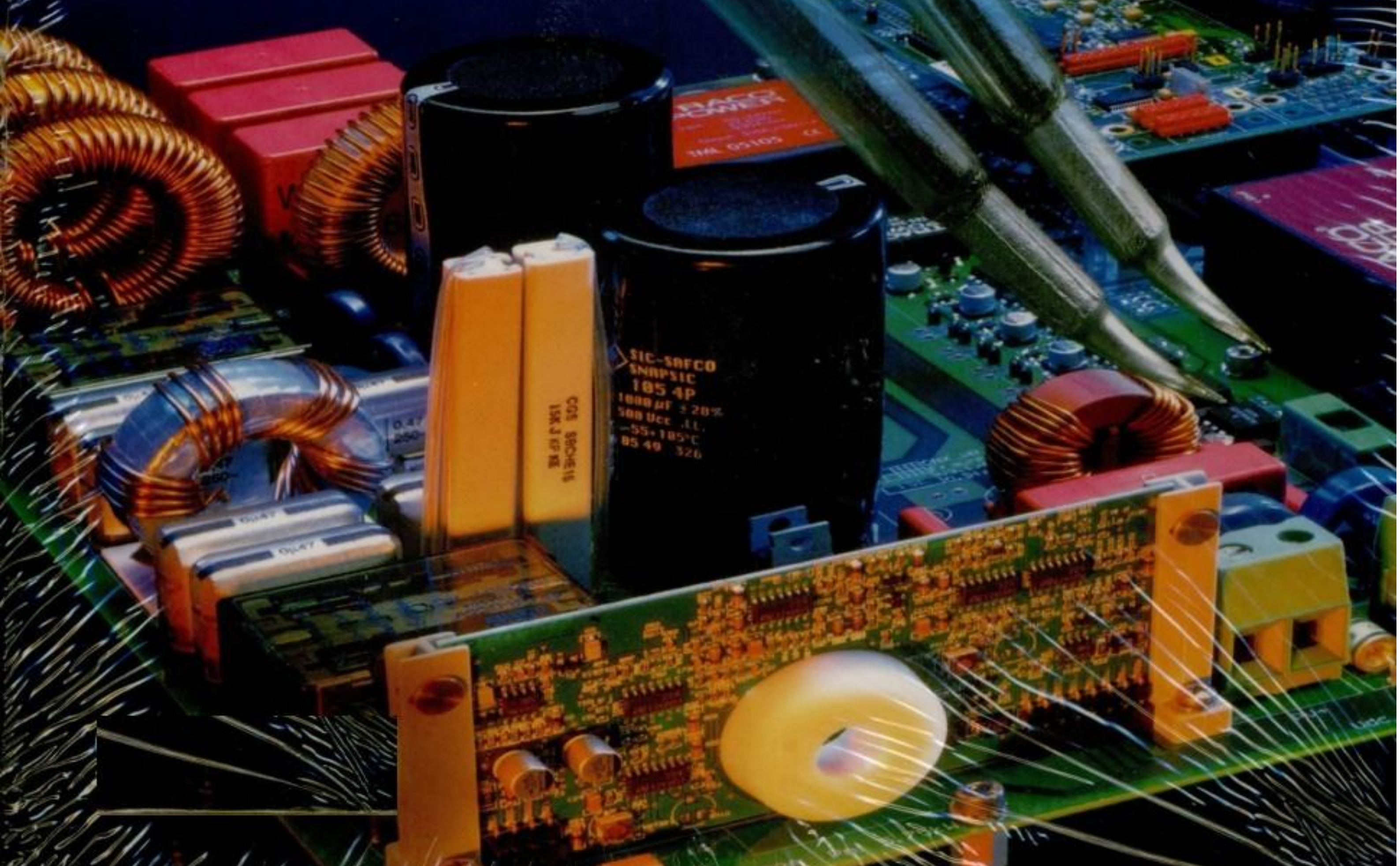
B.Sc. Physics

ELECTRONICS

Complete Notes

by MUHAMMAD ALI MALIK

HOUSE OF PHYSICS PUBLICATIONS



B.Sc. Physics
Complete Notes of
ELECTRONICS

SEMICONDUCTING MATERIALS

PN JUNCTION DIODE

TRANSISTOR

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DC LOAD LINE

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ELECTRONICS

Energy Bands Theory in Solids

Energy levels

The angular momentum of an electrons is always quantized and is integral multiple of $\frac{h}{2\pi}$. Thus the electrons can have certain orbital radii. The electrons in these orbits have only a certain values of energy. These certain values of energy of electrons in an atom are called the energy levels of the atom.

The energy levels of an isolated single atom are will defined usually represented by series of horizontal lines. When the two identical atoms are close to each other, their electrons move under the influence electromagnetic fields of two atoms. As the result, each energy level split into two levels, one higher and other lower than the corresponding level of the isolated atom.

Energy Band

When the numbers of atoms are brought together, as in a crystal, they interact with one another. As the result, each energy level splits up into several sub-levels. A group of such energy sub-levels are called an energy band.

The number of energy sub-levels in a band is equal to the number of atoms in a crystal. The energy band in a crystal corresponds to the energy level in an atom. And an electron in a crystal can have an energy that falls within one of these bands.

Forbidden Bands

The energy bands are separated by gaps in which there is no energy level. Such energy gaps are called forbidden bands. The electron may jump from one energy band to another by acquiring energy equal to the energy of forbidden energy gap.

Valence Bands

The electrons in the outermost shell of an atom are called valance electrons. Therefore, the energy band occupied by valance electrons is called the valance band. The valance band may be either completely filled or partially filled with the electrons but can never be empty.

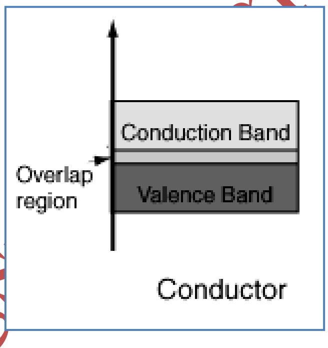
Conduction Band

The energy band next to the valance band is called the conduction band. The valance and conduction bands are separated by forbidden energy gaps. The conduction band may be empty or partially filled. The electrons in the conduction band can drift freely in the materials and are called free or conduction electrons.

The width of forbidden energy gap between valance and conduction band decide whether a material is a conductor, insulator or a semiconductor.

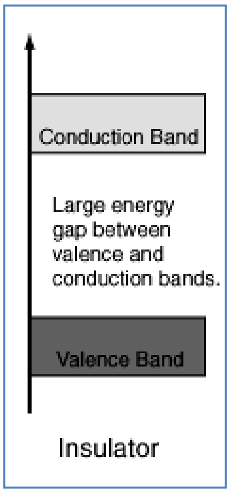
Distinction between Conductors, Insulators and Semiconductors on the basis of Band Theory of Solids

Conductors



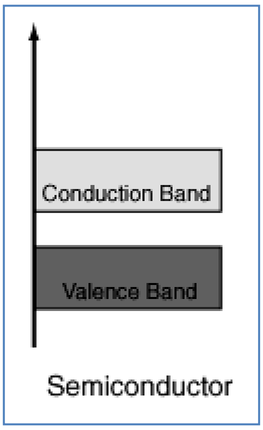
All metals are good conductors of electricity and their resistivity is of the order of $10^{-8}\ \Omega - m$. In case of conductors, there is no forbidden energy gap between the valance and the conduction band. The valance band and conduction band are partially filled at room temperature. So the electrons can easily jump from valance band to the conduction band. Due to this reason, the current can easily pass through conductors.

Insulators



The insulators have the very large value of resistivity which is of the order of $10^{10}\ \Omega - m$. In case of insulators, the valance band is completely filled and the conduction band is empty. The energy gap between the valance and conduction band is very large. Thus, no electron can jump from valence band to conduction band. As there are no free electrons in insulator, hence no current can pass through insulators.

Semiconductors

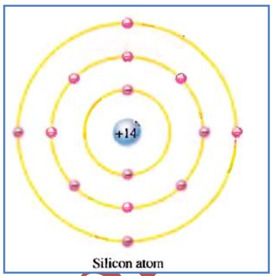


The materials which have intermediate values of resistivity (of the order of $10^{2}\ \Omega - m$) called semiconductor materials. The energy gap between the valance and conduction band is very small.

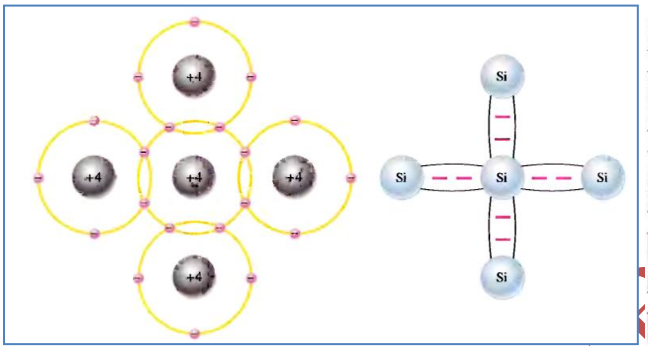
A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current. A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator. The most common single-element semiconductors are silicon,germanium, and carbon. Compound semiconductors such as gallium arsenide are also commonly used.

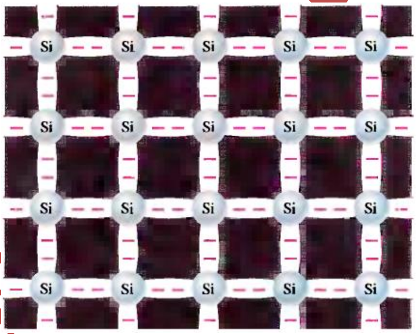
Intrinsic Semiconductors

A pure semiconductor is known as intrinsic semiconductor. The most common examples of intrinsic semiconducting materials are silicon. Each atom of silicon has four valance electrons. Moreover each atom of silicon is surrounded by four atoms.



A silicon (Si) atom with its four valence electrons shares an electron with each of its four neighbors to form covalent bond. This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability.

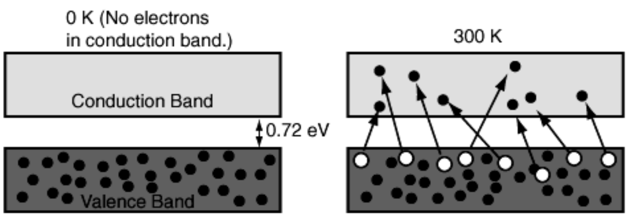




The semiconducting materials have negative temperature coefficient of resistivity. At low temperatures, the valence band is completely filled and conduction band is completely empty. Thus the semiconducting materials behave like insulator at low temperatures.

At comparatively higher temperature, the electrons in valance band acquire sufficient energy to jump in conduction band. As the temperature increases, the probability of the electrons to jump from valance to conduction band increases. Therefore, the conductivity of semiconductors increases with increase in temperature.

At absolute zero, the intrinsic semiconducting materials behaves like insulators because they have no free electrons. But as the temperature of increases, the thermal agitation in the atoms breaks some covelent bonds which result in formation of electron hole pairs. The electrons jump from valance band to conduction band by absorbing the thermal energy. As the result, the conductivity of semiconductor increases with increase in temperature.

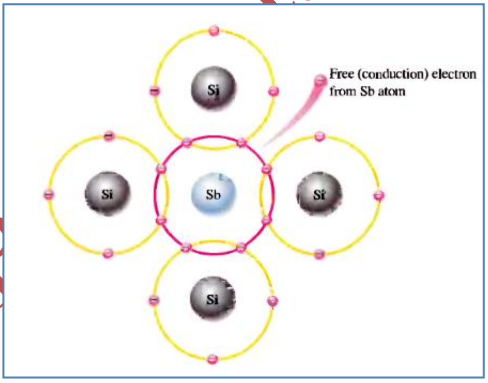


Extrinsic Semiconductors

The semiconductors doped with some impurity are called extrinsic semiconductors. The conductivity of silicon and germanium can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material. This process, called doping, increases the number of current carriers (electrons or holes). The two categories of impurities are n-type and p-type.

N-Type Semiconductor

To increase the number of conduction-band electrons in intrinsic silicon, pentavalent impurity atoms e.g., arsenic (As), phosphorus (P), bismuth (Bi), and antimony (Sb) are added. Each pentavalent atom (antimony, in this case) forms covalent bonds with four adjacent silicon atoms. Four of the antimony atom's valence electrons are used to form the covalent bonds with silicon atoms, leaving one extra electron. This extra electron becomes a conduction electron because it is not attached to any atom.



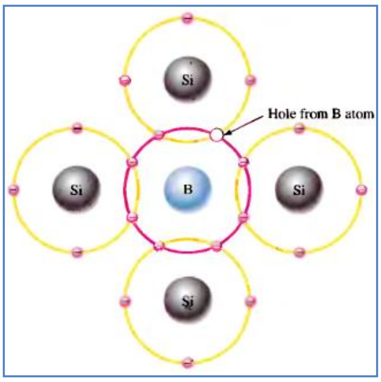
Because the pentavalent atom gives up an electron, it is often called a donor atom. The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon.

Majority and Minority Carriers in N-Type Semiconductor

In an n-type semiconducting material, most of the current carriers are electrons. So, the electrons are called the majority carriers in n-type material. Although the majority of current carriers in n-type material are electrons, there are also a few holes that are created when electron-hole pairs are thermally generated. Holes in an n-type material are called minority carriers.

P-Type Semiconductor

To increase the number of holes in intrinsic silicon, trivalent impurity atoms e.g., boron (B), indium (In), and gallium (Ga) are added. All three of the boron atom's valence electrons are used in the covalent bonds; and, since four electrons are required, a hole results when each trivalent atom is added. Because the trivalent atom can take an electron, it is often referred to as an acceptor atom. The number of holes can be carefully controlled by the number of trivalent impurity atoms added to the silicon.



Majority and Minority Carriers in P-Type Semiconductor

In a p-type semiconducting material, most of the current carriers are holes. Holes can be thought of as positive charges because the absence of an electron leaves a net positive charge on the atom. The holes are the majority carriers in p-type material. Although the majority of current carriers in p-type material are holes, there are also a few free electrons that are created when electron-hole pairs are thermally generated. Electrons in p-type material are the minority carriers.

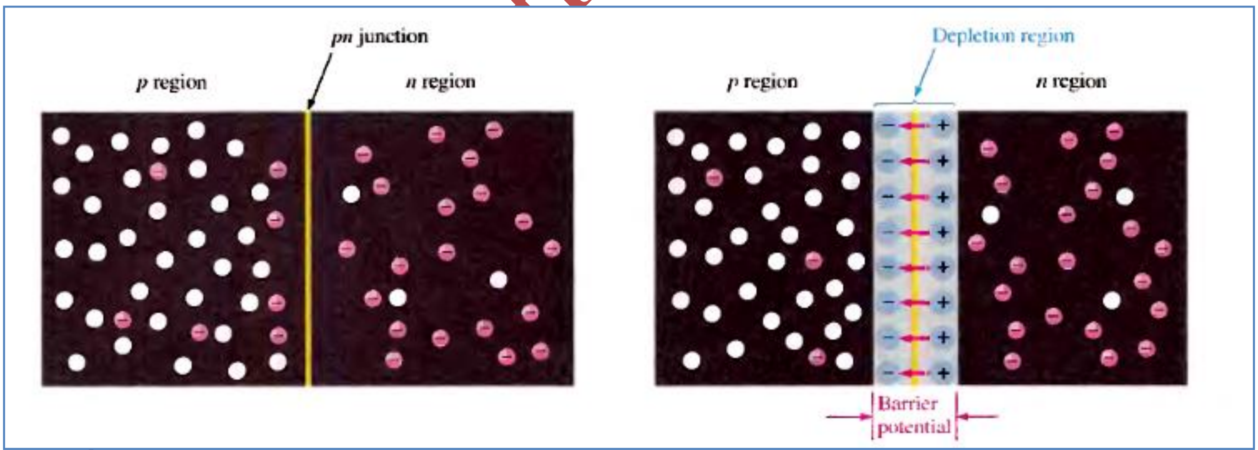
PN-Junction

If a piece of intrinsic silicon is doped so that a part is n-type and the other part is p-type, then the boundary between the p-type and n-type is called PN-junction.

The p region has many holes (majority carriers) from the impurity atoms and only a few thermally generated free electrons (minority carriers). The n region has many free electrons (majority carriers) from the impurity atoms and only a few thermally generated holes (minority carriers).

Formation of the Depletion Region

When a p-type semiconductor is brought close an n-type to form a PN-junction, then the free electrons near the junction in the n region begin to diffuse across the junction into the p-type region where they combine with holes near the junction, as shown in figure below:



When the PN-junction is formed, the n region loses free electrons as they diffuse across the junction. This creates a layer of positive charges (pentavalent ions) near the junction. As the electrons move across the junction, the p region loses holes as the electrons and holes combine. This creates a layer of negative charges (trivalent ions) near the junction. These two layers of positive and negative charges form the depletion region.

The term depletion refers to the fact that the region near the PN-junction is depleted of charge carriers (electrons and holes) due to diffusion across the junction. After the initial surge of free electrons across the PN-junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction. In other words, the depletion region acts as a barrier to the further movement of electrons across the junction.

Barrier Potential

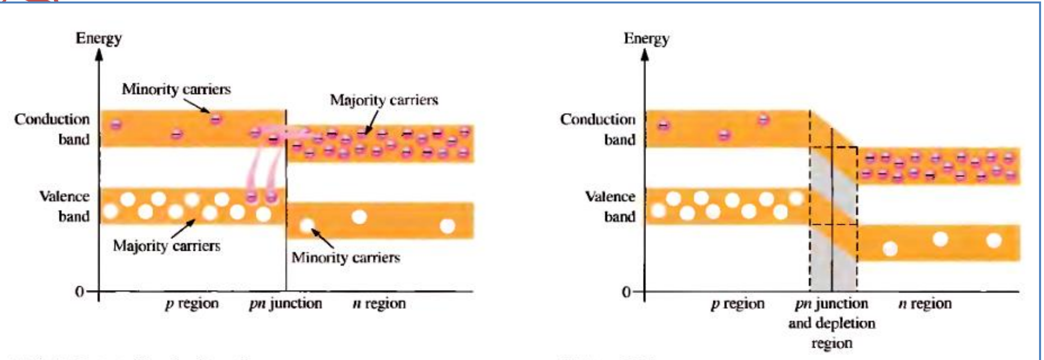
In the depletion region there are many positive charges and many negative charges on opposite sides of the PN-junction. The forces between the opposite charges form a "field of forces" called an electric field. This electric field is a barrier to the free electrons in the n region, and energy must be expended to move an electron through the electric field. That is, external energy must be applied to get the electrons to move across the barrier of the electric field in the depletion region.

The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the barrier potential and is expressed in volts. The typical barrier potential is approximately 0.7 V for silicon and 0.3 V for germanium at 25°C.

Energy Diagrams of the PN-Junction and Depletion Region

The valence and conduction bands in an n-type material are at slightly lower energy levels than the valence and conduction bands in a p-type material. This is due to differences in the atomic characteristics of the pentavalent and the trivalent impurity atoms. The valence and conduction bands in the n region are at lower energy levels than those in the p region, but there is a significant amount of overlapping.

The free electrons in the n region that occupy the upper part of the conduction band in terms of their energy can easily diffuse across the junction and temporarily become free electrons in the lower part of the p-region conduction band. After crossing the junction, the electrons quickly lose energy and fall into the holes in the p-region valence band as indicated in figure below:



(a) At the instant of junction formation (b) At equilibrium

As the diffusion continues, the depletion region begins to form and the energy level of the n-region conduction band decreases. The decrease in the energy level of the conduction band in the n region is due to the loss of the higher-energy electrons that have diffused across the junction to the p region. Soon, there are no electrons left in the n-region conduction band with enough energy to get across the junction to the p-region conduction band. At this point, the junction is at equilibrium; and the depletion region is complete because diffusion has ceased. There is an energy gradiant across the depletion region which acts as an "energy hill" that an n-region electron must climb to get to the p region.

Notice that as the energy level of the n-region conduction band has shifted downward, the energy level of the valence band has also shifted downward. It still takes the same amount of energy for a valence electron to become a free electron. In other words, the energy gap between the valence band and the conduction band remains the same.

Biasing

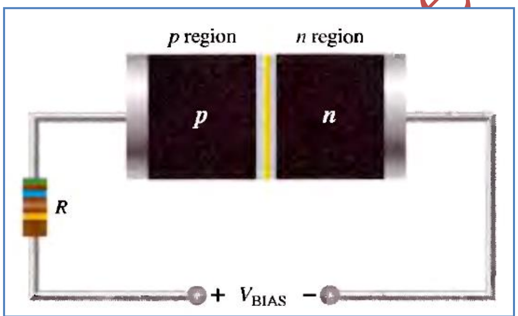
Application of an external voltage to the PN-junction is called biasing. There are two types of biasing:

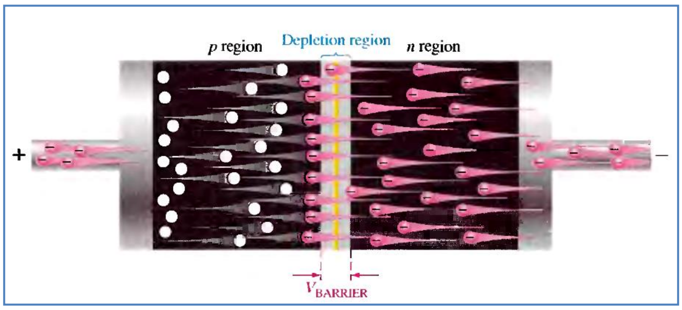
Forward Biasing

Reverse Biasing

Forward Biasing

A junction diode is said to be forward biased if its P-type region is connected to the positive terminal and N-type region is connected to the negative terminal of the battery.



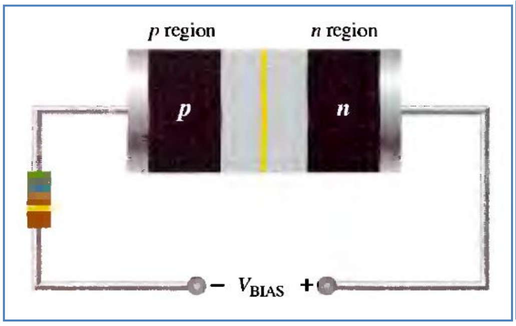


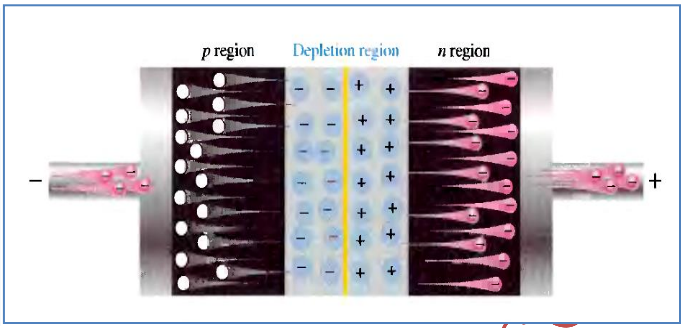
The emf of the battery should be greater than the barrier potential of the junction. Under such conditions, the electrons from N-type region and the holes from P-type region are pushed towards the junction and neutralize the positive and negative ions in depletion region. So the width of depletion region is decreased during forward biasing.

When the depletion region is decreased, then the electrons from N-type moves towards P-type and holes from P-type move towards N-type. This results in flow of current across the junction. Hence the junction diode is conductive when it is forward biased.

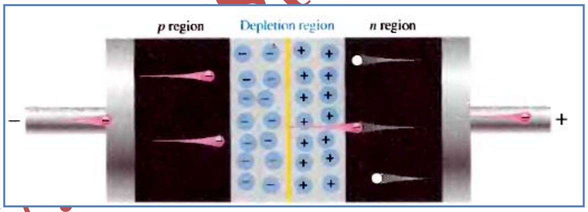
Reverse Biasing

A junction diode is said to be reversed biased, if its P-type region in connected with the negative terminal and N-type region with positive terminal of the battery.





In reverse biasing, the negative terminal attracts the holes and the positive terminal attracts the electrons away from the junction, so that the depletion region is widened and the barrier potential increases with increase in applied voltage. With increase of barrier potential there is no possibility of majority charge carriers to flow across the junction. Hence a junction diode does not conduct when it is reversed biased.



However a very small current (of the order of a few micro-amperes) flow in the circuit due to minority charge carriers, which is called a reverse current.

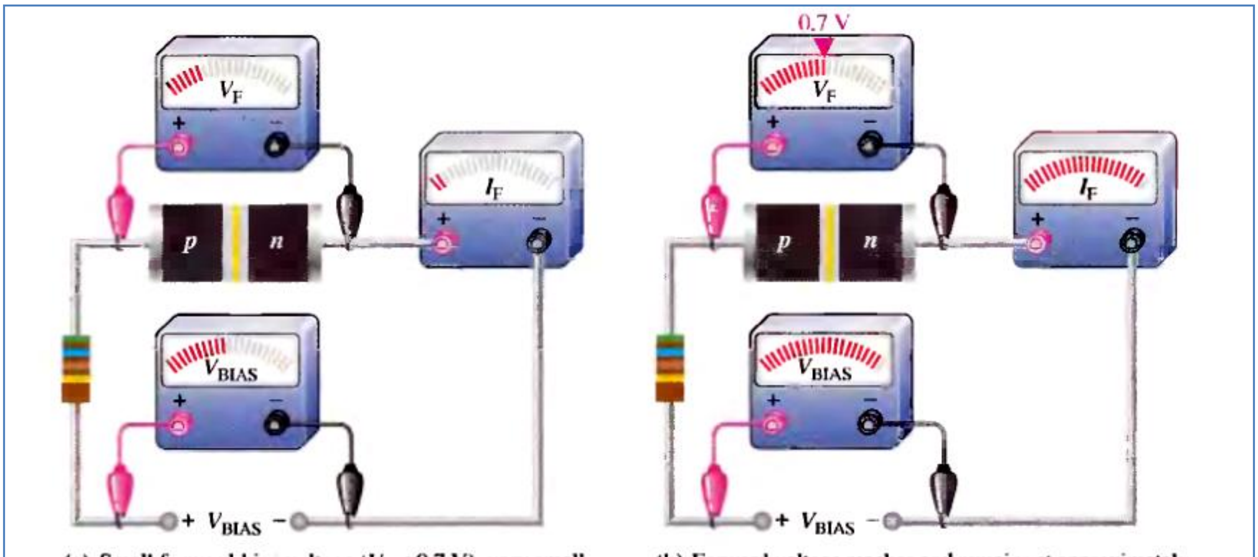
Characteristics of a PN-Junction

A graph between current and voltage applied across the PN-junction is called characteristics of PN-junction.

V-I Characteristic for Forward Bias

When a forward-bias voltage is applied across a diode, there is current. This current is called the forward current and is designated I_F as the forward-bias voltage is increased positively from 0 V. The resistor is used to limit the forward current to a value that will not overheat the diode and cause damage.

With 0 V across the diode, there is no forward current. As the forward-bias voltage is gradually increased, the forward current and the voltage across the diode gradually increase. When the forward-bias voltage is increased to a value where the voltage across the diode reaches approximately 0.7 V (barrier potential), the forward current begins to increase rapidly.

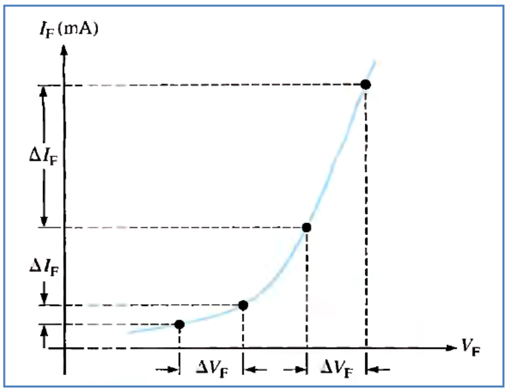


(a) Small forward-bias voltage (V_F < 0.7 V), very small forward current.

(b) Forward voltage reaches and remains at approximately 0.7 V. Forward current continues to increase as the bias voltage is increased.

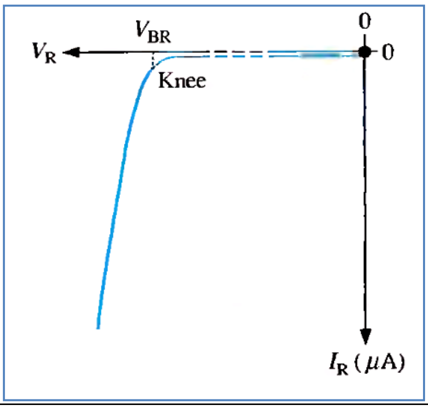
With 0 V across the diode, there is no forward current. As the forward-bias voltage is gradually increased, the forward current and the voltage across the diode gradually increase. When the forward-bias voltage is increased to a value where the voltage across the diode reaches approximately 0.7 V (barrier potential), the forward current begins to increase rapidly.

It can be seen from the curve that the forward current I_F is very small until the forward voltage V_F the barrier potential, of about 0.7 volts for silicon. As the forward voltage exceeds the value of barrier potential, called knee voltage, the current starts to increase rapidly. Beyond the knee of the forward characteristic, I_F increases almost linearly with increase in V_F.



V-I Characteristic for Reverse Bias

When a reverse-bias voltage is applied across a diode, there is only an extremely small reverse current (I_R) through the PN-junction. With 0 V across the diode. there is no reverse current. As you gradually increase the reverse-bias voltage, there is a very small reverse current and the voltage across the diode increases. When the applied bias voltage is increased to a value where the



reverse voltage across the diode (V_R) reaches the breakdown value (V_{BR}), the reverse current begins to increase rapidly.

As you continue to increase the bias voltage, the current continues to increase very rapidly, but the voltage across the diode increases very little above V_{BR}. Breakdown, with exceptions, is not a normal mode of operation for most PN-junction devices.

At breakdown voltage the covalent bonds of the crystal start breaking and charge carriers produced which result in heavy flow of reverse current through diode.

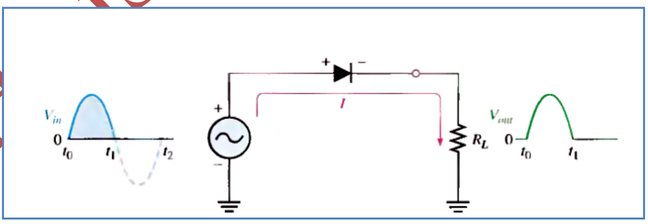
Rectification

The conversion of alternating current into direct current is known as rectification. A PN-junction diode can conduct current only when it is forward biased and a very weak current flow across PN-junction when it is reversed biased. This action of junction enables us to use it as a rectifier. Rectifiers may be placed into following two categories:

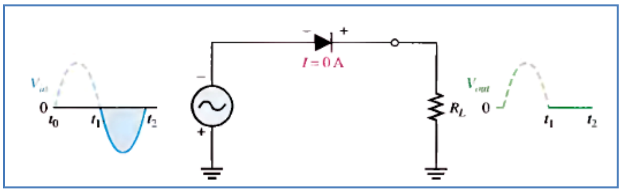
- **i)** Half wave rectification
- **ii)** Full wave rectification

Half Wave Rectification

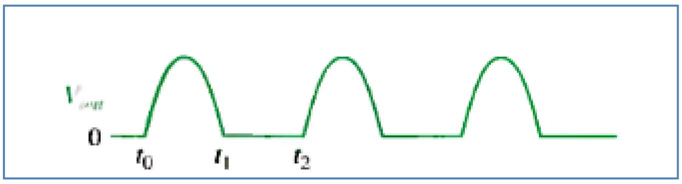
A half-wave rectifier allow current through the load only during one-half of the cycle. A diode is connected to an ac source and to a load resistor R_L forming a half-wave rectifier. When the sinusoidal input voltage (V_{in}) goes positive, the diode is forward-biased and conducts current through the load resistor. The current produces an output voltage across the load R_L which has the same shape as the positive half-cycle of the input voltage as shown in figure below:



When the input voltage goes negative during the second half of its cycle, the diode is reverse-biased. There is no current, so the voltage across the load resistor is 0 V, as shown in figure below:

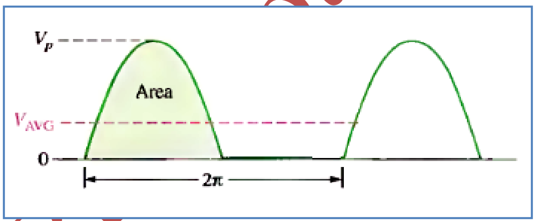


The net result is that only the positive ha]f-cycles of the ac input voltage appear across the load. Since the output does not change polarity, it is a pulsating dc voltage with a certain frequency as shown in the figure below:



Average Value of the Half-Wave Output Voltage

The average value of the half-wave rectified output voltage is the value you would measure on a de voltmeter. Mathematically, it is determined by finding the area under the curve over a full cycle, as illustrated in the figure below, then dividing by 2π, the number of radians in a full cycle.



$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\theta \, d\theta = \frac{V_m}{2\pi} \left|-\cos\theta\right|_0^{\pi}$$

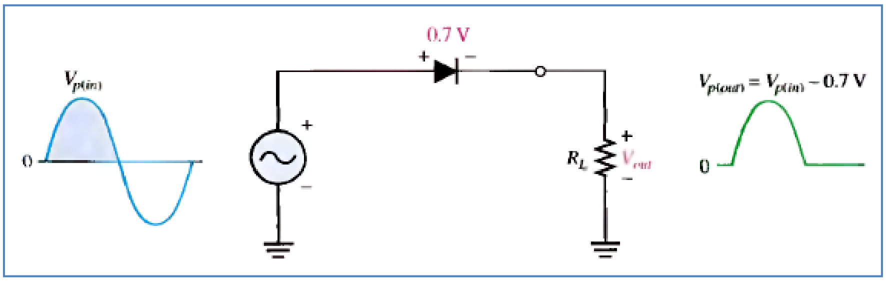
$$V_{dc} = \frac{V_m}{2\pi}[1-(-1)] = \frac{V_m}{2\pi}[2]$$

$$V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m$$

Note that $V_m \sin\theta$ is the instantaneous AC voltage.

Effect of the Barrier Potential on the Half-Wave Rectifier Output

In the previous discussion, the diode was considered ideal. When the practical diode model is used with the barrier potential of 0.7 V taken into account, this is what happens. During the positive half-cycle, the input voltage must overcome the barrier potential before the diode becomes forward-biased. This results in a half-wave output with a peak value that is 0.7 V less than the peak value of the input, as shown in figure below:



The expression for the peak output voltage is

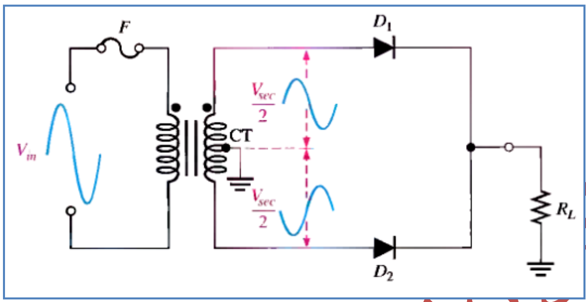
$$V_{p(out)} = V_{p(in)} - 0.7\ V$$

Full-Wave Rectifiers

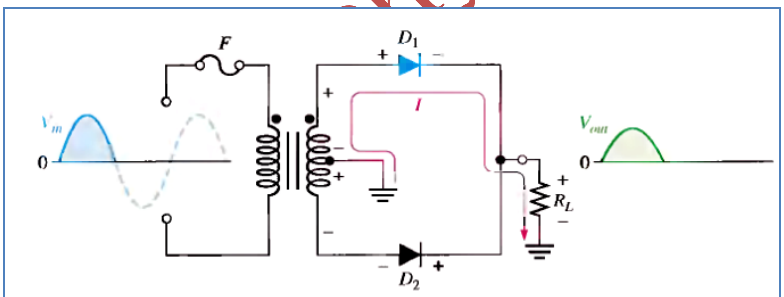
A full-wave rectifier allows unidirectional (one-way) current through the load during the entire 360˚ of the input cycle.

The Center-Tapped Full-Wave Rectifier

A center-tapped rectifier is a type of full-wave rectifier that uses two diodes connected to the secondary of a center-tapped transformer, as shown in figure below. The input voltage is coupled through the transformer to the center-tapped secondary. Half of the total secondary voltage appears between the center tap and each end of the secondary winding as shown.

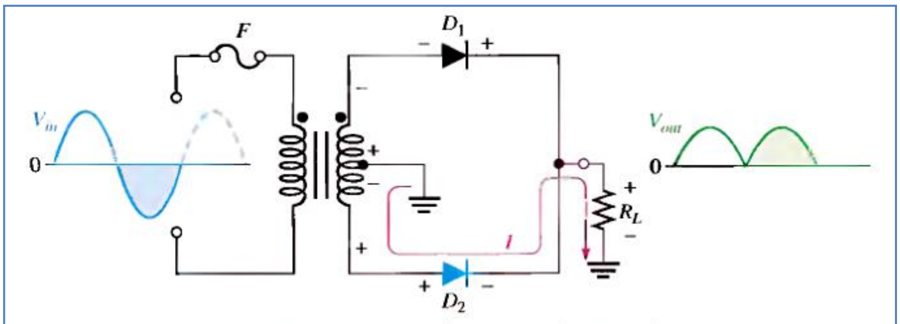


For a positive half-cycle of the input voltage, the polarities of the secondary voltages are as shown in Figure (a). This condition forward-biases diode D_1 and reverse-biases diode D_2. The current path is through D_1 and the load resistor R_L.



(a) During positive half-cycles, D_1 is forward-biased and D_2 is reverse-biased.

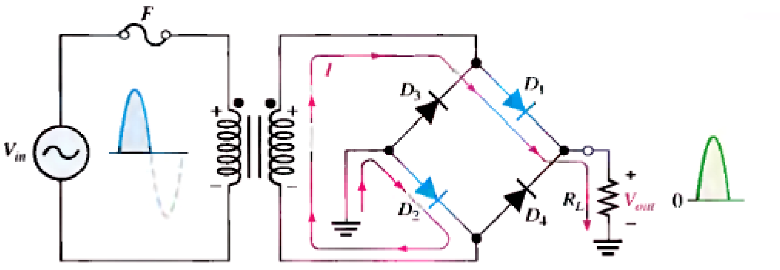
For a negative half-cycle of the input voltage, the voltage polarities on the secondary are as shown in Figure (b). This condition reverse-biases D_1 and forward-biases D_2. The current path is through D_2 and R_L as indicated. Because the output current during both the positive and negative portions of the input cycle is in the same direction through the load, the output voltage developed across the load resistor is a full-wave rectified dc voltage.



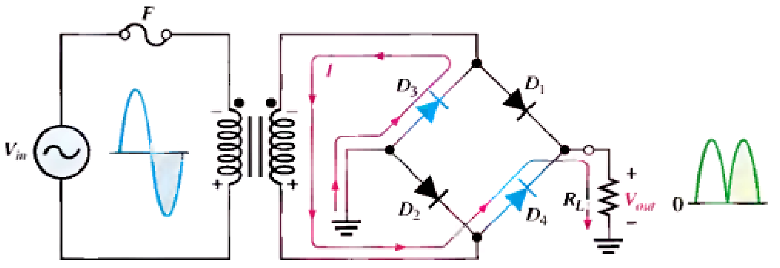
(b) During negative half-cycles, D_2 is forward-biased and D_1 is reverse-biased.

The Bridge Full-Wave Rectifier

The bridge rectifier uses four diodes connected as shown in Figure 2-20_ When the input cycle is positive as in part (a), diodes D_l and D_2 are forward-biased and conduct current in the direction shown. A voltage is developed across R_L that looks like the positive half of the input cycle. During this time, diodes D_3 and D_4 are reverse-biased.

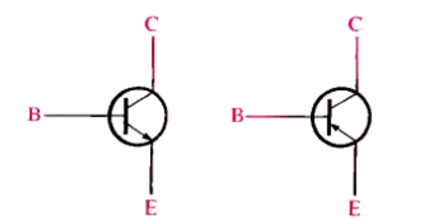


(a) During the positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.



(b) During the negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

When the input cycle is negative as in Figure (b), diodes D_3 and D_4 are forward-biased and conduct current in the same direction through R_L as during the positive half-cycle. During the negative half-cycle, D_l and D_2 are reverse-biased. A full-wave rectified output voltage appears across R_L as a result of this action.

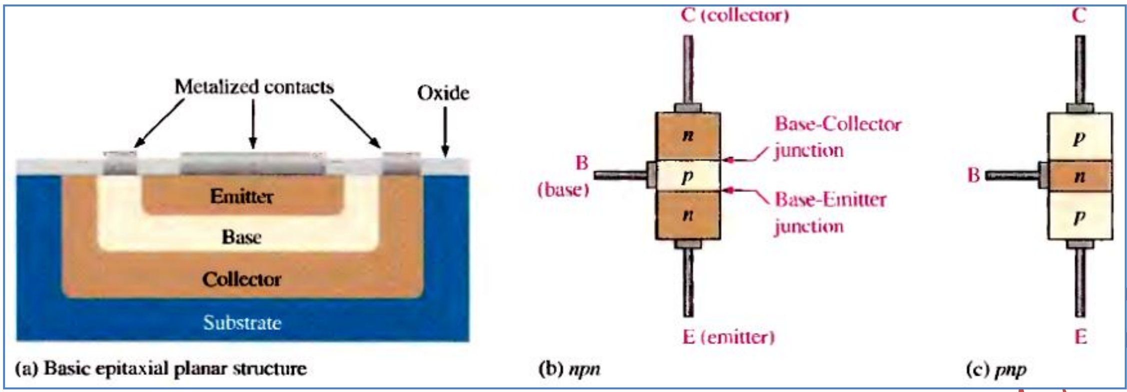


(a) *npn* (b) *pnp*

Transistor

The BJT (bipolar junction transistor) is constructed with three doped semiconductor regions separated by two pn junctions. The three regions are called emitter, base, and collector. One type consists of two n regions separated by a p region (npn), and the other type consists of two p regions separated by an n region (pnp). The term bipolar refers to the use of both holes and electrons as carriers in the transistor structure.

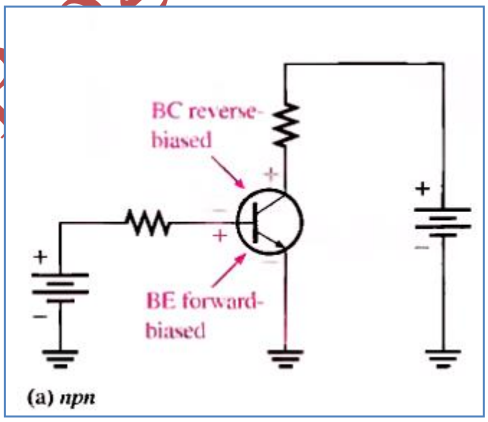
The pn junction joining the base region and the emitter region is called the base-emitter junction. The pn junction joining the base region and the collector region is called the base-collector junction. The base region is lightly doped and very thin compared to the heavily doped emitter and the moderately doped collector regions. The schematic symbols for the npn and pnp bipolar junction transistors is shown in the figure:



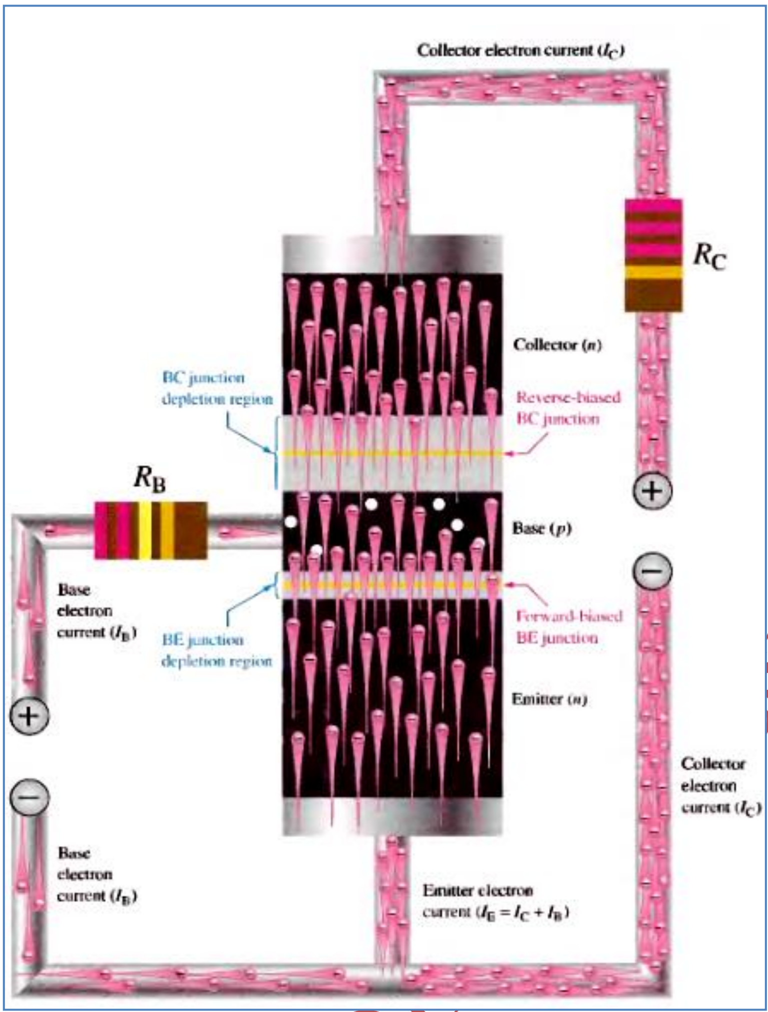
Transistor biasing

For the normal operation of a transistor, its emitter base junction is always forward biased and collector base junction is always reversed biased.

To illustrate transistor action, let's examine what happens inside the npn transistor. The forward bias from base to emitter narrows the BE depletion region, and the reverse bias from base to collector widens the BC depletion region. The heavily doped n type emitter region is teeming with conduction-band (free) electrons that easily diffuse through the forward-biased BE junction into the p-type base region. The base region is lightly doped and very thin so that it has a limited number of holes. Thus, only a small percentage of all the electrons flowing through the BE junction can combine with the available holes in the base. These relatively few recombined electrons flow out of the base lead as valence electrons, forming the small base electron current.



Most of the electrons flowing from the emitter into the thin, lightly doped base region do not recombine but diffuse into the BC depletion region. Once in this region they are pulled through the reverse-biased BC junction by the electric field set up by the force of attraction between the positive and negative ions. The electrons now move through the collector region, out through the collector lead, and into the positive terminal of the collector voltage source.



Transistor Currents

The arrow on the emitter of the transistor symbols points in the direction of conventional current.

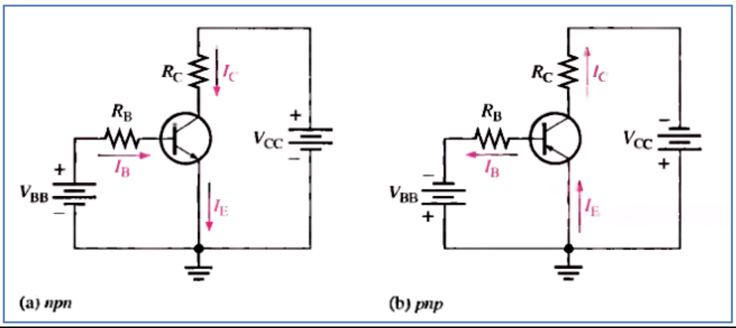
This diagrams shows that the emitter current (I_E) is the sum of the collector current (I_C) and the base current (I_B), expressed as follows:

$I_E = I_C + I_B$

Transistor Parameters

Consider a transistor is connected to dc bias voltages for both npn and pnp types. V_{BB} forward-biases the base-emitter junction, and V_{cc} reverse-biases the base-collector junction.

DC Beta (β_{dc})



The ratio of the dc collector current (I_C) to the dc base current (I_B) is the dc beta (β_{dc}), which is the dc current gain of a transistor. Typical values of β_{dc} lies in the range of 50 to 400.

$$\beta_{dc} = \frac{I_C}{I_B}$$

DC Alpha (α_{dc})

The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc alpha. Typically, values of α_{dc} range from 0.95 to 0.99 or greater, but α_{dc} is always less than 1.

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

Transistor in a Circuit

Transistor has three terminals:

(i) Emitter (ii) Base (iii) Collecor

When we put the transistor in a circuit, one terminal acts as input terminal and the other as output terminal. The third terminal acts as a common terminal to both input and output circuits. Any one of the three terminals can be made common. So a transistor con be connected in a circuit in three ways.

(i) Common Base Configuration
(ii) Common Emitter Configuration
(iii) Common Collector Configuration

Common Emitter Configuration

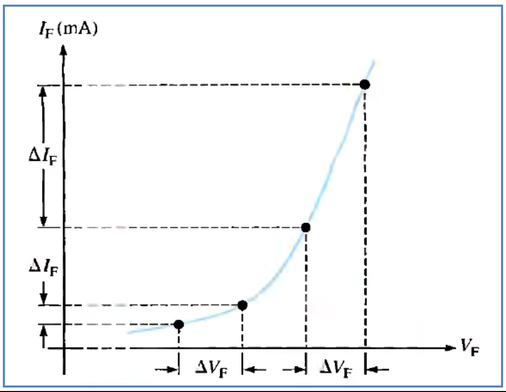
Figure shows the common emitter configuration of pnp transistor. It is called common emitter configuration because emitter is common to both input and output circuits. Two sets of curves are required to completely describe the behavior of CE configuration. One set of curves are called input characteristics and the other set is called output characteristics.

Input Characteristics

The input characteristics show a relationship between input current I_B and input voltage V_{BE} for different values of output voltage V_{CE}. The set of curves obtained from input characteristics is called base curves.

Base Curves

These are the curves obtained by plotting I_B against V_{BE} with V_{CE} as parameter as shown in the figure. The characteristics are similar to that of a forward biased diode. This is because of the reason that base emitter region is forward biased. We obtain two hybrid parameters or transistor constants from the input characteristics.



Input Resistance

It is the ratio of the change in base-emitter voltage (ΔV_{BE}) to the change in base current (ΔI_B) at constant V_{CE}. i.e.,

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

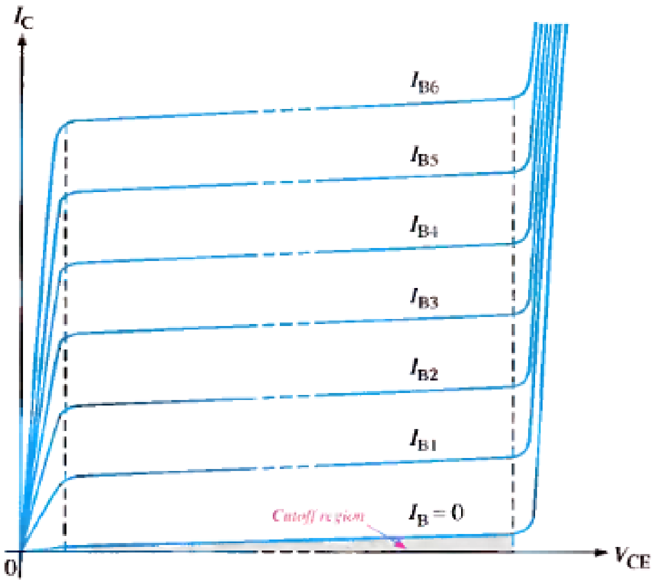
Voltage Gain

It is the ratio of the change in collector-emitter voltage (ΔV_{CE}) to the change in base-emitter voltage (ΔV_{BE}) at the constant values of I_B.

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

Output Characteristics

The output characteristics show a relation between the output current (I_C) and the output voltage (V_{CE}) for the different values of input current I_B. the set of curves obtained from input characteristics are called collector curves.



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$ etc.)

Collector Curves

These are the curves obtained by plotting I_C against V_{CE} with I_B used as parameter. These curves shows

- I_C increases rapidly with increase in V_{CE}
- These curves also show that for a fixed values of V_{CE}, I_C increases with increase in I_B.

The hybrid parameters obtained from output characteristics are

Output Resistance

It is the ratio of change in collector-emitter voltage ΔV_{CE} to the change in collector current ΔI_C at constant I_B.

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

Current Gain or Current Amplification Factor β

The ratio of change in collector current ΔI_C to the change in base current ΔI_B at constant V_{CE}. i.e.,

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

Relation Between α and β

α is the ratio of collector current ΔI_C and emitter current ΔI_E. i.e.,

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad \text{-------------} \ (1)$$

β is the current amplification factor for CE configuration, which is described as:

$$\beta = \frac{\Delta I_C}{\Delta I_B} \qquad \text{-------------} \ (2)$$

Now as

$$I_E = I_B + I_C$$

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

$$\Longrightarrow \Delta I_B = \Delta I_E - \Delta I_C$$

Putting values in (2), we get:

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

Dividing the numerator and denominator by ΔI_E

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}}$$

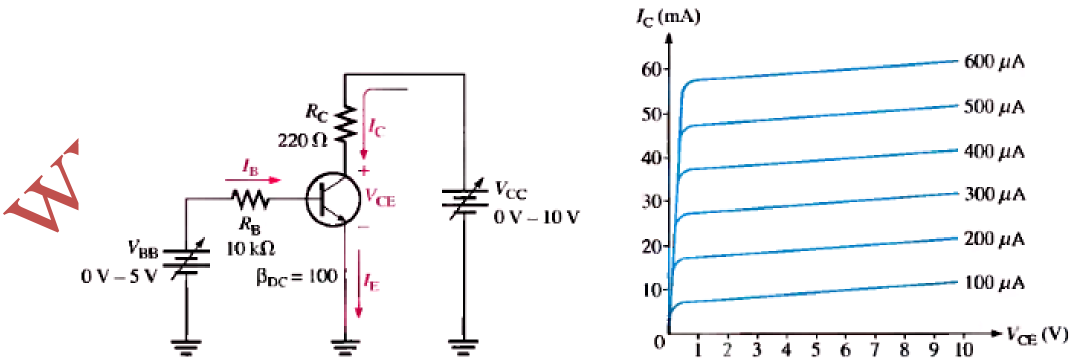
$$\beta = \frac{\Delta I_C / \Delta I_E}{1 - \frac{\Delta I_C}{\Delta I_E}}$$

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

This is the relation between α and β.

DC Load Line

It is the line on the output characteristics of a transistor circuit which gives the values of I_C and V_{CE} when no signal is applied. Consider an npn transistor used as a common emitter amplifier as shown in the figure below:



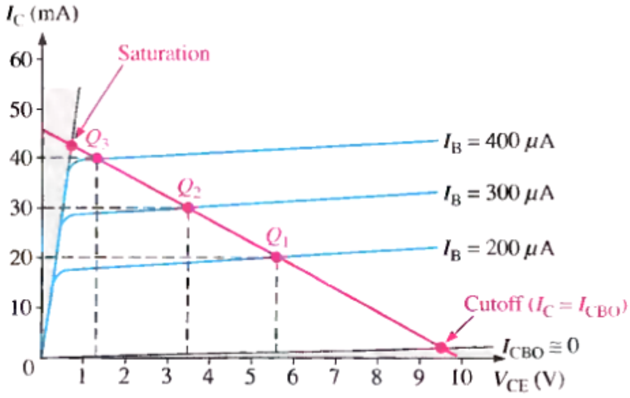
(a) DC biased circuit (b) Collector characteristic curves

From the output circuit, we have:

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

$$V_{CE} = V_{CC} - I_C R_L \qquad \text{------------} \ (1)$$

This is the equation of dc load line in V_{CE} - I_C plane. The dc load line can be plotted the two end points on the straight line.



To get the 1st end point on the I_C axis, we put $V_{CE} = 0$ in equation (1). So

$$0 = V_{CC} - I_C R_L$$

$$I_C = \frac{V_{CC}}{R_L}$$

To get the 2nd end point on V_{CE} axis, we put $I_C = 0$ in equation (1).

$$V_{CE} = V_{CC}$$

By joining the both end points, dc load line is obtained.

With the construction of dc load line on the output characteristics, we get the complete information about the output circuit of transistor amplifier in the zero signal condition.

Operating Point

The zero signal values of I_C and V_{CE} are called the operating points. It is also called Q point or quiescent point. It is the point where the load line intersects the collector curve for a given base current. It is usually selected at the middle of the load line.

Cut Off Region

If the signal voltage is made negative then the base current decreases and point Q moves downward along the load line. If the signal voltage is made very much negative, such that the base current $I_B = 0$, then the transistor is said to be in cut off region.
So the point where the load line intersects $I_B = 0$ curve is called the cut off point.

Saturation region

If the signal voltage is made positive then the base current increase and point Q moves upward along the load line. If the signal voltage is made very much positive such that $I_B = I_B(saturation)$, then the transistor is said to be in saturation region. So point where the load line intersects the $I_B = I_B(saturation)$ curve is called the saturation point.

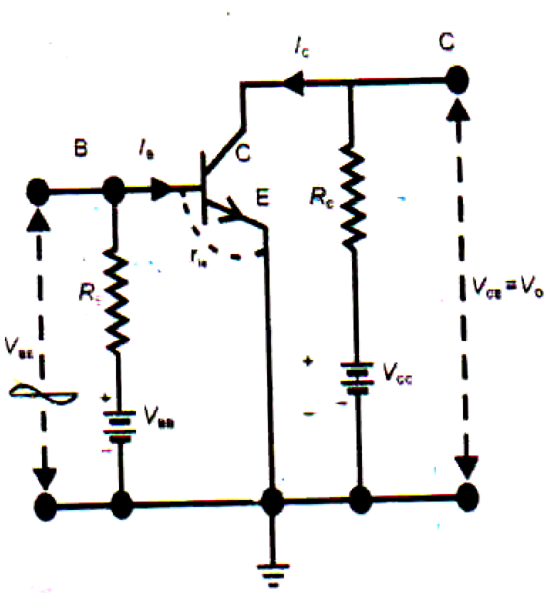
Active region

The region between the cut off and saturation region is called active region. A transistor is normally operated in active region.

Transistor as an Amplifier

Amplification is the process of linearly increasing the amplitude of an electrical signal. In majority of the electronic circuits, transistors are basically used as amplifiers. An amplifier is thus the building block of every complex electronic circuit.

Consider an npn transistor in common emitter mode. The common emitter mode is widely used, since it provides much greater power gain as compare to common base or common collector mode.



The input signal is applied between the emitter-base junction and output is taken across the load R_C connected in the collector circuit. The common emitter transistor as an amplifier is shown in the figure:

DC Analysis

The battery V_{BB} forward biases the base emitter junction and V_{CC} reverse biases the collector base junction. V_{BE} and V_{CE} are the input and output voltages respectively. The base current I_B current flowing through the input circuit is given by the relation:

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

Where r_{ie} is the base emitter resistance of the transistor.

The transistor amplifies the base current β −times. So the current passes through the output circuit is given by the expression:

$$I_C = \beta I_B = \beta \frac{V_{BE}}{r_{ie}}$$

The output voltage $V_0 = V_{CE}$ is determined by the applying the Kirchhoff Voltage Rule on the output loop:

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$\Rightarrow V_{CE} = V_{CC} - I_C R_C$$

$$\Rightarrow V_0 = V_{CC} - \beta \frac{V_{BE}}{r_{ie}} R_C \quad ---------- \quad (1)$$

AC Analysis

When small signal voltage ΔV_{in} is applied at the input, the input voltage changes from V_{BE} to $V_{BE} + \Delta V_{in}$. This causes a little changes in base from I_B to $I_B + \Delta I_B$ due to which the collector current changes from I_C to $I_C + \Delta I_C$. As the collector current changes, the voltage drop across R_C i.e., $I_C R_C$ also changes due to which the output voltage V_0 changes by ΔV_0. Substituting the changed values in equation (1), we get:

$$V_0 + \Delta V_0 = V_{CC} - \beta \left(\frac{V_{BE} + \Delta V_{in}}{r_{ie}} \right) R_C \quad - - - - - - - - - \quad (2)$$

Subtracting equation (1) and (2), we get:

$$\Delta V_0 = -\beta \left(\frac{\Delta V_{in}}{r_{ie}} \right) R_C$$

$$\Rightarrow \frac{\Delta V_0}{\Delta V_{in}} = -\frac{\beta R_C}{r_{ie}}$$

Where $\frac{\Delta V_0}{\Delta V_{in}} = A_v$ is the voltage gain.

$$\Rightarrow A_v = -\frac{\beta R_C}{r_{ie}}$$

The factor $\frac{\beta R_C}{r_{ie}}$ is of the order of hundred, so the input signal is amplified. The negative sign shows that there is a phase shift of 180^0 between the input and output signals.

Example

Suppose in a common emitter circuit, there is a load resistance R_C = 5 kΩ. Suppose the change of 0.1 V in the signal voltage produces a change of 1 mA in emitter current. The same change of current takes place in collector current i.e., 1 mA. This collector current through R_C produces a voltage = $(5\ k\Omega)(1\ mA) = 5\ V$.

Thus a change of 0.1 V in the input signal has produced a change of $5\ V$ in the output signal. So the transistor has raised the voltage from $0.1\ V$ to $5\ V$ i.e., the voltage amplification in this case is $= \frac{5}{0.1} = 50$.

Digital Systems

A system which deals with quantities and variables having two discrete values or states are called is called digital system. In these circuits, the input and output can have any one of the two values "1" or "0". Following are the examples of such quantities:

- A switch can either open or closed.
- The answer of a question can be either yes or no.
- A certain statement can be either true or false.
- A bulb can be either on or off.

In all these situations, one of the states is represented by "1" and the other state by "0".

- 1 represents:
    - **i.** ON circuit
    - **ii.** High voltage
    - **iii.** True statement
- 0 represents:
    - **i.** OFF circuit
    - **ii.** Low voltage
    - **iii.** False statement

Logic gates solve problems by using a special algebra, known as "Boolean Algebra". Boolean algebra is based upon three basic operations namely:

i. AND operation
ii. OR operation
iii. NOT operation

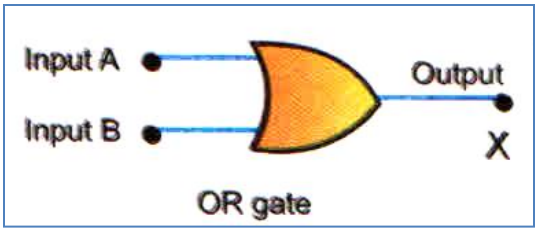
Logic Gates

The electronic circuits which implement the various logic operations are known as logic gates. There are three basic types of logic gates:

i. AND Gate
ii. OR Gate
iii. NOT Gate

OR Gate

OR gate implements the logic of OR operation. It has two or more inputs and a single output. The symbolic representation of an OR gate is shown in the figure.



The output of the OR gate has a value "0" when both of its inputs A and B is at 0. For all other operations of inputs $[(1,0),(0,1),(1,1)]$, the output is "1". It is also called "Any or All Gate". Thus it implements the truth table of OR operation. The mathematical notation of OR operation is:

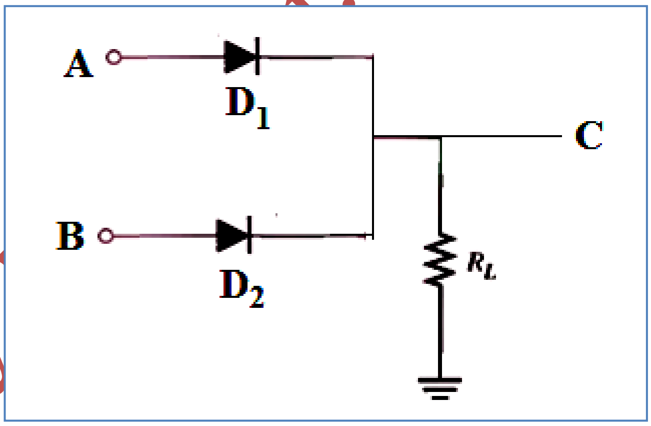
$$C = A + B$$

Truth Table of OR Operation

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

Electronic Circuit Diagram of OR Gate

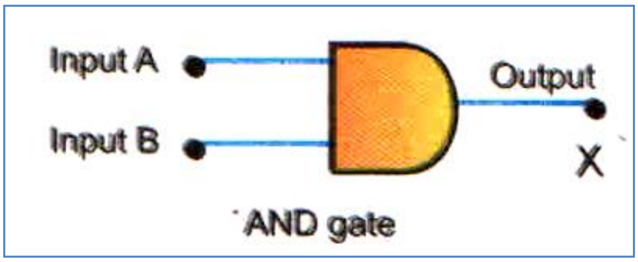
- If voltages A and B both are at 0, no current will flow through output resistance R_L and hence C will be at 0 potential. Thus if $A = 0, B = 0$, then $C = 0$.
- If a positive voltage (say +5 V) is given at A, then diode D_1 will be forward biased and will conduct, so current will flow through output resistance R_L. Hence C will be at same positive potential. Thus if $A = 1, B = 0$, then $C = 1$.



- Similarly if a positive voltage (say +5 V) is given at B, then diode D_2 will be forward biased and will conduct, so current will flow through output resistance R_L. Hence C will be at same positive potential. Thus if $A = 0, B = 1$, then $C = 1$.
- If a positive voltage (say +5 V) is applied both at A and B, then diode D_1 and D_2 will be forward biased and will conduct, so current will flow through output resistance R_L. Hence C will be at same positive potential. Thus if $A = 1, B = 1$, then $C = 1$.

AND Gate

AND gate implements the logic of AND operation. It has two or more inputs and a single output. The symbolic representation of an AND gate is shown in the figure.



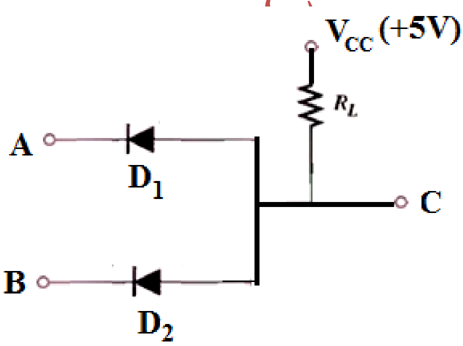
The output of the AND gate has a value "1" when all inputs are "1" and "0" for all other combinations of inputs. This gate is also called "All or Nothing Gate". Thus it implements the truth table of AND operation. The mathematical notation of OR operation is:

$$C = A.B$$

Electronic Circuit Diagram of AND Gate

Truth Table of AND Operation		
A	**B**	**Output**
0	0	0
0	1	0
1	0	0
1	1	1

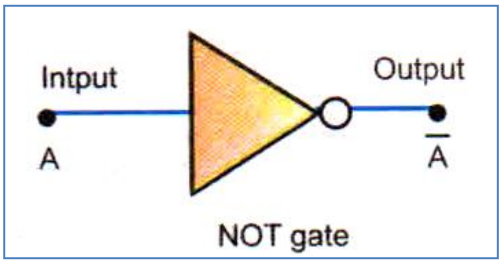
- If the potential at A and B are “0”, then both diodes (forward biased) will conduct and current will flow through diodes and hence all potential will drop at R_L. Therefore potential at C will be “0”. Thus if $A = 0$, $B = 0$ then $C = 0$.
- If A is given a positive potential (equal to +V_{CC}) and no potential is applied at B , then diode D_1 will be reversed biased but diode D_2 will be forward biased. Thus diode D_2 will conduct and current will flow through it and hence all potential will drop at R_L. Therefore potential at C will be “0”. Thus if $A = 1$, $B = 0$ then $C = 0$.



- If B is given a positive potential (equal to +V_{CC}) and no potential is applied at A, then diode D_2 will be reversed biased but diode D_1 will be forward biased. Thus diode D_1 will conduct and current will flow through it and hence all potential will drop at R_L. Therefore potential at C will be “0”. Thus if $A = 0$, $B = 1$ then $C = 0$.
- If the positive voltage (equal to +V_{CC}) is given to both A and B simultaneously, then both diodes will be reversed biased and will not conduct. Thus no current will flow through diode and hence potential drop at R_L is “0” and as the result the potential at C will become equal to +V_{CC}. Thus if $A = 1$, $B = 1$ then $C = 1$.

NOT Gate

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 symbolic representation of NOT gate is shown in the figure. The Boolean equation corresponding to NOT operation is described as:

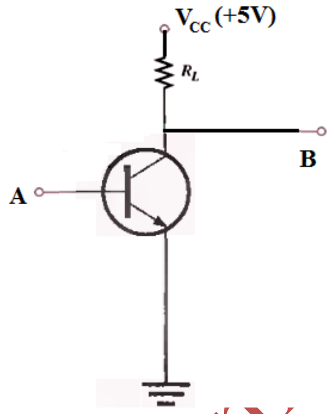


NOT gate

$$B = \bar{A}$$

Truth Table of NOT Operation	
Input	**Output**
0	1
1	0

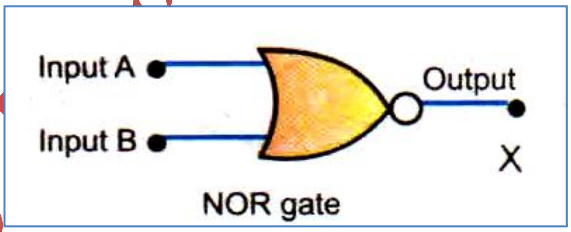
Electronic Circuit Diagram of NOT Gate



A simple electronic circuit working as NOT gate consist of a npn-transistor in common emitter configuration is shown in the figure.

- If the base of the transistor is at "0" potential, charge carriers will not move from emitter to base. So collector current in load resistance R_L will also be "0". So in this case the transistor will not conduct and potential at B will be equal to $+V_{CC}$ i.e., if $A = 0$ then $B = 1$.
- If the positive voltage is given at A, the transistor will conduct. As the result the collector current will flow through the load resistance R_L. Now whole of $+V_{CC}$ will fall across R_L and potential at B will be nearly equal to "0". Thus if $A = 1$ then $B = 0$.

NOR Gate



If a NOT Gate is connected at the output of an OR gate, then the combination acts as NOR Gate i.e., in NOR gate the output of the OR Gate is inverted. The symbolic representation of a NOR gate is shown in the figure. The output of the NOR gate is "1" when both inputs A and B are "0". And the output is "0" for all other combinations of inputs. Its Boolean equation is:

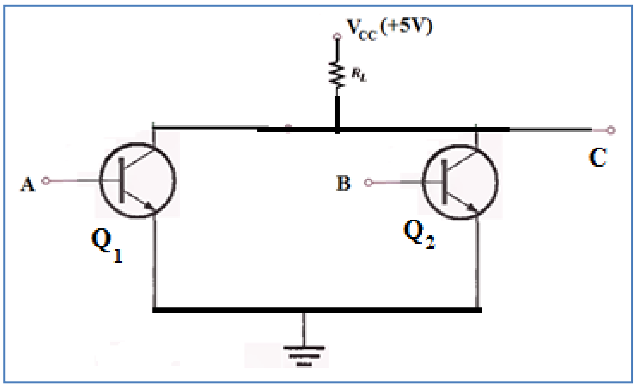
$$\mathrm{C} = \overline{\mathrm{A} + \mathrm{B}}$$

Truth Table of NOR Operation

Input		A + B	Output
A	**B**		$\overline{\mathrm{A}+\mathrm{B}}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

Electronic Circuit Diagram of NOR Gate

- If no voltage is applied at A and B, then none of the two transistors will conduct. As a result, no current will flow through R_L. Hence the potential at C will be equal to $+V_{CC}$ i.e., if $A = 0, B = 0$ the $C = 1$.
- If positive voltage is given at the base of one or both transistors, then one or both of them will conduct. So current flow in R_L, and potential at C will be zero. Thus for all inputs $(A, B) = (1,0), (0,1), (1,1)$, the output $C = 0$.

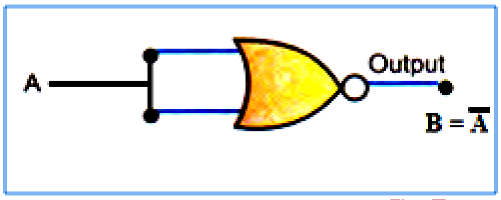


NOR Gate as a Universal Gate

NOR gate is called universal gate because a NOR gate or combinations of NOR gates can be used as OR gate, AND gate and NOT gate.

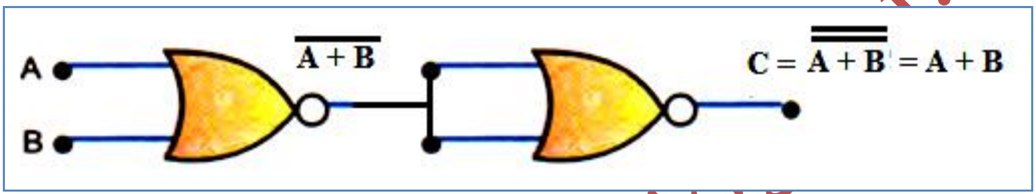
As NOT Gate

If two inputs of NOR gate are joined together, then it acts as NOT-gate. Its symbolic representation is shown in the figure.



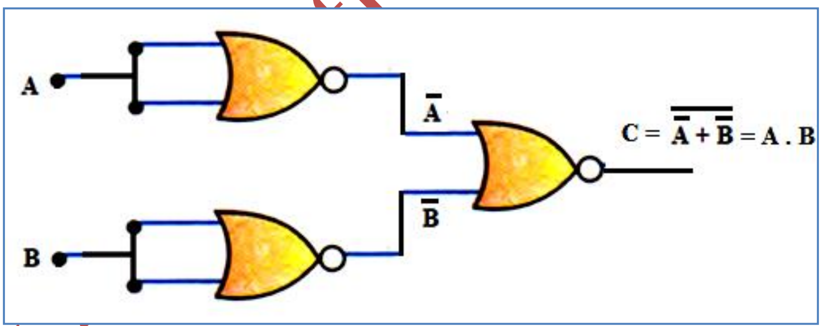
As OR Gate

If a NOT gate (made of NOR gate) is connected at the output of a NOR gate, then this combination acts as a OR gate.



As AND Gate

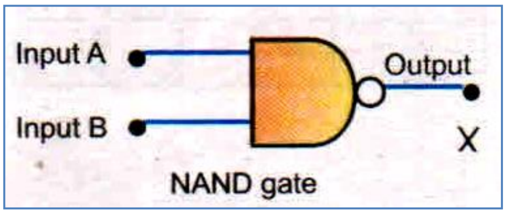
If the input are inverted by a NOT gate (made of NOR-gate) before they are fed to a NOR gate, then the combination will act as AND-gate.



Input		$\overline{A}$	$\overline{B}$	$\overline{A}+\overline{B}$	**Output**
A	**B**				$\overline{\overline{A}+\overline{B}}$
0	0	1	1	1	0
0	1	1	0	1	0
1	0	0	1	1	0
1	1	0	0	0	1

NAND Gate

If a NOT Gate is connected at the output of an AND gate, then the combination acts as NAND Gate i.e., in NAND gate the output of the AND Gate is inverted. The symbolic representation of a NAND gate is shown in the figure. The output of the NAND gate is "0" when both inputs A and B are "1". And the output is "1" for all other combinations of inputs. Its Boolean equation is:

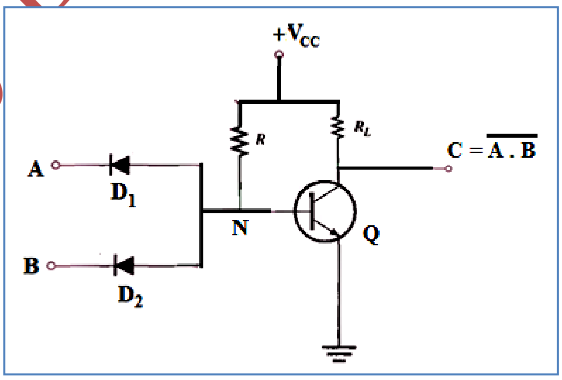


$$C = \overline{A\,.B}$$

Truth Table of NAND Operation			
Input		A. B	**Output**
A	**B**		$\overline{A.B}$
0	0	0	1
0	1	0	0
1	0	0	0
1	1	1	0

Electronic Circuit Diagram of NAND Gate

- For inputs $(A, B) = \{(0,0), (0,1), (1,0)\}$, any one or both diodes will conduct (forward biased). So in all these cases, current will flow through R and potential at N will be "0". Since N is connected to the base of the transistor, potential at the base of transistor will be "0". So transistor will not conduct. No current will flow in R_L and hence the potential at C will be nearly equal to $+V_{CC}$ i.e., for inputs $(A, B) = \{(0,0), (0,1), (1,0)\}$ the output $C = 1$.



- if positive voltage equal to $+V_{CC}$ is given to both A and B, none of the two diodes will conduct and potential at N will also be equal to $+V_{CC}$. Now the transistor will conduct and potential at C will become "0" i.e., for $(A, B) = (1,1)$, the output $C = 0$.

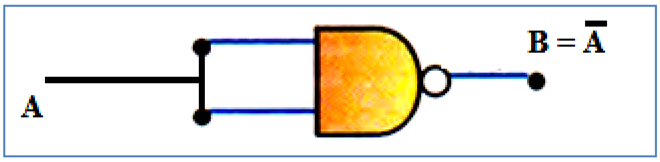
Thus this electronic circuit verifies the truth table of NAND gate.

NAND Gate as a Universal Gate

NAND gate is called universal gate because a NAND gate or combinations of NAND gates can be used as OR gate, AND gate and NOT gate.

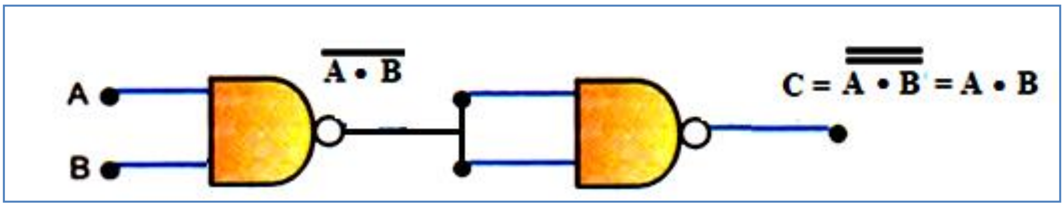
As NOT Gate

If two inputs of NAND gate are joined together, then it acts as NOT-gate. Its symbolic representation is shown in the figure.



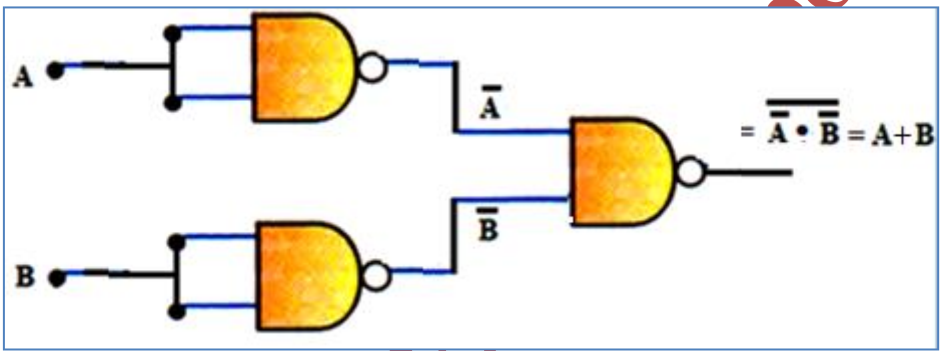
As AND Gate

If a NOT gate (made of NAND gate) is connected at the output of a NAND gate, then this combination acts as a AND gate.



As AND Gate

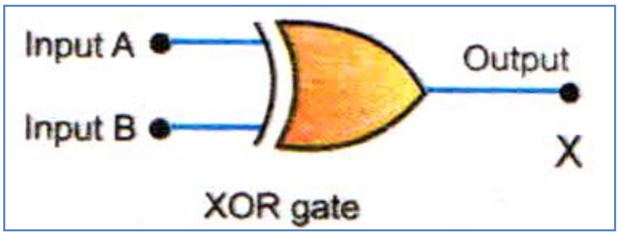
If the input are inverted by a NOT gate (made of NAND-gate) before they are fed to a NAND gate, then the combination will act as OR-gate.



Input		$\overline{A}$	$\overline{B}$	$\overline{A}.\overline{B}$	Output
A	B				$\overline{\overline{A}.\overline{B}}$
0	0	1	1	1	0
0	1	1	0	0	1
1	0	0	1	0	1
1	1	0	0	0	1

Exclusive OR Gate (XOR Gate)

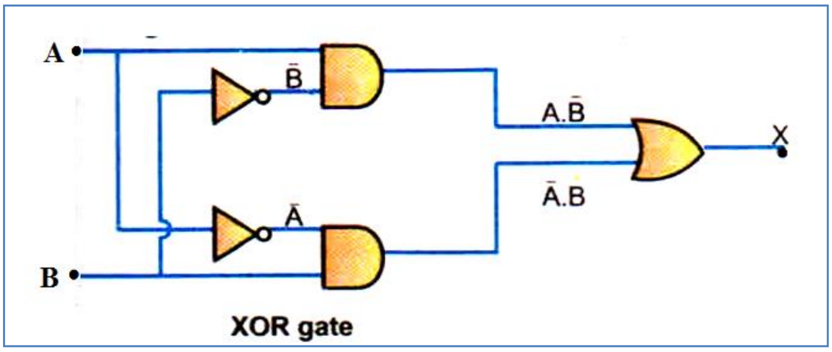
This gate has two inputs A, B and one output C. the output of XOR gate is "0" when both inputs are same i.e., $(A, B) = \{(0,0), (1,1)\}$ and the output is "1" when the inputs are different. The symolic representation of XOR gate is shown in the figure.



Its Boolean equation is:

$$C = A \oplus B = A.\overline{B} + \overline{A}.B$$

The circuit which acts as XOR gate consist of combinations of gates as shown in the figure:

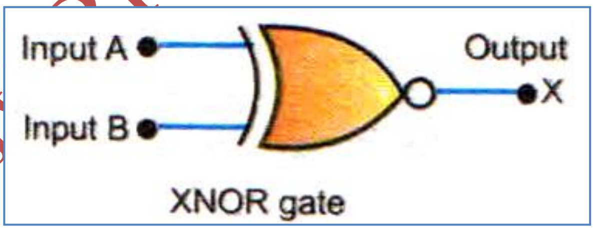


Truth Table of XOR Operation		
A	**B**	**Output**
0	0	0
0	1	1
1	0	1
1	1	0

In XOR gate, A and $\bar{B}$ (Complement of B) are applied to the inputs 1st AND gate and 2nd AND gate is gets the inputs $\bar{A}$ (Complement of A) and B as shown in the figure. The outputs from two AND gates are fed to OR gates. This circuit verifies the truth table of XOR operation.

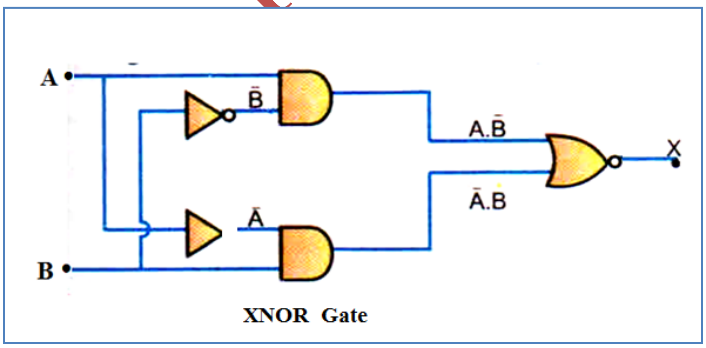
Exclusive NOR Gate (XNOR Gate)

if an inverter is connected in the output of and XOR gate, then the combination is called XNOR gate. It has two inputs A, B and one output C. The output of XOR gate is "1" when both inputs are same i.e., $(A,B) = \{(0,0),(1,1)\}$ and the output is "0" when the inputs are different. The symolic representation of XOR gate is shown in the figure. Its Boolean equation is:



$$C = \overline{A \oplus B} = \overline{A.\bar{B} + \bar{A}.B}$$

The circuit which acts as XOR gate consist of combinations of gates as shown in the figure:



Truth Table of XOR Operation			
A	**B**	**A ⊕ B**	**Output**
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

In XNOR gate, A and $\bar{B}$ (Complement of B) are applied to the inputs 1st AND gate and 2nd AND gate is gets the inputs $\bar{A}$ (Complement of A) and B as shown in the figure. The outputs from two AND gates are fed to NOR gates. This circuit verifies the truth table of XOR operation.

Multivibrators

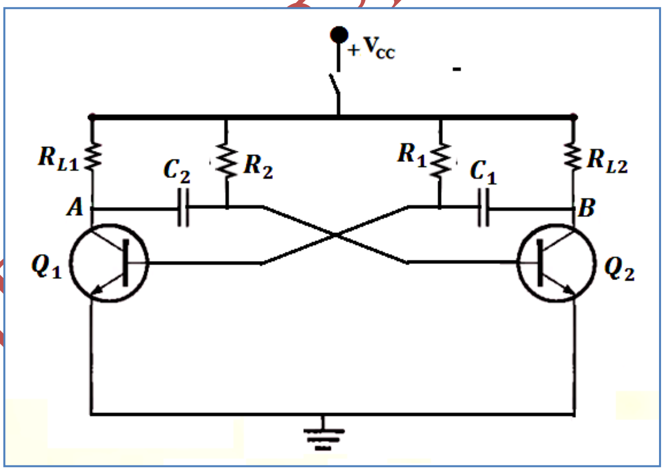
Multivibrators are originally two stage amplifier circuits with positive feedback from the output of one to the input of the other. Multivibrators are basically of three types:

- Astable Multivibrator
- Bistable Multivibrator
- Monostable Multivibrator

Astable Multivibrator

The Astable Multivibrator has no stable state but two Quasi-stable states and keeps oscillating between them without any external excitation. It has two available outputs which are out of phase.

Astable Multivibrator consists of two CE amplifiers, each providing feed back to other. The feedback is positive because each transistor produce a phase shift of 180^0 so total phase shift produced by the two transistors will be 360^0 or 0^0. Since the feedback is very strong, therefore the transistors are either driven to saturation or to cut off.



Circuit Operation

When V_{CC} is switched on, one of two transistors will conduct faster than the other because of the characteristics of no two transistors are exactly alike. Let's suppose that the transistor Q_1 starts conducting earlier than Q_2. Thus Q_1 is rapidly driven to the saturation and Q_2 to cut-off. Afterwards, the events occur in following sequence:

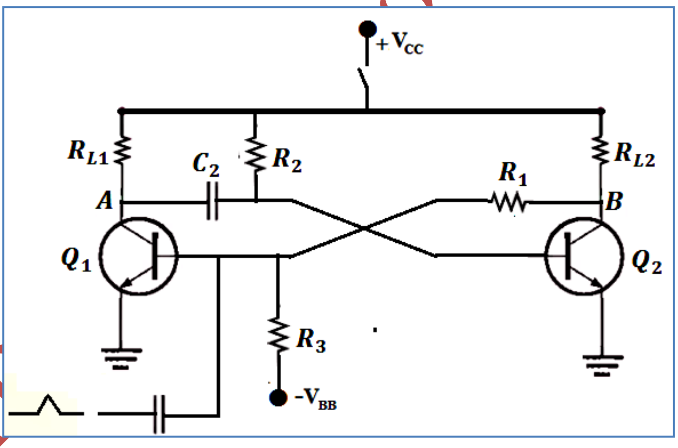
- Since Q_1 is in saturation, whole of V_{CC} will drop at R_{L1} and the point A will be at zero potential. Since the base of Q_2 is connected to A, potential at the base of Q_2 is zero, so Q_2 will be cut-off.
- Since Q_2 is cut-off, no current will flow in R_{L2} and potential at B will be maximum ($+V_{CC}$). This potential is given to the base of Q_1, which keeps Q_1 in saturation. Thus conduction of Q_1 keeps Q_2 cut-off and cut-off state of Q_2 keeps Q_1 in saturation.
- Since A is at zero potential, the capacitor C_2 will begin to charge through R_2. When the voltage across C_2 rises sufficiently (about 0.7 V), it forward biases base emitter junction of Q_2. So Q_2 begins to conduct and attains saturation very soon.

- When Q_2 begins to conduct in saturation, potential at B falls to zero. As a result, potential at base of Q_1 becomes zero. So Q_1 goes to cut-off position.
- As soon as Q_1 is cut-off, potential at A rises to maximum value ($+V_{CC}$). As it is connected to the base of Q_2, it keeps Q_2 conducting in saturation.
- Since potential at B is now zero, capacitor C_1 will begin to charge through R_1. After some time, the voltage across C_1 rises to such a value that it provides sufficient potential to the base of Q_2 for forward biased of base-emitter junction. So Q_1 starts conducting and Q_2 is cut-off.

Thus one-cycle completed which repeats itself periodically without any external excitation.

Monostable Multivibrator

In Monostable Multivibrator, there are two transistors in common emitter configuration. Each transistor provides the positive feedback to the base of the other. Also, the base of the Q_1 is kept at small negative potential by battery V_{BB}. Also, an external signal of positive voltage may also be given to the base of Q_1 through C_1. If is called Trigger Pulse.



Working

(a) When the Trigger Pulse is not Applied

- V_{CC} provides collector voltage to both Q_1 and Q_2. But the base voltage is applied only to Q_2, so it conducts at saturation.
- V_{BB} and R_B reverse biases the base-emitter junction of Q_1 so it keeps Q_1 at cut-off. So initially, Q_1 is cut-off and Q_2 is conducting in saturation state. It is the stable state until a trigger pulse is applied.

(b) When Trigger Pulse is Applied

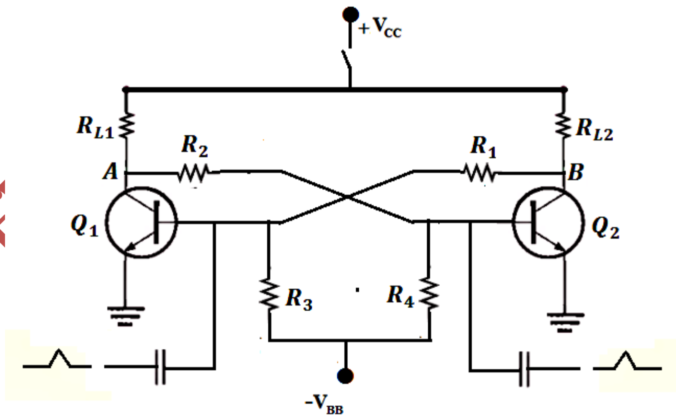
- If the positive voltage is applied at the base of Q_1, the base of Q_1 will become positive. So Q_1 will start conducting and will attain saturation soon. The trigger pulse must be of sufficient amplitude to over ride the negative voltage V_{BB}.

- As Q_1 conducts in saturation, the potential at A and hence at base of Q_2will become "0". Therefore, Q_2 will go cut-off state and potential at B will rise to $+V_{CC}$. Hence potential at the base of Q_1 will remain positive as long as Q_2 is cut-off.
- Since the potential at A is zero, capacitor C_2 will begin to charge throughR_2. So the potential at the base of Q_2 will begin to rise. As soon as potential at base of Q_2 attains required minimum value, Q_2 begins to conduct and potential at B falls to zero. As a result, potential at base of Q_1 is become negative and it goes to cut-off state which is a stable state.

Bistable Multivibrator (Flip Flop Multivibrator)

It has two absolutely stable states and can remain in any one of the two states as long as power is supplied to it. One state changes to the other state only when it receives a trigger pulse from outside. It remains stable in its state. Also it goes back to its original state only when it receives another trigger pulse at the base of the other transistor.

Working

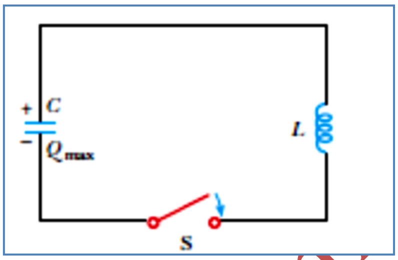


- If Q_1 is conducting, then point A is at zero potential. Also, $-V_{BB}$ makes the potential of base of Q_2 negative. Hence Q_2 will remain in cut-off position. Therefore, potential at B is equal to $+V_{CC}$ which provides the sufficient positive voltage to the base of Q_1 and keeps it in saturation i.e., Q_1 is on and Q_2 is off. It is a stable state.
- If a positive trigger pulse is applied at the base of Q_2, it begins to conduct and soon saturation is attained. As a result, potential at B falls to zero and so potential at the base of Q_1 becomes negative due to $-V_{BB}$. Therefore Q_1 is cut-off. Moreover, the potential at A becomes equal to $+V_{CC}$ which provides the positive voltage at the base of Q_2 and keeps it conducting in saturation. Now Q_1 is off and Q_2 is on. It is another stable state.

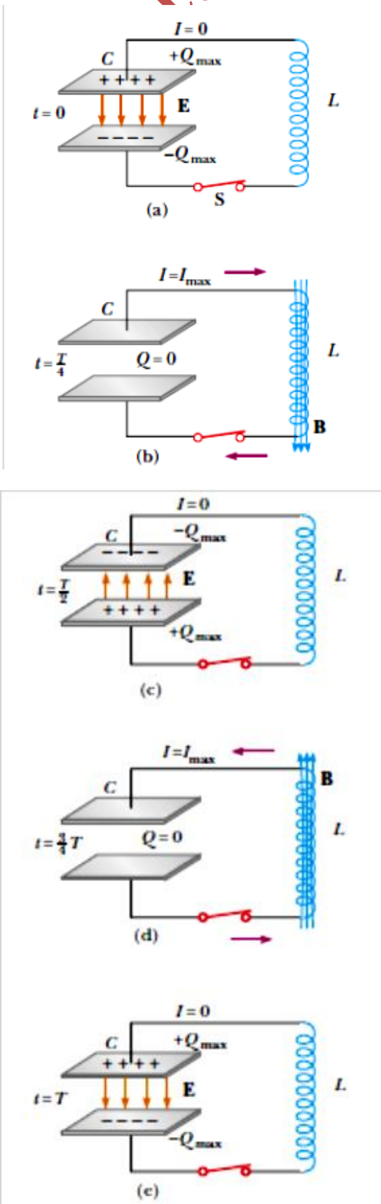
Oscillator

An oscillator is a device which is used to produce sine, square or triangular waves of constant amplitude.

Electromagnetic Oscillations in LC Circuit



Consider an oscillating circuit which consists of a capacitor and an inductor. If the capacitor is initially charged and the switch is then closed, we find that both the current in the circuit and the charge on the capacitor oscillate between maximum positive and negative values. If the resistance of the circuit is zero, no energy is transformed to internal energy. In the following analysis, we neglect the resistance in the circuit. We also assume an idealized situation in which energy is not radiated away from the circuit.



When the capacitor is fully charged, the energy U_E in the circuit is stored in the electric field of the capacitor and is equal to

$$U_E = \frac{1}{2}\frac{(q_{max})^2}{C}$$

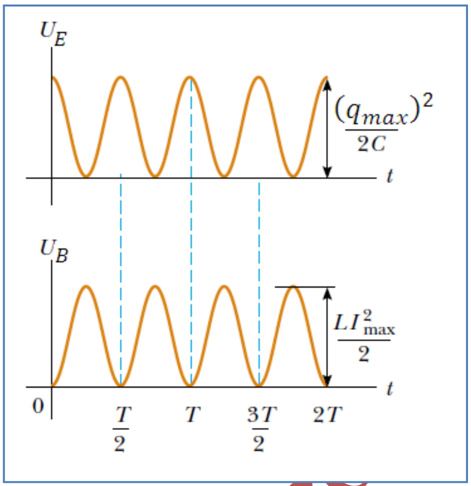
At this time, the current in the circuit is zero, and therefore no energy is stored in the inductor.

$$U_B = 0$$

As the switch S is closed, the capacitor begins to discharge and the energy stored in its electric field decreases. The discharge of the capacitor represents a current in the circuit, and hence some energy is now stored in the magnetic field of the inductor. Thus, energy is transferred from the electric field of the capacitor to the magnetic field of the inductor. When the capacitor is fully discharged, it stores no energy. At this time, the current reaches its maximum value, and all of the energy is stored in the inductor.

$$(U_E)_{min} = 0,\ (U_B)_{max} = \frac{1}{2}L(I_{max})^2$$

The current continues in the same direction, decreasing in magnitude, with the capacitor eventually becoming fully charged again but with the polarity of its plates now opposite the initial polarity. This is followed by another



discharge until the circuit returns to its original state of maximum charge q_{max}. The energy continues to oscillate between inductor and capacitor. When the energy stored in the capacitor is maximum, the energy stored in inductor is minimum and vice versa. But the total energy $U = U_E + U_B$ remains constant.

As the energy in such circuit is used to oscillate between capacitor and inductor, therefore, it is also called 'Oscillating Circuit'.

Feedback

The process of injection a fraction of output energy to the input is called feedback. When the feedback energy (current or voltage) is in phase with input signal, it is called positive feedback.

Positive Feedback Amplifier Oscillator

A transistor amplifier with proper positive feedback acts as an oscillator i.e., it can produce oscillation without any external signal (voltage).

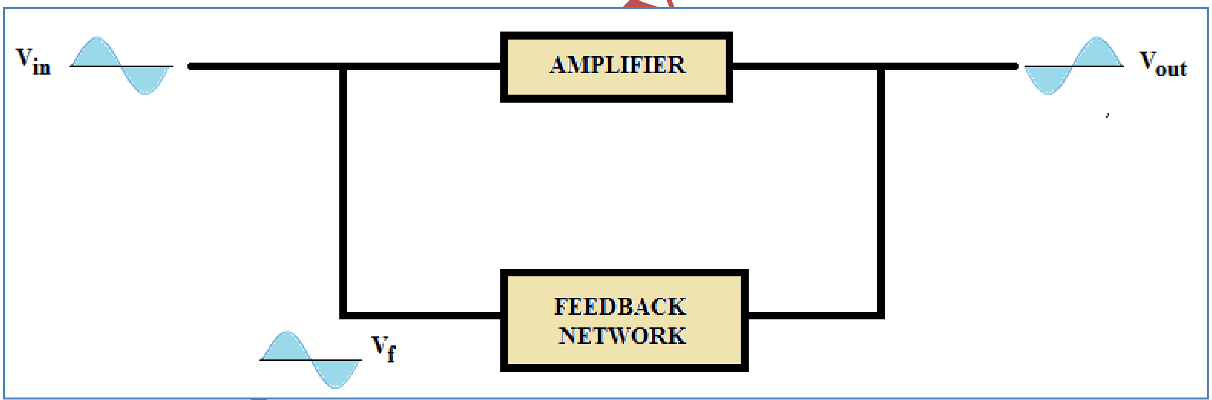


Figure shows a transistor amplifier with positive feedback. A positive feedback amplifier is that which produces a feedback voltage that is in phase with the original input signal.

A phase shift of 180^0 is produced by amplifier and a further phase shift of 180^0 is produced by the feedback network. Hence the signal is shifted by 360^0 and fed to the input i.e., the feedback signal is in phase with the input signal.

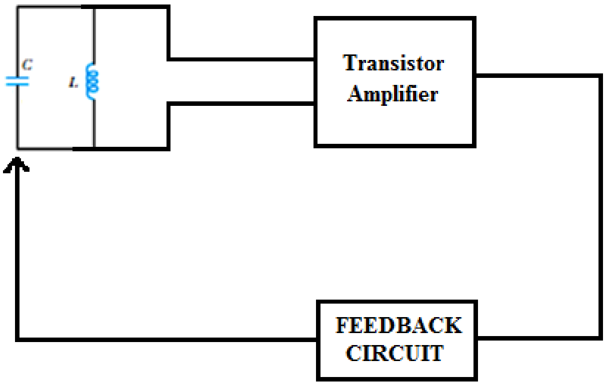
This feedback signal is amplified by the amplifier. A portion of the output signal will go to the feedback network again, which send it back to input. So the amplifier receives another input cycle and another output cycle is produced. This process will continue and in this way the amplifier produces oscillations with no external source.

Essentials of Transistor Oscillator

The essential components of transistor oscillators are:

i. Tank Circuit

It consists of inductor and a capacitor connected in parallel. The frequency of oscillations in the circuit depends upon the values of inductance L of inductor and capacitance C of capacitor.



ii. Transistor Amplifier

The oscillations of the tank circuit are applied to the input of the transistor amplifier. The amplifier amplifies these oscillations.

iii. Feedback Circuit

The feedback circuit sends a portion of the output back to the input i.e., it provides positive feedback.

TUNED COLLECTOR OSCILLATOR

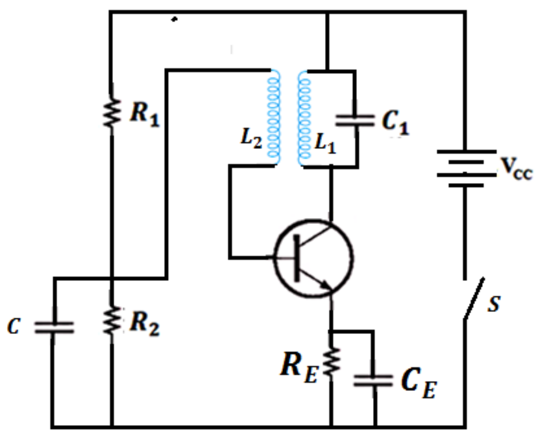
This oscillator contains a tuned circuit L_1C_1 which is connected with collector. That's why it is called tuned collector oscillator. The frequency of oscillations depend upon the values of L_1 and C_1:

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

The feedback coil L_2 in the base circuit is magnetically coupled to L_1C_1 circuit. In fact, L_1 and L_2 acts as primary and secondary coil of transformer.

Circuit Operation

When the switch S is open, the capacitor C_1 gets charged. When C_1 gets fully charged, it discharges through inductance L_1 and oscillations of frequency f are set up. These oscillations produce same voltage in L_2 by mutual inductance. The frequency in the voltage in the coil L_2 is the same as that of L_1C_1 circuit. The magnitude of voltage in L_2 depends on the number of turns of in L_2 and coupling between L_1 & L_2.



The voltage across L_2 is applied between base-emitter junction of transistor and appears in the amplified form in the collector. A phase shift of 180^0 is produced by amplifier and a further phase shift of 180^0 is produced between the voltages of L_1 and L_2 by the transformer function. Hence the signal is shifted by 360^0 and fed to the input i.e., the feedback signal is in phase with the input signal.

This feedback signal is amplified by the amplifier. A portion of the output signal will go to the input. So the amplifier receives another input cycle and another output cycle is produced. This process will continue and in this way the amplifier produces oscillations with no external source.

B Sc 1st Annual Examination 2011

Q # 1. (a) How the N-type and P-type materials are formed? Explain.

(b) Describe action of a semiconductor diode for half wave rectification.

(c) What is the effect of temperature on the resistivity of intrinsic semiconductors

Q # 2. (a) Describe the input and output characteristics of a PNP transistor in common emitter configuration.

(b) Explain the action of a transistor as oscillator.

(c) What do you understand by positive feedback on an electric circuit?

Q # 3. (a) Draw the circuit diagram of a mono-stable Multivibrators and explain its operation.

(b) Describe the two input NAND gate, giving its symbolic representation, truth table and use.

(c) What is the net charge on N-type material and P-type material?

B Sc 1st Annual Examination 2010

Q # 1. (a) Explain full wave rectification.

(b) What are logic gates? Describe the exclusive OR-gate.

(c) Differentiate among rectification and oscillation.

Q # 2. (a) What is load line? Define operating point, why does it select at mid-way of load line in case of amplification.

(b) Explain transistor as an amplifier.

(c) Explain intrinsic and extrinsic semiconductors. Also define hole.

Q # 3. (a) Explain mono-stable Multivibrator.

(b) If for the transistor in CB configuration $\propto = 0.95$ and $I_E = 1\ mA$. Find I_B and I_C.

(c) Define the positive and negative feedback.

B Sc 1st Annual Examination 2009

Q # 1. (a) Explain the classification of solid on the basis of Band Theory.

(b) Explain the transistor as an oscillator.

(c) Is the net charge on P-type or N-type material zero. If so, why?

Q # 2. (a) Explain the characteristics of a transistor in common emitter configuration.

(b) At room temperature, a given applied electric field will generate a drift speed for the conduction electrons of silicon that is about 40 times as greater as that for the conduction electrons of copper. Why not silicon is better conductor of electricity than copper?

(c) In a common base circuit of a transistor, what value of R_L causes $V_{CB} = 5V$. If $\propto = 1, V_{EE} = 10\ V, R_E = 10\ k\Omega$ and $V_{CC} = 20\ V$.

Q # 3. (a) What is the difference between the Monostable and Bistable Multivibrators? Hence write down the uses of Multivibrators.

(b) Explain the classification of non-sinusoidal oscillators.

(c) Identity the following as P-type or N-type semiconductors:

(i) Sb in Si (ii) In in Ge (iii) Al in Ge (iv) P in Si

B Sc 1st Annual Examination 2008

Q # 1. (a) What is the difference between intrinsic and extrinsic semi-conductor materials? Explain the role of doping an impurity in a semi-conductor material.

(b) Explain the working of a bridge rectifier.

Q # 2. (a) Explain semi-conductor materials on the basis of energy band theory.

(b) What is depletion region of semi-conductor diode? What is the effect of biasing the diode on this region? Graphically explain the variation of current due to variation in voltage by the forward biased and reversed biased operations.

Q # 3. (a) Explain the hybrid parameters in common emitter configuration.

(b) Explain the transistor circuit as

(i) NOR gate (ii) NAND gate

(c) What is the importance of base in a transistor?

B Sc 1st Annual Examination 2007

Q # 1. (a) Explain the depletion region. What is the effect of forwad and reversed biasing of diode on the width of depletion region?

(b) Explain the difference among electrical behavior of conductors, insulators and semi-conductors on the basis of energy band theory.

Q # 2. (a) What is rectification? Explain the action of a semiconductor diode as:

- Half wave rectifier
- Full wave rectifier

Is transistor a voltage device or a current device?

Q # 3. (a) What is effect of temperature on semiconductor and conductor?

(b) Discuss two input OR and NOR logic gates giving the symbolic form and truth table. Also write one application of logic gates in control systems.

UNIVERSITY OF SARGODHA

B.A. / B.Sc. 1st Annual Exam 2017

Physics **Paper: C**

Time Allowed: 3 Hours **Maximum Marks: 50**

Note: Attempt any five questions in all, selecting at least two questions from each part. All questions carry equal marks.

SECTION-I

Q # 1. (a) How the N-Type and P-Type materials are formed? Explain in detail.

(b) Describe the action of a semi-conductor diode for half wave rectification.

(c) What is the effect of temperature on resistivity of intrinsic semi-conductor?

Q # 2. (a) Explain the circuit of common emitter amplifier.

(b) Discuss two input AND logic gate giving their symbolic form and truth table.

(c) Name minority charge carriers in an N-type and P-Type semi-conductor.

Q # 3. (a) What is an oscillator? Explain the action of a transistor as an oscillator.

(b) What is load line? Define quiescent point.

(c) Define positive and negative feedback.

SECTION-II

Q # 4. (a) State Compton Effect and derive an expression for Compton shift in wave length.

(b) A particular X-ray photon has a wavelength of 41.6 pm. Calculate the energy and frequency of photon.

(c) Why a threshold frequency is necessary for the photoelectric effect.

Q # 5. (a) Using Schrodinger wave equation. Discuss the motion of free electron.

(b) What do you mean by wave function? How it is related to probability of a particle?

(c) Does a photon have a de-Broglie wavelength? Explain.

Q # 6. (a) Derive a relation for the radii of quantized orbits for hydrogen atom and also for quantized energy.

(b) What is the wavelength of series limit for the Balmer series?

Q # 7. (a) What is magnetic moment? Find the relation for Bohr's magnetron and also calculate its numerical value.

(b) An LED is constructed from PN Junction based on certain semiconductor material whose energy gap is 1.97 eV. Find the wavelength of emitted light.

Q # 8. (a) State the law of radioactive decay and show that it obeys exponential law. What is meant by half-life and mean life of a radioactive element?

(b) The half-life of a radioactive isotope is 140 days. How many days would it take for the activity of a sample to fall to one fourth of its initial decay rate?

Q # 9. (a) Describe the principle, construction and working of a nuclear reactor?

(b) A large electric generator station is powered by a pressurized water nuclear reactor. The thermal power in the reactor core is 34000 MW, and 1100 MW of electricity is generated. The fuel consists of 86000 kg of uranium in the form of 110 tons of uranium oxide, distributed among 57000 fuel rods. What is plant efficiency?

Q # 10. Write note on the following:

a) Space quantization.

b) Nuclear fission.

UNIVERSITY OF SARGODHA

B.A. / B.Sc. 1st Annual Exam 2016

Physics **Paper: C**

Time Allowed: 3 Hours **Maximum Marks: 50**

Note: Attempt any five questions in all, selecting at least two questions from each part. All questions carry equal marks.

SECTION-I

Q # 1. (a) Distinguish between a conductor, an insulator and a semi-conductor using the concept of energy bands.

(b) In common emitter amplifier, calculate collector current I_C and β when I_E= 12mA, I_B=150 µA and α=0.98.

(c) Draw the symbols of NPN transistor and PNP transistor. Also name its regions.

Q # 2. (a) What is junction diode? Describe its application as rectifier.

(b) The current following into the-base of a transistor is l00uA. Find the collector current I_C if β = 100.

(c) What is the net charge on N-type and P-type substance?

Q # 3. (a) Describe the two inputs AND gate and OR gate, using their symbol and truth table.

(b) A LED is constructed from PN junction based on a certain semiconductor material whose energy gap is l.97eV. What is the wavelength of emitted light?

(c) Define biasing and rectification

SECTION-II

Q # 4. (a) State Stefan Boltzmann's law and Wein's law. Give Plank's assumption and Plank's formula for energy distribution in black body radiation spectrum

(b) Calculate intensity of the sun with a surface temperature of 5800 K.

Q # 5. (a) What is Compton effect? Explain this effect using quantum theory.

(b) X-rays with λ=100 pm are scattered from a carbon target. The scattered radiation is viewed at 90^0 to the incident beam. What is Compton shift?

Q # 6. (a) Define Heisenberg uncertainty principle. Prove that $\Delta x.\Delta p \approx h$. Also discuss behavior of uncertainty principle and single slit diffraction.

(b) If de-Broglie wavelength of an electron is $1.1 \times 10^{10}\ m$. Find the speed of electron.

Q # 7. (a) Define wave function and probability density. Find an expression for time dependent Schrodinger wave equation.

(b) Calculate Fermi energy for copper, given the number of conduction electrons per unit volume is$8.49 \times 10^{28}\ m^{-3}$.

Q # 8. (a) Define excitation energy and excitation potential. Hww Bohr's theory was verified by Frank Hertz Experiment.

(b) Consider an atom absorbs a photon of frequency 6.2×10^{14} Hz. By what amount does the energy of the atoms increase?

Q # 9. (a) What is meant by the binding energy of a nucleus? Discuss variation of binding energy per nucleon as a function of mass number.

(b) Calculate the binding energy of Deuteron $_1H^2$ when the mass of $_1H^2$ is 2.014l02 µ and mass of proton = 1.007825 µ, mass of Neutron = l.008665 µ.

UNIVERSITY OF SARGODHA

B.A. / B.Sc. 1st Annual Exam 2015

Physics **Paper: C**

Time Allowed: 3 Hours **Maximum Marks: 50**

Note: Attempt any five questions in all, selecting at least two questions from each part. All questions carry equal marks.

SECTION-I

Q # 1. (a). What is transistor? Explain pnp-transistor in common-emitter configuration used as amplifier. Also calculate its gain.

(b). In common emitter amplifier, calculate collector current I_c and β, when $I_E = 12\ mA, I_B = 150\ \mu A$ and $\alpha = 0.98$.

(c). What are the differences between hole and positive charge.

Q # 2. (a). What is pn-junction? Define depletion region, barrier potential and describe its forward and reverse biased characteristics.

(b). What is the speed of a conduction electron in copper with K.E. equal to its Fermi energy 7 eV.

(c). Identify following as p-type or n-type semiconductors:

(i) Al in Ge **(ii)** In in Ge **(iii)** Sb in As **(iv)** P in Si

Q # 3. (a). What are logic gates? Describe:

(i) XNOR gate **(ii)** NAND gate

(b). A LED is constructed from pn-junction based on GaAsP semiconductor material whose energy gap is 1.97 eV. What is the wavelength of emitted light and color?

(c). Differentiate among analog and digital quantities.

SECTION-II

Q # 4. (a). What is Plank's quantum theory? Derive Plank's law of radiation in terms of frequency and wavelength.

(b). Find the maximum wavelength shift for the Compton collision between a photon and free electron.

(c). What arc differences between a photon and a material particle?

Q # 5. (a). Describe the phenomenon of photoelectric effect and give its quantitative analysis.

(b). Find the maximum K.E (eV) of photoelectrons if the work function of material is 2.33 eV and frequency of radiation is $3.19 \times 10^{15}\ Hz$.

(c). In both photoelectric and Compton effect there is an incident photon and ejected electron. What is the difference between these two effects?

Q # 6. (a). What is de-Broglie hypothesis? Explain Davisson and Germer experiment for its verification.

(b). Calculate de-Broglie wavelength of an electron with energy 120 eV.

(c). If the particle listed below all have same energy, which has shortest wave length: electron, proton, neutron and α-particle.

Q # 7. (a). Find the radii and energy of different Bohr's orbits of a hydrogen atom.

(b). An atom absorbs a photon of frequency $6.2 \times 10^{14}\ Hz$. By what amount does the energy of the atom increase?

(c). Why does the concept of Bohr's orbits violate the uncertainty principle?

Q # 8. (a). Define mass defect and describe nuclear binding energy in detail.

(b). Calculate the mass defect and binding energy of carbon atom if m_p=1.007660 μ, m_n= 1.008665 μ and experimental value of mass of carbon is 12.011 μ.

(c). Why is the binding energy per nucleon is low at low mass number and at high mass number?

Q # 9. (a). What is radioactivity? Show that the mean life of a radioactive element is greater than the half-life of that element.

(b). The half-life of a radioactive element is 140 days. How many days should it take for activity of this isotope to fall one fourth of its initial decay rate?

(c). Define critical mass.

Q # 10. Write note on the following:

i. Full wave Rectification

ii. Schrodinger Wave Equation

UNIVERSITY OF SARGODHA

B.A. / B.Sc. 1st Annual Exam 2014

Physics **Paper: C**

Time Allowed: 3 Hours **Maximum Marks: 50**

Note: Attempt any five questions in all, selecting at least two questions from each part. All questions carry equal marks.

SECTION-I

Q # 1. (a). Distinguish between a conductor, an insulator and semiconductor using concept of energy bands.

(b). Calculate maximum wavelength that will produce photoconduction in diamond which have band gap of 5.5 eV.

(c). Define rectification. Give its types.

Q # 2. (a). What is load line? Define operating point and why it is selected at midway of the load line in case of amplification?

(b). Explain the action of transistor as an amplifier.

(c). Does pure semiconductor obeys Ohm's Law?

Q # 3. (a). Discuss the two inputs NAND logic gate giving their symbolic form and truth table.

(b). Derive the relation α and γ , α and β.

(c). Name the minority charge carriers in an N-type and P-type semiconductors.

SECTION-II

Q # 4. (a). State Compton effect and derive an expression for the Compton shit in wavelength.

(b) A particular x-ray photon has a wavelength of 41.6 pm. Calculate the photon's (i) Energy (ii) Frequency.

(c) Why a threshold frequency is necessary for the photoelectric effect?

Q # 5. (a). What is de Broglie's hypothesis? Describe the experimental evidence in support of de Broglie's hypothesis.

(b) Consider an electron confined by electrical force to an infinitely deep potential well, whose length L is l00 pm. What is the energy of its lowest allowed state'?

(c) Why the wave nature of large size object is not apparent in our daily life'?

Q # 6. (a). Explain Bohr's theory of hydrogen atom and derive an expression for the energies of its stationary states.

(b) What is the wavelength of the least energetic photon in the Balmer's Spectrum?

(c) Can a hydrogen atom absorb a photon whose energy is greater than l3.6 eV.

Q # 7. (a). What is meant by laser? Discuss the working of He-Ne laser?

(b) A He-Ne laser emits light of 632.8 nm and has an output power of 2.3 mW. How many photons are emitted each minute by this laser when operating?

(c) Write down four uses of x-rays.

Q # 8. (a). What is meant by radioactive decay? Derive relation between the half-life and disintegration constant.

(b). In a sample of rock. The ratio ^{206}Pb to ^{238}U nuclei is found to be 0.65. What is the age of the rock if half-life of ^{238}U is $4.5 \times 10^9\ Years$.

(c). Does the temperature affect the rate of decay of radioactive nuclides? If so, how?

Q # 9. (a). Explain the basic process in nuclear fusion.

(b). How much energy is required to remove a neutron from ^{236}U nucleus in its ground state, leaving a ^{235}U nucleus behind? The needed atomic masses are ^{236}U=236.045563 μ, ${}^{1}_{0}n = 1.008665\ \mu$.

(c). What do you mean by critical mass?

Q # 10. Write note on the following:

i. Moseley's Law

ii. Half wave Rectification

UNIVERSITY OF SARGODHA

B.A. / B.Sc. 1st Annual Exam 2013

Physics **Paper: C**

Time Allowed: 3 Hours **Maximum Marks: 50**

Note: Attempt any five questions in all, selecting at least two questions from each part. All questions carry equal marks.

SECTION-I

Q # 1. (a). What is pn-junction? Define depletion region and potential barrier. Describe forward and reverse characteristics of pn-junction diode.

(b). A LED is constructed from pn-junction based on certain semiconductor whose energy gap is 1.9 eV. What is the wavelength of its emitted light?

(c). Distinguish between drift and Fermi speed of conduction electrons in metal.

Q # 2. (a). What is transistor? Describe the characteristics for common-emitter configuration.

(b). The current flowing into the base of transistor is $200\ \mu A$, find its collector current I_C and emitter current I_E and the ration ${}^{I_C}/_{I_E}$ if $\beta = 200$.

(c). How does motion of electron in N-type substance differ from the motion of hole in P-type substance?

Q # 3. (a). What is an oscillator? Explain RL phase shift oscillator?

(b). What is load line? Define quiescent point.

(c). Define positive and negative feedback.

SECTION-II

Q # 4 (a). Define photoelectric effect. Explain photoelectric effect on the basis of Plank's quantum theory.

(b) Find maximum kinetic energy in eV of photoelectrons if work function of material is 2.33 eV and frequency of radiation is $3.19 \times 10^{15}\ Hz$.

(c) Why are photoelectric measurements so sensitive to the nature of photoelectric surface?

Q # 5 (a). Using Schrodinger wave equation, discuss the motion of free electron (particle).

(b) What do you mean by wave function? How it is related to probability of a particle?

(c) Does a photon have a de Broglie wavelength?

Q # 6 (a). Define Stern-Gerlach experiment and discuss its theory and result.

(b) A hydrogen atom state is known to have a quantum number $l = 3$. What are possible n, m_l and m_s quantum numbers?

(c) Why does the concept of Bohr orbits violate the uncertainty principle?

Q # 7 (a). Define x-rays. Discuss continuous and characteristics x-rays spectrum.

(b) What is minimum p.d. across the x-ray tube that will produce X-rays with the wavelength of 0.126 nm.

(c) Write down four uses of x-rays.

Q # 8 (a). Define mass defect and describe binding energy of a nuclide.

(b) The mass no. of an atom is I20 and charge no. is 50. Find the binding energy per nucleon for its nucleus, if the mass of nucleus is 119.902199 μ, mass of proton = l.007825 μ and mass of neutron = l.008665 μ.

(c) Define endothermic and exothermic reactions.

Q # 9 (a). What is alpha decay. Discuss the theory of alpha decay.

(b) Calculate the distance of closest approach for head-on-collision between a 5.30 MeV α-particle and nucleus of copper atom.

(c) What do you mean by critical mass?

Q # 10. Write note on the following:

i. Full wave Rectification

ii. Half-life of a Radioactive Element

UNIVERSITY OF SARGODHA

B.A. / B.Sc. 1st Annual Exam 2012

Physics **Paper: C**

Time Allowed: 3 Hours **Maximum Marks: 50**

Note: Attempt any five questions in all, selecting at least two questions from each part. All questions carry equal marks.

SECTION-I

Q # 1. (a). Describe qualitatively the formation of energy bands in solids and their classification into metal, semiconductors and insulators.

(b). Calculate the maximum wavelength that will produce photoconduction in diamond which has a band gap of 5.5 eV.

(c). Do pure semiconductors obey Ohm's Law?

Q # 2. (a). Explain the circuit of Common Emitter Amplifier.

(b). How does positive Feedback to an amplifier leads to sustain oscillations?

(c). Name the minority carries in N-type and P-type semiconductors.

Q # 3. (a). Discuss the two input AND logic gate giving their symbolic form and truth table.

(b). Describe the basic circuit for a bistable multivibrator.

(c). Does a slab of N-type material carry a net negative charge?

SECTION-II

Q # 4: (a) What are cavity radiation and the factors on which they depend? Also describe three interrelated properties of cavity radiations which can be verified in any laboratory and can be explained by the theory of cavity radiation.

(b) Calculate the wavelength of maximum spectral radiancy and identify the region of electromagnetic spectrum to which it belongs for your body assuming a skin temperature of 34℃.

(c) Is energy quantized in classical physics?

Q # 5: (a) What is de Broglie's hypothesis? Describe the experimental evidence in support of de Broglie's hypothesis.

(b) Calculate the de Broglie's wavelength of virus particle of mass$1.0 \times 10^{-15} kg$ moving at a speed of 2.0 mm/s and an electron whose kinetic energy is I20 eV.

(c) Why is the wave nature of matter not more apparent in our daily observations?

Q # 6: (a) Stale the Bohr postulates as applied to hydrogen atom. Also derive expression for the radius of permitted orbits.

(b) What is the wavelength of the least energetic photon in the Balmer spectrum? What is the wavelength of the series limit for the Balmer series?

(c) Compare Bohr's Theory and wave mechanics.

Q # 7: (a) What are X-rays? How K_α and K_β lines are produced?

(b) What is the minimum potential difference across an x-ray tube that will produce x-rays with a wavelength of 0.l26 nm?

(c) Can atomic hydrogen be caused to emit it-rays? If so, describe how? If not, why not?

Q # 8: (a) What is natural radioactivity? Define half-life of a radioactive material and determine an expression for the half life?

(b) The radioactive isotope ^{40}K decays at an absolute rate of I600 counts per second. The radioactive isotope constitutes 1.13% of l.00g sample of KCI. The molar mass of KCI is 74.9 g/mol. Avogadro's number = 6.02×10^{23} per mole. What is the half-life in years for this decay'?

(c) Explain why, in alpha decay, short half-lives correspond to large disintegration energies and conversely.

Q # 9: (a) Discuss the theory of nuclear fission due to Neil Bohr and John Wheeler.

(b) How much energy is required to remove a neutron from a ^{236}U nucleus in its ground state, leaving a ^{235}U nucleus behind? The needed atomic masses are ^{236}U: 236.045563μ.

(c) If it's so much harder to get a nucleon out of a nucleus than to get an electron out of an atom why try?

Q # 10: Write the explanatory notes on the following:

i. He-Ne Gas Laser

ii. Radioactive Dating