1.1 Classification of Metals, Semiconductors and Insulators

On the basis of the relative value of electrical conductivity (σ) or resistivity $\left(\rho = \frac{1}{\sigma}\right)$, the solids are broadly classify as

- **Metals** They possess very low resistivity or high conductivity.

$$\rho \sim 10^{-2}\text{-}10^{-8}\,\Omega\text{m},\quad \sigma \sim 10^{2}\text{-}10^{8}\,\text{Sm}^{-1}$$

- **Semiconductors** They have resistivity or conductivity intermediate to metals and insulators.

$$\rho \sim 10^{-5}\text{-}10^{-6}\,\Omega\text{m},\quad \sigma \sim 10^{-5}\text{ to }10^{0}\,\text{Sm}^{-1}$$

- **Insulators** They have high resistivity or low conductivity.

$$\rho \sim 10^{11}\text{-}10^{19}\,\Omega\text{m},\quad \sigma \sim 10^{-11}\text{-}10^{-19}\,\text{Sm}^{-1}$$

Types of Semiconductors on the basis of their chemical composition are given below

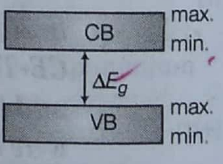
(*i*) **Elemental Semiconductors** These semiconductors are available in natural form, e.g. silicon and germanium.

(*ii*) **Compound Semiconductors** These semiconductors are made by compounding the metals, e.g. CdS, GaAs, CdSe, InP, anthracene, polyaniline, etc.

1.2 Energy Band

In a crystal due to interatomic interaction, valence electrons of one atom are shared by more than one atom. Now, splitting of energy level takes place. The collection of these closely spaced energy levels are called an energy band.

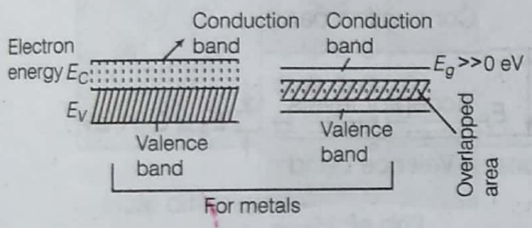
- **Valence Band** Valence band is the highest energy band which includes the energy levels of the valence electrons.
- **Conduction Band** Conduction band is the energy band above the valence band. The lowest unfilled allowed energy band next to valence band is called conduction band.
- **Energy Band Gap** The minimum energy required for shifting electrons from valence band to conduction band is called energy band gap (E_g).
- **Forbidden Energy Gap** (ΔE_g) Energy gap between conduction band and valence band, $\Delta E_g = (\text{CB})_{\text{min}} - (\text{VB})_{\text{max}}$

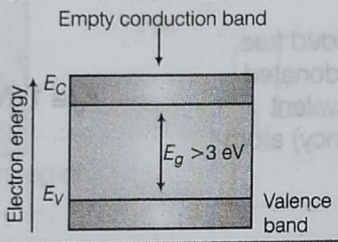


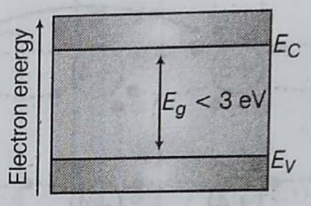
- **Fermi Energy** The highest energy level in the conduction band filled up with electrons at absolute zero is called **Fermi level** and the energy corresponding to the Fermi level is called **Fermi Energy**. It is the maximum possible energy possessed by free electrons of a material at absolute zero temperature (i.e. 0 K).

Differences between conductor, insulator and semiconductor on the basis of energy bands

Conductor (Metal)	**Insulator**	**Semiconductor**
In conductor, either there is no energy gap between the conduction band which is partially filled with electrons and valence band or the conduction band and valence band overlap each other.	In insulator, the valence band is completely filled, the conduction band is completely empty and energy gap is quite large that small energy from any other source cannot overcome it.	In semiconductor also, like insulators the valence band is totally filled and the conduction band is empty but the energy gap between conduction band and valence band, unlike insulators is very small.
Thus, many electrons from below the fermi level can shift to higher energy levels above the fermi level in the conduction band and behave as free electrons by acquiring a little more energy from any other sources.	Thus, electrons are bound to valence band and are not free to move and hence, electric conduction is not possible in this type of material.	Thus, 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.







1.3 Semiconductors

Semiconductors are the materials whose conductivity lies between metals and insulators. They are characterised by narrow energy gap $(\sim 1\,\text{eV})$ between the valence band and conduction band.

Classification of Semiconductor on the Basis of Purity

Intrinsic Semiconductors

It is a pure semiconductor without any significant dopant species present.

$$n_e = n_h = n_i$$

where, n_e and n_h are number densities of electrons and holes respectively and n_i is called intrinsic carrier concentration. An intrinsic semiconductor is also called an **undoped semiconductor** or *i*-type semiconductor.

The total current I is the sum of the electron current I_e and hole current I_h.

$$I = I_e + I_h.$$

where, I_e = electron current, I_h = hole current

Extrinsic Semiconductors

Pure semiconductor when doped with the impurity, it is known as extrinsic semiconductor.

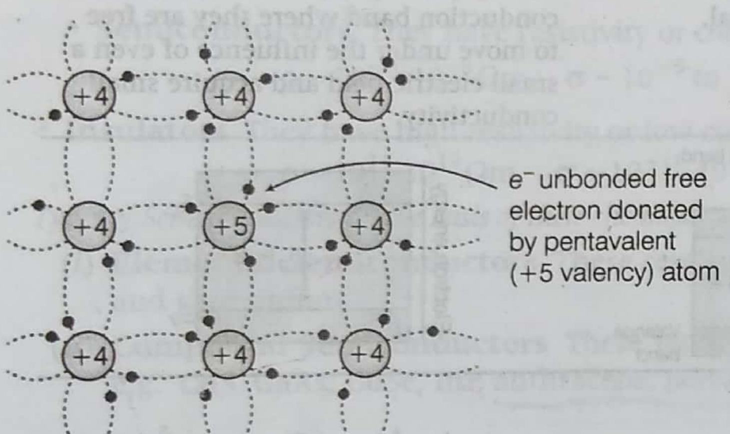
Extrinsic semiconductors are basically of two types:

n-type Semiconductor

In this type of extrinsic semiconductor majority charge carriers are electrons and minority charge carriers are holes, i.e. $n_e > n_h$.

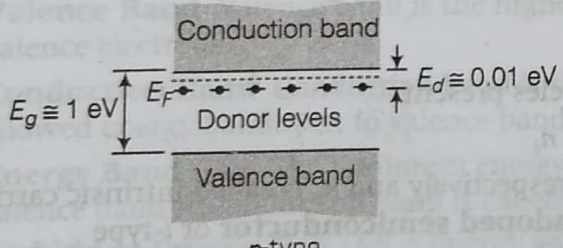
Here, we dope Si or Ge with a pentavalent element, such as As, P or Sb of group V, then four of its electrons bond with the four silicon neighbours, while fifth remains very weakly bound to its parent atom.

Formation of n-type semiconductor is shown below:



Pentavalent donor atom (As, Sb, P, etc.) doped for tetravalent Si or Ge giving n-type semiconductor

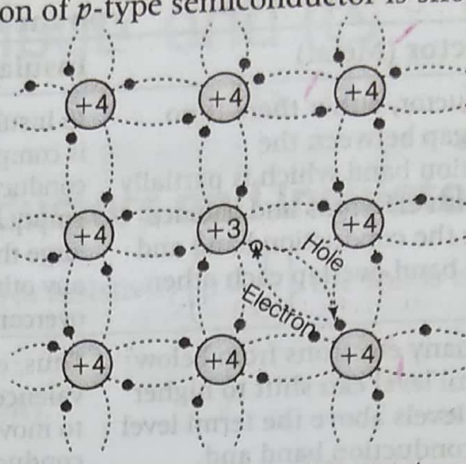
Donor energy level lies just below the conduction band



n-type

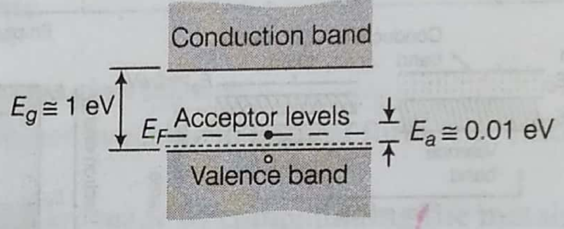
p-type Semiconductor

- In this semiconductor, majority charge carriers are holes and minority charge carriers are electrons i.e. $n_h > n_e$.
- In a p-type semiconductor, doping is done with trivalent impurity atoms. i.e. Those atoms which have three valence electrons in their valence shell.
- Formation of p-type semiconductor is shown below:



Trivalent acceptor atom (In, Al, B, etc) doped in tetravalent Si or Ge lattice giving p-type semiconductor

Acceptor energy level lies just above the valence band



p-type

- At equilibrium condition, $n_e n_h = n_i^2$
- Minimum energy required to create a hole-electron pair, $h\nu \geq E_g$ where, E_g is energy band gap.
  i.e. $E_g = h\nu_{\min} = \dfrac{hc}{\lambda_{\max}}$
- Electric current, $I = eA\,(n_e v_e + n_h v_h)$ where, A is area of cross-section and v_e and v_h are speed of electron and hole respectively.
- Mobility of charge carriers, $\mu = \dfrac{v}{E}$, where E is applied electric field.
  Hence, $v_e = \mu_e E$ and $v_h = \mu_h E$
- Electrical conductivity, $\sigma = \dfrac{1}{\rho} = e\,(\mu_e n_e + n_h \mu_h)$
  where, n_e and n_h are concentration of electron and hole respectively and μ_e and μ_h are mobilities of electron and hole, respectively, applying the formula
  $$I = \frac{V}{R} = \frac{E \times l}{\frac{\rho l}{A}} = \frac{EA}{\rho} = l(n_e v_e + n_h v_h)$$

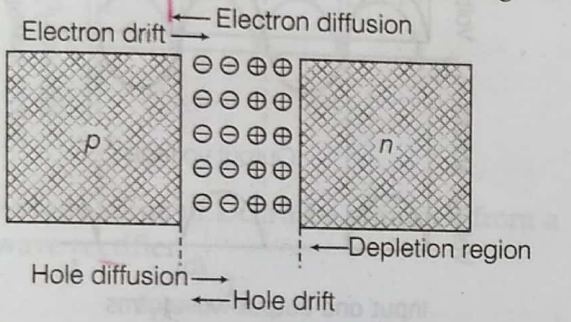
1.4 *p-n* Junction

A *p-n* junction is an arrangement made by a close contact of *n*-type semiconductor and *p*-type semiconductor.

Formation of Depletion Region in *p-n* Junction

During formation of *p-n* junction, due to the concentration gradient across *p* and *n*-sides, holes diffuse from *p*-side to *n*-side($p \to n$) and electrons diffuse from *n*-side to *p*-side ($n \to p$).

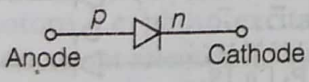
This space charge region on either side of the junction together is known as depletion region.



Depletion region is the small region in the vicinity of the junction which is depleted of free charge carriers. Width of depletion region is of the order of 10^{-6}m. The potential difference developed across the depletion region is called the **potential barrier.**

Semiconductor Diode/ *p-n* Junction Diode

- A semiconductor diode is basically a *p-n* junction with metallic contacts provided at the ends for the application of an external voltage.
- A *p-n* junction diode is represented as

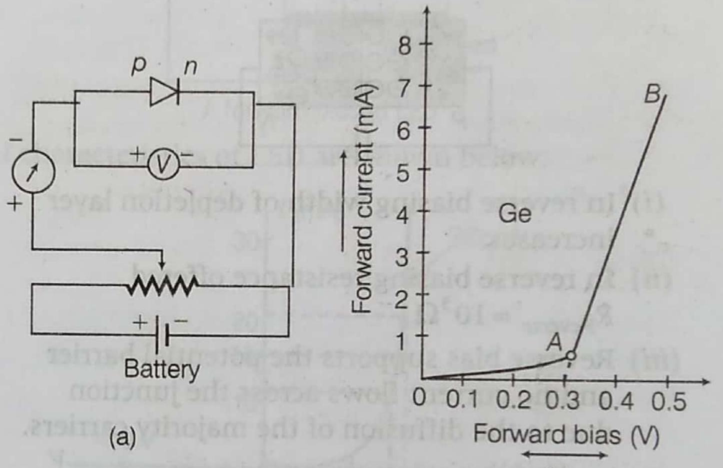


- The direction of arrow indicates the conventional direction of current (when the diode is under forward bias).
- The graphical relations between voltage applied across *p-n* junction and current flowing through the junction are called *I-V*.

I-V (Current-Voltage) Characteristic of *p-n* Junction Diode

Forward Biased Characteristic

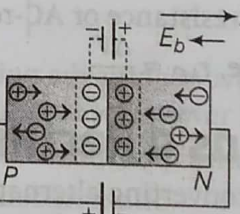
- Junction diode is said to be forward bias when the positive terminal of the external battery is connected to the *p*-side and negative terminal to the *n*-side of the diode.
  Similarly, if the positive terminal of a battery is connected to *n*-side and negative terminal to the *p*-side, then the *p-n* junction is said to be reverse biased. The circuit diagram and *I-V* characteristics of a forward biased diode is shown below:



(a)

(b)

Forward bias



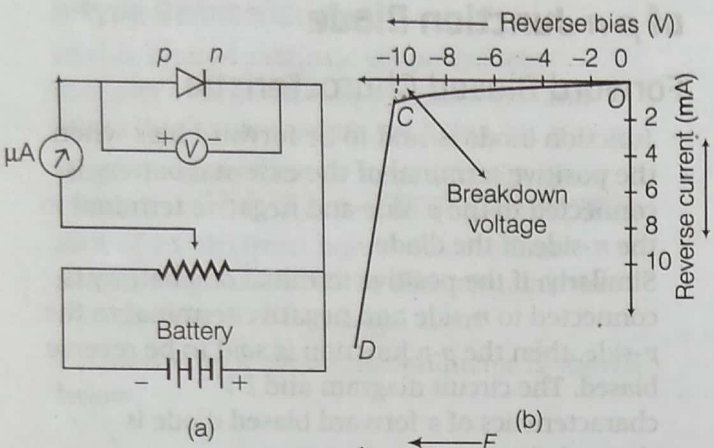
(*i*) In forward biasing width of depletion layer decreases.

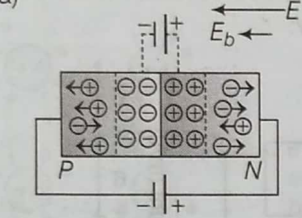
(*ii*) In forward biasing resistance offered $R_{\text{Forward}} \approx 10\Omega - 25\Omega$

Reverse Biased Characteristic

In reverse biased, the applied voltage supports the flow of minority charge carriers across the junction. So, very small current flows across the junction due to minority charge carriers.

The circuit diagram and *I*-*V* characteristics of a reverse biased diode is shown below.





(*i*) In reverse biasing width of depletion layer increases.

(*ii*) In reverse biasing resistance offered $R_{\text{Reverse}} \approx 10^5 \Omega$

(*iii*) Reverse bias supports the potential barrier and no current flows across the junction due to the diffusion of the majority carriers.

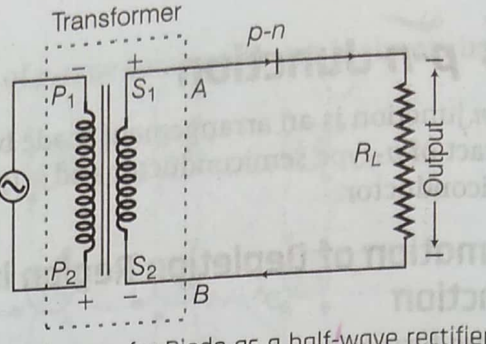
- The DC resistance of a junction diode, $r_{\text{DC}} = \dfrac{V}{I}$
- The dynamic resistance or AC-resistance of junction diode, $r_{\text{AC}} = \dfrac{\Delta V}{\Delta I}$

1.5 Diode as a Rectifier

The process of converting alternating voltage/current into direct voltage/current is called **rectification.** Diode is used as a rectifier for converting alternating current/voltage into direct current/voltage. There are two ways of using a diode as a rectifier i.e.

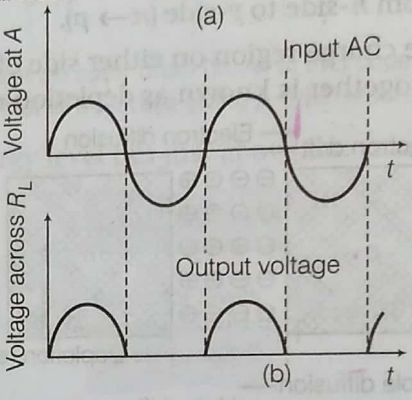
Diode as a Half-Wave Rectifier

Diode conducts corresponding to positive half cycle and does not conduct during negative half cycle. Hence, AC is converted by diode into unidirectional pulsating DC. This action is known as **half-wave rectification.**



Circuit diagram for Diode as a half-wave rectifier

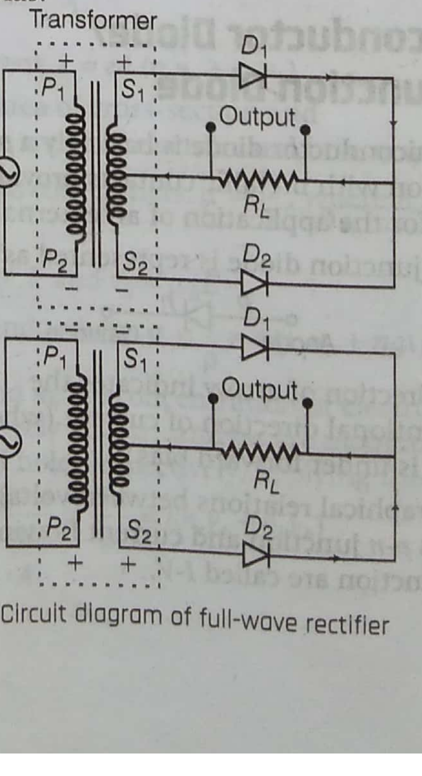
The input and output waveforms have been given below:



Input and output waveforms

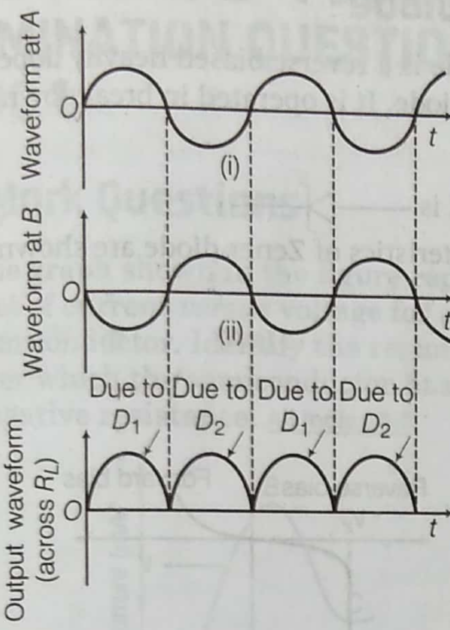
Diode as a Full-Wave Rectifier

In the full-wave rectifier, two *p*-*n* junction diodes, D_1 and D_2 are used. Its working is based on the principle that junction diode offer very low resistance in forward bias and very high resistance in reverse bias.



Circuit diagram of full-wave rectifier

The input and output waveforms have been given below:



- The average value or DC value obtained from a half-wave rectifier,

$$I_{DC} = \frac{I_0}{\pi}$$

- The average value or DC value obtained from a full-wave rectifier,

$$I_{DC} = \frac{2I_0}{\pi}$$

- The pulse frequency of a half-wave rectifier is equal to frequency of AC.
- The pulse frequency of a full-wave rectifier is double to that of AC.

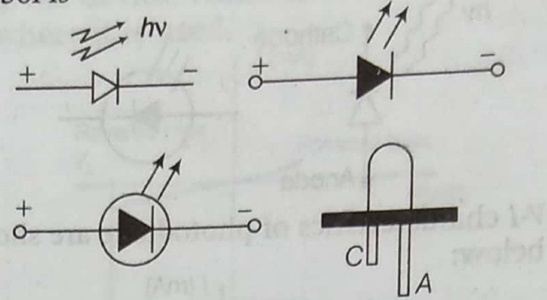
1.6 Optoelectronic Junction Devices

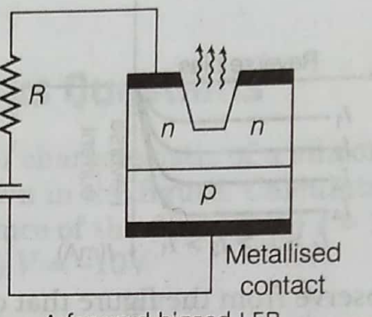
Semiconductor diodes in which carriers are generated by photons. i.e. photo-excitation, such devices are known as optoelectronic devices. These are as follows:

Light Emitting Diode (LED)

It is a heavily doped forward biased *p-n* junction diode which spontaneously converts electrical energy into light energy, like infrared and visible light.

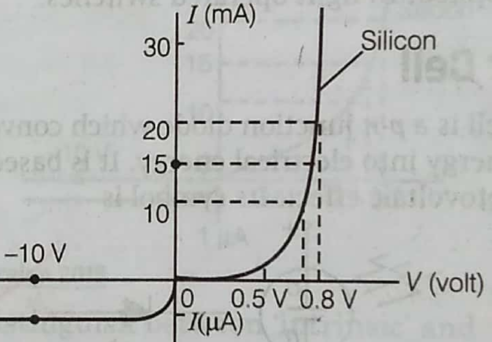
Its symbol is





A forward biased LED

V-I characteristics of LED are shown below:



LEDs has the following advantages over conventional incandescent low power lamps.

(a) Fast action and no warm up time required

(b) It is nearly monochromatic

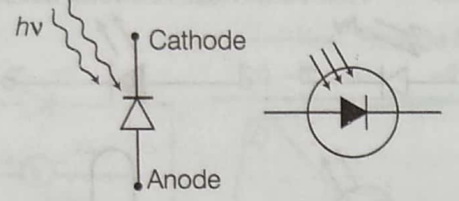
(c) Low operational voltage and less power consumed, long life, ruggedness

(d) Fast ON-OFF switching capability in nanoseconds.

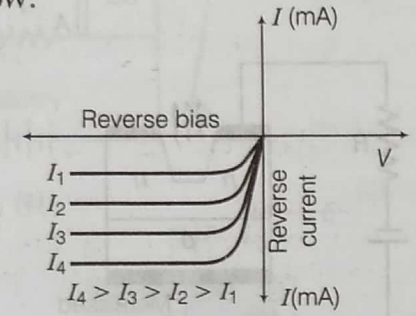
Photodiode

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. Such a way that light can fall on its junction.

Its symbol is



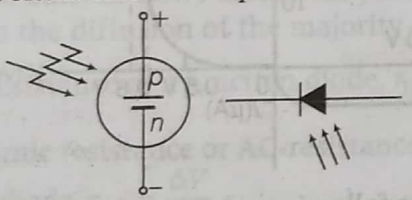
V-I characteristics of photodiode are shown below:



We observe from the figure that current in photodiode changes with the change in light intensity (I), when reverse bias is applied. In light operated switches.

Solar Cell

Solar cell is a *p-n* junction diode which converts solar energy into electrical energy. It is based on the photovoltaic effect. Its symbol is



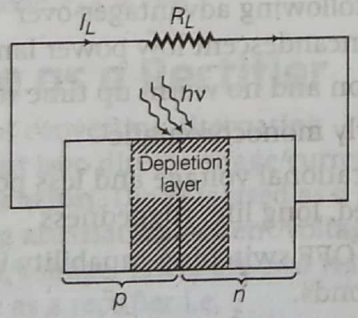
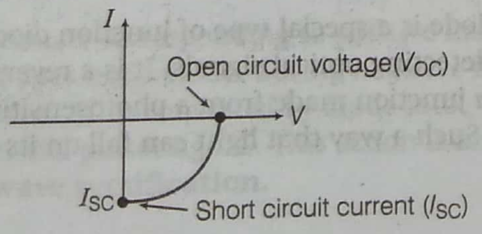


Photo current through an illuminated *p-n* junction

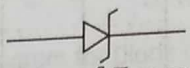
V-I characteristics of solar cell are shown below:



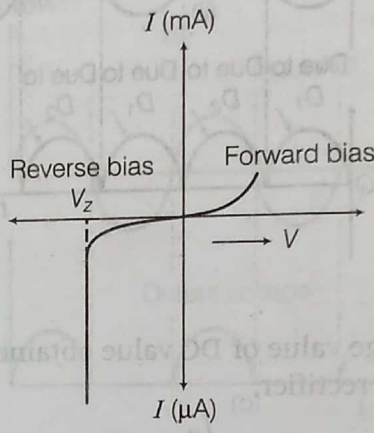
The materials used for solar cell are Si and GaAs.

Zener Diode

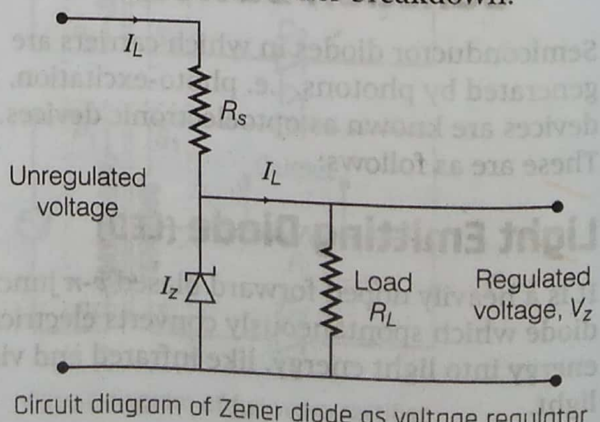
Zener diode is a reverse biased heavily doped *p-n* junction diode. It is operated in breakdown region.

Its symbol is 

V-I characteristics of Zener diode are shown below:



- **Zener Diode as a Voltage Regulator** When the applied reverse voltage (V) reaches the breakdown voltage (V_z) of the Zener diode there is a large change in the current. So, after the breakdown voltage V_z, a large change in the current can be produced by almost insignificant change in the reverse bias voltage i.e. Zener voltage remains constant even though the current through the Zener diode varies over a wide range. The circuital arrangement is shown here.
- This breakdown in a diode due to the band to band tunneling is called Zener breakdown.



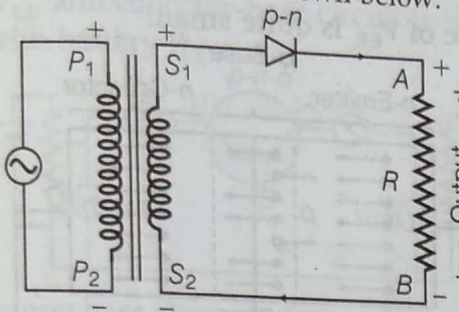
Circuit diagram of Zener diode as voltage regulator

60. (i) Refer to Ans. 52. **(3)**

(ii) Refer to Ans. 46. **(2)**

61. (i) Refer to Ans. 56. **(3)**

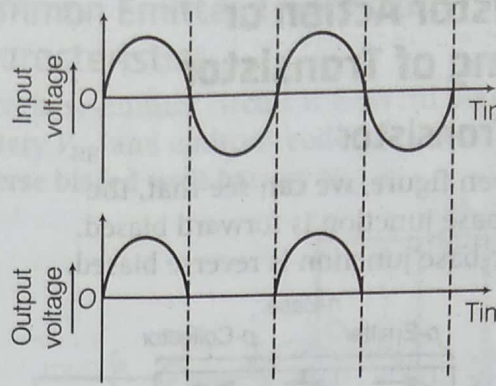
(ii) Circuit diagram of p-n junction diode as half-wave rectifier is shown below:



(1)

Diode conducts corresponding to positive half cycle and does not conduct during negative half cycle, hence AC is converted by diode into unidirectional pulsating DC.

This action is known as half-wave rectification.



(1)

62 (i) Refer to Ans. 52. **(3)**

From these two graphs we see that the junction diodes operates mainly in forward bias, this characteristic of junction diode can be used to make it a rectifier.

(ii) Refer to Ans. 40. **(2)**

[TOPIC 2] Transistors and Its Applications and Logic Gates

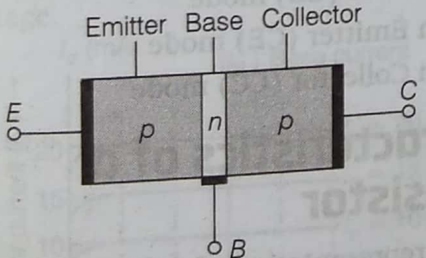
2.1 Junction Transistor

A junction transistor is three terminal semiconductor device consisting of two p-n junctions formed by placing a thin layer of doped semiconductor (p-type or n-type) between two thick similar layers of opposite type.

There are two types of transistor:

p-n-p transistor

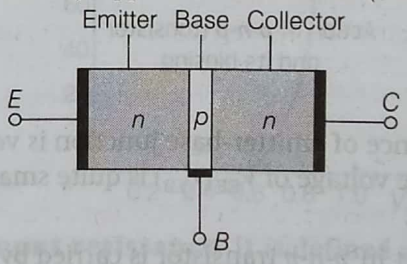
Here, two thicker segments of p-type (termed as emitter and collector) are separated by a segment of n-type semiconductor (base).



p-n-p transistor

n-p-n transistor

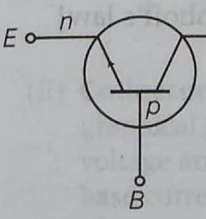
Here, two thicker segments of n-type semiconductor (emitter and collector) are separated by a segment of p-type semiconductor (base).



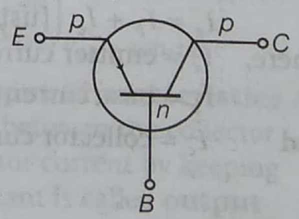
n-p-n transistor

Transistors Schematic Representation

n-p-n transistor



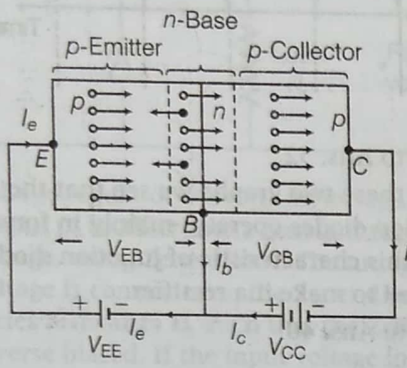
p-n-p transistor



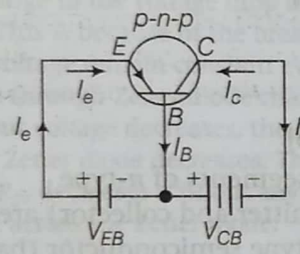
Transistor Action or Working of Transistor

p-n-p Transistor

From given figure, we can see that, the emitter-base junction is forward biased. Collector-base junction is reverse biased.



Flow of charge carriers in *p-n-p* transistor



Action of *p-n-p* transistor and its biasing

The resistance of emitter-base junction is very low. So, the voltage of V_{EE} (V_{EB}) is quite small (i.e., 1.5 V).

The current in *p-n-p* transistor is carried by holes and at the same time their concentration is maintained.

But in external circuit, the current is due to the flow of electrons.

In this case,

$I_e = I_b + I_c$ [using Kirchhoff's law]

where, I_e = emitter current

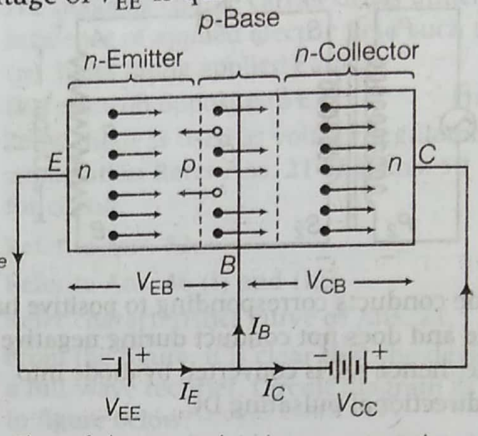
I_b = base current

and I_c = collector current

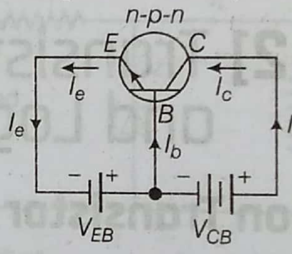
n-p-n Transistor

In the base, I_C and I_C flow in opposite directions. In this transistor, the emitter-base junction is forward biased and its resistance is very low.

So, the voltage of V_{EE} is quite small.



Flow of charge carriers in *n-p-n* transistor



Action of *n-p-n* transistor and its biasing

The collector base junction is reverse biased. The resistance of this junction is very high. So, the voltage of V_{CC} (V_{CB}) is quite large (45 V). In *n-p-n* transistor, the current is carried inside as well as in external circuit by the electrons. Thus, in this $[I_b << I_c]$ case also, $I_E = I_B + I_C$ [Kirchhoff's first law]

In the base, I_E and I_C flow in opposite direction.

Transistors Configuration

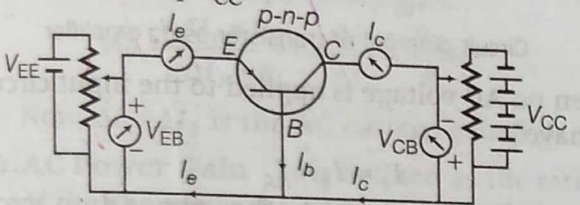
(*i*) Common Base (CB) mode
(*ii*) Common Emitter (CE) mode
(*iii*) Common Collector (CC) mode

2.2 Characteristics of a Transistor

The graphical representation of the variations among the various current and voltage variables of a transistor are called transistor characteristics.

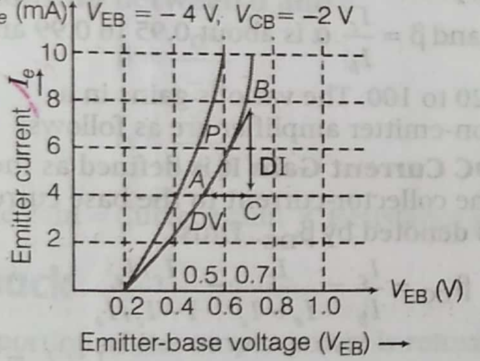
Common Base Transistor Characteristics

Here emitter-base circuit is forward biased with battery V_{EE} and collector-base circuit is reverse biased with battery V_{CC}.

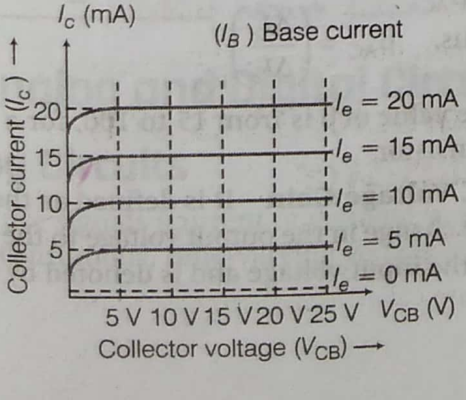


The common base characteristics of a transistor are of two types:

(i) **Emitter or Input Characteristics** A graphical relation between the emitter voltage and emitter current at constant collector voltage, is called emitter or input characteristics. The graph is plotted between emitter current and corresponding emitter voltage.

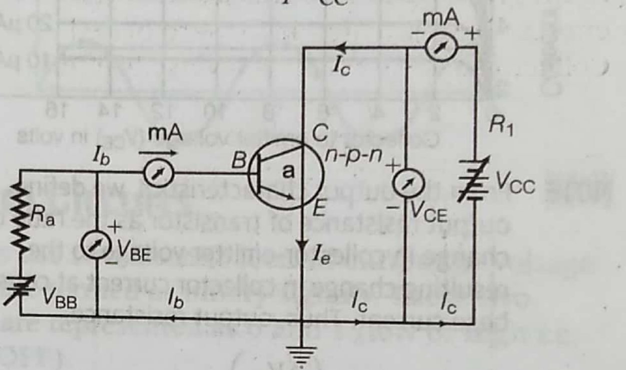


(ii) **Collector or Output Characteristics** A graphical relation between the collector voltage and collector current at constant emitter current, is called collector or output characteristics. The graph is plotted between collector current and corresponding collector voltage.



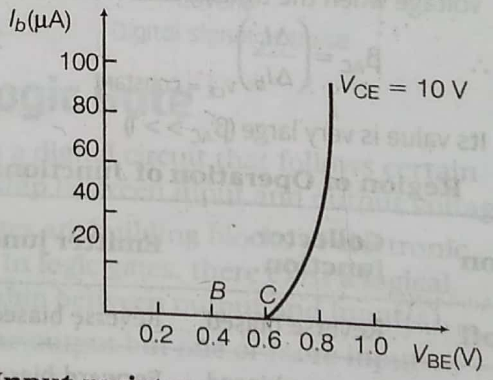
Common Emitter Transistor Characteristics

Here, base-emitter circuit is forward biased with battery V_{BE} and emitter- collector circuit is reverse biased with battery V_{CC}.



These two characteristics can be studied as shown below:

(i) **Emitter or Input Characteristics** A graphical relation between the emitter voltage and the emitter current by keeping collector voltage constant is called **input characteristics** of the transistor.

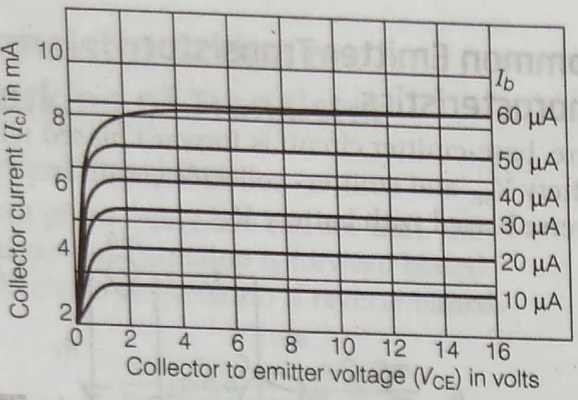


Input resistance It is defined as the ratio of change in base-emitter voltage (ΔV_{BE}) to the resulting change in the base current (ΔI_b) at constant collector-emitter voltage (V_{CE}). It is reciprocal of slope of I_b-V_{BE} curve. Input resistance,

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

$\frac{\Delta V_{BE}}{\Delta I_b}$

(ii) **Collector or Output Characteristics** A graphical relation between the collector voltage and collector current by keeping base current constant is called **output characteristics** of the transistor.



NOTE From the output characteristics, we define output resistance of transistor as the ratio of change in collector-emitter voltage to the resulting change in collector current at constant base current. Thus, output resistance,

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

= Reciprocal of slope of I_c - V_{CE} curve.

The current amplification factor (β) of a transistor in CE configuration is defined as the ratio of change in collector current to the change in base current at a constant collector-emitter voltage when the transistor is in active state.

$$\therefore \quad \beta_{AC} = \left(\frac{\Delta I_c}{\Delta I_b}\right)_{V_{CE} = \text{constant}}$$

Its value is very large ($\beta_{AC} >> 1$)

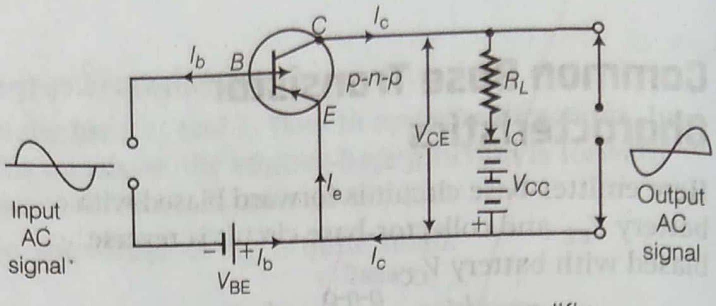
Region of Operation of Junctions

Region	Collector junction	Emitter junction
Cut-off	Reverse biased	Reverse biased
Active	Reverse biased	Forward biased
Saturation	Forward biased	Forward biased

2.3 Transistor as an Amplifier

(CE configuration)

An amplifier is a device which is used for increasing the amplitude of input signal. The circuit diagram for *p-n-p* transistor as an amplifier is shown in the figure given below:



Circuit diagram of transistor as an amplifier

When no AC voltage is applied to the input circuit, we have

$$I_e = I_b + I_c \qquad \ldots\text{(i)}$$

Due to collector current I_c, the voltage drop across load resistance (R_L) is I_cR_L. Therefore, the collector-emitter voltage V_{CE} is given by

$$V_{CE} = V_{CC} - I_CR_L \qquad \ldots\text{(ii)}$$

Gains in Common-Emitter Amplifier

α and β parameters of a transistor are defined as $\alpha = \frac{I_c}{I_e}$ and $\beta = \frac{I_c}{I_b}$. α is about 0.95 to 0.99 and β is about 20 to 100. The various gains in a common-emitter amplifier are as follows:

(*i*) **DC Current Gain** It is defined as the ratio of the collector-current to the base current and is denoted by β_{DC}. Thus,

$$\beta_{DC} = \frac{I_c}{I_b} = \frac{I_c}{I_e - I_c} = \frac{I_c/I_e}{1 - I_c/I_e} \qquad [\because I_e = I_b + I_c]$$

$$\beta = \frac{\alpha}{1-\alpha} \qquad [\because \alpha = I_c/I_e]$$

(*ii*) **AC Current Gain** It is defined as the ratio of the change in the collector-current to the change in the base-current at a constant collector to emitter voltage and is denoted by β_{AC}.

Thus, $\beta_{AC} = \left(\frac{\Delta I_c}{\Delta I_b}\right)_{V_{CE}}$

The value of β is from 15 to 100, for a transistor.

(*iii*) **AC Voltage Gain** It is defined as the ratio of the change in the output voltage to the change in the input voltage and is denoted by A_V.

Suppose, on applying an AC input voltage signal, the input base-current changes by ΔI_b and correspondingly the output collector-current changes by ΔI_c. If R_{in} and R_{out} be the resistances of the input and the output circuits respectively, then

$$A_V = \frac{\Delta I_c \times R_{out}}{\Delta I_b \times R_{in}} = \frac{\Delta I_c}{\Delta I_b} \times \frac{R_{out}}{R_{in}}$$

Now, $\Delta I_c / \Delta I_b$ is the AC current gain β_{AC}.

(*iv*) **AC Power Gain** It is defined as the ratio of the change in the output power to the change in the input power.

Since, power = current × voltage, we have

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

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

$$= \beta_{AC} \times A_V$$

- **Relationship between α and β**

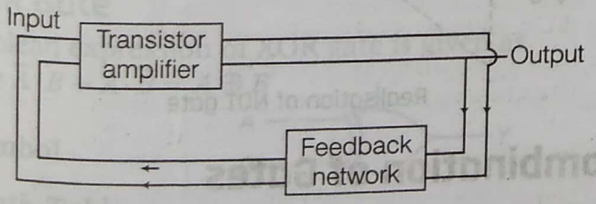
$$\beta = \frac{\alpha}{1-\alpha}$$

and $$\alpha = \frac{\beta}{1+\beta}$$

Voltage gain = Current gain × Resistance gain

Feedback

When a portion of the output power is returned back to the input in phase, this is termed as positive feedback.

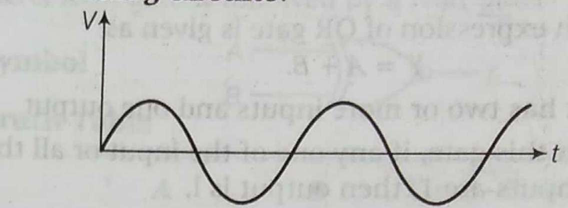


2.4 Analog and Digital Circuits

Analog Circuits

Circuits use signals (current or voltage) in the form of continuous, time-varying voltage or current.

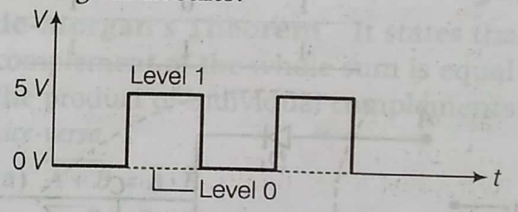
A sinusoidally varying alternating voltage as shown in figure is the simplest analog signal. The electronic circuits which process analog signals are called **analog circuits**.



Digital Circuits

Circuits use two discrete level of current or voltage which are termed as binary signals. These two values are represented as 0 and 1 (low or high i.e. ON or OFF)

The electric circuits which process digital signals are called digital circuits.



Digital signal or pulse

2.5 Logic Gate

A gate is a digital circuit that follows certain relationship between input and output voltage.

Logic gates are building blocks of electronic circuits. In logic gates, there exist a logical relationship between output and input(s).

It has one output but one or more inputs.

- **Truth Table** It is a table that shows all possible input combinations and the corresponding output combinations for a logic gate.
- **Boolean Operators** Just as in ordinary algebra, mathematical operators like addition, subtraction and multiplication are used, similarly, in Boolean algebra three basic operators like OR, AND and NOT are used.
- **Boolean Expression** The expression shows the combination of two Boolean variables that results into a new Boolean variable is known as Boolean expression.

Basic Logic Gates

There are three basic logic gates:

OR Gate

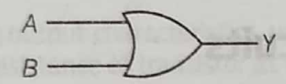
Boolean expression of OR gate is given as

$$Y = A + B.$$

(a) It has two or more inputs and one output.

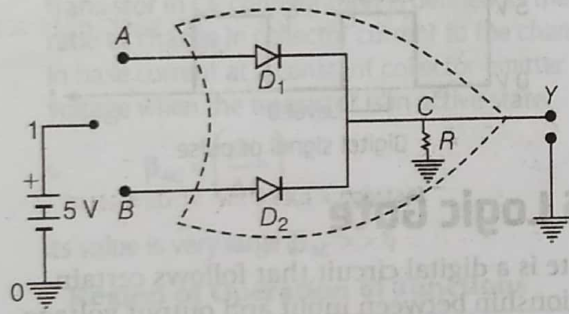
(b) In this gate, if any one of the input or all the inputs are 1, then output is 1.

Symbol



Truth Table

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



Realisation of OR gate

AND Gate

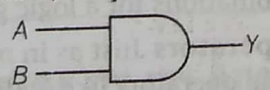
Boolean expression of AND gate is given as

$$Y = A \cdot B$$

(a) It has two or more inputs and one output.

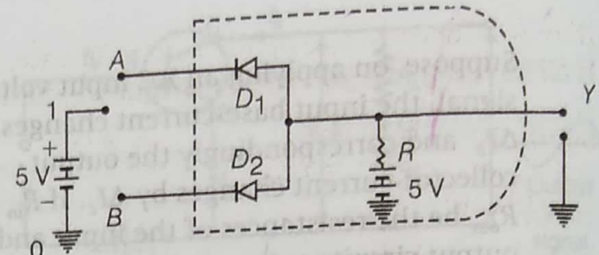
(b) It has output 1, only when all inputs are 1.

Symbol



Truth Table

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



Realisation of AND gate

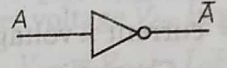
NOT Gate

Boolean expression of NOT gate is given as $Y = \bar{A}$.

(a) It has one input and one output.

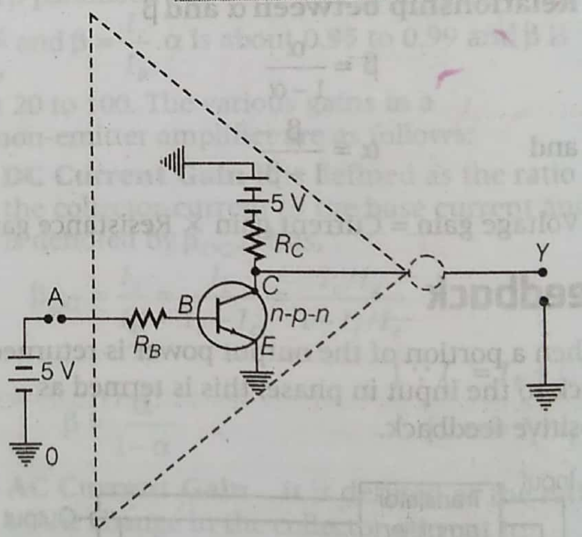
(b) It gives an inverted version of its input i.e. if input is 1, then output is 0 and *vice-versa*.

Symbol



Truth Table

A	Y
0	1
1	0



Realisation of NOT gate

Combination of Gates

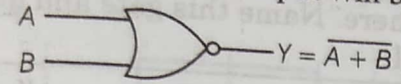
Various combinations of three basic gates can be used to produce complicated digital circuits, which are also called gates. Different combinations of basic gates are given below:

NOR Gate

Boolean expression of NOR gate is given as $Y = \overline{A + B}$.

Here NOT operation is applied after OR gate.
If all its inputs are 0, then its output will be 1.

Symbol



Truth Table

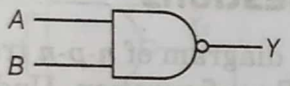
Input		Output
A	B	$Y = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0

NAND Gate (NOT AND)

Boolean expression of NAND gate is given as $Y = \overline{A \cdot B}$.

Here, AND gate followed by a NOT gate.
If all the inputs are 1, then output will be 0.

Symbol



Truth Table

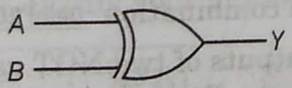
A	B	$Y = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

NAND and NOR gates are called **universal gates.**

XOR Gate

Boolean expression of XOR gate is given as $Y = \overline{A} \cdot B + A \cdot \overline{B} = A \oplus B$

Symbol



Truth Table

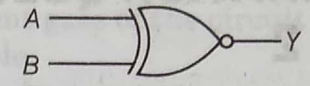
A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

XNOR Gate

Boolean expression of XNOR gate is given as $Y = \overline{A \cdot B} = \overline{AB} + AB$.

Here, XOR gate is followed by a NOT gate.

Symbol



Truth Table

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

Some Useful Laws of Boolean Algebra

(*i*) **de-Morgan's Theorem** It states that the complement of the whole sum is equal to the product of individual complements and *vice-versa.*

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

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

de-Morgan's theorem also states that

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

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

(*ii*) **Commutative laws**

(a) $A + B = B + A$

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

(*iii*) **Associative laws**

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

(b) $A \cdot (B \cdot C) = (A \cdot B) \cdot C$

(*iv*) **Distributive laws**

(a) $A \cdot (B + C) = A \cdot B + A \cdot C$

(b) $(A + B) \cdot (A + C) = A + B \cdot C$

(*v*) **Absorption laws**

(a) $A + A \cdot B = A$

(b) $A \cdot (A + \overline{A}) = A$

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