R_L.Thus, during both the cycles of the input signal DC current is flowing through load R_L and DC voltage is obtained across R_L. Hence, this circuit is called full wave rectifier.

The rectification efficiency of full wave rectifier is high compared to half wave rectifier. Therefore, it is widely used in the power supply.

Filter Circuit : The DC output voltage of the half wave rectifier and full wave rectifier does not-remain constant – with time. This DC voltage is known as pulsating DC voltage. This DC voltage contains DC component as well as AC components.

Different types of the filters are used to remove these AC components. Filter circuits consist of only capacitor, of only inductor or combination of capacitor and inductor.

A filter circuit containing only capacitor is shown in the figure 7.27. Here the value of capacitance of capacitor is large as a result its impedance $\left(\frac{1}{\omega C}\right)$ for AC mains frequency (50 Hz) is very low. In this condition, the AC component present on the output voltage of rectifier can be grounded through the capacitor. This leaves only the DC component-across the load R_L. (The filtering action of capacitor can be also explained by charging and discharging of the capacitor).

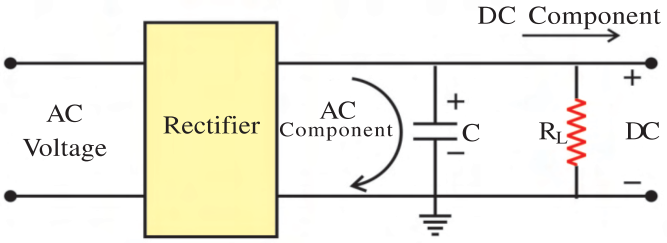
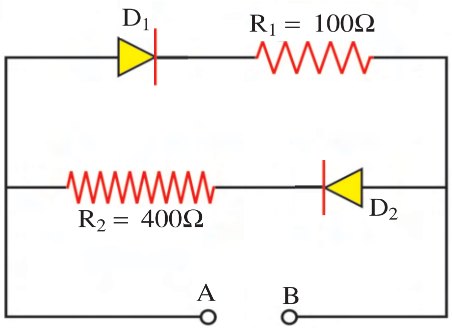


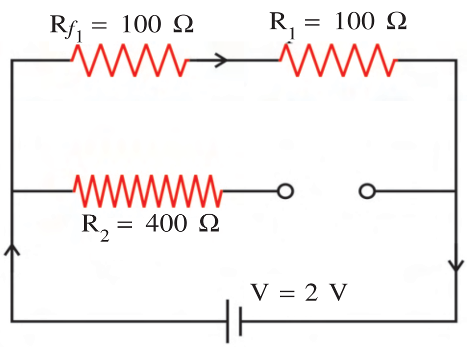
Figure 7.27 Filter Circuit

Illustration 1 : Calculate the current flowing through the diode D_1 and D_2 when the positive terminal the 2V battery is connected at point A and the negative terminal is connected at point B in figure (1). What will be the current flowing through the diodes if the battery terminals are interchanged? The resistance of the diodes D_1 and D_2 are 100 Ω in the forward and infinite in reverse bias mode.



(i)

Solution : (1) In the first part of the question, diode D_1 is forward biased and diode D_2 is reverse biased. The resistance of the diode D_1 is 100 Ω in the forward bias mode and the resistance of the diode D_2 in the reverse bias mode is infinite. The equivalent circuit is shown in figure (2) :



(ii)

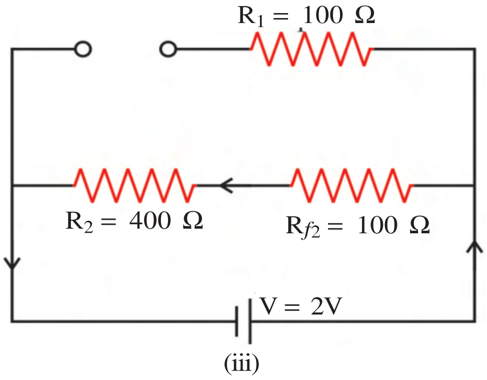
The current flowing through the diode D_1 will be equal to

$$I_1 = \frac{V}{R_{f_1} + R_1}$$

$$= \frac{2}{100+100} = 10 \text{ mA}$$

No current will flow through the diode D_2 since its resistance is infinite.

(2) When the terminal of the diodes are reversed, diode D_1 becomes reverse biased while diode D_2 becomes forward biased. The equivalent circuit in this situation will be as per figure (iii).



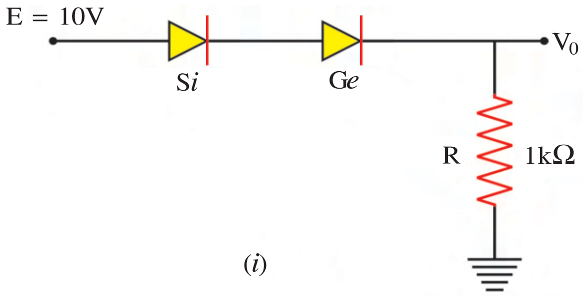
(iii)

The currnet through the diode D_2 will be,

$$I_2 = \frac{V}{R_{f2} + R_2}$$

$$= \frac{2}{100 + 400} = 4 \text{ mA}$$

Illustration 2 : As shown in figure diode made of *Si* and *Ge* are connected in series with resistor R. Calculate the current I_D flowing through the diode and also the output voltage V.



(*i*)

Solution : The potential drop across the diode is equal to the knee voltage when the diode is forward biased. This voltage for the *Si* diode is 0.7 V and for the *Ge* diode it is 0.3 V.

Now, E > (0.7 + 0.3 = 1V). Hence both the diodes will be forward biased. The equivalent circuit in this case can be as in figure (ii).

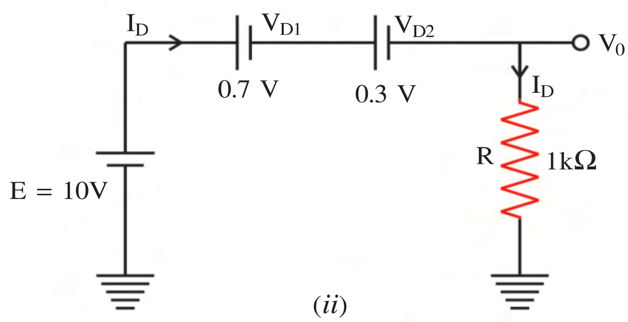
As per the Kirchhoff's law,

$$E - V_{D1} - V_{D2} - I_D R = 0$$

$$\therefore \ I_D = \frac{10 - 0.7 - 0.3}{10^3}$$

$$\therefore \ I_D = 9 \text{ mA}$$

$$\therefore \ \text{Output voltage } V_0 = I_D R$$



(*ii*)

$$= 9 \times 10^{-3} \times 10^{+3} = 9 \text{ V}$$

7.8 Special Types of PN Junction Diode

(a) Zener Diode : We have studied in the earlier section that very little current flows due to the minority charge carriers when the diode is reverse biased. This current is of the order of μA. As we go on increasing the reverse bias, at one particular voltage the current starts suddenly increasing. This voltage is called the breakdown voltage. The reverse current can be obtained in the order of milliampere near the breakdown voltage if the concentration of the impurity atoms is increased. Two types of effects are responsible for the current which is obtained in the breakdown region of the diode in the reverse mode. (1) Zener effect (2) Avalanche effect.

The width of the depletion region is very less when the impurity concentration is high. As a result at a very low reverse voltage we get a high intensity electric field at the depletion region. As for example if the reverse voltage is 2 V and the width of the depletion region is

200 Å, the electric field intensity will be $\frac{2}{200 \times 10^{-8}} = 10^6$ V/cm. This magnitude of electric field intensity is sufficient to break the covalent bonds and make the electrons free. A large number of covalent bonds are broken. This results in large number of electron and hole pair formation as well as the sudden increase in the reverse current (I_R). This explanation was given by a scientist known as C.E. Zener. Hence it is known as the Zener effect. Such diodes are known as Zener diodes.

The breakdown voltage can be obtained at a large value by decreasing the concentration of the impurity atoms. At the high value of the breakdown voltage the intensity of the electric field becomes high. When the charge carriers cross the depletion region (like the electron as for example) then it gets accelerated due to high electric field. This accelerated charge breaks many covalent bonds in the depletion region and creates electron hole pair. This newly created electron also gets accelerated and breaks many more covalent bonds to further create more electron hole pairs. This process keeps on repeating. This results in increase in the electric current flowing through the diode. We say that the diode has reached the breakdown point. This type of breakdown is called the Avalanche Effect. The diode in which the breakdown is due to the Avalanche effect is known as the Avalanche Diode.

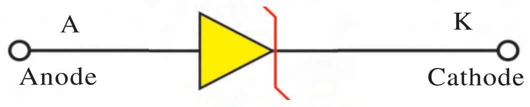


Figure 7.28 Symbol of Zener Diode

If the breakdown voltage is less than 4 V, then the breakdown is due to the Zener effect. If the breakdown is obtained at voltages greater than 6 V then the breakdown is due to the Avalanche effect. At voltages between 4 V and 6 V, the breakdown is due to both Zener and Avalanche effects. All these types of diodes are called Zener diodes.

The symbolic diagram of the zener diode is shown in figure 7.28. The symbolic representation of Zener diode is similar to that of normal diode. The only difference being that the cathode has been shaped in the form of the letter Z.

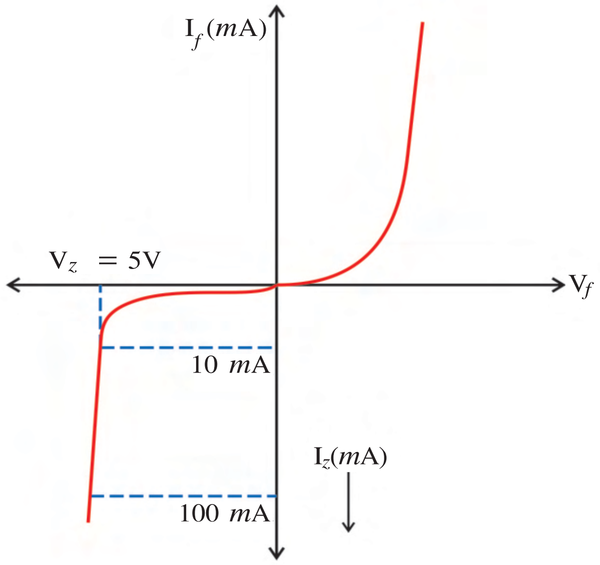


Figure 7.29 Characteristics of Zener Diode

Figure 7.29 shows the characteristic of the zener diode. The forward bias characteristic of the zener diode is very similar to that of the PN junction diode. In the voltage less than the breakdown voltage the magnitude of the current obtained is very low (of the order of μA). Near the breakdown voltage (V_Z) this current suddenly increases to the order of milliampere. This current is called the zener current (I_Z).

The breakdown obtained in this case is very sharp. It can be seen from the reverse bias characteristic that a small change in the voltage near the breakdown voltage produces a large change in the current. This means that in this situation the voltage across the zener diode remains constant over large changes in the current. Hence such a diode can be used in a voltage regulator circuit.

Zener Diode as a Voltage Regulator : Rectifier circuits are used in power supply. When there is a change in the AC mains voltage, the secondary voltage v_s of the transformer also changes. As a result DC output voltage across R_L is also changes. This type of power supply is called unregulated power supply. If the output voltage remains constant with the change in the input voltage, such power supply is called regulated power supply.

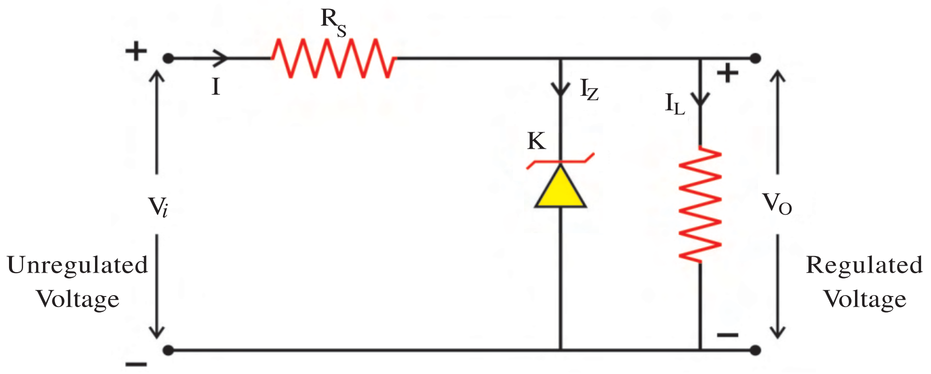


Figure 7.30 Regulator Circuit Using Zener Diode

Figure 7.30 shows the circuit-diagram of a regulated power supply using zener diode.

As shown in the circuit, zener diode is connected in a reverse bias mode. A resistance R_S connected in series with zener diode controlles the current. The output voltage is obtained across the load R_L, which is connected parallel to the zener diode. Applied input voltage (V_i) is always greater then regulated output voltage (V_O). Zener diode connected in the circuit must have zener break down voltage(V_Z) equal to required regulated output voltage.

When the input voltage(V_i) increases, the current (I) through R_S also increases so that voltage drop across R_S also increases. This change in the voltage is the same as change in the input voltage. This increases in the current increase in the zener current (I_Z), but the voltage (V_Z) across zener diode remains constant, hence the output voltage across R_L also remains constant. The decreases in the input voltage produces a reverse process. The voltage across R_S is reduced which will be equal to the decrease in the input voltage and voltage across zener diode remains constant. Thus, the output voltage across load R_L remains constant. In this way. using a zener diode, we can get regulated output voltage.

(b) LED (Light Emitting Diode) : Whenever electron in a Germanium of Silicon atom makes a transition from the conduction band to the valence band then the excess energy of the electron is obtained in the form of heat energy.

In some of the semiconductors like Gallium Arsenide the energy is obtained in the form of Light. The maximum wavelength of the electromagnetic waves have a wavelength

$\lambda = \frac{hc}{E_g}$. Here, (E_g) is the band gap energy.

In order to effectively obtain the intensity of the light, it is essential that the number of electron in the conduction band and the number of holes in the valence band have to be large. The above mentioned requirement is not satisfied adding impurity atoms in a pure semiconductor.

In order to achieve the above mentioned objective, two different types of doped semiconductors are taken and their junction is formed. As shown in the figure N and P type of semiconductors with large concentration of impurities is taken and a P-N junction is formed.

The PN junction diode is kept in fairly large forward bias condition. This results in a large current as shown in the figure 7.31, due to large concentration of electron in the N region and large concentration of holes in the P region of the diode. As explained earlier, the width of the depletion region is extremely small (of the order of few μm). As a result the electrons are easily able to cross the junction and recombine with the holes.

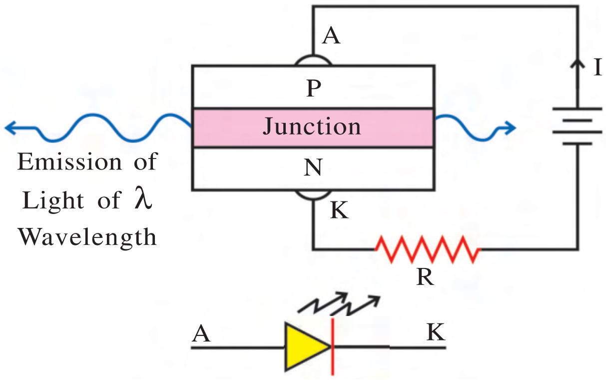


Figure 7.31 LED and Its Symbol

In order to obtain emission in the visible region, Arsenic and Phosphrous impurities are added in Gallium semiconductor.

LED that can emit red, yellow, orange, green and blue lights are commercially available. The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 *e*V. The compound semiconductor Gallium Arsenide – phosphide ($Ga\ As_{1-x}P_x$) is used for making LEDs of different colours.

These LEDs are widely used in remote control, ON/OFF indicator, optical communication, display board and decorative lighting.

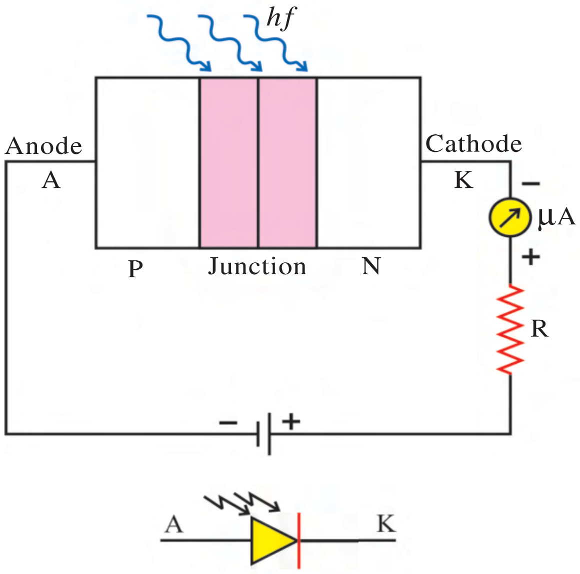


Figure 7.32 Photodiode and its Symbol

(c) Photo Diode : The construction of photo diode is similar to the normal diode. The only difference between the two is that there is window in a photo diode through which the light enters and incident on the junction. This diode is always connected in a reverse bias mode. (see figure 7.32)

Reverse saturation current flows through the PN junction diode on connecting it in a reverse bias mode. The reverse saturation current can be increased either by increasing the temperature of the diode or by making more light incident over it. When the energy of the light incident on the junction $\frac{hc}{\lambda} > E_g$, large number of covalent bonds are broken near the junction. This further produces large number of electron hole pair. (or due to the incident light many electrons from the valence band move over to the conduction band). Thus the increase in the minority charge carriers contribute towards increase in the reverse current. This reverse current is of the order of μA.

The reverse current flowing through the diode in the absence of the incident light is known as dark current. The electrone hole pair increases on increasing the intensity of the incident light. This results in proportionate increase in current.

Photo diode converts the light into electrical signal. Hence it is widely used in optical communication. It is also used in CD player, computer as well as in security systems.

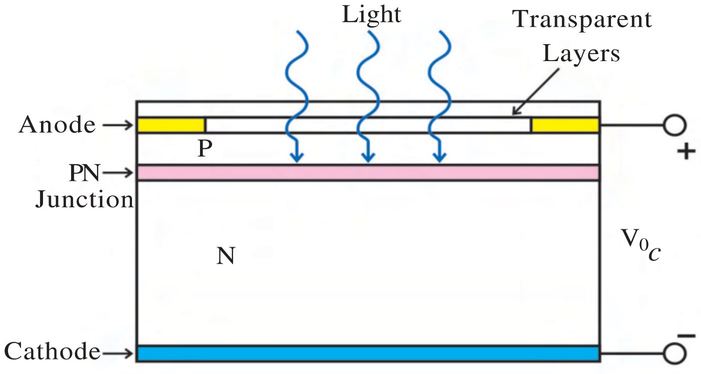


Figure 7.33 Construction of a Solar Cell

(d) Solar Cell : Solar cell is a semiconductor device. There is an emf induced at the two ends of a solar cell when the light is incident on the PN junction. This device converts light energy into electrical energy. The principle of the working of the photo diode and solar cell are same. The only difference is that there is no need of an external battery in case of a solar cell.

The figure 7.33 shows the construction of a solar cell. A thin layer of N-type semiconductor layer is combined with a thin layer of P-type semiconductor and a PN junction is constructed. The metal lead connected with the N-section of the PN junction is called the cathode and the metal lead taken from the P-section of the PN junction is the anode. Which is made in the shape of finger so that anode is not covered by it, as shown in the figure 7.34.

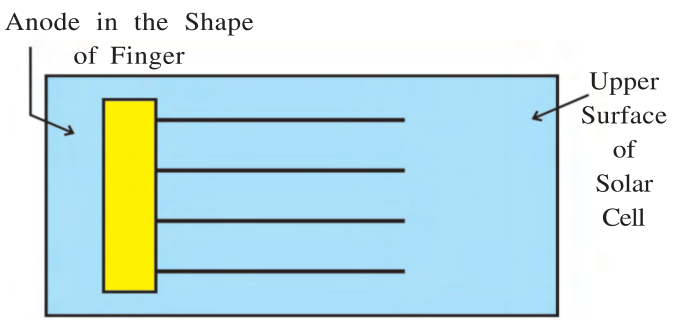


Figure 7.34

The thin layer of P-type semiconductor is called the emitter and the N-type semiconductor is known as the base. The incident light is directly incident on the PN junction since the P type material is made up of a very thin layer.

The region of the PN junction is kept large in order to obtain large amount of power. Electron-hole pair is produced when the incident photon energy $hf > E_g$. These electron and hole will move in mutually opposite direction due to the junction potential. The electron produced due to the incident photon will move towards the N-type material while the hole will move towards the P-type material if it is not connected to the external circuit with a resistor. This produces emf whose value is of the order of 0.5 V to 0.6 V.

As shown in figure 7.35 the current I_L known as photo current flows in the external circuit when it is connected with a resistor R_L. The value of this current and photo voltage both depend on the intensity of the light.

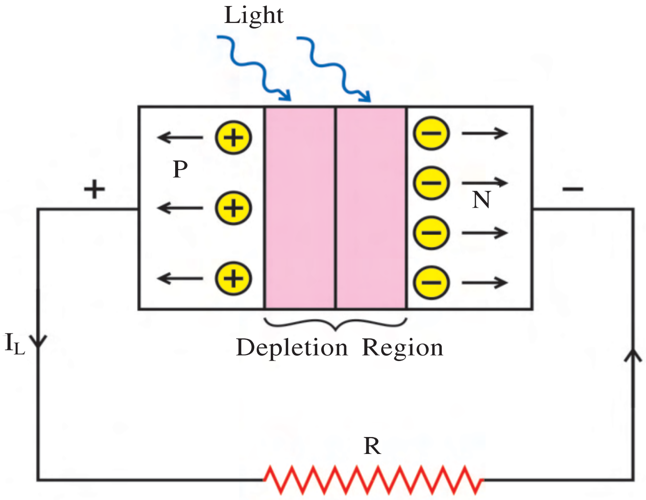


Figure 7.35

Si, GaAs, Cadmium Sulphide (CdS), Cadmium Selenide (CdSe) are some of the semiconductors used in the manufacturing of the solar cell.

The important criteria for the selection of a material for a solar cell fabrication are (i) Band gap energy (~1.0eV to 1.8eV), (ii) high optical absorption (iii) electrical conductivity and (iv) availability of the raw material.

Note that sunlight is not always required for a solar cell. Any light-with photon energy greater than the band gap will also produce photo voltage.

The solar cells can be connected in series or parallel connection to obtain the desired value of the voltage and current. Such an arrangement is called a solar panel. Such panels are used in converting light energy into electricity in the satellites. Such panels can be used as a storage battery, which can be charged during the day time and can be utilized during night time. Solar cells are used in calculators, electronic watch and camera.

Circuit Symbols of Different Types of P-N Junction Diodes

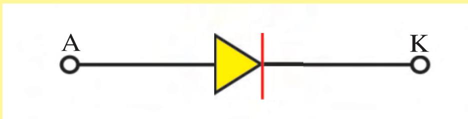
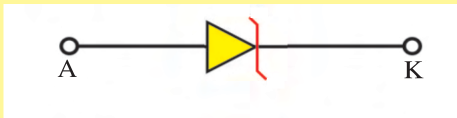
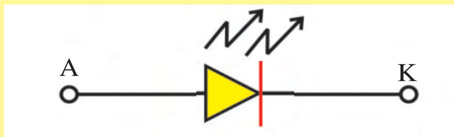
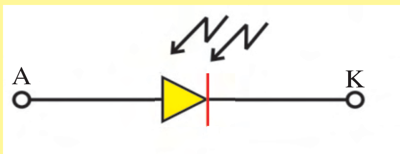
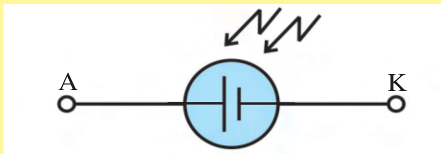
(1)	P-N junction diode	
(2)	Zener diode	
(3)	LED	
(4)	Photo diode	
(5)	Solar cell	

Illustration 3 : A photodiode is made from a semiconductor having 2.8eV band gap. Will it be able to detect a 6620 nm wavelength radiation ? (h = 6.62 × 10^{-34} Js)

Solution : $E_g = 2.8eV = 2.8 \times 1.6 \times 10^{-19} = 4.48 \times 10^{-19}$ J

The wavelength of the radiation $\lambda = 6620 \text{ nm} = 6.620 \times 10^{-6}$ m

The energy of the radiation, $E = hf = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{6.620 \times 10^{-6}} = 3 \times 10^{-20}$ J

Here, $E < E_g$ hence the diode will not detect 6620 nm wavelength radiation.

7.9 Transistor

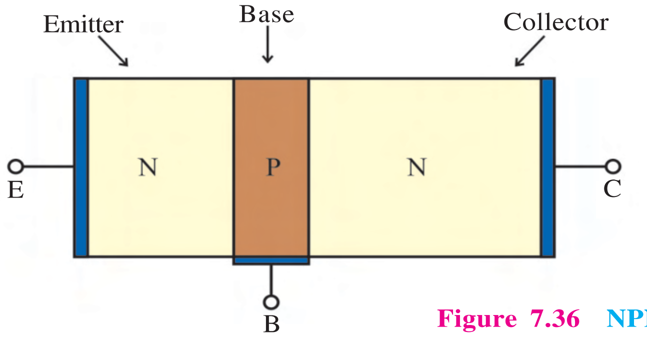
In 1948, transistor was invented in the Bell laboratory by three scientists namely John Bardeen, Walter Barten and William Schotky. They were awarded the Nobel prize for their invention. The size of the transistor is equal to the size of a groundnut but it is still able to perform various tasks performed by the vacuum tube. A revolution was brought about after this discovery in the electronic industry. The dimension of the electronic appliances have reduced due to the small size of the transistor. The weight has also reduced due to the lighter weight of the transistor.

Transistor is a device made up of two PN junction diodes. It is of two types.

(1) PNP Transistor : In this type of transistor, a thin N-type semiconductor wafer is sandwiched between two P-type semiconductors.

(2) NPN Transistor : In this type of transistor, a P-type of thin semiconductor wafer is sandwiched between two N-type semiconductors.

Figure 7.36 shows the construction and the symbol of the NPN transistor. Figure 7.37 shows the construction and the symbol of the PNP transistor.



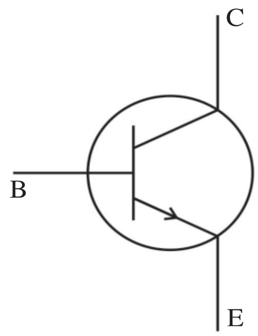
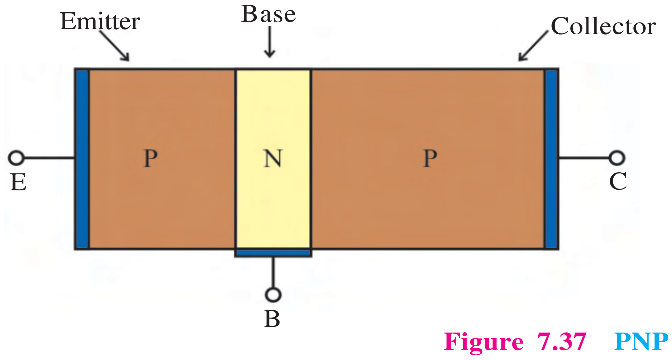


Figure 7.36 NPN Transistor

(Circuit Symbol)



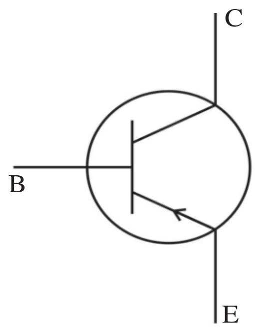


Figure 7.37 PNP Transistor

(Circuit Symbol)

The chip in the centre of the transistor is called the base. The region on one side of the base is the emitter and the other side is called the collector. The volume of the emitter and collector and their electrical properties are different.

The volume of the collector is more than that of the emitter. The concentration of impurities in the base is less, while its resistivity is higher. The impurity concentration in the emitter is high while its resistivity is very less. Impurity concentration in collector is relatively more than that of the base, but is less then that of the emitter.

The junction between the emitter and base is known as the emitter base junction. The junction between the base and the collector is known as the collector base junction. A transistor is operated with its emitter base junction is forward biased, while collector base junction is reverse biased. The direction of the conventional current when the NPN and PNP transistors are biased as mentioned above is along the direction of the arrow indicated in the emitter of the symbolic diagram 7.36 and 7.37.

The current in the transistor is due to both electrons and the holes. Hence, it is called Bipolar Junction transistor or BJT.

7.9.1 The Working of a Transistor : In practice NPN transistors are more widely used. In this section, we shall discuss the working of a NPN transistor.

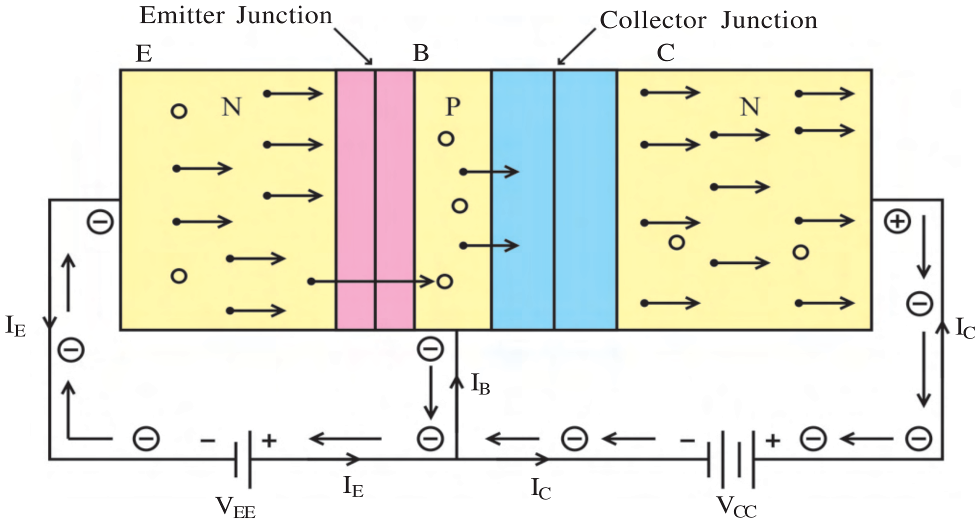


Figure 7.38 Working of NPN Transistor

Let us consider the circuit shown in figure 7.38 to understand the working of a NPN transistor. The emitter junction is forward biased with the help of a battery V_{EE} and the collector junction is reverse biased with the help of the battery V_{CC}. The value of the forward bias voltage is approximately between 0.5 V to 1 V and the reverse voltage V_{CC} is between 5 V to 10 V. The width of the emitter junction is reduced since it is forward biased while the collector junction's width is more since it is reverse biased. In a NPN transistor, electrons are the majority charge carriers in the emitter while holes are the majority charge carriers in the base.

The electrons from the emitter are easily able to go into the base, since the emitter junction is forward biased under the effect of the battery V_{EE}. The current constituted due to this is known as the emitter current (I_E). The base width is small and has fewer concentration of the impurity. As a result only 5% of the electrons entering the base recombine with the holes. The rest of the electron enter the collector region due to the influence of the battery V_{CC}. For every electron entering the collector one electron flows in the external circuit and constitutes the collector current I_C. Similarly for every electron recombining with the hole in the base section, there is one electron which gets attracted by V_{EE} and flows as base current I_B in the external circuit.

Applying the Kirchhoff's first law near the junction point.

$$I_E = I_B + I_C$$

The magnitude of I_E and I_C is normally in the mA range, while I_B is of the order of μA.

Similarly we can understand the working of a PNP transistor. The majority carriers leaving the emitter are holes in case of a PNP transistor. It enters the narrow region of the base and goes to the collector and constitutes the collector current I_C.

In any normal electronic circuit, there are two inputs and two output terminals. There is a total of 4 terminals in all. In a transistor there are only 3 terminals: Base (B), Emitter (E) and Collector (C). Hence, any one terminal is kept common to the both input and output. Hence, in this way three different types of circuits are possible in case of a transistor: (1) Common Base circuit (CB), (2) Common Emitter circuit (CE), (3) Common Collector circuit (CC).

In a CB circuit, I_C is the output current and I_E is the input current. The ratio of I_C and I_E is called the current gain α_{dc}.

$$\alpha_{dc} = \frac{I_C}{I_E}$$

Here, $I_E > I_C$ hence $\alpha_{dc} < 1$

For a CE circuit I_C is the output current and I_B is the input current. Hence for a CE circuit, the current gain $\beta_{dc} = \dfrac{I_C}{I_B}$.

Here, $I_C >> I_B$ hence $\beta_{dc} >> 1$

All the three circuits CB, CE and CC have different characteristics. Hence all the three circuits have different applications.

Most of the electronic circuits employ CE circuit. Hence we shall study the characteristics of CE circuit in detail.

7.9.2 Characteristics of a Transistor : We need to understand the relationship between the applied voltage and the current flowing through the transistor in order to understand the working of a transistor. The curve showing the relationship between the voltage and the corresponding current for a transistor is known as it's static characteristic curves. The curve showing the relationship between the input voltage and the input current for any given value of the output voltage is known as the input characteristics curve. The curve indicating the relationship between the output voltage and the output current for any given value of the input current is known as the output characteristics.

The figure 7.39 shows the circuit to study the static characteristics of a CE transistor circuit.

The emitter junction is forward biased due to the battery V_{BB} and the collector junction is reverse biased with the help of battery V_{CC}. Rheostat R_1 is used to vary the base voltage V_{BE} and rheostat R_2 is used to vary the collector voltage V_{CE}.

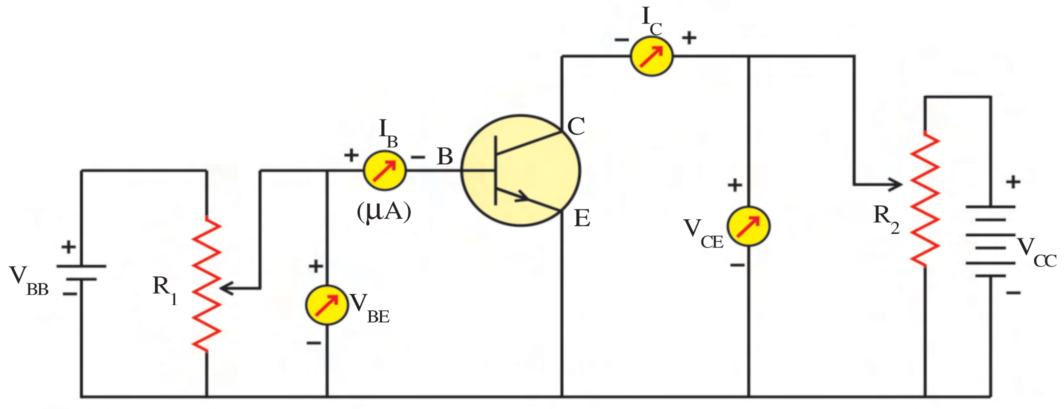
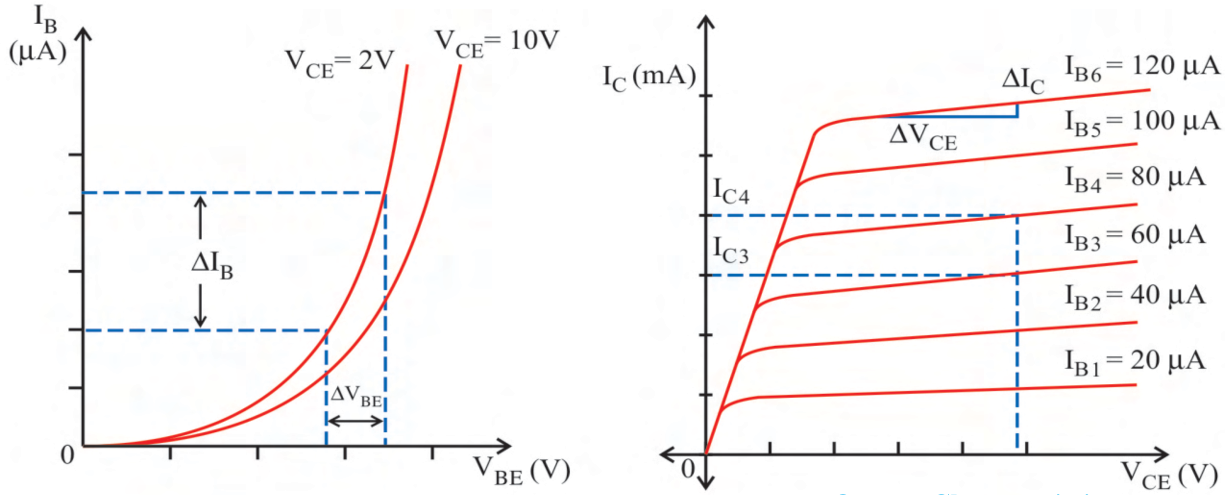


Figure 7.39 Circuit Diagram to Obtain Characteristics of a Transistor



Input Characteristics **Output Characteristics**

Figure 7.40 Characteristics of a Transistor

For studying the characteristics the collector voltage V_{CE} is set to any one value (for example, V_{CE} = 2 V) and with the help of the rheostat R_1, base current I_B is noted for different values of the voltage V_{BE}. Next keep the voltage V_{CE} to some high value (as for example, V_{CE} = 10 V) and obtain the relationship between I_B and V_{BE} and plot the graph I_B – V_{BE}. The above procedure gives us the input characteristics. Such an input characteristics curve is shown in figure 7.40. Such a characteristic curve is similar to the one for a PN junction diode.

In order to study the output characteristics the base current I_B is kept constant (as for example I_B = 20 μA), the collector voltage V_{CE} is varied and the corresponding changes in the collector current I_C is noted down. Repeat the above experiment for three to four different values of the base current I_B (as for example 40 μA, 60 μA and 80 μA). Plot the graph between I_C – V_{CE}

for different values of the base current. This graph gives the output characteristic curve (refer to figure 7.40). The central position of the curve is known as the active region. In this region the collector current is not dependent on the value of V_{CE} and it is almost constant. The transistor is operated in this region if it has to be used as an amplifier.

The transistor parameters can be found from the characteristic curves as follows :

(1) Input Resistance : The ratio of the change in the input base voltage (ΔV_{BE}) to the change in the input base current (ΔI_B) at a constant collector voltage (V_{CE}) is known as the input resistance (r_i).

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}} = \text{constant}$$

This parameter can be found from the input characteristic curve. Normally r_i is of the order of k Ω.

(2) Output Resistance : The ratio of the change in the collector voltage (ΔV_{CE})to the change in the collector current for a constant base current (I_B) is known as the output resistance r_0.

$$r_0 = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B} = \text{constant}$$

This parameter can be found from the output characteristic curve. Normally it's value is found between 50k Ω to 100k Ω.

(3) Current Gain : The ratio of the change in the collector current, (ΔI_C) to the corresponding change in the base current (ΔI_B) at constant value of the collector voltage (V_{CE}) is known as the current gain β.

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}} = \text{constant}$$

This parameter can be found from the active region of the output characteristic curve. Normally the value of β is between 10 and 1000.

Taking the ratio of β and r_i for a CE circuit,

$$\frac{\beta}{r_i} = \frac{\Delta I_C / \Delta I_B}{\Delta V_{BE} / \Delta I_B} = \frac{\Delta I_C}{\Delta V_{BE}}$$

This ratio of the change in the current in the output circuit (ΔI_C) to the change in the input voltage (ΔV_{BE}) is known as the transconductance (g_m).

$$\therefore \; g_m = \frac{\Delta I_C}{\Delta V_{BE}} \quad \text{or} \quad g_m = \frac{\beta}{r_i}$$

Its unit is *mho*.

(*c*) Transistor as an Amplifier : Amplifier circuits are one of the most important circuits in electronics. Most of the electronic appliances use amplifier circuits. Amplifier circuits are used in amplifying small signals. As for example the output voltage of a microphone, the signal received from a TV antenna or a radio antenna etc. are of the order of microvolt. Such type of signals can be amplified by means of an amplifier.

Let us understand the working of the widely used CE transistor amplifier. The circuit diagram of a CE transistor amplifier using a NPN transistor is shown in the figure 7.41. The emitter junction is forward biased with the help of the battery V_{BB} and the collector junction is reverse biased with the help of battery V_{CC}. The A.C. signal which has to be amplified is connected between the base and emitter of the transistor. The amplified signal is obtained between the collector and emitter terminals or in other words across the two ends of the resistor R_L.

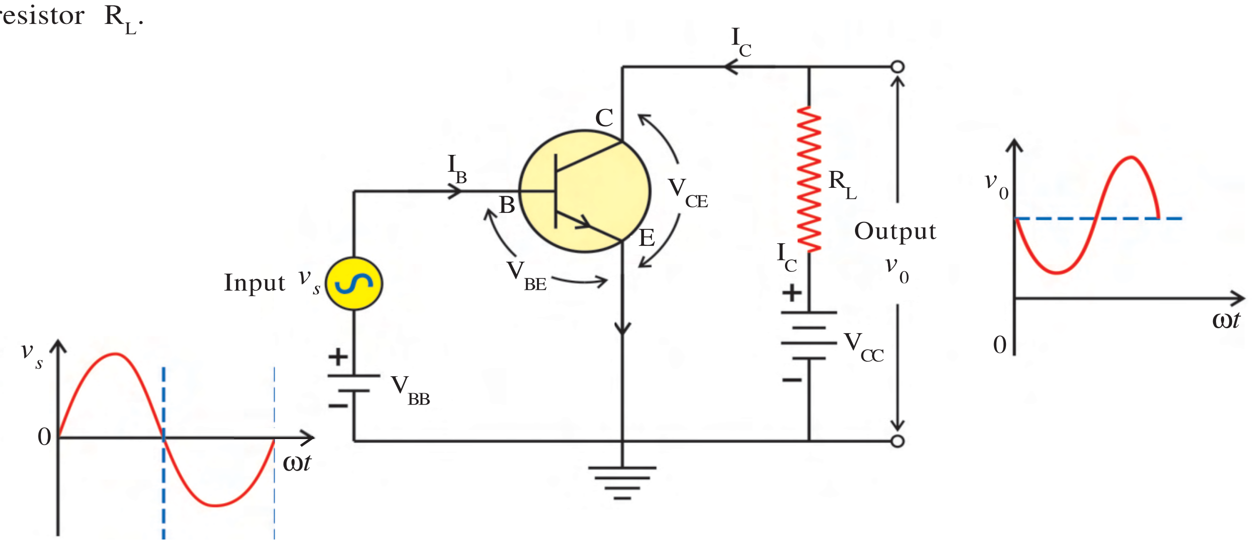


Figure 7.41 CE Transistor Amplifier

The A.C. signal (V_S) causes the change in the base emitter voltage V_{BE}. This results in the change in the base current I_B. The changes in the base current (ΔI_B) is of the order of microampere. This results in the change in the collector current equal to $\beta \Delta I_B$, which is of the order of milliampere. A large voltage is obtained by connecting a large value of (R_L) in the output circuit and taking the voltage drop across it. This is the output voltage of the circuit. This is how a transistor works as an amplifier. The ratio of the output voltage (v_0) and the input voltage (v_S) is known as the voltage gain (A_V).

The Working of the Circuit :

(1) Input Circuit : v_S is the input voltage of the amplifier which has to be amplified. In the absence of the signal v_S (i.e. $v_S = 0$) as per the Kirchhoff's second law,

$$V_{BB} = V_{BE} \tag{7.9.1}$$

In the presence of the signal v_S, the change in the base emitter voltage is $\Delta V_{BE.}$

$\therefore\ V_{BB} + v_S = V_{BE} + \Delta V_{BE}$ (7.9.2)

Substituting the equation (7.9.2) in the equation (7.9.1), we get

$v_S = \Delta V_{BE}$ (7.9.3)

The change in the base current ΔI_B is due the voltage change ΔV_{BE}. As per the definition of the input resistance r_i we have,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

or

$\Delta V_{BE} = v_S = r_i \Delta I_B$ (7.9.4)

(2) Output circuit : The collector current changes by an amount ΔI_C due to the change in the base current ΔI_B. As a result the voltage change by an amount $R_L \Delta I_C$ across the resistor R_L.

As per the Kirchhoff's second law,

$V_{CC} = I_C R_L + V_{CE}$ (7.9.5)

$\therefore\ \Delta V_{CC} = R_L \Delta I_C + \Delta V_{CE}$

But the battery voltage V_{CC} remains constant. $\therefore\ \Delta V_{CC} = 0$

$\therefore\ 0 = R_L\ \Delta I_C\ +\ \Delta V_{CE}$

$\therefore\ \Delta V_{CE} = -R_L \Delta I_C$

$\therefore\ v_0 = -R_L \Delta I_C$ (7.9.6)

Here, ΔV_{CE} is obtained across the two ends of the load resistor and is known as the output voltage v_O.

Voltage gain (A_V) : As per the definition of the voltage gain,

$$\text{Voltage gain, } A_V = \frac{\text{Output Voltage}}{\text{Input Voltage}} = \frac{v_O}{v_S}$$

Substituting equation (7.9.6) and equation (7.9.4), we have,

$$A_V = -\frac{R_L \Delta I_C}{r_i \Delta I_B} \quad (7.9.7)$$

$$A_V = -\beta \frac{R_L}{r_i} \quad (7.9.8)$$

Where, $\beta = A_i = \frac{\Delta I_C}{\Delta I_B}$ and is known as the current gain of the transistor. $\frac{\beta}{r_i}$ is known as the transcondutance (g_m) of the transistor.

$\therefore\ A_V = -g_m R_L$ (7.9.9)

Here, the negative sign indicates that the phase difference between the input (v_S) and the output voltage (v_O) is 180°. Whenever the input voltage increases the output voltage decreases and vice versa.

Power Gain (A_P) : As per the definition of the gain A_P,

$$A_P = \frac{\text{Output AC Power}}{\text{Input AC Power}}$$

$$A_P = \frac{\Delta V_{CE} \Delta I_C}{\Delta V_{BE} \Delta I_B}$$

$$A_P = A_V A_i$$

$$= \left(-\beta \frac{R_L}{r_i}\right)(\beta)$$

$$\therefore \ |A_P| = \beta^2 \frac{R_L}{r_i} \qquad (7.9.10)$$

The question which can arise in our mind is that from where did the extra power come from ? Is conservation law of the energy violated ? The answer to the above question is that the DC energy from the battery gets converted into the AC energy.

Illustration 4 : The current gain of a common base (CB) circuit is α and the current gain of a common emitter (CE) circuit is β. Find the relationship between α and β.

Solution : For a common base circuit, $\alpha = \frac{\Delta I_C}{\Delta I_E}$

For a CE circuit, $\beta = \frac{\Delta I_C}{\Delta I_B}$

Now for any configuration of a transistor circuit,

$\Delta I_E = \Delta I_C + \Delta I_B \quad (\because \ I_E = I_B + I_C)$

$$\therefore \frac{\Delta I_E}{\Delta I_C} = 1 + \frac{\Delta I_B}{\Delta I_C} \qquad \text{(Dividing both sides by } \Delta I_C\text{)}$$

$$\therefore \frac{1}{\alpha} = 1 + \frac{1}{\beta} \qquad \text{(As per the definition of } \alpha \text{ and } \beta\text{)}$$

$$\therefore \frac{1}{\beta} = \frac{1}{\alpha} - 1 = \frac{1-\alpha}{\alpha}$$

$$\therefore \beta = \frac{\alpha}{1-\alpha}$$

Similarly you can try to derive the relationship, $\alpha = \frac{\beta}{1+\beta}$

Illustration 5 : In a NPN transistor about 10^{10} electrons enter the emitter in 1 μs when it is connected to a battery. About 2 % electrons recombine with the holes in the base. Calculate the values of I_E, I_B, I_C, α_{dc} and β_{dc} (e = 1.6 × 10^{-19} C).

Solution : As per the definition of the current,

$$\text{Emitter current } I_E = \frac{Q}{t} = \frac{ne}{t} = \frac{10^{10} \times 1.6 \times 10^{-19}}{10^{-6}} = 1600 \ \mu A$$

2 % of the total electrons entering the base from the emitter recombine with the holes which constitutes the base current I_B. The rest of the 98 % electrons reach the collector and constitute the collector current.

$\therefore \ I_B = 0.02 \ I_E = 0.02 \times 1600 = 32 \ \mu A$

$\therefore \ I_C = 0.98 \ I_E = 0.98 \times 1600 = 1568 \ \mu A$

$$\text{Now, } \alpha_{dc} = \frac{I_C}{I_E} = \frac{1568 \times 10^{-6}}{1600 \times 10^{-6}} = 0.98 \qquad \left(\text{or } \alpha_{dc} = \frac{I_C}{I_E} = \frac{98\% I_E}{I_E} = 0.98\right)$$

$$\beta_{dc} = \frac{I_C}{I_B} = \frac{1568 \times 10^{-6}}{32 \times 10^{-6}} = 49 \qquad \left(\text{or using the equation } \beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}}\right)$$

Illustration 6 : A change of 0.02 V takes place between the base and emitter when an input signal is connected to the CE transistor amplifier. As a result, 20 μA change takes place in the base current and a change of 2 mA takes place in the collector current. Calculate the following quantities : (1) Input resistance (2) A.C. current gain (3) Transconductance (4) If the load resistance is 5 kΩ, what will be the voltage gain and power gain.

Solution : Here, $\Delta I_B = 20 \ \mu A = 20 \times 10^{-6}$ A, $\Delta V_{BE} = 0.02$ V $= 2 \times 10^{-2}$ V

$\Delta I_C = 2$ mA $= 2 \times 10^{-3}$ A, $R_L = 5$ kΩ = 5000 Ω

$$(1) \text{ Input resistance, } r_i = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{2 \times 10^{-2}}{20 \times 10^{-6}} = 1 \ k\Omega$$

$$(2) \text{ AC current gain } A_i = \beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2 \times 10^{-3}}{20 \times 10^{-6}} = 100$$

$$(3) \text{ Transconductance } g_m = \frac{\beta}{r_i} = \frac{100}{1000} = 0.1 \text{ mho}$$

$$(4) \text{ Voltage gain, } |A_V| = g_m R_L$$

$$= (0.1)\ (5000)$$

$$= 500$$

(5) Power gain, $A_P = A_V A_i$

$= (500)\ (100)$

$= 5 \times 10^4$

Illustration 7 : The collector supply voltage in a CE transistor amplifier is 10 V. The base current is 10 μA in the absence of the signal voltage and the voltage between the collector and the emitter is 4 V. The current gain (β) of the transistor is 300. Calculate the value of the load resistance R_L.

Solution : Here, $V_{CC} = 10$ V, $I_B = 10\ \mu A = 10 \times 10^{-6}$ A, $V_{CE} = 4V$, $\beta = 300$, $R_L = ?$

Now, $I_C = \beta I_B = (300)(10 \times 10^{-6}) = 3$ mA

Applying Kirchhoff's second law to the output circuit of amplifier we have,

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

$$\therefore R_L = \frac{V_{CC} - V_{CE}}{I_C} = \frac{10-4}{3\times10^{-3}} = 2000 = 2\ k\Omega$$

7.9.4 Transistor as a Switch : In an ideal ON/OFF switch, when it is OFF the current is not flowing in the circuit because switch offers infinite resistance. When switch is in ON condition, maximum current flows because its resistance is zero. We can prepare such an electronic switch by using the transistor.

Figure 7.42 shows the circuit diagram for the transistor as a switch. Apply the Kirchoff's law to the input section of the transistor.

$$V_i = I_B R_B + V_{BE} \qquad (7.9.11)$$

Apply the Kirchhoff's law to the output section of the transistor.

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

$$\therefore V_O = V_{CC} - I_C R_L \qquad (7.9.12)$$

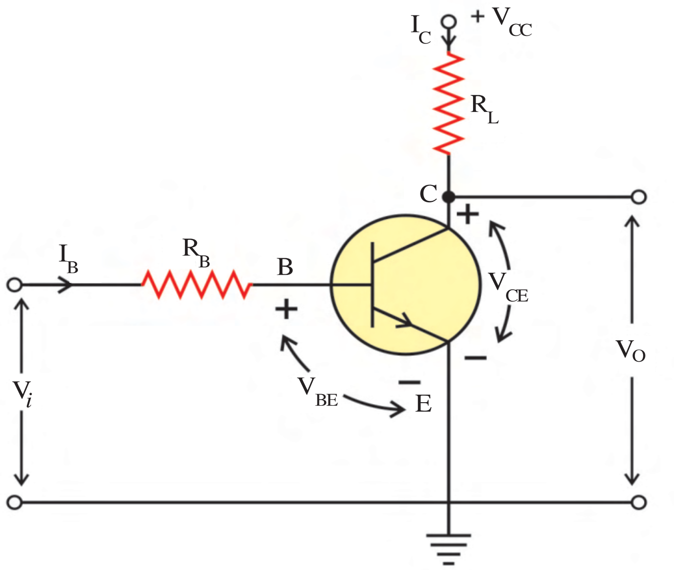


Figure 7.42 Transistor as a Switch

(i) When input voltage $V_i = 0$ or it is less than transistor's cut in voltage, the base current I_B will be zero ($I_B = 0$). Hence the collector current will also be zero ($I_C = 0$).

From equation 7.9.12.

$V_O \approx V_{CC}$

In this situation resistance of output circuit of the transistor is very large. Hence the current is not flowing through it. This shows the 'OFF' or 'cut off' condition of the transistor.

(ii) When the input voltage will be $V_i \approx V_{CC}$, the base current will be maximum, hence the collector current will also be maximum. The voltage drop ($I_C R_L$) across the load resistance R_L will be approximately V_{ec}. According to equation (7.9.12),

$$V_0 \approx 0$$

In this condition resistance of the output circuit of the transistor is very small to the effect that maximum current is flowing through it. This is called the 'ON' condition or saturation condition of the transistor.

This circuit is used to make a 'NOT' gate in the digital electronics.

7.9.5 Transistor as an Oscillator : We have studied the electrical oscillation in LC circuit in the chapter of the AC circuits. These oscillations get damp with time. If such an oscillation has to be sustained, then necessary energy has to be supplied to the circuit. This can be achieved with the help of oscillator circuit.

We know that in amplifier circuit input signal has to be applied to obtain the output signal while in oscillator circuit without input signal, we can obtain the output signal. The oscillator circuit can generate a signal of desired frequency with desired amplitude.

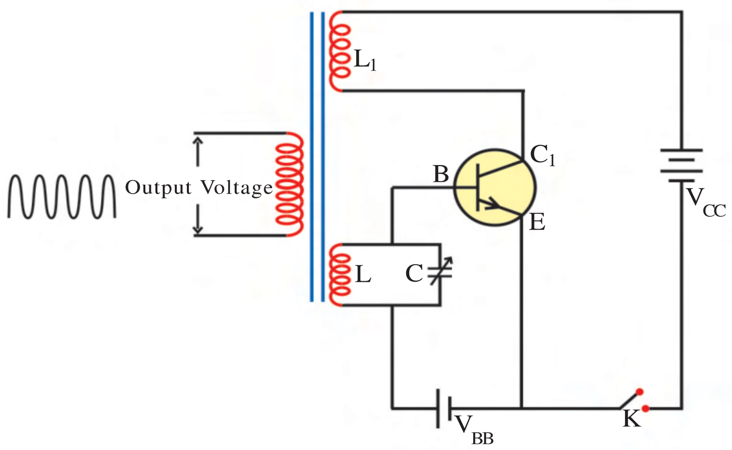


Figure 7.43 Transistor Oscillator

As shown in the figure 7.43, V_{BB} battery provides the forward bias to BE junction and V_{CC} battery provides the reverse bias to BC junctions of a transistor. LC network is introduced between input and output sections of the circuit. Inductors L_1 and L are associated with each other by means of a mutual inductance.

When the key is closed, the current starts flowing in the collector circuit through inductor L_1. This collector current increases with time. Hence, the magnetic flux linked with coil L_1 and as a result the magnetic flux linked with coil L starts increasing and positively charged the upper plate of the capacitor C. This increases the forward bias voltage of the transistor. As a result collector current is also increases. This process continues till the collector current reaches saturation.

When the collector current reaches saturation, the flux linked with the coil L_1 stops changing. As a result induced e.m.f. across the inductor L becomes zero. Now capacitor gets discharged through inductor L, which reduces the forward bias voltage of a transistor. As a result the magnitude of a collector current-decreses. Since the flux through the coil L decreases the other plate of the capacitor becomes more positive. This process continues till the collector current does not become zero. In this situation the capacitor is completely discharged and there is no opposition to the forward bias. The collector current again starts to increase. The above mentioned process keeps repeating. Here, the collector current oscillates between the maximum and zero value.

The frequency of oscillation is,

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

Here, LC network gets the necessary energy from the battery V_{CC} for the sustained oscillation. Thus, oscillator converts the DC energy into the AC energy.

Oscillators are used in the communication, radio, TV and transmitter to generate the high frequency. Such an oscillator circuit can generate the signal of low frequency upto 10^9 Hz.

Illustration 8 : In Transistor oscillator circuit an output signal of 1 MHz frequency is obtained. The value of capacitance C = 100 *p*F. What should be the value of the capacitor if a signal of 2 MHz frequency is to be obtained?

Solution : $C_1 = 100\ pF = 100 \times 10^{-12}$ F, $f_1 = 1$ MHz $= 10^6$ Hz,

$f_2 = 2$ MHz $= 2 \times 10^6$ Hz, $C_2 = ?$

$$f_1 = \frac{1}{2\pi\sqrt{LC_1}} \text{ and } f_2 = \frac{1}{2\pi\sqrt{LC_2}}$$

$$\therefore \frac{f_1}{f_2} = \frac{2\pi\sqrt{LC_2}}{2\pi\sqrt{LC_1}} = \sqrt{\frac{C_2}{C_1}}$$

$$\therefore C_2 = \left(\frac{f_1}{f_2}\right)^2 \times C_1 = \left(\frac{1}{2}\right)^2 \times 100 \times 10^{-12}$$

$C_2 = 25\ pF$

7.10 Digital Electronics and Logic Circuits

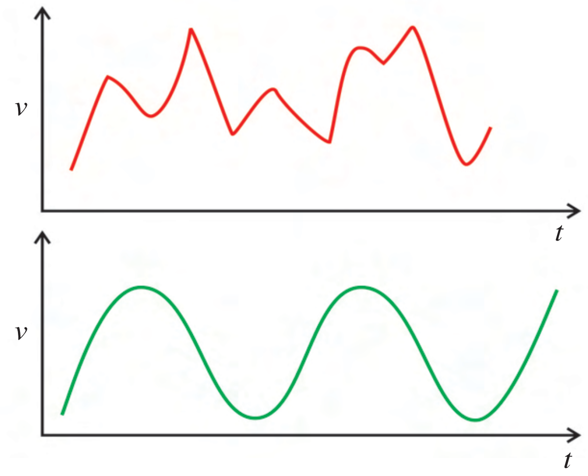
There are problems which have answer in either yes or no. As for example the answer to the question, 'whether it will rain tomorrow or not ?' 'Whether Indian cricket team will win the world cup ?' is either yes or no.

George Boole, mathematician developed, Boolean algebra based on the science of logic. In 1938 a scientist Shannon developed electrical circuit based on the Boolean algebra which are known as logic circuits. As a result branch of digital electronics is developed. Switching action takes place in such a logic circuit. If there is a presence of output voltage, then it is said to be in the ON position or state '1'. If the voltage at the output is zero then it is said to be in the OFF state or '0' state. In such a circuit the output voltage has only two states hence such a circuit used the binary number system.

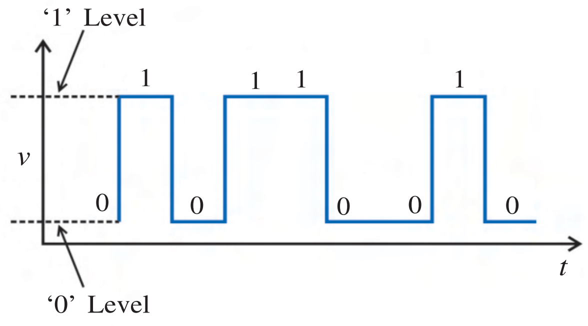
In the present age, digital electronics is widely used in computers, microprocessors communications. T.V., CD player as well as in many medical appliances.

In amplifier or oscillator circuits the current or the voltage are constantly changing with time. These signals can take any value between the minimum and the maximum value of voltage or current. Such a signal is called Analog signal. Figure 7.44 (*a*) shows two different types of Analog signals.

Refer to the signal shown in figure 7.44 (*b*). Here the voltage or the current has only two values. [The maximum value of the voltage is indicated by '1' and the minimum value of the voltage is indicated by '0'. Such a signal is known as digital signal.]



(*a*) Analog Signal



(*b*) Digital Signal

Figure 7.44 Analog and Digital Signal

There are two types of systems used in logic circuit.

(1) Positive Logic System : In this type of system the higher positive voltage is taken as high level of '1' and the less positive voltage is taken as low level or '0'.

(2) Negative Logic System : In this type of system, the more negative voltage is taken as '1' and the less negative voltage is taken as '0'.

We shall be employing positive logic system in our subsequent discussions. We shall consider +5V as '1' state and 0 V as '0'state.

Let us get familiarized with some of the terms used in digital electronics.

Logic Gate : The logic circuit in which there is one or more than one input but only one output is called a logic gate. It's output has only two states, '0' or '1', which depends on condition of input signal.

Logic gates are the most important components of the digital electronics circuit. OR gate, AND gate and NOT gates are the basic logic gates. The other gates like the NAND and NOR gates can be obtained from these basic gates.

Boolean Equation : The Boolean equation represents the special type of algebraic representation, which describes the working of the logic gates.

Truth Table : The table which indicates the output for different combinations of the input voltage is known as the truth table.

7.10.1 OR gate : The figure 7.45 shows the circuit containing the bulb and the two switches A and B to illustrate the working of an OR gate.

Table 1

A	B	Bulb
Open	Open	OFF
Open	Close	ON
Close	Open	ON
Close	Close	ON

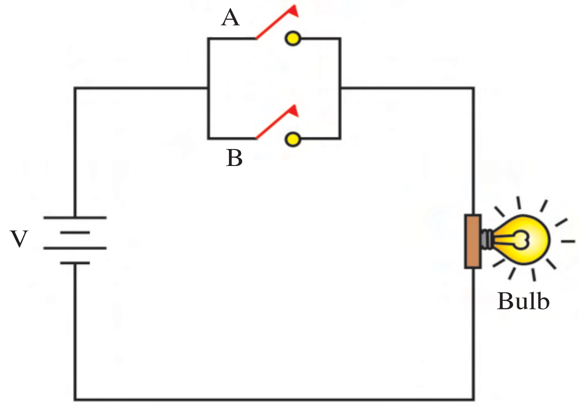


Figure 7.45

When any one of the switches or both the switches will be ON, then bulb will be ON. When both switches will be OFF then only bulb will remain OFF.

The status of the bulb with respect to the switch positions is shown in table 1. In this table if the switch A is taken as input A the switch B is taken as input B and the status of the bulb is taken as output Y, we get the truth table of an OR gate.

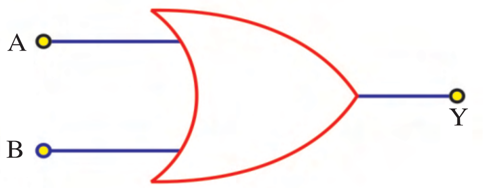


Figure 7.46 Symbol of OR Gate

Table 2

A	B	Y = A + B
0	0	0
0	1	1
1	0	1
1	1	1

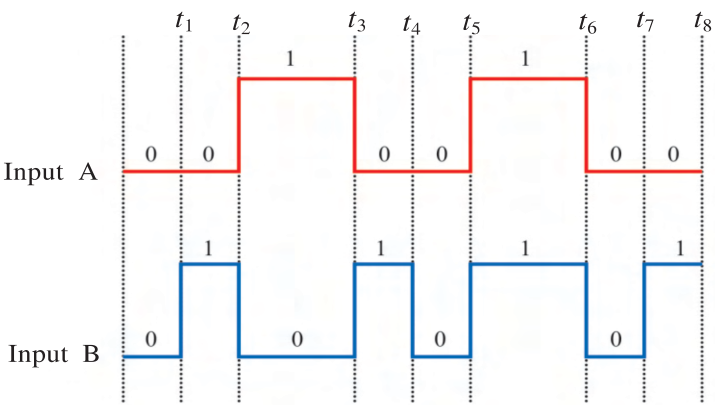
In this table the ON state is taken as '1' and off state is indicated as '0'. We can describe the characteristics of the OR gate based on the above truth table.

Whenever any one input or both the inputs are '1', then we get output '1'.

Boolean equation : Y = A + B : Here, the '+' sign does not indicate the sign of addition but it indicates the OR operator. The above equation is read as follows : "Y is equal to A or B"

The symbol of the OR gate is shown in figure 7.46.

Illustration 9 : Figure shows the digital signals for the two input OR gate. Draw the shape of the output signal of the output of the OR gate.



Solution : First obtain the output (Y) for different states of the input A and B from the truth table then draw the output signal.

When $t < t_1$; A = 0, B = 0, Y = 0

$t_1 < t < t_2$; A = 0, B = 1, Y = 1

$t_2 < t < t_3$; A = 1, B = 0, Y = 1

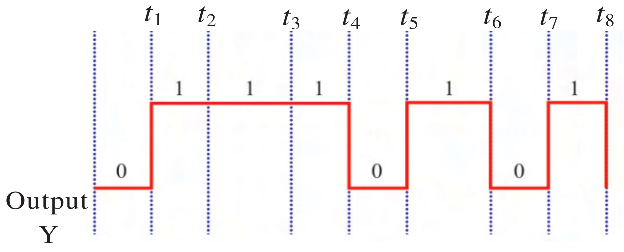
$t_3 < t < t_4$; A = 0, B = 1, Y = 1

$t_4 < t < t_5$; A = 0, B = 0, Y = 0

$t_5 < t < t_6$; A = 1, B = 1, Y = 1

$t_6 < t < t_7$; A = 0, B = 0, Y = 0

$t_7 < t < t_8$; A = 0, B = 1, Y = 1



7.10.2 AND Gate : Let us consider the circuit shown in figure 7.47 in order to understand the working of an AND gate. Here, the two switches A and B are connected in series with the bulb. Therefore, when any one of the switches will be OFF, current will not flow in the circuit and bulb will remain OFF. When both switches will be ON then only bulb will be ON.

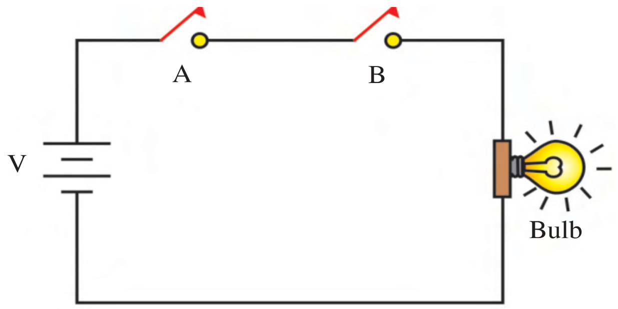


Figure 7.47

Table 3

A	B	Bulb
Open	Open	OFF
Open	Close	OFF
Close	Open	OFF
Close	Close	ON

Table 3 indicates the position of the switch and its corresponding state of the bulb. The truth table of the AND circuit can be prepared from this truth table as follows.

Figure 7.48 Symbol of AND Gate

Table 4

A	B	Y = A . B
0	0	0
0	1	0
1	0	0
1	1	1

From the truth table, function of the AND gate can be defined as follows.

The output of the AND gate is '1'only if all the inputs are '1'. For all other conditions of the input, it is '0'.

The Boolean equation is given as : Y = A·B.

Here '**.**' is known as AND operator. The equation is read as : "Y is equal to A AND B".

7.10.3 NOT Gate : NOT gate has one input and one output terminal. This gate inverts the input voltage. To understand the operation of the NOT gate, refer to figure 7.49.

Table 5

A	Bulb
Open	ON
Close	OFF

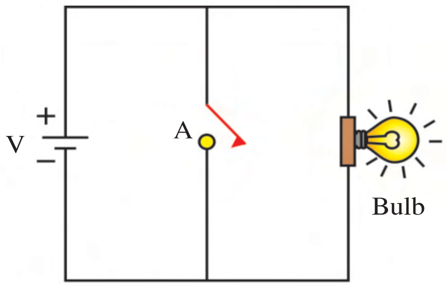


Figure 7.49

When the switch A is open, the current flows through the bulb and the bulb is in ON state. When the switch A is closed no current flows through the bulb and the bulb is in the OFF state. The working of this circuit is summarized in table 5. It is evident from the table 5 that the output reverses the input state. The truth table of the NOT gate is as per the table 6.

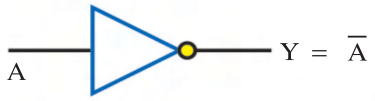


Figure 7.50 Symbol of NOT Gate

Table 6

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

From the truth table, function of the gate can be defined as follows.

"Whenever input is '1' the output is '0' and when the input is '0' the output is '1'."

Hence this gate is also called the inverter.

Boolean Equation : $Y = \overline{A}$: The NOT operator is indicated by the '–' (bar) symbol. The above equation is read as follows : "Y is equal to NOT A."

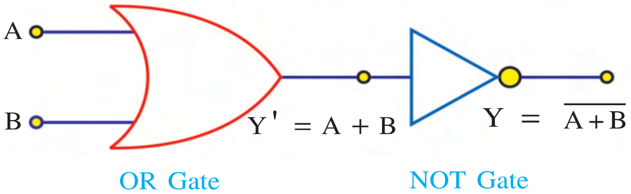
The AND, OR and NOT logic gates are called the basic logic gates in digital electronics. These gates can be combined in different ways to construct newer logic gates. We shall now study two such logic gates.

7.10.4 NOR Gate : The NOR gate is constructed by combining the OR gate and the NOT gate. (OR + NOT = NOR). Here, the output of the OR gate is given as input to the NOT gate. The Boolean expression for the NOR gate is given as follows :

$Y = \overline{A+B}$

This equation is read as : "Y is equal to NOT A or B."

The circuit diagram of the NOR gate and its symbol is shown in figure 7.51. The bubble on the OR gate indicates that the output of the OR gate gets inverted. The truthtable of the NOR gate is shown in table 7.



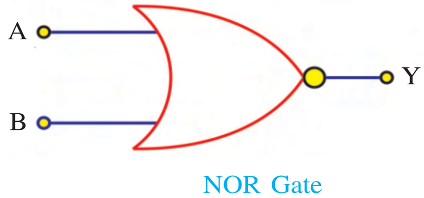


Figure 7.51 Logic Circuit and Symbol of NOR Gate

Table 7

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

The characteristic of the NOR gate can be given as follows :

The output is '0' whenever any one input is '1'. Whenever all the inputs are '0', the output is equal to '1'.

7.10.5 NAND Gate : NAND gate is constructed using the combination of AND gate and the NOT gate. (AND + NOT = NAND). Here, the output of the AND gate is given as input to the NOT gate. The Boolean expression is given as follows :

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

This equation is read as : "Y is equal to NOT A and B".

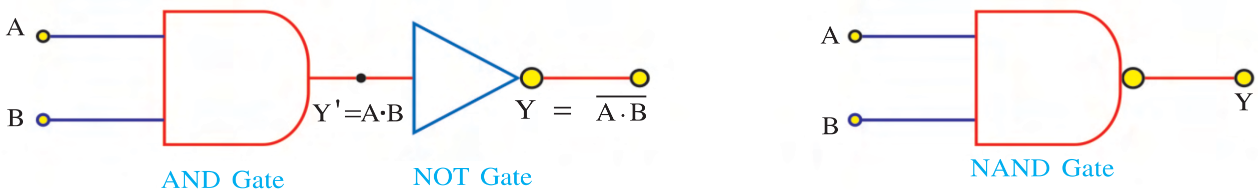


Figure 7.52 Logic Circuit and Symbol of NAND Gate

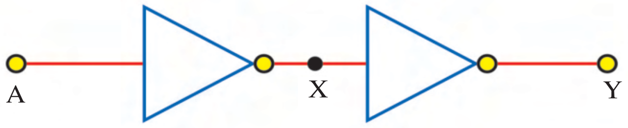
Table 8

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

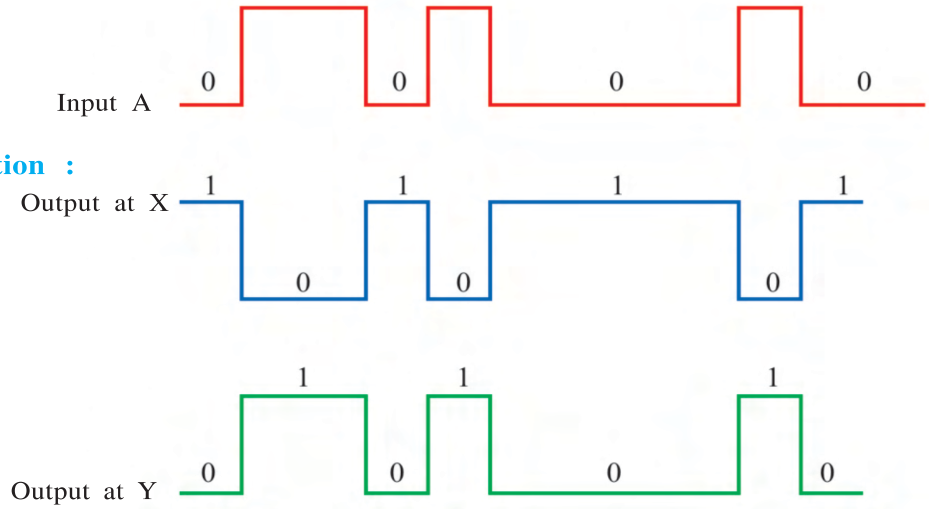
The circuit diagram and the symbol of the NAND gate is given by figure 7.52. The table gives its truth table. The truth table can be summarized as follows :

"The output is equal to '1' when any one input is equal to '0' and the output is equal to '0', when all the inputs are equal to '0'.

Illustration 10 : A logic circuit is shown in the diagram. Draw the output signal at the point X and Y for the input signal shown in the figure at point A.

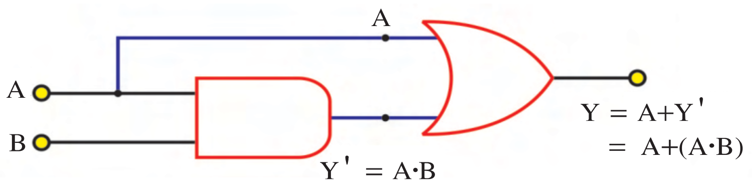


Solution :



Here, the output of the NOT gate will be equal to $X = \overline{A}$. Hence the output obtained will be equal to opposite of A. This signal is given as input to another NOT gate. The signal again gets inverted. As a result we again get back the original signal A. ($Y = \overline{X} = \overline{\overline{A}} = A$)

Illustration 11 : Prepare the truth table for the logic circuit given below.



Solution : Here Y' is the output of the AND gate having A and B as the input. The input to the OR gate is A and Y' (= A · B). Hence the output Y = A + Y' = A + (A · B). The truth table of the circuit can be given as under :

Table 9

A	B	Y' = A · B	Y = A + Y'
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	1

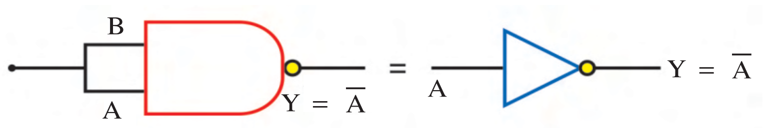
Illustration 12 : Which gate will be obtained by joining the two inputs of the NAND gate ?

Solution : When the two inputs are joined both the inputs will be identical. i.e. A = B. As per the characteristics of the NAND gate,

$Y = 1$ when $A = 0$ and $B = 0$ and

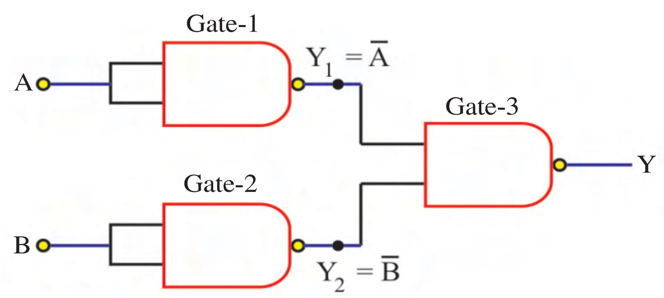
$Y = 0$ when $A = 1$ and $B = 1$

Here, the output Y will be opposite to that of the inputs A or B. Hence, we have a relation $Y = \overline{A}$. Hence the above logic circuit will behave as a NOT gate.



(**Note :** We can obtain a NOT gate by even joining the input terminals of a NOR gate.)

Illustration 13 : Show that the circuit drawn in the figure comprising of 3 NAND gates behaves as an OR gate.



Solution : As explained in the earlier illustration, the gates 1 and 2 will behave as a NOT gate. Hence $Y_1 = \overline{A}$ and $Y_2 = \overline{B}$. $\overline{A}$ and $\overline{B}$ are the inputs to the gate 3. The output Y of the gate 3 can be prepared using the truth table of the NAND gate.

Input A	Input B	$Y_1 = \overline{A}$	$Y_2 = \overline{B}$	Output $Y = \overline{Y_1 Y_2}$
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

It is clear from the truth table that the above truth table resembles the truth table of an OR gate. Hence we have shown that the above circuit behaves as an OR gate.

Note : Since the basic gates can be constructed from the NAND and NOR gates they are known as universal logic gates.

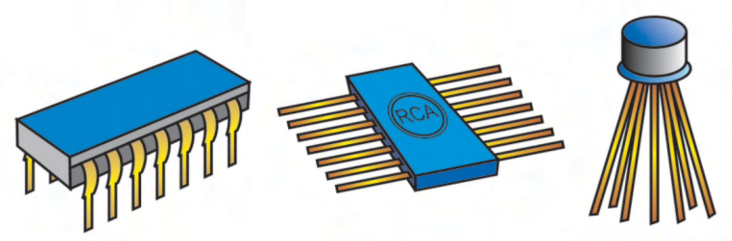
7.11 Primary Concept of IC

Present day electronic gadgets are smaller in size and at the same time are very efficient too. As for e.g. the size of the computers in 1960s was equal to the size of a big room. The present day laptop computers as well as the computers called palm top computers which can be kept in a pocket are commercially available. The Integrated circuits have a big role to play in miniaturization of these electronic gadgets.

About 50 years back the electronic circuits prepared from transistors, diodes and resistors which were joined using conducting wires were not reliable at the same time were huge in size. In the next generations the printed circuit board (PCB) came into existence. The components in a PCB are all arranged on a board and are connected with the help of metal strips.

The PCB helped in reducing the size of the electronic circuits. The circuits in a PCB are in three dimensions (3D). Later on attempt was made to make it two dimensional (2D) to further reduce the size. This gave rise to integrated circuits (IC). The size of the IC is about 1 mm × 1mm. In an IC, a small sized crystal (or chip) is taken and transistors, diodes resistors and capacitors are constructed within it and all these components are internally connected. This has brought about a revolution in the electronics industry. This has resulted in the size of the electronic gadgets to be reduced as well as succeeded in reducing the cost considerably.

The classification of IC is based on the number of logic gates present in it. S.S.I (Small Scale Integration) IC has about 10 or less than 10 number of logic gates. MSI (Medium Scale Integrotion) chips (or ICs) has about less than 100 number of logic gates. Chips having 100 to 1000 number of gates are known as LSI (Large Scale Integration). VLSI (Very Large Scale Integration) chips contain more than 1000 logic gates. VLSI chips are used in computers.



Complete IC in standard package

Figure 7.53 Different Types of IC

IC is basically of three types :

(1) Film Circuit : In this type of IC, thin film technique is used to fabricate components like resistance and capacitance.

(2) Monolithic Integrated Circuit : This IC has components like transistor, diode, resistance and capacitors.

(3) Hybrid Integrated Circuit : This type of IC is combination of film circuit and Monolithic type. This contains more than one chip. We shall obtain information about the Monolithic type IC.

The word Monolithic in Greek language mean one (monos) stone. It is made from only one type of semiconductor (Si or Ge). Hence it is called Monolithic IC.

SUMMARY

1. **Conductor, Insulator and Semiconductor :** The electrical conduction is easily possible in conductors due to the presence of free electrons. The electrical resistance is very low. In insulators there are no free electrons. Hence their electrical resistivity is very large. Semiconductors have more resistivity than conductors but less resistivity than insulators. At 0 K temperature semiconductors behave as insulators.

2. **Electrical Conduction in Intrinsic Semiconductors :** There are two types of electric current in a semiconductor. (i) Due to motion of free electrons. (ii) Due to motion of bound electrons or holes ($I = I_h + I_e$).

3. **N-type and P-type Semiconductors :** N-type semiconductors can be prepared by doping pentavalent impurity in the intrinsic semiconductors. This type of impurity is called donor impurity. In N-type semiconductor, electrons are majority charge carriers and holes are minority charge carriers. For N-type semiconductor, $n_e > n_h$.

   P-type semi-conductor can be prepared by doping trivalent impurity in the intrinsic semiconductors. This type of impurity is called acceptor impurity. In P-type semiconductor, holes are majority charge carriers and electrons are minority charge carriers. For P-type semiconductors, $n_h > n_e$.

4. **Band Diagram for Semiconductors :** There are 8N valence state and corresponding energy levels in a silicon crystal of N atoms. According to electronic configuration of Si, 4 N energy levels are filled. As per Pauli's principle, 4 N electrons occupy these 4 N energy levels of band and this band is completely filled. This band is called valence band.

   Above the valence band there is a region where no energy levels are available. This region is known as forbidden gap.

   The region above the forbidden gap is known as the conduction band. The conduction band is completely empty.

   The difference of minimum energy level of conduction band (E_c) and maximum energy level of valence band (E_v) is called band gap (E_g).

   If the energy supplied to the valence electron is E_g or greater than E_g, the electron can jump from the valence band to conduction band. These electron will then contribute towards the current.

   For insulator, band gap is $E_g > 3\ eV$.

   For conductor, band gap is $E_g = 0$.

   For semiconductor band gap is $E_g < 3\ eV$.

5. **Forward Bias :** When the positive terminal of the battery is connected to P and negative terminal is connected to N of the PN junction diode, this connection is called forward bias.

   In forward bias mode, height of the depletion barrier and width of the depletion layer is decreasing.

   Resistance of the PN Junction is approximately 10 Ω to 100 Ω in forward bias.

6. **Reverse Bias :** When the negative terminal of battery is connected to P-type and positive terminal is connected to N-type of PN junction, this connection is called reverse bias.

   In reverse bias resistance of PN junction is in order of M Ω.

7. **Rectifier :** The process of converting AC energy into DC energy is called rectification. The circuit which performs this process is called rectifier. There are two types of rectifiers. (i) Half wave rectifier (ii) Full wave rectifier.

8. **Zener Effect :** The electric field in the depletion region of PN junction diode is strong when small reverse bias voltage is applied because of the thin width of the depletion region. This strong electric field is sufficient to break covalent bonds and make the electron free. This results in large number of electron and hole pair formation as well as sudden increase in the current. This effect is known as zener effect.

9. **Maximum Wavelength of the Light-emitted from the LED :**

$$\lambda = \frac{hc}{E_g}$$

where, E_g = Bandgap energy

h = Planck's constant

c = Velocity of light

10. The condition for detecting light-incident on the photo diode is,

$$\frac{hc}{\lambda} > E_g$$

11. **Transistor :** A device with two PN junction is called a transistor. Transistor has three terminals. (i) Emitter (E) (ii) Base (B) and (iii) Collector (C).

The junction between emitter and base is called emitter junction and junction between base and collector is called collector junction.

To operate the transistor, emitter junction should be in forward bias and collector junction should be in reverse bias.

The relationship between different currents of the transistor.

$$I_E = I_B + I_C$$

12. **Transistor's parameters :**

(a) Input Resistance :

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}} = \text{constant}$$

(b) Output Resistance :

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B} = \text{constant}$$

(c) Current Gain :

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}} = \text{constant}$$

(d) Transconductance :

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

The unit of g_m is mho.

13. **Transistor Amplifier :** Voltage gain of CE amplifier,

$$A_V = -\beta\frac{R_L}{r_i} = -gm\ R_L$$

Power gain of CE simplifier, $|A_P| = A_V A_i = \beta^2 \frac{R_L}{r_i}$

14. **Oscillator :** The circuit can generate desired frequency of desired amplitude is called an oscillator.

The frequency of an LC oscillator circuit, $f = \frac{1}{2\pi\sqrt{LC}}$.

15. **Logic Gate :** The logic circuit which has more than one input but only one output is called a logic gate. It has only two output state '0' or '1'.

OR, AND and NOT are the basic logic gates.

OR Gate : Whenever any one input or both the inputs are '1', then only output is '1'.

Boolean equation: $Y = A + B$.

AND Gate : The output of AND gate is '1' only if all the inputs are '1' for all other condition of input it is '0'.

Boolean equation : $Y = A \cdot B$.

NOT Gate : Whenever input is '1' the output is '0' and when the input is '0' the output is '1'.

Boolean equation : $Y = \overline{A}$

NOR Gate : The output is '0' whenever any one input is '1'. Whenever all the inputs are '0' the output is '1'.

Boolean equation : $Y = \overline{A + B}$

NAND Gate : The output is '1' when any one input is '0' and the output is '0', when all the inputs are '1'

Boolean equation : $Y = \overline{A \cdot B}$

EXERCISE

For the following statements choose the correct option from the given options :

1. The density of electron and holes in an intrinsic semiconductor is n_e and n_h respectively. Which of the following options are true ?

(A) $n_h > n_e$ (B) $n_e > n_h$ (C) $n_e = n_h$ (D) $n_h >> n_e$

2. The energy band diagram of a Si semiconductor crystal at absolute zero temperature,

(A) has completely empty valence band and completely filled conduction band.

(B) has completely empty conduction band and completely filled valence band.

(C) has completely empty valence and conduction band and completely filled forbidden gap.

(D) the conduction band is partially filled.

3. The band gaps of a conductor, semiconductor and insulator are respectively E_{g_1}, E_{g_2} and E_{g_3}. The relationship between them can be given as....

(A) $E_{g_1} = E_{g_2} = E_{g_3}$ (B) $E_{g_1} > E_{g_2} > E_{g_3}$

(C) $E_{g_1} < E_{g_2} < E_{g_3}$ (D) $E_{g_1} < E_{g_2} > E_{g_3}$

4. When will the conductivity of a Ge semiconductor decrease ?

(A) On adding donor impurity (B) On adding acceptor impurity

(C) In making UV light incident (D) On decreasing the temperature

5. For detecting the light,

(A) The photodiode has to be forward biased.

(B) The photodiode has to be reverse biased.

(C) The LED has to be connected in forward bias mode.

(D) The LED has to be connected in a reverse bias mode.

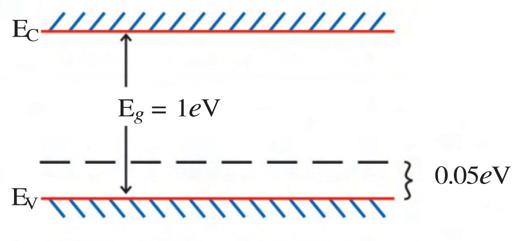
6. What is the type of the semiconductor, for the energy band diagram shown in the figure ?

(A) N-type semiconductor

(B) P-type semiconductor

(C) Intrinsic semiconductor

(D) Both N and P type semiconductors



7. In order to operate .... type of semiconductor, we have to apply the forward bais.

(A) photo diode (B) zener diode

(C) varactor diode (D) light emitting diode (LED)

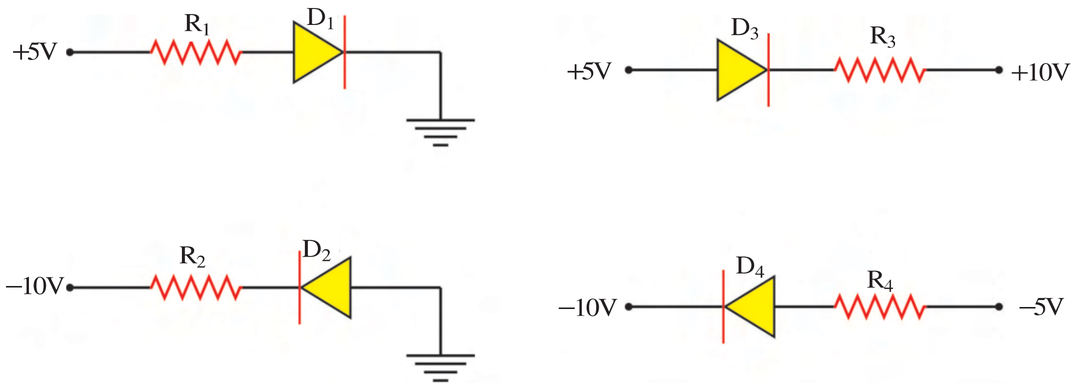
8. Which type of semiconductor device does not need any bias voltage ?

(A) photo diode (B) varactor diode (C) solar cell (D) transistor

9. A potential barrier of 0.50 V exists acrros of PN junction. If the depletion region is 5.0×10^{-7} m wide the intesisty of the electric field in this region is ....

(A) 1.0×10^9 V/m (B) 1.0×10^6 V/m (C) 2.0×10^5 V/m (D) 2.0×10^6 V/m

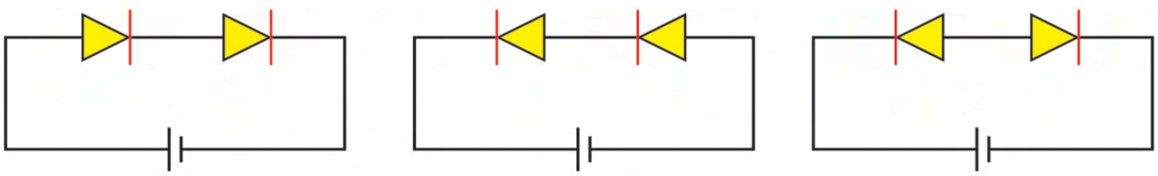
10. Which of the following P-N junction diode is reverse biased ?



(A) P-N junction diode D_1 (B) P-N junction diode D_2

(C) P-N junction diode D_3 (D) P-N junction diode D_4

11. Two identical P-N junction diodes are connected with the battery in three different ways (refer to the figure). For which circuit will the potential difference between the diodes be identical.



(1) (2) (3)

(A) For circuit (1) and (2) (B) For circuit (2) and (3)

(C) For circuit (3) and (1) (D) None of the above circuits

12. V_m is the maximum voltage between the ends of the secondary terminal of a transformer used in a half wave rectifier. When the PN junction diode is reverse biased, what will be the potential difference between the two ends of the diode ?

(A) Zero (B) $\frac{V_m}{2}$ (C) V_m (D) 2 V_m

13. In LC oscillator, the angular frequency of oscillation of current is obtained from ....

(A) $f = \frac{1}{2\pi LC}$ (B) $\omega^2 = \frac{1}{LC}$ (C) $\omega = \frac{1}{2\pi\sqrt{LC}}$ (D) $\sqrt{f} = \frac{1}{2\pi LC}$

14. The frequency of the output signal becomes .... times by doubling the value of the capacitance in the LC oscillator circuit.

(A) $\frac{1}{\sqrt{2}}$ (B) $\sqrt{2}$ (C) $\frac{1}{2}$ (D) 2

15. The emitter junction of the CE transistor amplifier is .... biased while the collector junction is .... biased.

(A) Reverse, forward (B) Forward, forward

(C) Reverse, reverse (D) Forward, reverse

16. The amplifier has voltage gain equal to 200 and its input signal is 0.5 cos(313 t) V. The output signal will be equal to .... volt.

(A) 100 cos(313 t + 90°) (B) 100 cos(313 t + 180°)

(C) 100 cos(493 t) (D) 0.5 cos(313 t + 180)

17. The collector has current of the NPN transistor is equal to 10 mA. If 90% of the electron from the emitter reaches collector then......

(A) $I_E \approx 9$ mA, $I_B \approx 1$ mA (B) $I_E \approx 11$ mA, $I_B \approx 9$ mA

(C) $I_E \approx 11$ mA, $I_B \approx 1$ mA (D) $I_E \approx 10$ mA, $I_B \approx 1$ mA

18. $\alpha = 0.99$ for a CE transistor amplifier circuit. The input resistance is equal to 1 kΩ and the load resistance is equal to 10 kΩ. The voltage gain of the circuit is......

(A) 99 (B) 990 (C) 9900 (D) 99000

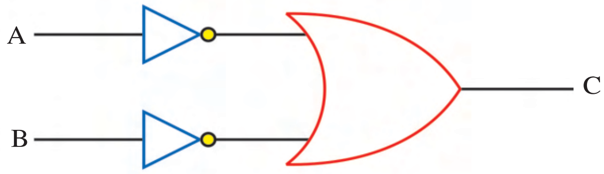
19. The logic circuit shown in the figure represents characteristic of which logic gate ?

(A) OR gate

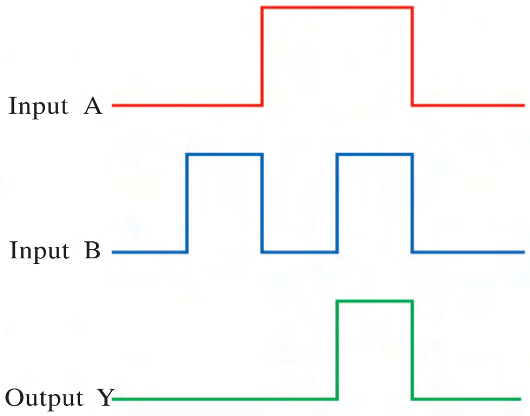
(B) AND gate

(C) NOR gate

(D) NAND gate



20. The figure shows the input signal A, input signal B and the output Y. Which logic gate does it represent ?



(A) OR gate

(B) AND gate

(C) NAND gate

(D) NOR gate

21. Which logic gate characteristic is represented by the truth table shown below :

(A) NAND gate

(B) NOR gate

(C) AND gate

(D) OR gate

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

ANSWERS

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

Answer the following questions in brief :

1. Give the electronic configuration of silicon.
2. What is a hole ?
3. Can we consider a bound electron as a free electron? Why ?
4. What is intrinsic semiconductor ?
5. What is forbidden gap ?
6. Draw a band diagram of a N-type semiconductor at room temperature.
7. What is depletion barrier ?
8. Draw a circuit symbol of a PN junction diode. What does the arrow indicate ?
9. What is rectification ?
10. What is called filter circuits ?
11. Write the equation for maximum wavelength of a light emitted from LED.
12. What is the value of photovoltage produced in a photo cell ?
13. Give the relation between I_E, I_C and I_B. Also give the order of their magnitude.
14. What is the phase difference between input and output signal of a CE amplifier ?
15. What is a logic gate ?
16. Write the Boolean equation of a NOR gate.
17. Which are the basic logic gates and universal logic gates ?
18. Write full form of VLSI.

Answer the following questions :

1. Explain the electrical conduction in intrinsic semiconductor with the help of a diagram.
2. Write a short note on P-type semiconductor.
3. Explain the valence band, conduction band and forbidden gap of Si semiconductor.
4. Draw and explain the band diagram of N-type semiconductor at 0 K temperature and room temperature.
5. Explain the depletion layer and depletion barrier of a PN junction diode.
6. Draw the circuit diagram to obtain forward bias characteristics of a PN junction and discuss the forward bias characteristics of it.
7. Draw the circuit diagram of a half wave rectifier and explain the working of the circuit.
8. Write short note on LED.
9. Draw the circuit of a CE amplifier using NPN transistor. Obtain the expression for the voltage gain and power gain of CE amplifier.

10. Explain the working of a OR gate. Give the symbol, Boolean expression and truth table of a OR gate.

11. Draw the logic diagram of a NAND gate. Give the symbol, Boolean expression and truth table of it.

Solve the following examples :

1. There are 6×10^{19} electrons per unit cubic metre of pure semiconductor. What will be the number of holes for this semiconductor of dimension 1 cm × 1 cm × 2 cm ?

   [**Ans. :** 12×10^{13}]

2. The density of electron hole pair in a pure semiconductor at 300 K temperature is 1.5×10^{16} m^{-3}. The number density of the majority charge carriers becomes equal to 4.5×10^{22} m^{-3} on adding trivalent impurity atoms. What will be the number density of the minority charge carriers in the above sample ? [**Ans. :** 5×10^{9} m^{-3}]

3. A electron hole pairs are formed when maximum 6000 Å wavelength of light is incident on the semiconductor. What will be the band gap energy of the semiconductor ?

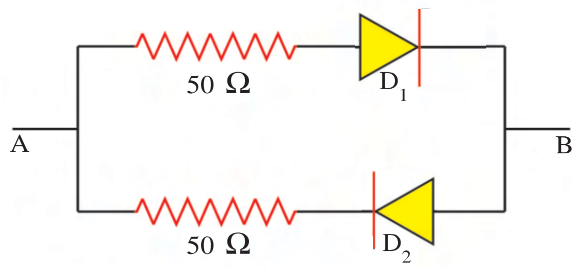
   [$h = 6.62 \times 10^{-34}$ J s] [**Ans. :** 2.07 eV]

4. If an LED has to emit 662 nm wavelength of light then what should be the band gap energy of its semiconductor ? [$h = 6.62 \times 10^{-34}$ J s] [**Ans. :** 1.875 eV]

5. The width of a depletion region is 400 nm. The intensity of the electric field at the depletion region is 5×10^{5} V/m. Then calculate the following quantities : (1) The value of the potential barrier. (2) The minimum energy required by an electron to move from the N-type to the P-type region of the diode. [**Ans. :** 0.2 V, 0.2 eV]

6. For the circuit shown in the figure, calculate the equivalent resistance for the two cases given as : (1) $V_A > V_B$ and (2) $V_B > V_A$. Here consider D_1 and D_2 to be ideal diodes.

   [**Ans. :** For both the cases R_{AB} = 50 Ω]



7. The voltage gains of a N-P-N common emitter amplifier is 200. Its load resistance is 10 kΩ. Calculate the value of the transconductance. If the input resistance is 1 kΩ, what will be the value of the A.C. current gain. [**Ans. :** g_m = 0.02 mho, A_i = 20]

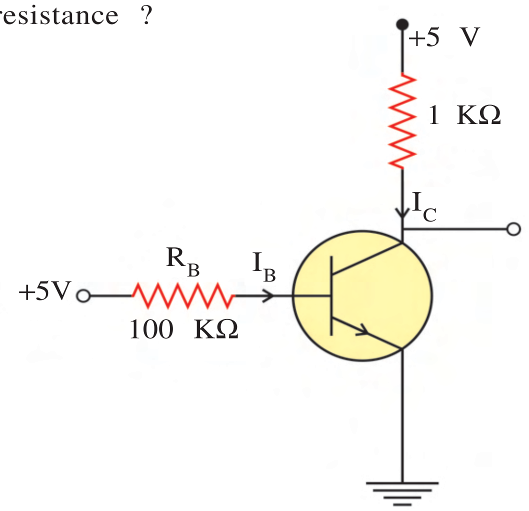
8. For an NPN transistor about 7 % of the electron entering the base from the emitter recombines with the hole. This results in the collector current being 18.6 mA. Calculate the emitter current and the current gain.

   [**Ans. :** I_{EV} = 20 mA, α = 0.93]

9. The base current changes by 200 μA when a 200 mV signal is applied at the input of a CE amplifier. Find input resistance. If the output voltage is 2 volt, what is the voltage gain?

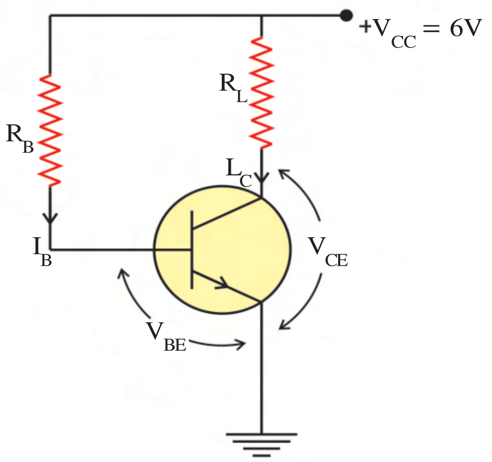
   [**Ans. :** r_i = 1 kΩ, A_V = 10]

10. The collector current changes by 10 mA when the input voltage of the NPN common emitter amplifier changes by 100 mV. The A.C current gain of this circuit is equal to 150. If we have to obtain a power gain of 4500 then what should be the value of the load resistance ? [**Ans. :** $R_L = 300\ \Omega$]

11. 

In the circuit shown in the figure, on applying +5V at the base resistor R_B, both the V_{BE} and V_{CE} voltages become zero. Then calculate the values of I_C, I_B and β.

[**Ans. :** $I_B = 50\ \mu A$, $I_C = 5$ mA, $\beta = 100$]



12. For the circuit shown in the figure, $I_B = 5\ \mu A$, $R_B = 1\ M\Omega$, $R_L = 1.1\ k\Omega$, $I_C = 5$ mA and $V_{CC} = 6V$. Calculate the values of V_{BE} and V_{CE}.

[**Ans. :** $V_{BE} = +1.0V$, $V_{CE} = +0.5V$]

13. The A.C current gain of a PNP common emitter circuit is 100. The value of the input resistance is 1 kΩ. What should be the value of the load resistor R_L in order to obtain power gain of 2000 ?

[**Ans. :** $R_L = 200\ \Omega$]

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