ELECTRONICS

ELECTRONICS

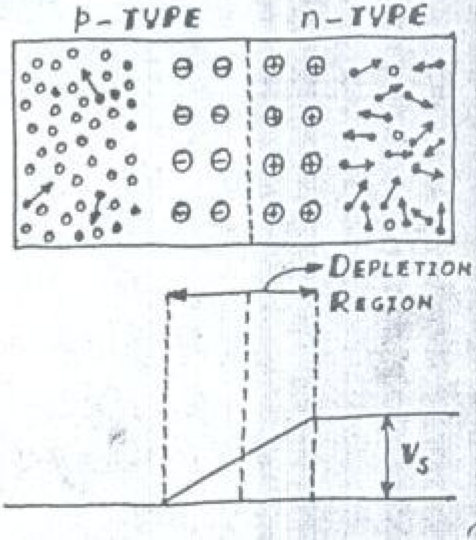
That branch of applied physics which concerned with the development of electrical circuits using semi-conductors, thermionic valves and other devices in which the motion of electrons is controlled, called electronics.

P-N JUNCTION OR SEMI-CONDUCTOR DIODE

A p-n junction is formed when a crystal of germinium (Ge) or silicon (Si) is grown in such a way that its one part is doped with a trivalent impurity and the remaining part with a pentavalent impurity and the device is called semi-conductor diode.

The part of semi-conductor which is doped with a trivalent impurity is the p-type semi-conductor while the remaining part which is doped with the pentavalent impurity is the n-type semi-conductor. The n-region of semi-conductor diode contains free electrons as majority carriers and its p-region contains holes as majority charge carriers. Just after the formation of p-n junction, the free electrons in the n-region diffuse into the p-region because of their random motion.

DEPLETION REGION



When p-n junction is formed, then the free electrons moves across the junction from n-tye to p-type region, so a net positive charge is produced on the n-side of the junction and at the same time, a net negative charge is produced on the p-side of the junction and further diffusion of electrons is stopped. As a result of this diffusion, a chargeless region is formed around the junction in which charge carriers are not present. This region is known as deplition region as shown in figure.

In the figure, black dots represent the free electrons and the small circles show the holes. The circles with + and − signs show the positive and negative ions which form the deplition region.

POTENTIAL BARRIER

Due to charge on the ions around the junction, a P.D. develops across the depletion region which stops further diffusion of electrons into the p-region. This P.D. is called potential barrier or junction barrier.

For Silicon, potential barrier is 0.7 volt.

For Germinium, potential barrier is 0.3 volt.

BIASING

The application of some external P.D. across the semi-conductor diode is known as biasing.

The P.D. across the semi-conductor diode can be applied in two ways

(i) Forward biasing

(ii) Reverse biasing

FORWARD BIASED P-N JUNCTION

When an external P.D. is applied across a p-n junction by connecting a battery such that its positive terminal is connected to p-side and its negative terminal is connected to n-side. In this stat the p-n junction is said to be forward biased as shown in figure.

The external P.D. supplies energy to free electrons in the n-region and to holes in the p-region. When this energy is sufficient to overof few milli-amperes begins to flow across the p-n junction.

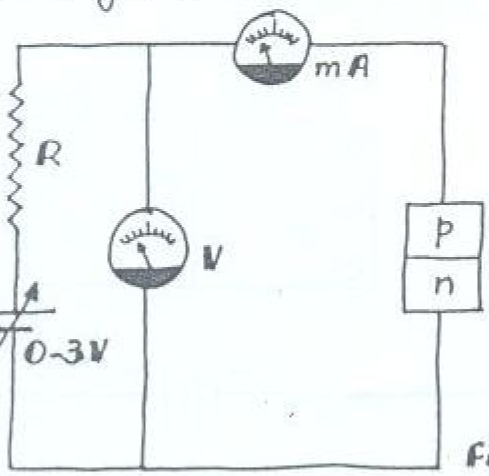


Fig (b)

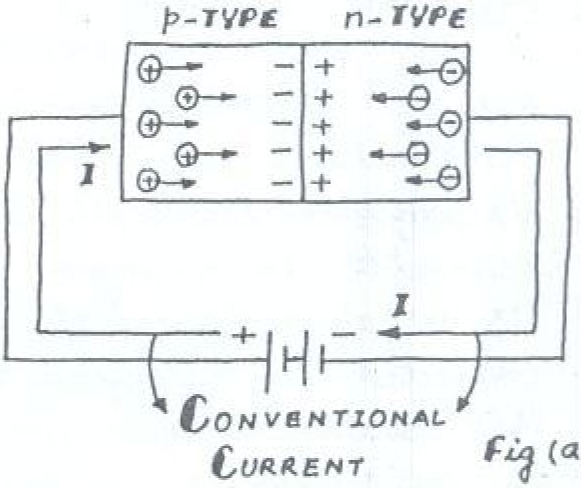
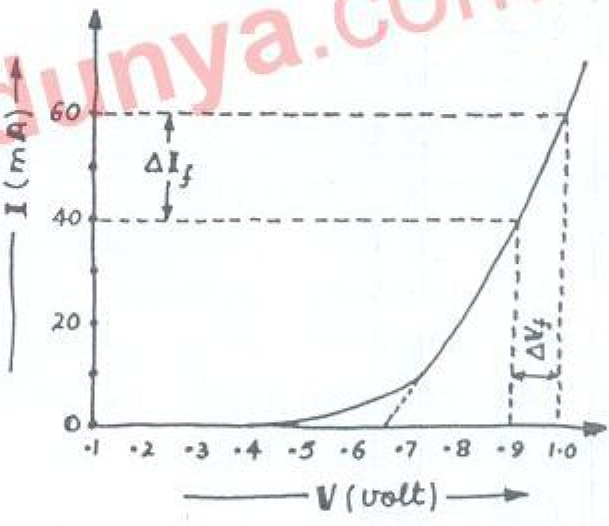


Fig (a)

The variation of current through the p-n junction with the bias voltage can be studied by the circuit as shown in figure (b).

CHARACTERISTIC CURVE

The value of current for different values of bias voltage is noted and current-bias voltage graph is plotted as shown in figure. Figure shows the graph for typical low power silicon diode.



If forward bias voltage is increased by ΔV_f and the current increases by ΔI_f, then the ratio between forward voltage ΔV_f and the forward current ΔI_f is known as the forward resistance r_f of the p-n junction i-e;

$$\boxed{r_f = \frac{\Delta V_f}{\Delta I_f}} \longrightarrow (1)$$

It is the resistance offered by the p-n junction when it is forward bias and it is conducting. The value of r_f is only a few ohms.

REVERSE BIASED P-N JUNCTION

When an external P.D. is applied across a p-n junction such that its positive terminal is connected to n-region and its negative terminal is connected to p-region. In this state, the p-n junction is said to be reverse biased as shown in figure (c). In this situation, no current flows due to the majority charge carriers because negative terminal of the battery pulls the holes away from the junction and its positive terminal attracts the electrons. However a very small current of the order of few micro-amperes flows across the junction due to flow of minority charge carriers. <u>This current is known as reverse current or leakage current.</u>

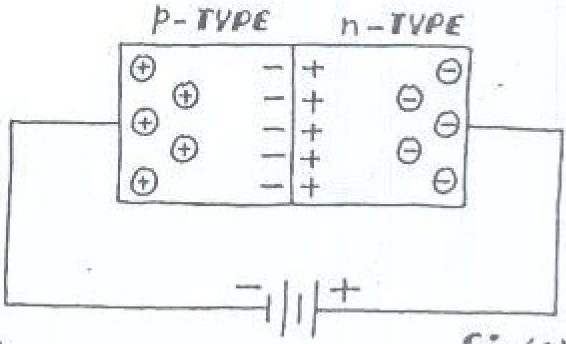


Fig (c)

The variation of the reverse current with the applied bias voltage can be studied by the circuit as shown in figure (d).

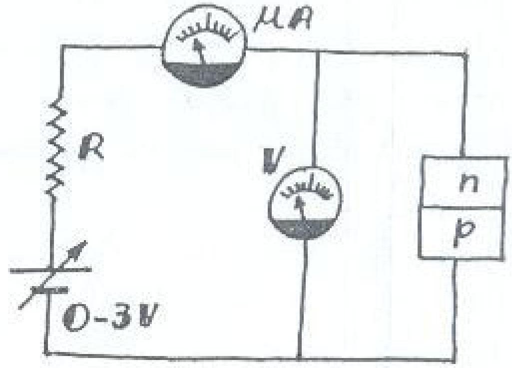
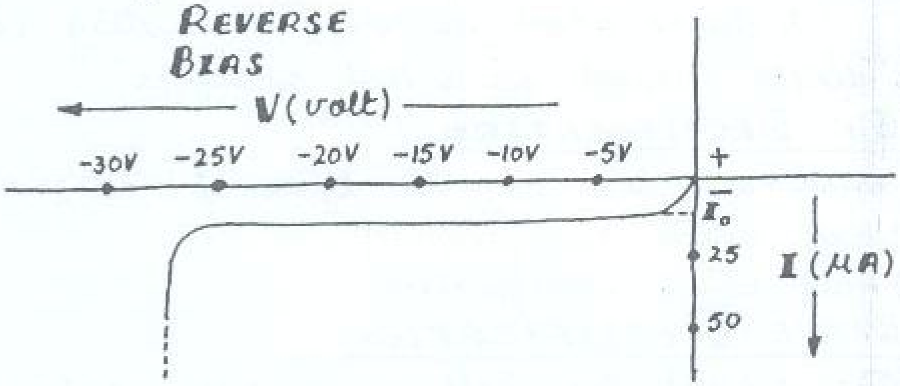


Fig (d)

CHARACTERISTIC CURVE

The value of current for different values of applied bias voltage is noted and current-bias voltage graph is plotted as shown in figure. The figure shows the reverse characteristics for the p-n junction.

It can be seen that as the reverse voltage is increased from 0, the reverse current quickly rise to its saturation value I_o. As the reverse voltage is further increased, the reverse current remains almost constant. Here the resistance offered by the diode is very high of the order of several mega-ohms.

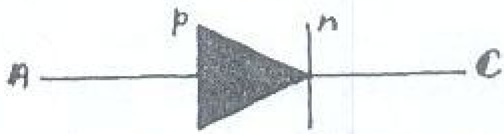


When the reverse voltage is increased, then the K.E. of the minority charge carriers with which they cross the depletion region also increases till it is sufficient to break a covalent bond. As the covalent bond breaks, more electron-hole pairs are created and the reverse current begin to increase till a point is reached when the junction breaks down and reverse current rise sharply as shown in figure. The value of reverse voltage at which break-down occurs is called break down voltage for the p-n junction.

After break-down, the reverse current will rise to a very high value which will damage the junction.

SYMBOLICAL REPRESENTATION OF DIODE

The symbolical representation of a semi-conductor diode is shown in figure. The arrow head represents the p-region and known as anode A. The vertical line represents the n-region and known as cathode C. The current flows in the direction of arrow when the diode is forward biased.



RECTIFICATION

The conversion of alternating current into the direct current is called rectification.

RECTIFIER

A device which converts alternating current into the direct current is called rectifier.

TYPES OF RECTIFICATION

There are two common types of rectification.

(i) Half wave rectification

(ii) Full wave rectification

HALF-WAVE RECTIFICATION

The circuit for half-wave rectification is shown in figure (a).

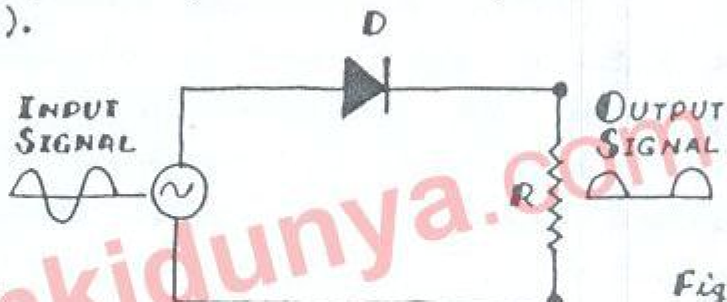


Fig (a)

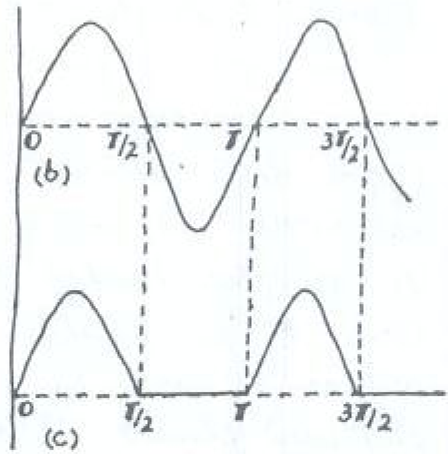
CONSTRUCTION

Half-wave rectifier circuit consists of an alternating voltage of period T called input voltage is applied to a diode D which is connected in series with a load resistance R. In this method only one half of the alternating current cycle is converted into the direct current.

WORKING

During the positive half cycle of the input alternating voltage i-e; during the interval $0 - T/2$, the diode D is forward biased, so it offers a very low resistance and current flows through R. The flow of current through R causes a potential drop across it which varies according to the alternating input voltage as shown in figure (c).

Now during the negative half cycle i-e; during the interval $T/2 - T$, the diode is reverse biased, so it offers a very high resistance and practically no current flows through R. In this case the potential drop across it is almost zero as shown in figure (c).



The same events repeat during the next cycle and so on.

It can be observed that the current flows through the diode only for positive half cycles of input A.C. voltage and it is blocked during negative half cycles. So, current flows through R in one direction after every half cycle which means it is a direct current. However, this current flows in pulses as shown in figure (c). The voltage appears across load resistance R is known as output voltage.

Full-Wave Rectification

In full-wave rectification, the current flows through the load resistance R in the same direction for both half cycles of input A.C. voltage.

Construction

The full-wave rectifier circuit is shown in figure (a). The circuit consists of four diodes D_1, D_2, D_3 and D_4 connected in the form of a bridge. This circuit arrangement is known as bridge type rectifier.

Working

During the positive half cycle i-e; during the time interval $0 - T/2$, the terminal A of the bridge is positive with respect to the other terminal B. Now the diodes D_1 and D_3 becomes forward biased and conduct current while diodes D_2 and

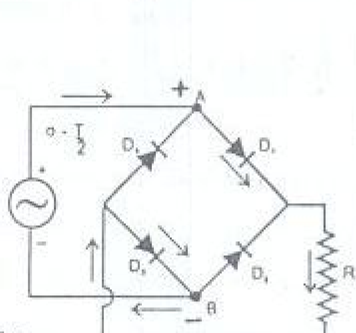


Fig (a)

D_4 are reverse biased and not conduct the current. So, current flows through the circuit as shown in figure (a).

During negative half cycle i-e; during the time interval $T/2 - T$, the terminal A of the bridge is negative and B is positive. Now, the diodes D_2 and D_4 conduct and current flows through the circuit in the direction as shown in figure (b).

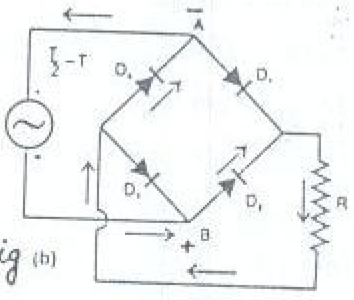


Fig (b)

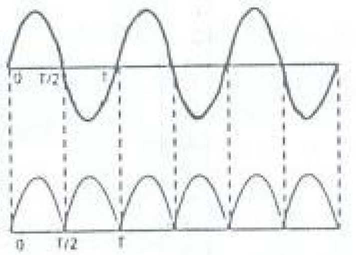


Fig (c)

From figures (a) and (b), it can be seen that the direction of current flow through the load resistance R is the same in both the halves of the cycle. Graphically, the input and output voltages are shown in figure (c). However, the output voltage is not smooth but fluctuating. The output voltage can be made smooth by using a circuit known as "Filter Circuit".

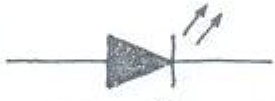
Specially Designed P-n Junction

The most commonly used semi-conductor diodes or p-n junctions for special purposes are

(i) Light Emitting Diode or LED
(ii) Photo Diode
(iii) Photo Voltaic Cell.

Light Emitting Diode or LED

LED's are types of p-n junction diode and these are always forward biased. LED's are made from special semi-conductors like gallium arsenide (Ga As) and gallium arsenide phosphide (Ga As P).



LED Symbol

Working Of LED

At a certain potential barrier between p and n-sides of the diode, the electrons move across the junction from n-side to p-side and combine with holes near the junction during forward bias conduction. Here they emitted energy in the form of photons. Such a diode is called light emitting diode or LED as shown in figure.

Uses Of LED's

(i) LED's are commonly used as small light sources e.g; indicator etc.

(ii) A specially formed array of seven LED,s is used for displaying digits etc. in electronic appliances as shown in figure.

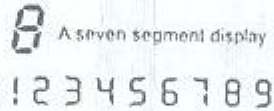
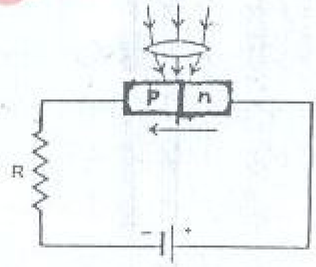


Photo Diode

A photo diode is a semi-conductor diode made from silicon. It converts light energy into electrical energy and used for the detection of light.

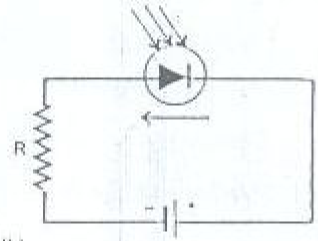
The symbol of photo diode is shown in figure (b).



(a)

Working

The circuit of photo diode is shown in figure (a). It is operated in the reverse biased condition. When no light is incident on the junction, the reverse current is almost negligible but when light is incident on the junction, the reverse current increases with the intensity of light as shown in the graph



(b)

A photo diode can turn its current ON and OFF in nano-seconds, so it is one of the fastest photo detection device.

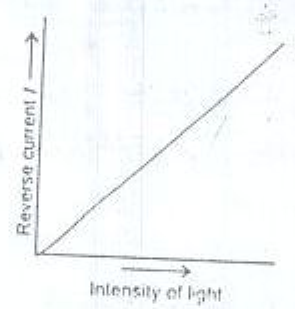
APPLICATIONS OF PHOTO DIODE

(i) Photo diodes used for the detection of both visible and invisible light.

(ii) These are used for automatic switching.

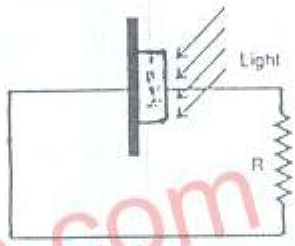
(iii) These are used in optical communication equipments.

(iv) These are used in logic circuits.



PHOTOVOLTAIC CELL OR SOLAR CELL

A photovoltaic cell is a type of p-n junction in which potential barrier between p and n regions is used to drive a current through external circuit when light is incident on the junction as shown in figure.



The current flowing through the external circuit is directly proportional to the intensity of incident light. A single silicon photovoltaic cell produces a small voltage of 0·6V and a current of the order of a few milli-amperes.

In order to produce greater power, thousands of such cells are connected in series or parallel. They are called photovoltaic panels and are used in satellites and space stations to convert solar energy into electrical power needed to operate electronic devices

TRANSISTORS

A transistor consists of a single crystal of germinium or silicon which is grown such a way that it has three regions, namely

(i) Base (ii) Emitter

(iii) Collector

Types Of Transistors

There are two types of transistors

(i) n-p-n transistor

(ii) p-n-p transistor

If the central region is p-type which is sandwiched between two n-type regions, then the transistor is known as n-p-n transistor as shown.

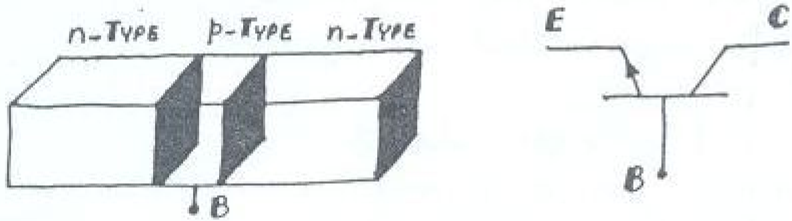


Fig (a)

If the central region is n-type which is sandwiched between two p-type regions, then the transistor is known as p-n-p transistor as shown.

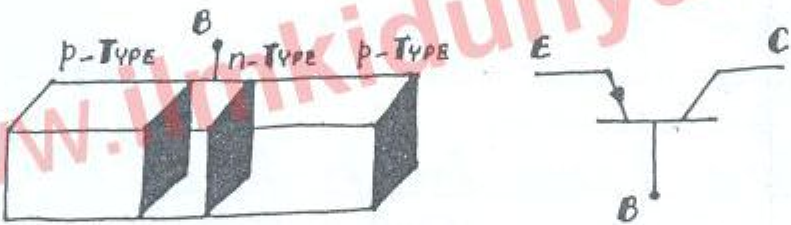


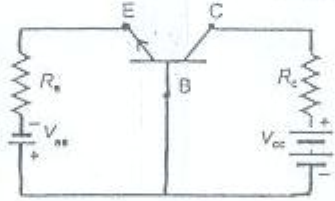
Fig (b)

The central region is known as base and the one end region is known as emitter while other end region is known as collector. In symbolical form of transistor, the emitter is represented with arrow mark as shown in figures. Usually, the base region is very thin, of the order of 10^{-6} m. The collector is comparatively larger than the emitter. The emitter has greater concentration of impurity as compared to the collector.

It can be seen from figures (a) and (b) that a transistor is a combination of two back to back p-n junctions i-e; emitter-base junction and collector-base junction.

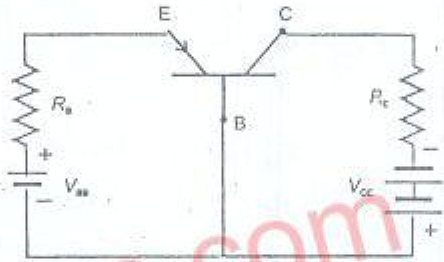
For normal operation of the transistor, batteries V_{BB} and V_{CC} are connected in such a way that its emitter-base junction is forward biased and its collector-base junction is reverse biased. V_{CC} is much higher than V_{BB}.

Figure (c) shows the biasing arrangement for n-p-n transistor when the transistor has been represented in symbol form.



(C)

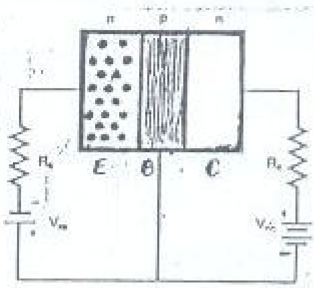
Figure (d) shows the same for a p-n-p transistor. It may be noted that the polarities of the biasing batteries V_{BB} and V_{CC} are opposite in the two types of the transistors. In actual practice, n-p-n transistors are generally used for operation.



(d)

CURRENT FLOW IN n-P-n TRANSISTOR

Figure (a) shows a biased n-p-n transistor with emitter-base junction as forward biased and collector-base junction as reverse biased. As emitter-base junction is forward biased, so emitter injects a large number of electrons in base region as shown in figure (b). These free electrons in the base region can flow in either of two directions. They can flow out of the base to the positive terminal of battery V_{BB} or these electrons can be attracted towards the collector because of



Fig(a)

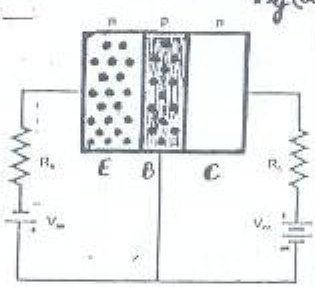
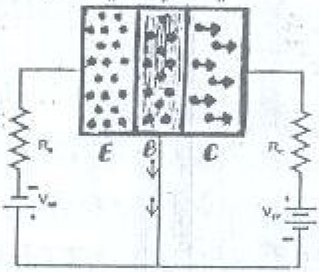


Fig (b)

battery V_{CC}.

As, the base region is very thin, so a few electrons manage to recombine with holes and escape out of the base. Hence, almost all the free electrons flow from emitter into the base are attracted into the collector by the large positive V_{CC} as shown in figure (C).



Fig(C)

From the above discussion, it can be observed that in a normally biased transistor, the electronic current I_E flows from emitter into the base. A very small part of it, current I_B flows out of the base and the remaining current I_C flows out of the collector as shown in figure (d).

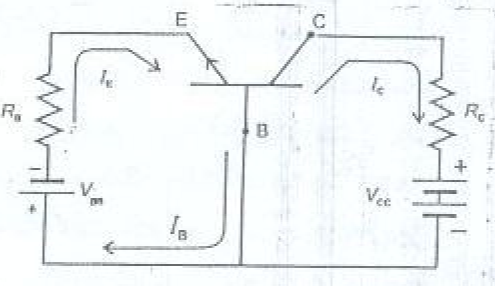


Fig (d)

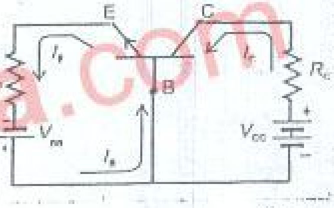


Fig (e)

From figure, it can be seen that

$$\boxed{I_E = I_C + I_B} \longrightarrow (1)$$

The flow of conventional current is shown in figure (e). As very few electrons flow out of base, so I_B is very small as compared to I_C.

CURRENT GAIN OF TRANSISTOR

For a given transistor, the ratio of collector current I_C to base current I_B is nearly constant called current gain of transistor.

It is denoted by β and given as

$$\boxed{\beta = I_C/I_B} \longrightarrow (2)$$

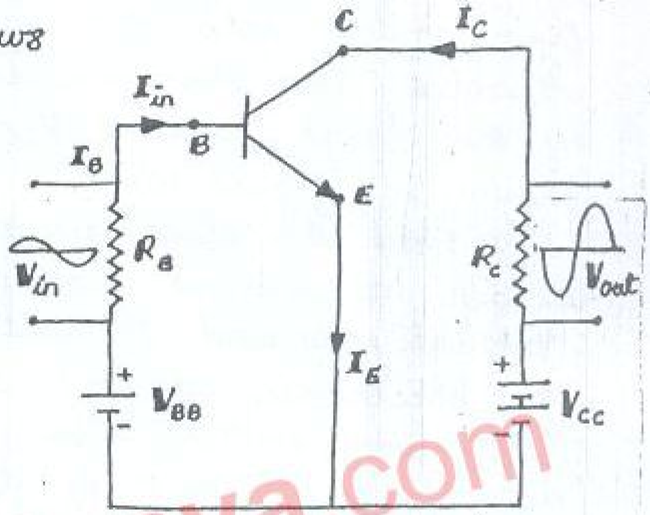
Its value is quite large, of the order of hundreds. Equations (1) and (2) are the fundamental equations of all the transistors.

Transistor As An Amplifier

A circuit used to convert low voltage or current to high voltage or current is called an amplifier and such a process is called the amplification.

Explanation

Figure shows the circuit in which a transistor is used as an amplifier with base-emitter as input terminals and collector-base as output terminals. The battery V_{BB} forward biases the base-emitter junction and V_{CC} reverse biases the collector-base junction. V_{CC} is much larger than V_{BB}.



When a small input voltage V_{in} is applied across a resistance R_B, it adds a small alternating current I_{in} into the base current I_B. This small alternating current is amplified by transistor β-times, so that an alternating current I_{out} is added in collector resistance R_C.

Here

I_{in} = Change in the base current i-e;

$I_{in} = \Delta I_B$

and I_{out} = Change in the collector current i-e;

$I_{out} = \Delta I_C$

It should be noted that $R_B >> r_{ie}$, where r_{ie} is the internal resistance of the transistor between its base and emitter terminal, then I_{in} and I_{out} given as

$$I_{in} = \frac{V_{in}}{r_{ie}} \quad \text{and} \quad I_{out} = \frac{V_{out}}{R_C}$$

As we know that the current gain (β) of a transistor is the ratio between collector current (ΔI_C) to base current (ΔI_B), given as

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{I_{out}}{I_{in}}$$

$$\Rightarrow \quad \beta = \frac{V_{out}/R_C}{V_{in}/r_{ie}}$$

$$\Rightarrow \quad \beta = \frac{V_{out}}{V_{in}} \cdot \frac{r_{ie}}{R_C}$$

$$\Rightarrow \quad \frac{V_{out}}{V_{in}} = \beta \cdot \frac{R_C}{r_{ie}}$$

For a typical arrangement

$R_C = 10\,K\Omega$, $r_{ie} = 1\,K\Omega$ if $\beta = 50$

then

$$\frac{V_{out}}{V_{in}} = \frac{50 \times 10\,K\Omega}{1\,K\Omega}$$

$$\Rightarrow \quad \frac{V_{out}}{V_{in}} = 500$$

This shows that the output voltage is 500 times greater than the input voltage.

VOLTAGE GAIN OF AMPLIFIER

The ratio of the output voltage to input voltage is called voltage gain (A) of amplifier.

$$\text{Voltage Gain} = \frac{\text{Output Voltage}}{\text{Input Voltage}}$$

or

$$\boxed{A = \frac{V_{out}}{V_{in}}}$$

TRANSISTOR AS A SWITCH

Figure (a) shows a circuit in which an n-p-n transistor is used as a switch. The collector C and emitter E act as the terminals of the switch. The circuit in which the current is to be turned **OFF** and **ON**, is connected across these terminals.

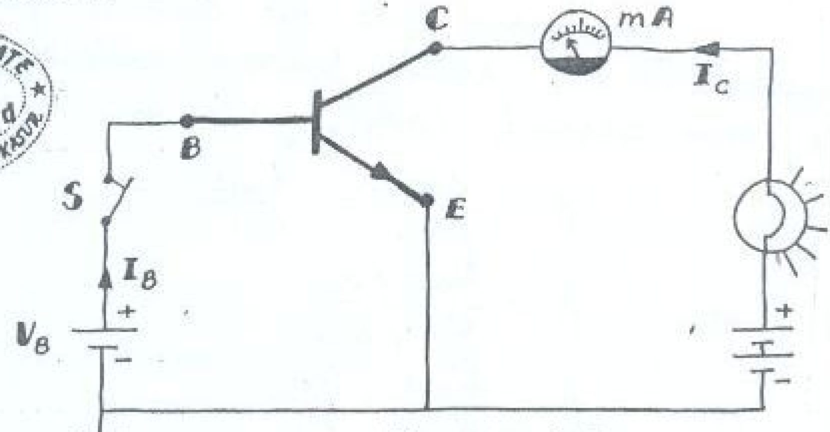


FIGURE (a)

The base **B** and emitter **E** act as control terminals which decide the state of the switch.

TURN ON THE SWITCH

In order to turn **ON** the switch, a large potential V_B is applied between control terminals **B** and **E** as shown in figure (a). So, a large current I_B flows into the base circuit due to which a very heavy current I_C begins to flow in the **CE**-circuit. This large value of collector current I_C is possible only when the resistance between **C** and **E** drops down to such a small value that the potential drop across **C** and **E** is nearly **0.1** volt. As emitter **E** is at ground as shown in figure (a), so we can assume that collector **C** is also at ground. So **CE**- circuit as in figure (a) can be drawn as shown in figure (b).

As **CE** switch is closed, so bulb glows due to flow of large collector current.

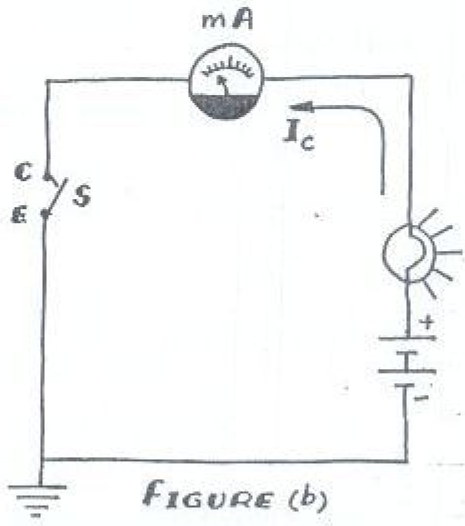


FIGURE (b)

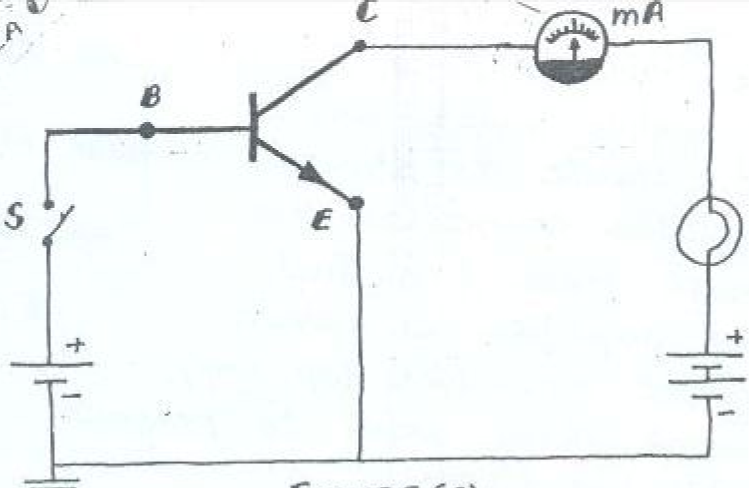


FIGURE (c)

Turn OFF The Switch

In order to turn OFF the switch, the base current I_B is set to zero by opening the base circuit as shown in figure (c).

FIGURE (d)

As current gain β is

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

$$\Rightarrow I_C = \beta I_B$$

$$\Rightarrow I_C = \beta(0) = 0 \qquad (\because I_B = 0)$$

As collector current I_C becomes zero, so CE-circuit becomes open as shown in figure (d). Now the resistance between C and E becomes infinity which opens the terminals C and E of the switch.

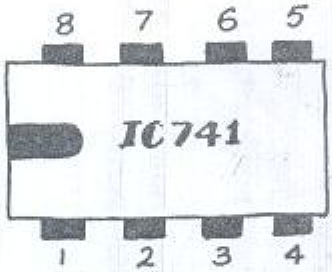
Application Of Switch

An electronic computer is basically a vast arrangement of electronic switches which are made from transistors.

Operational Amplifier or OP-AMP

An amplifier circuit is making by a small silicon chip and enclosed in a capsule, called an operational amplifier.

The pins connected with working terminals such as input, output and power supply are outside the capsule as shown in figure (a). The connections are made through these pins. Such an modified amplifier is known as operational amplifier (op-amp). as it is some times used to perform some mathematical operations.



FIGURE(a)

SYMBOLICAL REPRESENTATION OF OP-AMP

Symbolically, an op-amp is represented by arrow head as shown in figure (b). It has two input terminals and one output terminal. The input terminals are named as

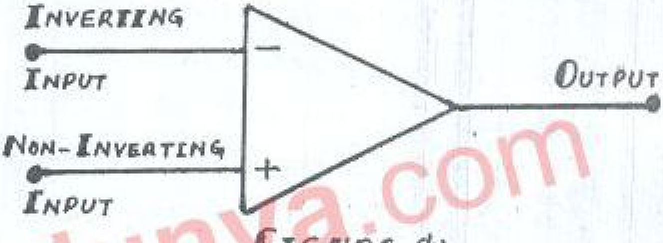


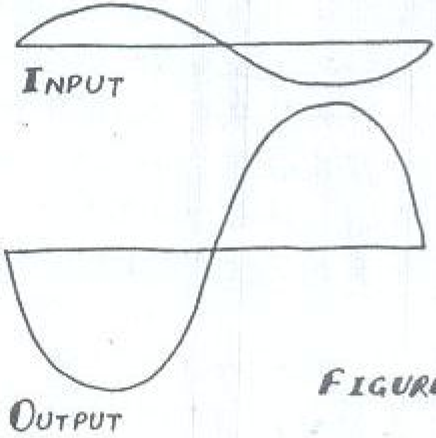
FIGURE (b)

(i) Inverting input. (−)

(ii) Non-inverting input. (+)

INVERTING INPUT (−)

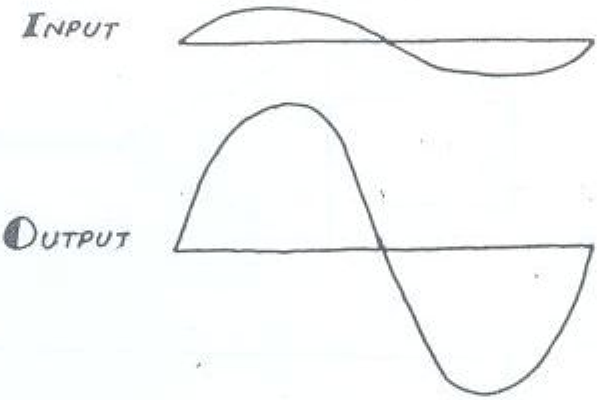
This terminal is called inverting terminal as the signal applied to this terminal appears at the output with a phase shift of 180° after amplification that is the signal is inverted as shown in figure (c).



FIGURE(c)

NON-INVERTING INPUT (+)

The signal applied at this terminal is amplified at the output without any change of phase as shown in figure (d).



FIGURE(d)

CHARACTERISTICS OF OP-AMP

An op-amp has a large number of characteristics. Here we will discuss only three characteristics.

(i) Input Resistance (R_{in})
(ii) Output Resistance (R_o)
(iii) Open Loop Gain (A_{OL})

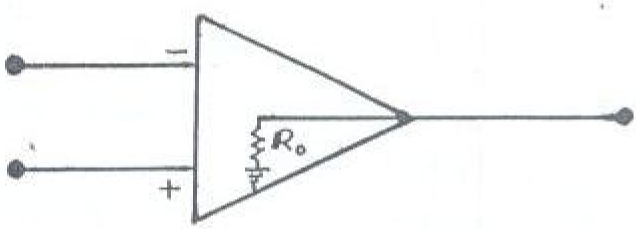
INPUT RESISTANCE

It is the resistance between the (+) and (−) inputs of the op-amp as shown in figure, represented by R_{in}. Its value is very high of the order of several mega ohms. Due to high value of R_{in}, practically no current flows between the two input terminals.

It is very important feature of op-amp.

OUTPUT RESISTANCE

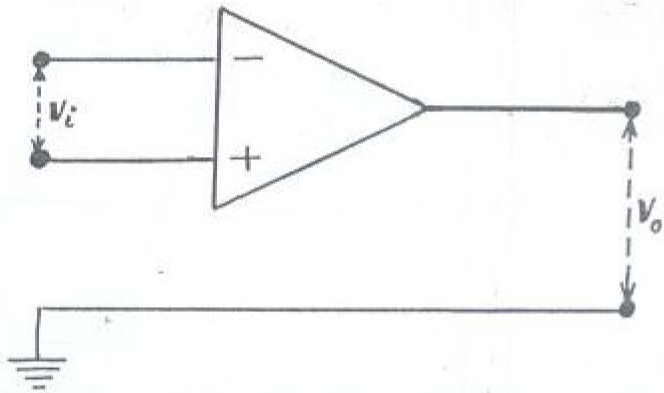
It is the resistance between the output terminal and ground as shown in figure, represented by R_o.



Its value is only a few ohms.

Open Loop Gain

It is the ratio of output voltage V_o to the voltage difference between non-inverting and inverting inputs when there is no external connection between the output and the inputs.



Open loop gain is denoted by A_{OL} and given as

$$A_{OL} = \frac{V_o}{V_+ - V_-} \qquad \text{Where } V_+ - V_- = V_i$$

$$\Rightarrow \boxed{A_{OL} = \frac{V_o}{V_i}}$$

The open loop gain of the amplifier is very high. <u>It is of the order of 10^5.</u>

Op-Amp As Inverting Amplifier

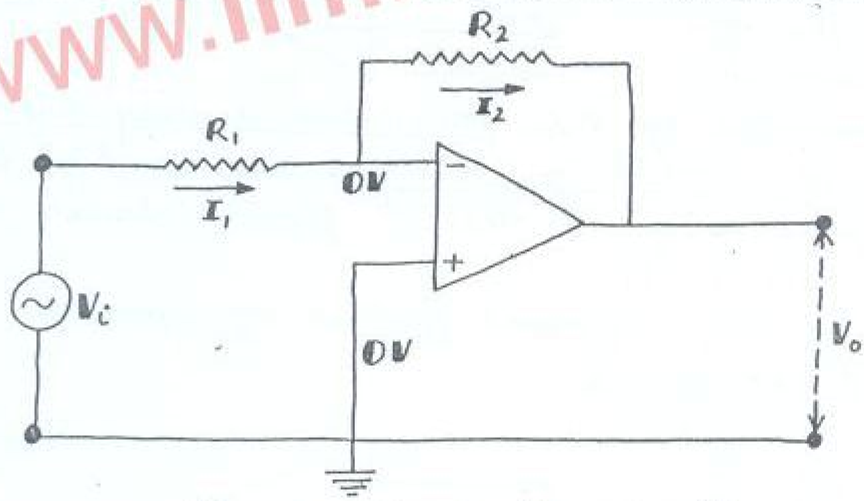


Figure shows the circuit of an op-amp when used as an inverting amplifier.

Operation Of Inverting Amplifier

The input signal V_i which is to be amplified is applied at inverting input terminal (−) through a resistance R_1. V_o is its output. The non-inverting input terminal (+) is grounded, so its potential is zero. As we know that A_{OL} is very high of the order of 10^5, so A_{OL} is given as

$$A_{OL} = \frac{V_o}{V_+ - V_-} = \frac{V_o}{V_i}$$

For any value of V_o

$$V_+ - V_- \approx 0$$

or $$V_+ \approx V_-$$

As V_+ is at ground, so V_- is virtually is at ground potential or zero potential. i-e;

$$V_- \approx 0 \quad \text{as } V_+ \approx 0$$

Now from figure, Current through R_1 is

$$I_1 = \frac{V_i - V_-}{R_1} = \frac{V_i - 0}{R_1} \qquad (\because V_- \approx 0)$$

$$\Rightarrow \quad I_1 = \frac{V_i}{R_1}$$

And current through R_2 is

$$I_2 = \frac{V_- - V_o}{R_2} = \frac{0 - V_o}{R_2} \qquad (\because V_- \approx 0)$$

$$\Rightarrow \quad I_2 = -\frac{V_o}{R_2}$$

As practically no current flows through (−) and (+) terminals of amplifier, so according to Kirchhoff's current rule

$$I_1 = I_2$$

$$\Rightarrow \quad \frac{V_i}{R_1} = -\frac{V_o}{R_2}$$

$$\Rightarrow \quad \boxed{\frac{V_o}{V_i} = -\frac{R_2}{R_1}}$$

The ratio V_o/V_i is the gain G of inverting amplifier.

Gain Of Inverting Amplifier

The ratio of output voltage V_o to input voltage V_i is called the gain of inverting amplifier.

It is denoted by G given as

$$G = \frac{V_o}{V_i} \qquad \text{As} \quad \frac{V_o}{V_i} = -\frac{R_2}{R_1}$$

or $$\boxed{G = -\frac{R_2}{R_1}}$$

The negative sign shows that the output signal is 180° out of phase with respect to input signal. It should be noted that the closed loop gain depends upon the two resistances R_1 and R_2. The gain is independent of what is happening inside the amplifier.

EXAMPLE

If $R_1 = 10\,K\Omega$ and $R_2 = 100\,K\Omega$, then the gain of amplifier is

$$G = \frac{V_o}{V_i} = -\frac{R_2}{R_1} = -\frac{100\,K\Omega}{10\,K\Omega}$$

$$\Rightarrow \boxed{G = -10}$$

OP-AMP AS NON-INVERTING AMPLIFIER

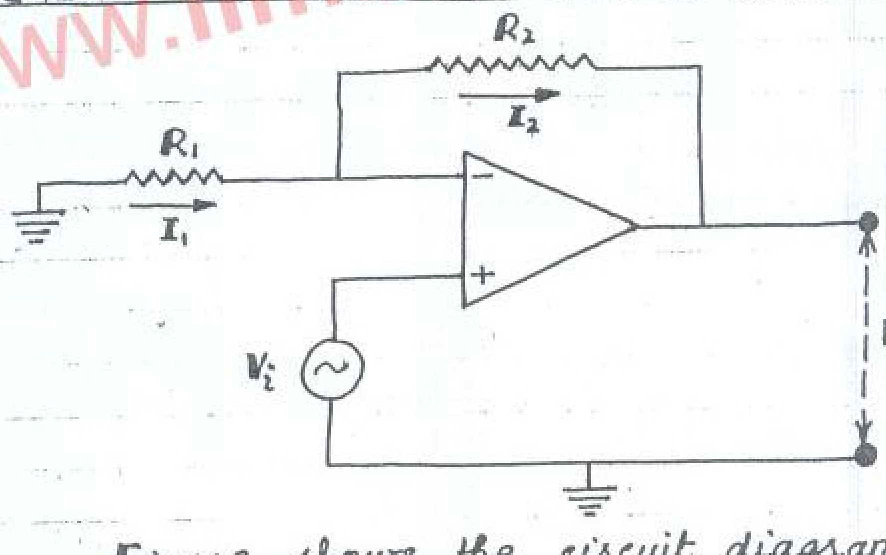


Figure shows the circuit diagram of op-amp as non-inverting amplifier.

OPERATION OF NON-INVERTING AMPLIFIER

The input signal V_i is applied at the non-inverting input terminal (+) and V_o is its output. Due to high open loop gain of amplifier, the inverting (−) and non-inverting (+) inputs are virtually at the same potential, so

$$V_- \approx V_+ \approx V_i$$

From figure, the current through R_1 is

$$I_1 = \frac{0 - V_-}{R_1} = -\frac{V_-}{R_1}$$

$$\Rightarrow \quad I_1 = -\frac{V_i}{R_1} \qquad (\because V_- \approx V_i)$$

And current through R_2 is

$$I_2 = \frac{V_- - V_o}{R_2}$$

$$\Rightarrow \quad I_2 = \frac{V_i - V_o}{R_2} \qquad (\because V_- \approx V_i)$$

As practically no current flows between (−) and (+) terminals, so according to Kirchhoff's current rule, we have

$$I_1 = I_2$$

$$\Rightarrow \quad -\frac{V_i}{R_1} = \frac{V_i - V_o}{R_2}$$

$$\Rightarrow \quad -\frac{V_i}{R_1} = \frac{V_i}{R_2} - \frac{V_o}{R_2}$$

$$\Rightarrow \quad \frac{V_o}{R_2} = \frac{V_i}{R_2} + \frac{V_i}{R_1}$$

$$\Rightarrow \quad \frac{V_o}{R_2} = V_i\left(\frac{1}{R_2} + \frac{1}{R_1}\right)$$

$$\Rightarrow \quad \frac{V_o}{V_i} = R_2\left(\frac{1}{R_2} + \frac{1}{R_1}\right)$$

$$\Rightarrow \quad \frac{V_o}{V_i} = \frac{R_2}{R_2} + \frac{R_2}{R_1}$$

$$\Rightarrow \quad \boxed{\frac{V_o}{V_i} = 1 + \frac{R_2}{R_1}}$$

The ratio V_o/V_i is defined as the gain G of the non-inverting amplifier.

Ch. KHALID MAHMOOD ASHRAF

GAIN OF NON-INVERTING AMPLIFIER

The ratio between output voltage V_o and input voltage V_i is called the gain of amplifier. It is denoted by G given as

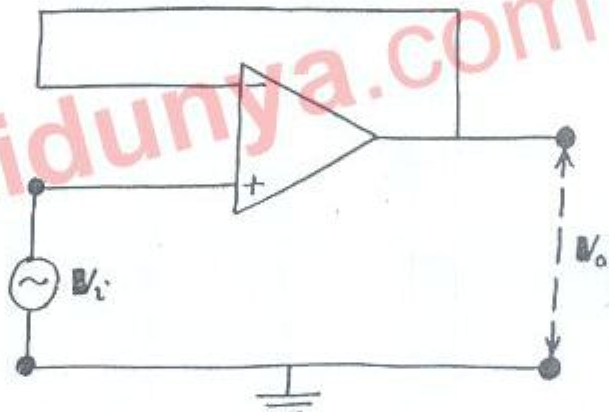
$$G = \frac{V_o}{V_i} \qquad \text{As } \frac{V_o}{V_i} = 1 + \frac{R_2}{R_1}$$

or

$$\boxed{G = 1 + \frac{R_2}{R_1}}$$

This equation shows that the gain of the amplifier is independent of the internal structure of the op-amp. It depends upon the two externally connected resistances R_1 and R_2. As gain G is positive which shows that the input and output signals are in phase.

The closed loop gain circuit of OP-AMP as non-inverting amplifier is shown in the figure.

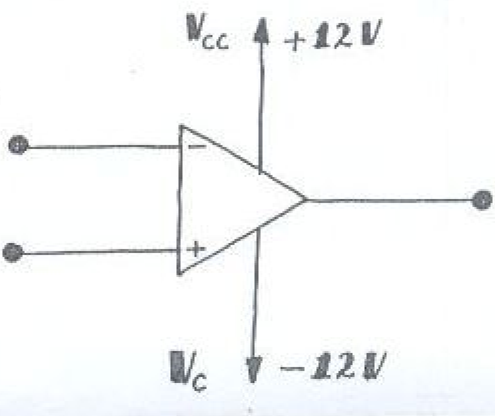


OP-AMP AS A COMPARATOR

OP-AMP is used to compare two voltages, so it can be used as a comparator.

EXPLANATION

OP-AMP requires two power supplies of equal voltages but of opposite polarities. Usually op-amp operate with voltage $V_{cc} = \pm 12V$ as shown in figure.



As the open loop gain of the op-amp is very high (10^5), so a very small potential difference between the inverting (−) and non-inverting (+) inputs is so much amplified that the amplifier gets saturated i-e; its output either becomes equal to $+V_{CC}$ or $-V_{CC}$. This feature of op-amp is used to compare two voltages.

Operation Of OP-AMP As A Comparator

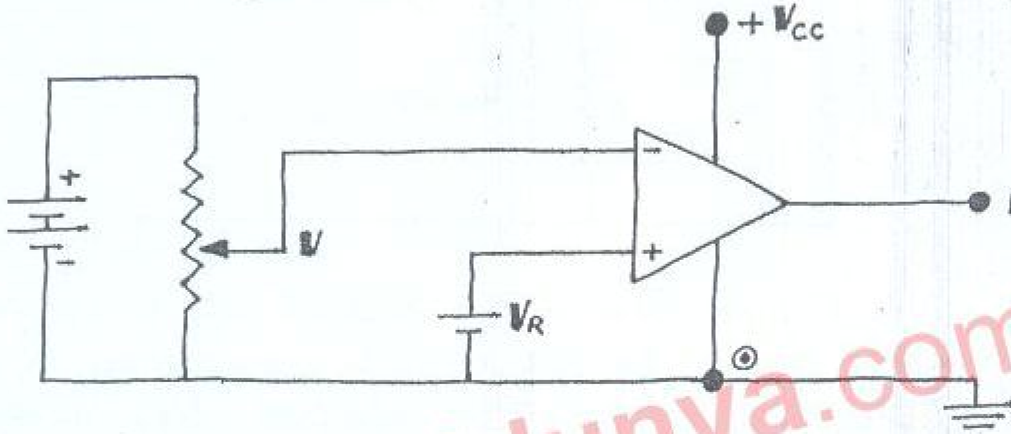


Figure shows the circuit of an op-amp used as a comparator. In the circuit, V_R is the refrence voltage which is connected with (+) terminal and V is the voltage which is to be compared with the refrence voltage V_R. V is connected with the (−) terminal of the amplifier.

When

$V_- > V_+$ or $V > V_R$, then

$$\boxed{V_o = -V_{CC}}$$

And if

$V_- < V_+$ or $V < V_R$, then

$$\boxed{V_o = +V_{CC}}$$

Comparator As A Night Switch

OP-AMP as a comparator can be made possible that when intensity of light falls below a certain level, the light is automatically switched on.

Operation Of Comparator As A Night Switch

Ch. Khalid Mahmood Ashraf
Lecturer In Physics
Govt. Islamia College Kasur

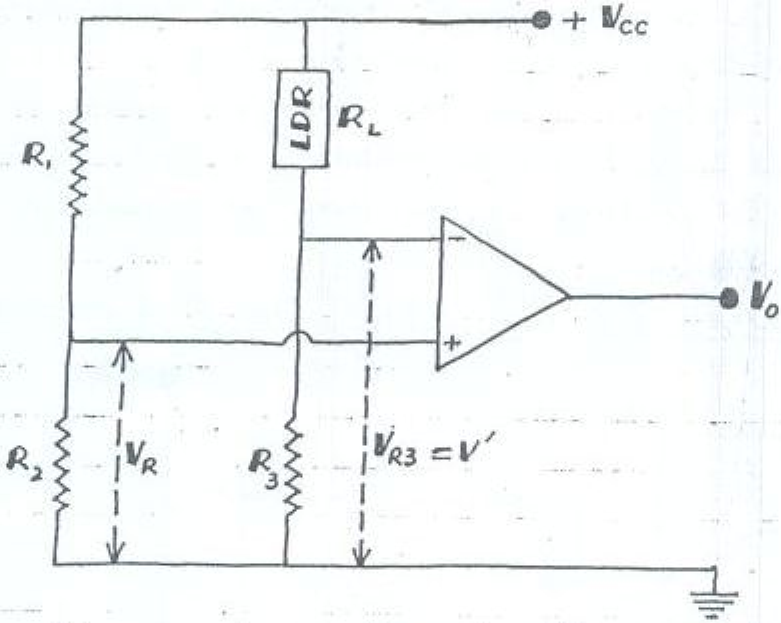


Figure shows the circuit of a comparator as a night switch. In the circuit, resistances R_1 and R_2 form a potential divider. The potential drop across R_2 provides the refrence voltage V_R connected to the (+) terminal of the amplifier. From figure, the refrence voltage V_R is given as

$$\boxed{V_R = \frac{R_2}{R_1 + R_2} \times V_{CC}} \longrightarrow ①$$

In figure, LDR is a light dependent resistance. The value of its resistance R_L depends upon the intensity of light falling upon it. R_L and R_3 form another potential divider. The potential drop across R_3 is V' which is given as

$$\boxed{V' = \frac{R_3}{R_L + R_3} \times V_{CC}} \longrightarrow ②$$

V' provides the voltage to (−) terminal of the amplifier. V' will not be a constant voltage but it will vary with the intensity of light.

Switched Off The Light

During day time, when light is falling upon LDR, R_L is small. So according to equation ②, V' will be large such that

$$V' > V_R$$

So that $$V_o = -V_{CC}$$

The output of the op-amp is connected with a relay system which energizes only when

$$V_o = +V_{CC}$$

and then it turns ON the light. As here $V_o = -V_{CC}$, so the light will not be switched ON. Hence during day time, the light will be switched OFF.

Switched ON The Light

During evening or night time, when faint light or no light falls upon the LDR, R_L becomes large and so V' decreases. So when

$$V' < V_R$$

then $$V_o = +V_{CC}$$

As $V_o = +V_{CC}$, it energizes the relay system and the lights are turned ON.

Digital Systems

A digital system deals with the quantities or variables which have only two discrete values or states.

Examples of such quantities are

(i) A switch can be either open or closed.

(ii) The answer of a question can be either yes or no.

(iii) A certain statement can be either true or false.

(iv) A bulb can be either off or on.

Representation Of Two States

Various designations are used to represent the two states of digital quantities.

The most common states used are

	1	2	3	4	5	6
One Of The States	True	High	1	Yes	On	Closed
The Other State	False	Low	0	No	Off	Open

Mathematical operation of these quantities are usually represented by binary digits 1 and 0. When we are dealing with voltages, then the designation 'High' and 'Low' is also a convinient representation.

In explaining functions of digital systems, a closed switch will be shown as 1 and an open switch will be shown as 0. For example, a lighted bulb will be described as 1 and an off bulb will be described as 0.

BOOLEAN ALGEBRA

In order to express two basic mathematical operations i-e; addition and subtraction of the ordinary quantities which can possess all the continuous values, we require a special algebra, known as Boolean algebra.

OR

A special algebra used for the mathematical operation of quantities which have values 1 and 0, is called Boolean algebra.

1 and 0 are designated as Boolean variables. Boolean algebra is based upon three basic operations named as

(i) OR operation
(ii) AND operation
(iii) NOT operation

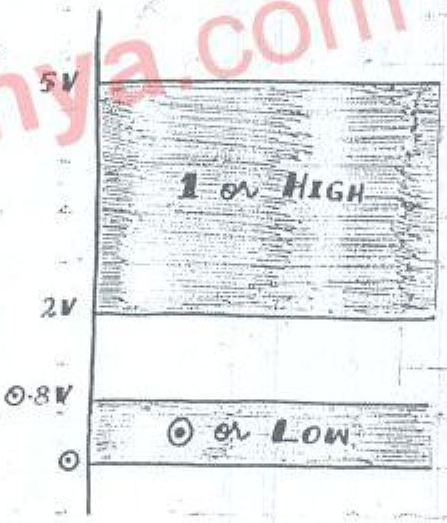
Khalid Mahmood Ashraf
Lecturer In Physics
College Kasur

FUNDAMENTAL LOGIC GATES

The electronic circuits which implement the various logic operations are known as logic gates.

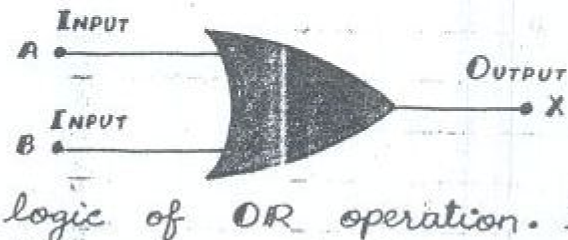
In these gates, the high and low states i-e; 1 and 0 states are at certain voltage levels. One particular voltage level represents a high or 1 and another voltage level represents a low or 0. In practical digital circuits, a high or 1 may have any voltage between a specified minimum value and a specified maximum value. Similarly, a low or 0 may have any voltage between a specified minimum value and a specified maximum value.

Figure shows the range of 1 and 0 levels for a certain type of digital gate. If we apply a voltage of 3.5V to a gate, it will accept it as high or 1. If a voltage of 0.5V is applied to a gate, then it will accept it as low or 0.



OR GATE

OR gate is represented as symbolically as shown in figure.



It implements the logic of OR operation. It has two or more inputs and a single output X. The output has a value 1 when at least one of its inputs A and B is at level 1. So, it implements the truth table of OR gate as shown in the table.

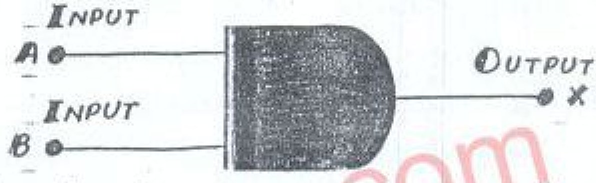
Truth Table Of OR Gate		
A	B	Output X
0	0	0
0	1	1
1	0	1
1	1	1

The mathematical notation for OR gate is

$$\boxed{X = A + B}$$

AND Gate

AND gate is represented symbolically as shown in figure.



It implements the logic of AND operation. It has two or more inputs and a single output X. It is designed such that it implements the truth table of AND operation i-e; its output X is at 1 only when both of its inputs A and B are at 1 and for all other combinations of the values of A and B, output X is 0 as shown in the table.

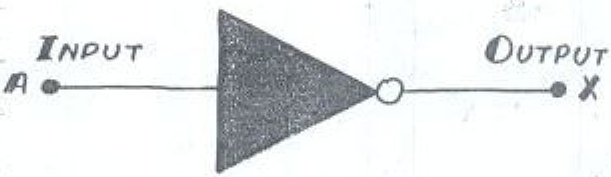
Truth Table Of AND Gate		
A	B	Output X
0	0	0
0	1	0
1	0	0
1	1	1

The mathematical notation for AND operation is

$$\boxed{X = A \cdot B}$$

NOT Gate

NOT gate is represented symbolically as shown in figure.



It performs the operation of inversion or complementation that is why it is also known as inverter. It changes a logic level to its opposite level i-e; it changes 1 to 0 and 0 to 1. The bubble (O) shown in the figure indicates the operation of inversion. It has a single input A and a single output X. The truth table of NOT gate is given as

Truth Table Of NOT Gate	
A	Output X
0	1
1	0

The mathematical notation for NOT gate is

$$\boxed{X = \bar{A}}$$

Whenever a bar (—) is placed on any variable, it shows that the value of the variable has been inverted.

For example

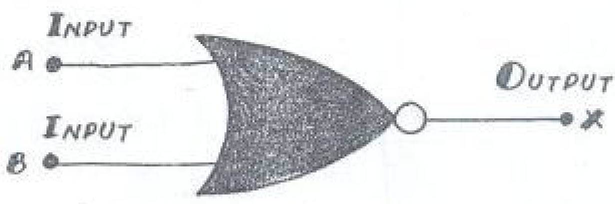
$$\bar{1} = 0$$

and $$\bar{0} = 1$$

Other Logic Gates

NOR Gate

The inverse of OR gate is NOR gate. In NOR gate, the output of OR gate is inverted. Its symbol is shown in the figure.



Its truth table is given as

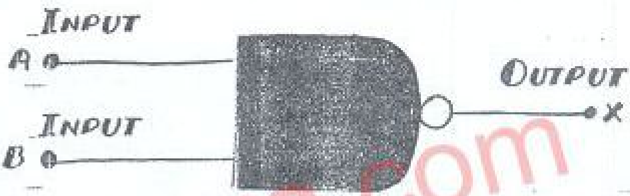
TRUTH TABLE OF NOR GATE		
A	B	OUTPUT X
0	0	1
0	1	0
1	0	0
1	1	0

The mathematical notation for NOR operation is

$$\boxed{X = \overline{A + B}}$$

NAND GATE

In NAND gate, the output of an AND gate is inverted. Its symbol is shown in



the figure. The bubble (O) in this figure shows that the output of AND gate is inverted. The truth table of NAND gate is given as

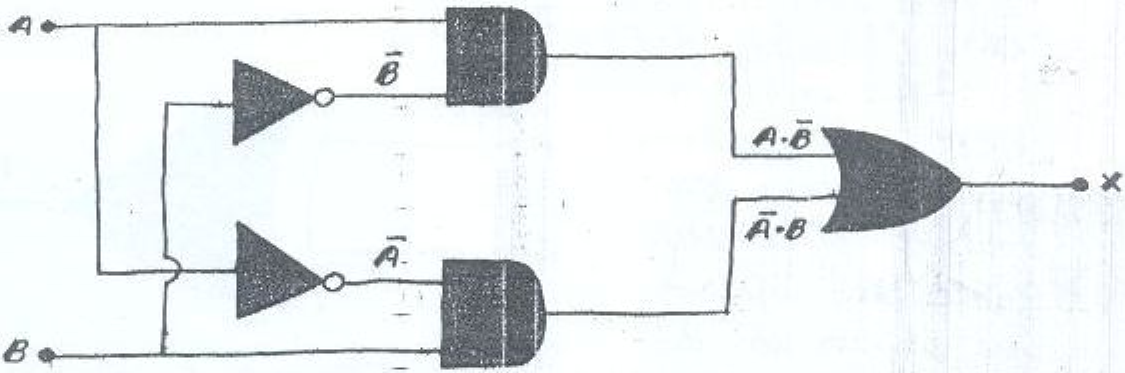
TRUTH TABLE OF NAND GATE		
A	B	OUTPUT X
0	0	1
0	1	1
1	0	1
1	1	0

The mathematical notation for NAND operation is

$$\boxed{X = \overline{A \cdot B}}$$

EXCLUSIVE-OR GATE OR XOR GATE

Exclusive OR gate can be formed by combining AND, OR and NOT gates as shown in the schematic diagram.



Consider a Boolean function X of two variables A and B such that

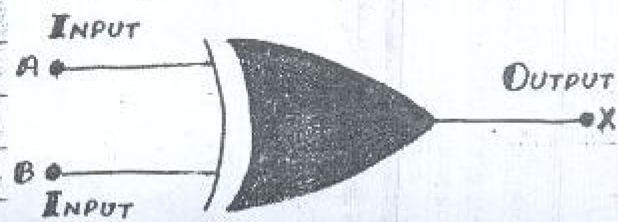
$$\boxed{X = A\bar{B} + \bar{A}B}$$

The first term $(A\bar{B})$ of function X is obtained by ANDing the variable A with NOT of B. The second term $(\bar{A}B)$ is obtained by NOTing the variable A with AND of B. The function X is obtained by ORing these two terms.

The value of function X can be obtained by the truth table which gives the value of X for all the values of the variables A and B.

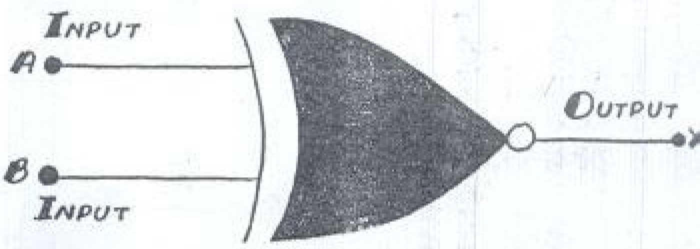
TRUTH TABLE OF XOR GATE		

The value of X is 0 when the two inputs have the same values and it is 1 when the inputs have different values as shown in the table. The truth table can be verified by the circuit. The symbol of XOR gate is shown in the figure.



EXCLUSIVE-NOR GATE OR XNOR GATE

The exclusive-NOR gate is obtained by inverting the output of a XOR gate. Its symbol is shown in the figure.



The bubble (o) at the output as shown in figure shows that the output of XOR gate has been inverted.

The mathematical notation or Boolean expression of XNOR gate is

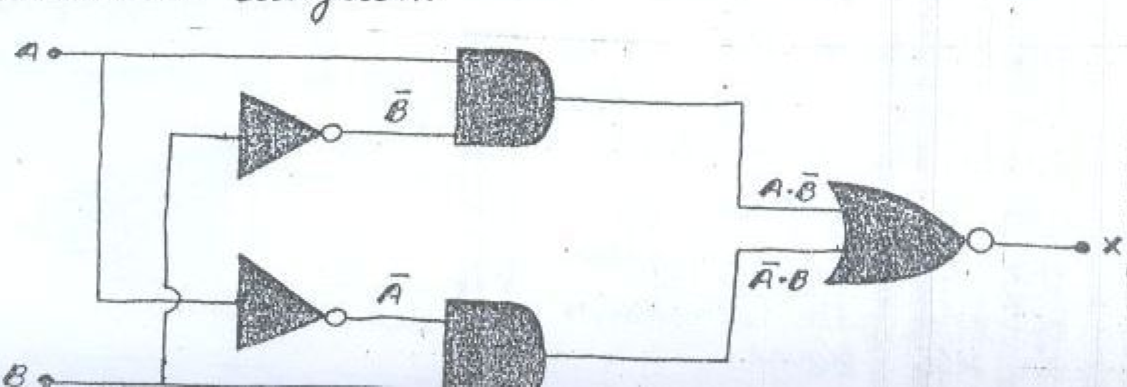
$$\boxed{X = \overline{A\bar{B} + \bar{A}B}}$$

The truth table of XNOR gate is given as

TRUTH TABLE OF XNOR GATE		
A	B	OUTPUT X
0	0	1
0	1	0
1	0	0
1	1	1

From truth table, it is clear that the output of XNOR gate is 1 when its two inputs are identical and 0 when the two inputs are different.

XNOR gate is formed by a combination of NOT, AND and NOR gates as shown by the schematic diagram.



APPLICATION OF GATES IN CONTROL SYSTEMS

Gates are widely used in control systems. Gates control the function of the system by observing some phyical parameters like temperature, pressure or some other physical quantity of the system.

SENSORS

Those devices which convert various physical quantities into electrical voltage are known as sensors

FOR EXAMPLE

1. In night lamp, LDR (Light Dependent Resistance) is a sensor because it convert changes in the intensity of light into electric voltage.
2. Thermistor is a sensor for temperature.
3. Microphone is a sound sensor.
4. Level sensors give electrical signal when the level of the liquid in a vessel attains a limit.
5. Sensors are used to monitor the pressure and temperature of a chemical solution.

APPLICATION OF SENSORS

In order to monitor the pressure and the temperature of a chemical solution, sensors are used which explained as

The circuit of each sensor is such that it produces a **HIGH** or **1** when the temperature or pressure exceeds a specified value. A circuit is to be designed which will ring an alarm when either the temperature or pressure or both cross the maximum specified limit. The alarm requires a **LOW** or 0 voltage for its activation.

The block diagram of this problem is shown in figure (a). In figure, **C** is the circuit to be designed. Its inputs are **A** and **B** fed by the temperature and pressure sensors **T** and **P** fitted into the vat. Whenever output of the circuit **C** is LOW, the alarm is activated. So, the circuit C should be such that its output is LOW or 0 as soon as the limit for temperature or pressure is exceeded. It is only possible when

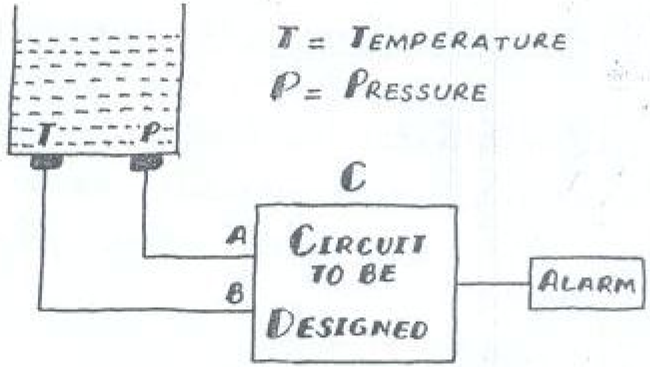


Figure (a)

$$A = 0 \ , \ B = 1$$
or $$A = 1 \ , \ B = 0$$
or $$A = B = 1$$

The output of C should be HIGH or 1 when temperature or pressure are within the specified limit i-e; when $A = 0$, $B = 0$. This gives the truth table for circuit C. It can be seen that it is the truth table of NOR gate. So, the circuit C in fig. (a) should be a NOR-gate as shown in figure (b).

Truth Table

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

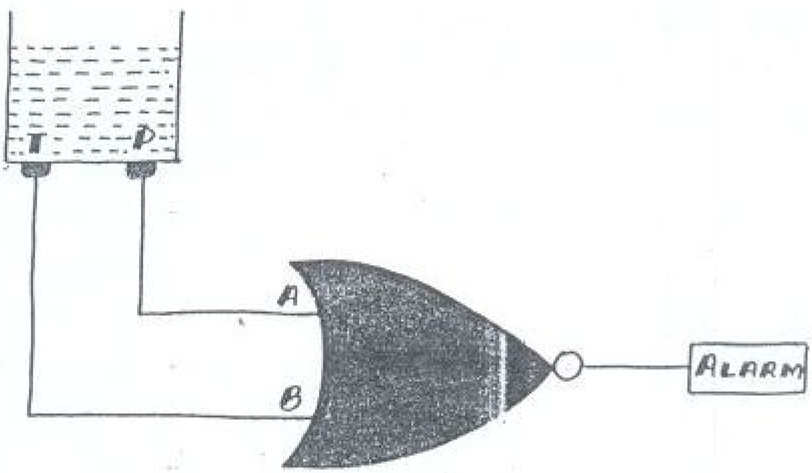


Figure (b)

QUESTIONS

18.1. *How does the motion of an electron in a n-type substance differ from the motion of holes in a –type substance?*

Ans. The motion of electron in N-type semiconductor is more mobile than motion of holes in P-type semiconductor.

18.2. *what is the net charge on an n-type or a p-type substance?*

Ans. The net charge on P-type or on N-type semiconductor is zero. Because these are formed by the combination of two neutral chemists.

18.3. *The anode of a diode is 0.2 V positive with respect to its cathode. Is it forward biased?*

Ans. When electric potential of anode (P-type) is greater (by 0.2v) w.r.t cathode (N-type) then such = P-N junction is in forward biased.

18.4. *Why charge carriers are not present in the depletion region.*

Ans. The depletion region is formed when free electrons diffuse from N-type side into P-type side and these electrons set themselves in the holes of P-type side to give no free charge region called depletion region.
As there is no free charge carrier in this region, so it offers resistances for the flow of current.

18.5. *What is the effect of forward and reverse biasing of a diode on the width of depletion region?*

Ans. The width of depletion region is decreased when P-N junctions in forward based and depletion region increases when the P-n junction is in reverse bias.

18.6. *Why ordinary silicon diodes do not emit light?*

Ans. The ordinary silicon diode do not emit light because it has low value of forward bias as compared with h LE $_D$.>.

18.7. *Why a photo diode is operated in reverse biased state?*

Ans. The photodiode is operated in reversed bias because in forward bias in it acts like very low resistance and there is no need for the extra energy to conduct the current, which is supplied by incident light.

18.8. *Why is the base current in a transistor very small?*

Ans. The base current is very small during the action f a transistor. It is due to the reason that while passing through base, the emitter current and the collector's current are in opposite direction and these try to cancel each other, according to the following relation.

$$I_B = I_E - I_C$$

18.9. *What is the biasing requirement of the junctions of a transistor for its normal operation? Explain how these requirements are met in a common emitter amplifier?*

Ans. For the transistor's normal action, the input circuit is made forward bias while output circuit is made reversed bias. In case of common emitter amplified the Base- Emitter circuit is made forward bias while collector – emitter circuit is made reversed bias, for the normal action of transistor.

18.10. *What is the principle of virtual ground? Apply it to find the gain of an inverting amplifier?*

Ans. The input impedance of an op-amp, is so high that virtually all input current is shunted to the resistor when it works as inverter.

18.11. *The inputs of a gate are 1 and 0. Identify the gate if its output is (a) 0, (b)1.*

Ans. (a) When input are 1, 0 then out put is zero, only when the gate is exclusive NOR gate.
(b) For inputs 1, 0 the output is 1 when there is exclusive OR gate

18.12. *Tick (ü) the correct answer*

(i) A diode characteristic curve is plotted between.

(a) current and time (b) voltage and time
(c) voltage and current (d) forward voltage and reverse voltage

(ii) The colour of light emitted by a LED depends on

(a) is forward bias (b) is reverse bias
(c) the amount of voltage and current (d) the type of semi-conductor material used

(iii) In a half-wave rectifier the diode conducts during.

(a) both halves of the input cycle.
(b) a portion of the positive half of the input cycle.
(c) a portion of the negative half of the input cycle.
(d) One half of the input cycle.

(iv) In a bridge rectifier of Fig. Q. 18.1 when V_i is positive at point B with respect to point A, which diodes are ON.

(a) D_1 and D_4 (b) D_1 and D_3
(c) D_2 and D_3 (d) D_1 and D_4

(v) The common emitter current amplification factor β is given by

(a) a. $\frac{I_C}{I_E}$ (b) b. $\frac{I_E}{I_B}$ (c) c. $\frac{I_E}{I_B}$ (d) d. $\frac{I_B}{I_E}$

(vi) Truth table of logic function

summarizes its output values.
tabulates all its input conditions only
display all its input / output possibilities.
is not based on logic algebra

(vii) The output of a two inputs OR gate is 0 only when its.

(a) both inputs are 0 (b) either input is 1
(c) both inputs are 1 (d) either input is 0

(viii) The two inputs NAND gate with inputs A and B has an output 0 if. The two inputs NAND gate with inputs A and B has an output 0 if.

(a) A is 0 (b) B is 0
(c) both A and B zero (d) both A and B are

(ix) The truth table shown below is for _______ gate.

a. XNOR
b. OR
c. AND
d. NAND

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