into saturation state. With further increase in V_i the output voltage is found to decrease further towards zero though it may never become zero. If we plot the V_0 vs V_i curve, [also called the transfer characteristics of the base-biased transistor (figure b], we see that between cut off state and active state and also between active state and saturation state there are regions of non-linearity showing that the transition from cutoff state to active state and from active state to saturation state are not sharply defined.

As long as V_i is low and unable to forward-bias the transistor, V_0 is high (at V_{CC}). If V_i is high enough to drive the transistor into saturation very near to zero. When the transistor is not conducting it is said to be switched off and when it is driven into saturation it is said to be switched on. This shows that if we define low and high states as below and above certain voltage levels corresponding to cutoff and saturation of the transistor, then we can say that a low input switches the transistor off and a high input switches it on.

(ii) Transistor as an Amplifier (CE-Configuration) : To operate the transistor as an amplifier it is necessary to fix its operating point somewhere in the middle of its active region. If we fix the value of V_{BB} corresponding to a point in the middle of the linear part of the transfer curve then the dc base current I_B would be constant and corresponding collector current I_C will be constant The dc voltage $V_{CE} = V_{CC} - I_C R_C$ would also remain constant. The operating values of V_{CE} and I_B determine the operating point, of the amplifier. If a small sinusoidal voltage with amplitude v_s is superposed on the dc base bias by connecting the source of that signal in series with the V_{BB} supply, then the base current will have sinusodial variations supperimposed on the value of I_B. As a consequence the collector current also will have sinusoidal variations superimposed on the value of I_C producing in turn corresponding change in the value of V_0. We can measure the ac variations across the input and output terminals by blocking the dc voltages by larger capacitors.

In the discription of the amplifier given above we have not considered any ac signal. In general, amplifiers are used to amplify alternating signals. Now let us superimpose an ac input signal v_i (to be amplified) on the bias V_{BB} (dc) as shown in Figure. The output is taken between the collector and the ground. The working of an amplifier can be easily understood, if we first assume that $v_i = 0$. Then applying Kirchhoff's law to the output loop, we get

$V_{CC} = V_{CE} + I_C R_L$

Likewise, the input loop gives $V_{BB} = V_{BE} + I_B R_B$

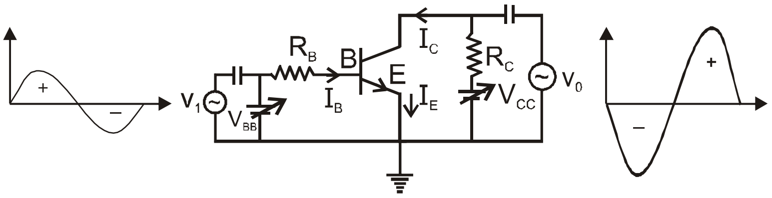
when v_i is not zero, we get

$V_{BE} + v_i = V_{BE} + I_B R_B + \Delta I_B (R_B + r_i)$

The change in V_{BE} can be related to the input resistance r_i and the change in I_B. Hence

$v_i = \Delta I_B (R_B + r_i) = r\Delta I_B$

The change in I_B causes a change in I_C. We define a parameter β_{ac}, which is similar to the β_{dc} defined in equation as $\beta_{ac} = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{i_c}{i_b}$



which is also known as the ac current gain A_i. Usually β_{ac} is close to β_{dc} in the linear region of the output characterstics.

The change in I_C due to a change in I_B causes a change in V_{CE} and the voltage drop across the resistor R_L because V_{CC} is fixed.

These changes can be given by Eq. as

$\Delta V_{CC} = \Delta V_{CE} + R_L\Delta I_C = 0$ or $\Delta V_{CE} = -R_L\Delta I_C$

The change in V_{CE} is the output voltage v_0. From equation we get

$v_0 = \Delta V_{CE} = -\beta_{ac}R_L\Delta I_B$

The voltage gain of the amplifier is $A_v = \frac{v_0}{v_i} = \frac{\Delta V_{CE}}{r\Delta I_B} = -\frac{\beta_{ac}R_L}{r}$

The negative sign represents that output voltage is opposite with phase with the input voltage.

From the discussion of the transistor characteristics you have seen that there is a current gain β_{ac} in the CE configuration. Here we have also seen the voltage gain A_v. Therefore the power gain A_p can be expressed as the product of the current gain and voltage gain. Mathematically $A_p = \beta_{ac} \times A_v$

Since β_{ac} and A_v are greater than 1, we get ac power gain. However it should be realised that transistor is not a power generating device. The energy for the higher ac power at the output is supplied by the battery.

Note : Transistor as CE amplifier

(i) ac current gain $\beta_{ac} = \left(\frac{\Delta i_C}{\Delta i_b}\right)$ V_{CE} = constant

(ii) dc current gain $\beta_{dc} = \frac{i_c}{i_b}$

(iii) Voltage gain : $A_v = \frac{\Delta V_0}{\Delta V_i} = \beta_{ac} \times$ Resistance gain

(iv) Power gain = $\frac{\Delta P_0}{\Delta P_i} = \beta^2_{ac} \times$ Resistance

(v) Transconductance (g_m) : 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.

(v) Phase difference (between output and input) : opposite phase

(vi) Application : For audible frequency

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

Solved Examples

Example 29. Let i_E, i_C and i_B represent the emitter current, the collector current and the base current respectively in a transistor. Then

(1) i_C is slightly smaller than i_E.
(2) i_C is slightly greater than i_E.
(3) i_B is much smaller than i_E.
(4) i_B is much greater than i_E.

Answer : (1,3)

Example 30. In a common base transistor amplifier, the input and the output resistance are 500 Ω and 40kΩ, and the emitter current is 1.0mA. Find the input and the output voltages. Given $\alpha = 0.95$.

Solution : The input voltage is emitter current multiplied by input resistance, that is,

$V_{in} = i_E \times R_{in} = (1.0 \times 10^{-3}\ A) \times 500\Omega = 0.5\ V$

Similarly, the output voltage is

$V_{out} = i_C \times R_{out} = \alpha\ i_E \times R_{out} = 0.95\ (1.0 \times 10^{-3}\ A) \times (40 \times 10^3\ \Omega) = 38\ V$. **Ans.**

Example 31. A P–N–P transistor is used in common–emitter mode in an amplifier circuit. A change of 40μA in the base current brings a change of 2mA in collector current and 0.04 V in base–emitter voltage. Find the :

(i) input resistance ($R_{inp.}$), and (ii) the base current amplification factor (β).

If a load of 6kΩ is used, then also find the voltage gain of the amplifier.

Solution : Given $\Delta I_B = 40\mu A = 40 \times 10^{-6}\ A$

$\Delta I_C = 2mA = 2 \times 10^{-3}\ A$

$\Delta V_{BE} = 0.04$ volt, $R_L = 6k\Omega = 6 \times 10^3\ \Omega$

(i) Input Resistance, $R_{inp.} = \dfrac{\Delta V_{BE}}{\Delta I_B} = \dfrac{0.04}{40 \times 10^{-6}} = 10^3\ \Omega = 1\ k\Omega$ **Ans.**

(ii) Current amplification factor, $\beta = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{2 \times 10^{-3}}{40 \times 10^{-6}} = 50$ **Ans.**

(iii) Voltage gain in common–emitter configuration,

$A_\upsilon = \beta \dfrac{R_L}{R_{inp.}} = 50 \times \dfrac{6 \times 10^3}{1 \times 10^3} = 300$. **Ans.**

Example 32. In an N–P–N transistor 10^{10} electrons enter the emitter in 10^{-6} s. 2% of the electrons are lost in the base. Calculate the current transfer ratio and current amplification factor.

Solution : We know that current = charge/time

The emitter current (I_E) is given by $I_E = \dfrac{Ne}{t} = \dfrac{10^{10} \times (1.6 \times 10^{-19})}{10^{-6}} = 1.6$ mA

The base current (I_B) is given by $I_B = \dfrac{2}{100} \times 1.6 = 0.032$ mA

In a transistor, $I_E = I_B + I_C$

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

Current transfer ratio = $\dfrac{I_C}{I_E} = \dfrac{1.568}{1.6} = 0.98$

Current amplification factor = $\dfrac{I_C}{I_B} = \dfrac{1.568}{0.032} = 49$. **Ans.**

Example 33. When the voltage between emitter and the base V_{EB} of a transistor is changed by 5mV while keeping the collector voltage V_{CE} fixed when then its emitter current changes by 0.15 mA. Calculate the input resistance of the transistor.

Answer : 33.33 ohm

Example 34. A transistor is used in common-emitter mode in an amplifier circuit. When a signal of 20 mV is added to the base–emitter voltage, the base current changes by 20μA and the collector current changes by 2 mA. The load resistance is 5 kΩ. Calculate (a) the factor β, (b) the input resistance $R_{BE'}$ (c) the transconductance and (d) the voltage gain.

Solution : (a) $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2\ \text{mA}}{20\mu A} = 100$

(b) The input resistance $R_{BE} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{20mV}{20\mu A} = 1k\Omega$

(c) Transconductance = $\frac{\Delta I_c}{\Delta V_{BE}} = \frac{2mA}{20mV} = 0.1$ mho.

(d) The change in output voltage is $R_L \Delta I_c$ = (5 kW) (2mA) = 10V.
The applied signal voltage = 20 mV.
Thus, the voltage gain is, $\frac{10V}{20mV} = 500$.

Example 35. The a-c current gain of a transistor is β= 19. In its common-emitter configuration, what will be the change in the collector-current for a change of 0.4 mA in the base-current ? What will be the change in the emitter current ?

Solution. By definition, the a-c current gain β is given by $\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$

∴ $\Delta I_C = \beta \times \Delta I_B = 19 \times 0.4$ mA = 7.6 mA.

The emitter - current is the sum of the base- current and the collector-current ($i_E = i_B + i_C$)

∴ $\Delta I_E = \Delta I_B + \Delta I_C$ = 0.4 mA + 7.6 mA = 80 mA.

Example 36. A transistor is connected in common-emitter (C-E) configuration. The collector-supply is 8 V and the voltage drop across a resistor of 800 Ω in the collector circuit is 0.5 V. If the current-gain factor (α) is 0.96, find the base-current.

Solution : The alternating-current gain is $\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = 24$

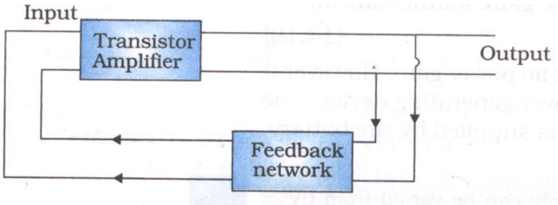
The collector - current is $i_C = \frac{\text{voltage} - \text{drop across collector resistor}}{\text{resistance}} = \frac{0.5V}{800\Omega} \times 10^{-3}$ A.

But $\beta = \frac{i_C}{i_B}$, where i_B is base - current.

∴ $i_B = \frac{i_C}{\beta} = \frac{0.625 \times 10^{-3}\ A}{24} = 26 \times 10^{-6}\ A = 26\ \mu A$.

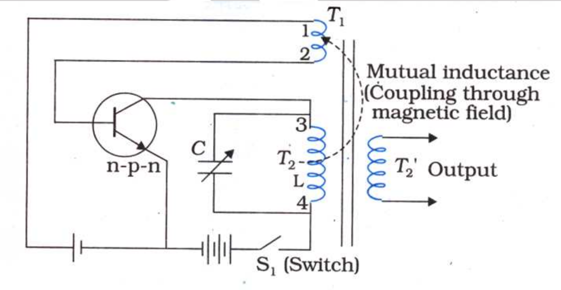
8. Feedback amplifier and transistor oscillator :

In an oscillator, we get ac output without any external input singnal. A portion of the output power is returned back (feedback) to the input in phase with the starting power (this process is termed positive feedback) as shown in figure(a). The feedback can be achieved by inductive coupling (through mutual inductance) or LC or RC networks.



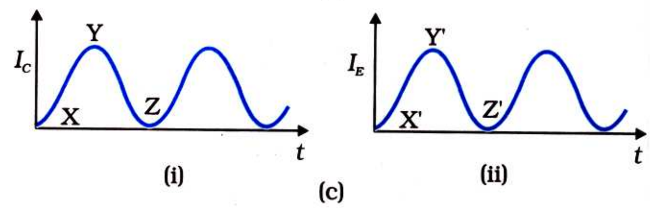
(a)

Suppose switch S_1 is put on to apply proper bias for the first time. Obviously, a surge of collector current flows in the transistor. This current flows through the coil T_2 where terminals are numbered 3 and 4 (Fig. b).



(b)

This current does not reach full amplitude instantaneously but increases from X To Y, as shown in figure(C). The inductive coupling between coil T_2 and coil T_1 now causes a current to flow in the emitter circuit (note that this actually is the 'feedback' from input to output). As a result of this positive feedback, this current (in T_1 emitter current) also increases from X' to Y' Fig. (C) (ii).



(c)

The current in T_2 (collector current), connected in the collector circuit acquires the value Y when the transistor becomes saturated. This means that maximum collector current is flowing and can increase no further. Since there is no further change in collector current, the magnetic field around T_2 ceases to grow. As soon as the field becomes static, there will be no further feedback from T_2 to T_1. Without continued feedback, the emitter current begins to fall. Consequently, collector current decreases causes the magnetic field to decay around the coil T_2. Thus, T_1 is now seeing a decaying field in T_2 (opposite from what it saw when the field was growing at the initial start operation). This causes a further decrease in means that both I_E and I_C cease to flow. Therefore, the transistor has reverted back to its original state (when the power was first switched on). The whole process now repeat itself. The transistor is driven to saturation, then to cut-off, and then back to saturation. The time for change from saturation to cut-off and back is determined by the constant of the tank circuit or tuned circuit (inductance L of Coil T_2 and C connected in parallel to it). The resonance frequency (v) of this tuned circuit determines the frequency at which the oscillator will oscillate.

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

9. Analogue Circuits and Digital Circuits and signal :

There are two types of electronic circuits : analogue circuits and digital circuits :

In analogue circuits, the voltage (or current) varies continuously with time (figure a). Such a voltage (or current) signal is called an ‘analogue signal’.Figure shows a typical voltage analogue signal varying sinusoidally between 0 and 5V.

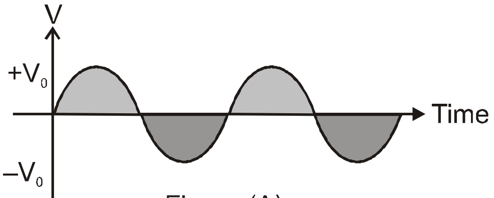


Figure (A)

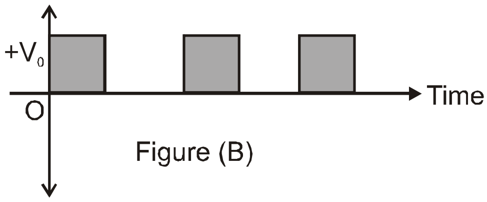


Figure (B)

On the other hand, in digital circuits, the voltage (or current) has only two levels, either zero or some constant value of voltage (figure b). A signal having only two levels of voltage (or current) is called a ‘digital signal’. Figure shows a typical digital signal in which the voltage at any time is either 0 or 5V.

In digital circuits, the binary number system is used, according to which the two levels of the (digital) signal are represented by the digits 0 and 1 only.

The digital circuits are the basis of calculators, computers, etc.

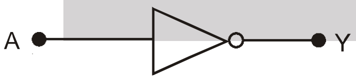
10. Logic Gates :

A logic gate is a digital circuit which works according to some logical relationship between input and output voltages. It either allows a signal to pass through or stops it.

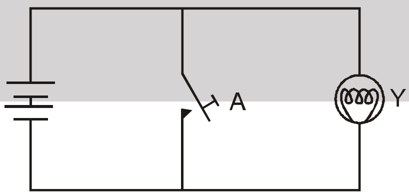
A gate is a digital circuit that follows curtain logical relationship between the input and output voltages. Therefore, they are generally known as logic gates — gates because they control the flow of information. The five common logic gates used are NOT, AND, OR, NAND, NOR. Each logic gate is indicated by a symbol and its function is defined by a truth table that shows all the possible input logic level combinations with their respective output logic levels. Truth tables help understand the behaviour of logic gates. These logic gates can be realised using semiconductor devices.

(a) The NOT Gate :

The NOT gate has only one input and one output. It combines the input A with the output Y, according to the Boolean expression, read as ‘NOT A equals Y’. It means that Y is negation (or inversion) of A. Since there are only two digits 0 and 1 in the binary system, we have, Y = 0, if A = 1 and Y = 1 if A = 0 . The logic symbol of the NOT gate is shown in figure.



(a)



(b)

Truth table

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

(c)

The possible combinations of the input A and the output Y of the NOT gate can be known with the help of electric circuit, shown in figure. In this circuit, a switch A (input) is connected in parallel to a battery and a bulb Y(output). The working of the circuit is as follows :

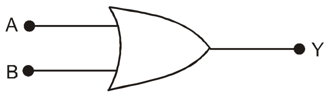
If switch A is open (A = 0), the bulb wil glow (Y = 1).

If switch A is closed (A = 1), the bulb will not glow (Y = 0).

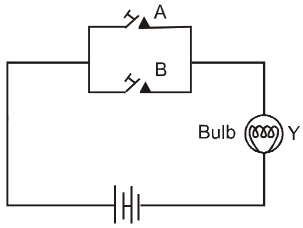
These two possible combinations of input A and output Y are tabulated in figure, which is the truth table of the NOT gate.

(b) The OR Gate :

The OR gate is a device that has two input variables A and B and one output variable Y, and follows the Boolean expression, A + B = Y, read as' A OR B equal Y'. Its logic symbol is shown in figure.



(a)



(b)

Truth Table

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

(c)

The possible combinations of the inputs A and B and the output Y of the OR gate can be known with the help of an electrical circuit, shown in figure. In this circuit, two switches A and B (inputs) are connected in parallel with a battery and a bulb Y (output).

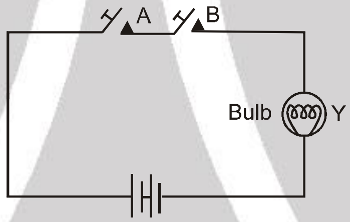
(c) The AND Gate :

The AND gate is also a two-input and one-output logic gate. It combines the inputs A and B to give the output Y, according to the Boolean expression

A.B = Y

read 'A AND B equals Y'

(a)



(b)

Truth table

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

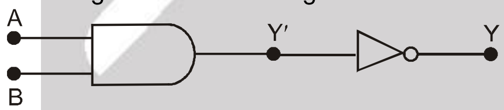
(c)

Combinations of gates :

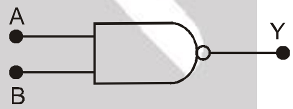
Various combinations of the three basic gates, namely, OR, AND and NOT, produce complicated digital circuits, which are also called 'gates'. The commonly used combinations of basic gates are NAND gate, NOR, gate. These are also called universal gates.

(i) The NAND gate :

This gate is a combination of AND and NOT gates. If the output Y' of AND gate is connected to the input of NOT gate, as shown in figure, the gate so obtained is called NAND gate. The logic symbol of NAND gate is shown in figure.



(a)



(b)

The Boolean expression for the NAND gate is $\overline{A \cdot B} = Y$

read as 'A AND B negated equals Y'.

The truth table of the NAND gate can be obtained by logically combining the truth tables of AND and NOT gates. In figure, the output Y' of the truth table of AND gate have been negated (NOT operation) to obtain the corresponding outputs Y for the NAND gate. The resulting table is the truth table of the NAND gate.

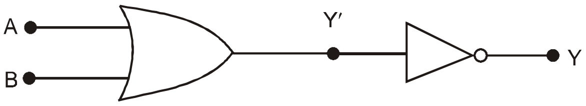
A	B	Y' (= A. B)	Y (= $\overline{A.B}$) = $\overline{Y'}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

$\Rightarrow$

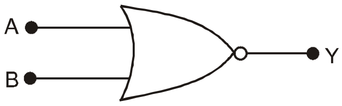
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(ii) The NOR Gate :

The NOR gate is a combination of OR and NOT gates. If the output Y′ of OR gate is connected to the input of NOT gate, as shown in figure, the gate so obtained is NOR gate.



(a)



(b)

The Boolean expression for the NOR gate is $\overline{A+B} = Y$
read as 'A OR B negated equals Y' :

A	B	Y′ (= A+B)	Y (= $\overline{A+B}$) = $\overline{Y'}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

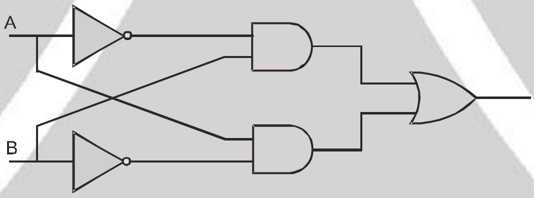
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

The truth table of the NOR gate can be obtained by logically combining the truth tables of OR and NOT gates. In figure(a), the outputs Y′ of the truth table of OR gate have been negated to obtain the corresponding outputs Y for the NOR gate.

(iii) The XOR Gate :

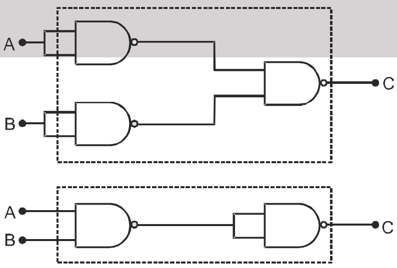
The Boolean expression for the XOR gate is

$y = A \cdot \overline{B} + \overline{A} \cdot B$



Solved Miscellaneous Problems

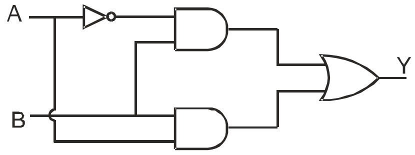
Problem 1. The combination of 'NAND' gates shown here under are equivalent to-



(1) An OR gate and an AND gate respectively
(2) An AND gate and a NOT gate respectively
(3) An AND gate and an OR gate respectively
(4) An OR gate and a NOT gate respectively

Answer : (1)

Problem 2. Truth table for the following is-



(1)

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

(2)

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

(3)

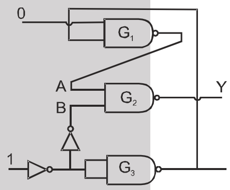
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

(4)

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

Ans. (2)

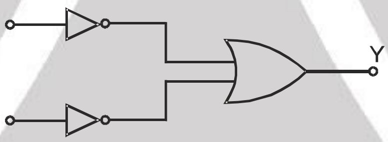
Problem 3. In circuit in following figure the value of Y is-



(1) zero
(2) 1
(3) fluctuates between 0 and 1
(4) indeterminate as the circuit cannot be realized

Answer : (1)

Problem 4. The output Y for the following logic gate circuit will be-



(1) AB (2) $\bar{A} \cdot \bar{B}$ (3) $\overline{A + B}$ (4) $\overline{A \cdot B}$

Answer : (4)

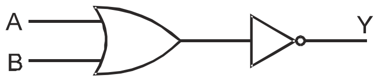
Problem 5. The following truth-table belongs to which one of the four gates-

A	B	X
1	1	0
0	1	0
1	0	0
0	0	1

(1) OR (2) NAND (3) XOR (4) NOR

Answer : (4)

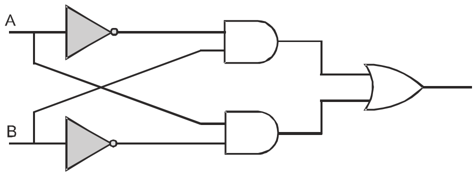
Problem 6. The given circuit is for the gate-



(1) NOR (2) NAND (3) NOT (4) XOR

Answer. (1)

Problem 7. The truth table of the logic circuit shown-



(1)

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

(2)

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

(3)

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

(4)

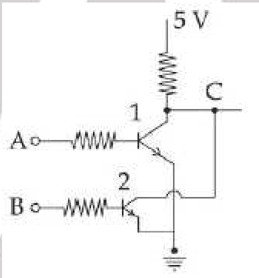
A	B	Y
0	0	0
1	0	0
0	1	0
1	1	1

Answer : (2)

Solution : It is also called XOR gate the Boolean expression for XOR gate is Y = $A \cdot \bar{B} + \bar{A} \cdot B$

JEE (Main) ONLINE QUESTIONS

1. Consider two npn transistors as shown in figure. If 0 volts corresponds to false and 5 volts correspond to true then the output at C corresponds to : **[JEE (Main) 2013_ONLINE TEST]**



(1) A NAND B (2) A OR B (3) A AND B (4*) A NOR B

Ans. **(4)**

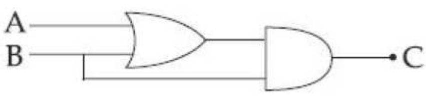
Sol. It is equivalent to NAND gate

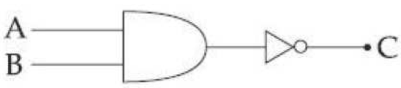
A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

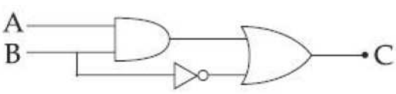
2. Which of the following circuits correctly represents the following truth table ?

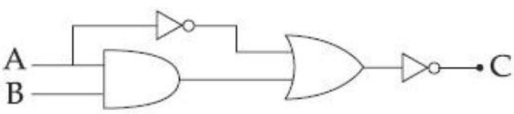
[JEE (Main) 2013_ONLINE TEST]

A	B	C
0	0	0
0	1	0
1	0	1
1	1	0

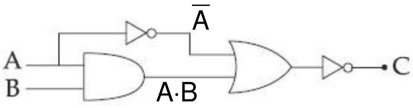
(1) 

(2) 

(3) 

(4*) 

Sol.

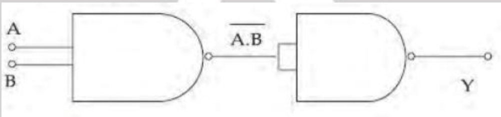


$C = \overline{\overline{A} + A \cdot B} = A \cdot (\overline{A \cdot B}) = A \cdot (\overline{A} \cdot \overline{B}) = A \cdot \overline{A} + A\overline{B}$

$C = A\overline{B}$

A	B	C
0	0	0
0	1	0
1	0	1
1	1	0

3. Identify the gate and match A, B, Y in Bracket to check **[JEE(Main)-2014_ONLINE TEST]**



(1) Not (A = 1, B = 1, Y = 1) (2) OR (A = 1, B = 0, Y = 0)

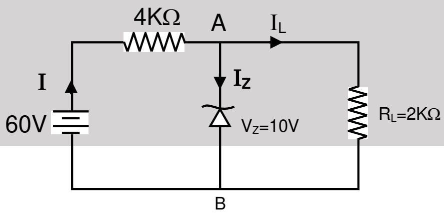
(3) XOR (A = 0, B = 0, Y = 0) (4*) AND (A = 1, B = 1, Y = 1)

4. An n-p-n transistor has three leads A, B and C. Connecting B and C by moist fingers, A to the positive lead of an ammeter, and C to the negative lead of the ammeter, one finds large deflection. Then A, B and C refer respectively to : **[JEE(Main)-2014_ONLINE TEST]**

(1) Base, emitter and collector (2*) Emitter, base and collector

(3) Collector, emitter and base (4) Base, collector and emitter

5. A Zener diode is connected to a battery and a load as shown below. The currents I, I_Z and I_L are respectively. **[JEE(Main)-2014_ONLINE TEST]**



(1) 12.5 mA, 5mA, 7.5 mA (2) 15mA, 7.5 mA, 7.5 mA

(3) 15mA, 5mA, 10mA (4*) 12.5 mA, 7.5 mA, 5 mA

6. For LED's to emit light in visible region of electromagnetic light, it should have energy band gap in the range of : **[JEE (MAIN) 2014_ONLINE TEST]**

(1) 0.9 eV to 1.6 eV (2) 0.1 eV to 0.4 eV (3*) 1.7 eV to 3.0 eV (4) 0.5 eV to 0.8 eV

7. In an unbiased n-p junction electrons diffuse from n-regionto p-region because : **[JEE (MAIN) 2015_ONLINE TEST]**

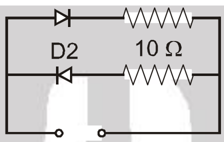
(1) electrons travel across the junction due to potential difference

(2*) electron concentration in n-region is more as compared to that in p-region

(3) only electrons move from n to p region and not the vice-versa

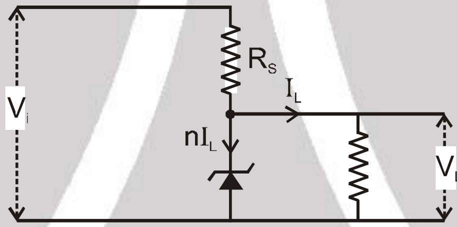
(4) holes in p-region attract them

8. A 2V battery is connected across AB as shown in the figure. The value of the current supplied by the battery when in one case battery's positive terminal is connected to A and in other case when positive terminal of battery is connected to B will respectively be :



(1*) 0.4 A and 0.2 A (2) 0.2 A and 0.4 A (3) 0.1 A and 0.2 A (4) 0.2 A and 0.1 A

9. The value of the resistor, R_S, needed in the dc voltage regulator circuit shown here, equals :



(1*) $\frac{(V_i - V_L)}{(n+1)I_L}$ (2) $\frac{(V_i + V_L)}{(n+1)I_L}$ (3) $\frac{(V_i - V_L)}{n \quad I_L}$ (4) $\frac{(V_i + V_L)}{n \quad I_L}$

10. An unknown transistor needs to be identified as npn or pnp type. A multimeter, with +ve and –ve terminals, is used to measure resistance between different terminals transistor. If terminal 2 is the base of the transistor then which of the following is correct for a pnp transistor ?

(1) +ve terminal 3, –ve terminal 2, resistance high

(2) +ve terminal 2, –ve terminal 3, resistance low

(3) +ve terminal 1, –ve terminal 2, resistance high

(4*) +ve terminal 2, –ve terminal 1, resistance high

11. An experiment is performed to determine the I - V characteristics of a Zener diode, which has a protective resistance of R =100 Ω, and maximum power of dissipation rating of 1W. The minimum voltage range of the DC source in the circuit is :

(1) 0 – 12V (2) 0 – 5V (3*) 0 – 24 (4) 0 – 8V

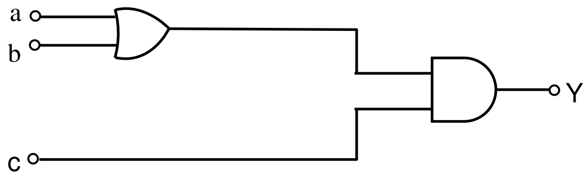
12. The truth table given in fig. represents :

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

(1) AND - Gate (2*) OR - Gate (3) NOR - Gate (4) NAND – Gate

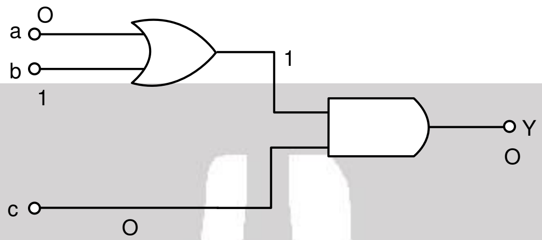
Sol. from truth table its clear.

13. To get an output of 1 from the circuit shown in figure the input must be :



(1) a =1, b =1, c = 0 (2) a =1, b =0, c = 0 (3) a =0, b = 0, c = 1 (4*) a =1, b =0, c = 1

Sol. Checking options one by one



We must note that c = 1
and output of OR gate must also be 1 therefore

Exercise-1

✍ **Marked Questions can be used as Revision Questions.**

OBJECTIVE QUESTIONS

Section (A) : Energy Band

A-1. The forbidden energy band gap in conductors, semiconductors and insulators are EG_1, EG_2 and EG_3 respectively, The relation among them is
(1) $EG_1 = EG_2 = EG_3$
(2) $EG_1 < EG_2 < EG_3$
(3) $EG_1 > EG_2 > EG_3$
(4) $EG_1 < EG_2 > EG_3$

A-2. Fermi energy is the
(1) Minimum energy of electrons in metal at 0 K
(2) Minimum energy of electrons in metal at 0°C
(3) Maximum energy of electrons in metal at 0 K
(4) Maximum energy of electrons in metal at 0°C

A-3. Which of the following statements is true
(1) In insulators the conduction band is completely empty.
(2) In conductor the conduction band is completely empty.
(3) In semiconductor the conduction band is partially empty at low temperature.
(4) In insulators the conduction band is completely filled with electrons.

A-4. Which of the following statement is true-
(1) At absolute zero temperature, the semiconductor behave as a conductor
(2) The energy gap in semiconductor is more than that for insulator
(3) The resistance of semiconductor increases with increase in temperature
(4) The resistance of semiconductor decreases with increase in temperature

A-5. The valence band at (0 K) is-
(1) completely filled
(2) completely empty
(3) partially filled
(4) nothing can be said

A-6. The free electron concentration (n) in the conduction band of a semiconductor at a temperature T Kelvin is described in terms of E_g and T as –
(1) $n = ATe^{-Eg/kT}$
(2) $n = AT^2e^{-Eg/kT}$
(3) $n = AT^2e^{-Eg/2kT}$
(4) $n = AT^{3/2}e^{-Eg/2kT}$

A-7. Electric conduction in a semiconductor takes place due to
(1) electrons only
(2) holes only
(3) both electrons and holes
(4) neither electron nor holes

A-8. An electric field is applied to a semiconductor. Let the number of charge carries be n and the average drift speed be v. If the temperature is increased,
(1) both n and v will increase
(2) n will increase but v will decrease
(3) v will increases but n will decrease
(4) both n and v will decrease

A-9.✍ The mobility of free electron is greater than that of free holes because
(1) They carry negative charge
(2) They are light
(3) They mutually collide less
(4) They require low energy to continue their motion

Section (B) : Intrinsic semiconductor

B-1. Let n_p and n_e be the numbers of holes and conduction electrons in an intrinsic semiconductor
(1) $n_p > n_e$ (2) $n_p = n_e$ (3) $n_p < n_e$ (4) $n_p \neq n_e$

B-2. The electrical conductivity of pure germanium can be increased by
(1) increassing the temperature (2) doping acceptor impurities
(3) doping donor impurities (4) irradiating ultraviolet light on it.

Section (C) : Extrinsic semiconductor

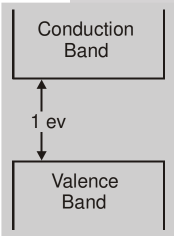
C-1. A N-type semiconductor is
(1) Negatively charged (2) Positively charged (3) Neutral (4) None of these

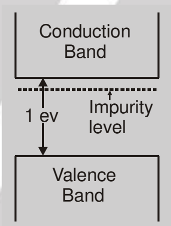
C-2. Let n_p and n_e be the numbers of holes and conduction electrons in an extrinsic semiconductor
(1) $n_p > n_e$ (2) $n_p = n_e$ (3) $n_p < n_e$ (4) $n_p \neq n_e$

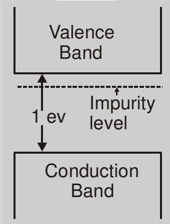
C-3. A semiconductor is doped with a donor impurity
(1) The hole concentration increases (2) The hole concentration decreases
(3) The electron concentration increases (4) The electron concentration decreases

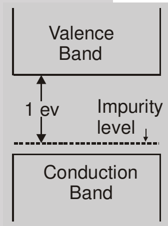
C-4. In a P-type semiconductor, the acceptor level is 57 meV, above the valence band. The maximum wave length of light required to produce a hole will be-
(1) 57 A° (2) 57×10^{-3} A° (3) 217100 A° (4) 11.61×10 A°

C-5. Which of the following energy band diagram shows the N-type semiconductor-

(1) 

(2) 

(3) 

(4) 

C-6. A P-type silicon semiconductor is made by adding one atom of indium per 5×10^7 atoms of silicon is 25×10^{28} atom/m.^{3}. Point the number of acceptor atoms in per cubic cm. of silicon
(1) 2×10^{30} atom/cm^3 (2) 5×10^{15} atom/cm^3
(3) 1×10^{15} atom/cm^3 (4) 2.5×10^{36} atom/cm^3

C-7. If N-type semiconductor is heated then-
(1) The number of electrons increases and the number of holes decreases
(2) The number of holes increases and the number of electrons decreases
(3) The number of electrons and holes both remain equal
(4) The number of both electrons and holes increases equally

C-8. GaAs is-
(1) an elemental semiconductor (2) a compound semiconductor
(3) an insulator (4) a metallic semiconductor

C-9. What will be conductance of pure silicon crystal at 300K temp.? If electron hole pairs per cm^3 is 1.072×10^{10} at this temp., $\mu_n = 1350$ cm^2/volt sec and $\mu_p = 480$ cm^2/volt sec-
(1) 3.14×10^{-6} mho/cm (2) 3×10^6 mho/cm
(3) 10^{-6} mho/cm (4) 10^6 mho/cm

C-10. Forbidden energy gap of Ge is 0.75 eV, maximum wave length of incident radiation for producing electron-hole pair in germanium semiconductor is-
(1) 4200 A° (2) 16500 A° (3) 4700 A° (4) 4000 A°

C-11. Mobility of electrron in N-type Ge is 5000 cm^2 / volt sec and conductivity 5 mho/cm. If effect of holes is negligible then impurity concentration will be-
(1) $6.25 \times 10^{15}/cm^3$ (2) $9.25 \times 10^{14}/cm^3$ (3) $6 \times 10^{13}/cm^3$ (4) 9×10^{13} / cm^3

C-12. The intrinsic carrier density in germanium crystal at 300 K is 2.5×10^{13} per cm^3. If the electron density in an N-type germanium crystal at 300 K be 0.5×10^{17} per cm^3, the hole density (per cm^3) in this N-type crystal at 300 K would be expected around-
(1) 2.5×10^{13} (2) 5×10^6 (3) 1.25×10^{10} (4) 0.2×10^4

C-13. Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium increases n_h to 4.5×10^{22} m^{-3}. Calculate n_e in the doped Si-
(1) 5.0×10^9 m^{-3} (2) 6.0×10^6 m^{-3} (3) 7.0×10^3 m^{-3} (4) 4.0×10^9 m^{-3}

C-14. The length of a germanium rod is 0.58 cm and its area of cross-section is 1mm^2. If for germanium $n_i = 2.5 \times 10^{19}$ m^{-3}, $\mu_h = 0.19$ m^2/ V-s, $\mu_e = 0.39$ m^2/ V-s, then the resistance of the rod will be -
(1) 2.5 KΩ (2) 5.0 KΩ (3) 7.5 KΩ (4) 10.0 KΩ

C-15. The contributions in the total current flowing through a semiconductor due to electrons and holes are $\frac{3}{4}$ and $\frac{1}{4}$ respectively. If the drift velocity of electrons is $\frac{5}{2}$ times that of holes at this temperature, then the ratio of the concentrations of electrons and holes is-
(1) 6 : 5 (2) 5 : 6 (3) 3 : 2 (4) 2 : 3

Section (D) : Diodes

D-1. The P-N junction is-
(1) an ohmic resistance (2) an non ohmic resistance
(3) a positive resistance (4) a negative resistance

D-2. Diffusion current in a p-n junction is greater than the drift current in magnitude
(1) if the junction is forward-biased (2) if the junction is reverse-biased
(3) if the junction is unbiased (4) in no case

D-3. A hole diffuses from the p-side to the n-side in a p-n junction. This means that
(1) a bond is broken on the n-side and the electron freed from the bond jumps to the conduction band
(2) a conduction electron on the p-side jumps to a broken bond to complete it
(3) a bond is broken on the n-side and the electron freed from the bond jumps to a broken bond on the p-side to complete it
(4) a bond is broken on the p-side and the electron freed from the bond jumps to a broken bond on the n-side to complete it.

D-4. The depletion region of a P-N diode, under open circuit condition contains-
(1) Electrons (2) Holes
(3) Unmasked immobile impurity ions (4) Impurity atoms

D-5. Which is the wrong statement in following sentence? A device in which P and N type semiconductors are used is more useful then a vacuum tube because-
(1) power is not necesary to heat the filament
(2) it is more stable
(3) very less heat is producted in it
(4) its efficiency is high due to a high voltage drop across the junction

D-6. Depletion layer in P-N junction is caused by-
(1) Drift of holes (2) Diffusion of free charge carriers
(3) Migration of impurity ions (4) Drift of electrons

D-7. The contact potential at the junction site in a P-N junction is-
(1) positive on P side and negative on N side (2) negative on P side and positive on N side
(3) zero (4) infinite

D-8. When value of current increase in P-N junction, then the value of contact potential-
(1) decrease (2) increase
(3) remain unchanged (4) depends on temperature

D-9. What accounts for the flow of charge carriers in forward and reverse biasing of silicon P-N diode-
(1) Drift in both reverse and forward bias
(2) Drift in forward bias and diffusion in reverse bias
(3) Drift in reverse bias and diffusion in forward bias
(4) Diffusion in both forward and reverse bias

D-10. The barrier potential in a P-N junction is maximum in-
(1) the reverse bias condition
(2) the forward bias condition
(3) the condition when the junction diode is used as rectifier
(4) zero bias condition

D-11. The diffusion current in a P-N junction flows-
(1) from the N-side to the P-side
(2) from the P-side to the N-side
(3) from the N-side to the P-side if the junction is forward-biased and in the opposite direction if it is reverse baised
(4) from the P-side to the N-side if the junction is forward-biased and in the opposite direction if it is reverse biased

D-12. The drift current in a P-N junction flows -
(1) from the N-side to the P-side
(2) from the P-side to the N-side
(3) from the N-side to the P-side if the junction is forward-biased and in the oposite direction if it is reverse biased.
(4) from the P-side to the N-side if the junction is forward-baised and in the opposite direction if it is reverse baised.

D-13. For a reverse bias P-N junction-
(1) P region is positive and current is due to electrons
(2) P region is positive and the current is due to holes
(3) P region is negative and the current is due to electrons
(4) P region is negative and current is due to both electrons and holes

D-14. During P-N junction formation when the electron and holes stops moving from P to N and N to P, then
(1) There is increase in number of +ve and –ve ions at junction
(2) There is increase in number of electrons at junction
(3) There is increase in number of holes at junction
(4) There is increase in number of holes and electrons at junction

D-15. The value of barrier potential of P-N junction in Ge is-
(1) 0.03 volt in the direction of forward current
(2) 0.3 volt in the direction opposite of the forward current
(3) 25 volt in the direction opposite to the forward current
(4) 25 volt in the direction of the forward current

D-16. Region which have no free electron and holes in a P-N juction is-
(1) P-region (2) N-region (3) junction (4) depletion region

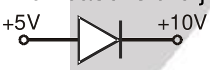
D-17.✍ A device whose one end is connected to –ve terminal and other end connected to +ve terminal. If both ends are interchanged with supply then current is not flowing then device will be-
(1) P-N junction (2) Transistor (3) Zener diode (4) Triode

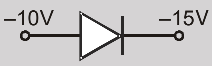
D-18. Potential barrier developed in a junction diode opposes-
(1) Minority carriers in both regions only (2) Majority carriers
(3) Electrons in N-region (4) Holes in P-region

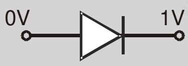
D-19. The P-N junction diode works as insulator, if connected-
(1) To a.c. (2) In forward bias (3) In reverse bias (4) None of these

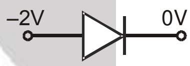
D-20. If the forward voltage in a diode is increased, the width of the depletion region-
(1) Decreases (2) Increases (3) Fluctuates (4) does not change

D-21. The resistance of a reverse baised P-N junction diode is about-
(1) 1 ohm (2) 10^2 ohm (3) 10^3 ohm (4) 10^6 ohm

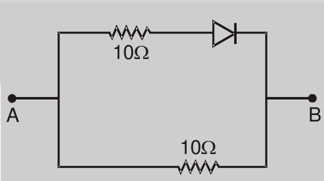
D-22.✍ In which case is the juction diode is not reverse bias-
(1) 

(2) 

(3) 

(4) 

D-23. If V_A and V_B denote the potentials of A and B, then the equivalent resistance between A and B in the adjoint electric circuit is-

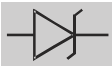
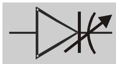
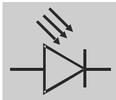
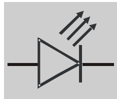


(1) 10 ohm if $V_A > V_B$ (2) 5 ohm if $V_A < V_B$
(3) 5 ohm if $V_A > V_B$ (4) 20 ohm if $V_A > V_B$

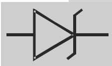
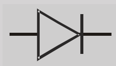
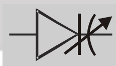
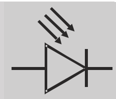
D-24. The avalanche breakdown in P-N junction is due to-
(1) Shift of Fermi level
(2) Cumulative effect of conduction band electron collision
(3) Widening of forbidden gap
(4) Low impurity concentration

D-25. If the two ends of a P-N junction are joined by a wire-
(1) There will not be a steady current in the circuit
(2) There will be a steady current from the N-side to the P-side
(3) There will a steady current from the P-side to the N-side
(4) There may or may not be a current depending upon the resistance of the connecting wire.

D-26. Symbolic representation of photodiode is-

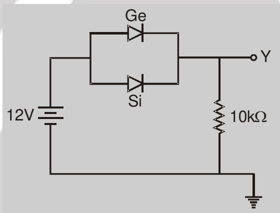
(1)  (2)  (3)  (4) 

D-27. Symbol of zener diode

(1)  (2)  (3)  (4) 

D-28. Consider the following statements 1 and 2 and identify the correct answer-
[1] A zener diode is always connected in reverse bias.
[2] The potential barrier of a P-N junction lies between 0.1 to 0.3 V approximately.
(1) [1] and [2] are correct (2) [1] and [2] are wrong
(3) [1] is correct, but [2] is wrong (4) [1] is wrong, but [2] is correct

D-29. Two junction diodes one of germanium (Ge) and other of silicon (Si) are connected as shown in figure to a battery of emf 12 V and a load resistance 10 kΩ. The germanium diode conducts at 0.3 V and silicon diode at 0.7 V. When a current flows in the circuit, the potential of terminal Y will be-



(1) 12 V (2) 11 V (3) 11.3 V (4) 11.7 V

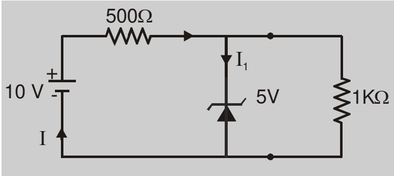
D-30. When light falls on a photo diode, its conductivity increases. Experimentally it is found that the conductivity changes only when the wavelength of the incident light is less than 620 nm. The band gap of the diode is-
(1) 0.75 eV (2) 1.1 eV (3) 1.5 eV (4) 2.0 eV

D-31. If the forward voltage in a semiconductor diode is changed form 0.5V to 2V, then the forward current changes by 1.5 mA. The forward resistance of diode will be-
(1) 1KΩ (2) 2KΩ (3) 4KΩ (4) 8KΩ

D-32. When the reverse potential in a semiconductor diode are 10V and 20V, then the corresponding reverse currents are 25µA and 50µA respectively. The reverse resistance of junction diode will be-
(1) 40Ω (2) 4×10^5 Ω (3) 40KΩ (4) 4×10^{-5} Ω

D-33. If the frequency of input alternating potential is n, then the ripple frequency of output potential of full wave rectifier will be-
(1) 2n (2) n (3) $\frac{n}{2}$ (4) $\frac{n}{4}$

D-34. The current flowing through the zener diode in fig. is-

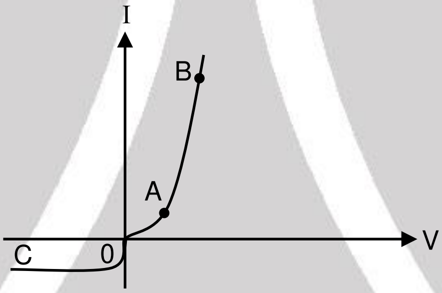


(1) 20 mA (2) 25 mA (3) 15 mA (4) 5 mA

D-35. Function of rectifier is
(1) To convert ac into dc (2) To convert dc into ac
(3) Both (1) and (2) (4) None of these

D-36. The electrical circuits used to get smooth d.c. output from a rectified circuit is called
(1) oscillator (2) full wave rectifier (3) amplifier (4) filter

D-37. The adjacent figure shows I – V characteristics of a silicon diode. In this connection three statements are made – (I) the region OC corresponds to reverse bias of the diode, (II) the voltage at point A is about 0.2 volt, and (III) different scales have been used along +ve and –ve directions of Y-axis. Therefore,



(1) only statement (I) is correct
(2) only statements (I) and (II) are correct
(3) only statements (I) and (III) are correct
(4) all statements (I),(II) and (III) are correct

Section (E) : Transistors

E-1. In a transistor
(1) The emitter has the least concentration of impurity
(2) The collector has the least concentration of impurity
(3) The base has the least concentration of impurity
(4) All the three region have equal concentration of impurity

E-2. The thinest part of a transistor is-
(1) emitter (2) base
(3) collector (4) according to transistor parameters none of these

E-3. In transistor symbols, the arrows shows the direction of-
(1) current in the emitter (2) electron current in the emitter
(2) holes current in the emitter (4) none of these

E-4. Input resistance of transistor in comparision to output resistance is (Amplifier)-
(1) Low (2) High (3) Low and high (4) None of these

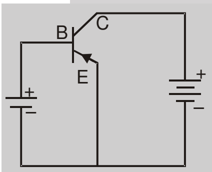
E-5. In a normal operation of a tranistor,
(1) the base-emitter junction is forward-biased
(2) the base-collector junction is forward-biased
(3) the base-emitter junction is reverse-baised
(4) the base-collector junction is reverse-baised

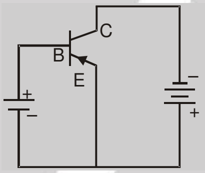
E-6. In a properly biased transistor-
(1) Both depletion layers are equally large.
(2) Both depletion layers are equally small.
(3) Emitter-base depletion layer is large but base collector depletion layer is small.
(4) Emitter-base depletion layer is small but base-collector depletion layer is large.

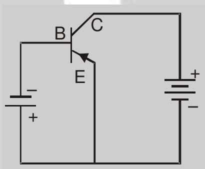
E-7. In an N-P-N transistor, the emitter current is-
(1) Slightly more than the collector current
(2) Slightly less than the collector current
(3) Equal to the collector current
(4) Equal to the base current

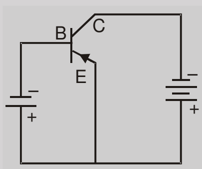
E-8. A N-P-N transistor conducts when-
(1) Both collector and emitter are positive with respect to the base.
(2) Collector is positive and emitter is negative with respect to the base.
(3) Collector is positive and emitter is at same potential as the base.
(4) Both collector and emitter are negative with respect to the base.

E-9.✍ Which one of the following circuits shows correct biasing of a PNP transistor to operate in active region in the CE mode-

(1) 

(2) 

(3) 

(4) 

E-10. To use trasistor as an amplifier-
(1) emitter base junction is in forward biased and collector junction is reverse biased.
(2) biasing voltage are not required
(3) both junction are forward biased
(4) both junction are reverse biased

E-11. An amplifier is nothing but an oscillator with –
(1) positive feedback
(2) high gain
(3) no feed back
(4) negative feed back

E-12.✍ When N-P-N transistor is used as an amplifier-
(1) Electrons move from base to emitter
(2) Electrons move from emitter to base
(3) Electrons move from collector to base
(4) Holes move from base to emitter

E-13. A common emitter circuit is used as an amplifier, its current gain is 50. If input resistance is 1 kΩ and input voltage is 5 volt then output current will be-
(1) 250 mA
(2) 30 mA
(3) 50 mA
(4) 100 mA

E-14.✍ In a N-P-N transistor circuit, the collector current is 10 mA. If 90% of the electrons emitted reach the collector, the emiitter current (I_E) and base current (I_B) are given by-
(1) I_E = 1mA; I_B = 11 mA
(2) I_E = 11 mA; I_B = 1 mA
(3) I_E = –1 mA; I_B = 9 mA
(4) I_E = 9 mA ; I_B = –1 mA

E-15. Which of the following is true-
(1) Common base transistor is commonly used because current gain is maximum.
(2) Common-emitter is commonly used because current gain is maximum.
(3) Common collector is commonly used because current gain is maximum.
(4) Common emitter is the least used transistor.

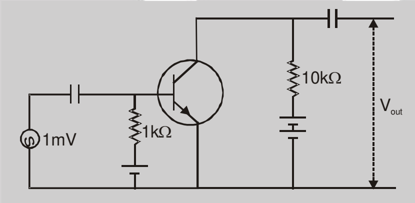
E-16. For transistor relation in current amplification factors is-
(1) $\alpha = \frac{\beta}{1-\beta}$ (2) $\beta = \frac{\alpha}{1-\alpha}$ (3) $\alpha = \frac{1+\beta}{\beta}$ (4) $\beta = \frac{\alpha}{1+\alpha}$

E-17. For a transistor, α = 0.9, the value of β is-
(1) 1 (2) 0.09 (3) 0.9 (4) 9

E-18. In a P-N-P transistor working as a common-base amplifier current gain is 0.96 and emitter current is 7.2 mA The base current is-
(1) 0.4 mA (2) 0.2 mA (3) 0.29 mA (4) 0.35 mA

E-19. In an NPN transistor 10^{10} electrons emitted from the emitter in 10^{-6} s and 2% electrons recombine with holes in base, then current gain α and β are-
(1) 0.49, 9.8 (2) 0.58, 4.9 (3) 0.78, 49 (4) 0.98, 49

E-20. In the fig. a common emitter configuration on N-P-N transistor with current gain β = 100 is used. The output voltage of the amplifier will be-



(1) 10 mV (2) 0.1 V (3) 1.0 V (4) 10 V

E-21. A N-P-N transistor is connected in common emitter configuration in which collector supply is 8 volt and the voltage drop across the load resistor of 800 ohm connected to the collector circuit is 0.8 volt. If current amplification factor α is $\frac{25}{26}$ and the input resistance of the transistor is 200 ohm then the collector emitter voltage, base current, the voltage and power gain are-
(1) 3.5 V, 2×10^{-5} A and A_V = 50V, A_P = 6500 (2) 7.2 V, 4×10^{-5} A and A_V = 100V, A_P = 2500
(3) 4.5 V, 3×10^{-5} A and A_V = 50V, A_P = 6500 (4) 5.6 V, 3×10^{-5} A and A_V = 60V, A_P = 7500

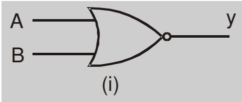
E-22. In an NPN transistor the values of base current and collector current are 100μA and 9 mA respectively, the emitter current will be-
(1) 9.1mA (2) 18.2mA (3) 9.1μA (4) 18.2μA

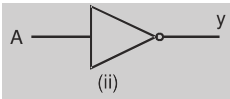
E-23. In a common emitter circuit, if V_{CE} is changed by 0.2V, then collector current changed by 4×10^{-3} mA. Output resistance will be-
(1) 10 kΩ (2) 30 kΩ (3) 50 kΩ (4) 70 kΩ

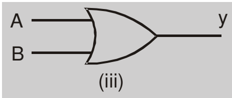
E-24. The following statement is not true-
(1) The oscillations in an oscillator are maintained.
(2) Oscillator is an active circuit.
(3) There is no voltage gain in an oscillator.
(4) Oscillator works as an amplifier having infinite voltage gain.

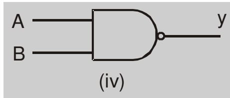
Section (F) : Logic Gates

F-1. Given below are four logic gates symbols. NAND, NOR and OR are respectively-





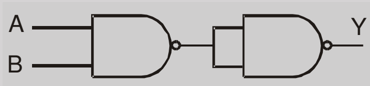




(1) (iv), (i), (iii) (2) (i), (iii), (iv) (3) (i), (ii), (iii) (4) (i), (iv), (ii)

F-2. The output of OR gate is 1-
(1) if both inputs are zero
(2) if either or both inputs are 1
(3) only if both inputs are 1
(4) if either input is zero

F-3. Following diagram performs the logic function of-



(1) AND gate (2) NAND gate (3) OR gate (4) XOR gate

F-4. Given truth table is for which GATE -

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

(1) AND (2) OR (3) NOR (4) NAND

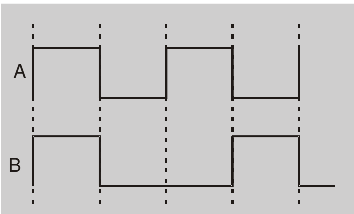
F-5. NAND gate is-
(1) a basic gate
(2) not a universal gate
(3) a universal gate
(4) none of these.

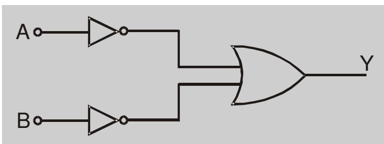
F-6. The given truth table is for which logic gate-

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

(1) NAND (2) XOR (3) NOR (4) OR

F-7. In a given circuit as shown the two inputs waveform A and B applied simultaneously.

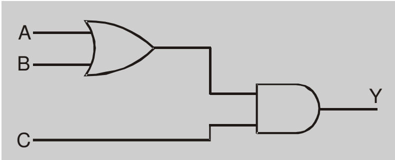




The resultant wave form Y is-

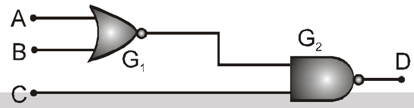
(1)  (2)  (3)  (4) 

F-8. For the logic circuit shown the Boolean relation is-



(1) Y = ABC (2) Y = A + BC (3) Y = (A + B) C (4) Y = AB + C

F-9. For the given combination of gates, if the logic states of inputs A, B, C are as follows A = B = C = 0 and A = B = 1, C = 0 then the logic states of output D are



(1) 0, 0 (2) 0, 1 (3) 1, 0 (4) 1, 1

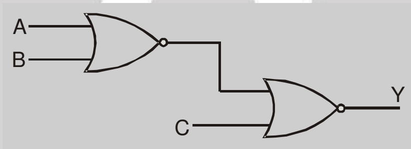
F-10. The Boolean equation of NOR gate is-

(1) C = A + B (2) $C = \overline{A+B}$ (3) C = A + B (4) $C = \overline{A \cdot B}$

F-11. What will be the input of A and B for the Boolean expression $(\overline{A+B}) \cdot (\overline{A \cdot B}) = 1$.

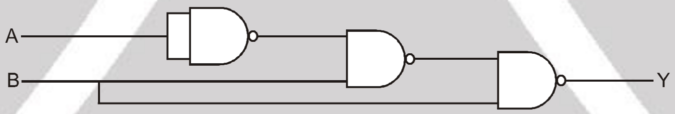
(1) 0, 0 (2) 0, 1 (3) 1, 0 (4) 1, 1

F-12. The Boolean expression for the output Y of the logic operation shown, is-



(1) $(\overline{A+B}) + C$ (2) $(A+B) + \overline{C}$ (3) $\overline{(\overline{A+B}) + C}$ (4) $(\overline{A+B+C})$

F-13. The arrangement of NAND gates shown below effectively works as



(1) AND gate (2) OR gate (3) NAND gate (4) NOR gate

Exercise-2

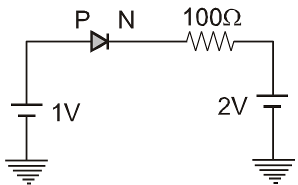
Marked Questions can be used as Revision Questions.

PART - I : OBJECTIVE QUESTIONS

1. The depletion layer in silicon diode is 1 μm wide and the knee potential is 0.6 V, then the electric field in the depletion layer will be

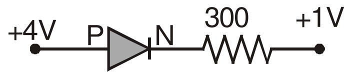
(1) Zero (2) 0.6 Vm^{-1} (3) 6 × 10^4 V/m (4) 6 × 10^5 V/m

2. The current through an ideal PN-junction shown in the following circuit diagram will be



(1) Zero (2) 1 mA (3) 10 mA (4) 30 mA

3. In the circuit given below, the value of the current is

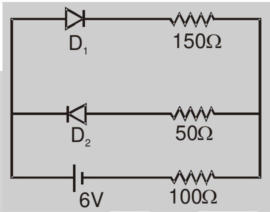


(1) 0 amp (2) 10^{-2} amp (3) 1 amp (4) 0.10 amp

4. The maximum efficiency of full wave rectifier is

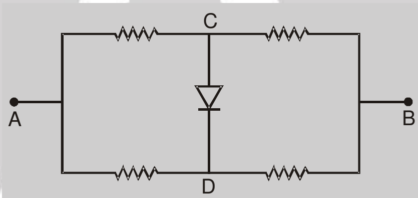
(1) 100 % (2) 25.20 % (3) 40.2 % (4) 81.2 %

5.✍ The circuit shown in the figure contains two diodes each with a forward resistance of 50 ohm and with infinite reverse resistance. If the battery voltage is 6V, find the current through the 100 ohm resistance-



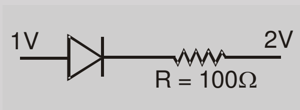
(1) 0.01 A (2) 0.05 A (3) 0.02 A (4) 0.03 A

6.✍ Four equal resistors, each of resistance 10 ohm are connected as shown in the adjoining circuit diagram. Then the equivalent resistance between points A and B is-



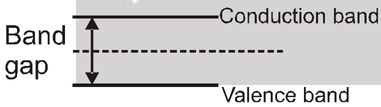
(1) 40 ohm (2) 20 ohm (3) 10 ohm (4) 5 ohm

7. In the arrangement shown in fig. the current through diode is-

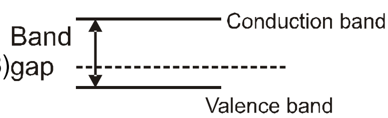


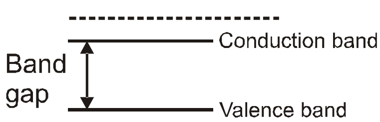
(1) 10 mA (2) 1 mA (3) 20 mA (4) Zero

8. Which one of the following diagrams correctly represents the energy levels in the p–type semiconductor?

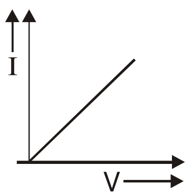
(1) 

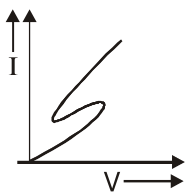
(2) 

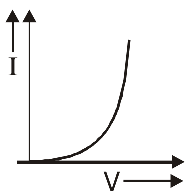
(3) 

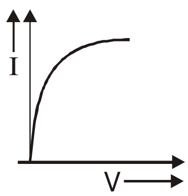
(4) 

9. Choose the correct option for the forward biased characteristics of a p–n junction.

(1) 

(2) 

(3) 

(4) 

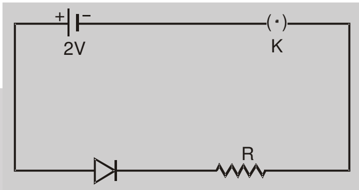
10. In the case of constants α and β of a transistor

(1) $\alpha = \beta$ (2) $\beta < 1$, $\alpha > 1$ (3) $\alpha\beta = 1$ (4) $\beta > 1$, $\alpha < 1$

11. If $\alpha = 0.98$ and current through emitter $i_e = 20$ mA, the value of β is

(1) 4.9 (2) 49 (3) 96 (4) 9.6

12.✍ A diode made forward biased by a two volt battery however there is a drop of 0.5 V across the diode which is independent of current. Also a current greater then 10 mA produces large joule loss and damages diode. If diode is to be operated at 5 mA, the series resistance to be put is-

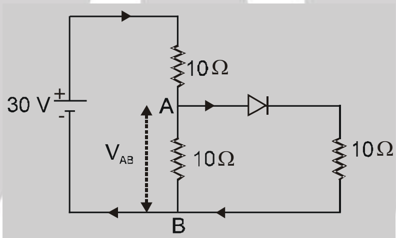


(1) 3 KΩ (2) 300 KΩ (3) 300 Ω (4) 200 KΩ

13. The ratio of resistance for forward to reverse bias of P–N junction diode is-

(1) $10^2 : 1$ (2) $10^{-2} : 1$ (3) $1 : 10^{-4}$ (4) $1 : 10^4$

14.✍ For given circuit potential difference V_{AB} is



(1) 10 V (2) 20 V (3) 30 V (4) None

15. Zener diode is used-

(1) As an amplifier (2) As a rectifier

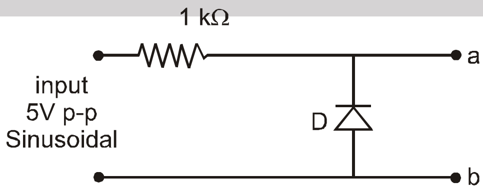
(3) As an oscillator (4) As a voltage regulator

16. Zener breakdown will occur if-

(1) Impurity level is low (2) Impurity level is high

(3) Impurity is less in n-side (4) Impurity is less in p-side

17.* Refer to the circuit given below. Output voltage V_0 is measured between points a and b. Then,



(1) the peak value of V_0 is 2.5 volt above the minimum if the diode is assumed to be ideal.

(2) the positive half cycle of the input is clipped.

(3) the circuit acts as a rectifier.

(4) the peak value of V_0 is about 3.2 volt above the minimum if D is silicon diode (non-ideal).

18. An ac source (sinusoidal source with frequency 50 Hz) is connected in series with a rectifying diode, a 100 Ω resistor, a 1000 μF capacitor and milliammeter. After some time the milliammeter reads zero. The voltage measured across the capacitor with a dc voltmeter is
(1) the peak voltage of the ac source
(2) rms voltage of the ac source
(3) average voltage of the ac source over a half cycle
(4) average voltage of the ac source over a full cycle.

19. The fundamental frequency of the output of a bridge rectifier driven by ac mains is
(1) 50 Hz (2) zero (3) 100 Hz (4) 25 Hz

20. Which one of the following devices does not respond to the intensity of light incident on it ?
(1) Photoresistor (LDR) (2) Photodiode
(3) Light Emitting Diode (4) Solar Cell

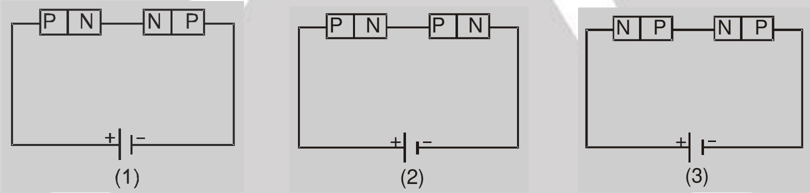
21.*_ In a bipolar junction transistor
(1) the most heavily doped region is the emitter
(2) the level of doping is the same in both the emitter and the collector
(3) its base is the thinnest part
(4) when connected in common emitter configuration a base current is generally of the order of μA

Exercise-3

✍ Marked Questions may have for Revision Questions.

PART - I : JEE (ADVANCED) / IIT-JEE PROBLEMS (PREVIOUS YEARS)

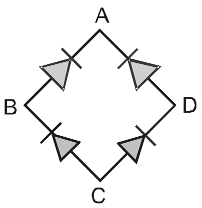
1. Two identical P-N junction may be connected in series with a battery in three ways (fig below). The potential drops across the two P-N junction are equal in-



(1) Circuit 1 and 2 (2) Circuit 2 and 3 (3) Circuit 3 and 1 (4) Circuit 1 only

2. In a P-N junction diode which is not connected to any circuit-
(1) Potential is the same every where
(2) The P-type side is at a higher potential than the N-type side
(3) There is an electric field at the junction directed from the N-type side to the P-type side
(4) There is an electric field at the junction directed from the P-type side to the N-type side

3.✍ For the given circuit shown in fig, to act as full wave rectifier, a.c. input should be connected across ....and........the d.c. output would appear across........and........



(1) A, C and B, D (2) B, D and A, C (3) A, B and C, D (4) C, A and D, B

4. In a......biased P-N junction the net flow holes is from N-region to the P-region-
(1) forward (2) reverse (3) no (4) both 1 and 2

PART - II : JEE (MAIN) / AIEEE PROBLEMS (PREVIOUS YEARS)

1. At absolute zero, Si acts as : **[AIEEE-2002]**
(1) non-meta (2) metal
(3) insulator (4) none of these

2. By increasing the temperature, the specific resistance of a conductor and semiconductor: **[AIEEE-2002]**
(1) increases for both
(2) decreases for both
(3) increases, decreases respectively
(4) decreases, increases respectively

3. The energy band gap is maximum in : **[AIEEE-2002]**
(1) metals (2) superconductors
(3) insulators (4) semiconductors

4. The part of a transistor which is most heavily doped to produce large number of majority charge carries is : **[AIEEE-2002]**
(1) emitter (2) base
(3) collector (4) can be any of the above three

5. A strip of copper and another of germanium are cooled from room temperature to 80 K. The resistance of : **[AIEEE-2003]**
(1) each of these decreases
(2) copper strip increases and that of germanium decreases
(3) copper strip decreases and that of germanium increases
(4) each of these increases

6. The difference in the variation of resistance with temperature in a metal and a semiconductor arises essentially due to the difference in the : **[AIEEE-2003]**
(1) crystal structure
(2) variation of the number of charge carries with temperature
(3) type of bonding
(4) variation of scattering mechanism with temperature

7. When P-N junction diode is forward biased, then- **[AIEEE-2004]**
(1) the depletion region is reduced and barrier height is increased.
(2) the depletion region is widened and barrier height is reduced.
(3) both the depletion region and barrier height are reduced.
(4) both the depletion region and barrier height are increased.

8. When npn transistor is used as an amplifier: **[AIEEE-2004]**
(1) electrons move from base to collector
(2) holes move from emitter to base
(3) electrons move from collector to base
(4) holes move from base to emitter

9. The electrical conductivity of a semiconductor increases when electromagnetic radiation of wavelength shorter than 2480 nm, is incident on it. The band gap in (eV) for the semiconductor is : **[AIEEE-2005]**

(1) 1.1 eV (2) 2.5 eV (3) 0.5 eV (4) 0.7 eV

10. In a common base amplifier, the phase difference between the input signal voltage and output voltage is : **[AIEEE-2005]**

(1) $\frac{\pi}{4}$ (2) π (3) zero (4) $\frac{\pi}{2}$

11. In a full wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be : **[AIEEE-2005]**

(1) 50 Hz (2) 25 Hz (3) 100 Hz (4) 70.7 Hz

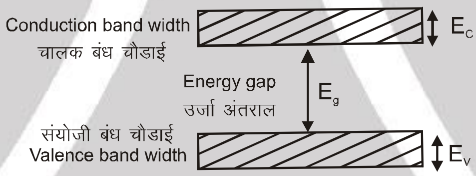
12.✍ If the ratio of the concentration of electrons to that of holes in a semiconductor is $\frac{7}{5}$ and the ratio of currents is $\frac{7}{4}$, then what is the ratio of their drift velocities ? **[AIEEE 2006]**

(1) 5/8 (2) 4/5 (3) 5/4 (4) 4/7

13. In a common–base of mode of transistor, the collector current is 5.488 mA for an emitter current of 5.60 mA. The value of the base current amplification factor (β) will be : **[AIEEE 2006]**

(1) 49 (2) 50 (3) 51 (4) 48

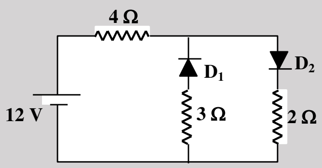
14. If the lattice constant of this semiconductor is decreased, then which of the following is correct? **[AIEEE 2006]**



(1) All E_C, E_g , E_v increase (2) E_C and E_V increase, but E_g decreases

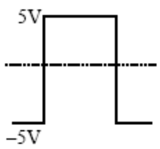
(3) E_c and E_v decrease, but E_g increases (4) All E_C,E_g , E_v decrease

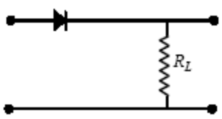
15.✍ The circuit has two oppositely connected ideal diodes in parallel. What is the current flowing in the circuit? **[AIEEE 2006]**

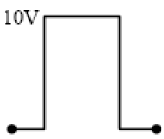


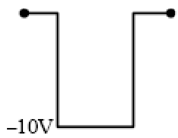
(1) 2.31 A (2) 1.33 A (3) 1.71 A (4) 2.00 A

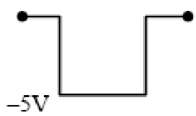
16. If in p-n junction diode, a square input signal of 10 V is applied as shown. Then the output signal across R_L will be **[AIEEE 2007]**

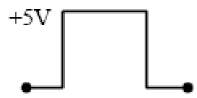




(1) 

(2) 

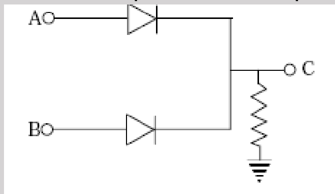
(3) 

(4) 

17. Carbon, silicon and germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate? **[AIEEE 2007]**
(1) the number of free conduction electrons is significant in *C* but small in *Si* and *Ge*.
(2) the number of free conduction electrons is negligibly small in all the three.
(3) the number of free electrons for conduction is significant in all the three.
(4) the number of free electrons for conduction is significant only in *Si* and *Ge* but small in *C*.

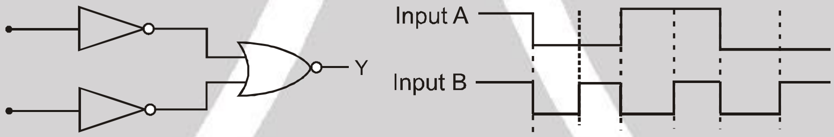
18. A working transistor with its three legs marked P, Q and R is tested using a multimeter. No conduction is found between P and Q. By connecting the common (negative) terminal of the multimeter to R and the other (positive) terminal to P or Q, some resistance is seen on the multimeter. Which of following is true for the transistor ? **[AIEEE 2008]**
(1) It is a pnp transistor with R as collector
(2) It is a pnp transistor with R as emitter
(3) It is an npn transistor with R as collector
(4) It is an npn transistor with R as base

19. In the circuit below, A and B represent two inputs and C represents the output. **[AIEEE 2008]**



The circuit represents
(1) AND gate (2) NAND gate (3) OR gate (4) NOR gate

20. The logic circuit shown below has the input waveforms 'A' and 'B' as shown. Pick out the correct out put waveform. **[AIEEE 2009]**



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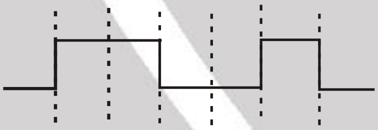
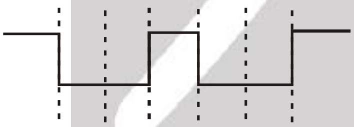
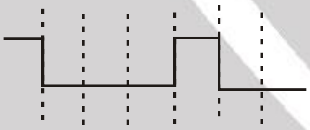
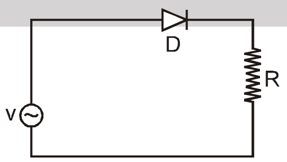
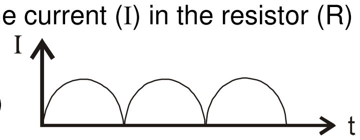
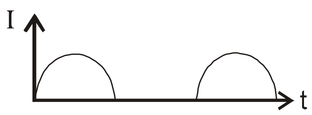
(2) 
(3) 
(4) 

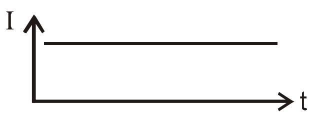
21. A p-n junction (4) shown in the figure can act as a rectifier. An alternating current source (V) is connected in the circuit. **[AIEEE 2009]**

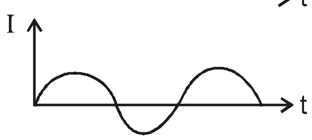


The current (I) in the resistor (R) can be shown by:

(1) 

(2) 

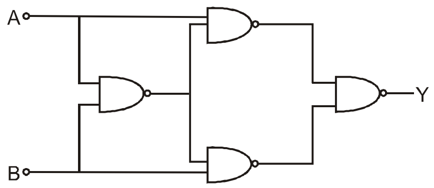
(3) 

(4) 

22. The output of an OR gate is connected to both the inputs of a NAND gate. The combination will serve as a : **[AIEEE 2011, 11 May; 4, –1]**

(1) NOT gate (2) NOR gate (3) AND gate (4) OR gate

23. Truth table for system of four NAND gates as shown in figure is : **[AIEEE 2012 ; 4, –1]**



(1)

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

(2)

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

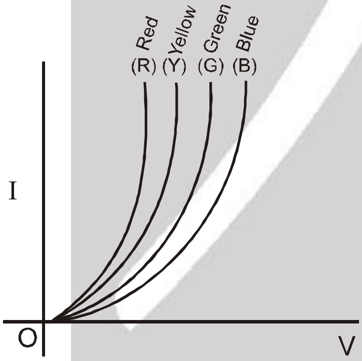
(3)

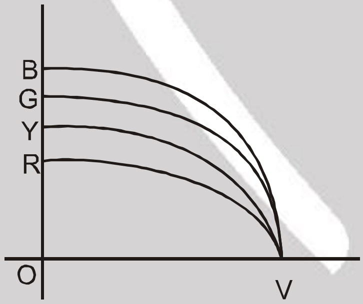
A	B	Y
0	0	1
0	1	1
1	0	0
1	1	0

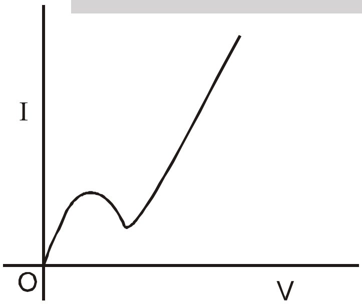
(4)

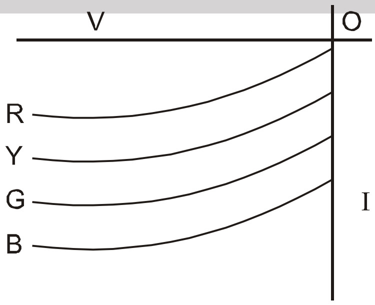
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

24. The I – V characteristic of an LED is **[JEE (Main) 2013, 4/120, –1]**

(1)


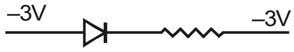
(2)


(3)


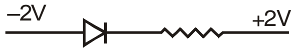
(4)


25. The forward biased diode connection is **[JEE-MAIN 2014 ; 4/120. –1]**

(1) 

(2) 

(3) 

(4) 

26. The temperature dependence of resistances of Cu and undoped Si in the temperature range 300 – 400 K, is best described by : **[JEE-MAIN 2016 ; 4/120. –1]**

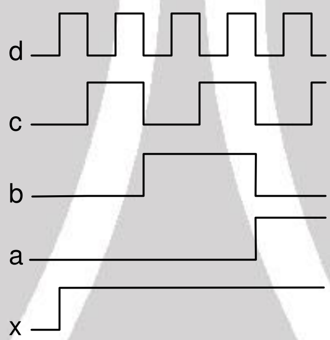
(1) Linear increase for Cu, exponential increase for Si

(2) Linear increase for Cu, exponential decrease for Si

(3) Linear decrease for Cu, linear decrease for Si

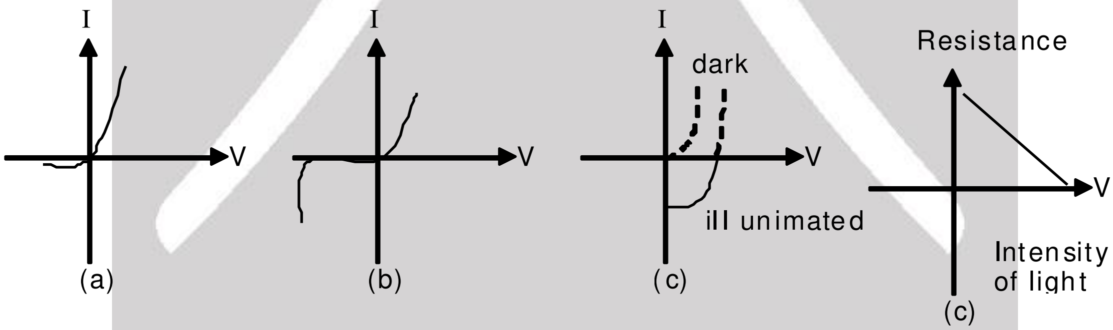
(4) Linear increase for Cu, linear increase for Si

27. If a,b,c,d are inputs to a gate and x is its output, then, as per the following time graph, the gate is : **[JEE-MAIN 2016 ; 4/120. –1]**



(1) AND (2) OR (3) NAND (4) NOT

28. Identify the semiconductor devices whose characteristics are given below, in the order (1),(2),(3),(4)



(1) zener diode, simple diode, Light dependent resistance, Solar cell

(2) Solar cell , Light dependent resistance, Zener diode, simple diode

(3) Zener diode, Solar cell, Simple diode, Light dependent resistance

(4) Simple diode, Zener diode, Solar cell, Light dependent resistance.

29. For a common emitter configuration, if α and β have their usual meanings, the **incorrect** relationship between α and β is. **[JEE (Main) 2016 ; 4/120, –1]**

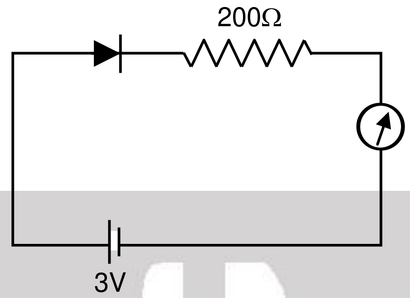
(1) $\alpha = \frac{\beta}{1-\beta}$ (2) $\alpha = \frac{\beta}{1+\beta}$ (3) $\alpha = \frac{\beta^2}{1+\beta^2}$ (4) $\frac{1}{\alpha} = \frac{1}{\beta} + 1$

30. In a common emitter amplifier circuit using an n-p-n transistor, the phase difference between the input and the output voltages will be: **[JEE (Main) 2017; 4/120, –1]**

(1) 180° (2) 45° (3) 90° (4) 135°

31. The reading of the ammeter for a silicon diode in the given circuit is :

[JEE (Main) 2018, 4/120, –1]



(1) 11.5mA (2) 13.5 mA (3) 0 (4) 15 mA

Answers

EXERCISE – 1

Section (A)

A-1.	(2)	**A-2.**	(3)	**A-3.**	(1)
A-4.	(4)	**A-5.**	(1)	**A-6.**	(4)
A-7.	(3)	**A-8.**	(2)	**A-9.**	(4)

Section (B)

B-1.	(2)	**B-2.**	(1,2,3,4)

Section (C)

C-1.	(3)	**C-2.**	(4)	**C-3.**	(3)
C-4.	(3)	**C-5.**	(2)	**C-6.**	(2)
C-7.	(4)	**C-8.**	(2)	**C-9.**	(1)
C-10.	(2)	**C-11.**	(1)	**C-12.**	(3)
C-13.	(1)	**C-14.**	(1)	**C-15.**	(1)

Section (D)

D-1.	(2)	**D-2.**	(1)	**D-3.**	(3)
D-4.	(3)	**D-5.**	(4)	**D-6.**	(2)
D-7.	(2)	**D-8.**	(1)	**D-9.**	(3)
D-10.	(1)	**D-11.**	(2)	**D-12.**	(1)
D-13.	(4)	**D-14.**	(1)	**D-15.**	(2)
D-16.	(4)	**D-17.**	(1)	**D-18.**	(2)
D-19.	(3)	**D-20.**	(1)	**D-21.**	(4)
D-22.	(2)	**D-23.**	(3)	**D-24.**	(2)
D-25.	(1)	**D-26.**	(3)	**D-27.**	(1)
D-28.	(3)	**D-29.**	(4)	**D-30.**	(4)
D-31.	(1)	**D-32.**	(2)	**D-33.**	(1)
D-34.	(4)	**D-35.**	(1)	**D-36.**	(4)
D-37.	(3)				

Section (E)

E-1.	(3)	**E-2.**	(2)	**E-3.**	(1)
E-4.	(1)	**E-5.**	(1, 4)	**E-6.**	(4)
E-7.	(1)	**E-8.**	(2)	**E-9.**	(4)
E-10.	(1)	**E-11.**	(1)	**E-12.**	(2)
E-13.	(1)	**E-14.**	(2)	**E-15.**	(2)
E-16.	(2)	**E-17.**	(4)	**E-18.**	(3)
E-19.	(4)	**E-20.**	(3)	**E-21.**	(2)
E-22.	(1)	**E-23.**	(3)	**E-24.**	(3)

Section (F)

F-1.	(1)	**F-2.**	(2)	**F-3.**	(1)
F-4.	(1)	**F-5.**	(3)	**F-6.**	(1)
F-7.	(1)	**F-8.**	(3)	**F-9.**	(4)
F-10.	(2)	**F-11.**	(1)	**F-12.**	(3)
F-13.	(3)				

EXERCISE – 2

PART– I

1.	(4)	**2.**	(1)	**3.**	(2)
4.	(4)	**5.**	(3)	**6.**	(3)
7.	(4)	**8.**	(3)	**9.**	(3)
10.	(4)	**11.**	(2)	**12.**	(3)
13.	(4)	**14.**	(1)	**15.**	(4)
16.	(2)	**17.**	(1,2,3,4)	**18.**	(3)
19.	(3)	**20.**	(3)	**21.**	(1,3,4)

EXERCISE – 3

PART – I

1.	(2)	**2.**	(3)	**3.**	(2)
4.	(2)				

PART – II

1.	(3)	**2.**	(3)	**3.**	(3)
4.	(1)	**5.**	(3)	**6.**	(2)
7.	(3)	**8.**	(4)	**9.**	(3)
10.	(3)	**11.**	(3)	**12.**	(3)
13.	(1)	**14.**	(2)	**15.**	(4)
16.	(4)	**17.**	(4)	**18.**	(4)
19.	(3)	**20.**	(4)	**21.**	(2)
22.	(2)	**23.**	(1)	**24.**	(1)
25.	(1)	**26.**	(2)	**27.**	(2)
28.	(4)	**29.**	(1,3)	**30.**	(1)
31.	(1)				