SEMICONDUCTOR DEVICES AND DIGITAL CIRCUITS

Electronic Devices

Any device whose action is based on the controlled flow of electrons through it is called an electronic device. The branch of physics that deals with the study of these electronic devices is called ***electronics.*** Electronics devices are the basic ***building blocks*** of all the electronic circuits.

The electronic devices are of *two basic types:*

A. **Vacuum tubes:** These include vacuum diodes (consisting of two electrodes – cathode and anode), triode (with three electrodes) and pentode (with 5 electrodes)

B. **Solid–state electronic devices:** Semiconductors are the basic materials used in the present solid electronic devices like junction diode (a 2–electrode device), transistor (a 3–electrode device) and integrated circuits (ICs).

Classification of Solids on the Basis of their Electrical Properties

On the basis of their relative values of electrical conductivity (σ) or resistivity ($\rho = 1/\sigma$), we can broadly classify solids into *three* categories:

A. **Metals:** They have very low resistivity or high conductivity: $\rho \approx 10^{-2} - 10^{-8}\ \Omega m$, $\sigma \approx 10^{2} - 10^{8}\ Sm^{-1}$

B. **Insulators:** They have high resistivity or low conductivity: $\rho \approx 10^{8}\ \Omega m$, $\sigma \approx 10^{-8}\ Sm^{-1}$

C. **Semiconductors:** They possess resistivity or conductivity intermediate to metals and insulators.

$\rho \approx 10^{5} - 10^{0}\ \Omega m$ $\sigma \approx 10^{-5} - 10^{0}\ Sm^{-1}$

Classification of Semiconductors

Classification of semiconductors on the basis of their chemical composition

This scheme divides semi–conductors broadly into elemental and compound semiconductors.

A. ***Elemental semiconductors:*** Si and Ge.

B. ***Compound semiconductors:*** Examples are:

(i) *Inorganic:* CdS, GaAs, CdSe, InP, etc.

(ii) *Organic polymers*: Polypyrrole, polyaniline, polythiophene, etc.

Classification of semiconductors on the basis of the source and the nature of the charge carriers

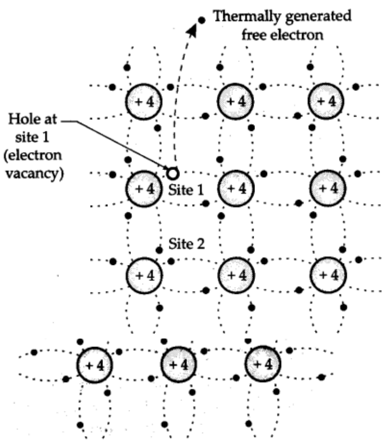
A. **Intrinsic semiconductors:** *The pure semi–conductors* (impurity less than 1 part in 10^{10}) *are called intrinsic semiconductors.* The presence of the mobile charge carries (electrons and holes) is an *intrinsic* property of the material and these charges are obtained as a result of thermal excitation. *Holes* are essentially the *electron vacancies* with an effective positive charge. In an intrinsic semiconductor, the number density of the electrons (n_e) is equal to the number density of holes (n_h).

B. **Extrinsic semiconductors:** *The semiconductors obtained by adding or doping the pure semiconductor with small amounts of certain specific impurity atoms having valency different from that of the host atoms are called extrinsic semiconductors.* Doping drastically changes the number density of mobile electrons and holes. The electrical conductivity of such semiconductors is essentially due to the foreign atom *i.e.*, *extrinsic* in nature.

Valence Bond Model for Intrinsic Semiconductors

Consider the crystal of semiconductor Ge or Si. Each Ge atom has four valence electrons which is shares with the four nearest neighbouring atoms to form four covalent bonds. Thus each Ge atom is tetrahedrally bonded to four neighbouring Ge atoms, as shown in figure. Such a crystal structure is called *diamond–like structure*. The shared pair of electrons oscillates back–and–forth between the two associated atoms.

However, such a structure with all bonds intact (or no bond broken) exists at low temperature.



As the temperature increases, the thermal energy of the valence electrons increases. As shown in figure, an electron may break away from the covalent bond and becomes *free* to conduct electricity. This electron leaves behind a vacancy in the covalent bond (at site 1). This vacancy of an electron with an effective *positive electronic charge is called a* ***hole.*** It behaves as an *apparent free particle* with a charge + e. The process of setting free an electron from a covalent bond and the simultaneous creation of a hole requires a kind of *ionization energy* E_g. The number of electrons (n_e) set free at absolute temperature T is given by

$$n_e = Ce^{-E_g/2kT}$$

where k is the Boltzmann constant. For a given E_g, n_e increases as the temperature increases.

As each free electron creates one hole, so in an intrinsic semiconductor, the number density of free electrons (n_e) is equal to the number density of holes (n_h) and each is equal to the *intrinsic charge carrier concentration (n_i).*

$$n_e = n_h = n_i$$

Doping

Limitations of intrinsic semiconductors

When intrinsic semiconductors are used for developing semiconductor devices, they have many limitations as discussed below:

1. Intrinsic semiconductors have low intrinsic charge carrier concentration (of hole and electrons) $\approx 10^6\ m^{-3}$. So they have low electrical conductivity.
2. As intrinsic charge carriers are always thermally generated, so flexibility is not available to control their number.
3. For intrinsic semiconductors, $n_e = n_h$. They cannot have predominant hole or electron conduction. This puts a limit to the usefulness of such materials.

Doping

In order to increase the conductivity of pure semiconductors and to overcome their other limitations, a small amount, say, 1 part per million (ppm), of impurity atoms having valency different from 4, is added to the pure semiconductor. *The process of deliberate addition of a desirable impurity to a pure semiconductor so as to increase its conductivity is called doping. The impurity atoms added are called* ***dopants*** *and the semiconductors doped with the impurity atoms are called* ***extrinsic or doped semiconductors.***

Essential requirements for a doping process:

1. The semiconductor material should be of very high purity, 99.9999% or more.
2. The dopant atom should neatly replace the semiconductor atom.
3. The size of the dopant atom should be almost the same as that of the semiconductor atom. For this the atoms of third and fifth group of the periodic table are most suitable.
4. The dopant atoms should not distort the crystal lattice.
5. The concentration of dopant atoms should be small, about 1 part per million.

Two types of dopants : There are two types of dopants used in doping the tetravalent Si or Ge:

(i) ***Pentavalent dopants:*** They have 5 valence electrons. i.e., arsenic (As),antimony (Sb) & phosphorous (P)

(ii) ***Trivalent dopants:*** They have 3 valence electrons. i.e. indium (ln), boron (B) and aluminium (Al).

On doping Si or Ge with pentavalent and trivalent impurity atoms, we get two entirely different types of semiconductors, called *n*–type and *p*–type semiconductors respectively.

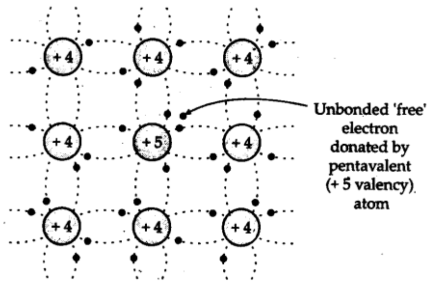
Methods of doping :

1. By adding the impurity atoms to an extremely pure sample of a molten semiconductor.
2. By heating the crystalline semiconductor in an atmosphere containing dopant atom or their molecules so that the dopant atoms diffuse into the semiconductor.
3. By bombarding the semiconductor with the ions of dopant atoms, the dopant atoms can be implanted into the semiconductor

Extrinsic semiconductors

A semiconductor doped with some suitable impurity atoms so as to increase its number of charge carriers is called an extrinsic semiconductor. Extrinsic semiconductors are of two types :

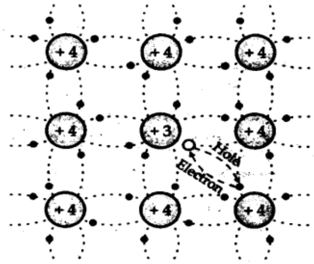
1. ***n*–type semiconductor :** This semiconductor is obtained by doping the tetravalent semiconductor *Si* (or *Ge*) with pentavalent impurities such as As, *P* or *Sb* of group *V* of the periodic table. As shown in figure. When a pentavalent impurity atom substitutes the tetravalent *Si* atom, it uses four of its five valence electrons in forming four covalent bonds with neighbouring *Si* atoms while the fifth electron is loosely bound to the impurity atom. A very small amount of ionization energy (≈ 0.01 eV for *Ge* and 0.05 ev for *Si*) is required to detach this electron.



At room temperature, the thermal energy is enough to set free this electron. The dopant atom gets converted into an ionised +ve core. As each pentavalent impurity atom donates one extra electron for conduction, it is called a **donor**.

The electrons are the majority charge carriers and holes are the minority charge carriers. As most of the current is carried by the negatively charged electrons. So the semiconductors doped with donor type impurities are known as *n*–type semiconductors. For such semiconductors $n_e >> n_h$

2. ***p*–type semiconductor :** Such a semiconductor is obtained by doping the tetravalent semiconductor *Si* (or *Ge*) with trivalent impurities such as In, *B*, *Al* or *Ga*. The impurity atom uses its three valence electrons in forming covalent bonds with three neighbouring *Si* atoms and one covalent bond with a neighbouring *Si* atom is left incomplete due to the deficiency of one electron. An electron from the neighbouring *Si*–*Si* covalent bond can slide into this vacant bond, creating a vacancy or hole in that bond. This hole is now available for conduction.



The trivalent impurity atom becomes negatively charged when all its valence bonds get filled. The material can be regarded as a fixed core of one negative charge alongwith its associated hole, as shown in figure. The trivalent impurity atom is called an acceptor because it creates a hole which can accept an electron from the neighbouring bond. Obviously, there are holes created by the acceptor atoms in addition to the thermally generated holes while the free electrons are only due to thermal generation. Hence, holes are the majority charge carriers and electrons are the minority charge carriers. The semiconductors doped with acceptor type impurities are called *p*–type semiconductors, because most of the current in these semiconductors is carried by holes which have effective positive charge. For such semiconductors, $n_h >> n_e$.

Thermodynamic relation between the number densities of electrons and holes for an extrinsic semiconductor : When conduction electrons and holes are created in a semiconductor, a process of destruction occurs simultaneously in which electrons and holes recombine with each other. At equilibrium, the rate of generation of charge carriers is equal to the rate of destruction of charge carriers.

The recombination process occurs due to the collision of an electron with a hole. Larger the value of number density of electrons or holes (n_e or n_h), higher is the probability of their recombination with each other. Hence for an intrinsic semiconductor,

$$\text{Rate of recombination} \propto n_e n_h . \qquad \text{or} \qquad \text{Rate of recombination} = R n_e n_h \quad ....(1)$$

where R is a constant known as recombination coefficient.

For an intrinsic semiconductor, $n_e = n_h = n_i$, the intrinsic charge carrier concentration. So the equation (1) becomes

$$\text{Rate of recombination} = R n_i^2 \quad ....(2)$$

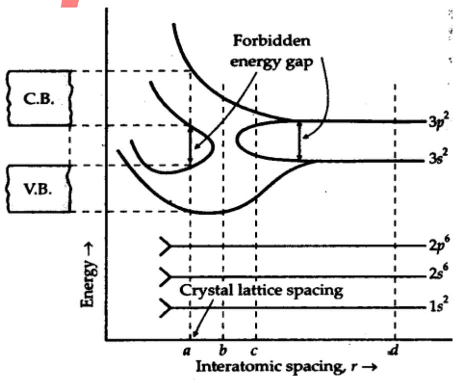
As long as the lattice structure of the semi-conductor remains the same, the values of R, the rate of combination or the rate of generation (which are governed by the laws of thermodynamics) remain the same. Hence the rates of recombination given by equations (1) and (2) for extrinsic and intrinsic semiconductors must be equal. Hence

$$R n_e n_h = R n_i^2 \qquad \text{or} \qquad n_e n_h = n_i^2 \quad ....(3)$$

Energy Bands in solids

Each energy level splits into a number of energy levels forming a continuous band, called energy band.

An enormously large number of energy levels closely spaced in a very small energy range constitute an energy band. Consider a small single crystal of silicon. Suppose it has N atoms. Imagine that these atoms are being brought closer from infinity so as to form a crystal of lattice spacing 'a' (2 or 3Å). This is depicted in figure, in which the interatomic spacing is plotted along x–axis and the energy along y–axis.

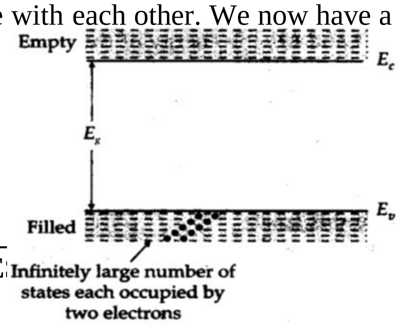


1. When $r = d >> a$. At this large interatomic spacing, there is no interaction between neighbouring atoms. All the N atoms have identical energy levels. In the outer shells, N energy levels associated with 3s orbitals are completely filled with 2N electrons. Out of 3N energy levels associated with 3p orbitals, only N energy levels are filled with 2N electrons and the remaining levels are empty.

2. **When $r = c >> a$ but $c < d$:** As interatomic separation decreases, the valence electrons of the neighbouring atoms begin to interact. The energies of 3s and 3p levels of each atom get slightly changed (both increase and decrease). We now have N different energy levels of 3s–type and 3N different levels of 3p–type. Energy gap between 3s and 3p levels decreases. As N is very very large ($\approx 10^{23}$ atoms/cm^3), we have an enormously large number of energy levels (N of 3s–type and 3N of 3p–type) spaced in a very small energy range. Such sets of closely spaced energy levels are called **energy bands.**

3. **When $r = b > a$:** As the separation r decreases further, the energy gap between 3s and 3p levels completely disappears and the upper and lower energy bands merge with each other. We now have a set of continuously distributed 4N energy levels.

4. **When $r = a$:** At this equilibrium separation, the band of 2N filled energy levels gets separated from the band of 2N empty energy levels by an energy gap. The highest energy band filled with valence electrons is called **valence band**. The lowest unfilled allowed energy band next to valence band is called



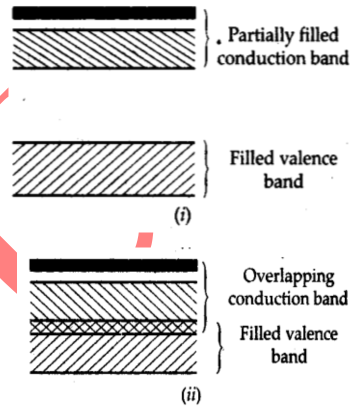
conduction band. The gap between top of valence band and bottom of the conduction band in which no allowed energy levels for electrons can exist is called **energy band gap or energy gap.**

Distinction between metals, insulators and semiconductors on the basis of band theory

1. **Metals:** Conduction band is partially filled with electrons. Two types of band structures are found in metals

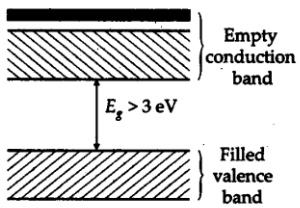
(i) Either there is energy gap between the completely filled valence band and the partially filled conduction band.

(ii) The conduction and valence band partly overlap. The valence band is completely filled but the upper unoccupied band partly overlaps the valence band. The highest energy level in the conduction band filled up with electrons at absolute zero is called Fermi level and the energy corresponding to the Fermi level is called **Fermi Energy**.

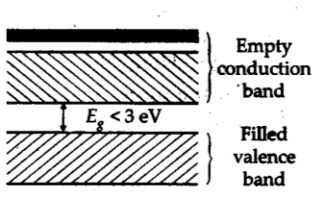


Many electrons after gaining a slight amount of energy from any source get excited to the empty energy levels lying immediately above the Fermi level and become free to conduct electricity. This makes available a large number of conduction electrons. So metals have low resistivity or high conductivity. Even a small electric field applied across the metal causes a current flow through it.

2. **Insulators :** In insulators, the valence band is completely filled while the conduction band is empty. As shown in figure, there is a large energy gap (E_g > 3eV) between the valence and conduction bands. For example, in case of diamond, E_g = 6eV. Even an electric field cannot give this much energy to an electron to make it jump from the valence band into the conduction band. Hence due to the lack of free electrons in the conduction band, the insulators are poor conductors of electricity.



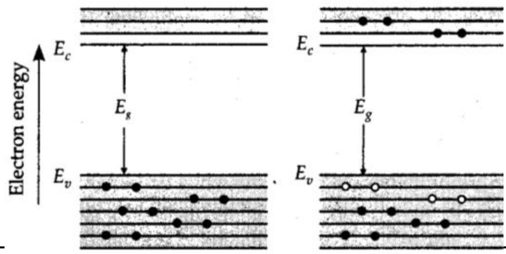
3. **Semiconductors :** At 0K, the conduction band is empty and the valence band is filled. So the material is essentially insulator at low temperatures. However, the energy gap between cconduction and valence bands is small $(E_g < 3\text{eV})$. For example, $E_g = 1.17$ eV for *Si* and $E_g = 0.74$ eV for *Ge*. At room temperature, some valance electrons acquire enough thermal energy and jump to the conduction band



where they are free to conduct electricity. Thus the semiconductor acquires a small conductivity at room temperature. The resistance of a semi-conductor would not be as high as that of insulator.

Energy Bands of Intrinsic and extrinsic semiconductors

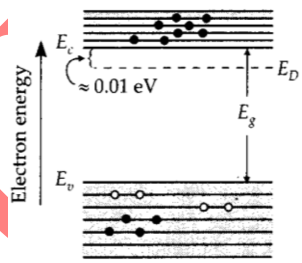
At T = 0K, the valence band of a semiconductor is completely filled with electrons while the conduction band is empty, as shown in figure (i). Hence an intrinsic semiconductor behaves



(i) at $T = 0$ K (behaves like insulator) (ii) at $T > 0$ K like an insulator at T = 0K. At higher temperatures (T > 0K), some electrons of the valence band gain sufficient thermal energy and jump to the conduction band, creating an equal number of holes in the valence band. These thermally excited electrons occupy the lowest possible energy levels in the conduction band.

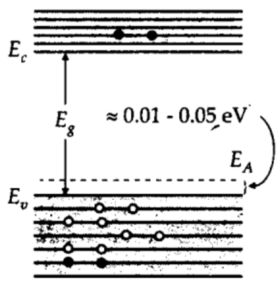
Therefore, the energy band diagram of an intrinsic semicondcutor at T > 0K is of the type shown in figure (ii). Clearly the number of electrons in conduction band is equal to the number of holes in valence band.

Energy band diagram of *n*–type semiconductor : In *n*–type semiconductors, the extra (fifth)) electron is very weakly attracted by the donor impurity. A very small energy (≈ 0.01 eV) is required to free this electron from the donor impurity.



When freed, this electron will occupy the lowest possible energy level in the conduction band i.e., the energy of the donor electron is slightly less than E_c. Thus the donor energy level E_D lies just below the bottom of the conduction band. At room temperature this small energy gap is easily converted by the thermally excited electrons. The conduction band has more electrons (than holes in valence band) as they have been contributed both by thermal excitation and donor impurities.

Energy band diagram of *p*–type semiconductors: In *p*–type semiconductors, each acceptor impurity creates a hole which can be easily filled by an electron of Si–Si covalent bond i.e., a very small energy (≈ 0.01 – 0.05eV) is required by an electron of the valence band to move into this hole.



Hence the acceptor energy level E_A lies slightly above the top of the valence band, as shown in the figure. At room temperature, many electrons of the valence band get excited to these acceptor energy levels, leaving behind equal number of holes in the valence band. These holes can conduct current. Thus the valence band has more holes than electrons in the conduction band.

Difference between intrinsic and extrinsic semiconductors

	Intrinsic Semiconductors	Extrinsic Semiconductors
1.	These are pure semi–conducting tetravalent crystals.	These are semi–conducting tetravalent crystals doped with impurity atoms of group III or V.
2.	Their electrical conductivity is low.	Their electrical conductivity is high.
3.	There is no permitted energy state between valence and conduction bands.	There is permitted energy state of the impurity atom between valence and conduction bands.
4.	The number of free electrons in the conduction band is equal to the number of holes in valence band.	The electrons are majority charge carriers in *n*–type semiconductors while holes are majority charge carries in *p*–type semiconductors.
5.	Their electrical conductivity depends on temperature.	Their electrical conductivity depends on temperature as well as on dopant concentration.

Difference between n–type and p–type semiconductors

	***n*–type semiconductors**	***p*–type semiconductors**
1.	These are extrinsic semiconductors obtained by doping impurity atoms of group *V* to *Ge*	These are extrinsic semiconductors obtained by doping impurity atoms of group III to *Ge* or *Si*

	or *Si* crystal.	crystal.
2.	The impurity atoms added provide free electrons and are called donors.	The impurity atoms added create vacancies of electrons (or holes) and are called acceptors
3.	The donor impurity level lies just below the conduction band.	The acceptor impurity level lies just above the valence band.
4.	The electrons are majority charge carriers while holes are minority charge carriers.	The holes are majority charge carriers while electrons are minority charge carriers.
5.	The free electron density is much greater than hole density, i.e., $n_e >> n_h$.	The hole density is much greater than free electron density, i.e., $n_h >> n_e$

Holes

The vacancy or absence of an electron in the bond of a covalently bonded crystal is called a hole. In terms of band theory, whenever an electron is removed from the completely filled valence band of a semiconductor, a vacancy is left behind in the valence band. This vacancy serves as a positive charge carrier and is called a hole.

A hole is not a physical entity. A hole is a convenient way of describing charge motion, though the motion can be described entirely in terms of electrons.

Characteristics of holes

1. A hole is just a vacancy created by the removal of an electron from a covalent bond of semiconductor.

2. It has the same mass as the (removed) electron.

3. It is associated with a positive charge of magnitude e.

Subjective Assignment – I

1. In a pure semiconductor, the number of conduction electrons is 6×10^{18} per cubic metre. How many holes are there in a sample of size 1cm × 1 cm × 1 mm?
2. Find the maximum wavelength of electromagnetic radiation which can create a hole–electron pair in germanium. The band gap in germanium is 0.65 eV.
3. A *p*–type semiconductor has acceptor levels 57 meV above the valence band. Find the maximum wavelength of light that can create a hole.
4. Suppose a pure *Si* crystal has 5×10^{28} atoms m^{-3}. It is doped by 1 ppm concentration of pentavalent As. Calculate the number of electrons and holes. Given that $n_i = 1.5 \times 10^{16}\ m^{-3}$.
5. A semiconductor has equal electron and hole concentration of $6 \times 10^8\ m^{-3}$. On doping with certain impurity, electron concentration increases to $9 \times 10^{12}\ m^{-3}$.
   (i) Identify the new semiconductor obtained after doping.
   (ii) Calculate the new hole concentration. (iii) How does the energy gap vary with doping?
6. A semiconductor has equal electron and hole concentration of $2 \times 10^8\ m^{-3}$. On doping with a certain impurity, the hole concentration increases to $4 \times 10^{10}\ m^{-3}$.
   (i) What type of semiconductor is obtained on doping?
   (ii) calculate the new electron concentration of the semi–conductor.
   (iii) How does the energy gap vary with doping?

Answers

1.	6×10^{11}	2.	1.9×10^{-6} m	3.	2.17×10^{-5} m
4.	$5 \times 10^{22}\ m^{-3}$; $4.5 \times 10^9\ m^{-3}$	5.	$4 \times 10^4\ m^{-3}$	6.	(ii) $10^6\ m^{-3}$

Mobility of a charge carrier

The drift velocity acquired by a charge carrier in a unit electric field is called its electrical mobility and is denoted by μ. In a semiconductor. ,

Drift velocity of a charge carrier $\propto$ Applied electric field

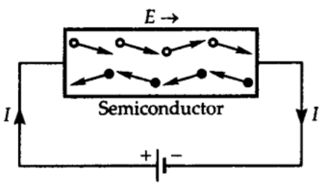
or $v \propto E$ or $v = \mu E$, $\therefore$ $\mu = \frac{v}{E}$

Hence, the electrical mobility μ is the drift velocity per unit electric field.

The mobility of an electron in the conduction band of a semiconductor is greater than the mobiloity of a hole in the valence band. The electrons in the conduction band are almost free. They get easily accelerated by an electric field. But the electrons in the valence band are bound between the atoms of a semiconductor. They are less accelerated by an electric field and so acquire drift velocity smaller than that of electrons in the conduction band. The mobility of electrons in the conduction band. As the motion of an electron in the valence band is equivalent to the motion of a hole in the opposite direction, hence the mobility of hole in the valence band is smaller than the mobility of an electron in conduction band.

Electrical conductivity of a semiconductor

Consider a block of semiconductor of length *l*, area of cross-section *A*, and having free electron density n_e and hole density n_h. Suppose a potential difference *V* is applied across its ends. The electric field set up inside it will be $E = \frac{V}{l}$ ....(1)



electrons begin to drift with velocity v_e in the opposite direction of *E* while the holes drift in the direction of *E* with velocity v_h, as shown in the figure.

$\therefore$ Total current = Electron current + Hole current or $I = I_e + I_h$ ....(2)

As electrons in the conduction band and holes in the valence band move randomly like free electrons in metals, therefore, we can write

$I_e = en_e\ Av_e$ and $I_h = en_h\ Av_h$

$\therefore$ $I = en_e\ Av_e + en_h\ Av_h = eA(n_e v_e + n_h v_h)$ ....(3)

If *R* is the resistance of the semiconductor block and ρ its resistivity, then

$$r = \rho \frac{l}{A}$$ ....(4)

If the applied electric field *E* is low, the semiconductors obey Ohm's law so that

$$I = \frac{V}{R} = \frac{El}{\rho l / A}$$ [By using (1) and (4)]

or $I = \frac{EA}{\rho}$ ....(5)

From equations (3) and (5), we get $I = \frac{EA}{\rho} = eA(n_e v_e + n_h v_h)$ ....(6)

or $\frac{E}{\rho} = e(n_e v_e + n_h v_h)$

As mobility μ is defined as drift velocity per unit electric field, therefore

Electron mobility, $\mu_e = \frac{v_e}{E}$ or $v_e = \mu_e E$

Hole mobility, $\mu_h = \frac{v_h}{E}$ or $v_h = \mu_h E$

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

The conductivity, which is reciprocal of resistivity, is given by

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

....(7)

Also, the resistivity of the semiconductor is given by $\rho = \frac{1}{e(n_e\mu_e + n_h\mu_h)}$

....(8)

Effect of temperature on the conductivity of semiconductors

Variation of conductivity of a semiconductor with temperature : The conductivity of a semiconductor is given by $\sigma = e(n_e\mu_e + n_h\mu_h)$

As the temperature increases, the mobilities μ_e and μ_h of electrons and holes decrease due to the increase in their collision frequency. But due to the small energy gap of semiconductors, more and more electrons $\left[n \propto e^{-E_g/kT}\right]$ from the valence band cross over to the conduction band. The increase in carrier concentrations, n_e and n_h is so large that the decrease in the values of μ_e and μ_h has no influence. The overall effect is that the conductivity increases or the resistivity decreases with the increase of temperature.

Subjective Assignment – II

1. A semiconductor is known to have an electron concentration of 8×10^{13} per cm^3 and a hole concentration of 5×10^{12} per cm^3. (a) Is the semiconductor *n*–type or *p*–type?
   (b) What is the resistivity of the sample if the electron mobility is 23,000 cm^2/Vs and hole mobility is 100cm^2/Vs?
2. Determine the number density of donor atoms which have to be added to an intrinsic germanium semi-conductor to produce an *n*–type semiconductor of conductivity $5\Omega^{-1}cm^{-1}$, given that the mobility of electron in *n*–type *Ge* is 3900 cm^2/Vs. Neglect the contribution of holes to conductivity.
3. A battery of emf 2V is connected across a block of length 0.1 m and area of cross–section 1×10^{-4} m^2. If the block is of intrinsic silicon at 300K, find the electron and hole currents. What will be the magnitude of total current? What will be the magnitude of the total current if germanium is used instead of silicon?
4. The resistivity of pure silicon is 3000Ωm and the electron and hole mobilities are 0.12 $m^2V^{-1}s^{-1}$ and 0.045 $m^2V^{-1}s^{-1}$ respectively, determine (a) the resistivity of a specimen of the material when 10^{19} atoms of phosphorus are added per m^3, (b) the resistivity of the specimen if further 2×10^{19} boron atoms per m^3 are also added.
5. The resistivity of pure germanium at a particular temperature is 0.52 Ωm. If the material is doped with 10^{20} atoms m^{-3} of a trivalent impurity material, determine the new resistivity. The electron and hole mobilities are given to be 0.2 and 0.4 $m^2 V^{-1}s^{-1}$.

Answers

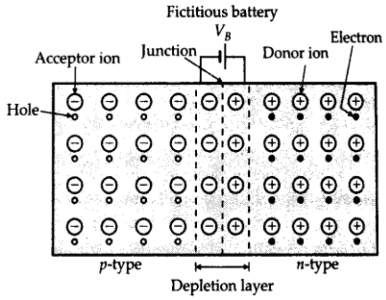
1. (a) *n*–type (b) 3.395Ωcm
2. 8.01×10^{15} cm^{-3}
3. 6.48×10^{-7} A, 2.3×10^{-7} A, 0.878×10^{-6}A, 2.995×10^{-3} A, 1.495×10^{-3} A, 4.45×10^{-3} A

4. 5.21Ωm, 25 Ωm   5. 0.195 Ωm

p–n Junction

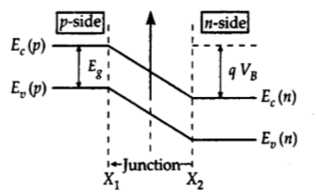
It is a single crystal of *Ge* or *Si* doped in such a manner that one half portion of its acts as *p*–type semi-conductor and the other half an *n*–type semiconductor. A *p-n* junction cannot be made just by placing a *p*-type semiconductor in close contact with *n*-type semiconductor. The two separate semiconductors cannot have a continuous contact at the atomic level. The junction will behave as a discontinuity for the flowing charge carries. So both acceptor and donor impurities must be grown in a single *Si* or *Ge* crystal. A *p-n* junction is the key, to all semiconductor devices.

A *p*-type or *n*-type silicon crystal can be obtained by adding suitable acceptor or donor-impurity into silicon melt while growing a crystal. These crystals are cut into thin slices called wafers. Semiconductor devices are usually made on these wafers.



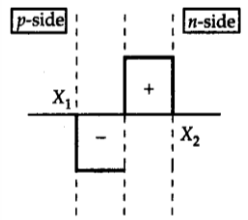
Unbiased p-n junction : Depletion region and potential barrier in a p-n junction.

As soon as a *p-n* junction is formed, the majority charge carriers begin to diffuse from the regions of higher concentration to the regions of lower concentrations. Thus the electrons from the n-region diffuse into the *p*-region and where they combine with the holes and get neutralised. Similarly, the holes from the *p*-region diffuse into the *n*-region where they combine with the electrons and get neutralized. This process is called electron-hole recombination.



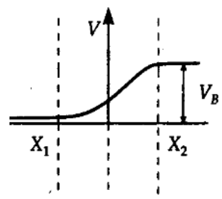
The *p*-region near the junction is left with immobile–ve ions and *n*-region near the junction is left with + ve ions, as shown in the figure. The small region in the vicinity of the junction which is depleted of free charge carriers and has only immobile ions is called the **depletion layer**.

The distribution of charge near the junction is shown in figure. The accumulation of negative charges in the *p*–region and positive charges in the *n*–region sets up a potential difference across the junction. This acts as a barrier and is called barrier potential V_B which opposes the further diffusion of electrons and holes across the junction. It appears as if a sort of fictitious battery has been setup across the junction with the –ve terminal connected to the *p*–region and +ve terminal connected to the *n*–region.



The distribution of potential near the junction is shown in figure. The barrier potential sets up a **barrier field** $\vec{E}_B$ in direction from *n*–region to *p*–region.

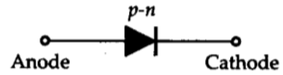
To Cross the barrier potential V_B, an electron of *n*–region must be imparted an energy eV_B i.e., the difference between the electron energies on the *n*–and *p*–sides is eV_B. Hence the energy band diagram for a *p*–*n* junction is of the type shown in the figure.



The barrier potential V_B depends on (i) the nature of the semiconductor, (ii) temperature, and (iii) the amount of doping. The value of barrier pontifical is 0.6 V for Si and 0.2 V for *Ge* semicondcutors.

If doping concentrations are small, then the diffusing electrons and holes will cover reasonably large distances before they suffer a collision with another hole or electron to get animated or recombined. Hence the width of the depletion layer will be large and the barrier field will be weak. On the other hand, if the doping concentrations are large, the depletion layer width will be small and the barrier field will be strong. Thus by simply changing the doping levels, we can obtain p-n junctions of different types.

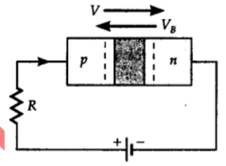
Circuit symbol for a p-n junction.



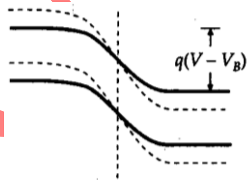
A *p-n* junction has two electrode connections -one on the p-side and another on the n-side. Hence it is also known as junction diode.(diode : di-means two and ode comes from electrode). The direction of the arrow is from p-region to n-region. The arrow indicates the direction in which the conventional current can flow easily (when the diode is forward biased). The p-side is known as the anode and the n-side is known as the cathode.

Working of A p–n Junction

An external potential difference can be applied to a *p–n* junction in two ways :



1. **Forward biasing :** If the positive terminal of a battery is connected to the *p*-side and the negative terminal to the *n*-side, then the *p–n* junction is said to be forward biased. As shown in the figure, here the applied voltage V opposes the barrier voltage V_B. As a result of this

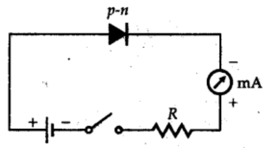


(i) The effective barrier potential decreases to $(V_B - V)$ and hence energy barrier across the junction decreases, as shown in figure.

(ii) The majority charge carries i.e., holes from *p*–side and electrons from *n*–side begin to flow towards the junction,

(iii) The diffusion of electrons and holes into the depletion layer decreases its width,

(iv) the effective resistance across the *p–n* junction decreases.



When V exceeds V_B, the majority charge carriers start flowing easily across the junction and set up a large current (≈ mA), called forward current, in the circuit. The current increases with the increase in applied voltage.

2. Reverse biasing: The applied voltage V and barrier potential V_B are in the same direction. As a result of this

(i) The barrier potential increases to $(V_B + V)$ and hence the energy barrier across the junction increases.

(ii) The majority charge carriers move away from the junction, increasing the width of the depletion layer.

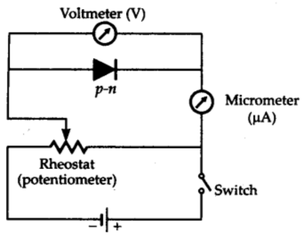
(iii) The resistance of the *p–n* junction becomes very large, and

(iv) no current flows across the junction due to majority charge carriers.

At room temperature there are always present some minority charge carriers like holes in *n*-region and electrons in *p*-region. The reverse biasing pushes them towards junction, setting a current, called reverse or leakage current, in the external circuit in the opposite direction. As the minority charge carriers are much less in number than the majority charge carriers, hence the reverse current is small (≈ μA).

V–I Characteristics of a p–n Junction Diode

A graph showing the variation of current flowing through a p-n junction with the voltage applied across it (both when it is forward and reverse biased) is called the voltage- current or V-I characteristic of a p-n junction



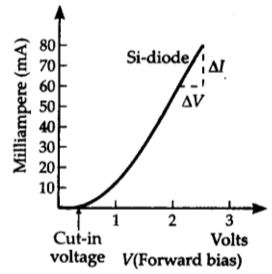
1. **Forward bias characteristic :** As shown in the figure, experimental arrangement for studying the characteristic curve of a *p–n* junction when it is ***forward biased***.

Important features of the graph :

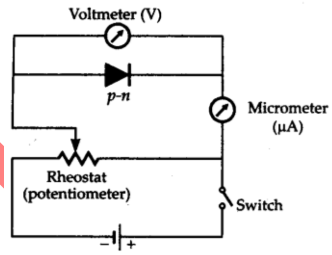
(i) The V-I graph is not a straight line i.e., a junction diode does not obey Ohm's law.

(ii) Initially, the current increases very slowly almost negligibly, till the voltage across the diode crosses a certain value, called the threshold-voltage or cut-in voltage. The value of the cut-in voltage is about 0.2 V for a Ge diode and 0.6 V for a Si diode. Before this characteristic voltage, the depletion layer plays a dominant role in controlling the motion of charge carriers.

(iii) After the cut-in voltage, the diode current increases rapidly (exponentially), even for a very small increase in the diode bias voltage. Here the majority charge carriers feel negligible resistance at junction i.e., the resistance across the junction is quite low.



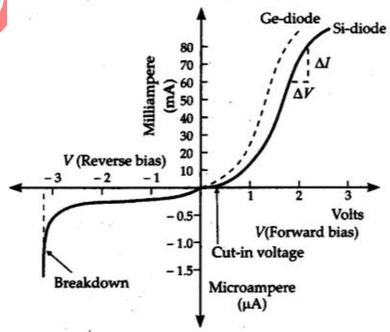
2. Reverse bias characteristic: In the figure the experimental arrangement for studying characteristic curve of a *p–n* junction when it is reverse biased.



Important features of the graph :

(i) When the diode is reverse biased, the reverse bias voltage produces a very small current, about a few microamperes which almost remains constant with bias. This small current is called reverse saturation current. It is due to the drift of minority charge carriers (a few holes in n-region and a few electrons in p-region) across the junction.

(ii) When the reverse voltage across the p-n junction reaches a sufficiently high value, the reverse current suddenly increases to a large value. This voltage at which breakdown of the junction diode occurs is called Zener breakdown voltage or peak-inverse voltage of the diode.



A junction diode offers a very small resistance when forward biased and has a very large resistance when reverse biased i.e., the diode can conduct current well only in one direction. This property is used to convert a.c. into d.c. The conversion of a.c. into d.c. is called rectification.

Dynamic Resistance of A junction Diode:

The current- voltage graph of junction diode is non-linear, i.e., Ohm's law is not obeyed. The resistance of the junction diode varies with the applied voltage. In such cases, it is useful to define a quantity called dynamic or ac-resistance of the diode. It is the ratio of the small change in applied voltage ΔV to the corresponding change in current ΔI. It is given by $r_d = \frac{\Delta V}{\Delta I}$.

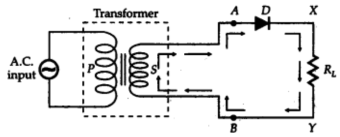
Junction Diode as a rectifier

Rectifier : The process of converting alternating current into direct current is called **rectification** and the device used for this process is called **rectifier**. The $p-n$ junctions can be used as

(i) a half–wave rectifier, and (ii) a full–wave rectifier.

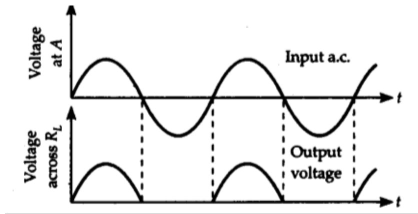
Junction Diode as a Half–wave rectifier

A half-wave rectifier consists of a transformer, a junction diode D and a load resistance R_L. The primary coil of the transformer is connected to the a.c. mains and the secondary coil is connected in series with the junction diode D and load resistance R_L.



Working : When a.c. is supplied to the primary, the secondary of the transformer supplies desired alternating voltage across *A* and *B*. During the positive half cycle of a.c., the end *A* is positive and the end *B* is negative.

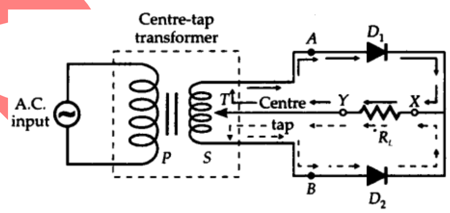
The diode D is forward biased and a current *I* flows through R_L. As the input voltage increases or decreases, the current *I* also increases or decreases and so does output voltage (= IR_L) across the load R_L. Output voltage across R_L is of same waveform as the positive half wave of the input. During the negative half cycle, the end A becomes negative and *B* positive. The diode is reverse biased and no current flows. No voltage appears across R_L. In the next positive half cycle, again we get output voltage. The output voltage is unidirectional but pulsating.



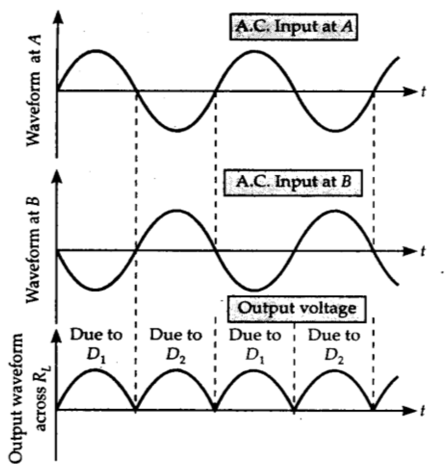
Since the voltage across the load appears only during the positive half cycle of the input a.c., this process is called **half–wave rectification** and the arrangement used is called a **half wave rectifier**.

Junction Diode as a full wave rectifier

A full wave rectifier consists of a transformer, two junction diodes D_1 and D_2 and a load resistance R_L. The input a.c. signal is fed to the primary coil *P* of the transformer. The two ends *A* and *B* of the secondary *S* are connected to the *p*–ends of diodes D_1 and D_2. The secondary is tapped at its central point *T* which is connected to the *n*–ends of the two diodes through the load resistance $R_{L'}$.



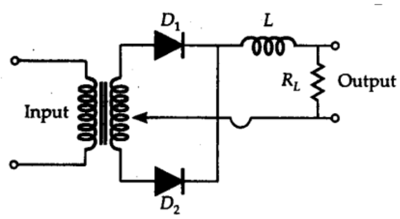
Working : At any instant, the voltages at the end *A* (input of D_1) and end *B* (input of D_2) of the secondary with respect to the centre tap *T* will be out of phase with each other. Suppose during the positive half cycle of a.c. input, the end *A* is positive and the end *B* is negative with respect to the centre tap *T*. Then the diode D_1 gets forward biased and conducts current along the path AD_1XYTA, as indicated by the solid arrows. The diode D_2 is reverse biased and does not conduct. During the negative half cycle, the end *A* becomes negative and the end *B* becomes positive. Hence D_1 is reverse biased and does not conduct. The diode D_2 conducts current along the path BD_2XYTB, as indicated by broken arrows. As during both half cycles of input a.c. the current through load R_L flows in the same direction ($X \rightarrow Y$), so we get pulsating d.c. voltage across R_L. Since output voltage across the load resistance R_L is obtained for both half cycles of input a.c., this process is called **full wave rectification** and the arrangement used is called **full-wave rectifier**.



Filter circuits

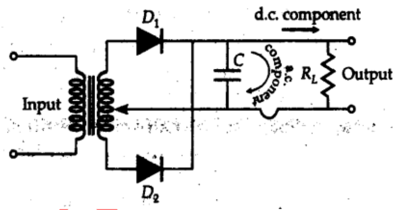
The output obtained from a junction diode rectifier is unidirectional but pulsating. Such a signal can be considered as the sum of a d.c. signal superimposed with many a.c. signals of different harmonic frequencies. We can obtain d.c. voltage by filtering out the a.c. components.

1. **Series inductor filter :** As shown in the figure, the circuit of a full wave rectifier with an inductor of inductance *L* connected in series



with its load resistance R_L. The inductance L offers a reactance $X_L = 2\pi f L$ to the flow of current though it. Clearly, it blocks high frequency a.c. component and allows low frequency d.c. component to pass through it. A smooth d.c. voltage appears across the load resistance.

2. **Shunt capacitor filter :** As shown in the figure, the circuit of a full wave rectifier with a capacitor of capacitance C connected in parallel with its load resistance R_L. The capacitor has a reactance of $X_C = 1/2\pi fC$. A high capacitance C offers a low impedence path to high frequency a.c. component but high, almost infinite, impedance to low frequency d.c. component. Hence the a.c. component is bypassed through C or filtered. A smooth d.c. voltage appears at load resistance.



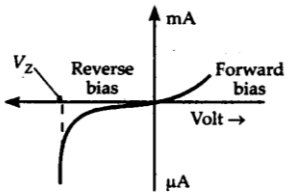
Cause of Reverse Breakdown of a Junction diode

Cause of reverse breakdown of a junction diode : The breakdown of a junction diode may occur through two different processes:

1. **Zener breakdown :** This process occurs in heavily doped junction diodes. Due to high dopant density, the width of the junction layer is small and the barrier field ($E = V/d$) is high. When a large reverse bias is applied across such a diode, the depletion layer and the energy bands get modified.

   As the depletion width is very small (< 10^{-7}m), even a small voltage (say 4V) will setup a high electric field of 4×10^7 Vm^{-1}.

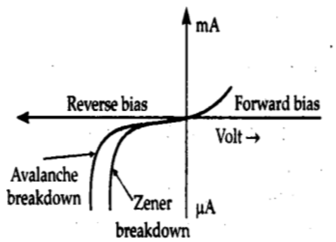
   This high electric field strips off many electrons from valence band which tunnel to the n–side through the thin depletion layer.



This method of emission of electrons beyond a certain reverse bias voltage V_Z is called internal field emission.

It gives rise to a large reverse current or breakdown current, as shown in the figure. This breakdown in a diode due to the band–to–band tunneling is called Zener breakdown and such diode is called **zener diode**.

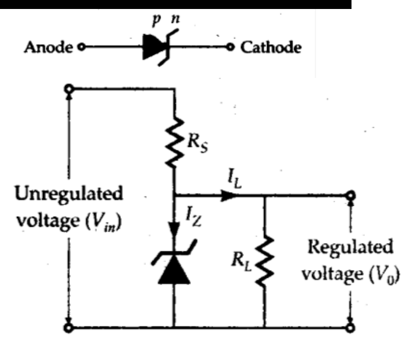
2. **Avalanche Breakdown :** This process occurs in diodes having low level of doping and hence wide depletion layer. When the reverse bias voltage is sufficiently high, the minority charge carriers get highly accelerated. Their kinetic energy becomes high enough and they knock-off electrons from the covalent bonds of the semiconductor. The newly generated electron-hole pairs also get accelerated and cause ionisation. Thus a chain of collisions is set up which gives rise to a very large number of charge carriers.



   This leads to a large reverse current, as shown in the figure. This phenomenon is called Avalanche breakdown and the device is called Avalanche diode.

Zener Diode as a voltage Regulator

A junction diode specially designed to operate only in the reverse breakdown region continuously (without getting damaged) is called a Zener diode.



Zener diode as a voltage regular : Principle : When a Zener diode is operated in reverse breakdown region, the voltage across it remains practically constant (equal to the breakdown voltage V_Z) for a large change in reverse current.

Working : As shown in the figure the circuit for using Zener diode as a voltage regulator. Here the Zener diode is connected in reverse bias to a source of fluctuating d.c. (e.g., the output from a rectifier) through a dropping resistor R_S. If the input voltage increases, the current through and Zener diode also increases.

This increases the voltage drop across R_S without any change in the voltage across the Zener diode. This is because in the breakdown region, Zener voltage remains constant even though the current through the Zener diode changes. Similarly, if the input voltage decreases, the voltage across R_S decreases without any change in the voltage across the Zener diode.

Thus any increase/decrease of the input voltage results in, increase/decrease of the voltage drop across R_S without any change in voltage across Zener diode. Hence the Zener diode acts as a voltage regulator.

Photonic p–n Junction Devices

The *p*–*n* junction can be designed so that current through them changes either by causing electron excitation (from valence band to the conduction band) by light photons, or conversely through electron excitation by a suitable bias voltage resulting in the emission of light photons. These semi–conducting devices are called photonic or opto-electronic devices. In such devices, light photons play an important role in the overall functioning of the device.

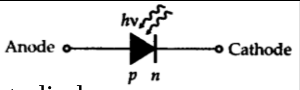
The photonic p-n junction devices can be classified as follows

(i) Photo-defectors used for detecting light signals e.g., photodiodes and photo conducting cell.

(ii) Photo voltaic devices which convert light energy into electricity e.g., solar cells.

(iii) Devices for converting electrical energy into light e.g., light emitting diodes and diode lasers.

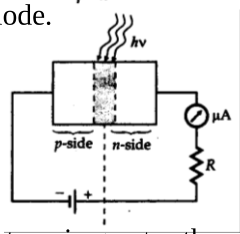
Photodiodes



A photodiode is a *p*–*n* junction made from a photosensitive semiconducting material in such a way that light can fall on its junction.

As shown in figure, a resistance *R* is connected in series with a reverse biased photodiode.

The voltage is kept slightly less than the breakdown voltage.

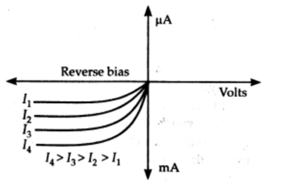


When no light is incident on the junction, a small reverse saturation current flows through the junction. This reverse current is due to thermally generated electron-hole pairs and is called dark current.

When light of frequency *v* is incident on the junction, such that the energy of its photons is greater than the band gap of the semiconductor (i.e., $hv > E_g$) additional electron- hole pairs are created due to the excitation of electrons from valence band to the conduction band. The photogenerated charge carriers increase the conductivity of the semiconductor. Larger the intensity of incident light, larger would be the increase in the conductivity of the semiconductor.

When a photodiode is illuminated with light photons of energy $hv > E_g$, and increasing intensities I_1, I_2, I_3, etc., the value of reverse saturation current increases with the increase in intensity of incident light.

A photodiode is preferably operated in reverse bias condition : Consider an *n*–type semiconductor. Its majority carrier (electron) density is much larger than **the minority hole density** i.e., $n >> p$. When illuminated with light, both types of carriers increase equally in number.



$$n' = n + \Delta n,$$

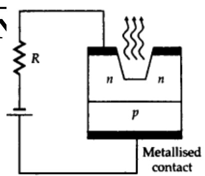
$$p' = p + \Delta p$$

Now, $n >> p$ and $\Delta n = \Delta p$. $\therefore$

$$\frac{\Delta n}{n} << \frac{\Delta p}{p}$$

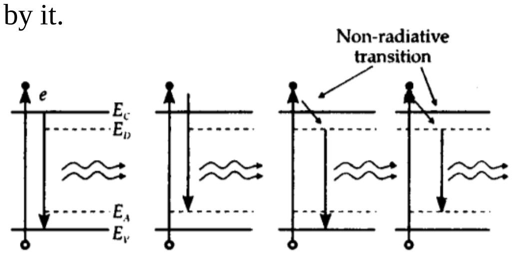
That is, the fractional increase in majority carriers is much less than the fractional increase in minority carriers. Consequently, the fractional change due to the photo-effects on the minority carrier dominated reverse bias current is more easily measurable than the fractional change in the majority carrier dominated forward bias current. Hence, photodiodes are preferable used in the reverse bias condition for measuring light intensity.

Light Emitting Diode



It is a forward-biased *p–n* junction which spontaneously converts the biasing electrical energy into optical energy, like infrared and visible light. A *p-n* junction made from a transulent semiconductor like gallium arsenide or indium phosphide is provided with metallised contacts, as shown in figure. When it is forward biased through a series resistance R, light photons are emitted from the non-metallised surface of the p-region. The series resistance R limits the current through the LED and hence controls the intensity of light emitted by it.

When the p-n junction is forward biased, its potential barrier reduces and its depletion region becomes so thin that holes and electrons are free to cross the barrier. Electrons injected into the p-region encounter holes and recombine. Similarly, holes injected into the n-region encounter electrons and recombine. When each electron-hole pair recombines, a single photon is released. The energy of the photon is equal to or less than the band gap of the semiconductor as is clear from figure.

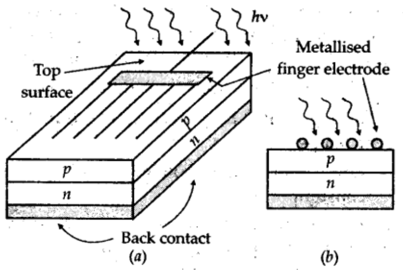


Choice of the semiconductor material used in LED : The wavelength of visible light ranges from 0.4 μm to 0.7 μm (energy from 3eV to 1.8 eV). For a semiconductor to emit visible light, the minimum band gap must be 1.8 eV. The compound semiconductor Gallium–Arsenide–Phosphide ($GaAs_{1-X}P_X$) is used for making LED of different colours. $GaAs_{0.6}\ P_{0.4}\ (E_g \approx 1.4)$ is used for infrared LED.

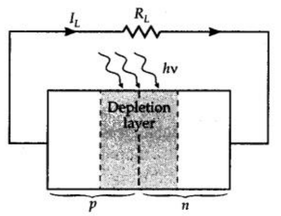
Solar Cell

It is a junction diode which converts solar energy into electricity and is based on photovoltaic effect (generation of voltage due to bombardment of light photons).

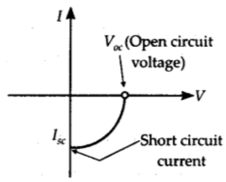
Construction : It consists of a *p–n* junction made from *Si* or *GaAs*. Here a thin layer of *p*–type is grown (by diffusion of a suitable acceptor impurity or by vapour deposition) on an *n*–type semiconductor. The top of the *p*–layer is provided with few finger electrodes. This leaves open enough space for the light to reach the thin *p*-layer and hence the underlying *p–n* junction. The bottom of the *n*–layer is provided with a current collecting electrode.



Working : When light photons with energy ($h\nu > E_g$) reach the junction, they excite electrons from the valence band to conduction band, leaving behind equal number of holes in the valence band. These electron-hole pairs generated in the depletion region move in opposite directions due to the barrier field. Photo-generated electrons move towards n-sides and holes towards *p*-side.



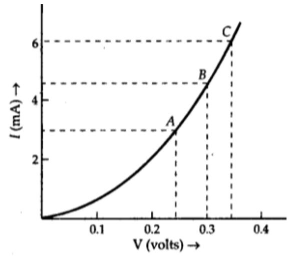
The collection of these charge carriers makes *p*-side a positive electrode and n-side a negative electrode. Hence photo-voltage is set up across the junction. When a load resistance R_L is connected in the external circuit, a photo-current I_L flows, as shown in figure. This current is proportional to the intensity of illumination.



Materials used in the fabrication of solar cells : The semiconductors with band gap close to 1.5 eV are ideal materials for this purpose. Solar cells are made with semiconductors like

Si	$(E_g = 1.1\text{ eV})$	*GaAs*	$(E_g = 1.43\text{ eV})$
CdTe	$(E_g = 1.45\text{ eV})$	$CuInSe_2$	$(E_g = 1.04\text{ eV})$, etc.

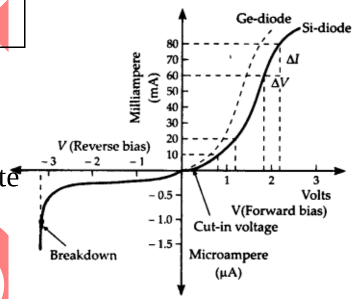
Subjective Assignment – III



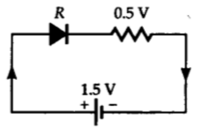
1. As shown in figure, the characteristic curve of a junction diode, Determine the d.c. and a.c. resistance of the diode, when it operator at 0.3*V*.
2. The following table provides the set of values of *V* and *I* obtained for a given diode :

	V	*I*
Forward biasing	2.0 V	60 mA
	2.4 V	80 mA
Reverse biasing	0 V	0 μA
	– 2 V	– 0.25 μA

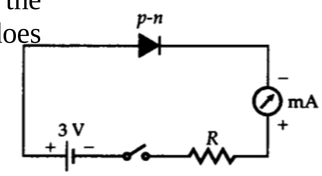
Assuming the characteristics to be nearly linear, over this range, calculate the forward and reverse bias resistance of the given diode.



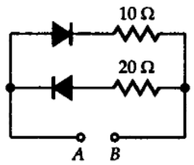
3. The *V–I* characteristic of a silicon diode is given in figure. Calculate the diode resistance in :
   (a) forward bias at $V = \pm 2V$ and $V = +1V$ and
   (b) reverse bias $V = -1V$ and $-2V$.



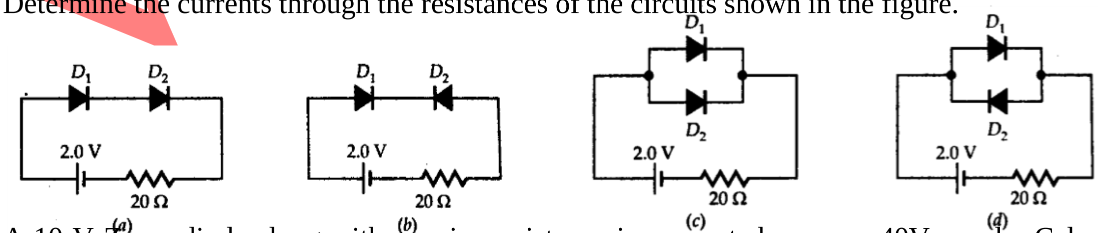
4. A *p–n* junction diode when forward biased has a drop of 0.5V which is assumed to be independent of current. The current in excess of 10mA through the diode produces a large Joule heating which damages (burns) the diode. If we want to use a 1.5V battery to forward bias the diode, what should be the value of resistor used in series with the diode so that the maximum current does not exceed 5mA?



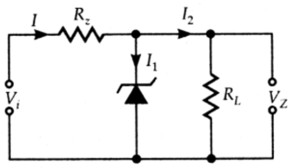
5. Draw the circuit to forward bias a diode. (The supply is 3V and 100mA battery). If the diode is made of silicon and knee voltage is 0.7 V, and a current of 20mA passes through the diode, find the wattage of the resistor and the diode.



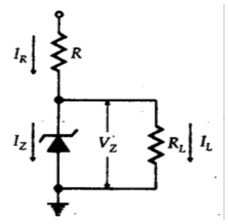
6. A battery of 2V may be connected across the point *A* and *B*, as shown in figure. Find the current drawn from the battery if the positive terminal is connected to (i) the point *A* and (ii) the point *B*. Assume that the resistance of each diode is zero in forward bias and infinity in reverse bias.
7. Determine the currents through the resistances of the circuits shown in the figure.



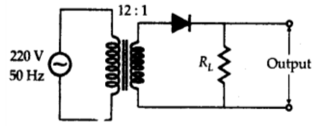
8. A 10 V Zener diode along with a series resistance is connected across a 40V supply. Calculate the minimum value of the resistance required, if the maximum zener current is 50mA.



9. As shown in figure, what is the voltage needed to maintain 15V across the load resistance R_L of $2K$ assuming that the series resistance R is 200Ω and the zener requires a minimum current of 10mA to work satisfactorily? What is the zener rating required?



10. Find the average value of dc voltage that can be obtained from the half–wave rectifier of figure. Assume the diode to be ideal one.



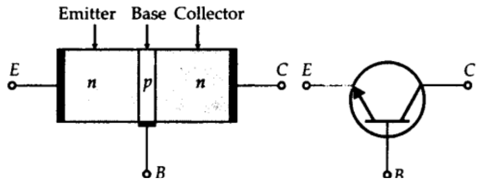
11. In a centre tap full wave rectifier, the load resistance $R_L = 1k\Omega$. Each diode has a forward bias dynamic resistance of 10Ω. The voltage across half the secondary winding is 220 sin 314t. Find (i) the peak value of current (ii) the dc value of current and (iii) the rms value of current.

Answers

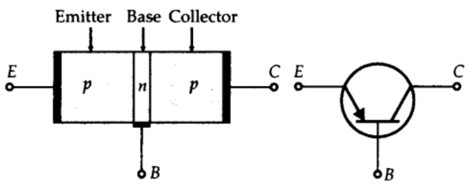
1. 66.67 Ω, 33.33 Ω
2. 20Ω , 8×10^6 Ω
3. (a) r_{2v} = 20Ω, r_{1v} = 400 Ω, (b) $r_{2v} = r_{1v} = 8 \times 10^6$ Ω
4. 200 Ω
5. 0.046 W, 0.014 W
6. (a) 0.2 A (b) 0.1 A
7. (i) 0.1 A (ii) zero (iii) 0.1 A (iv) 0.1 A
8. 600 Ω
9. 17.5 mA , 15V
10. 8.24 V
11. (i) 217.8 mA (ii) 138.66 mA (iii) 154 mA

Junction transistor

A junction transistor is a three terminal solid state device obtained by growing either a narrow section of *p*–type crystal between two relatively thicker sections of *n*–type crystals or a narrow section of *n*–type crystal between two thicker sections of *p*–type crystals.



1. ***n–p–n* transistor :** It consists of a thin section of *p*–type semiconductor sandwitched between two thicker sections of n type semiconductor.

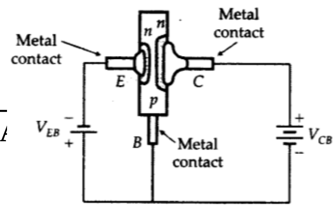


2. ***p–n–p* transistor :** It consists of a thin section of *n*–type semiconductor sandwitched between two thicker sections of *p*–type semiconductors.

Each type of transistor has three main parts.

1. **Emitter (E) :** It is a section on one side of the transistor. It is of moderate size and heavily doped semiconductor. It is normally forward biased w.r.t. any other part of the transistor. It supplies a large number of majority charge carriers for the flow of current through the transistor.
2. **Base (B) :** It is the middle section. It is very thin and lightly doped. It controls the flow of majority charge carriers from emitter to collector.

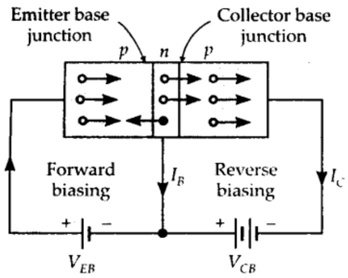
3. **Collector (C) :** It is section on the other side of the transistor. It is moderately doped and larger in size as compared to the emitter. It is



normally reverse biased w.r.t. any other part of the transistor. It collects the majority charge carriers for the circuit operation.

Action of n–p–n transistor

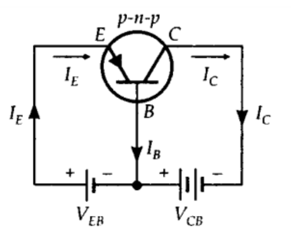
The *n*-type emitter of *n-p-n* transistor is forward biased by connecting it to the –ve terminal of battery V_{EB} and the *n*-type collector is reverse biased by connecting it to the +ve terminal of battery V_{CB}, as shown in figure. The forward bias of the emitter-base circuit repels the electrons of emitter towards the base, setting up emitter current I_E. As the base is very thin and lightly doped, a very few electrons (<5%) from the emitter combine with the holes of base, giving rise to base current I_B and the remaining electrons (> 95%) are pulled by the collector which is at high positive potential. The electrons are finally collected by the +ve terminal of battery V_{CB}, giving rise to collector current I_C.



As soon as an electron from the emitter combines with a hole in the base region, as electron leaves the negative terminal of the battery V_{EB} and at the same time the positive terminal of battery V_{EB} receives an electron from the base. This sets a base current I_B. Similarly, corresponding to each electron that goes from collector to positive terminal of $V_{CB'}$ an electron enters the emitter from negative terminal of $V_{EB'}$.

Hence Emitter current = Base current + Collector current

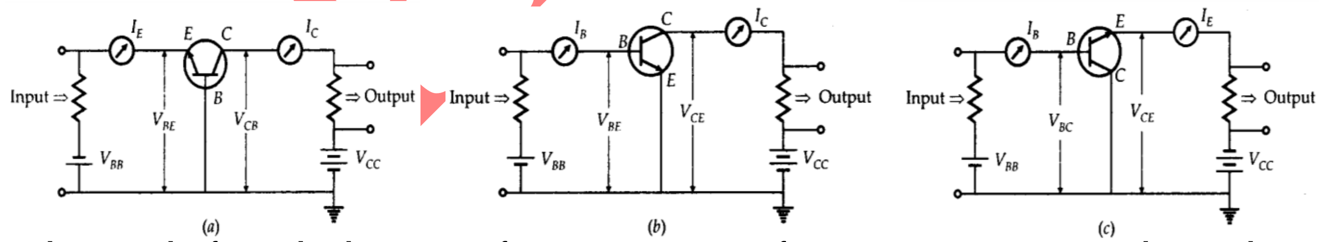
or $$I_E = I_B + I_C \qquad [I_B << I_C]$$



Three configurations of a transistor

A transistor is a three element device. One terminal has to be always common to the input and the output circuits. This terminal is connected to the ground and serves as a reference point for the entire circuit. So a transistor can be used in one of the following three configurations:

1. Common-base (CB) circuit.
2. Common-emitter (CE) circuit.
3. Common-collector (CC) circuit.



As shown in the figure the three types of circuit arrangements for an n-p-n transistor. In each case, the emitter-base junction is forward biased while the collector-base junction is reverse biased.

Current gains in a transistor

Usually two types of current gains are defined for a transistor :

1. **Common base current amplification factor or a.c. current gain α :** it is defined as the ratio of the small change in the collector current to the small change in the emitter current when the collector–base voltage is kept constant. Thus $$\alpha = \left[\frac{\Delta I_C}{\Delta I_E}\right]_{V_{CB} = \text{constant}}$$

2. **Common emitter current amplification factor or a.c. current gain β :** It is defined as the ratio of the small change in the collector current to the small change in the base current when the collector–emitter voltage is kept constant. Thus $\beta = \left[\frac{\Delta I_C}{\Delta I_B}\right]_{V_{CE} = \text{constant}}$.

Relation between α and β : For both *n–p–n* and *p–n–p* transistors, we have

$$I_E = I_B + I_C$$

For small changes, we can write

$$\Delta I_E = \Delta I_B + \Delta I_C$$

Dividing both sides by ΔI_C , $\frac{\Delta I_E}{\Delta I_C} = \frac{\Delta I_B}{\Delta I_C} + 1$

or $\frac{1}{\alpha} = \frac{1}{\beta} + 1$ $\left[\because \frac{\Delta I_C}{\Delta I_E} = \alpha \, ; \, \frac{\Delta I_C}{\Delta I_B} = \beta\right]$

or $\boxed{\alpha = \frac{\beta}{1+\beta}}$ and $\boxed{\beta = \frac{\alpha}{1+\alpha}}$

As the value of I_B is about 1 – 5% of I_E or I_C is 95–99% of I_E, α is about 0.95 to 0.99 and β is about 20 to 100. The CE configuration is frequently used as it gives high current gain as well as voltage gain.

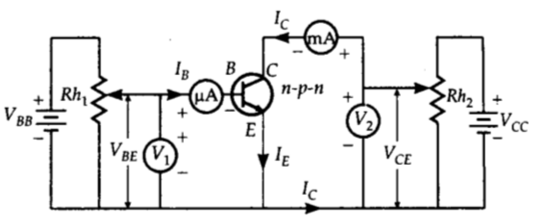
Note :

1. α and β are independent of current if the emitter–base junction is forward biased and the collector–base junction is reverse biased.

2. The above definition of α and β do not hold when both the junctions of a transistor are forward biased or reverse biased.

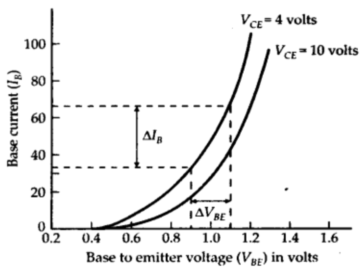
Common Emitter Characteristics

The common- emitter characteristics are the graphs drawn between appropriate voltages and currents for a transistor when its emitter is taken as the common terminal and grounded (zero potential), base is the input terminal and collector is the output terminal. The emitter–base junction is forward biased by means of battery V_{BB} through rheostat Rh_1. The emitter–collector circuit is reverse biased by means of battery V_{CC} through rheostat Rh_2.



The base–emitter voltage V_{BE} and the collector–emitter–voltage V_{CE} are measured by high resistance voltmeters. The base current I_B is measured by a microammeter and the collector current I_C by a milliammeter. There types of characteristic curves are studied.

1. **Input characteristic :** A graph showing the variation of base current I_B with base–emitter voltage V_{BE} at constant collector emitter voltage V_{CE} is called the input characteristic of the transistor. From the curves

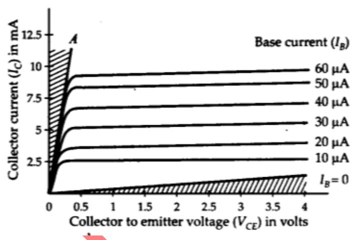


(i) As long as V_{BE} is less than the barrier voltage, the base current I_B is small as in the case of forward biased diode.

(ii) When the base–emitter voltage V_{BE} exceeds the barrier voltage, the base current I_B increases sharply with a small increase in V_{BE} as in the case of a forward biased diode.

(iii) The value of I_B is much smaller than that in a normal diode, more than 95% majority emitter carriers (electrons in *n–p–n* and holes in *p–n–p* transistor) go to the collector to constitute the collector current I_C.

1. **The input resistance :** (r_i) of the transistor in *CE* configuration is defined as the ratio of the small change in base–emitter voltage to the corresponding small change in the base current, when the collector–emitter voltage is kept fixed. Thus, $r_i = \left[\frac{\Delta V_{BE}}{\Delta I_B}\right]_{V_{CE} = \text{constant}}$



As input characteristic is non–linear, so r_i varies.

2. **Output characteristic :** A graph showing the variation of collector current I_C with collector-emitter voltage V_{CE} at constant base-current I_B is called the output characteristic of the transistor. From the curve

(i) When the voltage V_{CE} increases from 0 to about 0.5V, the collector current I_C increases rapidly. The value of V_{CE} upto which I_C increases rapidly is called knee voltage.

(ii) Once the voltage V_{CE} exceeds the voltage V_{BE} (so that the collector–base junction is reverse biased), the output current I_C varies very slowly but linearly with V_{CE} for a given base current I_B, i.e., beyond the knee voltage the output resistance of the transistor is high.

(iii) Larger the value of I_B, larger is the value of I_C for a given V_{CE}.

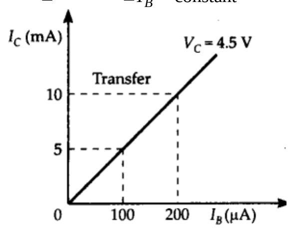
Three regions of the output characteristic

(a) The shaded region towards the left of line *OA* is called saturation region and the line *OA* is called saturation line. Here $V_{CE} < V_{BE}$. Both the junctions are forward biased. Here I_C does not depend on the input current I_B.

(b) The shaded region lying below the curve for $I_B = 0$ is called cut–off region. In this region, both the junctions are reverse biased. Here $I_C = 0$. In the shaded regions, the transistor works as switch, it turns over rapidly from OFF state for which $I_C = 0$ (cut–off) to the ON state for which I_C is maximum (saturation state).

(c) The non–shaded central region of the output characteristic is called active region. In this region, the emitter–base junction is forward biased and the collector–base junction is reverse biased. A transistor works as an audio amplifier in this region. The output resistance r_0 of a transistor in *CE* configuration is defined as the ratio of the small change in the collector–emitter voltage to the corresponding change in the collector current when the base current is kept constant. Thus $r_0 = \left[\frac{\Delta V_{CE}}{\Delta I_C}\right]_{I_B = \text{constant}}$.

3. **Transfer characteristic :** It is a graph showing the variation of collector current I_C with base current I_B at constant collector–emitter voltage V_{CE}.



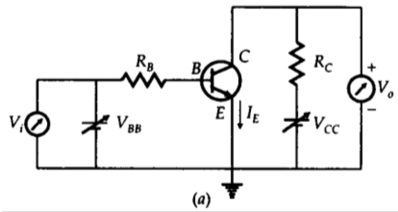
Current amplification factor (β) : It is defined as the ratio of the change in collector current to the small change in base current at constant collector-emitter voltage (V_{CE}) when the transistor is in the active state.

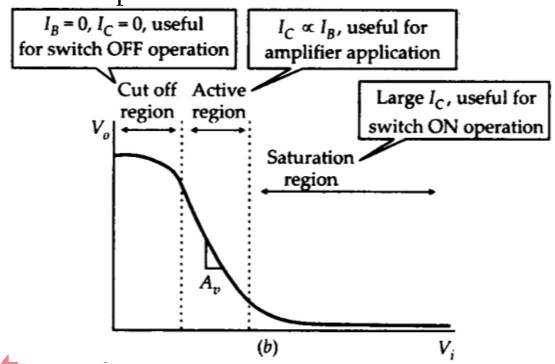
$$\beta_{ac} = \left[\frac{\Delta I_C}{\Delta I_B}\right]_{V_{CE} = \text{constant}}$$

This is also known as small signal current gain and its value is very large. The direct ratio of I_C and I_B gives the dc current gain (β_{dc}) of the transistor. Hence, $\beta_{dc} = \frac{I_C}{I_B}$. Since I_C increases with I_B almost linearly and $I_C = 0$ when $I_B = 0$, the values of both β_{ac} and β_{dc} are nearly equal.

Transistor as a switch

Three states of transistor : As shown in the circuit diagram of a base–biased *n–p–n* transistor in *CE* configuration. Here R_B is a resistor in the input circuit and R_C in the output circuit.





Applying Krichhoff's rule to the input and output circuits separately, we get $V_{BB} = I_B R_B + V_{BE}$

and $V_{CC} = I_C R_C + V_{CE}$ or $V_{CE} = V_{CC} - I_C R_C$

The voltage V_{BB} can be regarded as the dc input voltage V_i and V_{CE} as the *dc* output voltage V_0. So we can write $V_i = I_b R_B + V_{BE}$

and $V_0 = V_{CC} - I_C R_C$ ....(1)

fig. (b) shows typical output voltage (V_0) input voltage (V_i) characteristic, called the transfer characteristic of the base biased transistor. It has three well–defined regions as follows :

1. **Cutoff region :** When V_i increases from zero to a low value (less than 0.6 V in case of a Si transistor), the forward bias of the emitter–base junction is insufficient to start a forward current. That is $I_B = 0$ and hence $I_C = 0$. The transistor is said to be in the cutoff region. From equation (1), the output voltage $V_0 = V_{CC}$.
2. **Active region :** When V_i increases slightly above 0.6 V, a current I_C flows in the output circuit and the transistor said to be in the active state. From equation (1), as the term $I_C R_C$ increases, the output voltage V_0 decreases. Now as V_i increases, I_C increases almost linearly and so V_0 decreases linearly till its value becomes less than 1.0V.
3. **Saturation region :** When V_i is high i.e., the emitter–base junction is heavily forward biased, a large collector current I_C flows which produces such a large emitter collector junction also gets forward biased used. The output voltage V_0 decreases to almost zero. The transistor is said to be in the saturation state because it cannot pass any more collector current I_C. Obviously, the transitions from cutoff state to active state and from active state to saturation state are not sharply defined because these regions of the transfer characteristic are not-linear.

Switching action of a transistor : A transistor can be used as a switch if it is operated in its cutoff and saturation states only. A switch circuit is designed in such a manner that the transistor does not remain in the active state. As long as the input voltage is low and unable to forward-bias the transistor, the output voltage V_0 (at V_{CC}) is high. If V_i is high enough to drive the transistor into saturation, then is low, nearly 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 he switched on.

Concept of an amplifier

Amplifying action of a transistor : As the base-emitter junction of a transistor is forward biased, the depletion layer about this junction is much smaller than the depletion layer around the base-collector junction which is reverse biased. Thus the resistance R_{EB} of the emitter-base junction is much smaller than the resistance R_{BC} of the collector–base junction.

∴ Power dissipation in the emitter-base circuit, $P_{EB} = I_E^2 \, R_{EB}$

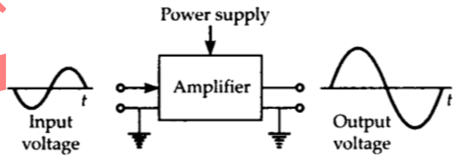
Power dissipation in the base–collector circuit, $P_{BC} = I_C^2 \, R_{BC}$

Now, $I_E \approx I_C$ and $R_{BC} >> R_{EB}$, $P_{BC} >> P_{EB}$

i.e., the power dissipated in the base–collector circuit is much higher than the power dissipated in the emitter–base circuit or output power is much greater than the input power. This is the amplifying action of a transistor.

The current is thus transferred from a low resistance circuit to a high resistance circuit. Hence the name transistor, which is combination of the words transfer and resistor. A thin and lightly doped base region contains a smaller number of majority charge carriers. This reduces the rate of recombination of electrons and holes at the emitter-base junction. Most (95 – 99%) of the majority charge carriers, diffusing from emitter to base, reach the collector. Thus the base current is small and the collector is almost equal to the emitter current. This results in the large voltage gain and power gain of the transistor.

Trans–conductance : It is defined as the ratio of the small change in the collector current to the small change in the emitter–base voltage. It is denoted by g_m. Thus



$$g_m = \frac{\Delta I_C}{\Delta V_{BE}}$$

The transconductance is also called transfer conductance. An amplifier is a circuit (consisting of at least one transistor) which is used for increasing the voltage, current or power of alternating form.

To amplify means to increase the size or to magnify an input signal. The output signal of an amplifier is an enlarged version of the input signal.

AC voltage gain A_v : The a.c. voltage gain of an amplifier is defined as the ratio of the change in the output voltage (ΔV_0) to the corresponding change in the input voltage (ΔV_i) . Thus $A_v = \dfrac{\Delta V_0}{\Delta V_i}$

The voltage gain of an amplifier is always greater than unity.

Transistor as a common emitter amplifier

The emitter is common to both input and output circuits. The emitter is forward biased by battery V_{BB} and the collector is reverse biased by battery V_{CC}. This decreases the resistance R_{in} of the output circuit. The low a.c. input signal V_i is superimposed on the forward bias V_{BE}. A load resistance R_L is connected between the collector and the d.c. supply and the amplified output is obtained between the collector and the ground.

When current I_C flows in the output circuit, the potential drop across the load resistance is $I_C R_L$. Hence the output voltage is $V_0 = V_{CE} = V_{CC} - I_C R_L$

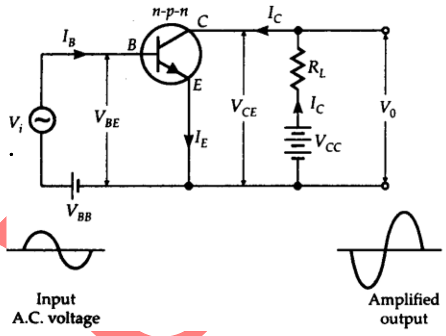
When the input signal is fed to the base–emitter circuit, the base-emitter voltage changes. This changes the emitter current I_E and hence the collector current I_C. The output voltage V_0 varies in accordance with the above relation. These variations in the collector voltage appear as amplified output.

Phase relationship between input and output signals : When an a.c. signal is fed to the input circuit, its positive half cycle increases the forward bias of the circuit which, in turn, increases the emitter current and hence the collector current. The increase in collector current increases the potential drop across R_L, which makes the output voltage V_0 less positive or more negative. So, as the input signal goes through its positive half cycle, the amplified output signal goes through a negative half cycle. Similarly, as the input signal goes through its negative half cycle, the amplified output signal goes through its positive half cycle. Hence in a common emitter amplifier, the input and output voltages are 180^o out of phase or in opposite phases.

Current, voltage and power gains of a common emitter amplifier : a.c. current gain : It is defined as the ratio of the small change in the collector current (ΔI_C) to the small change in base current (ΔI_B), when the collector-emitter voltage is kept constant. It is denoted by β_{ac} or A_i. Thus

$$\beta_{ac} \quad \text{or} \quad A_i = \left[\frac{\Delta I_C}{\Delta I_B}\right]_{V_{CE} = \text{constant}}$$

d.c. current gain : It is defined as the ratio of collector current to the base current, when collector–emitter voltage is constant. Thus



$$\beta_{dc} = \left[\frac{I_C}{I_B}\right]_{V_{CE} = \text{constant}}$$

In the linear region of the output characteristics, β_{ac} is usually close to β_{dc}.

a.c. voltage gain : It is defined as the ratio of small change in output voltage (ΔV_{CE}) to the small change in input voltage (ΔV_{BE}) to the small change in input voltage (ΔV_{BE}). It is given by

$$A_v = \frac{\Delta V_{CE}}{\Delta V_{BE}}$$

But $\quad \Delta V_{BE} = R_i \,.\, \Delta I_B \quad$ where R_i is the resistance of the input or the emitter base circuit.

and $\quad \Delta V_{CE} = R_0 \,.\, \Delta I_C$

where R_0 is the resistance of the output or collector-emitter circuit (including R_L)

$$\therefore \quad A_v = \frac{\Delta I_C}{\Delta I_B} \,.\, \frac{R_{out}}{R_{in}} = \beta_{ac} \,.\, \frac{R_{out}}{R_{in}} \quad \text{or} \quad A_v = A_i \,.\, A_r$$

i.e., Voltage gain = Current gain × Resistance gain

a.c. power gain : It is defined as the small change in output power to the small change in input power.

$$\text{a.c. power gain} = \frac{\text{change in ouput power}}{\text{Change in input power}}$$

$$= \frac{(\Delta I_C)^2 R_0}{(\Delta I_B)^2 R_i} = \beta_{ac}^2 \,.\, \frac{R_0}{R_i}$$

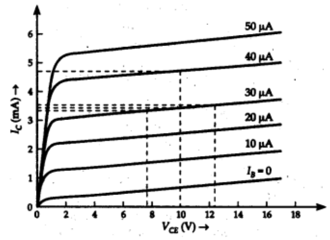
As $\beta_{ac}^2 >> \alpha_{ac}^2$ the a.c. power gain of a common emitter amplifier is much larger than that of a common base amplifier.

Subjective Assignment – IV

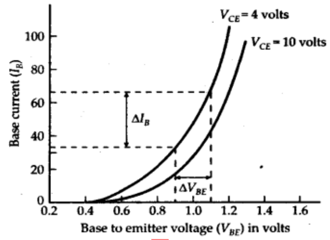
1. In p–n–p transistor circuit, the collector current is 10mA. If 90% of the holes reach the collector, find emitter and base currents.
2. For a transistor connected in common emitter mode, the voltage drop across the collector is 2V and β is 50. Find the base current, if R_C is 2kΩ.
3. The potential difference across the collector of a transistor, used in common emitter mode is 1.5V, with the collector resistance of 3kΩ. Find (i) the emitter and (ii) the base current, if the d.c. gain of the transistor is 50.
4. The current gain for common emitter amplifier is 59. If the emitter current is 6.0mA, find (i) base current (ii) collector current.
5. In a silicon transistor, a change of 80 mA in the emitter current produces a change of 7.9mA in the collector current. What change in the base current is necessary to produce an equivalent change in the collector current? Find the values of α and β.
6. The input resistance of a transistor is 1000Ω. On changing its base current by 10μA, the collector current increases by 2mA. If a load resistance of 5kΩ is used in the circuit, calculate:

(i) The current gain (ii) Voltage gain of the amplifier

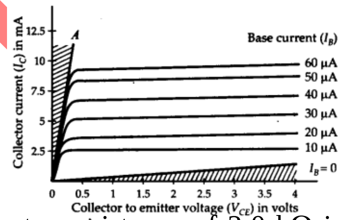
7. As shown in the figure the output characteristic of an *n–p–n* transistor in *CE* configuration. For this transistor, determine
(i) the dynamic output resistance
(ii) the dc current gain and
(iii) the ac current gain ;
at an operating point $V_{CE} = 10V$, when $I_B = 30\mu A$.



8. Calculate the input resistance of the transistor operating at $V_{CE} = 4V$ in *CE* configuration having its input characteristics as shown in figure.



9. From the output characteristics shown in figure. Calculate the value of current amplification factor of the transistor when V_{CE} is 2V.



10. For a *CE*–transistor amplifier, the audio signal voltage across the collector resistance of 2.0 kΩ is 2.0V. Suppose the current amplification factor of the transistor is 100, what should be the value of R_B in series with V_{BB} supply of 2.0 V if the dc base current has to be 10 times the signal current? Also calculate the dc drop across the collector resistance. Take $V_{BE} = 0.6V$.

11. A transistor has a current amplification factor (current gain) of 50. In a *CE*–amplifier circuit, the collector resistance is chosen as 5Ω and the input resistance is 1Ω. Calculate the output voltage if input voltage is 0.01V.

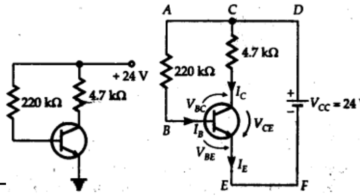
12. For a common emitter transistor amplifier, the audio signal voltage across the collector resistance of 2kΩ is 2V. If the current amplification factor of the transistor is 100, calculate (i) input signal voltage, (ii) base current, and (iii) power gain. Given that the value of the base resistance is 1kΩ.

13. The input resistance of a silicon transistor is 665Ω. Its base current is changed by 15μA which results in the change in collector current by 2mA. This transistor is used as a common emitter amplifier with a load resistance of 5kΩ. Calculate :
(i) current gain '$\beta_{a.c.}$'. (ii) trans–conductance 'g_m' and (iii) voltage gain 'A_v' of the amplifier

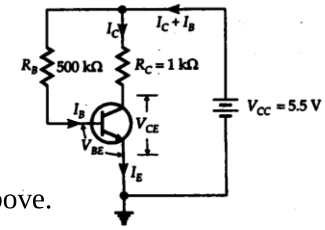
14. In a silicon transistor, the base current is changed by 20μA. This results in a change of 0.02 V in base to emitter voltage and a change of 2mA in the collector current.
(a) Find the input resistance β_{ac} and transconductance of the transistor.
(b) This transistor is used as a *CE* amplifier with load resistance 5kΩ. What is the voltage gain of amplifier?

15. An *n–p–n* transistor is connected in common-emitter configuration in which collector supply is 8V and the voltage-drop across the load-resistance of 800Ω connected in the collector circuit is 0.8V. If current amplification factor is 25, determine collector–emitter voltage and base–current. If the internal resistance of the transistor is 200Ω, calculate the voltage-gain and power-gain.

16. In the circuit shown in figure, the value of β is 100. Find I_B, V_{CE}, V_{BE} and V_{BC}, when $I_C = 1.5mA$. Discuss whether the transistor is in active, cut off or saturation state?

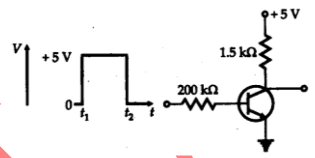


17. In the circuit shown in figure, the base current I_B is $10 \mu A$ and the collector current is 5.2 mA. (a) Can this transistor circuit be used as an amplifier?



(b) What happens if resistance R_C is 500Ω and I_B, I_C and R_B remain same as above.

18. In the circuit shown in figure, if we assume that when the input voltage at the base resistance is 5V, V_{BE} is zero and V_{CE} is also zero; what is I_B, I_C and β? When the input is zero, the I_B is zero. What will be the output waveform if the input waveform is as shown in figure.

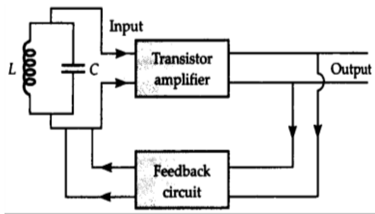


Answers

1.	11mA , 1 mA	2.	1 mA , 20 µA	3.	0.49 mA, 0.01 mA
4.	5.9 mA , 0.1 mA	5.	0.1 mA , 0.99, 79	6.	200, 1000
7.	(i) 25 kΩ , (ii) 120 (iii) 110	8.	6000 Ω	9.	40
10.	14kΩ , 20 V 2000	11.	2.5 V	12.	0.01 V , (ii) 10 µA , (iii)
13.	(i) 133, (ii) 0.2 Ω^{-1} , (iii) 1000	14.	(a)100, 0.1 Ω^{-1} (b) 500	15.	100, 2500
16.	15 µA, V_{CE} = 16.95V , V_{BE} = 20.7 V , V_{BC} = 3.75 V, saturation state				
17.	(a) No (b) Yes	18.	I_C = 3.3 mA , I_B = 25 µA , 133.3		

Transistor As an oscillator

An oscillator is an electronic device which produces electric oscillation of constant frequency and amplitude, without requiring any external input signal. It converts dc energy obtained from a battery into ac energy in some oscillatory circuit. An oscillator may be regarded as the self–sustained transistor amplifier with a positive feedback.

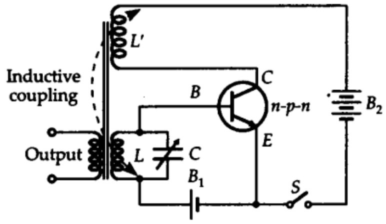


(i) **Tank circuit :** A tank circuit is just a parallel combination of an inductance *L* and a capacitance *C*. The electric energy once given to it alternately changes between electrostatic energy in the capacitor and the magnetic energy in the inductor. The frequency of electric oscillations in the tank circuit is $f = \frac{1}{2\pi\sqrt{LC}}$. However, the oscillations get damped due to resistive losses in the inductance, and dielectric losses in the capacitor.

(ii) **Transistor amplifier :** The oscillations of the tank circuit are fed to the transistor amplifier. The oscillations get amplified due to the amplifying action of the transistor.

(iii) **Feedback circuit :** To compensate for the energy losses occurring in the tank circuit, the feedback circuit returns (feeds back) a part of the output power of the transistor amplifier to the tank circuit in phase with the input signal. This process is called positive feedback and produces undamped oscillations. The feedback may be done through inductive coupling (mutual inductance).

Transistor as an oscillator : As shown in figure shows basic circuit using a common-emitter *n-p-n* transistor as an oscillator. A tank circuit consisting of an inductance L and a variable capacitor C is connected in the input or the emitter-base circuit which is forward biased. A small coil L' called feedback or tickler coil is connected in the output or the emitter-collector circuit which is reverse biased. The coil L' is inductively coupled with the coil L of the tank circuit.

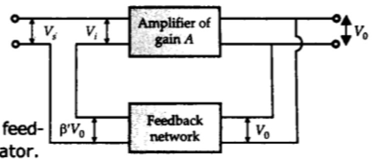


1. Working : When the switch S is closed, a small collector current starts growing through coil L'. This increases the magnetic flux linked with coil L' and hence with coil L. This induces emf in coil L in the direction of forward bias and a positive charge begins to build on the upper plate of capacitor C. The emitter current increases and also the collector current increases. This increases the magnetic flux linked with L' and hence with L. Consequently, the forward bias increases which further increases the emitter and collector currents. Charging of capacitor continues. This process continues till the collector current becomes maximum.

When the current through L' stops changing, the induced emf linked with L vanishes. This decreases the emitter current and hence the collector current. The decreasing current through L' induces emf in L in the opposite direction of the forward bias. This results in decrease in the emitter current and hence the collector current. At the same time positive charge on the lower plate of capacitor C begins to build up. The process continues till the collector current becomes zero. (In fact, inertia of the collapsing magnetic field carries the collector current below the zero value). The induced emf linked with L again becomes zero, i.e., the forward bias is now not being opposed by induced emf The emitter current and hence the collector current will start increasing. This cycle repeats again and again to give electric oscillations of constant amplitude and of constant frequency, $f = \dfrac{1}{2\pi\sqrt{LC}}$. The oscillations of a desired frequency can be obtained by changing the value of capacitance C of the variable capacitor. In this oscillator, we have connected tank circuit on the base side. Hence, it is known as tuned base oscillator. If the tank circuit is on the collector side, it will be known as tuned-collector oscillator.

Positive feedback : In common-emitter transistor circuit, a signal applied to the base-emitter circuit appears with a phase change of 180^o in the collector-emitter circuit. The coupling of L and L' produces a further phase change of 180° due to mutual induction. Hence the energy fed back to the tank circuit is in phase with the input signal. Due to this positive feedback, the oscillations of the tank circuit are correctly maintained.

Note : Barkhausen's criterion for sustained oscillations : When a part of the output is fed back to the input of an amplifier, the process is called feedback process. figure shows a feedback amplifier with input V_s and output V_0. The voltage gain of the feedback amplifier is $A_v' = \dfrac{\text{Output}}{\text{Input}} = \dfrac{V_0}{V_s}$.



Principle of feed-back oscillator.

- The input given to the feedback network is V_0. If β' is the feedback fraction of the feedback network, then output obtained from it is $\beta' V_0$. This fraction is mixed with the signal voltage V_s and is given to the amplifier.

∴ Input of the amplifier, $V_i = V_s + \beta' V_0$

The voltage gain of the amplifier is $A = \dfrac{\text{Output}}{\text{Input}} = \dfrac{V_0}{V_s + \beta' V_0}$

or $\quad AV_s + A\beta' V_0 = V_0 \quad$ or $\quad AV_s = V_0(1 - \beta' A)$

or $\quad \dfrac{A}{1-\beta' A} = \dfrac{V_0}{V_s}$

Hence the gain of the feedback amplifier is $A_v' = \dfrac{V_0}{V_s} = \dfrac{A}{1-\beta' A}$

When $\beta' A = 1,\ A'_v = \dfrac{V_0}{V_s} = \infty$. This means $V_s = 0$.

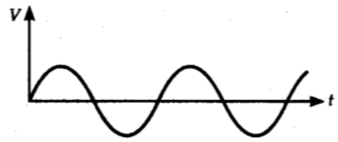
Thus the output voltage is obtained without the input voltage. The amplifier becomes a self–sustained oscillator. Hence the condition for stable oscillations to be sustained is : $\beta' A = 1$. This is known a **Barkhausen criterion** for sustained oscillations.

- ♦ If the feedback is negative, the gain of the amplifier becomes $A'_v = \dfrac{A}{1+\beta' A}$.
- ♦ In an oscillator, the feedback is in same phase (positive feedback). If the feedback voltage is in opposite phase (negative feedback), the gain is less than I and it can never work as an oscillator. It will be an amplifier with reduced gain. However, the negative feedback reduces the noise and distortion of an amplifier.
- ♦ Different oscillators use different feedback networks (such as inductive coupling or *LC* or *RC* networks) for coupling the output to the input apart from the resonant circuit for obtaining oscillations of a particular frequency. These give rise to different types of oscillators like Colpitt's oscillator, Hartley oscillator, RC-oscillator, etc.

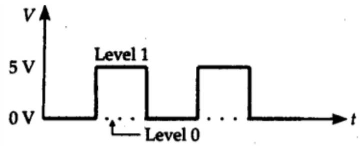
Analog and digital circuits

All electronic circuits can be broadly divided into two categories.

1. Analog circuits 2. Digital circuits



1. Analog circuits : A signal in which current or voltage varies continuously with time is called analog signal. A sinusoidally varying alternating voltage as shown in figure, is the simplest analog signal. The electronic circuits which process analog signals are called analog circuits. The devices like amplifiers radio, television, oscillators, etc; also make use of analog signals.



2. **Digital circuits :** A signal in which current or voltage can take only two discrete values is called a digital signal. A digital signal can take only two values 1 and 0 which are labelled as high and low values. In the square waveform shown in figure, a signal of 0 V represents binary 0 and a signal of 5 V represents binary 1. Thus digital signals are in the form of pulses of equal level. The electric circuits which process digital signals are called digital circuits.

The devices like pocket calculators, electronic watches, video cassette recorders, burglar alarms, robots, modern computers etc; are all digital circuits. Digital computers are more fast, reliable and accurate than analog computers.

Logic Gates

Logic gates are the building blocks of digital circuits in which diodes and transistors are used to perform switching functions. They form the heart of digital computers and are widely used in control systems. Basically, a gate is a circuit to provide an output which is dependent on the manner in which the inputs are applied. A gate is a digital circuit that is designed for performing a particular logical operation. As it works according to some logical relationship between input and output voltages, so it is generally known as a logic gate. A logic gate may have one or more input terminals but only one output terminal.

There are three basic gates:

1. OR gate, 2. AND gate, and 3. NOT gate.

Each logic gate is represented by a graphic symbol and its function is defined either by a truth table or by a Boolean expression.

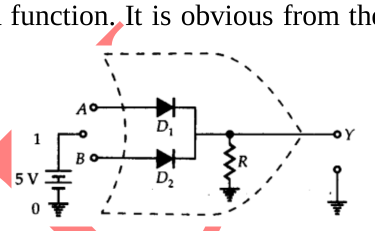
Truth Table : It is a table that shows all possible input combinations and corresponding outputs for a logic gate.

Boolean expression : It is a shorthand method to describe the functioning of a logic gate in the form of an equation or an expression. It also relates the all possible combinations of the inputs of a logic gate to the corresponding outputs.

The 'OR' Gate

An *OR* gate can have any number of inputs but only one output. It gives high output (1) if either input *A* or *B* or both are high (1), otherwise the output *Y* is low (0). As shown in figure the logic symbol and the truth table for an OR gate. The OR gate can be described by the Boolean expression $A + B = Y$

Which is read as '*A* or *B* equals *Y* '. Here the plus (+) sign denotes the OR function. It is obvious from the truth table of OR gate that the output is 1 when any of the inputs is 1.



Realisation of OR gate : As shown in figure, a two input OR gate can be realized by using two ideal diodes D_1 and D_2 and a resistor *R*. The negative terminal of the battery is grounded (i.e., it is at zero volt) and corresponds to the 0 state, and positive terminal (which is at, 5V) corresponds to the 1 state.

The following four cases are possible :

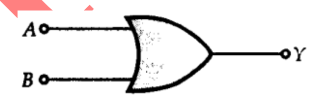
1. **When *A* = 0 and *B* = 0 :** Both the diodes are connected to earth (0V). They do not conduct. Output across *R* is zero, i.e., $Y = 0$.
2. **When *A* = 0 and *B* = 1 :** D_1 is connected to earth. It does not conduct. D_2 is connected to 5V, it gets forward biased and conducts. Voltage drop across D_2 is zero and the full voltage of 5*V* appears across *R*. So $Y = 1$.
3. **When *A* = 1 and *B* = 0 :** D_1 gets forward biased and D_2 does not conduct. Voltage drop across *R* is again 5*V*. So $Y = 1$.
4. **When *A* = 1 and *B* = 1 :** Both D_1 and D_2 get forward biased and conduct current. But D_1 and D_2 are in parallel. Voltage drop across *R* is still 5V. So $Y = 1$.

The 'AND' Gate

An AND gate can have any number of inputs but only one output. It gives high output (1) if either input *A* or *B* or both are high (1). Otherwise the output Y is low (0). Figure shows the logic symbol and the truth table of an AND gate. The AND gate is described by the Boolean expression :

$$A \, . \, B = Y$$

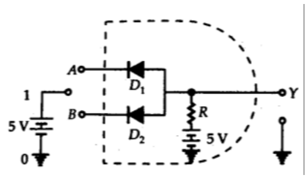
Boolean expression : $A \, . \, B = Y$



Truth Table

Inputs		Output
A	*B*	*Y = A . B*
0	0	0
0	1	0
1	0	0
1	1	1

Which is red as '*A* and *B* equal *Y*'. Here the dot(.) sign represents the AND function. It is obvious from the truth table of AND gate that the output is 1 only when both the inputs are 1.



Realisation of AND gate : As shown in figure, a two input AND gate can be realized by using two ideal junction diodes D_1 and D_2 . Here the resistance *R* is kept permanently connected to the +ve terminal of 5V battery.

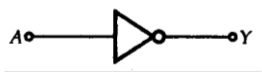
The following four cases are possible.

1. **When *A* = 0 and *B* = 0 :** The input terminals *A* and *B* are earthed (0V). The two diodes tet forward biased and conduct current. But both diodes are shorted. The point *Y* also gets earthed through the shorted diodes. Hence output $Y = 0$.
2. **When *A* = 0 and *B* = 1:** Diode D_1 is forward biased but shorted. Diode D_2 is not forward biased and does not conduct. Hence output $Y = 0$.

3. **When *A* = 1 and *B* = 0 :** D_1 does not conduct. D_2 is forward biased but shorted. Hence output $Y = 0$.
4. **When *A* = 1 and *B* = 1 :** Both D_1 and D_2 do not conduct as they are not forward biased. The output voltage is equal to the battery voltage of 5V. Hence $Y = 1$.

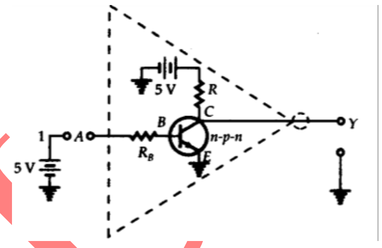
The 'NOT' gate

A NOT gate is the simplest gate, with one input and one output. It gives a high output (1), if the input A is low (0), and vice versa. Whatever the input, the NOT gate inverts it. As shown figure, the logical symbol and the truth table of NOT gate. The NOT gate is described by the Boolean expression : $\overline{A} = Y$, which is read as Y is the negation *A*. This means that $Y = 0$ if $A = 1$ and $Y = 1$ if $A = 0$.



Truth Table

Inputs	Output
A	*Y*
0	1
1	o



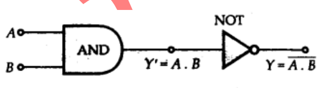
Realisation of Not gate : As shown in figure, a NOT gate can be obtained by using an *n–p–n* transistor. The base resistor R_B and the collector resistance R_C are so chosen that when a voltage of 5V is applied at the base of the transistor, a large collector current flows, the voltage at *Y* drops and the base–collector junction is forward biased.

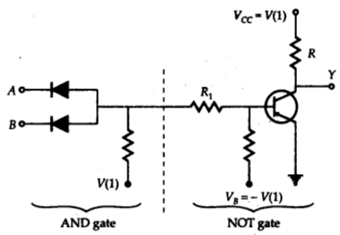
The following two cases are possible :

1. **When input *A* = 0 :** The base of the transistor is earthed, the base-emitter junction is not forward biased and the collector-base junction is reverse biased. Hence the base current and the collector current are both zero. The transistor is in the cut-off mode. No voltage drop occurs across *R*. The voltage at *Y* is 5 V. Hence output $Y = 1$.
2. **When input *A* =1 :** The input terminal *A* is at 5 V, both emitter and collector are forward biased. *A* large collector current flows. The transistor is in the saturation mode. The voltage drop across R_c is almost 5 V. Hence output $Y = 0$.

The 'NAND' Gate

The NAND gate is a combination of an AND and a NOT gate. It is obtained by connecting the output of an AND gate to the input of a NOT gate, as shown in figure. Its truth table can be obtained by using the truth table of AND gate and then finding the negation of its output.





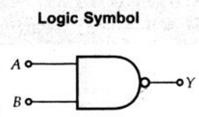
A	*B*	*Y'*=*A.B*	$Y = \overline{A.B} = \overline{Y}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

The NAND gate is described by the Boolean expression :

$$\overline{A \,.\, B} = Y \quad \text{or} \quad \overline{AB} = Y$$

Which is read as '*A* AND *B* negated equals *Y* '. The output of a NAND gate is low when both the inputs are high otherwise high. Boolean expression : $\overline{A \,.\, B} = Y$.

Logic Symbol

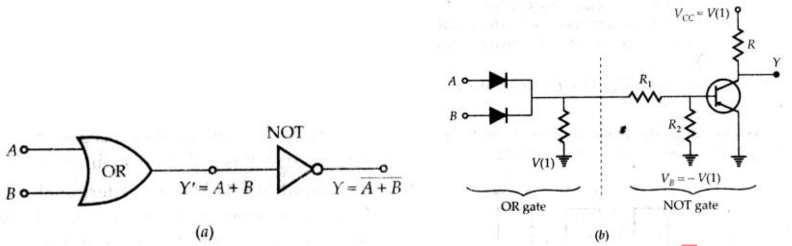


Truth Table

Inputs		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

'NOR' Gate

A NOR gate is a combination of an OR and a NOT gate. It is obtained by connecting the output of an OR gate to the input of a NOT gate, as shown in figure. Its truth table can be obtained by using the truth table of an OR gate and then finding the negation of the its output.



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

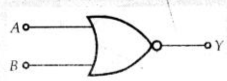
(c)

The NOR gate is described by the *Boolean expression;*

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

which is read as 'A OR B negated equals Y'. The output of a NOR gate is high when both the inputs are low otherwise low.

Logic Symbol



Truth Table

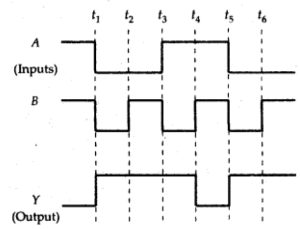
Inputs		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

NAND and NOR Gates as digital building blocks

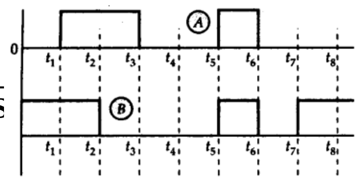
The repeated use of the OR, the AND or the NOT gates alone cannot give a different gate. But the repeated use of the NAND or the NOR gates alone can give all basic gates like OR, AND and NOT gates. Hence the NAND and the NOR gates are also called universal gates.

Subjective Assignment – V

1. Justify the output waveform (*Y*) of the OR gate for inputs (*A*) and (*B*) as given in figure.

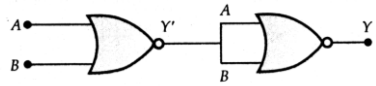


2. Two signals *A* and *B* shown in the figure are used as two input of

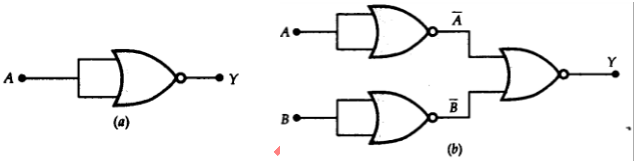


(i) AND gate (ii) NOR gate and (iii) NAND gate
Obtain the output in each of the three cases.

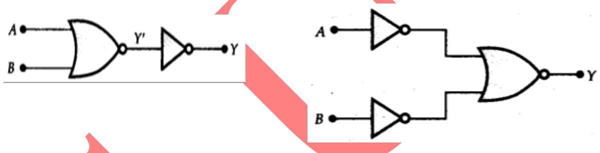
3. Write the truth table for circuit given in figure consisting of NOR gates and identify the logic operation (OR, AND, NOT) which this circuit is performing.



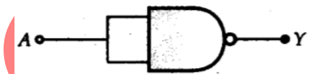
4. Write the truth table for circuit given in figure consisting of Nor gates only. Identify the logic operations (OR, AND, NOT) performed by the two circuits.



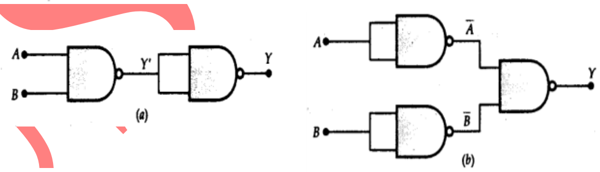
5. You are given the two circuit as shown in figure. Show that the circuit (a) acts as OR gate while the circuit (b) acts as AND gate.



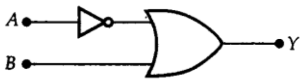
6. Write the truth table for a NAND gate connected as given in figure. Hence identify the exact logic operation carried out by this circuit.



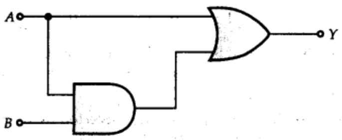
7. You are given two circuits as shown in figure, which consist of NAND gates. Identify the logic operation carried out by the two circuits.



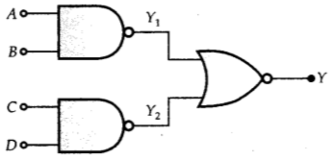
8. Write the Boolean equation and the truth table for the circuit shown in figure. What will be the output if both inputs are high?



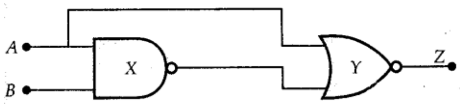
9. Express by a truth table the output Y for all possible inputs A and B in the circuit shown in figure.



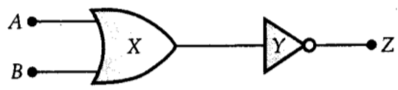
10. Write the Boolean equation and the truth table for the circuit shown in figure. Which input words does the circuit recognize?

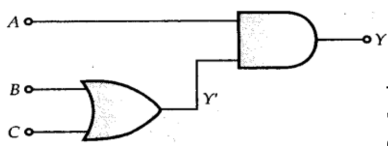


11. Identify the logic gates marked X, Y in the following figure. Write down the output at Z, when $A=1, B=1$ and $A=0, B=1$.

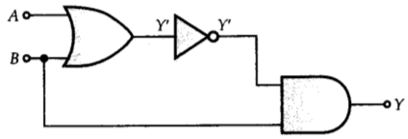


12. Identify the logic gates marked X, Y in the following figure. Write down the output Z, when A = 1, B = 1 and A = 0, B = 0.

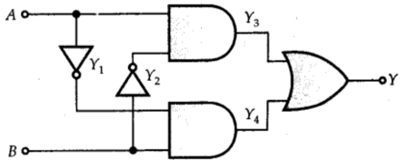




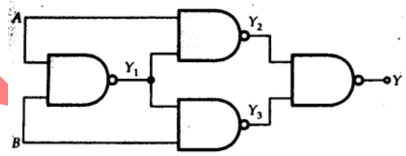
13. Write the Boolean equation and the truth table for the following circuit : If all the inputs are high, what is the output.



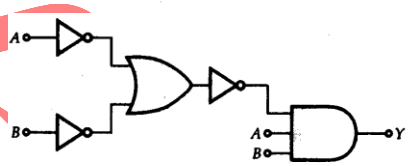
14. Write the truth table for the following circuit :



15. Write the logic table for the following circuit :



16. Write the truth table for the following circuit. Give the name of the resulting gate.



17. Find the output Y of the following circuit if the inputs are : $A=0,\ B=0;\ A=0,\ B=1,\ A=1,\ B=0$; $A=1,\ B=1$.

Integrated Circuits

The conventional circuit formed by connecting resistors, inductors, capacitors, diodes, transistors, etc. together, is called a discrete circuit. The discrete circuits are (i) bulky, (ii) less reliable and (iii) less shockproof. A miniature electronic circuit, consisting of many passive components like R and C and active devices like diode and transistor, fabricated within a single semiconductor chip is called an integrated circuit.

(A) **On the basis of the applications ,** ICs are further classified as follows :

1. Linear ICs. These are used for analog functions.
2. Non–linear ICs. These are used for digital or switching functions.

(B) **On the basis of the method of fabrication :** ICs are classified as follows :

1. **Monolithic ICs :** The most widely used technology is the monolithic integrated circuit. The word : monos means single and lithos means stone. This means that the entire circuit is formed on a single silicon crystal (or chip) as small as 1 mm × 1 mm or even smaller than this size. On the basis of the number of circuit components or logic gates, the monolithic ICs are further classified as follows

(i) Small Scale Integration (*SSI*) circuits. Here the number of logic gates $N \le 10$.
Examples of *SSI* chips are 7400, 7320, etc.

(ii) Medium Scale Integration (*MSI*) circuits. Here $10 < N \le 100$.
Examples are adders, counters, decoders, etc.

(iii) Large Scale Integration (*LSI*) circuits. Here $100 < N \le 100{,}000$.
Examples are Read/Write (*R/W*), Memory, Read Only Memory (*ROM*), Shift registers, etc.

(iv) Very Large Scale Integration (*VLSI*) circuits. Here $100{,}000 < N \le 10^6$.
Examples are micro-processor chips.

(v) Ultra Large Scale Integration (*ULSI*) circuits. Here $N > 10^6$.

2. **Film ICs :** In these ICs, the components like resistors, capacitors and thin film transistors are formed on an insulating substrate.

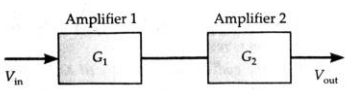
3. **Hybrid ICs :** These ICs consist of combinations of two or more integrated circuits or one integrated circuit and some discrete elements.
4. **Multichip ICs :** In multiple chip, the components are formed on two or more semiconductor chips which are separately attached to a substrate.

Advantages of ICs over conventional discrete circuits

1. ICs are highly compact and weightless.
2. They have high reliability.
3. They are shock-proof.
4. They have lower total cost.
5. They require low power for their operation.
6. They offer improved performance even at high temperatures.

NCERT Exercises

1. In an *n*–type silicon, which of the following statement is true :
(a) Electrons are majority carriers and trivalent atoms are the dopants.
(b) electrons are minority carriers and pentavalent atoms are the dopants.
(c) Holes are minority carriers and pentavalent atoms are the dopant.
(d) Holes are majority carriers and trivalent atoms are the dopants.
2. Which of the statements given in Q.1 is true for *p*-type semindutors?
3. Carbon, silicon and germanium have four valence electrons each. These are characterized by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_{C'}$ $(E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statements is true?
(a) $(E_g)_{Si} < (E_g)_{Ge}$, $(E_g)_C$ (b) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$
(c) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$ (d) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$
4. In an unbiased *p*–*n* junction, holes diffuse from the *p*–region to *n*–region because
(a) free electrons in the *n*–region attract them.
(b) they move across the junction by the potential difference
(c) hole concentration in *p*–type region is more as compared to *n*–region.
(d) All the above
5. When a forward bias is applied to a *p*–*n* junction, it
(a) raises the potential barrier. (b) reduces the majority carrier current to zero
(c) lower the potential barrier (d) none of the above
6. For transistor action, which of the following statements are correct :
(a) Base, emitter and collector regions should have similar size and doping concentrations.
(b) The base region must be very thin and lightly doped
(c) The emitter junction is forward biased and collector junction is reverse biased.
(d) Both the emitter junction as well as ‘collector junction are forward biased.
7. For a transistor amplifier, the voltage gain
(a) remains constant for all frequencies
(b) is high at high and low frequencies and constant in the middle frequency range.
(c) is low at high and low frequencies and constant at mid frequencies.
(d) none of the above.
8. In half–wave rectification, what is the output frequency if the input frequency is 50Hz. What is the output frequency of a full–wave rectifier for the same input frequency?
9. For a CE transistor amplifier, the audio signal voltage across the collector resistance of 2kΩ is 2V. Suppose the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1kΩ.
10. Two amplifiers are connected one after the other in series (cascaded). The first amplifier has a voltage gain of 10 and the second has a voltage gain of 20. If the input signal is 0.01V, calculate the output a.c. signal.



Q.11 A p–n photodiode is fabricated from a semiconductor with a band gap of 2.8 eV. Can it detect a wavelength of 6000 nm?

Q.12 The number of silicon atoms per m^3 is 5×10^{28}. This is doped simultaneously with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} per m^3 atoms of Indium. Calculate the number of electrons and holes. Given that $n_1 = 1.5 \times 10^6\ m^{-3}$. Is the material n–type or p–type?

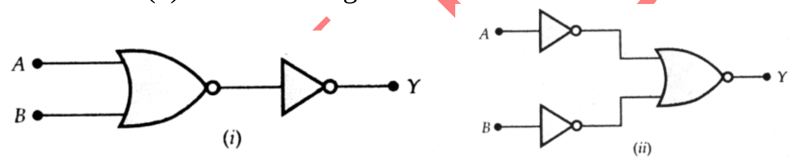
Q.13 In an intrinsic semiconductor, the energy gap E_g is 1.2 eV. Its hole mobility is very much smaller than electron mobility and in independent of temperature. What is the ratio between conductivity at 600 K and that at 300 K? Assume that the temperature dependence of intrinsic carrier concentration n_1 is expressed as $n_i = n_0 \exp\left[\frac{-E_g}{2k_BT}\right]$

where n_0 is a constant and $k_B = 8.62 \times 10^{-5}\ eVK^{-1}$ is the Boltzmann constant.

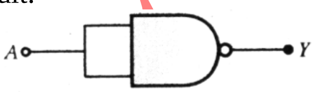
Q.14 In a p–n junction diode, the current I can be expressed as $I = I_0 \exp\left(\frac{eV}{2k_BT} - 1\right)$, where I_0 is called the reverse saturation current, V is the voltage across the diode and is positive for forward bias and negative for reverse bias, and I is the current through the diode, k_B is the Boltzmann constant (8.6×10^{-5} eV/K) and T is the absolute temperature. If for a given diode $I_0 = 5 \times 10^{-12}$ A and T = 300 K, then:

(a) What will be the forward current at a forward voltage of 0.6 V?
(b) What will be the increase in the current if the voltage across the diode is increased to 0.7 V?
(c) What is the dynamic resistance?
(d) What will be the current if reverse bias voltage changes from 1 V to 2 V?

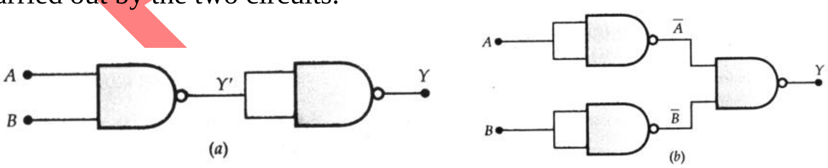
Q.15 You are given the two circuits the two circuits as shown in figure. Show that the circuit (a) acts as OR gate while the circuit (b) acts as AND gate.



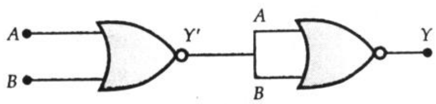
Q.16 Write the truth table for a NAND gate connected as given in figure. Hence identify the exact logic operation carried out by this circuit.



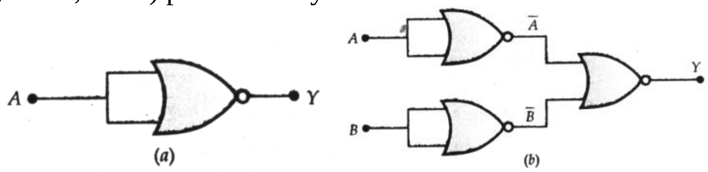
Q.17 You are given two circuits as shown in figure, which consist of NAND gates. Identify the logic operation carried out by the two circuits.



Q.18 Write the truth table for circuit given in figure, below consisting of NOR gates and identify the logic operation (OR, AND, NOT) which this circuit is performing.



Q.19 Write the truth table for circuit given in figure consisting of NOR gates only. Identify the logic operations (OR, AND, NOT) performed by the two circuits.



Answers

1. c	2. d	3. c	4. c	5. c
6. b, c	7. c	8. 50 Hz, 100 Hz	9. 0.01 V, 10 μA	10. 2 V
11. cannot detect	12. $n_e = 4.95 \times 10^{22}\ m^{-3}$, $n_h = 4.5 \times 10^{19}\ m^{-3}$		13. 1×10^5	

14. (a) 0.063 A, (b) 2.97 A, (c) 0.0336 Ω, (d) -5×10^{-12} A

Conceptual Assignment

Q.1 Why does a semiconductor get damaged when a heavy current flows through it?

Q.2 Why does a potential barrier set up across a junction diode?

Q.3 Can we measure the potential difference of a p–n junction by connecting a sensitive voltmeter across its terminals?

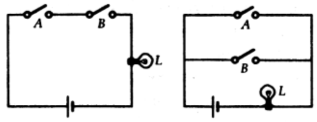
Q.4 Why does the width of depletion layer of a p–n junction increases in reverse biasing?

Q.5 What happens in a transistor when both the emitter and collector are reverse biased? What is this condition known as?

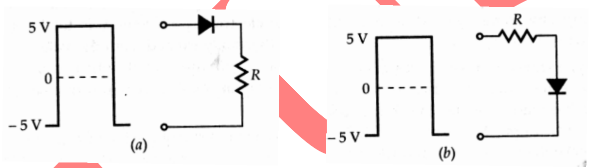
Q.6 What happens in a transistor when both the emitter and collector are forward biased? How will the collector current change if the emitter voltage is slightly increased?

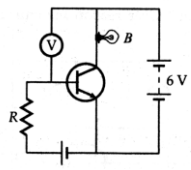
Q.7 If the emitter and the base of a transistor have same doping concentration, how will the base current and collector current be affected?

Q.8 In the circuits shown in figure, a switch which is open represents the logic state 0 and the switch which is closed represents the logic state 1. The lamp L is lit when output is logic state 1. What types of gate are represented by the circuits in (a) and (b)?



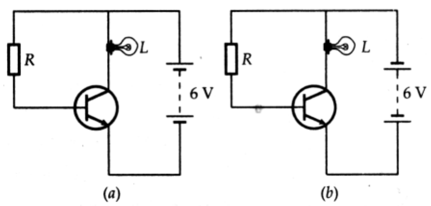
Q.9 In the following diagrams, indicate which of the diodes are forward biased and which are reverse biased.





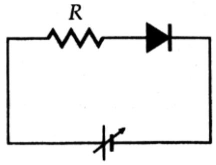
Q.10 Name the type of biasing which results in very high resistance of a p – n junction diode. In the given circuit, a voltmeter 'V' is connected across a bulb 'B'. What changes would occur in bulb 'B' and voltmeter 'V', if the resistor 'R' is increased in value? Give reason for your answer.

Q.11 In only one of circuits given below the lamp L lights. Which circuit is it? Give reason for your answer.



Q.12 Assume that the silicon diode in the circuit shown in figure requires a minimum current of 1 mA to be above the knee point (0.7 V) of its I – V characteristics. Also assume that voltage across the diode is independent of current above the knee point.

(a) If V_B = 5V, what should be the maximum value of R so that the voltage is above the knee point?



(b) If V_B = 5V, what should be the value of R to establish the current of 5 mA in the circuit?

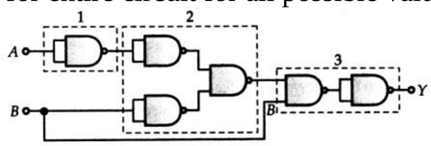
(c) What is the power dissipated in the resistance R and in the diode, when a current of 5 mA flows in the circuit at V_B = 6V?

(d) If R = 1kΩ, what is the minimum voltage V_B required to keep the diode above the knee point?

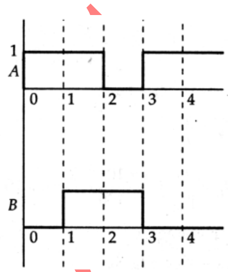
Q.13 A potential barrier of 0.50 V exists in a p–n junction. (i) If the depletion region is 5.0×10^{-7} m thick, what is the electric field in this region? (ii) If an electron approaches the p–n junction from the n–side with a speed of 5×10^{-7} ms^{-1}, with what speed will it enter the p–side?

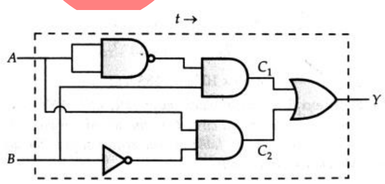
Q.14 An n–p–n transistor in a common–emitter mode is used as a simple voltage–amplifier with a collector–current of 4mA. The terminal of a 8–V battery is connected to the collector through a load–resistance R_L and to the base through a resistance R_B. The collector emitter voltage V_{CE} = 4 V, the base emitter voltage V_{BE} = 0.6 V and the current amplification factor β_{dc} = 100. Calculate the values of R_L and R_B.

Q.15 Identify which basic gate, OR, AND and NOT is presented by the circuits in the dotted line boxes 1, 2 and 3. Give the truth table for entire circuit for all possible values of A and B.



Q.16 Input signals A and B are applied to the input terminals of the 'dotted box' set–up show here. Let Y be the final output signal form the box. Draw the waveforms of the signals labeled as C_1 and C_2 within the box, giving (in brief) the reasons getting these waveforms. Hence draw the waveform of the final output signal Y. Give reasons for your choice.





What can we state (in words) as relation between the final output signal Y and input signals A and B?

Answers

8. (i) AND, (ii) OR

9.(i) forward biased, (ii) reverse biased, (iii) reverse biased, (iv) forward biased

10. decreases

11. circuit a

12. (a) 4.3×10^3 Ω, (b) 860 Ω, (c) P_R = 26.5 mW, P_D = 3.5 mW, (d) 1.7 V

13. (i) 1.0×10^6 Vm^{-1}, (ii) 2.7×10^5 ms^{-1}

14. R_L = 1 kΩ, R_B = 185 kΩ

15. NOT gate, OR gate, AND gate

IIT–JEE Objective Assignment

Multiple Choice Questions with One Correct Answer

Q.1 Probability of electrons to be found in conduction band of an intrinsic semiconductor at a finite temp.

(a) increases exponentially with increasing band gap
(b) decreases exponentially with increasing band gap
(c) decreases with increasing temperature
(d) is independent of the temperature and the band gap

Q.2 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

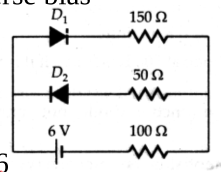
(a) 0.9 (b) 0.7 (c) 0.5 (d) 1.1

Q.3 Which of the following statements is not true?

(a) the resistance of intrinsic semiconductor decreases
(b) doping pure Si with trivalent impurities gives p–type semiconductors
(c) the majority carriers in n–type semiconductors are holes
(d) A p–n junction can act as a semiconductor diode

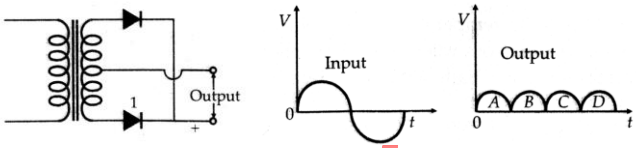
Q.4 The dominant mechanisms for motion of charge carriers in forward and reverse biased silicon p–n junctions are
(a) drift in forward bias, diffusion in reverse bias (b) diffusion in forward bias, drift in reverse bias
(c) diffusion in both forward and reverse bias (d) drift in both forward and reverse bias

Q.5 The circuit shown in the figure contains two diodes each with a forward resistance of 50 ohm and with infinite backward resistance. If the battery voltage is 6 V, the current through the 100 ohm resistance (in ampere) is



(a) zero (b) 0.02 (c) 0.03 (d) 0.036

Q.6 A full wave rectifier circuit alongwith the output is shown in figure. The contribution(s) from the diode is (are)



(a) C (b) A, C (c) B, D (d) A, B, C, D

Multiple Choice questions with One or More than One Correct Answers

Q.7 Holes are charge carrier in
(a) intrinsic semiconductors (b) ionic solids
(c) p–type semiconductors (d) metals

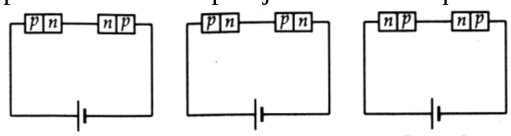
Q.8 The impurity atoms, with which pure silicon should be doped to make a p–type semiconductor, are those of
(a) phosphorus (b) boron (c) antimony (d) aluminium

Q.9 When a potential difference is applied across, the current passing through
(a) an insulator at 0 K is zero (b) a semiconductor 0 K is zero
(c) a metal at 0 K is finite (d) a p–n diode at 300 K is finite, if it is reverse biased

Q.10 In a p–n junction diode, not connected to any circuit
(a) the potential is the same everywhere
(b) the p–type side is at a higher potential than the n–type side
(c) there is an electric field at the junction directed from the n–type side to the p–type side
(d) there is an electric field at the junction directed from the p–type side to the n–type side

Q.11 In an n–p–n transistor circuit, the collector current is 10 mA. If 90% of the electrons emitted reach the collector,
(a) the emitter current will be 9 mA (b) the base current will be 1 mA
(c) the emitter current will be 11 mA (d) the base current will be –1 mA

Q.12 Two identical p–n junctions may be connected in series with a battery in three ways, as shown in figure. The potential drops across the two p–n junctions are equal in



Circuit 1 Circuit 2 Circuit 3

(a) circuit 1 and circuit 2 (b) circuit 2 and circuit 3
(c) circuit 3 and circuit 1 (d) circuit 1 only

Q.13 A transistor is used in the common emitter mode as an amplifier. Then
(a) the base–emitter junction is forward–biased (b) the base–emitter junction is reverse–biased

(c) the input signal is connected in series with the voltage applied to bias the base–emitter junction
(d) the input signal is connected in series with the voltage applied to bias the base–collector junction

Q.14 Select the correct statement from the following:
(a) a diode can be used as a rectifier (b) a triode cannot be used as a rectifier
(c) the current in a diode is always proportional to the applied voltage
(d) the linear portion of the 1–V characteristic of a triode is used fro amplification without distortion

Answers

1.	b	2.	c	3.	c	4.	b	5.	b
6.	b	7.	a, c	8.	b, d	9.	a, b, d	10.	c
11.	b, c	12.	b	13.	c	14.	a		

AIEEE Objective Assignment

Q.1 The manifestation of bond structure in solids is due to
(a) Heisenberg's uncertainty principle (b) Pauli's exclusion principle
(c) Bohr's correspondence principle (d) Boltzmann's law

Q.2 The energy band gap is maximum in
(a) metals (b) superconductors (c) insulators (d) semiconductors

Q.3 At absolute zero, Si acts as
(a) non–metal (b) metal (c) insulator (d) none of these

Q.4 A piece of copper & another of germanium are cooled from room temperature to 77 K. The resistance of
(a) each of these decreases
(b) copper strip increases and that of germanium decreases
(c) copper strip decreases and that of germanium increases
(d) each of these increase

Q.5 Carbon, silicon and germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate?
(a) the number of free electrons for conduction is significant only in Si and Ge but small in C
(b) the number of free conduct ion electrons is significant in C but small in Si and Ge
(c) the number of free conduction electrons is negligibly small in Si and Ge
(d) the number of free electrons for conduction is significant in all the three

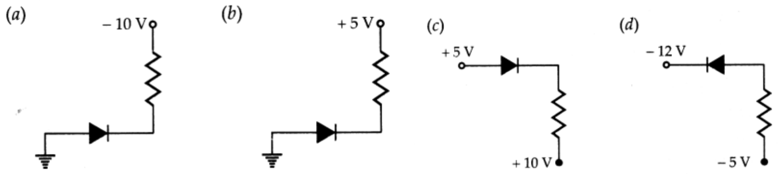
Q.6 The electrical conductivity of a semiconductor increases, when electromagnetic radiation of wavelength length shorter than 2480 nm is incident on it. The band gap in (eV) for the semiconductor is
(a) 1.1 eV (b) 2.5 eV (c) 0.5 eV (d) 0.7 eV

Q.7 If the ratio of the concentration of electrons to that of holes in a semiconductor is 7/5 and the ratio of currents is 7/4, then what is the ratio of their drift velocities?
(a) 5/8 (b) 4/5 (c) 5/4 (d) 4/7

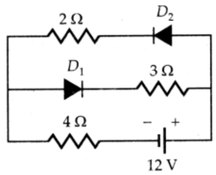
Q.8 In the middle of the depletion layer of reverse biased p–n junction, the
(a) electric field is zero (b) potential is zero
(c) potential is maximum (d) electric field is maximum

Q.9 When p–n junction diode is forward biased, then
(a) the depletion region is reduced and barrier height is increased
(b) the depletion region is widened and barrier height is reduced
(c) both the depletion region and barrier height are reduced
(d) both the depletion region and barrier height are increased

Q.10 In the following figures, which one of the diodes is reverse biased?

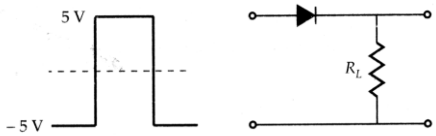


Q.11 The circuit has two oppositely connected ideal diodes in parallel. What is current flowing in the circuit?

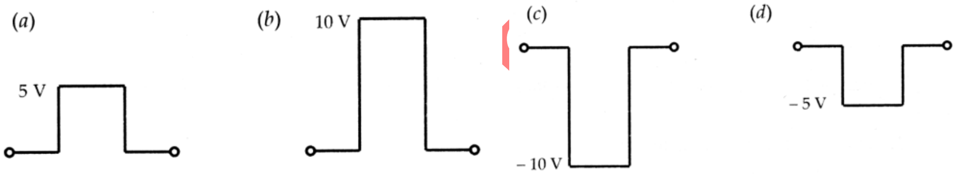


(a) 1.71 A (b) 2.0 A (c) 2.31 A (d) 1.33 A

Q.12 If in a p–n junction, a square input signal of 10 V is applied as shown,



then the output across R_L will be



Q.13 In a full wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be

(a) 50 Hz (b) 25 Hz (c) 100 Hz (d) 70.7 Hz

Q.14 The part of a transistor, which is heavily doped to produce a large number of majority carriers, is called

(a) emitter (b) base (c) collector

(d) any one out of emitter, base and collector

Q.15 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 one of the following is true for the transistor?

(a) it is an n–p–n transistor with R as collector (b) it is an n–p–n transistor w2ith R as base

(c) it is a p–n–p transistor with R as collector (d) it is a p–n–p transistor with R as emitter

Q.16 When n–p–n transistor is used as an amplifier, then

(a) electrons move from base to collector (b) holes move from emitter to base

(c) electrons move from collector to base (d) holes move form base to emitter

Q.17 In a common–base amplifier, the phase difference between the input signal voltage and the output voltage (across collector and base) is

(a) 0 (b) $\pi/4$ (c) $\pi/2$ (d) π

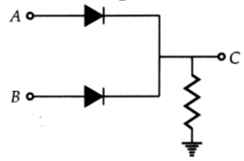
Q.18 In a common–base mode of a transistor, the collect or current is 5.488 mA for an emitter current of 5.60A. The value of the base current amplification factor (β) will be

(a) 49 (b) 50 (c) 51 (d) 48

Q.19 For a transistor amplifier in common emitter configuration for a load impedance of 1 kΩ ($h_{fe} = 50$; $h_{oe} = 25\ \mu V^{-1}$), the current gain is

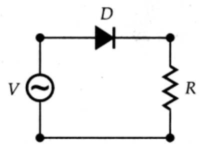
(a) – 5.2 (b) – 15.7 (c) – 24.8 (d) – 48.78

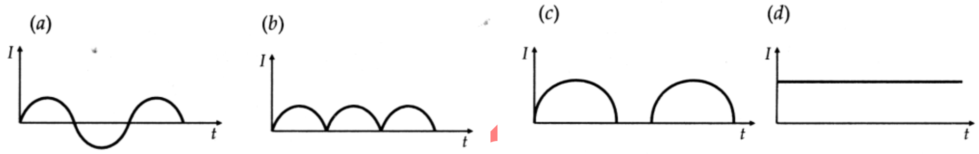
Q.20 In the circuit below, A and B represent two inputs and C represents the output. The circuit represents



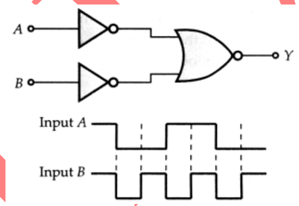
(a) OR gate (b) NOT gate (c) AND gate (d) NAND gate

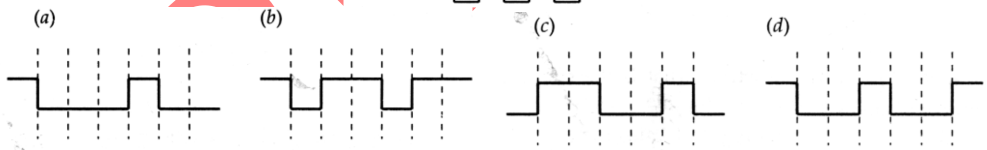
Q.21 A p–n junction(D) shown in the figure can act as a rectifier. An alternating current source (V) is connected in the circuit.





Q.22 The logic circuit shown below has the input waveforms 'A' and 'B' as shown. Pick out the correct output waveform.





Answers

1.	a	2.	b	3.	c	4.	c	5.	a
6.	c	7.	c	8.	a	9.	c	10.	b
11.	b	12.	a	13.	c	14.	a	15.	a
16.	a	17.	a	18.	a	19.	d	20.	a
21.	c	22.	A						

AIIMS Objective Assignment

Q.1 Crystalline solids are
(a) anisotropic (b) isotropic (c) amporphus (d) none of these

Q.2 Which of the following is an amorphous solid?
(a) glass (b) diamond (c) salt (d) sugar

Q.3 Energy required to break one bond in DNA is approximately
(a) ≈ 1 eV (b) ≈ 0.1 eV (c) ≈ 0.01 eV (d) ≈ 2.1 eV

Q.4 An intrinsic semiconductor, at the absolute zero temperature, behaves like a/an

(a) insulator (b) superconductor
(c) n–type semiconductor (d) p–type semiconductor

Q.5 In a semiconducting material the mobilities of electrons and holes are μ_e and μ_h respectively. Which of the following is true?
(a) $\mu_e > \mu_h$ (b) $\mu_e < \mu_h$ (c) $\mu_e = \mu_h$ (d) $\mu_e < 0$; $\mu_h > 0$

Q.6 A Ge specimen is doped with Al. The concentration of acceptor atoms is $\approx 10^{21}$ atoms m^{-3}. Given that the intrinsic concentration of electron–hole pair is $\approx 10^{19}$ m^{-3}, the concentration of electrons in the specimen is
(a) 10^{17} m^{-3} (b) 10^{15} m^{-3} (c) 10^{4} m^{-3} (d) 10^{2} m^{-3}

Q.7 In a pure semiconductor crystal, if current flows due to breakage of crystal bonds, then the semi–conductor is called
(a) acceptor (b) donor
(c) intrinsic semiconductor (d) extrinsic semiconductor

Q.8 What of the following, when added as an impurity, into the silicon, produces n–type semi–conductor?
(a) phosphorous (b) aluminium (c) magnetism (d) both (b) and (c)

Q.9 In n–type semiconductors, majority charge carriers are
(a) holes (b) protons (c) neutrons (d) electrons

Q.10 In p–type semiconductor,
(a) major current carrier are electrons (b) major carrier are mobile negative ions
(c) major carrier are mobile holes
(d) the number of mobile holes exceeds the number of acceptor atoms

Q.11 A small impurity is added to germanium to get p–type semiconductor. This impurity is a
(a) bivalent substance (b) trivalent substance
(c) pentavalent substance (d) monovalent substance

Q.12 To a germanium sample, traces of gallium are added as an impurity. The resultant sample would behave like
(a) a conductor (b) a p–type semiconductor
(c) an n–type semiconductor (d) an insulator

Q.13 The potential barrier in the depletion layer is due to
(a) ions (b) holes (c) electrons (d) forbidden band

Q.14 What accounts for the flow of charge carriers in forward and reverse biasing of silicon p–n diode?
(a) drift in forward bias and diffusion in reverse bias
(b) drift in reverse bias and diffusion in forward bias
(c) drift in both reverse and forward bias (d) diffusion in both forward and reverse bias

Q.15 When a p–n diode is reverse biased, then
(a) no current flows (b) the depletion is region is increased
(c) the depletion region is reduced (d) the height of the potential barrier is reduced

Q.16 If a p–n diode is reverse biased, then the resistance measured by an ohmmeter, will be
(a) zero (b) low (c) high (d) infinite

Q.17 Diode is used as a/an
(a) oscillator (b) amplifier (c) rectifier (d) modulator

Q.18 In the half wave rectifier circuit operating from 50 Hz main frequency, the fundament frequency in the ripple would be
(a) 25 Hz (b) 50 Hz (c) 70.7 Hz (d) 100 Hz

Q.19 Zener diode acts as a/an
(a) oscillator (b) regulator (c) rectifier (d) filter

Q.20 A light emitting diode (LED) has a voltage drop of 2 V across it and passes a current of 10 mA when it operates with a 6V battery through a limiting resistor R. The value of R is
(a) $40\ k\approx\Omega$ (b) $4\ k\Omega$ (c) $200\ \Omega$ (d) $400\ \Omega$

Q.21 A transistor is a/an

(a) chip (b) insulator (c) semiconductor (d) metal

Q.22 The minimum potential difference between the base and emitter required to switch a silicon transistor ON is approximately

(a) 1 V (b) 3 V (c) 5 V (d) 4.2 V

Q.23 When n–p–n transistor is used as an amplifier, then

(a) holes move from emitter to base (b) electrons move from base to collector

(c) holes move from base to emitter (d) electrons move from collector to base

Q.24 The current gain for a transistor working as common–base amplifier is 0.96. If the emitter current is 7.2 mA, then the base current is

(a) 0.29 mA (b) 0.35 mA (c) 0.39 mA (d) 0.43 mA

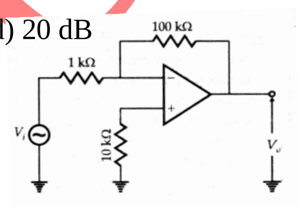
Q.25 Consider an n–p–n transistor amplifier in common–emitter configuration. The current gain of the transistor is 100. If the collector current changes by 1 mA, what will be the change in emitter current?

(a) 1.1 mA (b) 1.01 mA (c) 0.01 mA (d) 10 mA

Q.26 An amplifier has voltage gain = 1000. The voltage gain (in dB) is

(a) 30 dB (b) 60 dB (c) 3 dB (d) 20 dB

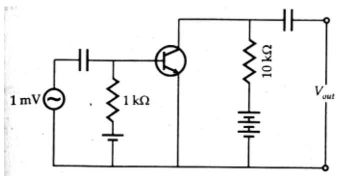
Q.27 The voltage gain of the following amplifier is



(a) 10 (b) 100

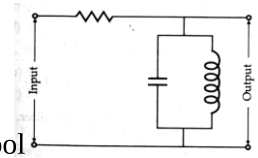
(c) 1000 (d) 9.9

Q.28 In the following common emitter configuration an n–p–n transistor with current gain = 100 is used. The output voltage of the amplifier will be



(a) 10 mV (b) 0.1 V (c) 1.0 V (d) 10 V

Q.29 The circuit shown below acts as



(a) tuned filter (b) low pass filter

(c) high pas filter (d) rectifier

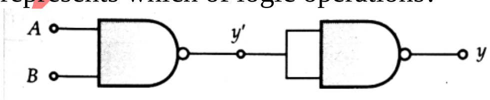
Q.30 Boolean algebra is essentially based on

(a) logic (b) truth (c) numbers (d) symbol

Q.31 The number (0) zero is required for

(a) transistor (b) abacus (c) computer (d) calculator

Q.32 The circuit given below represents which of logic operations?



(a) AND (b) NOT (c) OR (d) NOR

Q.33 Which of the following logic gates is a universal gate?

(a) OR (b) NOT (c) AND (d) NAND

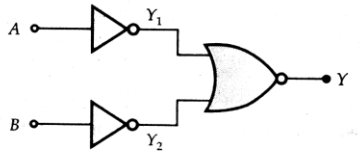
Q.34 A certain logic circuit has A and B as the two inputs and y as the output. What is the logic gate in the circuit, if the truth table of the circuits is as shown

A	B	y
0	0	0
1	0	1
0	1	1
1	1	0

(a) OR (b) NAND

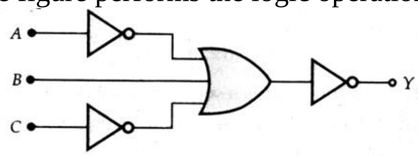
(c) XOR (d) NOR

Q.35 Which logic gate is represented by the following combination of logic gates?



(a) OR (b) NND (c) AND (d) NOR

Q.36 The logic circuit given in the figure performs the logic operation



(a) ABC (b) $AB\overline{C}$ (c) $A\overline{B}C$ (d) $\overline{A}B\overline{C}$

Answers

1.	a	2.	a	3.	a	4.	a	5.	a
6.	a	7.	c	8.	a	9.	d	10.	b
11.	b	12.	b	13.	a	14.	b	15.	b
16.	c	17.	c	18.	b	19.	b	20.	d
21.	c	22.	a	23.	b	24.	a	25.	b
26.	b	27.	b	28.	c	29.	a	30.	a
31.	c	32.	a	33.	d	34.	c	35.	c
36.	c								

Objective Assignment – IV

Q.1 p–n junction is said to be forward biased, when
(a) the positive pole of the battery is joined to the p–semiconductor and negative pole to the n–semiconductor
(b) the positive pole of the battery is joined to the n–semiconductor and p–semiconductor
(c) the negative pole of the battery is connected to n–semiconductor and p–semiconductor
(d) a mechanical force is applied in the forward direction

Q.2 The depletion layer in the p–n junction region is caused by
(a) drift of holes (b) diffusion of charge carriers
(c) migration of impurity ions (d) drift of electrons

Q.3 The cause of the potential barrier in a p–n diode is
(a) depletion of negative charges near the junction
(b) concentration of positive charges near the junction (c) depletion of positive charges near junction
(d) concentration of positive and negative charges near the junction

Q.4 In the depletion region of an unbiased p–n junction diode, there are
(a) holes (b) mobile ions (c) electrons (d) immobile ions

Q.5 In an unbiased p–n junction,
(a) high potential at n side and low potential at p side
(b) high potential at p side and low potential at n side
(c) p and n both are at same potential (d) undetermined

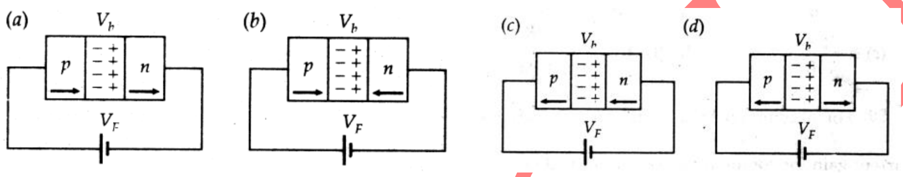
Q.6 In forwarded bias, the width of potential barrier in a p–n junction diode
(a) remains constant (b) decreases (c) increases (d) first (a) then (b)

Q.7 Reverse bias applied to a junction diode
(a) lowers the potential barrier
(b) raises the potential barrier
(c) increases the majority carrier current
(d) increase the minority carrier current

Q.8 Application of a forward bias to p–n junction
(a) widens the depletion zone
(b) increase the potential difference across the depletion zone
(c) increases the number of donors on the n side
(d) decreases the electric field in the depletion zone

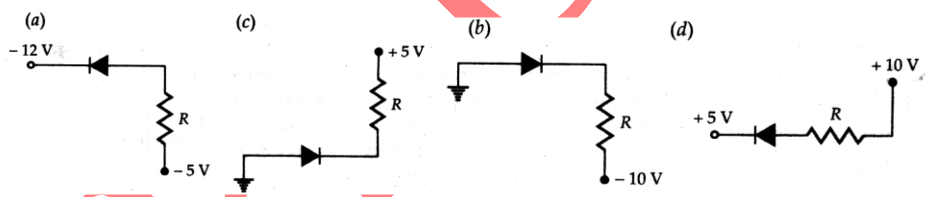
Q.9 Barrier potential of a p–n junction diode does not depend on
(a) diode design (b) temperature (c) forward bias (d) doping density

Q.10 In the case of forward biasing of p–n junction, which one of the following figures correctly depicts the direction of flow of carriers?



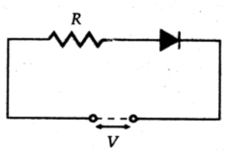
Q.11 A semiconducting device is connected in a series circuit with a battery and a resistance. A current is found to pass through the circuit. If the polarity of the battery is reversed, the current drops to almost zero. The device may be
(a) a p–type semiconductor
(b) an intrinsic semiconductor
(c) a p–n junction
(d) an n–type semiconductor

Q.12 Of the diodes shown in the following diagrams, which one is reverse biased?

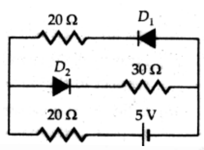


Q.13 A forward biased diode is

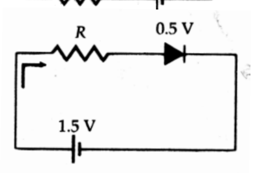
Q.14 For a given circuit of ideal p–n junction diode, which of the following is correct?
(a) in forward bias the voltage across R in V
(b) in reverse bias the voltage across R in V
(c) in forward bias the voltage across R in 2V
(d) in reverse bias the voltage across R in 2V



Q.15 The current in the circuit will be
(a) 5/40 V (b) 5/50 V
(c) 5/10 V (d) 5/20 A



Q.16 The diode used in the circuit shown in the figure has a constant voltage drop at 0.5 V at all currents and a maximum power rating of 100 milliwatts. What should be the value of the resistor R, connected in series with diode for obtaining maximum current?
(a) 6.76 Ω (b) 20 Ω (c) 5 Ω (d) 5.6 Ω



Q.17 If a full wave rectifier circuit is operating from 50 Hz mains, the fundamental frequency in the ripple will be
(a) 25 Hz (b) 50 Hz (c) 70.7 Hz (d) 100 Hz

Q.18 The peak voltage in the output of a half wave diode rectifier fed with a sinusoidal signal without filter is 10 V. The d.c. component of the output voltage is
(a) $10/\sqrt{2}\ V$ (b) 10 π/V (c) 10 V (d) 20/πV

Q.19 A p–n junction diode can be used as
(a) condenser (b) regulator (c) amplifier (d) rectifier

Q.20 Zener diode is used for
(a) amplification (b) rectification (c) stabilization
(d) producing oscillations in an oscillator

Q.21 In a p–n junction photocell, the value of the photo–electromotive force produced by monochromatic light is proportional to
(a) the barrier voltage at the p–n junction (b) the intensity of the light falling on the cell
(c) the frequency of the light falling on the cell (d) the voltage applied at the p–n junction

Q.22 An n–p–n transistor conducts when
(a) both collector and emitter are positive with respect to the base
(b) collector is positive and emitter is negative with respect to the base
(c) collector is positive and emitter is at same potential as the base
(d) both collector and emitter are negative with respect to the base

Q.23 To use a transistor as an amplifier
(a) the emitter base junction is forward biased and the base collector junction is reverse biased
(b) no bias voltage is required
(c) both junctions are forward biased (d) both junctions are reverse biased

Q.24 When n–p–n transistor is used as an amplifier, then
(a) electrons move from collector to base (b) holes move from base to emitter
(c) electrons move from base to collector (d) electrons move from emitter to base

Q.25 The correct relationship between the two current gains α and β in a transistor is
(a) $\alpha=\frac{\beta}{1+\beta}$ (b) $\alpha=\frac{1+\beta}{\beta}$ (c) $\beta=\frac{\alpha}{1+\alpha}$ (d) $\beta=\frac{\alpha}{\alpha-1}$

Q.26 The correct relation for α, β for a transistor is
(a) $\beta=\frac{1-\alpha}{\alpha}$ (b) $\beta=\frac{\alpha}{1-\alpha}$ (c) $\alpha=\frac{\beta-1}{\beta}$ (d) αβ = 1

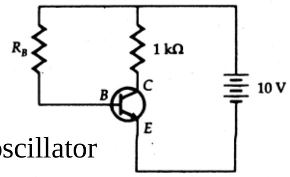
Q.27 For a common base circuit it $\frac{I_C}{I_E}=0.98$, then current gain for common emitter circuit will be
(a) 49 (b) 98 (c) 4.9 (d) 25.5

Q.28 A common emitter amplifier has a voltage gain of 50, an input impedance of 100 Ω and an output impedance of 200Ω. The power gain of the amplifier is
(a) 1000 (b) 1250 (c) 100 (d) 500

Q.29 A transistor is operated in common emitter configuration at constant collector voltage V_C = 1.5 V such that a change in the base current from 100 μA to 150 μA produces a change in the collector current from 5 mA to 10 mA. The current gain β is
(a) 50 (b) 67 (c) 75 (d) 100

Q.30 The transfer ratio β of a transistor is 50. The input resistance of the transistor when used in the common–emitter configuration is 1 kΩ. The peak value of the collector A.C. current for an A.C. input voltage of 0.01 V peak is
(a) 0.25 mA (b) 0.01 mA (c) 100 μA (d) 500 μA

Q.31 In the circuit shown, the transistor used has a current gain β = 100. What should be the bias resistor R_B, so that V_{CE} = 5V? Neglect V_{BE}.



(a) $200 \times 10^{-3}\ \Omega$ (b) $10^6\ \Omega$

(c) 500 Ω (d) $2 \times 10^5\ \Omega$

Q.32 Radiowaves of constant amplitude can be generated with

(a) FET (b) filter (c) rectifier (d) oscillator

Q.33 An oscillator is an amplifier with

(a) a large gain (b) negative feedback (c) positive feedback (d) no feedback

Q.34 A transistor oscillator using a resonant circuit with an inductor L (or negligible resistance) and a capacitor C in series produces oscillations of frequency f. If L is doubled and C is changed to 4C, the frequency will be

(a) f/2 (b) f/4 (c) 8 f (d) $f/2\sqrt{2}$

Q.35 The output of OR gate is 1

(a) if both inputs are zero (b) if either or both inputs are 1

(c) only if both inputs are 1 (d) if either input is zero

Q.36 The following truth table corresponds to the logical gate

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

(a) NAND (b) OR

(c) AND (d) XOR

Q.37 The following truth–table belongs to which one of the following four gates?

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

(a) XOR (b) NOR

(c) OR (d) NAND

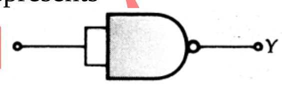
Q.38 The given truth table is for which logic gate

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

(a) NAND (b) XOR

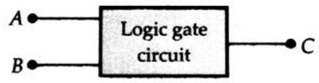
(c) NOR (d) OR

Q.39 The symbol shown in the figure represents



(a) NOT gate (b) OR gate (c) AND gate (d) NOR gate

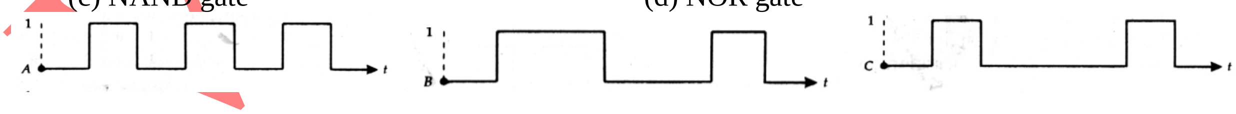
Q.40 The following figure shows a logic gate circuit with two inputs A and B and the output C. The voltage waveforms of A, B and C are as shown below:



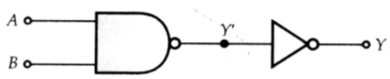
The logic circuit gate is

(a) OR gate (b) AND gate

(c) NAND gate (d) NOR gate

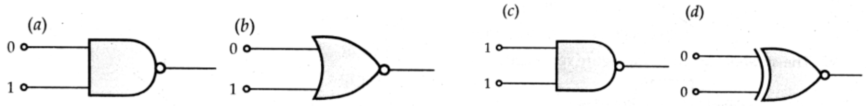


Q.41 Following diagram performs the logic function of

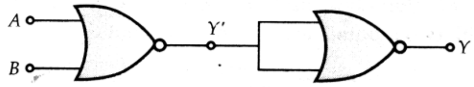


(a) AND gate (b) NAND gate (c) OR gate (d) XOR gate

Q.42 Which of the following gates will have an output of 1?



Q.43 In the following circuit, the output Y for all possible inputs A and B is expressed by the truth table.



(a)

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

(b)

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

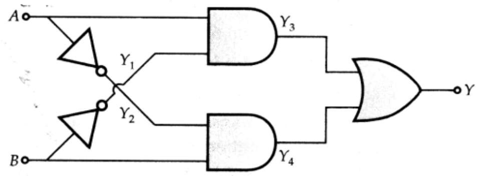
(c)

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

(d)

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

Q.44 Which true table is true is true for the following circuit:



(a)

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

(b)

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

(c)

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

(d)

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

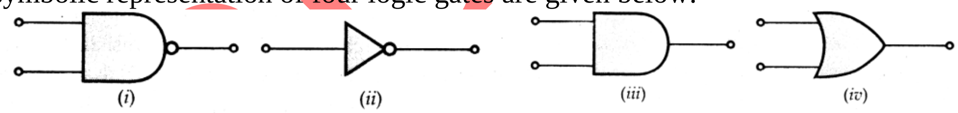
Q.45 A transistor is operated in common–emitter configuration at V_C = 2V such that a change in the base current from 100 μA to 200μA produces a change in the collector current from 5m to 10 mA. The current gain is

(a) 100 (b) 150 (c) 50 (d) 75

Q.46 A p–n photodiode is fabricated from a semiconductor with a band gap of 2.5 eV. It can detect a signal of wavelength

(a) 4000 nm (b) 6000 nm (c) 4000 Å (d) 6000 Å

Q.47 The symbolic representation of four logic gates are given below:



The logic symbols for OR, NOT and NAND gates are respectively:

(a) (iv), (i) & (iii) (b) (iv), (ii) & (i) (c) (i), (iii) & (iv) (d) (iii), (iv) & (ii)

Answers

1.	a	2.	b						
3.	d	4.	d	5.	a	6.	b	7.	b
8.	d	9.	a	10.	b	11.	c	12.	c
13.	a	14.	a	15.	b	16.	c	17.	d
18.	b	19.	d	20.	c	21.	b	22.	c
23.	a	24.	c	25.	a	26.	b	27.	a
28.	b	29.	d	30.	d	31.	d	32.	d
33.	c	34.	d	35.	b	36.	b	37.	b
38.	a	39.	a	40.	b	41.	a	42.	a
43.	c	44.	a	45.	c	46.	c	47.	b

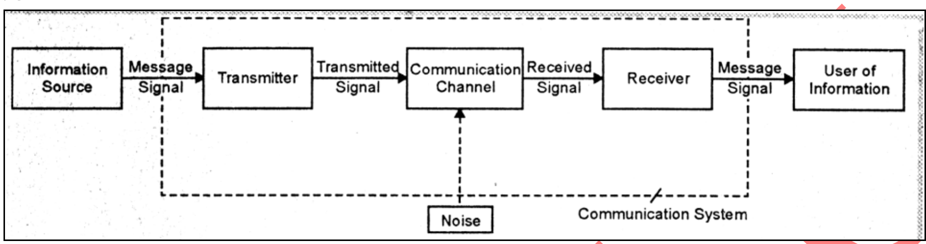
9. C **10.** D **11.** C **12.** A **13.** C

COMMUNICATION

Elements of Communication System

A communication system is the *set–up* used in the transmission and reception of information from one place to another. The present day communication systems are electrical, electronic or optical in nature. In principle, every communication system has the following three essential elements:

1. Transmitter
2. Communication Channel
3. Receiver



Basic Terminology used in Electronic Communication Systems

1. **Signal:** It is a single valued function of time that carries the information. It is usually in electrical form and is suitable for transmission. Signals can be analog or digital.
2. **Transducer:** Any device/arrangement that converts one form of energy into another is called a transducer. For example, *a microphone* converts speech signals into electrical signals. Similarly a *piezoelectric sensor* converts pressure variations into electrical signals. Again, a *photo detector* convert light signals into electrical signals.

   The devices like microphone, piezoelectric sensors and photo detectors, which convert a physical quantity (called information here) into electrical signals are called transducers. On the contrary, *a loud speaker* which converts electrical signals into sound waves is a transducer. Thus *a transducer provides output in electrical form or it has input in electrical form.*
3. **Noise:** It refers to the disturbance or distortion in the transmission and processing of message signals in a communication system. The noise may be due to channel imperfection or some sources inside or outside the system.
4. **Transmitter:** A transmitter is an arrangement that converts the message signals to a form suitable for transmission and then transmits it through some suitable communication channel.
5. **Receiver:** A receiver is an arrangement that picks up the transmitted signals at the channel output and processes it to reproduce the message signal in the suitable form.
6. **Attenuation:** Refers to the loss of strength of a signal during its propagation through the communication channel.
7. **Amplification**: It is the process of increasing the strength of the transmitted signal using some suitable electronic circuit. Amplification compensates for the attenuation of the signal. It can be done anywhere between the transmitter and receiver when signal strength becomes weaker than the required strength The energy required for additional signal strength is obtained from a d.c. power source.
8. **Range:** It is the largest distance between the transmitter and receiver where the signal is received in due strength.
9. **Band width:** Band width refers usually to the range of frequencies over which the communication system works.
10. **Modulation:** It is the most important step in communication. Modulation is the phenomenon of superimposing the low frequency message signal (called the **modulating signal)** on a high

frequency wave (called the **carrier wave).** The resulting wave is called the **modulated wave,** which is transmitted.

11. **Demodulation:** It is the reverse process of modulation. Demodulation is the phenomenon of retrieval of information from the modulated wave at the receiver.

12. **Repeater:** Repeaters are erected at suitable locations in between the transmitter and the receiver. Each repeater receives the transmitted signal, amplifies it properly keeping its original form intact, and then relays it to the next repeater. *A repeater is thus a combination of receiver, amplifier and transmitter. Its function is to extend the range of communication.* The cost of transmission increases.

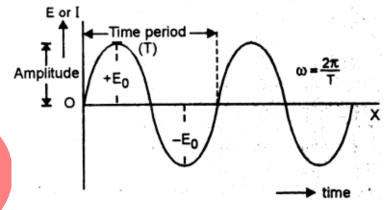
Message Signals

The electrical signals are of *two types:*

1. Analog signals 2. Digital signals

1. **Analog Signals:** *An analog signal is that in which current or voltage value varies continuously with time.* It is represented by the equation

$$E = E_0 \sin(\omega t + \phi)$$



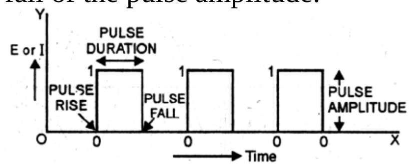
where E_0 is max. value of voltage, called the amplitude, T is time period and $\omega = \frac{2\pi}{T}$ is angular frequency of the signals and ϕ represents the phase angle. Such signals can have all sorts of values at different instants, but these values shall remain within the range of a maximum value ($+E_0$) and a minimum value ($-E_0$)

Examples of analog signals are speech, music, sound produced by a vibrating tuning fork, variations in light intensity from a picture. These are converted into current/voltage variations using suitable transducers.

2. **Digital Signals:** *A digital signal is a discontinuous function of time,* in contrast to an analog signal, wherein current or voltage value varies continuously with time. A typical digital signal is shown in figure. Such a signal is usually in the form of **pulses.** Each pulse has two levels of current or voltage, represented by 0 and 1. Zero (0) of a digital signal refers to *open* circuit and (1) of a digital signal refers to closed circuit. Zero (0) is also referred to as 'No' or space and (1) is referred to as 'Yes' or mark. Both 0 and 1 are called *bits.*

The significant characteristics of a digital signals are: *Pulse amplitude; Pulse duration or pulse width and pulse position,* representing the time of rise and time of fall of the pulse amplitude.

Examples of Digital Signals are



(i) letters printed in a book

(ii) listing of any data

(iii) output of a digital computer,

(iv) electronic transmission of a document at a distant place via telephone line i.e. FAX etc.

Note that for computer data, the band width allocated is about 600 MHz. An analog signal can be converted suitably into a digital signal and vice–versa. There are several coding schemes useful for digital communication. For example:

(i) **Binary coded Decimal** (BCD) in which a digit is represented by two binary bits (0 or 1).

(ii) **American Standard Code for Information Interchange** (ASCII) is a universally popular digital code to represent numbers, letters and certain characters.

(iii)

Transmission Medium or Communication Channel

The transmission medium or communication channel is a link through which information/message signal may propagate from the source to the destination, without any noise or distortion. It is a sort of electronic roadways along which signals travel. Broadly, transmission media have been divided into two types:

1. Guided Transmission Medium or point to point transmission
2. Unguided Transmission Medium or broadcast

1. **Guided Transmission Medium:** *It is that communication medium or channel which is used in point to point communication between a single transmitter and a receiver.* For example, parallel wire lines, twisted pair and co–axial cable are guided transmission media. Optical fibres are other examples of guided transmission medium. Thus, guided transmission medium is used in **line communication.**

2. **Unguided Transmission Medium:** *It is that communication medium which is used, where there is no point to point contact between the transmitter and receiver.* There are a large number of receivers corresponding to a single transmitter. Free space is an example of unguided transmission medium. It is used in **space communication and satellite communication,** such as in radio and television.

The characteristics and quality of transmission medium depend upon.

(i) nature of transmission medium, (ii) nature of signal

Band Width of Transmission Medium

In fact, different transmission media for communication of signals offer different band widths. The commonly used transmission media are wire, free space and optical fibre cable. Co–axial cable is a widely used wire medium. It offers a band width of 750 MHz. These cables are generally operated below 18 GHz.

Communication through free space using radiowaves occurs at frequencies ranging from 10^5 Hz to 10^9 Hz. This range is subdivided further and allocated for various services as indicated in table.

Name of Service	Frequency Band	Remarks
Standard amplitude modulated broadcast	540–1600 kHz	——
F.M. Broadcast	88 to 108 MHz	——
Television	$\left.\begin{matrix}54-72\ MHz\\76-88\ MHz\end{matrix}\right\}$ $\left.\begin{matrix}174-216\ MHz\\420-890\ MHz\end{matrix}\right\}$	Very high frequency (VHF) T.V. Ultra high frequency (UHF) T.V.
Cellular Mobile Radio	896–901 MHz 840–935 MHz	Mobile to base station Base station to mobile
Satellite Communication	5.925 – 6.425 GHz 3.7 – 4.2 GHz	Uplink Downlink

The optical fibre communication is used in the frequency range of 1 THz to 1000 THz (microwaves to ultraviolet). An optical fibre can offer a transmission band width in excess of 100 GHz.

Antenna

An antenna plays a vital role in a communication system. It is used in both, the transmission and reception of radio frequency signals. Infact, an antenna is a structure that is capable of radiating electromagnetic waves or receiving them, as the case may be. Basically, an antenna is generally a metallic object, often a wire or collection of wires, used to convert high frequency current into electromagnetic waves and vice–versa. Thus, a transmitting antenna converts electrical energy (high frequency current) into electromagnetic waves, whereas a receiving antenna converts electromagnetic waves into electrical energy (high frequency current). Apart from their different functions, transmitting and receiving antennas behave identically i.e. their behaviour is reciprocal.

When a transmitting antenna is held vertically, the electromagnetic waves produced are polarized vertically. When the same antenna is held horizontally, the em waves produced are polarized horizontally.

A Hertz antenna is a straight conductor of length equal to half the wavelength of radio signals to be transmitted or received i.e. $l = \lambda/2$. This antenna is not grounded. *A Marconi antenna is a straight conductor of length equal to a quarter of the wavelength of radio signals to be transmitted or received i.e.* $l = \lambda/4$. It is held vertically with its lower end touching the ground.

1. **Dipole antenna,** shown in figure (a) is used in transmission of radio waves. *It is omni directional.*

2. **Dish type antenna,** shown in figure (b) is a *directional antenna.*

   Such an antenna has a parabolic reflector with an active element, called the **dipole or horn feed at focus** of the reflector. The dish type antenna can transmit waves in a particular direction. Also, it can receive only those waves which are directed towards it. For transmission, the signal is fed to the active element, which directs it on to reflector. The signal is then transmitted in the form of a parallel beam.

(a) *(b)*

Modulation and its Necessity

A message signal usually spread over a range of frequencies, called the **signal band width.** That is why message signals are also called **base band signals** representing the band of frequencies of the original signal. Suppose we wish to transmit an electrical signal in the audio frequency (AF) range (20 Hz to 20 kHz) over a long distance. We cannot do it, as such because of the following reason:

1. **Size of the antenna or aerial**

   An antenna or aerial is needed, both for transmission and reception. Each antenna should have a size comparable to the wavelength of the signal, (atleast λ/4 in size). , so that time variation of the signal is properly sensed by the antenna.

   For an audio frequency signal of frequency v = 15 kHz, the wavelength, $\lambda = \frac{c}{v} = \frac{3\times10^8}{15\times10^3} = 20000\,m$. The length of the antenna = $\frac{\lambda}{4} = \frac{20000}{4} = 5000$ *metre.* To set up an antenna of vertical height 5000 metre is practically impossible to construct and operate. If transmission frequency were raised to 1 MHz, then $\lambda = \frac{c}{v} = \frac{3\times10^8}{10^6} = 300\,m$. The length of antenna would be 300/4 = 75 m, which is reasonable. Therefore, there is an urgent need of converting the information contained in our original low frequency by base–band signal into high or radio frequencies before transmission.

2. **Effective Power Radiated by Antenna**

Theoretical studies reveal that power P radiated from a linear antenna of length l is proportional $(l/\lambda)^2$, *i.e.*, $P \propto \left(\frac{l}{\lambda}\right)^2$. As high powers are needed for good transmission, therefore, for given antenna length wavelength λ should be small or frequency ν should be high. Thus, this factor also points out to the need of using high frequency transmission.

3. Mixing up of signals from different transmitters

When many people are talking at the same time, we just cannot make out who is talking what. Similarly, when many transmitters are transmitting base band information signals simultaneously, they get mixed up and there is no way to distinguish between them. The possible solution is, communication at high frequencies and allotting a band of frequencies to each transmitter so that there is no mixing. This is what is being done for different radio and T.V. broadcast stations.

All the three reasons explained above suggest that there is a need for transmission at high frequencies. This is achieved by a process, called *modulation, wherein we superimpose the low audio frequency base band message or information signals (called the modulating signals) on a high frequency wave (called, the carrier wave). The resultant wave is called the modulated wave, which is transmitted.*

Types of Modulation

We know that a carrier wave may be

(i) Continuous (sinusoidal) wave, or

(ii) (ii) Pulse, which is discontinuous

Let a sinusoidal carrier wave be represented as

$$c(t) = A_c \sin(\omega_c t + \phi)$$

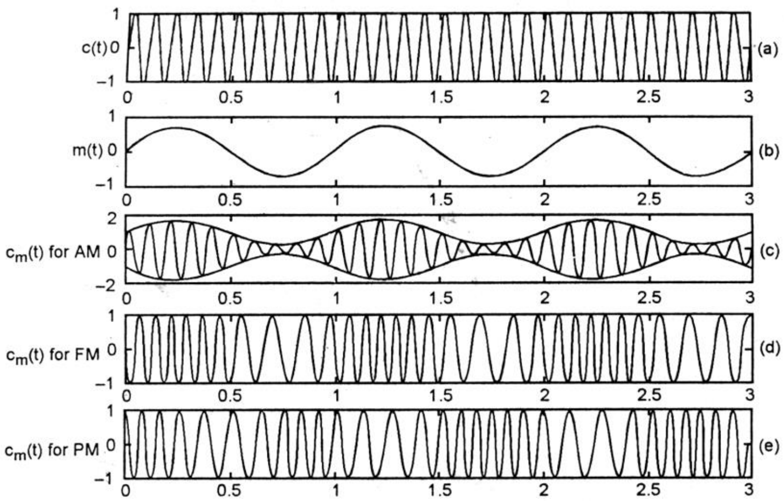
where c (i), is the signal strength (current or voltage) at any time t.

A_c = amplitude of carrier wave

$\omega_c = 2\pi \nu c$ is angular frequency of carrier wave (in rad/s)

ν_c = frequency of carrier wave in Hz

ϕ = initial phase of the carrier wave.



During the process of modulation, any one of the three parameters viz A_c; ω_c and ϕ of the carrier wave is varied in accordance with information or message signal, which is the modulating base band audio frequency signal m(t). This would result in three types of modulation.

(i) Amplitude Modulation (AM)

(ii) Frequency Modulation (FM) and

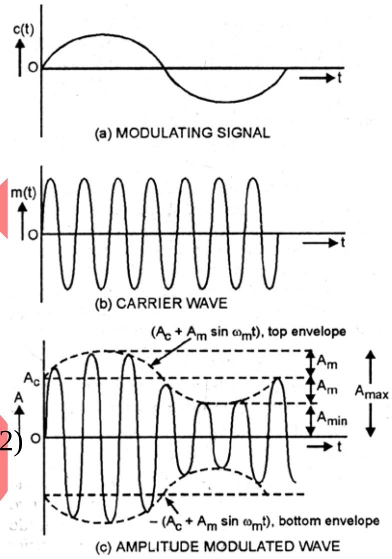
(iii) Phase Modulation (PM)

Amplitude Modulation

In amplitude modulation, the amplitude of the carrier wave is varied in accordance with the amplitude of the audio frequency modulating signal. However, the frequency of amplitude modulated wave remains the same as that of the carrier wave. To explain amplitude modulation, let us take a sinusoidal modulating signal, represented by $m(t) = A_m \sin \omega_m t$

where A_m is amplitude of modulating signal, and $\omega_m = 2\pi\nu_m$ is angular frequency of the modulating signal. This is representing in figure. Let the sinusoidal carrier wave be represented as $c(t) = A_c \sin \omega_c t$

where A_c is amplitude of carrier wave, and $\omega_c = 2\pi\nu_c$ is angular frequency of carrier wave. This is represented in figure. In amplitude modulation, the amplitude of modulated wave $c_m = (t)$ is $(A_c + A_m \sin \omega_m t)$. As its frequency is unchanged ($= \omega_c$), therefore, we represent amplitude modulated wave as



$$c_m(t) = (A_c + A_m \sin \omega_m t) \sin \omega_c t$$

$$= A_c \left(1 + \frac{A_m}{A_c} \sin \omega_m t\right) \sin \omega_c t \qquad \text{Put} \qquad \frac{A_m}{A_c} = \mu$$

where μ is called ***amplitude modulation index.***

$$\therefore \qquad c_m(t) = A_c \sin \omega_c t + \mu A_c \sin \omega_m t \sin \omega_c t \qquad \dots (1)$$

As $\sin A \sin B = \frac{1}{2}[\cos(A-B) - \cos(A+B)]$, we get from (1)

$$c_m(t) = A_c \sin \omega_c t + \frac{\mu A_c}{2} \times [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t] \qquad \dots (2)$$

Equation (2) shows that the amplitude modulated signal consists of the carrier wave of frequency ω_c plus two sinusoidal waves, one of frequency $(\omega_c - \omega_m)$ and other of frequency $(\omega_c + \omega_m)$. These two additional waves are called *side bands.* Their frequencies are called *side band frequencies.*

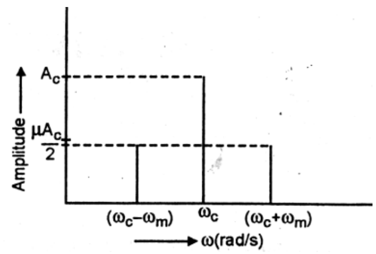
$$\omega_{SB} = \omega_c \pm \omega_M$$

$\therefore$ Frequency of lower side band, $\omega_{LSB} = \omega_c - \omega_m$

and frequency of upper side band, $\omega_{USB} = \omega_c + \omega_m$

Band width of amplitude modulated wave is

$$= \omega_{USB} - \omega_{LSB} = (\omega_c + \omega_m) - (\omega_c - \omega_m) = 2\omega_m$$



i.e., band width = twice the frequency of modulating signal.

The frequency spectrum of amplitude modulated wave is shown in figure. The two side band frequencies have equal amplitude ($= \mu A_c/2$), which *never exceeds half the carrier amplitude.* $(\because \mu \le 1)$

Note

The amplitude modulation index (μ) determines the quality of the transmitted signal. When modulation index is small, variation in carrier amplitude will be small, therefore, audio signal being transmitted will be weak. As the modulation index increases, the audio signal on reception becomes clearer.

Production of Amplitude Modulated Wave

Let the modulating signal be represented by $m(t) = A_m \sin \omega_m t$

and the carrier wave be represented by $c(t) = A_c \sin \omega_c t$

When the modulating signal is added to the carrier wave, let the signal produced by

$$x(t) = A_m \sin \omega_m t + A_c \sin \omega_c t \qquad \dots (1)$$

Let this signal be passed through a square law device, which is a **non linear device.** Let it produce an output.

$$y(t) = B\,x(t) + C\,[x(t)]^2$$

where B and C are arbitrary constants. Using equation (1), we get

$$y(t) = B[A_m \sin \omega_m t + A_c \sin \omega_c t] + C[A_m \sin \omega_m t + A_c \sin \omega_c t]^2$$

$$= B[A_m \sin \omega_m t + A_c \sin \omega_c t] + C[A_m^2 \sin^2 \omega_m^2 t + A_c^2 \sin^2 \omega_c t + 2A_m A_c \sin \omega_m t \sin \omega_c t]$$

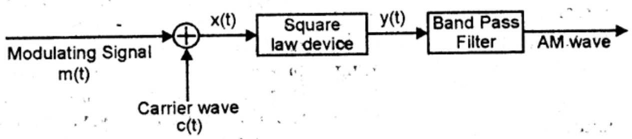
Using the trigonometrical relations

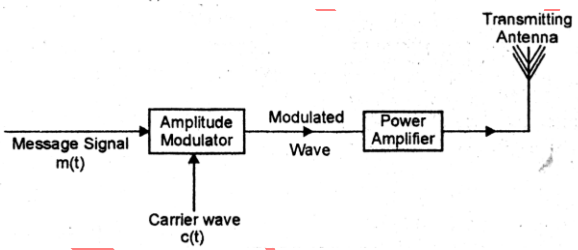
$$\sin^2 A = \frac{1-\cos 2A}{2}, \text{ and } \sin A \sin B = \frac{1}{2}[\cos(A-B) - \cos(A+B)], \text{ we get}$$

$$y(t) = BA_m \sin \omega_m t + BA_c \sin \omega_c t + \frac{C}{2}(A_m^2 + A_c^2) - \frac{C}{2}A_m^2 \cos 2\omega_m t$$

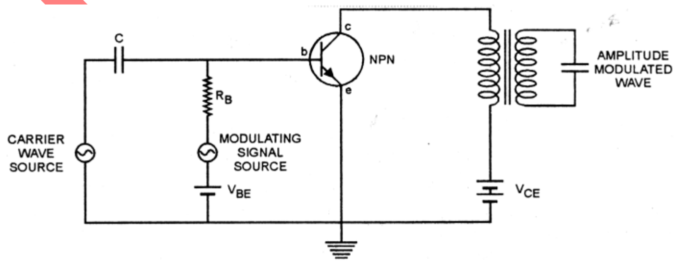
$$-\frac{C}{2}A_c^2 \cos 2\omega_c t + CA_m A_c \cos(\omega_c - \omega_m)t - CA_m A_c \cos(\omega_c + \omega_m)t$$

In this equation, there is a d.c. term $\frac{C}{2}(A_m^2 + A_c^2)$ and sinusoidal waves of frequency ω_m; $2\omega_m$, ω_c, $2\omega_c$; $(\omega_c - \omega_m)$ and $(\omega_c + \omega_m)$. This signal is passed through **band pass filter** centered at ω_c. Such a filter rejects low and high frequencies, and allows a particular band of frequencies to pass. In this case, the filter rejects d.c., and the sinusoids of frequencies ω_m, $2\omega_m$ and $2\omega_c$. The frequencies passed are ω_c, $(\omega_c - \omega_m)$ and $(\omega_c + \omega_m)$. The output of the band pass filter, therefore, contains waves of frequencies, ω_c, $(\omega_c - \omega_m)$ and $(\omega_c + \omega_m)$. This is an amplitude modulated wave.





The basic circuit of an *amplitude modulator* is shown in figure. It is essentially a common emitter amplifier for the carrier wave signal. The base biasing voltage, in this case, is the sum of d.c. and the modulating signal. As the base biasing voltage changes, amplification changes. Therefore, output voltage will be a carrier wave varying in amplitude in accordance with the biasing modulating voltage. This is the amplitude modulated wave.



Demodulation – Detection of Amplitude Modulated Wave

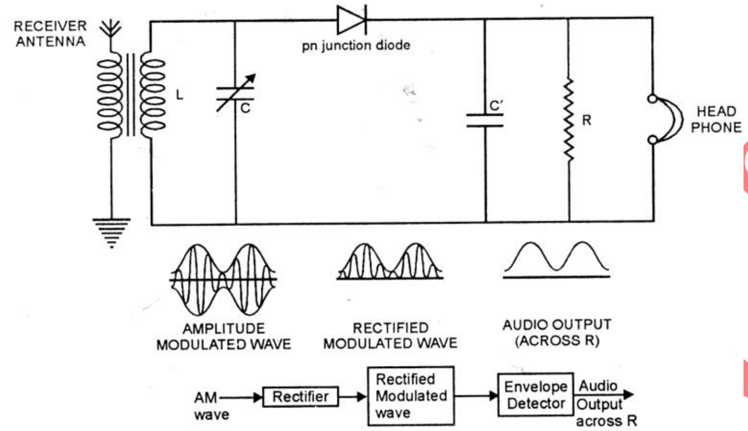
Demodulation is the reverse process of modulation, which is performed in a receiver to recover the original modulating signals. At the receiving end, the signal is generally quite weak due to attenuation in the channel. Therefore, the receiver must amplify the received signal first. As the signal is usually accompanied by lots of other unwanted signals (noise), only the desired signal is selected and others are rejected by the receiver. Finally, demodulation is performed in the receiver to recover the original modulating signals. Thus a demodulator or a receiver performs the following functions:

(i) Selecting the desired signal and rejecting the unwanted signals,

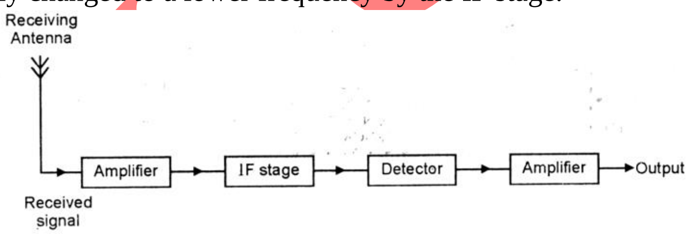
(ii) Amplifying and demodulating the desired signal,

(iii) Displaying the original modulating signal in a desired manner.

The input circuit consists of a *tuned circuit* comprising an inductor L and a variable capacitor C. This circuit selects the desired amplitude modulated wave signal from the different signals picked up by the receiver antenna. When this wave is passed through junction diode, we obtain rectified modulated wave, containing only positive half cycles. This occurs due to rectifying action of the junction diode.



The rectified output is then fed to the parallel combination of a capacitor C' and a resistor R. The value of C' is so chosen that its reactance $\left(X_{C'} = \frac{1}{\omega C'}\right)$ to the high frequency carrier wave is low. This reactance will obviously be high for the low frequency modulating signal. Therefore, the capacitor C' acts as a by pass for the carries waves and audio frequency modulating signal voltage appears across R. This sends current through headphone, and the original speech or music is reproduced. A block diagram of a typical receiver is shown in figure. Note that IF stage represents intermediate frequency stage preceding the detection. The carrier frequency is usually changed to a lower frequency by the IF stage.

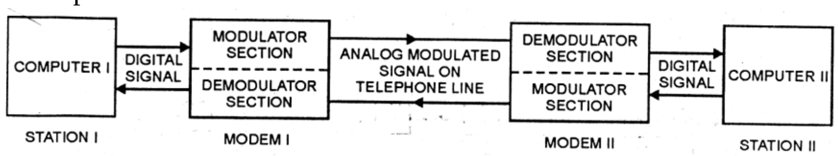


Modem

A modem is a device that can connect one computer to another across ordinary telephone lines. The name *'modem'* is short form of the terms modulator and demodulator i.e. a modem performs the functions of both, the modulator and the demodulator. Infact, a modem acts as a modulator in the transmitting mode and it acts as a demodulator, in the receiving mode.

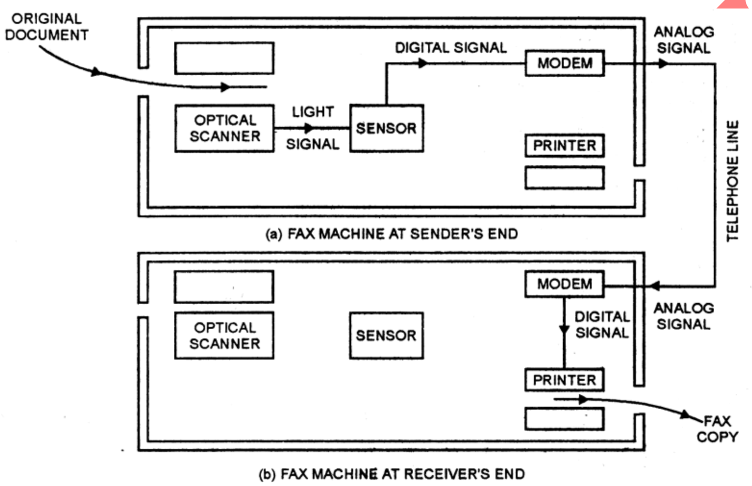
As digital signals cannot be transmitted along the telephone lines, therefore, the modem I at the transmitting station I converts the digital data from the machine into analog form, modulates a suitable carrier wave with this analog form of audio signal, and transmits the modulated wave along the telephone line. Modem II at the receiving station II demodulates the modulated carrier to retrieve the data, on computer II in digital form.

Similarly, for sending the data from station II to station I, modulator section of modem II and demodulator section of modem I are operative.



Fax (Facsimile)

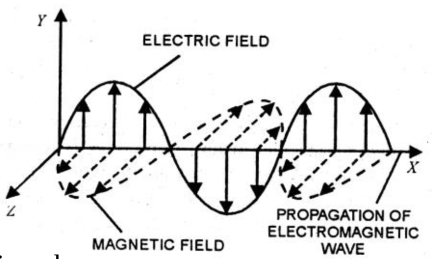
The fax of facsimile tele–graphy is the electronic transmission and repro–duction of a document at a distant place. It is the most popular example of a digital communication system. Fax transmission usually involves transmission of document or photograph. *The different regions of the document to be transmitted are first scanned by a light source.* The scanner gives optical signals carrying the information regarding the writings, patterns, signatures etc. in different parts of the document. *These optical signals are converted into electrical signals by a photo–detector. The electrical signals are coded and transmitted by some suitable communication method. Figure represents block diagram of transmission and reproduction of documents by Fax machines.*



Electromagnetic Waves

Electromagnetic waves are those waves in which there is a sinusoidal variation of electric and magnetic field vectors at right angles to each other as well as at right angles to the direction of propagation of waves. In electromagnetic waves, both the field vectors $(\vec{E}$ and $\vec{B})$ vary with time and space and have the same frequency and same phase.

In figure, the electric field vector $(\vec{E})$ and magnetic field vector $(\vec{B})$ are vibrating along Y and Z directions and propagation of electromagnetic wave is shown in X–direction.



According to Maxwell the electromagnetic waves are of transverse in nature and they can pass through vacuum with the speed of light
$(= 3 \times 10^8$ ms$^{-1})$. The velocity of electromagnetic wave in a medium is given by

$$v = \frac{1}{\sqrt{\mu_0 \mu_r \in_0 \in_r}}$$

where, μ_0, μ_r = absolute permeability of space and relative permeability of medium, $\in_0$, $\in_r$ = absolute permittivity of space and relative permittivity of medium.

The velocity of electromagnetic waves of different frequencies in vacuum is same, but in any other medium, it is different. It is more for red light and less for violet light.

When L – C circuit produces oscillations, the charge oscillates on capacitor. Due to which the two ends of the antenna become alternatively positive and negative. As a result of it, the electric field vector is always parallel to the plane of antenna, while the magnetic field vector is at right angle to it. Since the electric field vector is oriented in one particular direction with respect to the surface of earth, hence three is polarization of electromagnetic wave.

When the antenna is vertical w.r.t. earth, the electric field vector is vertically oriented w.r.t. earth, therefore, the electromagnetic wave is vertically polarized. When the antenna is held parallel to horizontal, the electromagnetic wave would be horizontally polarized. *It means the polarisation of electromagnetic wave is mainly the function of the antenna orientation.*

Earth's Atmosphere

The gaseous envelope surrounding the earth is called earth's atmosphere. The earth atmosphere mainly consists of nitrogen 78%, oxygen 21% and with a little portion of argon, carbon dioxide, water vapour. hydrocarbons, sulphur compounds and dust particles. The density of the atmospheric air goes on decreasing as we go up. The electrical conductivity of the atmospheric air increases as we go up. The earth atmosphere has no sharp boundary. It has been divided into various regions as given below.

1. Troposphere

It extends upto a height of 10 km. the atmosphere air in this region has maximum density which varies from 1 kg/m^3 at the surface of earth to 0.1 kg/m^3 at the top of this layer. The electrical conductivity of this region is least as compared to other regions of earth's atmosphere. In this portion of the atmosphere, the temperature decreases with height from 290 K to 220 K.

2. Stratosphere

It extends from 10 km to 50 km from the surface of earth. The density of air of this region varies from 0.1 kg/m^3 to 10^{-3} kg/m^3. There is an *ozone layer* in this region in between 30 km to 50 km from the surface of earth, which absorbs a large portion of *ultraviolet radiations* radiated by sun or coming from outer space. The temperature of this region varies from 220 K to 280 K.

3. Mesosphere

It extends from 50 km to 65 km from the surface of earth. The density of air in this layer varies from 10^{-3} kg/m^3 to 10^{-5} kg/m^3. The temperature of this region falls from 280 K to 180 K with height.

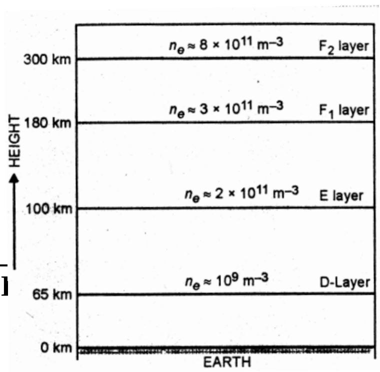
4. Ionosphere

It extends from 65 km to 400 km from the surface of the earth. The density of this region varies from 10^{-5} kg/m^3 to 10^{-10} kg/m^3. In this region temperature increases with height from 180 K to 700 K, that is why, it is called *thermosphere*. Ionosphere is the outermost part of the earth's atmosphere. It is composed of ionized matter (i.e. electrons and positive ions) which plays an important role in space communication. The value of refractive index of ionosphere is less than one.

There are four main layers in earth's atmosphere having high density of electrons and positive ions, produced due to ionization by the high energy particles coming from sun, stars or cosmos. These layers play their effective role in space communication. These layers are D, E, F_1 and F_2 (figure)

(i) **D–layer** is at a virtual height of 65 km from surface of earth and having electron density $\approx 10^9$ m^{-3}. The extent of ionization of D layer depends upon the altitude of sun. The smaller is normal altitude of sun, the greater will be the ionization of the atmospheric layer. This D–layer exists in day time and disappears at night. It is so because, at night, the sun light is absent which is responsible for the ionization of the D–layer. This layer reflects very low frequency (VLF) and low frequency (LF) electromagnetic waves but absorbs medium frequency (MF) and high frequency (HF) electromagnetic waves to a certain degree.

(ii) **E–layer** is at a virtual height of 100 km, from surface of earth, having electron density $\approx 2 \times 10^{11}$ m^{-3}. This layer exists during day time but disappears at night. The critical frequency* of this layer is about 4 MHz. This layer helps to MF surface–wave propagation a little but reflects some high frequency (HF) waves in day time.



(iii) **F_1–layer** is at a virtual height of 180 km from the surface of earth, having electron density merges with layer F_2 at night. This layers exists in day time and merges with layer F_2 at night. The critical frequency F_1 layer is 5 MHz. It absorbs some of the high frequency waves but most of the high frequency waves pass through it and they get reflected from layer F_2.

(iv) **F_2–layer** is at a vertical height of about 300 km in night time and about 250 to 400 km in day time. The electron density of this layer is $\approx 8 \times 10^{11}$ m^{-3}. The critical frequency of this layer is 8 MHz in day time and 6 MHz in night time. It reflects back the electromagnetic waves of frequency upto 30 MHz to 40 MHz but cannot reflect back the electromagnetic waves of frequency more than 40 MHz.

Thus earth's atmosphere helps in the propagation of electromagnetic waves from the place to another place, upto 40 MHz frequency.

Behaviour of Atmosphere towards Electromagnetic Waves

The atmosphere is transparent to electromagnetic waves of visible region of wavelength range 4000Å to 8000Å. The electromagnetic waves belong to infrared region of wavelength range 8×10^{-7} m to 3×10^{-5} m are not allowed to pass through atmosphere rather they get reflected by atmosphere. The ozone layer of earth's atmosphere blocks the electromagnetic waves of ultraviolet region of wavelength range 6Å to 4000Å. The behaviour of earth's atmosphere towards electromagnetic waves of wavelength 10^{-3} m and higher is of special interest in space communication. The lower part of atmosphere is more or less transparent to electromagnetic waves of wavelength 20m and higher, used in radio communication. But the top most layer, the ionosphere does not allow these waves to penetrate and reflects them back towards earth. Beyond a certain frequency, above 40 MHz, the ionosphere bends any incident electromagnetic wave a little but does not reflect it back towards earth.

Radio Waves

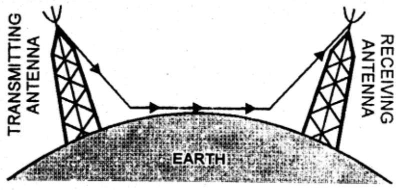
The radio waves are the electromagnetic waves of frequency ranging from 500 kHz to about 1000 MHz. These waves are used in the field of radio communication.

Space Communication

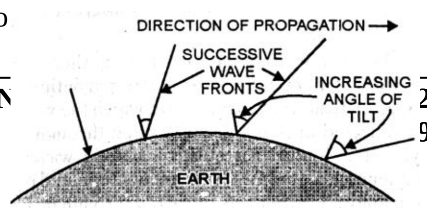
The term space communication refers to sending, receiving and processing of information through space. We have the following modes of space communication:

1. Ground or surface wave propagation.
2. Space wave or tropospheric wave propagation.
3. Sky or Ionospheric wave propagation.
4. Satellite communication.

Ground or Surface Wave Propagation



It is a mode of wave propagation in which the ground has a strong influence on the propagation of signal waves from the transmitting antenna to receiving antenna. In this propagation, the signal wave glides over the surface of earth. While progressing along the surface of the earth, the ground wave induces current in the ground and bends round the corner of the objects on earth. Due to it, the energy of ground wave is gradually absorbed by the earth and the power of g round wave decrease with the increase in distance from the transmitting station. This *phenomenon of loss of power of a ground wave is called* ***attenuation.*** Attenuation also occurs with distance along the surface of earth due to diffraction, as angle of tilt of successive wavefronts increases.



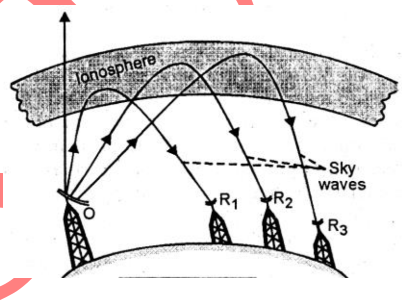
Finally the wavefront of the ground waves at some distance lies down and dies. The attenuation of ground/surface wave increases very rapidly with the increase in its frequency. For ground wave propagation, the maximum coverage range depends on (i) the transmitting power and (ii) frequency of the signal wave.

Since the loss of power in a ground wave during propagation increases rapidly with the increase in the frequency of the signal waves as well as with the increase in distance from the transmitter antenna, hence the ground wave propagation is useful for low frequency signal waves (roughly from 530 kHz to 1710 kHz), that too for short distances (about few hundred kilometers).

Therefore, the ground wave communication is not suited for high frequency signal wave and for very long range communication. The ground wave propagation is generally used for *local broadcasting* as a *medium wave broadcast service.* The part of the amplitude modulated band corresponding to frequencies from 530 kHz to 1710 kHz is called *medium wave band.*

Sky Wave Propagation

It is a mode of wave propagation in which the radiowaves emitted from the transmitter antenna reach the receiving antenna after reflection by the ionosphere. In sky wave propagation, the radiowaves of frequency range from generally 1710 kHz to 40 MHz are used. This mode of propagation is used by *short wave broadcast service.* Ionosphere is the uppermost layer of earth's atmosphere extending from a height of 65 km to about 400 km, above the surface of earth. The density of atmosphere decreases with height. The ultraviolet radiations and other high energy radiations coming from sun on entering ionosphere of earth's atmosphere, are largely absorbed by the molecules of that layer of atmosphere.



Due to it, the molecules get ionised. At great heights, the solar radiations intensity is high but the density of earth's atmosphere is low. Therefore, there are few air molecules to be ionised. However, at some intermediate heights, there occurs maximum ionization of earth's atmosphere molecules, resulting in ionised layers of maximum electrons and ions which are formed at different heights. Due to it, we get various ionised layers; D, E, F_1 and F_2 having different number density of electrons and ions at different heights as discussed in Art (figure). Each ionised ionospheric layers acts as a reflector for a certain range of radiowaves (between 1.71 MHz to 40 MHz). The 40 MHz penetrate the ionosphere and escape.

When a sinusoidal electromagnetic wave enters an ionised layer of earth's atmosphere present in ionosphere, the electron cloud will oscillate in the electric field of wave with a phase retardation of 90^o. The reflection mechanism of the electromagnetic waves from the layer of ionosphere can be understood easily as follows. The oscilating electric field of electromagnetic wave changes the velocity of the electrons in the ionosphere, which changes the effective dielectric constant ($\in$) and hence refractive index (μ). These quantities are related to the corresponding values for free space i.e. $\in_0$ and μ_0 by the relation given below:

$$\mu=\mu_0\left[1-\frac{Ne^2}{\in_0\ m\omega^2}\right]^{1/2} = \mu_0\left[1-\frac{Ne^2}{\in_0\ m\ 4\pi v^2}\right]^{1/2}$$

where N is the number density of electrons in the given layer. v is the frequency of electromagnetic waves in hertz. e and m are the charge and mass of electron. Putting the standard values for e, $\in_0$, m we have

$$\mu=\mu_0\left[1-\frac{N\times(1.6\times10^{-19})^2}{\left(\frac{1}{4\pi\times9\times10^9}\right)\times(9.1\times10^{-31})\times4\pi\ v^2}\right]^{\frac{1}{2}} = \mu_0\left[1-\frac{81.45\,N}{v^2}\right]^{1/2}$$

And, $\in = \in_0 \left(1 - \frac{Ne^2}{\in_0 m\omega^2}\right) = \in_0 \left(1 - \frac{81.45 N}{v^2}\right)$

From above equations we note that as the value of N for a layer increases, the value of refractive index (μ) and dielectric constant ($\in$) of that layer for the electromagnetic waves decreases. As the value of N for a layer in ionosphere increases with height, so the layer of ionosphere acts as a rarer medium weight height for electromagnetic wave. Due to it, the incident beam of electromagnetic wave suffers refraction in a layer of ionosphere and is gradually bent farther and farther away from the normal in a layer of ionosphere. The process continues till, it reaches upto the critical angle, after which it will be reflected back.

For every layer of ionosphere, there is a certain maximum frequency of electromagnetic wave (called *critical frequency),* above which the wave is not reflected back but gets refracted through that layer. It is found that electromagnetic waves of frequency more than 40 MHz are not reflected back from ionosphere but gets refracted through it. That is why, in sky wave propagation we use radiowaves of frequency range 1710 kHz to 40 MHz. The sky wave propagation is also known as *ionospheric propagation,* since sky waves reach the receiver after reflection from the ionosphere.

Important Terms for Sky Wave Propagation

(a) **Plasma frequency and critical frequency:** Plasma frequency is an important parameter in radio communication via the ionosphere. The plasma frequency v is related to the electron density N (in m^{-3}) of a layer of ionosphere by a relation $v = 9\sqrt{N}$

The plasma frequency at the peak of a layer is called *critical frequency* (v_c). It is the highest frequency of radio wave, which when sent straight (i.e. normally) towards the layer of ionosphere gets reflected from ionosphere and returns to the earth. If the frequency of the radiowave is more than critical frequency, it will not be reflected by ionosphere. The critical frequency of a sky wave for reflection from a layer of atmosphere is given by $v_c = 9\,(N_{max})^{1/2}$, where N_{max} is the maximum number density of electron/m^3.

(b) **Maximum usable frequency (MUF). It is that highest frequency of radio waves which when sent at some angle towards the ionosphere, gets reflected from that and returns to the earth.**

Quantitatively, MUF = $\frac{v_c}{\cos i} = v_c \sec i$

where i is the angle between normal and the direction of incidence of waves. The frequency normally used for ionosphere transmission is known as optimum working frequency (OWF), which is taken to be 15% of MUF.

(c) **Skip distance. It is the smallest distance between the transmitting antenna and the point R_v, where the sky wave of a fixed frequency, but not moiré than critical frequency is first received after reflection from ionosphere.**

If the angle of incidence of sky wave on the layer of ionosphere is large, then after reflection they will be reaching the earth at longer distance from the transmitting antenna. It means, the larger is the angle of incidence of sky wave, the greater is the value of skip distance on the surface of earth. This shows that the transmission path of sky waves is limited by the skip distance. The skip distance is given by the relation $D_{skip} = 2h\sqrt{\left(\frac{v_{max}}{v_c}\right)^2 - 1}$

where h is the height of reflecting layer of atmosphere, v_{max} is the maximum frequency of electromagnetic waves and v_c is the critical frequency for the layer of ionosphere.

(d) **Fading. *It is the variation in the strength of a signal at a receiver due to interference of waves.*** Fading is more at high frequencies. Fading causes an error in data transmission and retrieval.

The signals received due to sky wave propagation are subjected to fading in which the strength of the signal varies with time. It is so because, at the receiver, a large number of waves reach, following different number of paths.

(e) **Refractive index μ of a layer** in sky wave propagation is given by $\mu = \sqrt{1 - \frac{81.45N}{v^2}}$

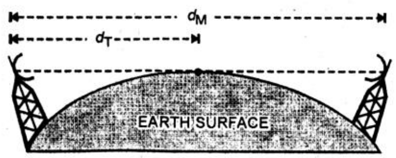
where N is the number density of electrons/m^3 of the layer of atmosphere under study and v is the frequency of electromagnetic wave in Hz. Relative permittivity or dielectric constant of the layer of atmosphere under study is given by $\epsilon_r = 1 - \frac{81.45\,N}{v^2}$

Space Wave Propagation

It is that mode of wave propagation in which the radiowaves emitted from the transmitter antenna reach the receiving antenna through space. These radiowaves are called space waves. The space waves are the radiowaves of frequency range from 54 MHz to 4.2 GHz. The space waves travel in straight line from transmitting antenna to receiving antenna. Therefore, the space waves are used for the line of sight communication as well as for the satellite communication. The space wave propagation is used for television broadcast, microwave link and satellite communication.

The communication through space wave between transmitter and receiver is limited to line of sight path. The line of sight communication is limited by (i) the line of sight distance and (ii) the curvature of the earth. The space waves following the line of sight propagation get blocked at some point by the curvature of the earth as illustrated in figure. Here, d_T is called the radio horizon of the transmit ting antenna, d_M is called the maximum line of sight distance between the two antennas.

The line of sight distance is that distance between transmitting antenna and receiving antenna at which they can see each other. It is also called **range of communication (d_M).** The range of space wave communication can be increased by increasing the heights of transmitting antenna and receiving antenna.



Television Signal Propagation

The television signal waves have the frequency range 54 MHz to 890 MHz. These signals are frequency modulated. The transmission of T.V. signals is not possible through ground wave propagation as the signals get absorbed by the ground due to their high frequency. Also, the transmission of T.V. signals is not possible through sky wave propagation, since the ionosphere cannot reflect these signals back to earth.

The transmission of T.V. signals is possible either (i) by using communication geostationary satellite which reflects the T.V. signals back to earth or (ii) by using fall receiving antenna which may directly intercept the signals coming from transmitting antenna.

Relation between Converge Distance and Height of Transmitting Antenna

Suppose PQ is a T.V. transmitting antenna of height h located at P on the surface of earth. due to finite curvature of earth, the T.V. signal transmitted from Q cannot be received beyond the trangent points T and S on earth (figure). The effective reception range of the T.V. broadcast is essential the region from S to T on earth which is covered by the line of sight during T.V. transmission.

Let SP = TP = d (distance to the horizon). This distance is limited by the curvature of earth. Therefore, the T.V. signals will be received on earth in a circle of radius d.

Here, R = radius of earth = OS = OT = OP;

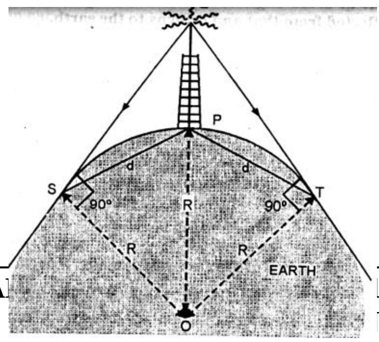
PQ = h and OQ = OP + PQ = R + h

In rt. angled triangle QPS $\quad SQ^2 = SP^2 + PQ^2 = d^2 + h^2$

In rt. angled triangle OSQ $\quad OQ^2 = OS^2 + SQ^2$

or $\quad (R + h)^2 = R^2 + (d^2 + h^2)$

or $\quad R^2 + 2hR + h^2 = R^2 + d^2 + h^2$



or $\quad 2hR = d^2 \quad$ or $\quad d = \sqrt{2hR}$

For T.V. signals, area covered = $\pi d^2 = \pi\, 2Rh$

Population covered = population density × area covered

The maximum line of sight distance (i.e., range of communication) d_M between two transmitting antenna of height h_T and receiving antenna of height h_R above the earth is given by $d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$

Microwave Link

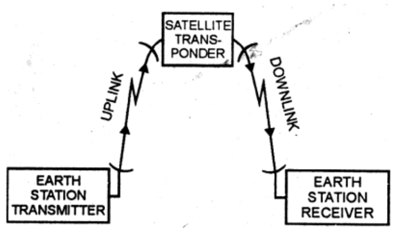
Microwaves are the electromagnetic waves of frequencies in the range of 1 GHz to 300 GHz, greater than those of T.V. signals. The wavelength of these waves is of the order of few millimeters. Microwaves have got good directional properties. Due to it, the microwaves can be directed as beam signals in a particular direction, much better than radiowaves, because microwaves do not spread or bend around the corners of any obstacle coming in their way; such as top of the buildings, mountains etc.

Microwave link on the surface of earth is possible if the transmitting antenna and receiving antenna are in the **line–of–sight.** Therefore, **microwave propagation is called line of sight propagation.** The range of microwave transmission is limited (i.e. upto a distance of about 50 km); (i) due to curvature in the surface of earth and (ii) due to absorption of signal by ground on account of high frequency; which causes the weakening of signal as it propagates on the surface of earth.

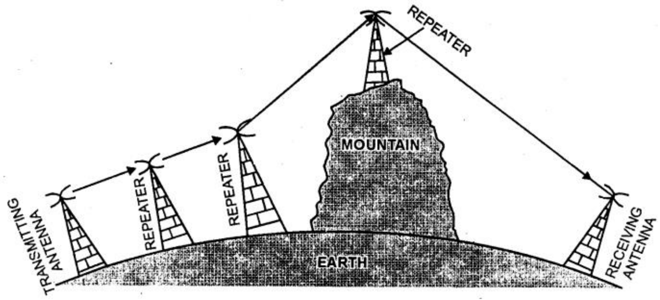
In order to increase the range of microwave transmission on the surface of earth, we have to overcome the above limitations. It is possible by erecting number of **repeaters** at suitable locations in between the transmitter and receiver (figure). Each repeater receivers the transmitted signal, amplifies it property, keeping its original form and then relays it to the next repeater. Finally, the signal reaches the receiving antenna. In this arrangement, the cost of transmission of signal between the stations becomes high.

Satellite Communication

The satellite communication is a mode of communication of signal between transmitter and receiver through satellite. The satellite communication is like the **line of sight microwave communication.** The basic principle of satellite communication is schematically shown in figure. A communication satellite is a space craft placed in an orbit around the earth provided with microwave transmitting and receiving equipment called as **Radio transponder.**



In satellite communication, a beam of modulated microwave from earth station transmitter is sent directly towards the satellite (i.e., the transmitted signal is uplinked with satellite), which receives the comings signal, amplifies and returns it to earth station receiver (i.e. down links it with earth station receiver) at a different frequency to avoid interference between the uplink and downlink. Both these frequencies are in UHF or microwave regions; hence they can cross the ionosphere of earth and reach the satellite which is situated well above the ionosphere. The signal received by receiver is generally weak. It is amplified by the receiver and then it is televised. Thus communication satellites act as a **big microwave repeater in the sky.**

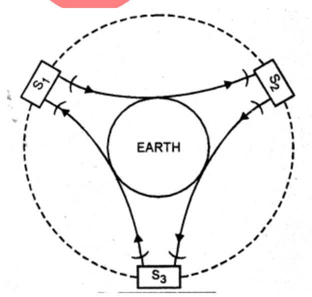


The line–of–sight microwave communication through satellite is possible if the communication satellite is always at a fixed location with respect to the earth, i.e. the satellite which is acting as a repeater must be at rest with respect to the earth. It is so for a satellite known as **geo–stationary satellite. The basic requirements for geostationary satellites** are as follows:

1. *The time period of revolution of the satellite around the earth is equal to the time period of rotation of earth about its polar axis i.e. 24 hours.*
2. *The sense of revolution of the satellite around the earth is the same as that of the earth about its polar axis i.e. from west to east.*
3. *The orbital plane of revolution of satellite is concentric and coplanar with the equatorial plane of earth.*
4. *The height of geostationary satellite above the equator of earth is nearly 36000 km and its orbital velocity is nearly 3.1 km/s.*

The orbit in which the geo–stationary satellite revolves around the earth is known as **geo–synchronous orbit.** As its angular speed is synchronized with the angular speed of the earth, therefore, the geo–stationary satellite is also known as **geo–synchronous satellite.**

A geostationary satellite can provide a communication link between two stations on earth at large distance apart, but a single satellite cannot cover the whole part of the earth for UHF or microwave communication. It is so because, the large part of the earth is out of sight due to the curvature of the earth. In order to have curvature of earth. In order to have UHF/microwave communication link over the entire globe of earth, at least three geostationary satellites are required, which are 120^o apart from each other.

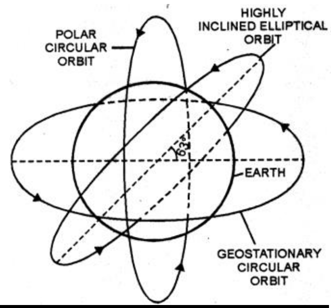


(i) Polar Circular Orbit

It is nearer to the earth as compared to the geostationary satellite, which is at a height of 918 km from the surface of earth. This orbit passes over or very close to the poles of earth. Its plane of orbit is inclined at 90^o with the equatorial plane of earth.

(ii) Highly inclined elliptical orbit

This orbit is generally inclined at an angle of 63^o with the equatorial plane of earth and is referred as being in 63^o slot. The satellites on these orbits are used for communications in regions of high altitudes, since the geostationary satellite cannot do so.



Merits of Satellite Communication

1. The satellite communication covers wide area for broadcasting as compared to other communication systems i.e. it has wide coverage range.
2. The satellite communication is also used effectively in mobile communication.
3. The satellite communication is found to be much economical as compared to other communication systems of earth. Infact, the cost involved in satellite communication is independent of the distance.
4. The satellite communication is most cost effective in remote and hilly areas, such as Ladakh, Himachal Pradesh etc.
5. The satellite communication permits transmission of data at high rate.
6. The satellite communication is very accurate and economical for search, rescue and navigation purposes.

Demerits of Satellite Communication

1. If a system on the satellite goes out of order due to environmental stresses, it is almost impossible to repair it.

2. In satellite communication, there is a time delay between transmission and reception, due to extremely large communication path length (greater than 2 × 36,000 km). This delay causes a time gap during talking, which proves quite annoying.

The Internet

The internet has become a house hold word especially for the younger generation. It permits communication and sharing of al types of information between any two or more computers. The applications of internet include the following five major uses:

(a) **E–mail** is the electronic mail. We can exchange text/graphic material with any number of people through internet service providers (ISP).

(b) **File Transfer Programme (FTP)** allows transfer of files/software from one computer to another through the internet.

(c) **World Wide Web (WWW).** The individuals, non–government departments can (NGO), companies, government departments can post information about their activities for restricted or free use on their websites. This information becomes accessible to the users. Several search engines like Yahoo! Google! etc. help us in finding relevant information from the various websites.

(d) **E–commerce** deals with the use of internet to promote business by electronic means. On line shopping from home/office, reservation and purchase of air tickets/railway tickets, making payments using credit cards are becoming common.

(e) **Chart:** The chart is real time conversation among people with common interest through typed messages on computers. All people belonging to the chat group receive the typed message instantly and can respond accordingly.

Mobile Telephony

Mobile phone is a full duplex device and walky tally is half duplex device. Full duplex device refers to the simultaneous transmission and reception of data in two directions at a time. Half duplex device refers to the transmission of data in one direction at a time. Mobile phones or cell phones are a rage amongst the younger generation. They operate typically in the ultra high frequency (UHF) range of 800–950 MHz.

The service area is divided into a suitable number of cells centred on an office, called **MTSO (mobile telephone switching office).** Each cell office contains a **low power transmitter** called a b**ase station** with a service area of a few square kilometers. it caters to a large number of mobile receivers in this area. When a mobile receiver crosses the coverage area of one station, it is transferred almost instantly to another base station. This procedure is called **hand over or hand off.**

Remote Sensing

Remote sensing is a technique of obtaining information about an object/area from a distance without being in physical contact with it. Any photography is a kind of remote sensing. Aerial photography was introduced for the first time in World War I for military uses. The latest development in this field is remote sensing from space through satellite. Remote sensing is widely used in forestry, in land use mapping, in agriculture, in meteorology, in climatology, in oceanography, in ground water surveys, in pollution control, in locating underground nuclear explosion, in tourism industry and in monitoring draught conditions.

Subjective Assignment – I

Q.1 A ground receiver station is receiving signal at (a) 6.0 MHz and (b) 110 MHz, transmitted from ground transmitter at a height of 300 m located at a distance of 100 km. Identify whether it is coming via space wave or sky wave propagation or satellite transponder. Radius of earth = 6.4×10^6 m; maximum number density of electrons in ionosphere = 10^{12} m^{-3}.

Q.2 Calculate the values of relative permittivity of E and F regions of the ionosphere in the case of an electromagnetic wave of frequency 50 MHz. Given electron density of E and F regions is 10^{11} m^{-3} and 8×10^{11} m^{-3} respectively.

Q.3 What is the value of frequency at which an e.m. wave must be propagated for the D–region to have a refractive index of 0.49? Electron density for D–layer is 10^9 m^{-3}.

Q.4 A T.V. tower has a height of 100 m. How much population is covered by the T.V. broadcast if the average population density around the tower is 1500 km^{-2}? (Radius of earth = 6.37×10^6 m).

Q.5 A transmitting antenna at the top of a tower has a height 32 m and that of the receiving antenna is 50 m. What is the maximum distance between them for satisfactory communication in line of sight mode? Given radius of earth is 6.4×10^6 m.

Answers

1.	≈ 62 km	2.	0.974	3.	3.27×10^5 Hz
4.	6×10^6	5.	45.5×10^3 m = 45.5 km		

Conceptual Problems

Q.1 Long distance radio broadcasts use short wave bands. Why? **OR**
Why are short waves sued in long distance radio–broadcasts?

Q.2 It is necessary to use satellites for long distance T.V. transmission. Why?

Q.3 Why does the electrical conductivity of earth's atmosphere increase with altitude?

Q.4 What mode of communication is employed for the transmission of T.V. signals?

Q.5 Explain, why T.V. transmission towers are usually made high.

Q.6 What is a carrier wave? Why high frequency carrier waves are employed for transmission?

Q.7 Optical and Radio telescopes are built on the ground but X–rays astronomy is possible only from satellites orbiting the earth. Why?

Q.8 What is an active satellite? How is it different from a passive satellite?

Subjective Assignment– II

Q.1 A ground receiver station is receiving a signal at (a) 5 MHz and (b) 100 MHz, transmitted from a ground transmitter at a height of 400 m located at a distance of 125 km. Identify whether it is coming via space wave or sky wave propagation or satellite transponder. Radius of earth = 6.4×10^6 m; maximum number density of electrons in ionosphere = 10^{12} m^{-3}.

Q.2 On a particular day, the maximum frequency reflected from the ionosphere is 9 MHz. On another day, it was found to increase by 1 MHz. Calculate, the ratio of the maximum electron densities of the ionosphere on the two days.

Q.3 Find radio of critical frequency for reflect ion of radiowaves from E, F_1 and F_2 layers in ionosphere of earth's atmosphere having electron density 2×10^{11}, 3×10^{11} and 8×10^{11} m^{-3} respectively.

Q.4 What is the value of frequency at which electromagnetic wave must be propagated for the D–region of atmosphere to have a refractive index of 0.5. Electron density for D–region is 400 electrons/c.c.

Q.5 A T.V. tower has a height of 75 m. What is the maximum distance and area upto which this T.V. transmission can be received? Take radius of the earth as 6.4×10^6 m.

Q.6 A T.V. transmission tower at a particular station has a height of 160 m.
(a) What is its coverage range?
(b) How much population is converted by transmission, if the average population density around the tower is 1200 km^{-2}?
(c) By how much the height of tower be increased to double its converge range?
Given radius of earth = 6400 km

Q.7 A T.V. tower has a height 100 m. What is the population density around the T.V. tower if the total population covered is 50 lakh? Radius of earth = 6.4×10^6 m.

Answers

1.	(a) sky waves (b) satellite communication			2.	1 . 23
3.	1 . 41 : 1 . 72 : 2. 83	4.	208.42 kHz	5.	31 km; 3018 km^2
6.	(a) 45255 m, (b) 77.24 lakh, (c) 480 m			7.	1242.9 km^{-2}

NCERT Questions

Q.1 Which of the following freqeuncy/frequenci3es will be suitable for beyond the horizon communication using sky waves.
(a) 10 kHz (b) 10 MHz (c) 1 GHz (d) 1000 GHz

Q.2 Frequencies in the UHF range normally propagate by means of
(a) ground waves (b) sky waves (c) surface waves (d) space waves

Q.3 Digital signals (i) do not provide a continuous set of values, (ii) represent values as discrete steps, (iii) can utilize only binary system, and (iv) can utilize decimal as well as binary system. Which of the following options is true.
(a) only (i) and (iii) (b) Only (ii) and (iii) (c) Only (i), (ii) and (iii) but not (iv)
(d) All the above (i) to (iv)

Q.4 Is it necessary for a transmitting antenna to be at the same height as that of the receiving antenna for the line of sight communication? A T.V. transmitting antenna is 81 m tall. How much service area it can cover if the receiving antenna is at the ground level?

Q.5 A carrier wave of peak voltage 12 V is used to transmit a message signal. What should be the peak voltage of the modulating signal in order to have a modulation index of 75%.

Q.6 A modulating signal is a square wave as shown in figure. The carrier wave is given by

$$C(t) = 2 \sin(8 \pi t) \text{ volt}$$

(i) Sketch the amplitude modulated wave form (ii) What is the modulation index?

Q.7 For an amplitude modulated wave, the maximum amplitude is found to be 10 V while the minimum amplitude is found to be 2 V. Determine the modulation index μ. what would be the value of μ if the minimum amplitude is zero volt?

Q.8 Due to economic reasons, only the upper side bands of an AM wave is transmitted, but at the receiving station, there is a facility for generating the carrier. Show that if device is available which can multiply two signals, then it is possible to recover the modulating signal at the receiver station.

Answers

1.	b	2.	d	3.	d	4.	3258.5 sq. km
5.	9 V	6.	0.5	7.	1		

Objective Assignment – I

Q.1 Which of the following is used in optical fibres?
(a) total internal reflection (b) scattering (c) diffraction (d) refraction

Q.2 Consider telecommunication through optical fibres. Which of the following statements is not true?
(a) optical fibres can be of graded refractive index
(b) optical fibres are subjected to electromagnetic interference from outside
(c) optical fibres have extremely low transmission loss
(d) optical fibres may have homogenous core with a suitable cladding

Q.3 Antenna is
(a) inductive (b) capacitive (c) resistive above its resonant frequency
(d) resistive at resonant frequency

Q.4 In frequency modulated wave
(a) frequency varies with time (b) amplitude varies with time
(c) both frequency and amplitude vary with time
(d) both frequency and amplitude are constant

Q.5 In the night, ionosphere consists of
(a) E, F_1 and F_2 layers (b) D, E, F_1 and F_2 layers (c) E and F_2 layers (d) D, E and F_2 layers

Q.6 Laser light is considered to be coherent because it consists of
(a) many wavelengths (b) uncoordinates wavelengths
(c) coordinates waves of exactly the same wavelength (d) divergent beams

Q.7 Advantages of optical fibres are
(a) high bandwidth and EM interference (b) low bandwidth and EM interference
(c) high bandwidth, low transmission capacity no EM interference
(d) high bandwidth, high data transmission capacity and no EM interference

Q.8 The waves used by artificial satellite for communication purposes are
(a) microwaves (b) AM radiowaves (c) FM radiowaves (d) X–rays

Q.9 An oscillator is producing FM waves of frequency 2 kHz with a variation of 10 kHz. What is the modulation index?
(a) 0.67 (b) 5.00 (c) 0.20 (d) 1.5

Q.10 A laser beam is used for locating distant objects because it
(a) has small angular spread (b) is not absorbed
(c) is coherent (d) is monochromatic

Q.11 In the communication systems, AM is used for broadcasting because
(a) its use avoids receiver complexity
(b) it is more noise immune than other modulation system (c) it requires less transmitting power
(d) no other modulation system can give the necessary bandwidth for faithful transmission.

Q.12 In short wave communication, waves of which of the following frequencies will be reflected back by the ionospheric layer having electron density 10^{11} m^{-3}?
(a) 2 MHz (b) 10 MHz (c) 12 MHz (d) 18 MHz

Q.13 For sky wave propagation of a 10 MHz signal, what should be the minimum electron density in ionosphere?
(a) $\approx 1.2 \times 10^{12}$ m^{-3} (b) $\approx 10^{6}$ m^{-3} (c) $\approx 10^{14}$ m^{-3} (d) $\approx 10^{22}$ m^{-3}

Q.14 An earthquake generates both transverse (S) and longitudinal (P) sound waves in earth. The speed of S waves is about 4.5 kms^{-1} and that of P waves is about 8.0 $km\ s^{-1}$. A seismograph records P and S waves from an earth–quake. The first P wave arrives 4.0 min before the first S wave. The epicenter of the earthquake is located at a distance of about:
(a) 25 km (b) 250 km (c) 2500 km (d) 5000 km

Q.15 The maximum distance upto which TV transmission from a TV tower of height h can be received is proportional to
(a) $h^{1/2}$ (b) h (c) $h^{3/2}$ (d) h^2

Q.16 Given the circuit diagram of an M demodulator. For a good demodulation of AM signal of carrier frequency f, the value of RC should be
(a) RC = 1/f (b) RC < 1/f (c) RC $\geq$ 1/f (d) RC > > 1/f

Q.17 If the highest modulating frequency of the wave is 5 kHz, the number of stations that can be accommodated in a 150 kHz bandwidth is
(a) 15 (b) 10 (c) 5 (d) none of these

Q.18 In communication with help of antenna if height is doubled, then the range covered which was initially r would become
(a) $\sqrt{2}\ r$ (b) 3r (c) 4r (d) 5r

Q.19 A laser beam is used for carrying out surgery, because it
(a) is highly monochromatic (b) is highly coherent
(c) is highly directional (d) can be sharply focused

Q.20 Ozone layer is present in
(a) troposphere (b) stratosphere (c) ionosphere (d) mesosphere

Q.21 Ozone layer blocks the radiation of wave–length
(a) $< 3 \times 10^{-7}$ m (b) $= 3 \times 10^{-7}$ m (c) $> 3 \times 10^{-7}$ m (d) none of these

Q.22 What is the cause of Green house effect?
(a) infrared rays (b) ultraviolet rays (c) X–rays (d) radiowaves

Q.23 Ozone layer in atmosphere is useful, because if
(a) stops ultraviolet radiation (b) stops green house effect
(c) stops increase in temperature of atmosphere (d) absorbs pollueent gases

Q.24 Biological important of ozone layer is
(a) ozone layer controls O_2/H ratio in atmosphere. (b) it stops ultraviolet rays
(c) ozone layer reduces green house (d) ozone layer reflects radio waves

Q.25 The principle used in the transmission of signals through an optical fibre is
(a) total internal reflection (b) refraction (c) dispersion (d) interference

Q.26 In satellite communication
1. The frequency used lies between 5 MHz and 10 MHz
2. The uplink and downlink frequencies are different
3. The orbit of the geostationary satellite lies in the equatorial plane at an inclination of 0^{o}

In the above statements
(a) only 2 and 3 are true (b) all are true (c) only 2 is true (d) only 1 and 3 are true

Q.27 LANDSAT series of satellites move in near polar orbits at an altitude of
(a) 3600 km (b) 3000 km (c) 918 km (d) 512 km

Q.28 Which of the following is not a transducer?
(a) loudspeaker (b) amplifier (c) microphone (d) all of these

Q.29 Modulation is a process of superposing
(a) low frequency audio signal on high frequency radiowaves
(b) low frequency radio signal on low frequency audiowaves
(c) high frequency radio signal on low frequency radiowaves
(d) high frequency audio signal on low frequency radiowaves

Q.30 Audio signals cannot be transmitted directly, because
(a) the signal has more noise
(b) the signal cannot be amplified for distance communication
(c) the transmitting antenna length is very small to design
(d) the transmitting antenna length is very large and impracticable

Q.31 In frequency modulation
(a) the amplitude of the modulated wave varies as frequency of the carrier wave
(b) the frequency of the modulated wave varies as amplitude of modulating wave
(c) the amplitude of modulated wave varies as amplitude of carrier wave
(d) the frequency of modulated wave varies as frequency of modulating wave

Q.32 Of the following which is preferred modulation scheme for digital communication?
(a) pulse code modulation (PCM) (b) pulse amplitude modulation (PAM)
(c) pulse position modulation (PPM) (d) pulse width modulation (PWM)

Q.33 If a radio receiver amplified all the signal frequencies equally well, it is said to have high
(a) fidelity (b) distortion (c) sensitivity (d) selectivity

Q.34 A radio station has two channels. One is AM at 1020 kHz and the other FM at 89.5 MHz. For good results you will use
(a) longer antenna for the AM channel and shorter for the FM
(b) same length antenna will work for both (c) same length antenna will work for both
(d) information given is not enough to say which one to use for which

Q.35 Which of the following statements is wrong?
(a) Ground wave propagation can be sustained at frequencies 500 kHz to 1500 kHz?
(b) Satellite communication is useful for the frequencies above 30 MHz.
(c) Space wave propagation takes place through tropospheric space
(d) sky wave propagation is useful in the range of 30 to 40 MHz.
(e) The phenomenon involved in skywave propagation is total internal reflection

Q.36 A signal wave of frequency 12 kHz is modulated with a carrier wave of frequency 2.51 MHz. The upper and lower sideband frequencies are respectively.
(a) 2512 kHz and 2508 kHz (b) 2522 kHz and 2488 kHz
(c) 2522 kHz and 2498 kHz (d) 2522 kHz and 2498 kHz

Q.37 The sky wave propagation is suitable for radiowaves of frequency
(a) upto 2 MHz (b) from 2 MHz to 20 MHz (c) from 2 MHz to 30 MHz (d) from 2 MHz 50 MHz

Q.38 Refractive index of ionosphere is
(a) zero (b) more than one (c) less than one (d) one

Q.39 When radiowaves pass through ionosphere, phase difference between space current and capacitive displacement current is
(a) 0 rad (b) $3\pi/2$ rad (c) $\pi/2$ rad (d) π rad

Q.40 A TV tower has a height of 100 m. What is the maximum distance upto which the TV transmission can be received? $R = 8 \times 19^6$ m.

(a) 34.77 km (b) 32.70 km (c) 40 km (d) 40.70 (e) 42.75 km

Q.41 When a low lying aeroplane passes overhead, we sometimes notice a slight of the picture of our TV screen. This is due to
(a) diffraction of the signal received from the antenna
(b) interference of direct signal received by the antenna with weak signal reflected by passing aircraft
(c) change of magnetic flux occurring due to the passage of aircraft
(d) vibrations created by the passage of aircraft

Q.42 Modem is a device which performs
(a) modulation (b) demodulation (c) rectification (d) modulation and demodulation

Q.43 Which of the following device is full duplex?
(a) mobile phone (b) walky–talky (c) loud–speaker (d) radio

Answers

1	a	2	b	3	d	4	a	5	c
6	c	7	d	8	a	9	b	10	a
11	a	12	a	13	a	14	c	15	d
16	d	17	a	18	a	19	d	20	b
21	a	22	a	23	a	24	b	25	a
26	a	27	c	28	b	29	a	30	d
31	b	32	a	33	a	34	b	35	d
36	d	37	c	38	c	39	a	40	c
41	b	42	d	43	a				