Electronics

It is the branch of science which deals with the electron's emission flow and its control through vacuum, gas or semiconductor.

Solid

We know that, each substance is composed of atoms. Substances are mainly classified into three categories namely solids, liquids and gases.

In each solid atoms are at a definite positions and the average distance between them is constant.

Depending upon the internal arrangement of atoms, solids are further divided into two groups.

1. Crystalline Solids

The solid in which the atoms are arranged in a regular order are called the crystalline solids. In other words, we can say that in a crystalline solid, there is periodicity and regularity of its component atoms in all the directions. For example sodium chloride (common salt), diamond, sugar, silver etc are the crystalline solids.

Their atoms are arranged in a definite geometrical shape.

They have a definite melting point.

They are anisotropic, i.e. their physical properties such as thermal conductivity, refractive index etc, are different in different directions.

They are the real solids.

2. Amorphous Solids

The solids in which the atoms do not have a definite arrangement are called the amorphous solids. They are also called the glassy solids. e.g. glass, rubber, plastic, power, etc are the amorphous solids.

They do not have a definite arrangement of its atoms, i.e. they do not have a characteristic geometrical shape.

They do not have a definite melting point.

They are isotropic, *i.e.,* their physical properties such as conductivity of heat refractive index etc, are same in all the directions.

They are not the real solids.

Classification of Solids on the Basis of Conductivity

(i) **Conductor** Conductors are those substances through which electricity can pass easily, e.g. all metals are conductors.

(ii) **Insulator** Insulators are those substances through which electricity cannot pass, e.g. wood, rubber, mica etc.

(iii) **Semiconductor** Semiconductors are those substances whose conductivity lies between conductors and insulators, *e.g.*, germanium, silicon, carbon etc.

Energy Bands of Solids

There are following energy bands in solids

(i) **Energy Band** In a crystal due to interatomic interaction valence electrons of one atom are shared by more than one atom in it. Thus, splitting of energy levels takes place. So, the collection of these closely spaced energy levels is called an energy band.

(ii) **Valence Band** This energy band contains valence electrons. This band may be partially or completely filled with electrons but never be empty.

The electrons in this band are not capable of gaining energy from external electric field to take part in conduction of current.

(iii) **Conduction Band** This band contains conduction electrons. This band is either empty or partially filled with electrons.

Electrons present in this band take part in the conduction of current.

(iv) **Forbidden Band** This band is completely empty. As temperature increases, forbidden energy gap decreases.

Note The minimum energy required to shift an electron from valence band to conduction band is called band gap (E_g).

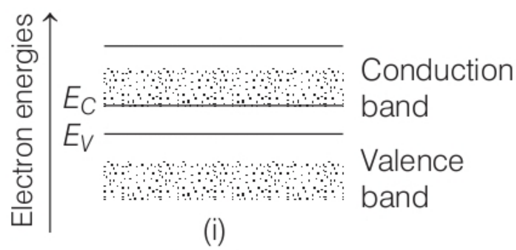
Classification of Solids on the Basis of Energy Bands

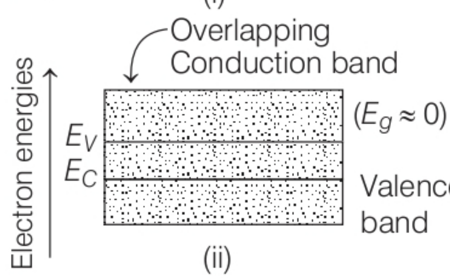
Depending on whether the energy band gap is zero, large or small, the solids may be classified into conductors, insulators and semiconductors, as explained below

1. **Conductors (Metals)**

In case of metals either the conduction band is partially filled and valence band is partially empty, or conduction band and valence band overlap In case of overlaping electrons from valence band can easily move into conduction band, thus large number of electrons available for conduction. In case valence band is empty, electrons from its lower level can move to higher level making conduction possible.

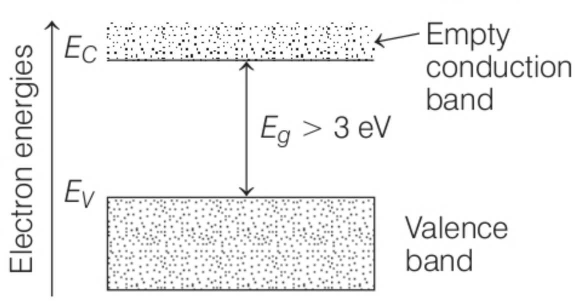
This is the reason why resistance of metals is low or the conductivity is high.





2. **Insulators**

In insulators, the valence band is completely filled whereas the conduction band is completely empty. As there is no electron in conduction band so no electrical conduction is possible. The energy gap between conduction band and valence band is so large ($E_g > 3$ eV) that no electron in valence band can be provided so much energy from any external source that it can jump this energy gap.



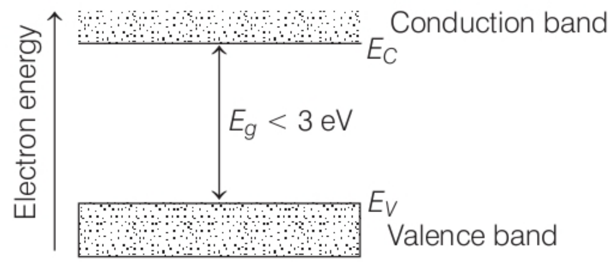
3. **Semiconductors**

The energy band structure of a semiconductor is shown in figure. It is similar to that of an insulator but with a comparatively small energy gap ($E_g < 3\text{eV}$). At absolute zero temperature, the conduction band of semiconductors is totally empty and valence band is completely filled.

Therefore, they are insulators at low temperatures.

However, at room temperature, some electrons in the valence band acquire thermal energy greater than energy band gap and jump over to the conduction band where they are free to move under the influence of even a small electric field and acquire small conductivity.

Hence the resistance of semiconductor is not as high as that of insulators.



Types of Semiconductor

(i) **Intrinsic Semiconductor** A semiconductor in its pure state is called intrinsic semiconductor.

(ii) **Extrinsic Semiconductor** A semiconductor doped with a suitable impurity to increase its conductivity is called extrinsic semiconductor.

On the basis of doped impurity extrinsic semiconductors are of two types

- ***n*-type Semiconductor** Extrinsic semiconductor doped with pentavalent impurity like As, Sb, Bi, etc in which negatively charged electrons works as charge carrier, is called n-type semiconductor. Every pentavalent impurity atom donate one electron in the crystal, therefore it is called a doner atom.
- ***p*-type Semiconductor** Extrinsic semiconductor doped with trivalent impurity like Al, B, etc, in which positively charged holes works as charge carriers, is called p-type semiconductor. Every trivalent impurity atom have a tendency to accept one electron, therefore it is called an acceptor atom.

In a doped semiconductor $n_e n_h = n_i^2$, where n_e and n_h are the number density of electrons and holes and n_i is number density of intrinsic carriers, i.e. electrons or holes.

In n-type semiconductor, $n_e >> n_h$

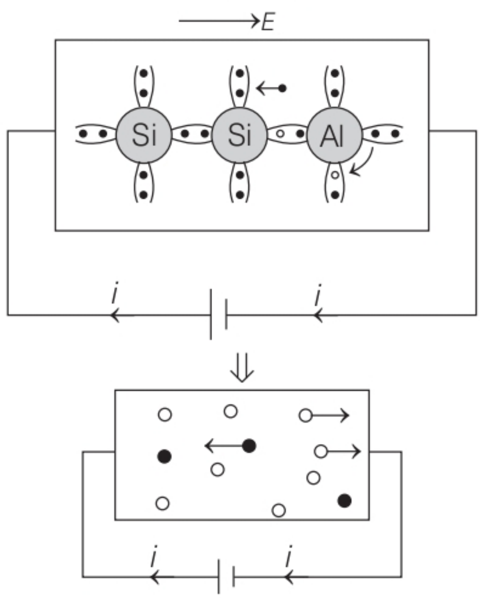
In p-type semiconductor, $n_h >> n_e$

Electrical Conduction through Semiconductors

When a battery is connected across a semiconductor (whether intrinsic or extrinsic) a potential difference is developed across its ends. Due to the potential difference an electric field is produced inside the semiconductors. A current (although very small) starts flowing through the semiconductor. This current may be due to the motion of (i) free electrons (i_e) and (ii) holes (i_h). Electrons move in opposite direction of electric field while holes move in the same direction.

The motion of holes towards right (in the figure) take place because electrons from right hand side come to fill this hole creating a new hole in their own position. Thus, we can say that holes are moving from left to right. Thus, current in a semiconductor can be written as,

$$i = i_e + i_h$$



But it should be noted that mobility of holes is less than the mobility of electrons.

Conductivity of semiconductors is given, $\sigma = n_e e\mu_e + n_h e\mu_h$

where n_e and n_h are densities of conduction electrons and holes respectively and μ_e and μ_h are their respective mobilities.

where, $\mu_e = \frac{V_e}{E}, \mu_n = \frac{V_h}{e}$

Electrical conductivity of extrinsic semiconductor is given by

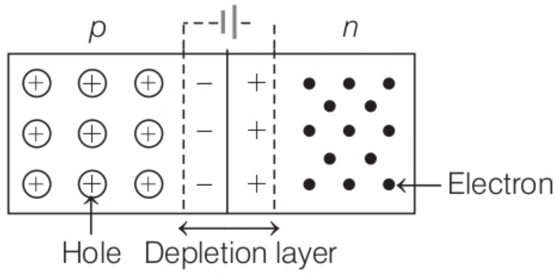
$$\sigma = \frac{1}{\rho} = e\,(n_e \mu_e + n_h \mu_h)$$

where ρ is resistivity, μ_e and μ_h are mobility of electrons and holes respectively.

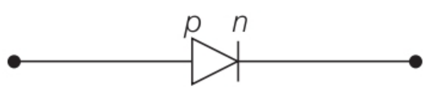
Note Energy gap for Ge is 0.72 eV and for Si it is 1.1 eV.

p-n Junction and diode

An arrangement consisting a p-type semiconductor brought into a close contact with n-type semiconductor, is called a p-n junction.



However, if this junction is provided with metallic contacts at the ends for the application of external voltage, then it is called p-n junction diode.



p-n junction diode

Terms Related to p-n Junction and diode

(i) **Depletion Layer** At p-n junction a region is created, where there is no charge carriers. This region is called depletion layer.

The width of this region is of the order of 10^{-6} m.

(ii) **Potential Barrier** The potential difference across the depletion layer is called potential barrier.

Barrier potential for Ge is 0.3 V and for Si is 0.7 V.

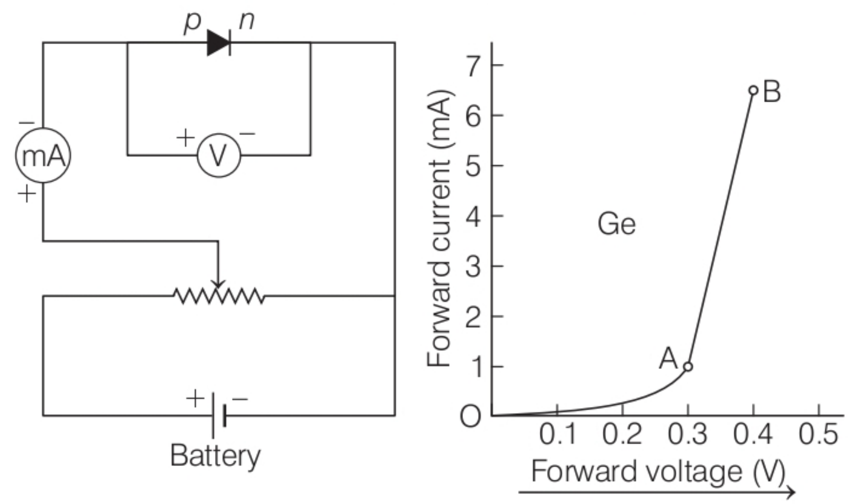
(iii) **Forward Biasing** In this biasing, the p-side is connected to positive terminal and n-side to negative terminal of a battery. In this biasing, forward current flows due to majority charge carriers. The width of deplation layer decreases.

(iv) **Reverse Biasing** In this biasing, the p-side is connected to negative terminal and n-side to positive terminal of a battery. In this biasing, reverse current flows due to minority charge carriers. The width of depletion layer increases.

Voltage-Current Characterstic Curve of a p-n Junction Diode

1. **Forward Biased Characterstics**

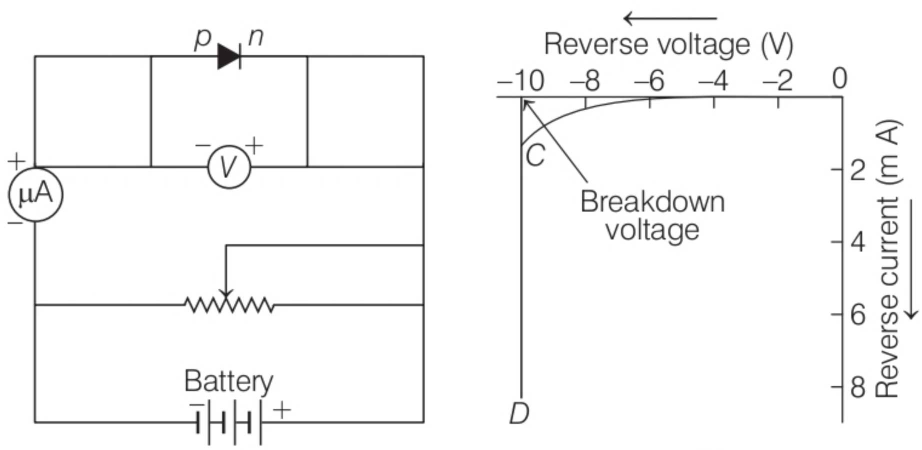
The forward current *versus* forward voltage plot is as shown below



Note The forward voltage beyond which the current through the junction starts increasing rapidly with voltage is called the threshold or knee voltage .

2. **Reverse Biased Characterstics**

The reverse current *versus* reverse voltage plot is as shown below



(a) (b)

The reverse current at a certain point is voltage independent upto certain voltage known as **breakdown voltage** and this voltage independent current is called reverse saturation current.

If the reverse biased voltage is too high, then *p*-*n* junction diode breaks. It is if two types

(a) **Zener Breakdown**

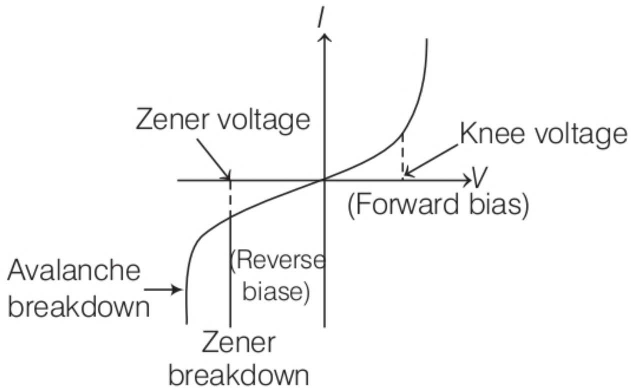
With the increase in reverse biased voltage **E** across the junction. also increases, At some point this breaks the covalent bond. Thus, increasing the number of charge carriess, causing large current to flow.

(b) **Avalanche Breakdown**

High reverse biased voltage, leads to high **E** this causes the minority charge carries to acquire high velocity while crossing the junction. These by collision breaksdown the covalent bond generating more carries. Thus, this leads to large current to flow.

Dynamic Resistance

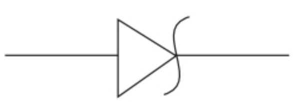
The complete *V-I* characterstic of a junction is shown in the figure below

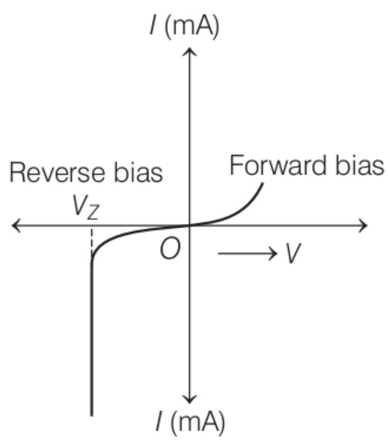


Here, dynamic resistance, $r_d = \dfrac{\Delta V}{\Delta I}$

Zener Diode

It is a reverse biased heavily doped *p-n* junction diode. It is operated in breakdown region. Its symbol and *V-I* characterstic is shown below as



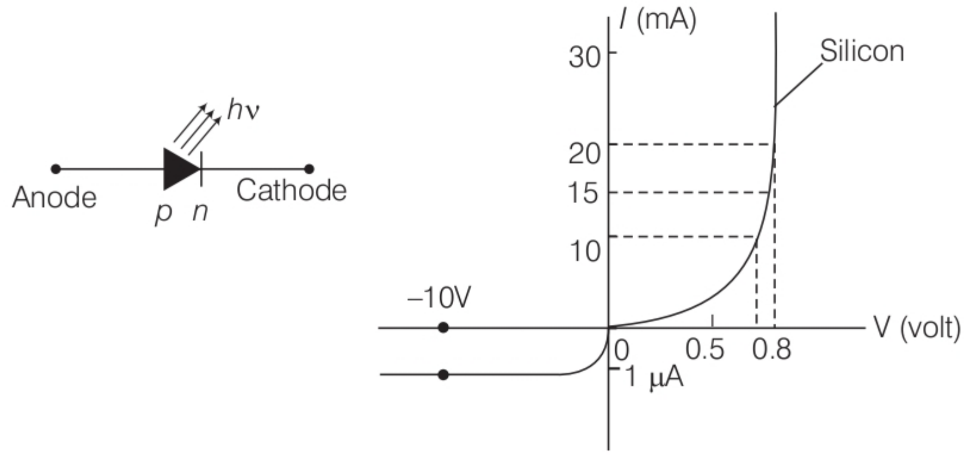


It is also used a voltage regulator.

Light Emitting Diodes (LED)

It is forward biased *p-n* junction diode which emits light when recombination of electrons and holes takes place at the junction.

If the semiconducting material of *p-n* junction is transparent to light, the light is emitting and the junction becomes a light source, i.e. Light Emitting Diode (LED). Its symbol and *V-I* characterstic is shown below as



The colour of the light depends upon the types of material used in making the semiconductor diode.

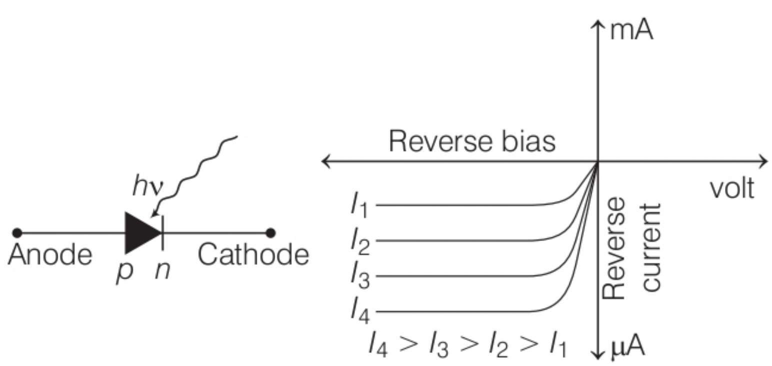
(i) Gallium – Arsenide (Ga-As) – Infrared radiation

(ii) Gallium – Phosphide (GaP) – Red or green light

(iii) Gallium – Arsenide – Phosphide (GaAsP) – Red or yellow light

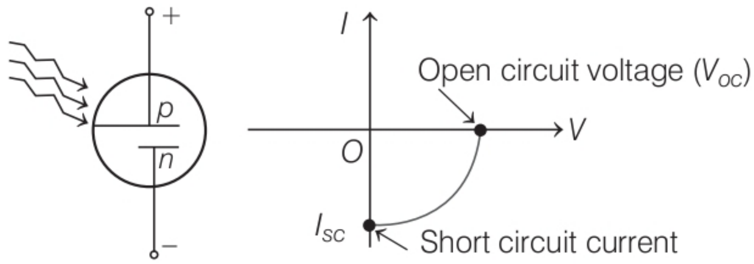
Photodiode

A photodiode is a special type of junction diode used for detecting optical signals. It is a reverse biased *p-n* junction made from a photosensitive material. In photodiode, current carriers are generated by photons through photo excitation. Its symbol and *V-I* characterstic is shown below



Solar Cell

Solar cell is a *p-n* junction diode which converts solar energy into electrical energy. Its symbol and *V-I* characterstic is shown below

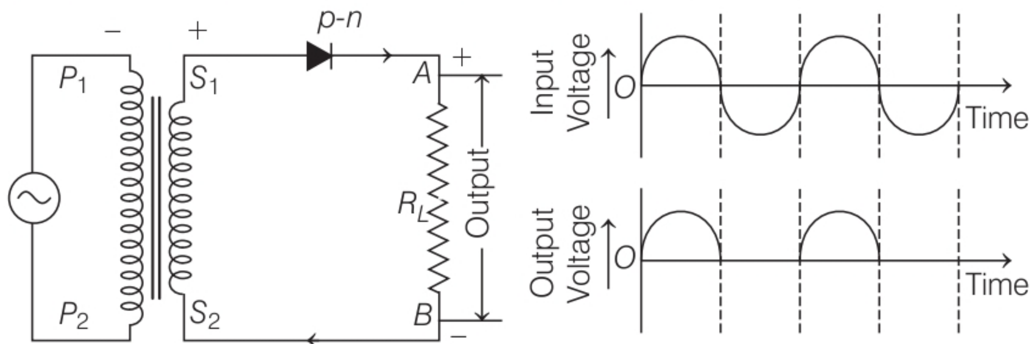


p-n Junction Diode as Rectifier

A device which converts alternating current or voltage into direct current or voltage is known as rectifier. The process of converting AC into DC is called **rectification**.

Half-Wave Rectifier

A half-wave rectifier converts the half cycle of applied AC signal into DC signal. Ordinary transformer may be used here.

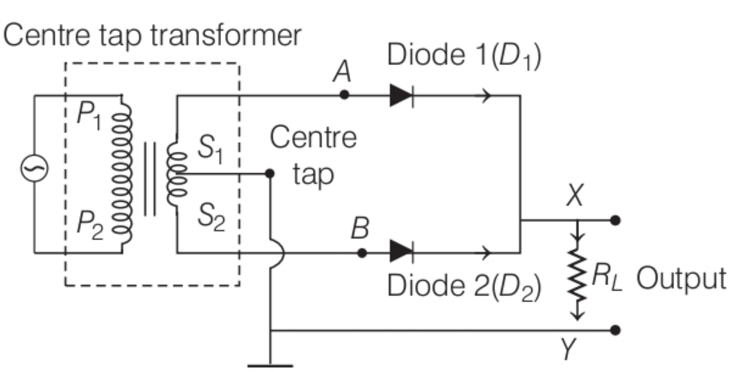


(a) (b)

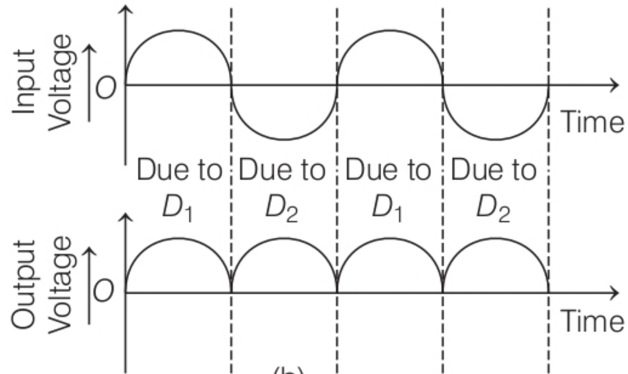
The ripple frequency (ω) for half wave rectifier is same as that of input AC.

Full-Wave Rectifier

A full-wave rectifier converts the whole cycle of applied AC signal into DC signal. Centre tap-transformer is used here.



(a)



(b)

The ripple frequency of full-mass rectifier is twice as that of input AC.

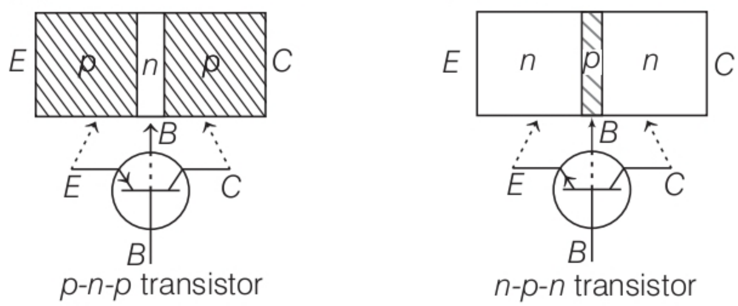
Half-wave rectifier converts only one-half of AC into DC, while full wave rectifier rectifies both halves of AC input.

Transistor

A transistor is an arrangement obtained by growing a thin layer of one type of semiconductor between two thick layers of other similar type semiconductor.

Types of Transistors

(i) *p-n-p* transistor (ii) *n-p-n* transistor



- The left side semiconductor is called **emitter,** the right side semi- conductor is called **collector** and the thin middle layer is called **base**.
- Emitter is highly doped and base is feebly doped.

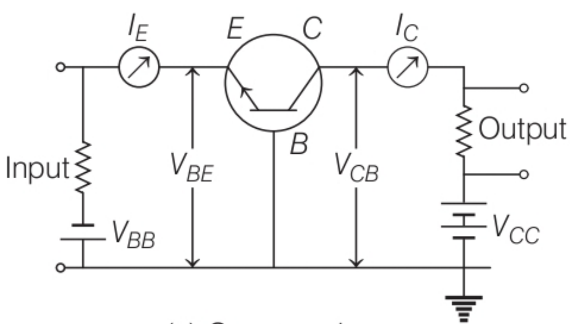
Biasing of a Transistor

It is defined as the process of applying external voltages to the transistors. Different modes of operation of a transistor is given below

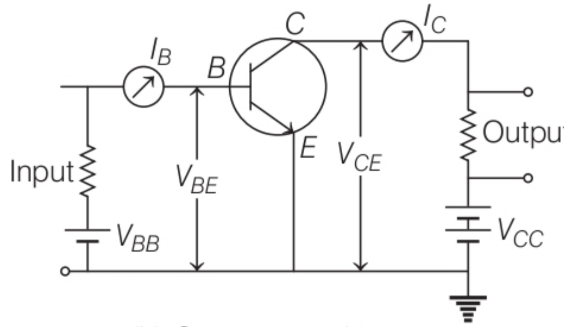
Operating mode	Emitter base bias	Collector base bias
Active	Forward	Reverse
Saturation	Forward	Forward
Cut-off	Reverse	Reverse
Inverse	Reverse	Forward

Transistor Circuit Configurations

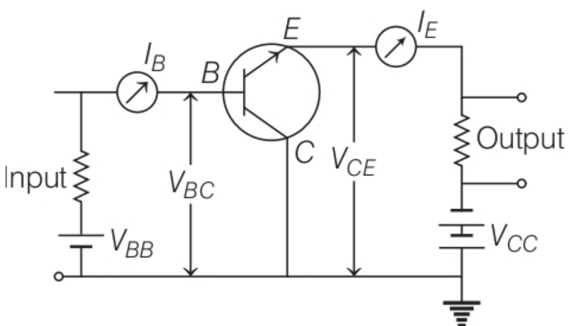
One terminal out of the three terminals of a transistor serves as a reference point for the entire circuit. This terminal should be common to the input and output circuits and is connected to ground. So, a transistor can be used in the following three configurations:



(a) Common-base



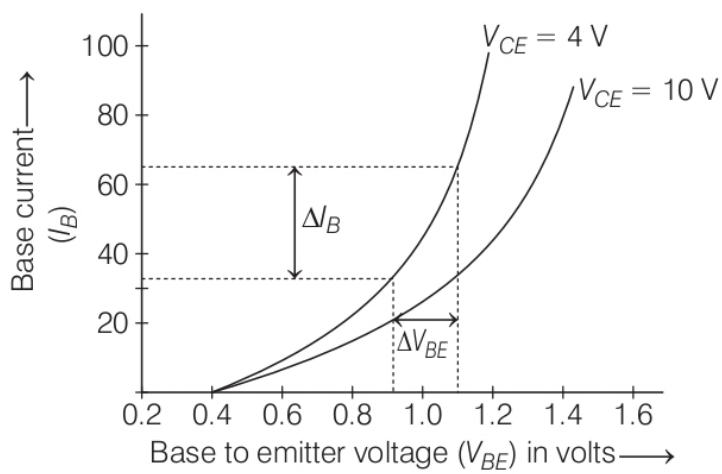
(b) Common-emitter

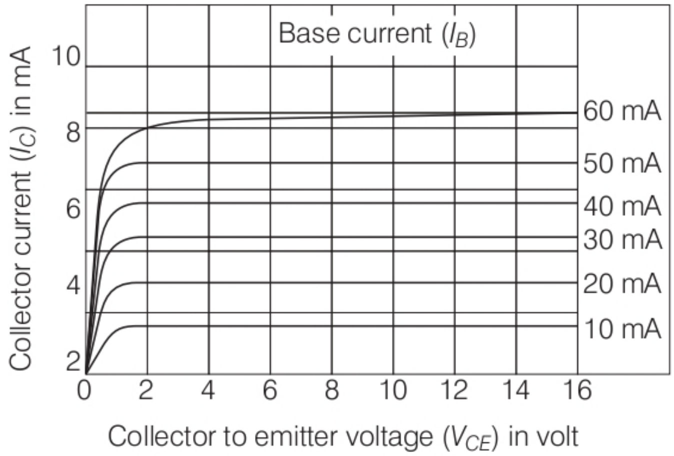


(c) Common-collector

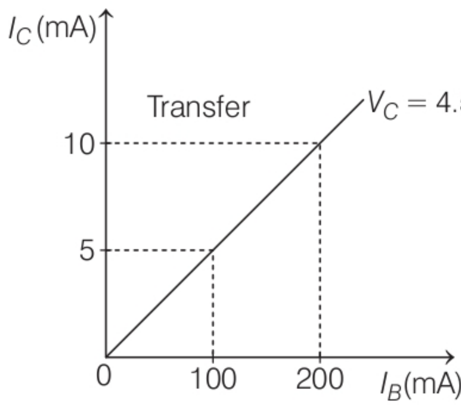
Input characteristics of a CE *n-p-n* transistor

The three types of characterstics curves that can be obtained for the common-emitter configurations are as follows.





Output characteristics of a CE *n-p-n* transistor

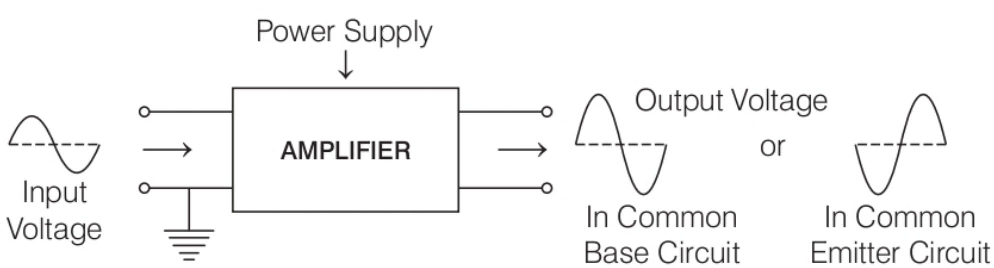


Transistor as an Amplifier

An amplifier is a device which is used for increasing the amplitude of variation of alternating voltage or current or power.

The amplifier thus produces an enlarged version of the input signal.

The general concept of amplification is repesented in figure. There are two input terminals for the signal to be amplified and two output terminals for connecting the load and a means of supplying power to the amplifier.



1. **In Common Base Amplifier**

$$\text{AC current gain } (\alpha_{AC}) = \frac{\Delta I_c}{\Delta I_e}$$

where ΔI_c is change in collector current and ΔI_e change in emitter current.

$$\text{AC voltage gain } (A_V) = \frac{\text{Output voltage}}{\text{Input voltage}} = \alpha_{AC} \times \text{Resistance gain}$$

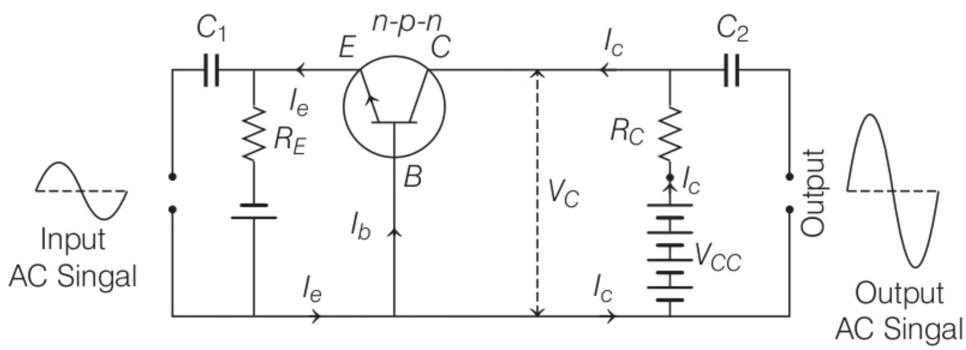
$$= \alpha_{AC} \times \frac{R_o}{R_i}$$

where R_o is output resistance of the circuit and R_i is input resistance of the circuit.

$$\text{AC power gain} = \frac{\text{Change in output power}}{\text{Change in input power}}$$

$$= \text{AC voltage gain} \times \text{AC current gain}$$

$$= \alpha_{AC}^2 \times \text{Resistance gain.}$$



The input and output signals are in the same phase.

There is no amplification in current of a given signal.

There is an amplification in voltage and power of the given signal.

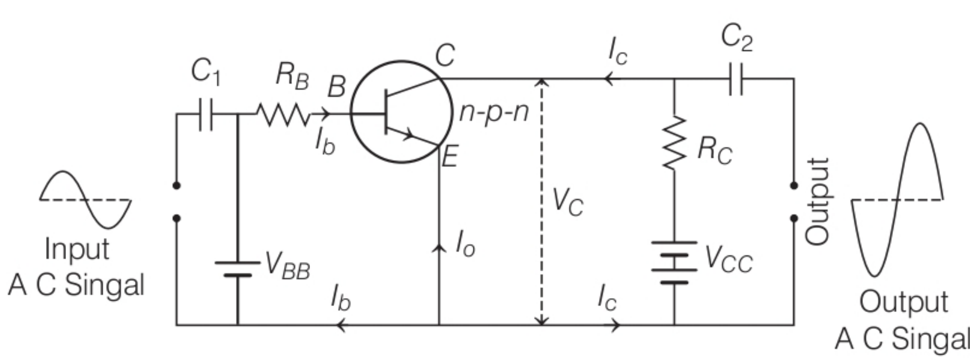
2. **In Common Emitter Amplifier**

$$\text{AC current gain } (\beta_{AC}) = \frac{\Delta I_c}{\Delta I_b}$$

where ΔI_c is change in collector current, and ΔI_b change in base current.

$$\text{AC voltage gain } (A_V) = \beta_{AC} \times \text{resistance gain}$$

$$\text{AC power gain} = \beta_{AC}^2 \times \text{resistance gain}$$



Relation between the current gain of common base and common emitter amplifier, $\beta = \frac{\alpha}{1-\alpha} = \frac{I_c}{I_b}$

The input and output signals are out of phase by π or 180°.

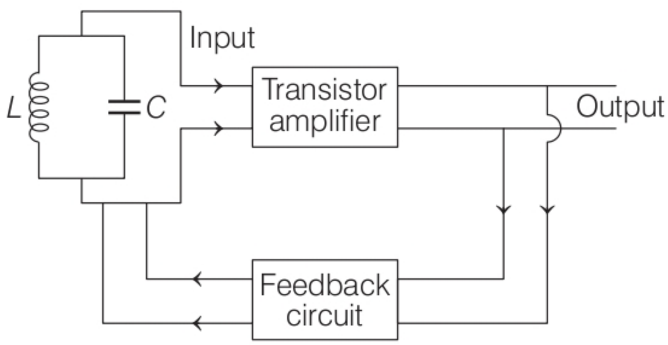
There is amplification in current, voltage and power of the given signal.

Transistor as an Oscillator

An oscillator is an electronic device which produces electric oscillation of constant frequency and amplitude, without any externally applied input signal. It converts DC energy obtained from a battery into AC energy.

Principle of an oscillator

Figure shows the block diagram of an oscillator. An oscillator may be regarded as amplifier which provides its own input signal.

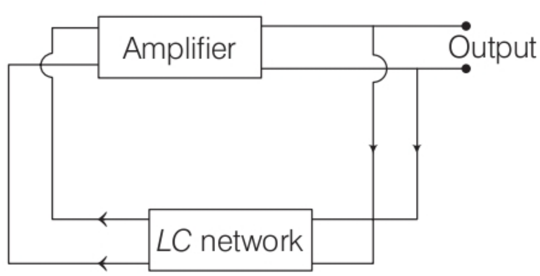


Essential parts of a transistor oscillator are

(i) **Tank Circuit** It is a parallel combination of an inductance L and a capacitance C. The frequency of electric oscillations in the tank circuit is $f = \frac{1}{2\pi\sqrt{LC}}$

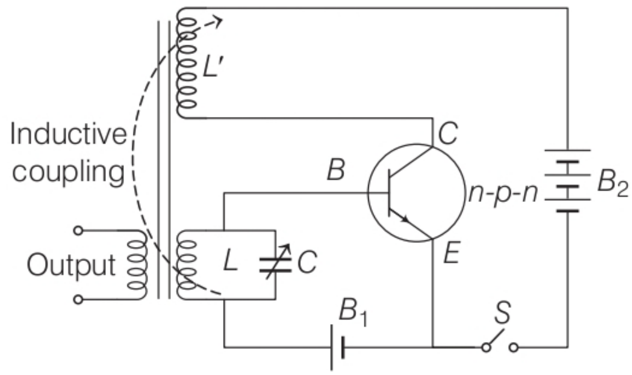
(ii) **Transistor Amplifier** The amplifier receives the oscillations from the tank circuit and amplifies it.

(iii) **Feedback Circuit** It returns a part of the output power of the transistor amplifier to the tank circuit and produces undamped oscillations. This process is called positive feedback.



Construction

A basic circuit using a common-emitter *n-p-n* transistor as an oscillator is given below. A tank circuit (*L-C* circuit) is connected in the emitter-base circuit. A small coil *L* called **feedback or tickler** coil is connected in the emitter-collector circuit. The coil *L* is inductively coupled with the coil *L* of the tank circuit.

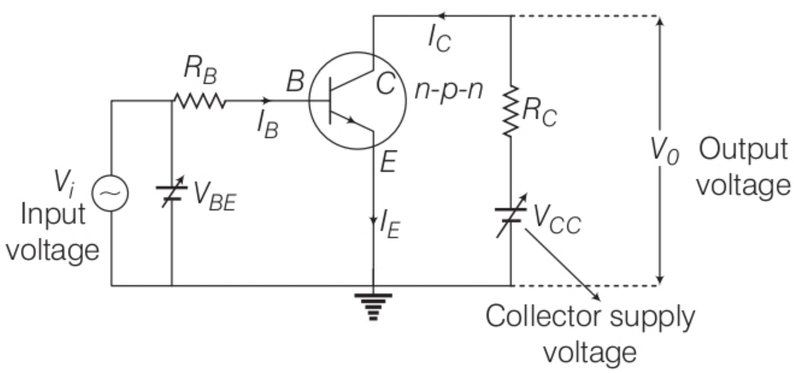


Transistor as a switch

Transistor has an ability to turn things ON and OFF. So, the most common use of transistor in an electronic circuit is as simple switches.

A transistor can be used as a switch because its collector current is directly controlled by the base current.

To understand it properly, letus consider a basic circuit using a common-emitter *n-p-n* transistor as a switch which is given below.



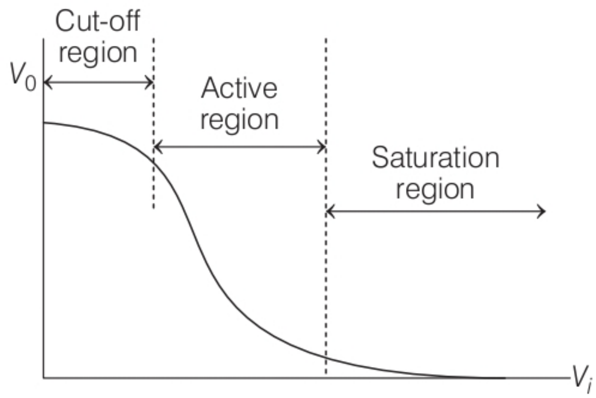
Apply Kirchhoff's voltage rule to the input and output sides of this circuit, we get

$$V_i = I_B \cdot R_B + V_{BE} \qquad (V_i = \text{DC input voltage})$$

and $$V_o = V_{CC} - I_C \cdot R_C \quad (V_i = \text{DC output voltage})$$

In case of silicon transistor, if $V_i < 0.6\,\text{V}$, I_B will be zero, hence, I_C will be zero and transistor will operate in **cut-off state,** and $V_0 = V_{CC}$.

When $V_i > 0.6\,\text{V}$, some I_B flows, so some I_C flows and transistor will now operate in **active state** and hence output V_0 decreases as the term $I_C R_C$ increases. With increase in V_i, the I_C increases almost linearly and hence V_0 decreases linearly till its value becomes less than about 1 volt.



Beyond this, the change becomes non-linear and transistor now goes into the saturation state. When V_i is further increased, V_0 is found to decrease towards zero (however, it may never become to zero).

Now the operation of transistor as a switch can be understood in the following way. When V_i is low (in cut-off region), V_0 is high. If V_i is high (in saturation region), then V_0 is low, almost zero.

Logic Gate

A digital circuit which allows a signal to pass through it, only when few logical relations are satisfied, is called a logic gate.

Truth Table

A table which shows all possible input and output combinations is called a truth table.

Boolean Expression

It is the expression for showing the combination of two boolean variables resulting into a new boolean variable.

- The Boolean expression obey commutative law associative law as well as distributive law.

  (i) $A + B = B + A$

  (ii) $A \cdot B = B \cdot A$

  (iii) $A + (B + C) = (A + B) + C$

- de-Morgan's theorems

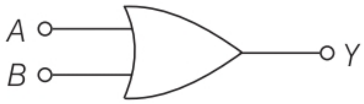
  (i) $\overline{A + B} = \overline{A} \cdot \overline{B}$

  (ii) $\overline{A} \cdot \overline{B} = \overline{A} + \overline{B}$

Basic Logic Gates

(i) **OR Gate** It is a two input and one output logic gate.

Symbol



Truth table

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

Boolean expression $Y = A + B$ (Y equals A OR B)

(ii) **AND Gate** It is a two input and one output logic gate.

Symbol

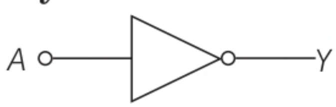
Truth table

A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

Boolean expression $Y = A \cdot B$ (Y equals A AND B)

(iii) **NOT Gate** It is a one input and one output logic gate.

Symbol



Truth table

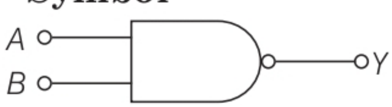
A	$Y = \overline{A}$
0	1
1	0

Boolean expression $Y = \overline{A}$ (Y equals NOT A)

Combination of Gates

(i) **NAND Gate** When output of AND gate is applied as input to a NOT gate, then it is called a NAND gate.

Symbol



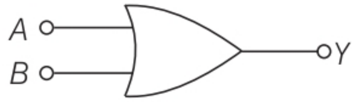
Truth table

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

Boolean expression $Y = \overline{A \cdot B}$ (Y equals negated of A AND B)

(ii) **NOR Gate** When output of OR gate is applied as input to a NOT gate, then it is called a NOR gate.

Symbol



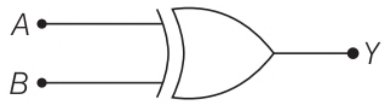
Truth table

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

Boolean expression $Y = \overline{A + B}$ (Y equals negated of A OR B)

(iii) **XOR gate** It is also called exclusive or function

Symbol



Truth table

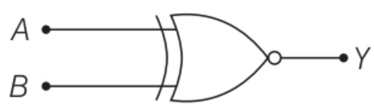
A	B	$\overline{A}$	$\overline{B}$	$A \cdot \overline{B}$	$\overline{A} \cdot B$	$A = A \cdot \overline{B} + \overline{A} \cdot B$
0	0	1	1	0	0	0
0	1	1	0	0	1	1
1	0	0	1	1	0	1
1	1	0	0	0	0	0

Boolean expression

$$Y = A \text{ XOR } B \quad \text{or} \quad Y = A \oplus B \quad \text{or} \quad Y = \overline{A}B + A\overline{B}$$

(iv) **XNOR gate** It is also called exclusive NOR function.

Symbol



Truth table

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

Boolean expression

$$Y = A \,\text{u}\, B \quad \text{or} \quad Y = \overline{A}\overline{B} + AB$$