UNIT 17

Electronics

After studying this chapter the students will be able to:

- distinguish between intrinsic and extrinsic semiconductors.
- distinguish between P & N type substances.
- explain the concept of holes and electrons in semiconductors.
- explain how electrons and holes flow across a junction.
- describe a PN junction and discuss its forward and reverse biasing.
- define rectification and describe the use of diodes for half and full wave rectifications.
- distinguish PNP & NPN transistors.
- describe the operations of transistors.
- deduce current equation and apply it to solve problems on transistors.
- explain the use of transistors as a switch and an amplifier.

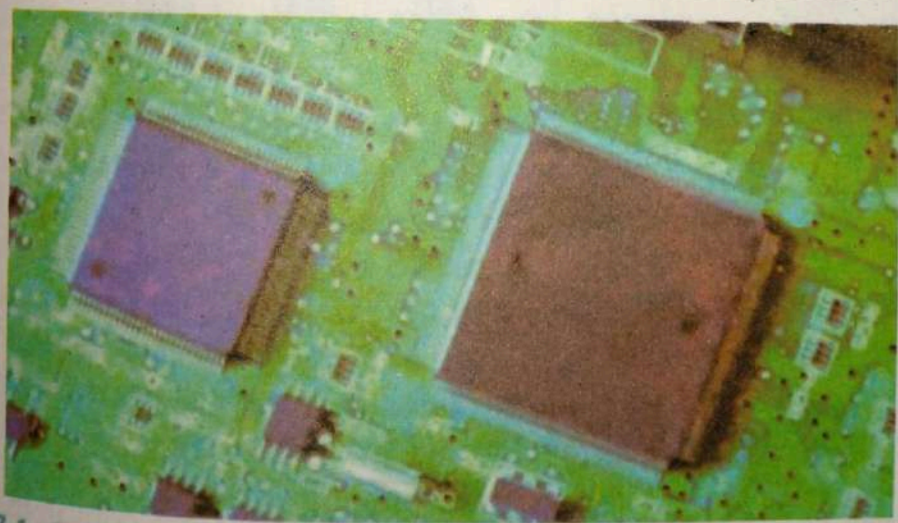


Figure 17.1: Semiconductors are materials having an intermediate electric conductivity between conductors and insulators. Semiconductors are essential to the good functioning of many modern appliances and are key products in the electronic systems.

Transistor is the basis of the integrated circuits that run our computers and many modern technologies, including programmable controllers. Many modern technologies use electro-mechanical principles to interface real world sensors and outputs to microprocessors, temperature controllers.
This unit increases students' understanding of the applications and uses of physics.

17.1 Intrinsic Semiconductor

A perfect, pure semiconductor crystal containing no impurities is called an intrinsic semiconductor. A semiconductor is considered to be pure when there is less than one impurity atom in a billion host atoms. In a silicon crystal at absolute zero temperature, the bonding arrangement may be represented by a two dimensional model, sketched in Fig17.2. In reality, the semiconductor is a three dimensional solid and the sharing of valence electrons occurs between nearest neighbour atoms in three dimensions.

In the Fig17.2: the hatched circles represent the core of the silicon atom. The four valence electrons are shown by the small black dots. The probability of valence electrons being in any place between the bonding atoms is indicated by the dotted curves. When temperature approaches to 0K, then all valence electrons are strongly bound to their atoms and they spend most of the time between neighbouring atoms. Since, all the valence electrons are engaged in covalent bonds, the bonds are complete. Free electrons do not exist in these solids. Consequently, the semiconductor nearly at 0K cannot conduct and behave as a perfect insulator.

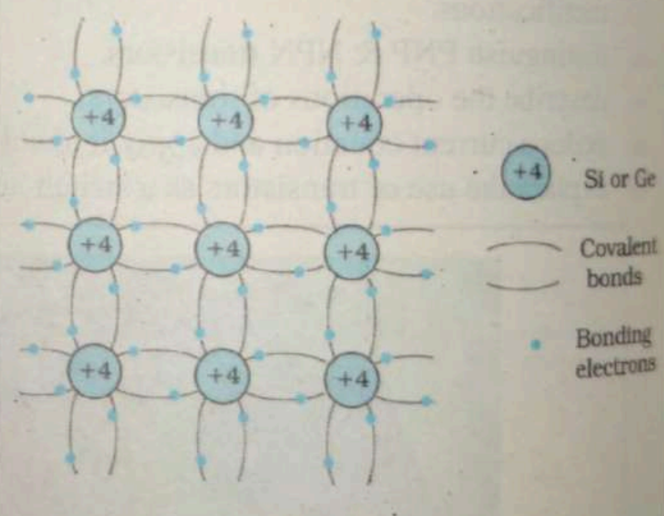


Figure 17.2 : two dimensional representation of Si or Ge structure. +4 symbols indicate inner cores of Si or Ge.

The energy band structure of a semiconductor is characterized by a valence band and a conduction band separated by the bandgap E_g as shown in the fig17.3:

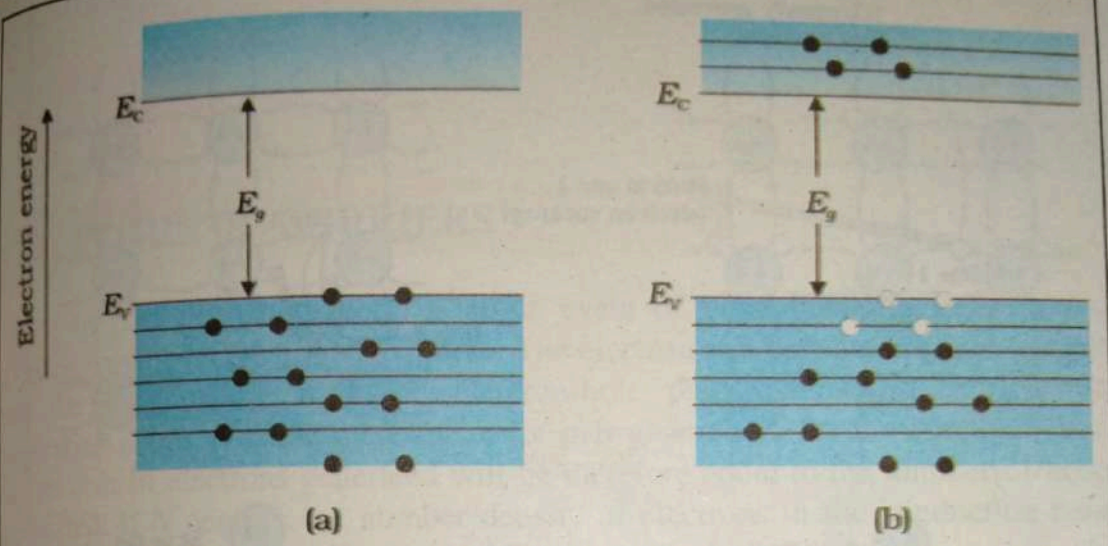


Figure 17.3: bandgap energy Eg (b) electron jumping from valence band to conduction band.

The electrons completely occupy the valence band leaving the conduction band vacant. As all the states in the valence band are full, electrons cannot be excited within the band. Electrons in the valence band do not possess enough energy to jump into the conduction band. Therefore, an externally applied electric field cannot cause a flow of current and the semiconductor nearly at 0K behaves as an insulator.

17.2 Intrinsic Semiconductor at Room Temperature

At higher temperatures, the finite thermal energy causes each atom in the crystal to vibrate about its mean position. When the vibration becomes violent, some of the electrons acquire sufficient energy and break away from the covalent bonds. The electrons librated from bonds become free electrons which vibrate more randomly in the empty spaces that exist in the atoms at fixed positions.

From an energy band point of view, it means that some of the electrons convert part of their thermal energy into potential energy. Those electrons, which acquire potential energy equal to, or in excess of, the bandgap energy E_g are excited from the valence band to the conduction band.

Thus, the *bandgap energy E_g is the minimum amount of energy required to excite an electron from valence band to conduction band.* E_g is a characteristic of the material. The number of electrons excited to the conduction band depends on the amount of thermal energy received by the crystal.

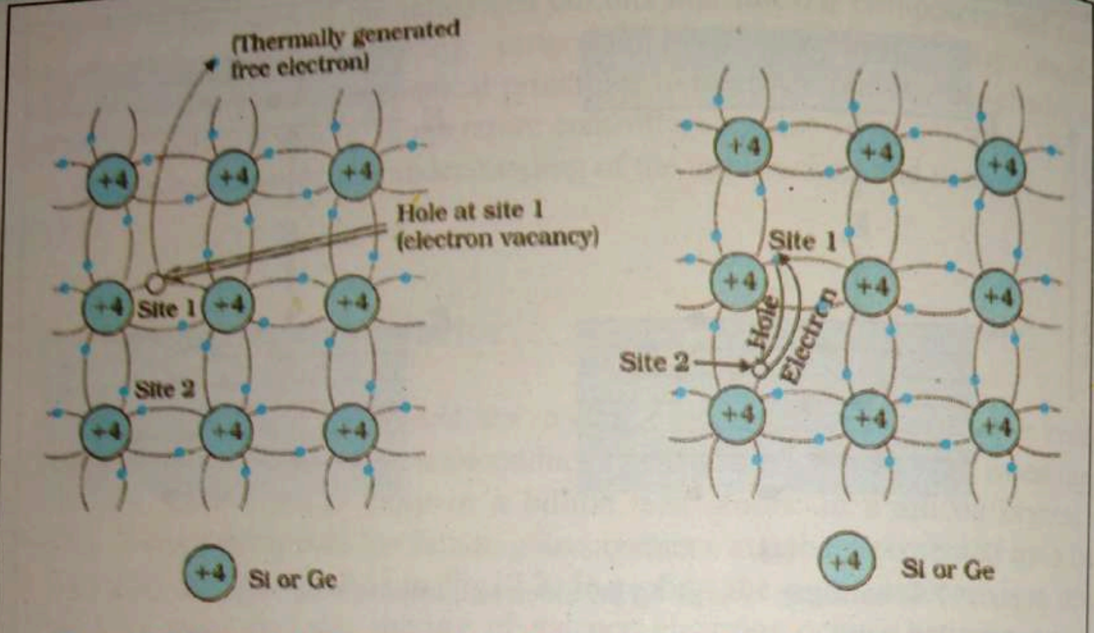


Figure 17.4: model of generation of hole at site 1 and conduction electron due to thermal energy. (b) movement of hole from site 1 to 2.

Let us now consider the situation in the valence band. When a covalent bond breaks and electron jumps to the conduction band, an empty state arises in the valence band. The electrons in the conduction band and the electrons in the valence band can be excited to upper vacant levels, within the respective bands. Therefore, if an electric field is applied, current flows in the crystal at ordinary temperatures. We may therefore, define intrinsic semiconductors as such materials in which conduction arises from thermally (or optically) excited electrons.

The motion of valence electrons in the valence band is customarily described in terms of a fictitious particle called hole which has positive charge $+e$ and its mass is equal to that of an electron m_e.

17.3 INTRINSIC CARRIERS

In pure semiconductors, a single event of bond breaking leads to two carriers, namely an electron and a hole. The electron and hole are created as a pair and the phenomenon is called electron-hole pair generation. The thermal generation is one possible mechanism for pair generation. At any temperature T, the number of electrons generated will be therefore equal to the number of holes generated. If N denotes the number density of electrons in the conduction band and P the number density of holes in the valence band, then,

$$N = P = N_i$$

where, N_i is called the intrinsic density or intrinsic concentration.

After the generation, the carriers move independently. The electron moves in the conduction band and the hole moves in the valence band.

We can also define a semiconductor as *intrinsic semiconductor in which free electrons and holes are created only by excitation of electrons from the valence band to the conduction band.*

17.3.1 DOPING OF IMPURITIES

The intrinsic semiconductors have low conductivity which is of little interest. But, when a small amount of impurity is added to semiconductor crystal then it greatly increases the conductivity of the intrinsic semiconductor.

An addition of impurity into an intrinsic semiconductor is called doping.

The impurity added is called a dopant. A semiconductor doped with impurity atoms is called an extrinsic semiconductor. Pentavalent elements from Group V or trivalent elements from Group III are used as dopants. The atoms belonging to these two groups are nearly of the same size as silicon or germanium atoms and easily substitute themselves in place of some of the host atoms in the semiconductor crystal. Thus, they are substitutional impurities and do not cause any distortion in the original crystal structure.

Two types of extrinsic semiconductors, namely N-type and P-type semiconductors are produced depending upon the group of impurity atom.

17.3.2 N-TYPE SEMICONDUCTOR

An N-type semiconductor is produced when a pure semiconductor is doped with a pentavalent impurity. Phosphorous and arsenic are the dopants normally used. Let us examine the effect of these pentavalent impurities on the carrier concentration and electrical conductivity. Suppose a phosphorous atom is doped with a silicon atom in the crystal. Phosphorus atom has five valence electrons. Out of the five electrons, only four can participate in the bonding, since there are only four bonds as shown in Fig. 17.5 (b). The fifth electron does not form a bond and remains loosely bound to the atom.

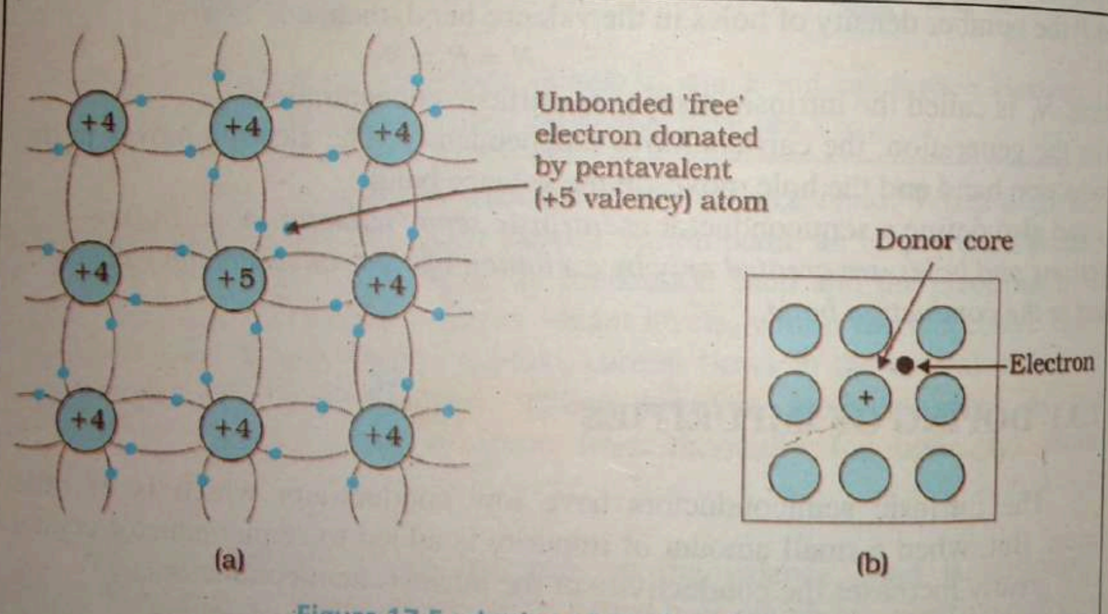


Figure 17.5 : doping of semiconductors

The impurity atoms which contribute electrons to the conduction band are called donor atoms. They produce electrons without producing holes in the valence band. At very low temperature, the donor atoms are not ionized and the conduction band is empty. At slightly elected temperatures, the donor electrons populate the conduction band. At ordinary temperatures, some electrons from the valence band are also excited into the conduction band through the intrinsic process. The holes in the valence band are smaller at ordinary temperatures. The electrons which are in majority are called majority carriers whereas the holes are called minority carriers since they are very small in number. As the current is mainly carried by electrons which are negative charge carriers, the semiconductor is called an N-type extrinsic semiconductor, where N indicates the negative sign of the majority carriers.

17.3.3 P-TYPE SEMICONDUCTOR

A P-type semiconductor is obtained by doping an intrinsic semiconductor with trivalent elements such as boron and aluminum. When a trivalent impurity atom is added with a silicon atom, it falls short of one electron for completing the four covalent bonds with its neighbors. The substitution of a host silicon atom with, say, a boron atom does not disturb the neutral environment around the boron atom. However, when an electron from a neighboring atom acquires energy and jumps to form a bond, it leaves behind a hole. The boron atom having acquired an additional electron becomes a negative ion. The hole can move freely in the valence band whereas the impurity ion is immobile.

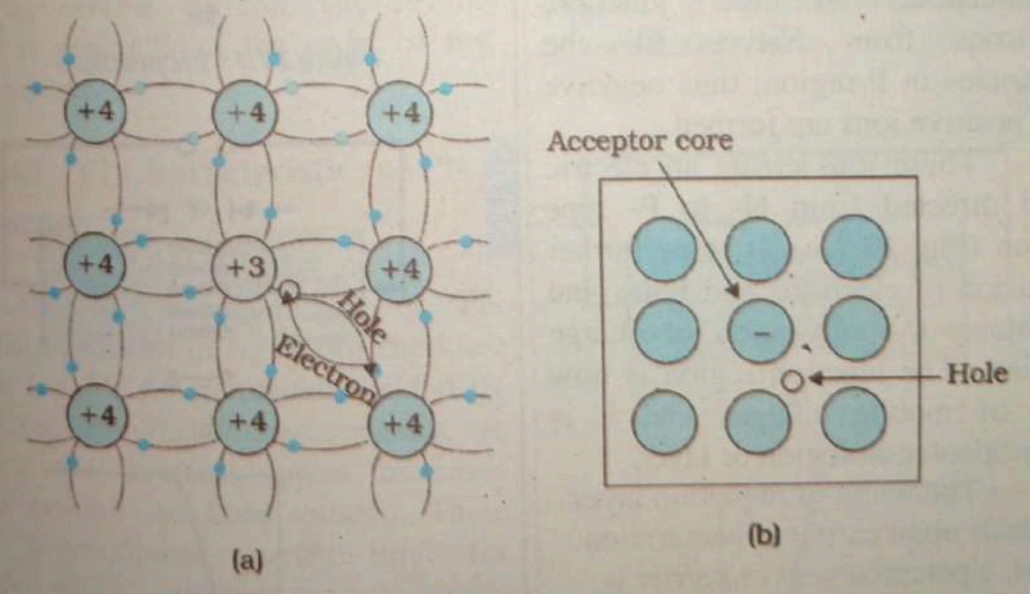


Figure 17.6: semiconductors doping

The impurity atoms which accept electrons from the valence band are known as acceptor atoms. The acceptor impurity atoms produce holes without the simultaneous generation of the electrons, in the conduction band. At ordinary temperatures, holes are produced due to intrinsic process also, by promoting electrons from valence band to conduction band. The result is that holes out number electrons in the semiconductor. Therefore, holes constitute the majority carriers and electrons are minority carriers in this type of semiconductor. As positively charged carriers are mainly contributing to the conduction process, this type of semiconductor is known as a P-type extrinsic semiconductor where P signifies positive sign of the majority carriers.

17.4 PN JUNCTION

Junction diode is formed by placing a P-type crystal with in contact with N-type crystal and subjected to high pressure so that it becomes a single piece. PN junction has special properties such as rectification. At the junction, electrons from N-type fill the vacancies in P-region; thus negative and positive ions are formed.

These ions create an electric field directed from N- to P- type region (Fig. 17.7 a). It stops further diffusion of electrons and holes and maintains the separation of charge carriers. The junction region is now free of mobile charges and it is called depletion region or layer.

The width of depletion layer depends upon carrier concentration. Thus, a potential wall or barrier is formed at the junction.

The symbol of PN junction (diode) is shown in Fig17.7.

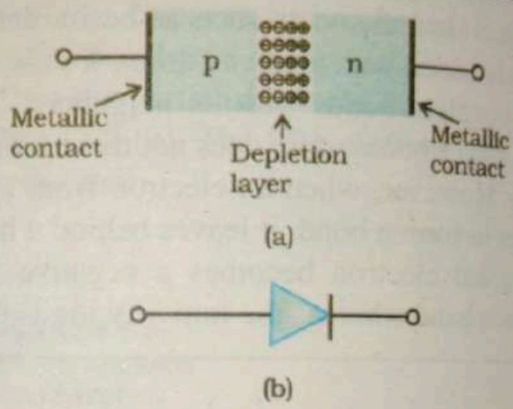


Figure 17.7 : PN junction

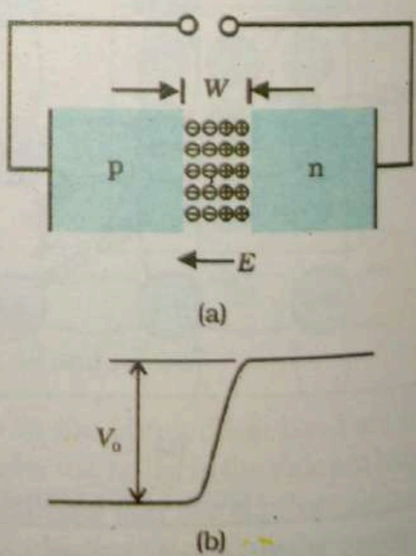
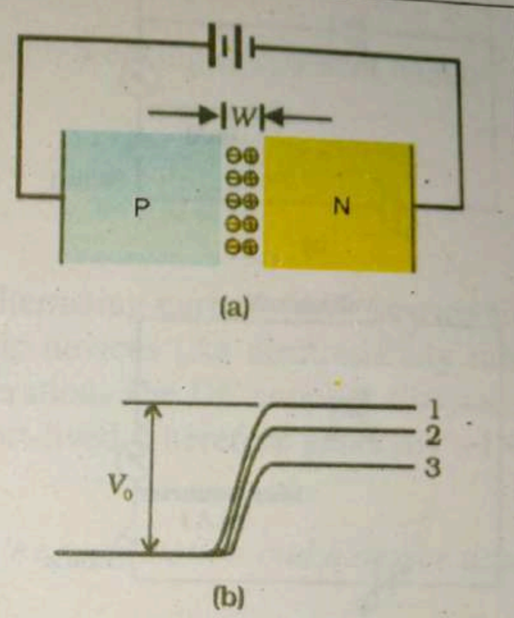


Figure 17.8 : PN junction potential barrier

When P-type region is connected with positive potential with respect to N-type region and the potential drop is increased slowly, the junction barrier-height decreases.

At one point, called as knee voltage, majority charge carriers cross the junction and the current flows, Fig17.9. This is called forward bias and the current is called forward current.



·Figure 17.9: P-N junction diode under forward bias current.

On the other hand, if P-type region is made negative with respect to N-type, no majority charge carriers cross the junction and hence there is no current. A small amount of current flows due to minority charge carriers. This biasing is called the reverse bias and the current is called as reverse current. The reverse current is generally of the order of few microamperes.

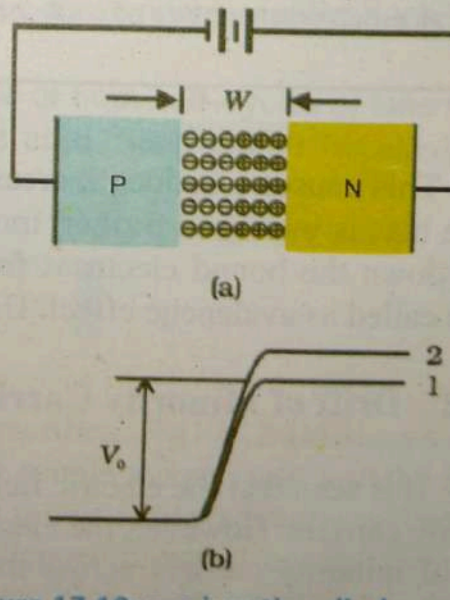


Figure 17.10: p-n junction diode under reverse bias current.

17.4.1 *VI* Characteristics of PN Junction

The *VI* characteristics of PN junction are shown in fig17.11. The knee voltage is 0.3V for germanium and 0.7V for silicon. From the *VI* characteristics, we see that the forward current increases rapidly beyond the knee voltage. There exists a maximum current limit for junction, which is decided by power ratio of the junction. Beyond that, the junction is destroyed. In reverse bias, if voltage is increased, due to available energy, covalent bonds break and large number of electrons are released.

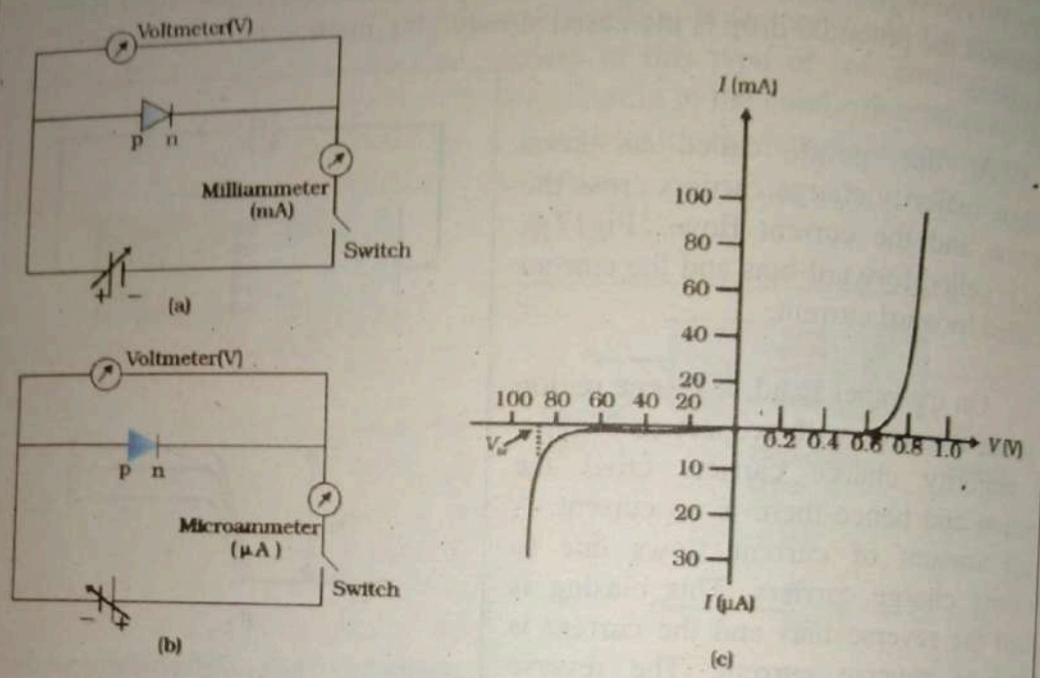


Figure 17.11: Experimental circuit arrangement for studying V-I characteristics of a p-n junction diode (a) in forward bias , (b) in reverse bias. (c) Typical V-I characteristics of a silicon diode.

This causes a sudden increase in current. This is called as zener effect. If reverse bias is increased further, minority charge carriers attain high velocity and knock down the bound electrons from covalent bonds and the current increases. This is called as avalanche effect. Using these effects, zener diodes are formed.

17.4.2 Drift of Minority Carrier

It is seen that the electric field across the junction prevents the diffusion of majority carriers. However, the electric field has the right direction to promote the flow of minority carriers across the junction. Electrons arriving at the junction from the bulk of P-region are assisted by the electric field to move into N-region. Similarly, holes in the N-region are helped to move into P-region. As a consequence, an electric current flows across the junction.

As the current is caused by an electric field it is a drift current. The net drift current through the junction is due to electron and hole which is given by.

$$I_{(drift)} = I_e + I_h$$

The minority carriers are generated through breaking of covalent bonds.

17.5 Rectification

Due to efficiency and safety reasons, alternating current (AC) is used for providing electrical power. But some electronic devices like electronically tune radio and TV receivers require DC for their operation. The DC supplies like cells, batteries etc. are expensive, low power, and short-lived. Therefore generally a DC supply is generated using an A.C. supply.

The conversion of AC into DC is called the rectification and a device used for rectification is called the rectifier.

Diodes provide compact, inexpensive means of rectification therefore it can be used as a rectifier. As we have seen, when diode is forward biased it allows the current to pass and in reverse bias it (almost) stops the current. Thus it can be used as unidirectional device (or rectifier). For most power applications, half-wave rectification is insufficient for task.

If we need to rectify AC power to obtain full use of both half-cycles of sine wave, different rectifier circuit configuration must be used. Such circuit is called full-wave rectifier.

17.5.1 Half wave rectifier

Simplest kind of rectifier circuit is half-wave rectifier. Fig17.12 (a) shows Half wave rectifier circuit which uses transformer to couple the ac input voltage from the source to the rectifier. Transformer coupling provides two advantages. First, it allows the source voltage to be stepped up or stepped down as needed. Second, the ac source is electrically isolated from the rectifier, thus preventing a shock hazard in the secondary circuit. The voltage across the secondary of the transformer, i.e. between A and B is represented as $V = V_m \sin\omega t$ and graphically it is shown in Fig 17.12 b. V_m is the peak value of the alternating voltage.

During the positive half cycle of AC, the point A becomes positive with respect to B. The diode is forward biased and the current flows through the load. For negative half cycle, point A becomes negative with respect to B and the diode is reveres biased. Practically, no current flows through the load. Thus, only half wave is rectified and it is called half-wave rectifier. During the negative half cycle of AC, diode is reverse biased and the total voltage appears across the diode. Peak inverse voltage (PIV) is the maximum voltage V_m that the rectifying diodes has to withstand, when it is reversed-biased. During negative half-cycle of the input voltage, the diode is reversed biased, no current flows through the load resistance. R_L and so causes no voltage drop across load resistance R_L and consequently the whole of the input voltage appears across the diode. Thus the maximum voltage that appears across the diode is equal to the peak value V_{max}. Thus for a half-wave rectifier

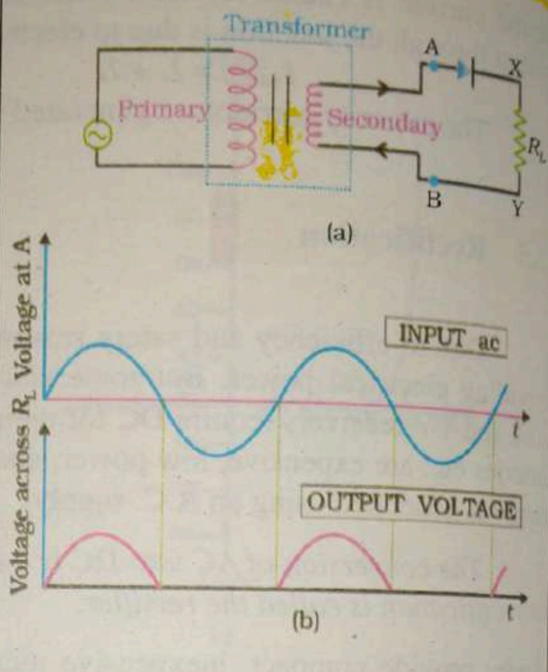


Figure 17.12 : (a) Half-wave rectifier circuit, (b) Input ac voltage and output voltage waveforms from the rectifier circuit.

$$PIV = V_{max}$$

17.5.2 Full-wave rectifier

One kind of full-wave rectifier, called center-tap design, uses transformer with center-tapped secondary winding and two diodes in alternate switching mode as shown in fig17.13. A full wave rectifier allows unidirectional (one way) current through the load during the entire cycle of the input cycle, whereas a half wave rectifier allows current through the load only during one half of the cycle.

The diodes D_1 and D_2 operate in alternate switching mode. For the first half cycle point, A becomes positive with respect to B and B becomes positive with respect to C. Thus, D_1 is forward biased and D_2 is reverse biased. The current through load is only due to D_1 while current due to D_2 is zero. For the second half cycle, point C becomes positive with respects to B and B becomes positive with respect to A. Now D_2 is forward biased ON and D_1 is reverse biased OFF. The current flows due to D_2. For the first half cycle, the current is due to D_1 and for the second half cycle, the current is due to D_2. Thus full wave is rectified.

One disadvantage of this full-wave rectifier design is necessity of transformer with center-tapped secondary winding.

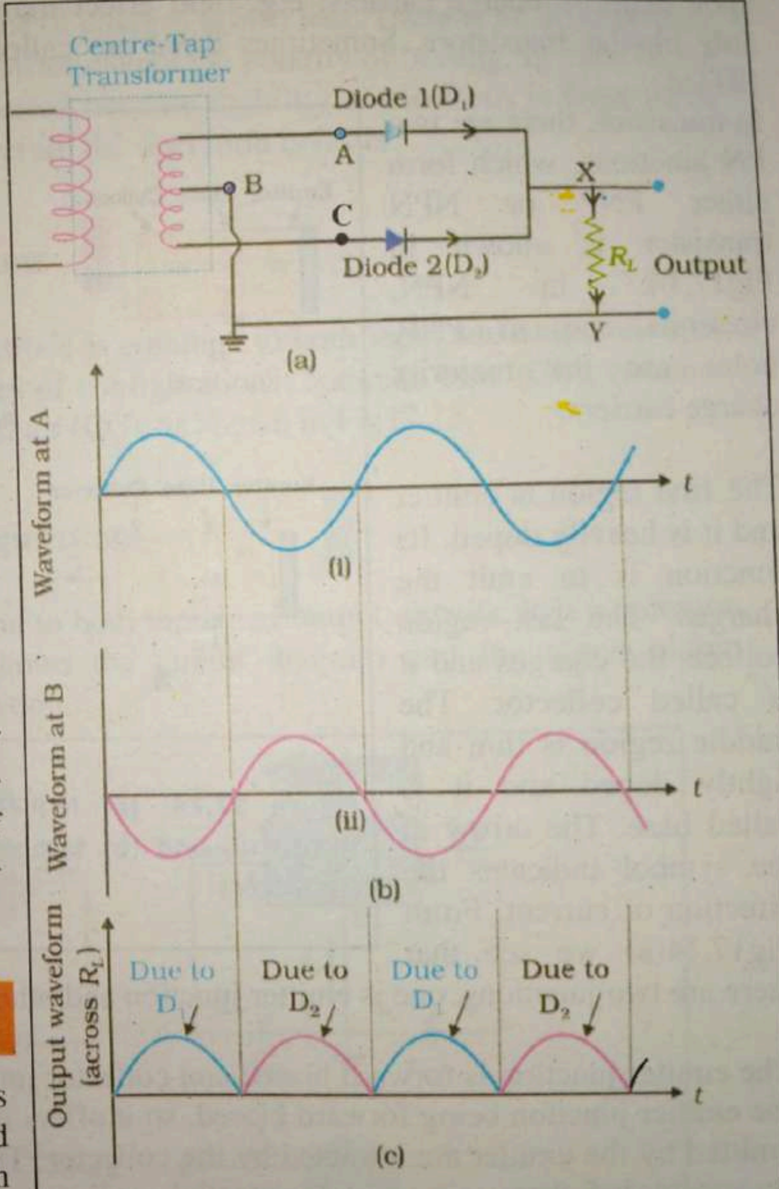


Figure 17.13:(a) A Full-wave rectifier circuit; (b) Input wave forms given to the diode D_1 at A and to the diode D_2 at B; (c) Output waveform across the load *RL* connected in the full-wave rectifier circuit.

17.6 Transistor

A transistor consists of three regions of doped semiconductors in which the current flowing is modulated by the voltage or current applied to one or more electrodes.

Modern transistors are of two types: bipolar, whose function depends upon both (majority and minority) charge carriers and unipolar, whose function depends upon majority charge carriers, e.g. field effect transistors. Here we shall study only bipolar transistors. Sometimes these are called bipolar junction transistor (BJTs).

In transistor, there are two PN junctions, which form either PNP or NPN transistor is shown in Fig17.14. In NPN, electrons and in PNP, holes are the majority charge carriers.

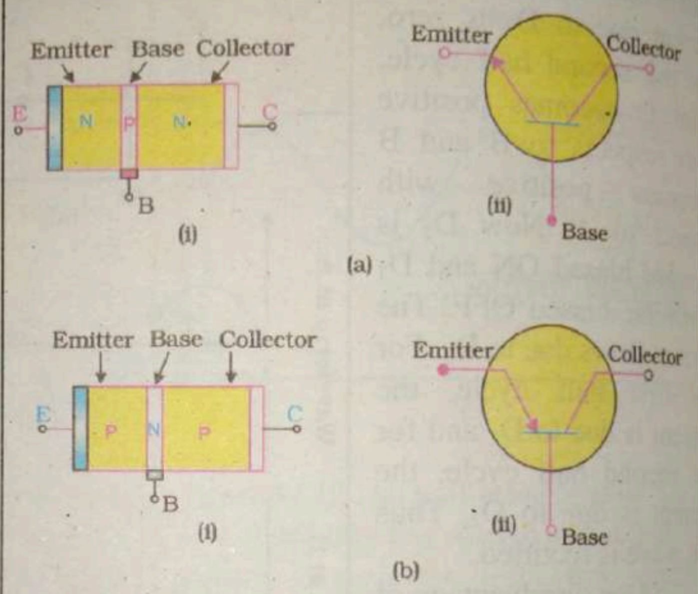


Figure 17.14: (a) N-P-N transistor and P-N-P transistor, and (b) Symbols for N-P-N and P-N-P transistors.

The first region is emitter and it is heavily doped. Its function is to emit the charges. The last region collects the charges and it is called collector. The middle region is thin and lightly doped and it is called base. The arrow in the symbol indicates the direction of current. From Fig17.14(a) we see that there are two junctions, one is emitter junction and other is collector junction.

The emitter junction is forward biased and collector junction is reveres biased. As the emitter junction being forward biased, so it offers low resistance. The charges emitted by the emitter are attracted by the collector. The collector junction being reverse biased, there exists a large potential gradient, which attracts the charges. If the collector is open (means not connected to power supply) charges return via base region. Most of the charges are collected by collector, therefore the collector current I_C is almost equal to the emitter current I_E.

Some charges, which cannot reach the collector, move via base, constituting the base current I_B, which is small. Thus addition of base current and collector current is equal to the emitter current.

Therefore,

$$I_E = I_B + I_C$$

The base is made thin and it is lightly doped, therefore, the recombination of charges is less and the transit time of charges is also less. There is no difference in operation of PNP and NPN transistor except the polarity of biasing. In most of the cases NPN, transistors are preferred because mobility of electrons is three times more than that of holes and therefore the operation is faster.

17.7 Types of configurations

In a transistor circuit, one electrode is common to both input and output circuits. Therefore there exist three types of configurations: common base (CB), common emitter (CE) and common collector (CC), as shown in Fig17.15.

17.7.1 Common base configuration

When a base is common to both input and output circuits, it is a common base configuration. Figure shows the circuit diagram and input and output characteristics of CB configuration.

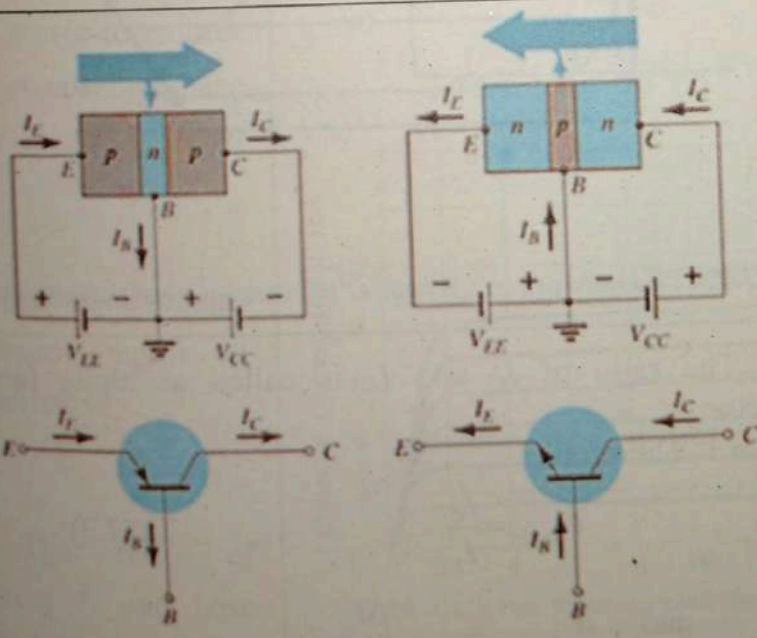


Figure 17.15: : transistors in CB mode: (a) circuit

The variation in the emitter current (I_E) with respect to change in the base-to-emitter voltage (V_{BE}) at the constant collector-to-base voltage (V_{CB}) is input characteristics and variation in the collector current (I_C) with change in collector-to-base voltage (V_{CB}) at the constant emitter current (I_E) is output characteristics. The output characteristic has three regions of operation, namely, active, cut-off and saturation. When the base-emitter junction is forward biased and the collector–base junction is revers biased, it is active region. When both, collector-base and base-emitter junctions are reverse biased it is cut-off region. The output current is zero in this case. When both the junctions are forward biased, it is saturation region. Figure shows these regions.

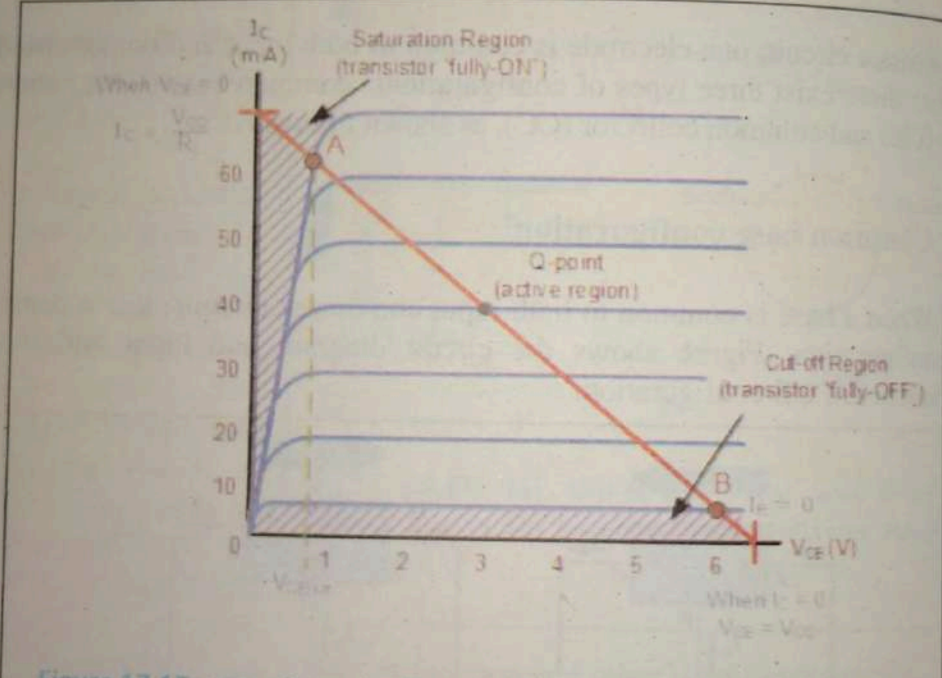


Figure 17.15: : transistors in CB mode: (b) output characteristics.

Alpha factor:. The ratio of I_C and I_E is called as alpha factor. It is an amplification factor.

Since $I_C \approx I_E$, $\alpha \approx 1$. Therefore,

$$\alpha_{static} = \frac{I_C}{I_E} \qquad ...(17.3)$$

and $$\alpha_{dynamic} = \frac{\Delta I_C}{\Delta I_E}$$

17.7.2 Common emitter configuration

In common emitter configuration the base emitter junction is forward based while base-collector junction is reverse biased.

Fig17.16: shows circuit diagram, input and output characteristics, respectively. The variation in base current (I_B) with change in base-to-emitter voltage (V_{BE}) at constant collector-to-emitter voltage (V_{CE}) are input characteristics and variation in collector current (I_C) with change in collector-to-emitter voltage (V_{CE}) at constant base current (I_B) are output characteristics.

Fig: 17.16 b shows active, cut-off and saturation region of output characteristics.

Beta factor: The ratio of collector current I_c and base current I_B is called as beta factor.

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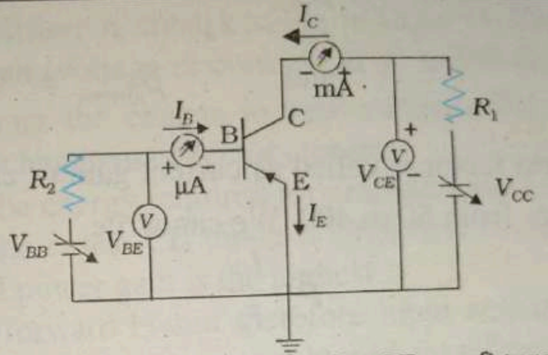
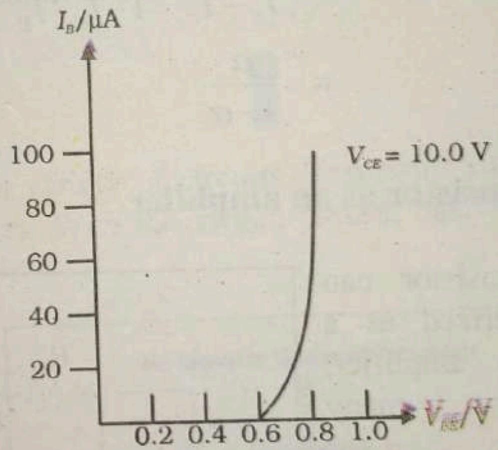
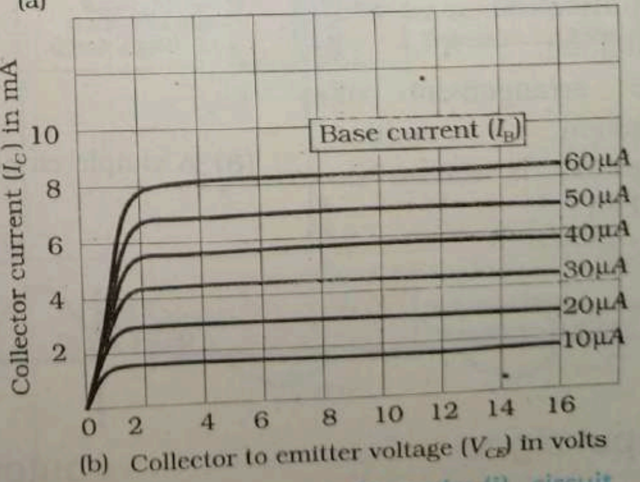


(i) Circuit arrangement for CE configuration.



(a)



(b) Collector to emitter voltage (V_{CE}) in volts

Figure 17.16: Transistor in CE mode: (i) circuit (a) input characteristics (b) output characteristics.

That is: $\beta_{static} = \frac{I_C}{I_B}$ ...(17.4)

and $\beta_{dynamic} = \frac{\Delta I_C}{\Delta I_B}$

The beta factor is called as current gain or current amplification factor. Generally it ranges from 50 to 400. We can write,

$$\beta = \frac{I_C}{I_B} \quad \text{...(17.5)}$$

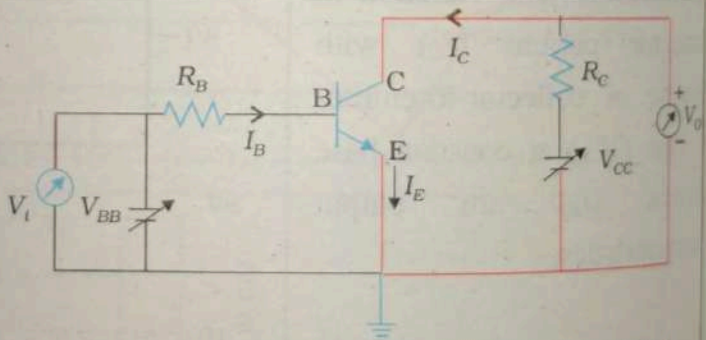
$$= \frac{I_C}{I_E - I_C} = \frac{I_C / I_E}{1 - I_C / I_E}$$

$$= \frac{\alpha}{1-\alpha} \quad \text{...(17.6)}$$

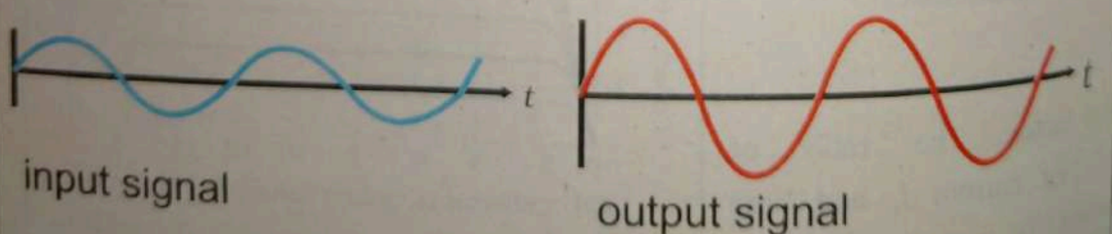
17.7.3 Transistor as an amplifier

A transistor can be characterized as a current amplifier, having many applications for amplification and switching.

The arrangement of common emitter amplifier is shown in fig17.17.



(a) A simple circuit of a CE-transistor amplifier.



(b)

Figure 17.17:

In which the input voltage appears across base and emitter, and the output voltage appears across the collector and emitter. i.e. the emitter terminal is shared by the input and output. An increase in voltage or current level is called as amplification. The transistor can be used as an amplifier. A small change in input (voltage or current) produces large change in output (voltage or current). If β is 100 then the change in collector current is 100 times the change in base current. The small change in base current produces large change in collector current.
Thus transistor acts as an amplifier. The energy required for amplification is taken from the power supply. In most of the cases, CE mode is preferred because its current and voltage gains are high and power gain is the highest.
At the input, the emitter junction is forward biased therefore input resistance is small and at the output, the collector junction is reverse biased therefore output resistance is high. The current is transferred from low-to-high resistance circuit.

17.7.4 Transistor as a switch

Transistor is used in a great variety of circuits. Transistor switches form the basis of all electronic computers. With the switch closed, base current flow causing collector to flow.
The output voltage is $V_{CE} = 0$ V (Fig17.18. **(a)**). The battery voltage is dropped across the load causing the collector voltage to fall to a very low value.
The transistor is said to be saturated. With the switch open no base current flow, therefore no collector current can flow.
The transistor is said to be cut off. $V_{CE} \approx +V$ (Fig17.18 **(b)**).
These two states are described as 0 and 1, or low and high.

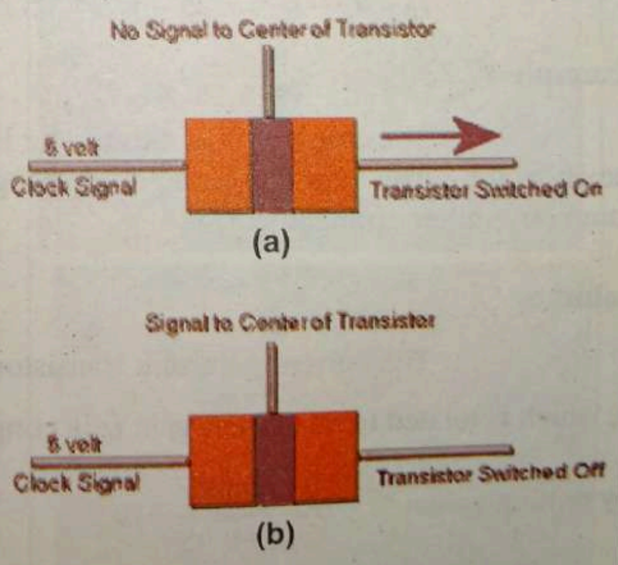


Figure 17.18: transistor on off switch

Example 17.1

A transistor is connected in a CE configuration. The collector supply voltage is 10V and the voltage drop across the 500Ω connected in the collector circuit is 0.6V. If $\alpha = 0.96$, find the (a) collector-emitter voltage (b) base current, and (c) the emitter current.

Solution:

To collector current, $I_C = \frac{V_c}{R_c} = \frac{0.6}{500}$

$= 1.2\text{ mA}$

(1) Collector-emitter voltage $V_{CE} = V_{CC} - V_C = 10\text{-}0.6$

$=9.4\text{V}$

(2)

$\alpha = \frac{I_c}{I_E} \quad or \quad I_E = \frac{I_C}{\alpha} = \frac{1.2}{0.96} = 1.25\text{ mA}$

(3) $I_E = I_B + I_C$ or

$I_B = I_E - I_C = 1.25 - 1.2 = .05\text{mA}$

Example 17.2

The constant α of a transistor is 0.95. What would be the change in the collector current corresponding to a change of 0.4mA in the base current in a common-emitter arrangement?

Solution:

The current gain of a transistor in common-emitter arrangement is β, which is related to its current-gain α in common-base arrangement $\beta = \frac{\alpha}{1-\alpha}$

by putting values $\beta = \frac{0.95}{1-0.95} = 19$

But, β is the ratio of change in collector current to the change in base current.

$$\beta = \frac{\Delta I_c}{\Delta I_b}$$

$$or\ \Delta I_c = \beta \times \Delta I_b = 19 \times 0.4 \times 10^{-3} A = 7.6 mA$$

Digital Electronics

Digital calculators, watches, modern communication systems and computers are widely used in everyday life. All persons working in various fields related to electronics must understand the performance of Digital Electronic Circuits. All sizes of computers, as we know, perform complicated task with fantastic speed and accuracy. At stores, the cash register read out digital display digital clock and watches flash the time in all city shops and restaurants. Most automobiles use microprocessors to control engine functions. Aircraft's defense sectors, factory machines and modern diagnostic in medical science are controlled by digital circuits.

The inexpensive fabrication of integrated circuits (ICs) has made the subject Digital Electronics easy to study. One small IC can perform the task of thousands of Transistors Diodes and Resistors. Many ICs are used to construct Digital Circuits. This is an exciting and rapidly growing field, which uses several principles for the working of computers, Communication systems, Digital machinery's etc.

Any device working under Digital Techniques are called Digital Systems and the Electronic Network used to make them operational is called Digital Circuits. The subject as a whole is often referred as Modern Digital Electronics.

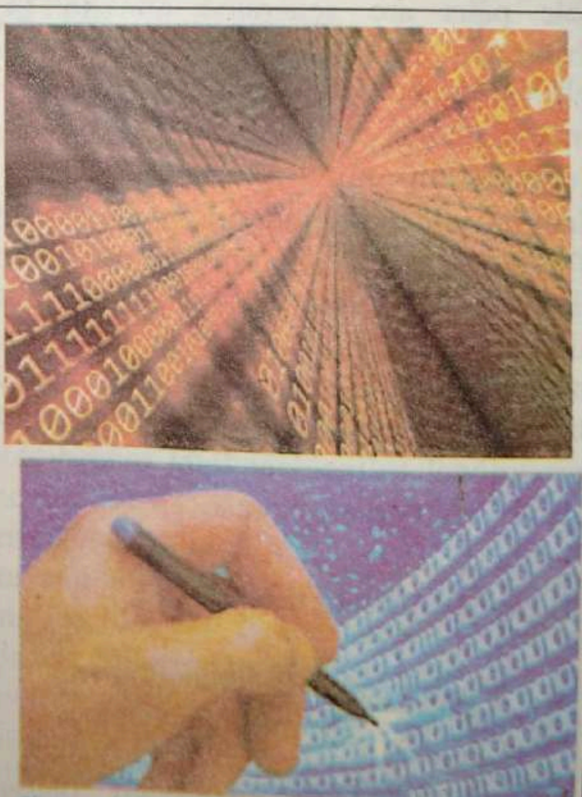


Figure 17.19

17.8 Optoelectronic junction devices

In semiconductor diodes carriers are generated by photons (photo-excitation). All such devices are called optoelectronic devices. Three commonly used such diodes are

(i) Photodiodes

(ii) Light emitting diodes (LED)

(iii) Photovoltaic

(i) Photo Diode

A Photodiode is a P-N junction diode, operated under reverse bias. When the photodiode is illuminated with light with energy ($h\nu$) greater than the energy gap (E_g) of the semiconductor, then electron-hole pairs are generated due to the absorption of photons. The diode is fabricated such that the generation of electrons holes pairs takes place in or near the depletion region of the diode. Due to electric field of the junction, electrons and holes are separated before they recombine. Electrons are collected on N-side and holes are collected on P-side giving rise to an e.m.f. When an external load is connected, current flows. The magnitude of the photocurrent depends on the intensity of incident light (photo current is proportional to incident light intensity). Hence photodiode can be used for the detection of optical signals.

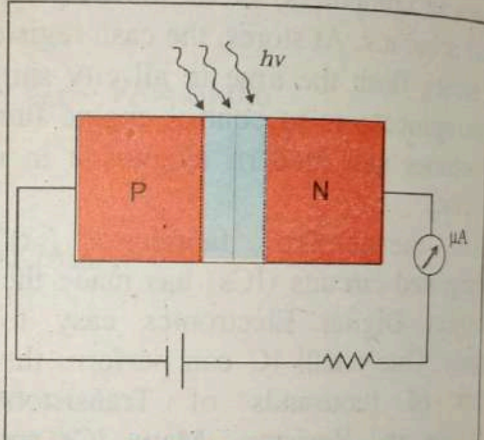


Figure 17.20: An illuminated photodiode under reverse bias

(ii) Light emitting diode

It is a heavily doped P-N junction which under forward bias emits spontaneous radiation.

When the diode is forward biased, electrons are sent from N → P (where they are minority carriers) and holes are sent

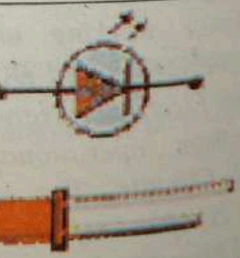


Figure17. 21: LED

from P → N (where they are minority carriers). At the junction boundary the concentration of minority carriers increases compared to the equilibrium concentration (i.e., when there is no bias). On either side of the junction, excess minority carriers are there which recombine with majority carriers near the junction. As a result energy is released in the form of photons. The diode is encapsulated with a transparent cover so that emitted light can come out (diode converts electrical energy into light). These LEDs are widely used in remote controls, burglar alarm systems, optical communication, etc. LEDs have fast action, long life and endurance and fast on-off switching capability.

(iii) Solar cell

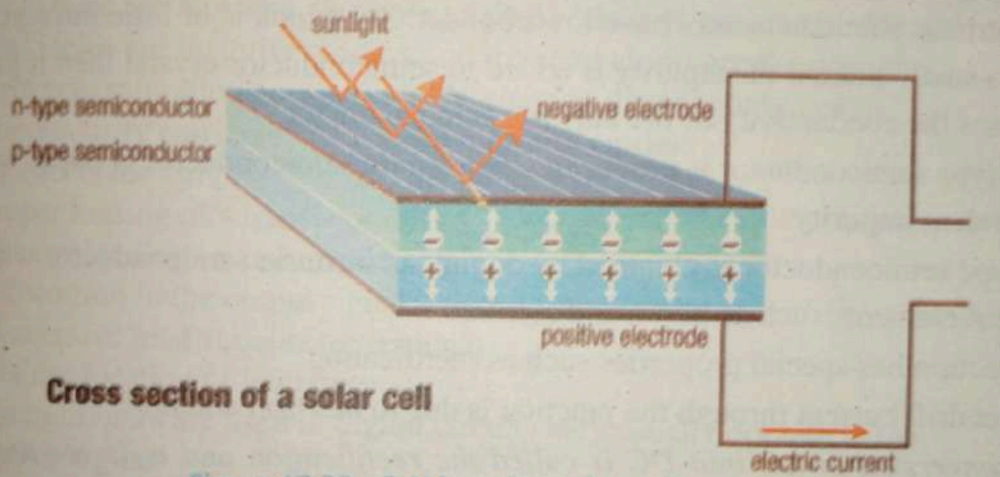


Figure 17.22 : P-N junction solar cell

A solar cell is also a P-N junction which generates e.m.f. when solar radiation falls on the P-N junction. It works on the same principle (photovoltaic effect) as the photodiode, except that no external bias is applied and the junction area is kept much larger. A simple P-N junction solar cell is shown in Fig17.22. The generation of emf by a solar cell, when light falls on, it is due to the (i) generation of e-h pairs (ii) separation of electrons and holes .(Electrons are swept to N-side and holes to P-side) (iii) the electrons reaching the N-side are collected by the front contact and holes reaching P-side are collected by the back contact. Thus P-side becomes positive and N-side becomes negative giving rise to photo voltage. When an external load is connected as shown in the Fig. 17.22 (a) a photocurrent I_L flows through the load. Solar cells are used to power electronic devices in satellites and space vehicles and calculators.

Key points

- Semiconductors are materials having an intermediate electric conductivity between conductors and insulators.
- Chemically pure semiconductors are known as intrinsic semiconductors.
- In pure semiconductors, a single event of bond breaking leads to two carriers, namely an electron and a hole.
- The minority carriers are generated through breaking of covalent bonds.
- The intrinsic semiconductors have low conductivity which is of little interest. But, when a small amount of impurity is added to semiconductor crystal then it greatly increases the conductivity of the intrinsic semiconductor.
- An N-type semiconductor is produced when a pure semiconductor is doped with a pentavalent impurity.
- A P-type semiconductor is obtained by doping an intrinsic semiconductor with trivalent elements such as boron and aluminum.
- PN junction has special properties such as rectification.
- The net drift current through the junction is due to electron and hole.
- *The conversion of AC into DC is called the rectification and a device used for rectification is called the rectifier.*
- In transistor, there are two PN junctions, which form either PNP or NPN transistor.
- An increase in voltage or current level is called amplification. The transistor can be used as an amplifier.

Exercise ?

Multiple choice questions:

Each of the following questions is followed by four answers. Select the correct answer in each case.

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 dopants.
   (d) Holes are majority carriers and trivalent atoms are the dopants.
2. The reverse saturation current in a PN junction diode is only due to
   (a) majority carriers (b) minority carriers
   (c) acceptor ions (d) donor ions
3. Improper biasing of a transistor circuit produces
   (a) heavy loading of emitter current
   (b) distortion in the output signal
   (c) excessive heat at collector terminal
   (d) faulty location of load line
4. When transistors are used in digital circuits they usually operate in the:
   a. active region
   b. breakdown region
   c. saturation and cutoff regions
   d. linear region
5. Most of the electrons in the base of an NPN transistor flow:
   a. out of the base lead b. into the collector
   c. into the emit d. into the base supply
6. In a transistor, collector current is controlled by:
   a. collector voltage b. base current
   c. collector resistance d. all of the above

Conceptual Questions

1. Explain the formation of depletion re[...] N-junction.

2. Explain why in a transistor (a) the base is thin lightly doped and (b) the collector is large in size.
3. Explain why the base current is weak as compared to collector current?
4. Why the emitter base junction is forward biased and collector base junction is reverse biased?
5. Draw the diagram of NPN and PNP transistors and explain how it works.
6. Distinguish between N-type semiconductors and P-type semiconductors.
7. A P-type semiconductor has a large number of holes but still it is electrically neutral. Why?
8. Explain why CE configuration is widely used in amplifier circuits?
9. Why transistor is called current amplification device?
10. A doped semiconductor has 10^{10} silicon atoms and 10 trivalent atoms. If the temperature is 25C°, how many free electrons and holes are there inside the semiconductor?

Comprehensive questions

1. Describe the energy band structure of insulator, semiconductor and conductor.
2. Explain the significance of depletion layer in an equilibrium state in a PN-junction. Give energy band diagram.
3. Explain how PN-junction acts as a half-wave rectifier.
4. Explain the working of transistor as an amplifier?
5. Draw the circuit for a half wave rectifier and full wave rectifier.
6. Compare the advantages and disadvantages of full wave rectifier and half wave rectifier.
7. Deduce the relation between α and β of a transistor.
8. Explain what is meant by the following terms.

   (a) P-type and N-type materials
   (b) Doping of semiconductors
   (c) P-N junction
   (d) Forward biasing
   (e) Reverse biasing
   (f) Minority carriers
   (g) Majority carriers

9. Discuss the conductivity of extrinsic semiconductor and its band gap energy.
10. Explain the formation of depletion region in a PN-junction.
11. What causes majority carriers to flow at the moment when P-region and N-region are brought together? Why does this flow not continue until all the carriers have recombined?
12. Discuss the carrier's movements across the emitter base and collector base junctions.
13. What is the effect of increasing the junction temperature of a diode on the reverse saturation current?
14. In a transistor the emitter and collector are of the same type of semiconducting material. Yet they cannot be interchanging in a circuit connection. Explain.
15. Is the frequency content of the output of a half wave rectifier and full wave rectifier the same? Explain.
16. Describe the advantages of digital electronics.

Numerical Problems

1. In a certain circuit, the transistor has a collector current of 10 mA and a base current of 40 μ A. What is the current gain of the transistor?

   (250)

2. The current flowing into the base of a transistor is 100 μ A. Find its collector current I_C, its emitter current I_E, and the ratio I_C / I_E if the value of current gain β is 100.

   (10 mA, 10.1mA, 0.99)

3. A transistor is connected in CE configuration. The voltage drop across the load resistance (R_C) 3 k Ω is 6 V. Find the base current. The current gain β of the transistor is 0.97.

   (2.06×10^{-3} A)