Unit 17

ELECTRONICS

Major Concepts (16 periods)

- Intrinsic and extrinsic semiconductors
- P & N types substances
- Electrical conductivity by electrons and holes
- PN junction
- Forward and reverse biased PN junction characteristics
- Half and full wave rectification
- Uses of specially designed PN junctions
- Transistor and its characteristics
- Transistor as an amplifier (C-E configuration)

Conceptual Linkage

This chapter is built on Introductory Electronics Physics X

Students Learning Outcomes

After studying this unit, 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 junctions 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.

INTRODUCTION

Electronics is the branch of Physics in which we study about the emission, flow behaviour, effects and control of electrons under the action of some devices, such as, diode, transistor etc. These devices are called semiconductor devices because the role of semiconductor materials is very important in fabrication of these devices. For example, when P-type and N-type semiconductors are prepared in the form of a single crystal such that its one half is P-type and the other half is N-type. Then the region dividing these two types is called PN-junction. The PN-junction is the first step towards the fabrication of semiconductor devices, such as diode, transistor, integrated circuits (ICs) etc. For example, a semiconductor diode consists of one PN-junction. Similarly, a transistor consists of two PN-junctions and so on. These semiconductor devices can be used as amplifier, filter, rectifier, oscillator, a switch and so many others. In this unit, we will study intrinsic and extrinsic semiconductors, various semiconductor devices and their fabrications. We will also explain the working principle, function and application of these semiconductor devices.

17.1 INTRINSIC AND EXTRINSIC SEMICONDUCTORS

Semiconductors are classified into two classes:

I. Intrinsic Semiconductor II. Extrinsic Semiconductor

I. Intrinsic semiconductors

An intrinsic semiconductor also called an undoped semiconductor is a pure semiconductor without any significant impurity or dopant species added.

In the previous unit, we have studied that the resistivity of semiconductor materials lies between insulators and conductors. For example, germanium (Ge) and silicon (Si) are semiconductor materials. In pure form and at low temperature i.e., at 0K, they act as insulators. Germanium and silicon have crystalline structure and these materials are tetravalent, i.e., each atom has four valence electrons in its outermost shell. Each atom shares its four valence electrons with each of its four neighbouring atoms as shown in Fig.17.1(a).

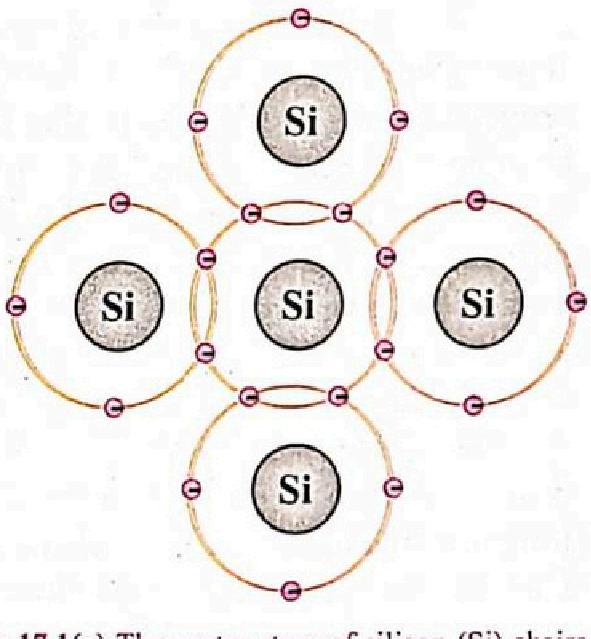

Fig.17.1(a) The centre atom of silicon (Si) shairs its electrons with its four neighbouring atoms of Si and the number of electrons in outermost shell become eight.

In this way, the number of electrons in the outermost shell become eight and their atoms make covalent bond to one another as shown in Fig. 17.1(b). This arrangement gives a very stable electronic configuration to semiconductor materials. At absolute zero temperature, the covalent bonds among the atoms are very strong and there are no free electrons. Thus, in this condition the semiconductor behaves as a perfect insulator. Similarly, in terms of energy band, valence band is completely filled, and conduction band is empty. Though the forbidden gap between valence and conduction bands is very small yet, there are no free electrons available to jump from valence band to conduction bond as shown in Fig.17.2. Therefore, semiconductor behaves like insulator at low temperature.

When the temperature is raised even at room temperature, some covalent bonds in semiconductor break down the electrons become free and leaving vacancies in the valence band called holes where holes act as positive charges. Let the covalent bond is broken and an electron is free from site A and it leaves behind a hole. The electron at site B may jump into the hole at site A. Another hole is created at site B. Similarly, another electron at site C may jump into the new hole at site B and so on. Due to the movement of electrons, the hole appears at site G while the electron moves from G to A as shown in Fig.17.3. Thus, both electrons and holes are movable charges and they contribute to conduction in semiconductor material.

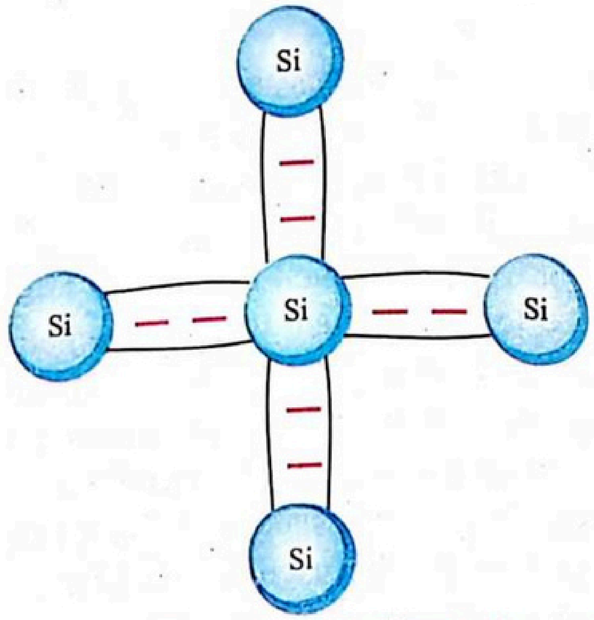

Fig.17.1(b) The atoms of silicon (Si) make covalent bond to one another.

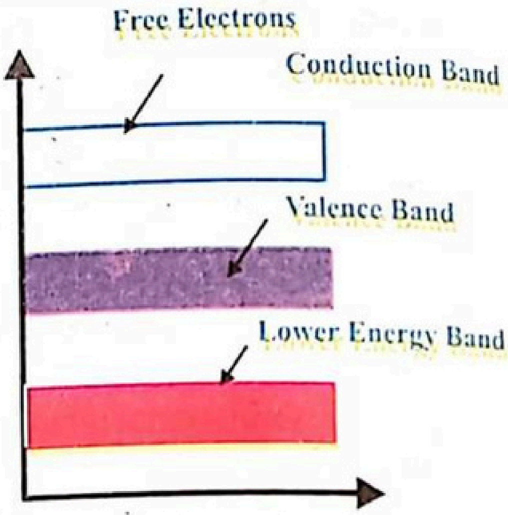

Fig.17.2 Valence band has no free electrons.

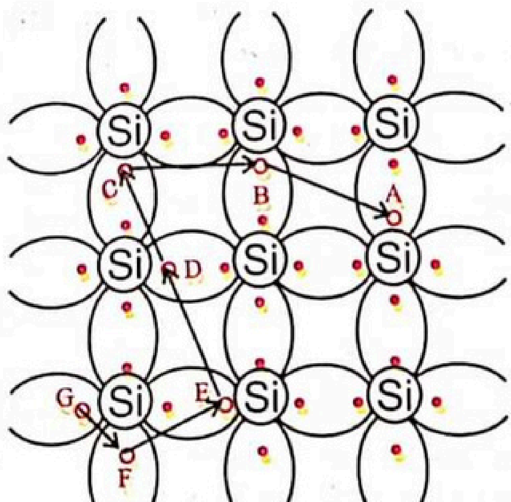

Fig.17.3 Moment of electrons and holes in a crystal structure of a semiconductor

In terms of energy band, when the temperature is increased, the valence electrons can gain enough thermal energy to jump from valence band to conduction band as shown in Fig.17.4. The number of electrons from valence band to conduction band depends upon the temperature of the semiconductor. It is a reason that semiconductor have negative temperature co-efficient of resistance.

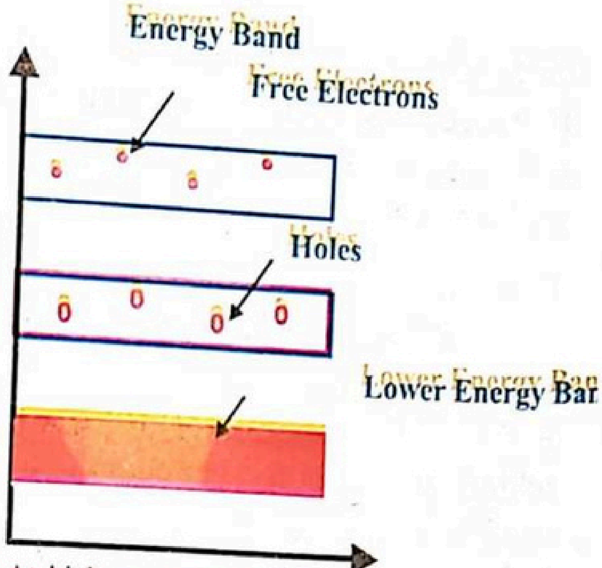

Fig.17.4 At high temperature, the energy bands have electrons and holes which cause of conduction

II Extrinsic semiconductors

The electrical conductivity of intrinsic semiconductor is small at room temperature. The conductivity of semiconductor can be improved by adding impurity of either pentavalent or trivalent atoms into a pure semiconductor. The process of adding impurity to a pure semiconductor is known as doping, and the doped semiconductors are known as extrinsic semiconductors. The doping should be done under a specific ratio of $1:10^8$, i.e., there should be only one atom of impurity in 10^8 atoms of pure semiconductor. The extrinsic semiconductors are classified into two classes.

i. N-type semiconductors ii. P-type semiconductors

N-type semiconductors

When an impurity of pentavalent (valency 5) element like arsenic (As), antimony (Sb), phosphorous (P) etc is added to a pure semiconductor (germanium, silicon) in a specific ratio then such doped semiconductor is called N-type semiconductor. An impurity of pentavalent element like phosphorous is added to a pure silicon. The phosphorus has five valence electrons in its outermost shell and silicon has four valence electrons. Therefore, the four valence electrons of phosphorus atom form covalent bonds with the four neighbouring silicon atoms. As there is no room in the Si crystal for the fifth electron of the phosphorus atom thus it becomes free as shown in Fig.17.5. It means each added phosphorus atom provides a free electron. In this way we have a number of free electrons which cause

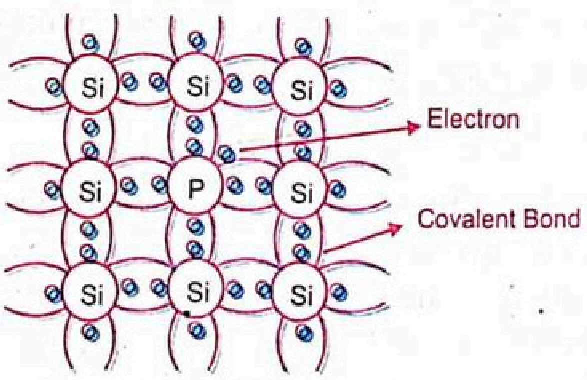

Fig.17.5 Doping of Silicon Si atoms with Phosphorus P, their covalent bonds have one free electron.

of conduction in such extrinsic semiconductor. Since pentavalent elements provide free electrons to the semiconductor crystal, so this type of extrinsic semiconductor is called donor or N-type semiconductor. In N-type semiconductors free electrons are majority charge carriers while holes are treated as minority carriers.

P-Type semiconductors

When an impurity of trivalent element (valency 3) like boron (B), gallium (Ga), Indium (In) etc. is added to a pure semiconductor (germanium, silicon) in a specific ratio then such doped semiconductor is called P-type semiconductor. To explain the formation of P-type semiconductor, consider a trivalent impurity like boron (B) which is added to a pure silicon. Boron has three valence electrons in its outermost shell while silicon has four electrons. Therefore, the three valence electrons of boron form covalent bonds with four neighbouring silicon atoms, this leaves one of the four silicon atoms with an unsatisfied bond i.e., leaves a vacancy called holes as shown in Fig.17.6. Since one added atom of boron provides one hole, so, a small amount of boron added to pure semiconductor provides a number of holes. These hole act as positive charge carrier and cause of conduction in the extrinsic semiconductor called P-type semiconductor. As the created hole accepts the electrons, so the P-type semiconductors are also called acceptor semiconductors. In P-type semiconductor holes are majority charge carriers while electrons while minority charge carriers.

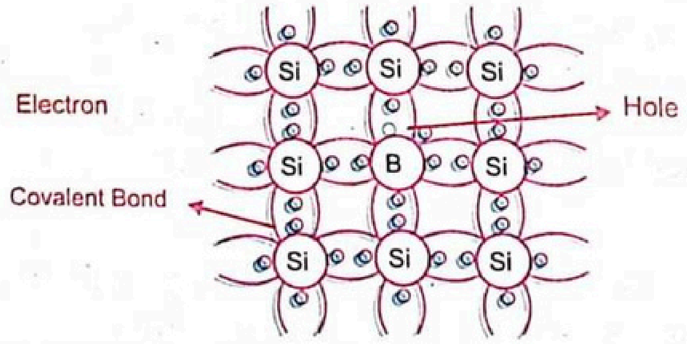

Fig.17.6 Doping of Silicon Si atoms with Boron B, their covalent bonds have one free hole.

17.2 THE PN JUNCTION

In this case semiconductor materials (Silicon or Germanium) are fabricated in such a way that its one half is doped by P-type impurities and the other half by N-type impurities. The boundary dividing the two halves as shown in Fig.17.7 is known as PN-junction. The PN-junction has important role in the fabrication of semiconductor devices such as diode, transistor, solar cell etc.

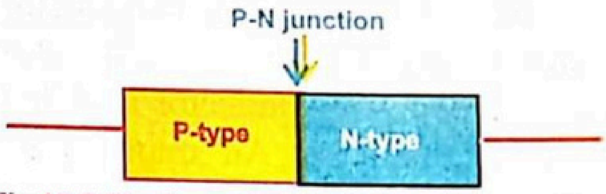

Fig.17.7 The formation of PN-Junction.

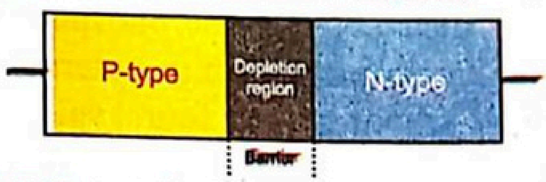

Fig.17.8 A deflection region layer at the PN-junction.

We have discussed that P-type semiconductor has holes as majority charge carriers and N-type semiconductor has free electrons as majority charge carriers. Therefore, there is a great concentration of holes in P-type than in N-type. Similarly, concentration of electrons is greater in N-type than in P-type. Thus, there is diffusion of majority carriers across the junction and they are allowed to recombine to one another. That is, holes diffuse from P-type to N-type. So P-type losses holes and this creates a region of negative charges called immobile negative charges. Similarly, electrons diffuse from N-type to P-type and N-type losses electrons. This creates a region of positive charges called immobile positive charges. These two regions of positive and negative immobile charges produce the narrow region at the junction called depletion region as shown in Fig.17.8. Once the depletion region is formed then further diffusion of charge carriers across the junction stops. Thus, one can say that depletion layer acts as a barrier to the moment of charge carrier across the junction. The width of the depletion region depends upon the concentration of the majority carriers i.e., more the carriers concentration less is the width of the depletion layer and vice versa.

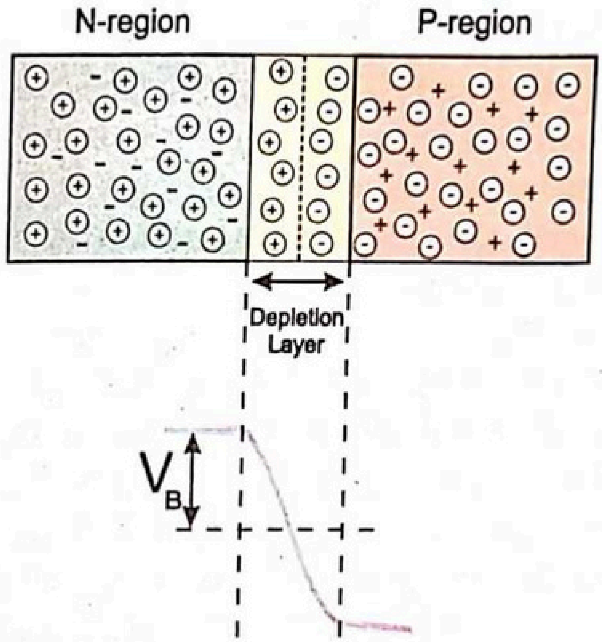

Fig.17.9 Applied potential V_o across the PN-junction

The depletion region consist of two oppositely immobile charged layers on its two sides. So the separation of these oppositely charged layers causes of potential barrier across the junction which is called junction or barrier potential as shown in Fig.17.9. Barrier potential depends upon level of doping, temperature and nature of materials. The typical value of potential barrier is about 0.3V for germanium and 0.7V for silicon.

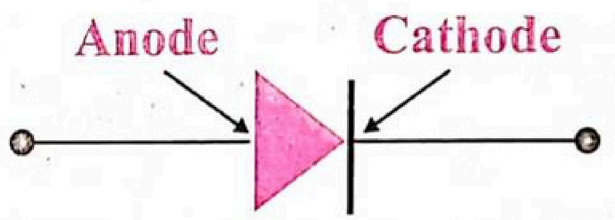

Fig.17.10 A symbol of semiconductor diode. Arrow represents P-type and bar N-type.

The PN-Junction is indeed an electronics device, named as a junction diode or semiconductor diode. The symbol of semiconductor diode is shown in Fig.17.10, which consists of an arrow and a bar. The arrow represents P-type and it is called anode, while bar represents N-type and it is called cathode.

17.3 BIASING A PN-JUNCTION

The process of applying an external voltage across the PN-Junction or any other semiconductor device is called biasing. In case of PN-Junction, there are two types of biasing.

I Forward biased   II Reverse biased

I Forward biased PN junction

When a PN-Junction is connected to a battery (source) such that the positive terminal of the battery is connected to P-type and the negative terminal of the battery is connected to N-type as shown in Fig.17.11, then such biasing is known as forward biased PN-Junction. In forward biased, the majority carriers of each region are repelled by the terminals of the battery towards the junction. Thus, the width of depletion region is further decreased, which results in less resistance across the junction. When the potential difference is applied across the junction then at certain value of voltage i.e., 0.7V for Si and 0.3V for Ge, the majority charge carrier gains enough energy to cross the junction. Thus, the flow of current starts in the circuit called forward biased current whose value can be increased by increasing the applied voltage.

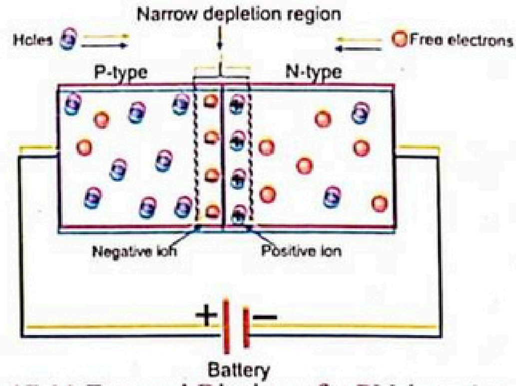

Fig.17.11 Forward Biasing of a PN-junction.

Forward biased characteristics of the PN-junction

The graph between the applied forward voltage across the PN-junction diode and flow of current through the diode is known as forward biased characteristics of the PN-junction diode.

A schematic circuit diagram for forward biased PN-Junction diode is shown in Fig.17.12. When the applied voltage across the diode is increased, the current through the diode also starts increasing which can be observed on a voltmeter and a milli-ammeter. Now when different values of the applied voltage and current are drawn on a graph then we have a curved line OPQ called forward bias

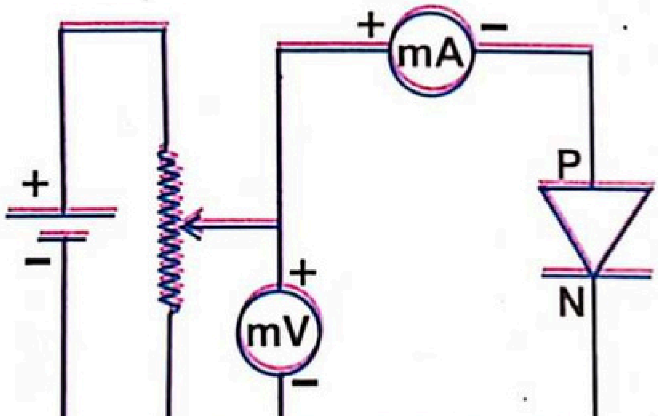

Fig.17.12 A schematic circuit diagram for forward biased characteristics of a PN-junction diode.

characteristics of a diode as shown in Fig.17.13. The reciprocal of the slope of this curved line is equal to the resistance of the diode. i.e.,

$$r = \frac{1}{\left(\frac{\Delta I}{\Delta V}\right)}$$

$$r = \frac{\Delta V}{\Delta I} \quad ......(17.1)$$

The nature of such curved line is explained as; initially when the applied voltage is increased from zero value, the current also increases but at very slow rate due to the barrier potential. It is represented by the section OP of the curved line, where the barrier potential is 0.3V for Ge and 0.7V for Si. This voltage is also called knee voltage. Once the applied voltage exceeds the knee voltage, the current through the diode increases rapidly. It is represented by the section PQ of the curved line. Below the knee voltage, we have a curve line but above the knee voltage, there is a straight line. i.e., where diode behaves like an ordinary conductor.

FOR YOUR INFORMATION

- Electrical circuit has passive components (resistor, capacitor, inductor etc.) that converts electrical energy into other form of energy such as: light, heat, sound, etc.
- Electronic circuit has active components (diode, transistor etc.) that controls the flow of electrons for particular task such as amplifier, rectifier, oscillator, etc.

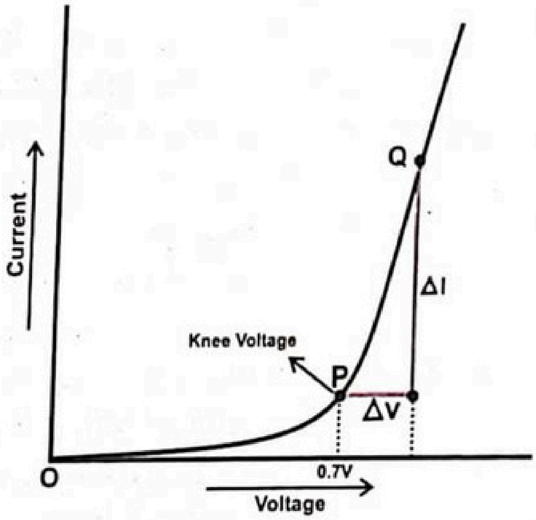

Fig.17.13 A forward biased characteristics of a diode due to the applied voltage V and flow of current I.

II Reverse biased

When PN-Junction is connected to a battery in such a way that its P-type is connected to negative terminal of the battery and its N-type is connected to positive terminal of the battery as shown in Fig.17.14 Then such biasing is known as reverse biased PN-junction. In reverse biasing, the majority carriers of each sides of the PN-Junction are attracted away from the junction by the terminals of the battery. Therefore, the width of the depletion region is further increased, and

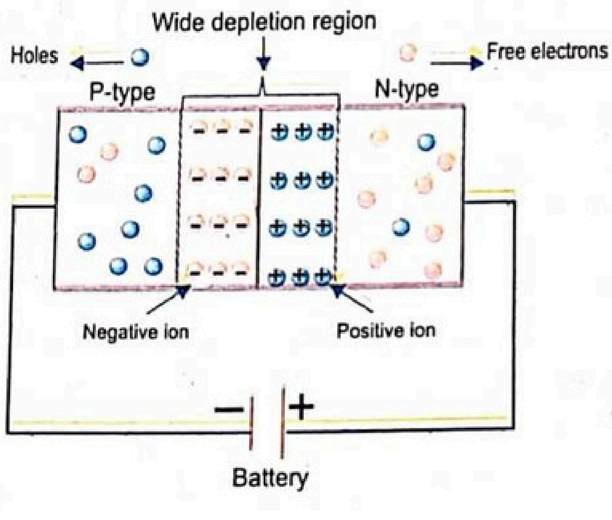

Fig.17.14 Reverse biasing of a PN-junction.

the junction offers a high resistance. Thus, there is no flow of current through a diode due to the majority carriers. However, a very small current of the order of micro-amperes flows due to minority carriers called reverse current which can be neglected.

Reverse bias characteristics

The graph between the applied reverse voltage across the PN-junction diode and the reverse current through the diode is known as reverse biased characteristics of the PN-junction diode.

A schematic circuit diagram for reverse bias PN-Junction diode is shown in Fig.17.15. The reverse voltage across the diode is increased from zero value and its corresponding value of reverse current is very small i.e., of the order of microampere. It is due to the reverse biasing of a diode, there is high resistance across the junction. This small reverse current is due to the minority carriers and graphically it is represented by the section OPQ as shown in Fig.17.16. When the reverse voltage is increased beyond the limit at point P, the minority charge carriers gain large kinetic energy and they may break the junction of the diode. If the junction of the diode breaks, the reverse current increases very rapidly. This large reverse voltage is called breakdown voltage. After breaking the junction, the reverse current increases very sharply. It is represented by the section PQ as shown in Fig.17.16.

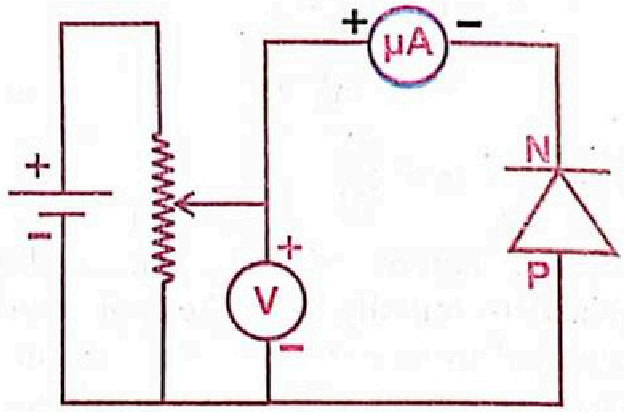

Fig.17.15 A schematic circuit diagram for reverse biased characteristics of a PN-junction diode.

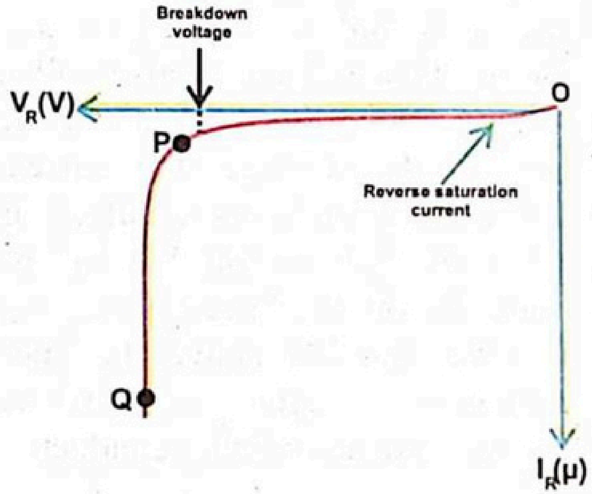

Fig.17.16 Reverse biased characteristics of a diode due to the applied reverse voltage V and reverse current I.

Example 17.1

How much is the forward current for 0.7V of forward voltage when the resistance across the PN-junction is 5Ω.

Solution:

Forward current = I_F = ?

Forward voltage = V_F = ?

Resistance across the junction = $r = 5\Omega$

As $V_F = I_F r$

$$I_F = \frac{V_F}{r} = \frac{0.7V}{5\Omega} = 140mA$$

17.4 RECTIFICATION

Majority of the electronic devices like radio, TV, computer etc., require the D.C. sources for their operation. The D.C. sources are cells, batteries etc. These D.C. sources are not only expensive and short-range supply but their voltage are also low. On the other hand, the supply of A.C. sources are long range with high voltage and its cost is also very low. Therefore, A.C. is more useful then D.C. and it can be applied to the electronic circuit only when it is converted into D.C. In this regard, we have a rectifier circuit which is used to convert A.C. into D.C. by using the property of a diode. i.e., a diode allows current to pass only in one direction, i.e. when it is forward biased.

There are two types of rectifications

I Half wave rectification   II Full wave rectification

I Half wave rectification

The schematic circuit diagram for half wave rectification is shown in Fig.17.17. The circuit consists of an A.C. source, transformer, diode D, and a load

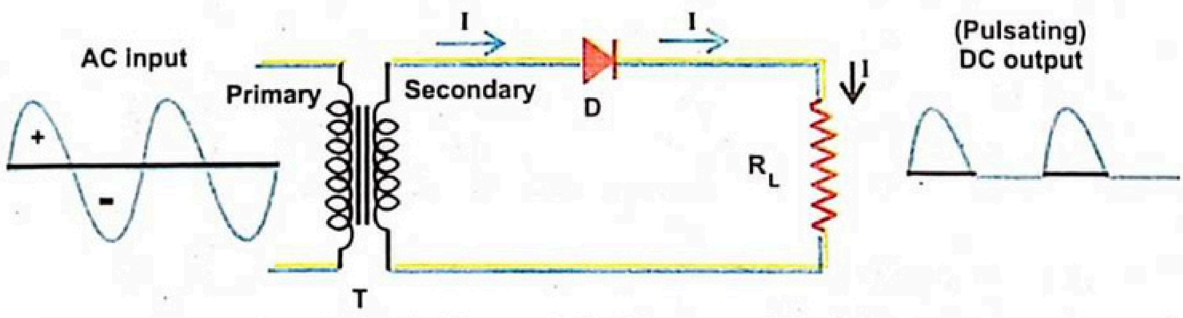

Fig.17.17 A schematic circuit diagram for half wave rectification using a single diode.

resistor R_L connected in series with the diode.

As we know that A.C. signal consists of a positive and a negative half cycle. When A.C. signal is applied to the input of rectifier circuit, during positive half cycle the anode of the diode becomes positive i.e., it makes diode forward biased and the diode conducts, so there is voltage drop across the load resistor R_L.

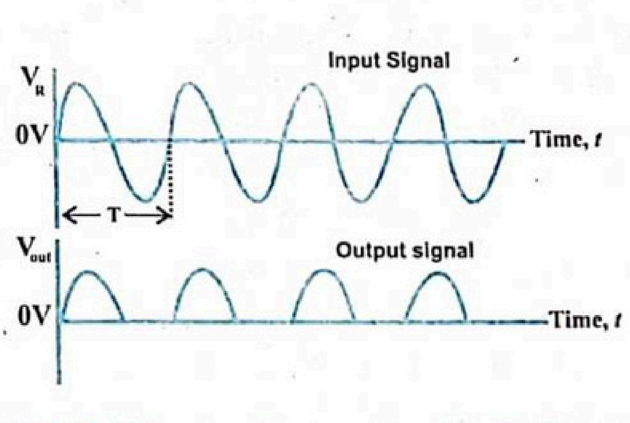

Fig.17.18 Input and output signals of half wave rectification due to a single diode.

During the negative half cycle of A.C. the anode of the diode becomes negative i.e., it makes the diode reverse biased and the diode does not conduct. Thus, there is no voltage drop across the load resistor R_L. For the next A.C. cycle the same process is repeated and so on. Hence at the output we have half wave rectification as shown in Fig.17.18. The result shows that there is no smooth D.C. signal at the output but there is a pulsating D.C. signal. Therefore, this pulsating output signal can further be smoothened by using the filter circuit.

II Full wave rectification

One of the disadvantages of the half wave rectification is that the power of half single is wasted, about 50%. To overcome this problem, we introduce a full wave bridge rectifier. It is used most frequently in electronic circuits. A schematic circuit diagram for full wave bridge rectifier is shown in Fig.17.19(a). The circuit consists of A.C. source, transformer, four diodes connected in the form of bridge loop and a load resistor R_L.

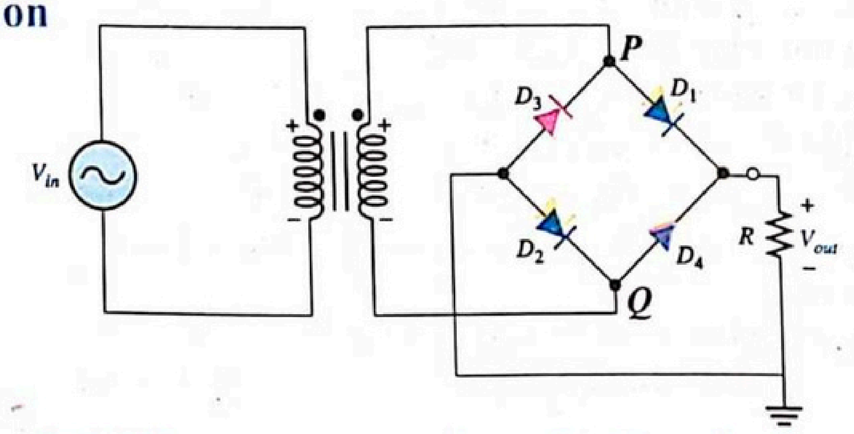

Fig.17.19(a). A schematic circuit diagram for full wave bridge rectification using four diodes.

When A.C. is applied then due to positive half cycle node P becomes positive and node Q negative. Therefore, the diodes D_1 and D_2 become forward biased and they conduct during first half of A.C., while, the diodes D_3 and D_4 becomes revers biased and they do not conduct as shown in Fig.17.19(b). Thus, there is voltage drop across the load

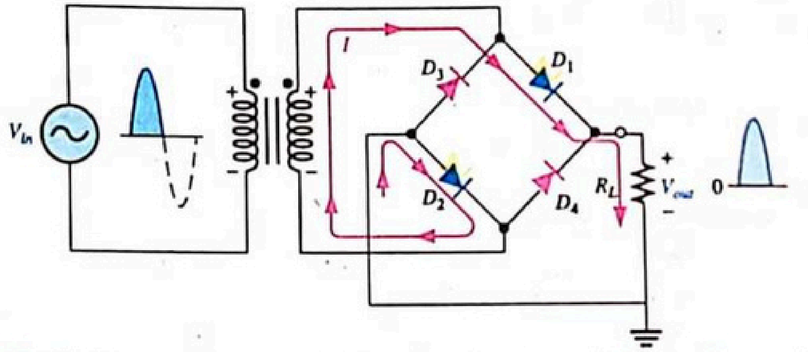

Fig.17.19(b). Due to positive half cycle, D_1 and D_2 are forward biased and conduct current, while D_3 and D_4 are reversed biased.

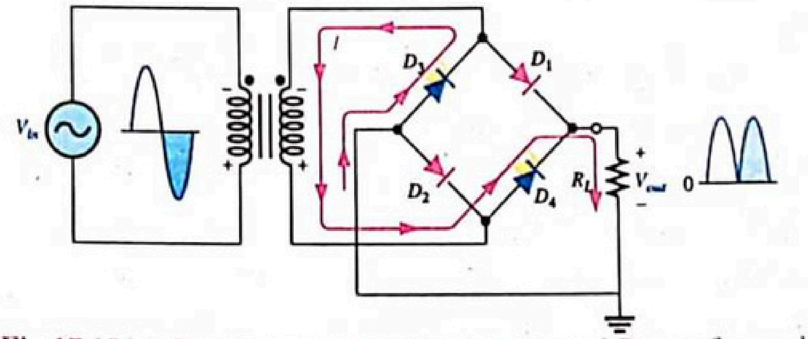

Fig.17.19(c). Due to negative half cycle, D_3 and D_4 are forward biased and conduct current, while D_1 and D_2 are reversed biased.

resistor R_L due to the diodes D_1 and D_2.

Similarly, during negative half cycle, the node P becomes negative and the node Q positive. So, this time the diodes D_3 and D_4 become forward biased and they conduct, while, the diodes D_1 and D_2 becomes reverse biased and they do not conduct as shown in Fig.17.19(c). Thus, there is a voltage drop across the load resistor R_L due to the diodes D_3 and D_4. For the next A.C. cycle, the same process is repeated. By combining these two results, we have full wave rectification. Graphically, the full wave rectifier signal is shown in Fig.17.20.

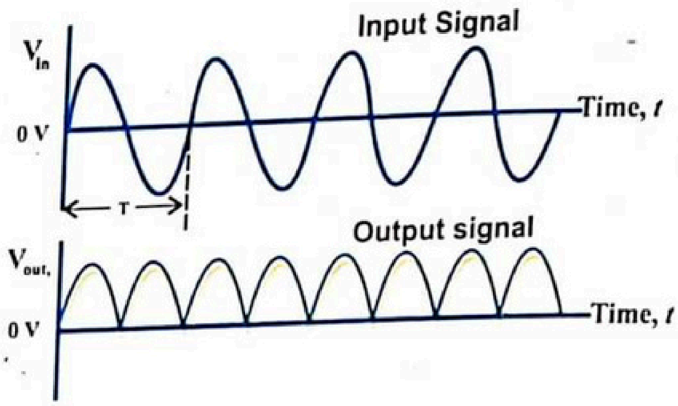

Fig.17.20 Input and output signal of full wave bridge rectifier.

17.5 TRANSISTOR

Like a diode, a transistor is also an important semiconductor device in which we study the transfer of charge carriers through a resistor. It is being used as an amplifier, switch etc.

A transistor consists of a single crystal of semiconductor in the form of two PN-junction with three electrodes named as emitter, base and collector.

In a transistor, a thin layer of one type of semiconductor is sandwiched between the two thick layers of the other type of semiconductor. For example, the Fig.17.21 shows that the thin layer of P-type semiconductor is sandwiched by the two thick layers of N-type semiconductor. It is named as NPN transistor. Similarly, Fig.17.22 shows that a thin layer of N-type semiconductor is sandwiched by the two thick layers of P-type semiconductor. Which is named as PNP transistor.

The symbols of NPN and PNP transistor are also shown in Fig.17.21 and Fig.17.22. The electrode with an arrow is emitter, the central electrode is base and the

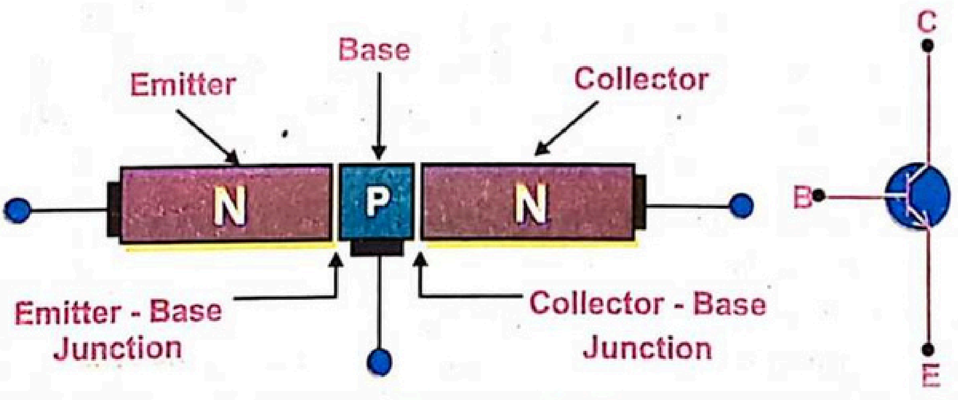

Fig.17.21 A NPN-transistor with its symbol, where the P-type semiconductor is sandwiched between two N-type semiconductors.

third one is collector. It is noted that the direction of the arrow representing the emitter of the NPN transistor is outward. And, the direction of the arrow of the PNP transistor is inward, which shows the direction of conventional current.

Now we are going to explain the functions of the three electrodes. The emitter has greater concentration of impurities as compare to the collector. Its main function is to supply the charge carriers either electrons or holes.

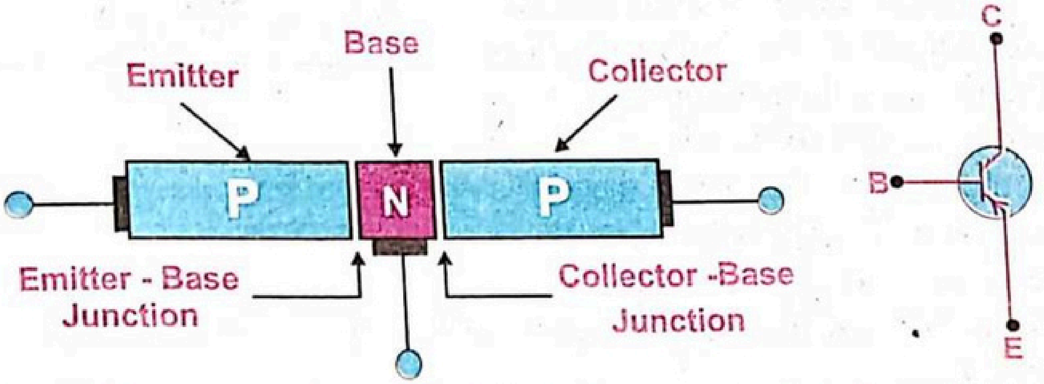

Fig.17.22 A PNP-transistor with its symbol, where the N-type semiconductor is sandwiched between two P-type semiconductors.

The central region, base of the transistor is very thin, of the order of 10^{-6}m. Its function is to control the flow of charges. The collector region of the transistor is made physically larger than the emitter region. The function of the collector is to collect the majority charge carriers coming from the emitter through the base region.

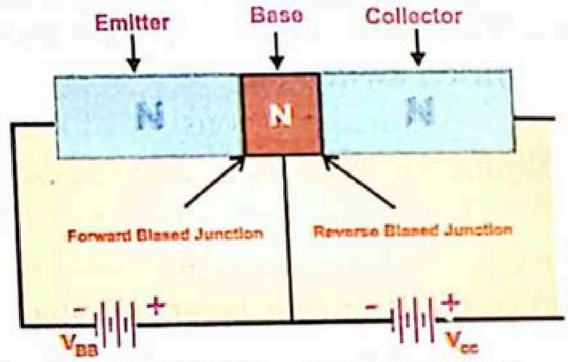

Fig.17.23 Biasing of NPN-transistor.

17.5.1 Transistor biasing

The application of voltage across the two junctions of a transistor is called biasing of a transistor. For normal operations of the transistors either NPN or PNP, their emitter-base junctions should be forward biased and collector-base junction should be reverse biased, such biasing of the transistor is taken place by using two batteries. The one battery is applied the forward voltage V_{BB} across the emitter-base junction, while the other one is applied the reversed voltage V_{CC} across the collector-base junction as shown in Fig.17.23 and 17.24.

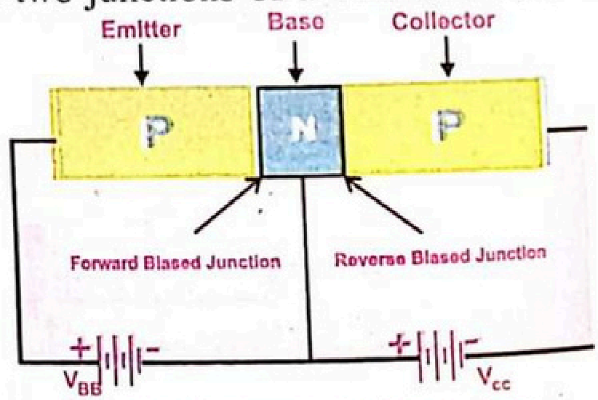

Fig.17.24 Biasing of PNP-transistor.

17.6 TRANSISTOR CONFIGURATION

A transistor has three electrodes named as; emitter, base and collector. Two batteries V_{BB} and V_{CC} are being used to operate the transistor, such that V_{bb} is applied across the input section of the transistor and V_{cc} across the output section. Thus, two electrodes are required for the input section and two for the output section, but the transistor has three electrodes. Therefore, one electrode of the transistor should be common to the input and output section of the circuit. This is named as common configuration of a transistor. There are three configurations of a transistor.

I Common emitter configuration (CEC)

In this configuration, emitter of the transistor is common to both input and output sections of the circuit as shown in Fig.17.25. In this case, the input signal is applied between the base and emitter. And, output signal is taken from the collector and emitter.

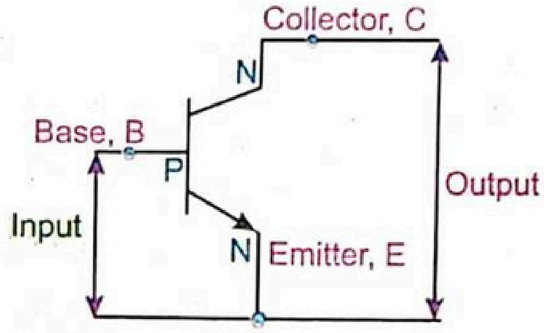

Fig.17.25 Common emitter configuration of NPN- transistor

II Common base configuration (CBC)

In this configuration, base of the transistor is common to input and output sections of the given circuit. The input signal is applied between the emitter and base. And, the output signal is taken from the collector and base as shown in Fig.17.26.

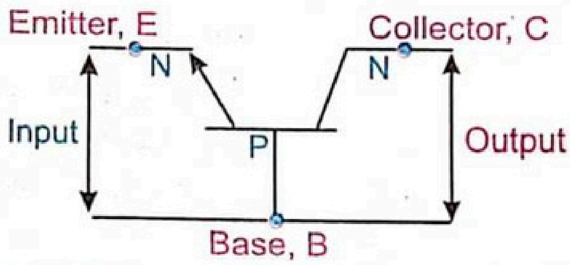

Fig.17.26 Common Base configuration of NPN- transistor.

III Common collector configuration (CCC)

In this configuration, collector of the transistor is common to both the input and output sections of the circuit. The input signal is applied between the base and collector. And the output signal is taken from the emitter and collector as shown in Fig.17.27.

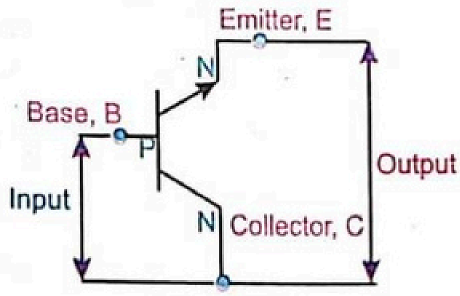

Fig.17.27 Common collector configuration of NPN-transistor.

17.7 OPERATION OF A TRANSISTOR

In the previous section, we have studied that a transistor can operate only when its emitter-base junction is forward biased and collector-base junction is reverse biased. Let us consider the operation of NPN transistor, as shown in Fig.17.28. As the emitter-base junction of the transistor is forward biased. Due to the applied forward voltage, so the electrons from emitter cross the junction and enter the base region, where base is very thin and lightly doped region. Therefore, the concentration of electrons from the emitter is more than the hole from the base. Thus only a few electrons (about 2%) recombine with the holes to constitute the base current. While most of the free electrons (about 98%) do not combine with the holes but move through the thin base region to the collector region. As collector is already reverse biased, and its reverse voltage attract these free electrons from the base region, therefore it causes collector current. In this way, the flow of charge carriers in a transistor is possible i.e., when the emitter current 'I_E' flows into the transistor, a very small amount of it 'I_B' flows out of the base, the rest of it 'I_C' flows out of the collector. Mathematically, this relation of current in a transistor is expressed as;

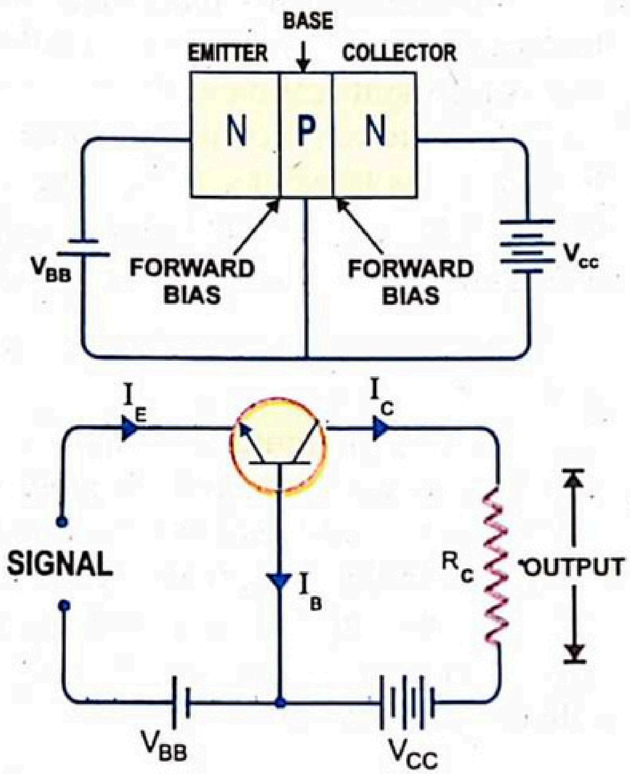

Fig.17.28 A flow of a current in PN-transistor.

$$I_E = I_B + I_C \quad ......(17.2)$$

This relation shows that the collector current 'I_C' is much greater than the base current 'I_B', but it is less than the emitter current 'I_E'. These can be expressed in terms of ratios, i.e.,

$$\alpha = \frac{I_C}{I_E} \quad ......(17.3)$$

and

$$\beta = \frac{I_C}{I_B} \quad ......(17.4)$$

where α and β are known as current gain. The typical values of α and β are 0.99 and 100 respectively for germanium transistors whereas, 0.995 and 200 respectively for silicon transistors. These results show that a small variation in the base current causes a large collector current. It is named as current amplification. It means a transistor can be used as an amplifier.

17.7.1 Characteristics of a Transistor

The curved line that is obtained due to the relationship between voltage and current by using a transistor is known as characteristics of a transistor. There are two important characteristics of a transistor named as input characteristics and output characteristics. Let us consider the operation of common emitter NPN transistor as shown in Fig.17.29. The voltage at the base with respect to emitter is V_{BE}, voltage at collector with respect to base is V_{CB} and the voltage at collector with respect to emitter is V_{CE}.

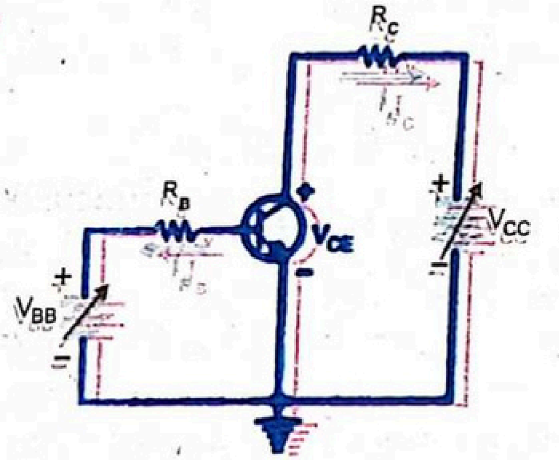

Fig.17.29 The operation of common emitter in NPN transistor .

I. Input Characteristics

This is the curved line between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE}.

When V_{BE} increases by increasing V_{BB}, I_B also starts increasing keeping V_{CE} constant, if different values of V_{BE} and I_{BE} are drawn on the graph of I_B versus V_{BE} then there is curved line as shown in Fig.17.30 which is known as input characteristics of a transistor. The reciprocal of the slop of such curved line is equal to the input resistance R_B of the transistor. That is,

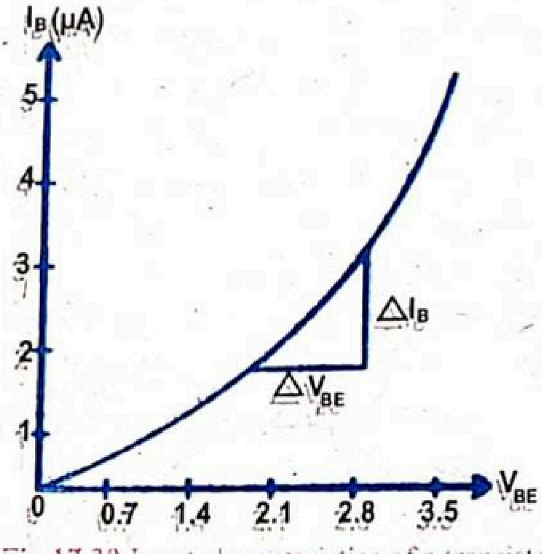

Fig.17.30 Input characteristics of a transistor.

$$R_B = \frac{1}{\left(\Delta V_{BE}/\Delta I_B\right)}$$

$$R_B = \frac{\Delta I_B}{\Delta V_{BE}} \quad ......(17.5)$$

II Output Characteristics

This is the curved line that is obtained due to the relationship between collector current I_C and collector-emitter voltage V_{CE} at fixed value of base current I_B.

For output characteristics of a transistor, V_{BB} is adjusted to get a fixed value of I_B while V_{CC} is zero at this stage. Now when V_{CE} is increased by increasing V_{CC} from zero in steps, I_C also starts increasing rapidly from zero to its maximum value at fixed value of I_B. The transistor at the maximum value of I_C is known as saturation level. Graphically, the characteristics curve of a transistor where I_C varies from zero to the saturation level is shown between the two points A and B in Fig.17.31(a). It may be noted that a small amount of collector current flows even when base current I_B is equal to zero. This is termed as cutoff or non-conducting state of a transistor. When V_{CE} exceeds the saturation level, collector current becomes almost constant and operation of the transistor enters into the active or linear region. Graphically, such linear characteristics of a transistor is shown between the two points B and C in Fig.17.31(a). If V_{CE} is allowed to increase too far, collector-base junction breaks down and the collector I_C increases rapidly. It is represented by a line above the point C in Fig.17.31(a).

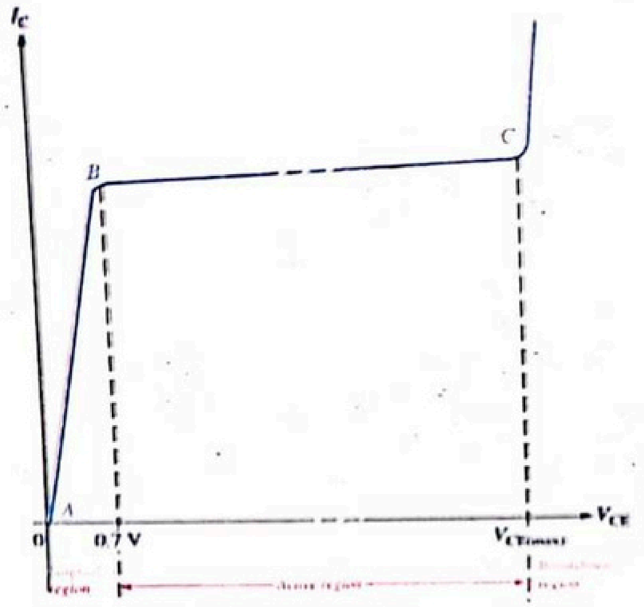

Fig.17.31(a) I_C versus V_{CE} curve for 1 value of I_B under saturation active and breakdown regions.

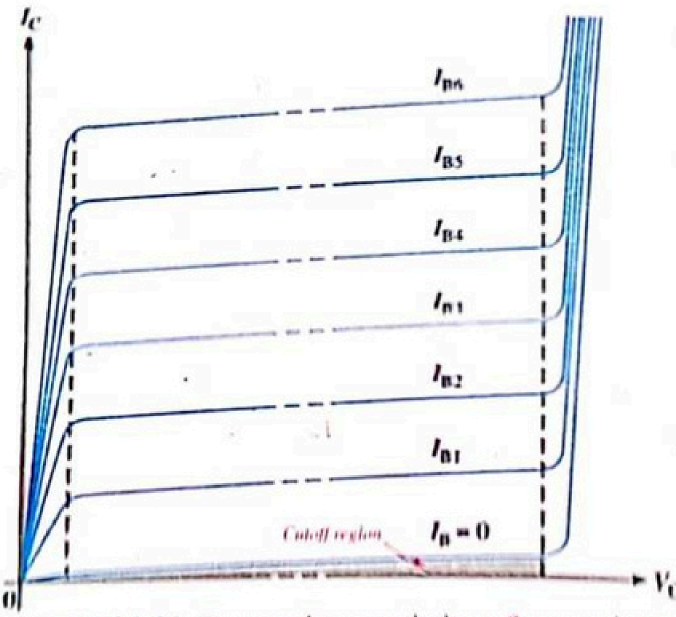

Fig.17.31(b) Output characteristics of a transistor in terms of family curves.

Again, V_{BB} is adjusted to get another fixed value of base current I_B and V_{CE} is reduced to zero. By repeating the same procedure, we have another curved characteristics of a transistor and so on. Thus, we obtain a family characteristics curves of a transistor when I_C verses V_{CE} which is plotted for several fixed value of I_B as shown in Fig.17.31(b).

Example 17.2

In a transistor I_C is 1mA and I_B is $200\mu A$, calculate I_E.

Solution:

$$I_C = 1mA$$
$$I_B = 20\mu A = 0.02mA$$
$$I_E = ?$$

According to the basic equation for flow of current in a transistor

$$I_E = I_C + I_B$$
$$I_E = 1mA + 0.02mA$$
$$I_E = 1.02mA$$

Example 17.3

In an electronic circuit, the emitter current of a transistor is 2.2mA and its collector current is 2mA. Calculate the value of α.

Solution:

DO YOU KNOW

Diode and transistor are active components and they do not obey Ohm's law.

$$\text{Emitter current} = I_E = 2.2mA$$
$$\text{Coll ector current} = I_C = 2mA$$
$$\alpha = ?$$
$$\alpha = \frac{I_C}{I_E}$$
$$\alpha = \frac{2mA}{2.2mA}$$
$$\alpha = 0.9$$

Example 17.4

Calculate the emitter current in a transistor when its base current is $50\mu A$ and the value of current gain is 100.

Solution:

$$\text{Emitter current} = I_E = ?$$
$$\text{Base current} = I_B = 50\mu A = 0.05mA$$
$$\text{Current gain} = \beta = 100$$

FOR YOUR INFORMATION

In most electronic circuit, the current I is only a small fraction of an ampere. A typical value of current I in an electronic circuit is 10mA.

The current gain is defined as

$$\beta = \frac{I_C}{I_B}$$
$$I_C = \beta I_B$$
$$= 100 \times 0.05mA$$
$$I_C = 5mA$$

$I_E = I_B + I_C$
$I_E = 0.05mA + 5mA$
$I_E = 5.05mA$

17.8 TRANSISTOR AS AN AMPLIFIER

An amplifier is an electronic circuit which converts a small input A.C. signal into a large output A.C. signal under the action of a transistor. The amplification takes place under the following three configurations i.e., common base amplifier, common emitter amplifier and common collector amplifier, but common emitter amplifier is used mostly.

Consider the operation of a common emitter NPN transistor as shown in Fig.17.32. The emitter-base junction is forward biased by using a battery V_{BB} and a resistor R_B called base or input resistor, whereas collector is reverse biased by using another battery V_{CC} through a resistor R_C known as collector or load resistor. The input A.C. signal is applied in the base and emitter section of the circuit. And the output signal is taken out from the collector-emitter section. In the absence of any input signal, the transistor is working in its normal mode. Now when an A.C. signal is applied at the input terminals of the circuit, then during the positive half cycle of the signal, the base of the transistor which acts as driven element becomes more positive and it increases the forward biasing across the emitter-base junction. Therefore, more electrons flow from the emitter to the collector through the base and it causes of an increase collector current I_C by β times the input base current I_B ($I_C = \beta I_B$). As a result, a greater voltage drops across the collector load resistance R_C due to the increased collector I_C. Thus, we have a large output half A.C. cycle but in

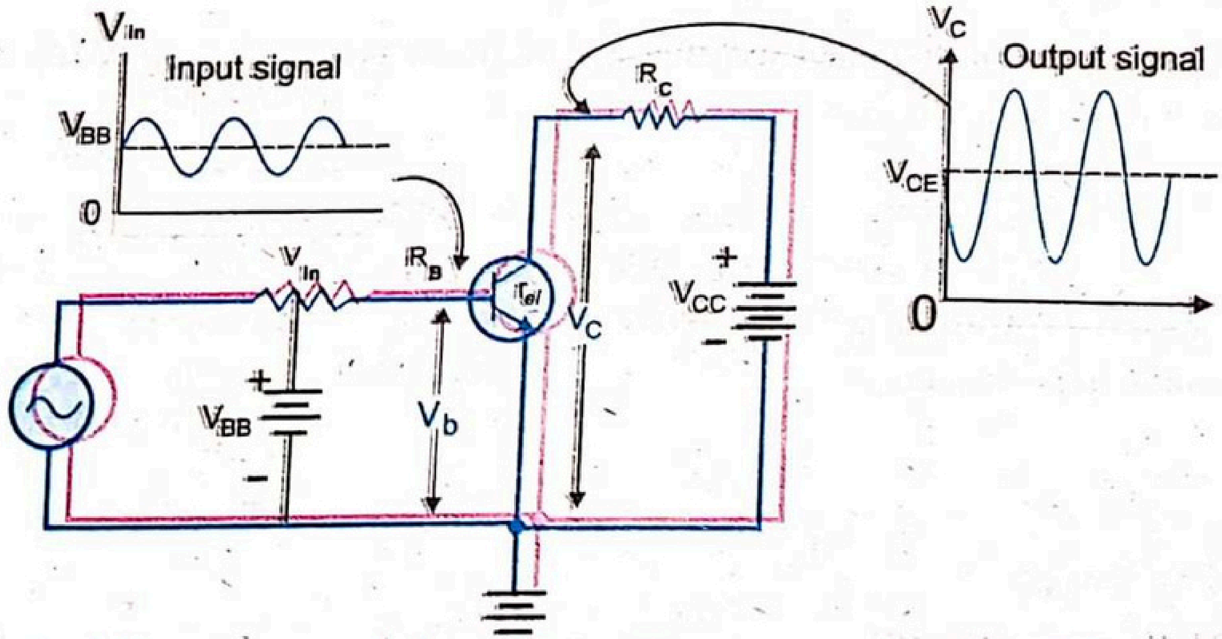

Fig.17.32 A schematic circle diagram for amplifier using common emitter NPN-transistor

the negative direction. i.e., there is a phase difference of 180° between the input and output signals.

Similarly, during the negative half cycle base becomes less positive and the forward biasing across the emitter-base junction is decreased. Therefore, there are a few electrons that flow from emitter to collector through the base. There is a very small collector current. In this condition, a large voltage drops across the load resistance R_C by V_{CC}. Thus, we have again a large half positive cycle of A.C. which is opposite in direction to the input signal as shown in Fig.17.32. For the next cycle, the same process is repeated. In this way, a transistor converts a small input A.C. signal into a large A.C. signal.

Analytically, the amplification of common emitter NPN transistor is explained as; Due to forward biasing, the base-emitter junction presents a very low internal resistance to the A.C. signal. It is represented by r_{ei} and appears in the series with the base resistance R_B. Thus, I_B in terms of r_{ei} is given as:

$$I_B = \frac{V_{BE}}{r_{ei}}$$

But $$V_{BE} = V_i \text{(Input voltage)}$$

So $$I_B = \frac{V_i}{r_{ei}} \quad \ldots\ldots(17.6)$$

By definition of current gain (β)

$$\beta = \frac{I_C}{I_B}$$

$$I_C = \frac{\beta V_i}{r_{ei}} \quad \ldots\ldots(17.7)$$

Now, the output voltage $(V_o = V_{CE})$ in the output section of the given circuit can be determined by using KVL. i.e.,

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

$$V_o = V_{CC} - I_C R_C \quad \ldots\ldots(17.8)$$

Putting the value of I_C from Eq. 17.7 in Eq. 17.8

$$V_o = V_{CC} - \frac{\beta V_i R_C}{r_{ei}} \quad \ldots\ldots(17.9)$$

This is the output voltage of a transistor without applied input signal. If an input signal is applied then both input and output voltages are increased. So Eq.17.9 becomes

$$V_o + \Delta V_o = V_{CC} + \frac{\beta(V_i + \Delta V_i)R_C}{r_{ei}} \quad \ldots\ldots(17.10)$$

Subtract Eq. 17.9 from Eq. 17.10

$$\Delta V_o = -\frac{\beta \Delta V_i R_C}{r_{ei}} \quad ......(17.11)$$

By definition of voltage gain (A_V)

$$A_V = \frac{\Delta V_o}{\Delta V_i}$$

$$A_V = -\beta \frac{R_C}{r_{ei}} \quad ......(17.12)$$

This is the voltage amplification of a transistor. Negative signs shows that input and output signals are out of phasé. Eq.17.12 shows that voltage amplification of a transistor depends upon R_C and r_{ei}. Since R_C is always greater than r_{ei} so output voltage in a transistor is greater than its input voltage.

Example 17.5

For a germanium crystal transistor, the current gain is 200 and voltage drop across a load resistance of $2k\Omega$ is 4volt. Find the base current for common emitter configuration.

Solution:

Current gain $= \beta = 200$

Voltage drop $= V_C = 4V$

Output resistance $= R_C = 2k\Omega = 2\times10^3\Omega$

Base current $= I_B = ?$

As $\quad V_C = I_C R_C$

$$I_C = \frac{V_C}{R_C}$$

$$I_C = \frac{4V}{2\times10^3\Omega} = 2\times10^{-3}A$$

$$I_C = 2\ mA$$

Now $\quad \beta = \frac{I_C}{I_B}$

$$I_B = \frac{I_C}{\beta}$$

$$I_B = \frac{2\times10^{-3}A}{200}$$

$$I_B = 10^{-5}A$$

17.9 TRANSISTOR AS A SWITCH

Like a diode, a transistor can also be used as switch under its cutoff and saturation regions. That is, a transistor is in cutoff region when its base-emitter is reverse biased. Similarly, it is in saturation region when its base-emitter is forward biased. These two states acts as an open and closed switch. It is explained by considering the operation of common emitter NPN transistor under two different cases.

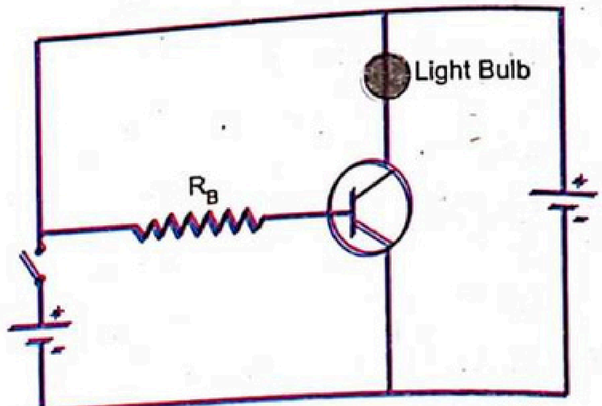

Fig.17.33 Transistor as an open switch.

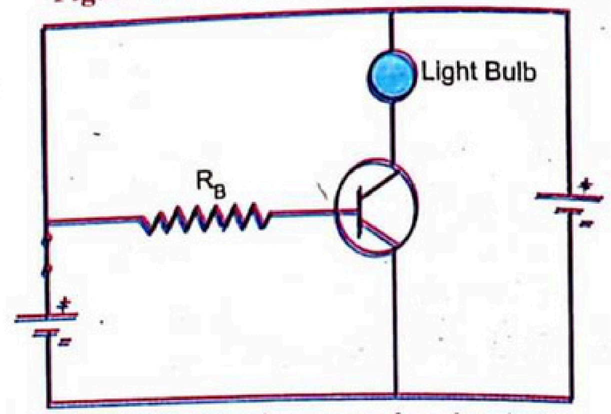

Fig.17.34 Transistor as a closed switch.

In the first case, the emitter-base junction is not forward biased, the base current I_B is zero. Therefore, the collector current is also zero under this condition, the transistor behaves as an open switch. Thus, the bulb is switched OFF as shown in Fig.17.33.

In the second case, the emitter-base junction is forward biased, there is an increase of base current. This causes maximum collector current. Under this condition, the transistor acts as a closed switch. Thus, the bulb is switched ON as shown in Fig.17.34.

SUMMARY

- **Semiconductor:** The solids whose resistivity or conductivity lies between insulators and conductors are known as semiconductor. e.g. germanium and silicon. There are two types of semiconductor.
- **Intrinsic Semiconductor:** An extremely pure form of semiconductor is known as intrinsic semi-conductor.
- **Extrinsic Semiconductor:** When an impurity of either trivalent or pentavalent atoms is added into a pure semiconductor then this is called extrinsic semiconductor.
- **N-Type Semiconductor:** When an impurity of pentavalent atoms is added to a pure semiconductor then it is known as N-type semiconductor.
- **P-Type Semiconductor:** When an impurity of trivalent atoms is added to a pure semiconductor then it is called P-type semiconductor.
- **PN-Junction:** PN junctions are formed by joining N-type and P-type semiconductor materials in the form of a single crystal.

- **Biasing of PN-Junction:** The process in which the potential difference is applied across the PN-Junction is called biasing.
- **Forward biased PN-Junction:** When PN-Junction is connected to a battery such that P-type is connected to positive terminal and N-type is connected with negative terminal of the battery, such biasing is called forward biased.
- **Reverse biased PN-Junction:** When PN-Junction is connected to a battery such that P-type is connected with the negative terminal and N-type with the positive terminal of the battery, such biasing is called reverse biased.
- **Semi-Conductor Diode:** Diode is indeed a PN-Junction which converts alternating current (A.C.) into direct current (D.C.)
- **Rectifier:** Rectifier is an electronic circuit that converts A.C. into D.C. under the action of a diode and the process of conversion of A.C. into D.C. is known as rectification. There are two type of rectifications:
  I Half wave rectification II Full wave rectification
- **Transistor:** Transistor is an electronic device which consists of two PN-Junctions with three electrodes named as emitter, base and collector. There are two kinds of transistors, NPN and PNP
- **Biasing of a transistor:** A transistor operates only when its emitter-base junction is forward bias and collector-base junction is reverse bias.
- **Amplifier:** Amplifier is an electronic circuit that converts a small input A.C. signal into a large output A.C. signal under the action of a transistor.

EXERCISE

Select the best option of the following questions.

1. A germanium at 0K is
   (a) Conductor (b) Semiconductor
   (c) Insulator (d) P&N types semiconductor
2. By increasing the temperature, the conductivity of the semiconductor is
   (a) Decreased (b) Increased (c) Constant (d) Not affected
3. Which one of the following is an intrinsic semiconductor?
   (a) Boron (b) Copper (c) Indium (d) Silicon
4. In extrinsic semiconductor, the doping level should be in the ratio
   (a) $1:10^{-6}$ (b) $1:10^{6}$ (c) $1:10^{-8}$ (d) $1:10^{8}$
5. In P-type semiconductor, the doping of Silicon is taken place with
   (a) Bivalent (b) Trivalent (c) Tetravelent (d) Pentavalent
6. When P-type and N-type semiconductor are combined then we have a
   (a) Resistor (b) Capacitor (c) Diode (d) Triode
7. The depletion region in PN-Junction carries

(a) Positively charge (b) Negatively charge
(c) Both positively and negatively charge (d) No mobile charge carrier

8. The potential difference across the silicon PN-junction is
(a) 0.3V (b) 0.5V (c) 0.7V (d) 0.9V

9. When P-type of the PN-Junction is connected with the negative terminal and N-type with positive terminal of the battery, the width of the depletion region
(a) decreases (b) increases (c) remain constant (d) vanished

10. In forward biasing, the knee voltage for Germanium PN-junction is
(a) 0.3V (b) 0.7V (c) 3V (d) 7V

11. One of the most important property of a diode
(a) Allow current in one direction (b) Allow current in bidrection
(c) Use as an amplifier (d) Use as an oscillator

12. The number of diodes used in a bridge rectifier is
(a) One (b) Two (c) Three (d) Four

13. Transistor stands for
(a) Transfer of Resistance (b) Transfer of charge carriers
(c) Transfer of power (d) Transfer of voltage

14. Which region of the transistor is most wide in terms of area?
(a) Emitter (b) Base (c) Collector (d) All have equal area

15. In biasing of a transistor, which region must be reverse biased?
(a) Emitter-Base (b) Collector-Base
(c) Emitter-Collector (d) None of these

16. The thickness of the base region of a transistor is
(a) 10^{-2}m (b) 10^{-4}m (c) 10^{-6}m (d) 10^{-8}m

17. Which one of the following relation is true for a transistor?
(a) $I_E = I_C - I_B$ (b) $I_E = I_B - I_C$ (c) $\alpha = \frac{I_C}{I_E}$ (d) $\beta = \frac{I_B}{I_E}$

18. Which one of the following relations holds for cutoff mode of transistor?
(a) $I_C = I_B$ (b) $I_C = \beta I_B$ (c) $I_C = \alpha I_B$ (d) $I_C = 0$

19. The flow of charge carriers in a transistor is controlled by
(a) Emitter (b) Base (c) Collector (d) All of them

20. If the base current of a silicon transistor is 0.01mA, its collector current is
(a) 0.99mA (b) 9.9μA (c) 0.1mA (d) 1mA

21. V_{CE} drops across the load resistor of a transistor when
(a) $I_C = 0$ (b) $I_C = I_B$ (c) $I_C = \alpha I_B$ (d) $I_C = \beta I_B$

22. When a transistor starts its working in its active region
(a) Before its saturation (b) After its saturation
(c) After its cutoff (d) At the end of its cutoff

23. A transistor is used as a switch when it operates in its
(a) Normal mode (b) Active mode
(c) Breakdown mode (d) Saturation and cutoff mode

SHORT QUESTIONS

1. Distinguish between intrinsic and extrinsic semiconductors?
2. What are the advantages of extrinsic semiconductor over the intrinsic semiconductor?
3. Under what conditions, the semiconductor materials behave as conductor and as an insulator.
4. What is meant by the process of doping?
5. What are the facts about holes?
6. What do you know about the depletion region in PN-Junction?
7. What is the diffusion in the PN-Junction?
8. How can the conductivity of semiconductor be increased by increasing the temperature?
9. How does the width of depletion region in PN-Junction increases and decreases?
10. How does a diode convert A.C. into D.C.?
11. What is the rectification of a diode?
12. Distinguish between half and full wave rectifications.
13. What is the biasing of a diode?
14. Distinguish between forward and reverse biased characteristics of a diode.
15. What is meaning of a transistor?
16. How does a transistor operate?
17. How does the biasing of a transistor take place?
18. Why is the base region of a transistor thin and lightly doped?
19. Why is the collector of a transistor anode wider than the emitter and the base?
20. Why the input resistance of a transistor is low while its output resistance is high?
21. Why the current gain α is less than β?
22. Why a common emitter configuration transistor is mostly used?
23. Under what conditions a transistor acts as an open and a closed switch?
24. What do you know about the saturation, cutoff and active regions of a transistor?

COMPREHENSIVE QUESTIONS

1. State and explain intrinsic and extrinsic semiconductors.
2. What do you know about the N-type and P-type semiconductors? Explain the development of N-type and P-type semiconductor crystals.

where p = 1, 2, 3, ... and n = p + 1

and $$R_H = \frac{E_1}{hc} = 1.0974 \times 10^7 \text{ m}^{-1} \quad \text{......(19.15)}$$

The result of Eq.19.14 is the same as that of the empirical formula in Eq.19.6 for wavelengths of spectral lines, so it is concluded that when different transitions of electron are taking place from the higher orbits the lower orbits as shown in Fig.19.5 then we have Lyman, Balmer, Paschen, Bracket and Pfund series. All these spectral series are shown on energy level diagram (Fig.19.6).

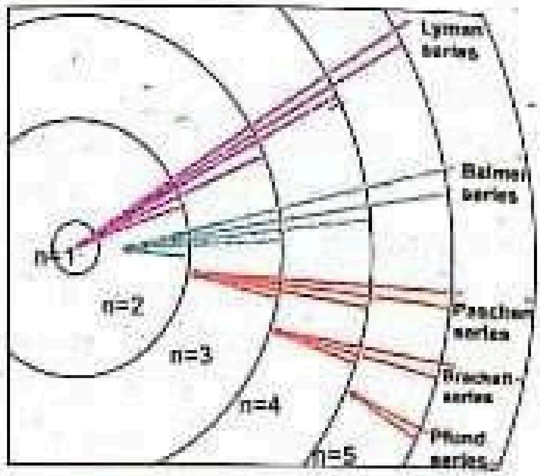

Fig.19.5 Transition of electron from various excited states in hydrogen atom.

I Lyman series

If the electrons of hydrogen atom jump from outer orbits (n = 2, 3, 4, ...) to the 1st orbit (p = 1) then we have a set of spectral lines called the Lyman series and it is the ultraviolet region of electromagnetic spectrum. The wavelength of this series is calculated as;

$$\frac{1}{\lambda} = \frac{E_1}{hc}\left(\frac{1}{p^2} - \frac{1}{n^2}\right) = R_H\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \qquad P = 1, \quad n = 2,3,4...$$

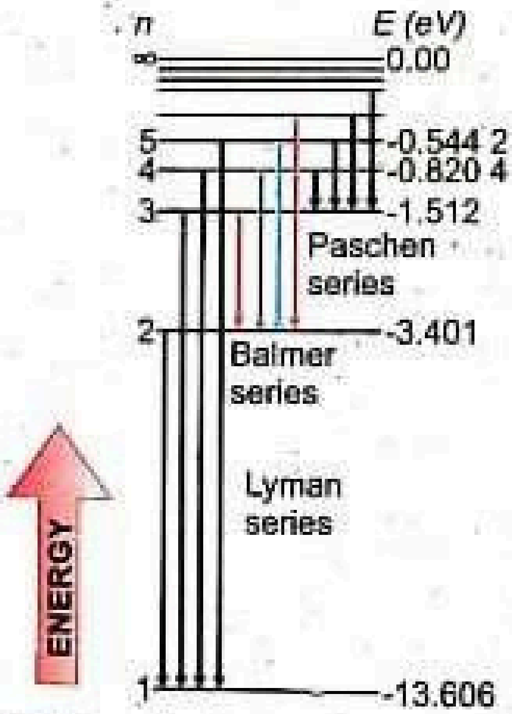

Fig.19.6 Energy level diagram of hydrogen atom.