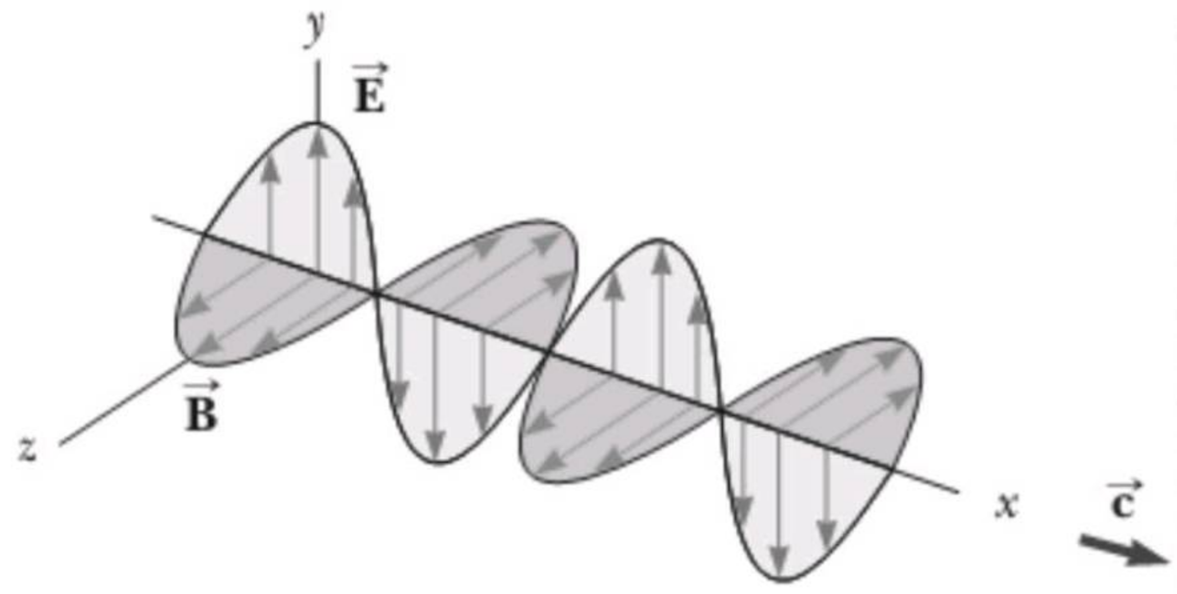
Chapter = 16

Electromagnetic Waves and Electronics

Maxwell's Electromagnetic Theory:

In 1865 James Clerk Maxwell with the help of mathematical analysis proved that light is wave in nature but it is different from other waves.



According to Maxwell theory:

- Light is the visible part of spectrum of electromagnetic waves
- Electromagnetic waves travel by the changing electric and magnetic field.
- As electric field and magnetic field does not require any medium electromagnetic field can travel through vacuum.
- The direction of magnetic field, Electric field and direction of propagation are mutually perpendicular to each other.
- The strength of Electric field at the same location and time is equal to the velocity of light times the strength of magnetic field.
- Velocity of light is dependent on the electric and magnetic properties of medium. Velocity of light in vacuum can be expressed as

$$c = \frac{1}{\sqrt{\epsilon_o \mu_o}}$$

$$c = 2.998 \times 10^8 ms^{-1} = 3 \times 10^8 ms^{-1}$$

Information Carried by Electromagnetic Waves:

In the field of telecommunication, it is common practice to send information by wireless mean to do it electromagnetic waves are used.

Modulation:

The superimposing of a low energy EM signal on a high frequency signal so that information can be transmitted is called Modulation.

Modulating Signal:

The low frequency signal that contain message to be transmitted is called modulating signal.

Carrier Signal:

The high frequency signal on which modulating signal is super imposed is called carrier signal.

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Modulated signal:
The signal obtain after the modulation is called modulated signal.

Types of Modulation:
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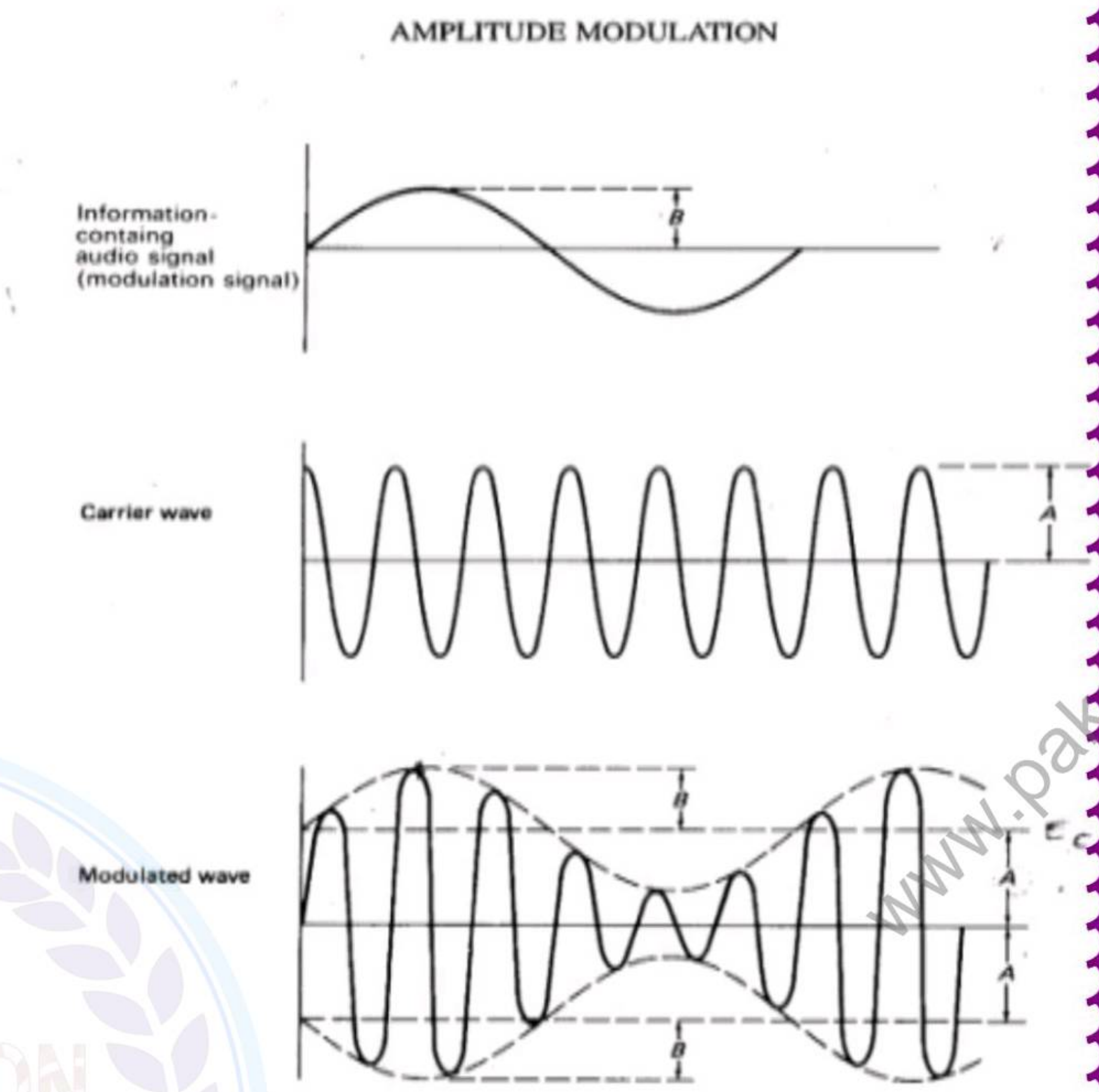
There are following two (basic) types of (analog) modulation:

1) Amplitude Modulation.
2) Frequency Modulation.

Amplitude Modulation:
A type of modulation, in which amplitude of a carrier wave is modulated by an impose signal, usually at audio frequency. The variation in the amplitude of the carrier signal is proportional to the variation of the modulating signal while the frequency of the carrier remains constant.



Percentage Modulation:
In amplitude modulation it is common to calculate percentage of modulation (M).

Mathematically percentage modulation (A.M) can be expressed as

$$M = \frac{Amplitude\ of\ modulating\ signal\ (volts)}{Amplitude\ of\ carrier\ signal\ (volts)} \times 100$$

$$M = m_a \times 100$$

Here, m_a is called Modulation index and it may be defined as

"It is the ratio peak amplitude of modulating signal to the peak amplitude of carrier signal."

Modulation for error free purposes m_a should be less than or equal to 1.

Application:
Amplitude modulation is used in variety of telecommunication application such as

- Transmitting video signals in television transmission.
- Armature AM radio.
- Walky Talkies.

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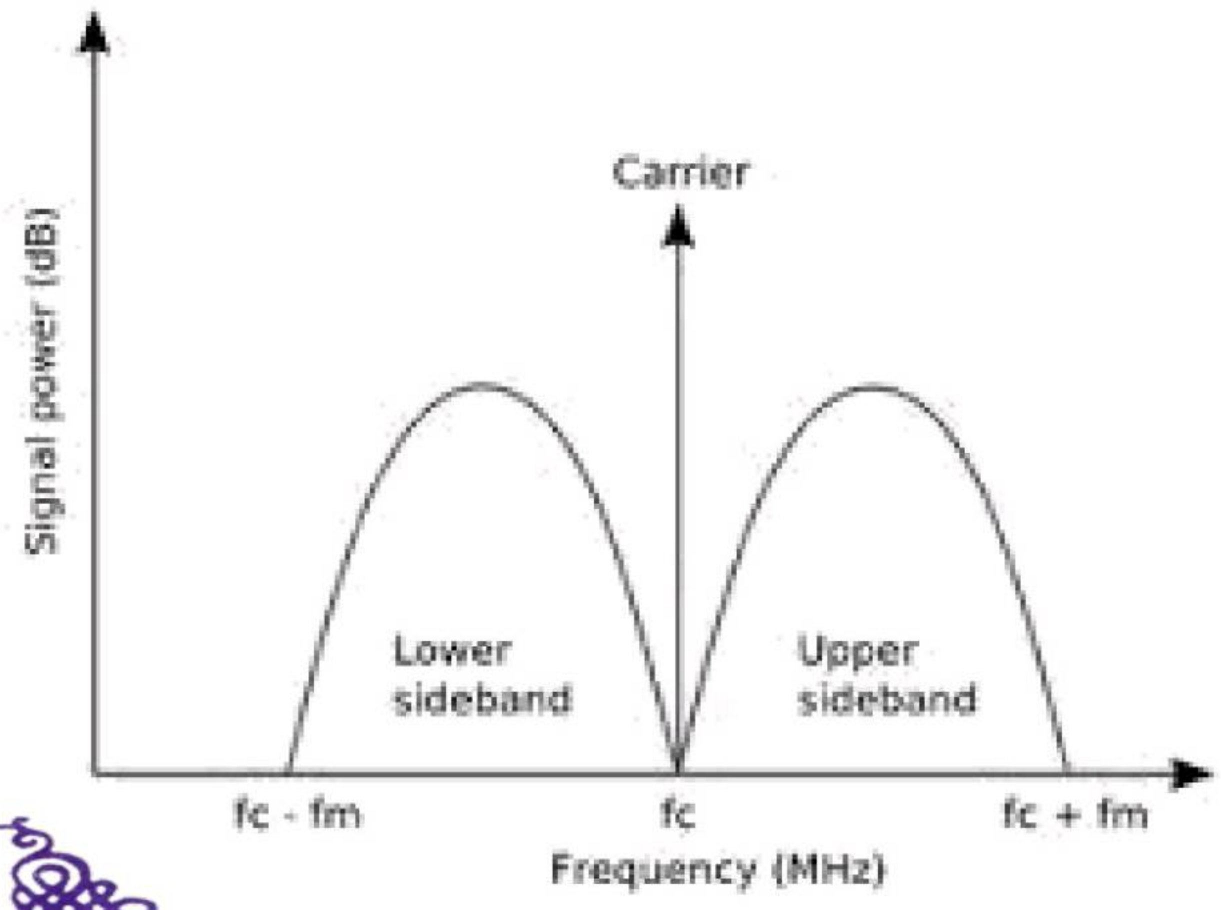
Sidebands:

In radio communications sidebands is a band of frequencies higher than or lower than the carrier frequency, containing power as a result of the modulation process.

Amplitude modulation of a carrier wave normally results in two mirror-image sidebands. The signal components above the carrier frequency constitute the upper sideband (USB), and those below the carrier frequency constitute the lower sideband (LSB). In conventional A.M transmission



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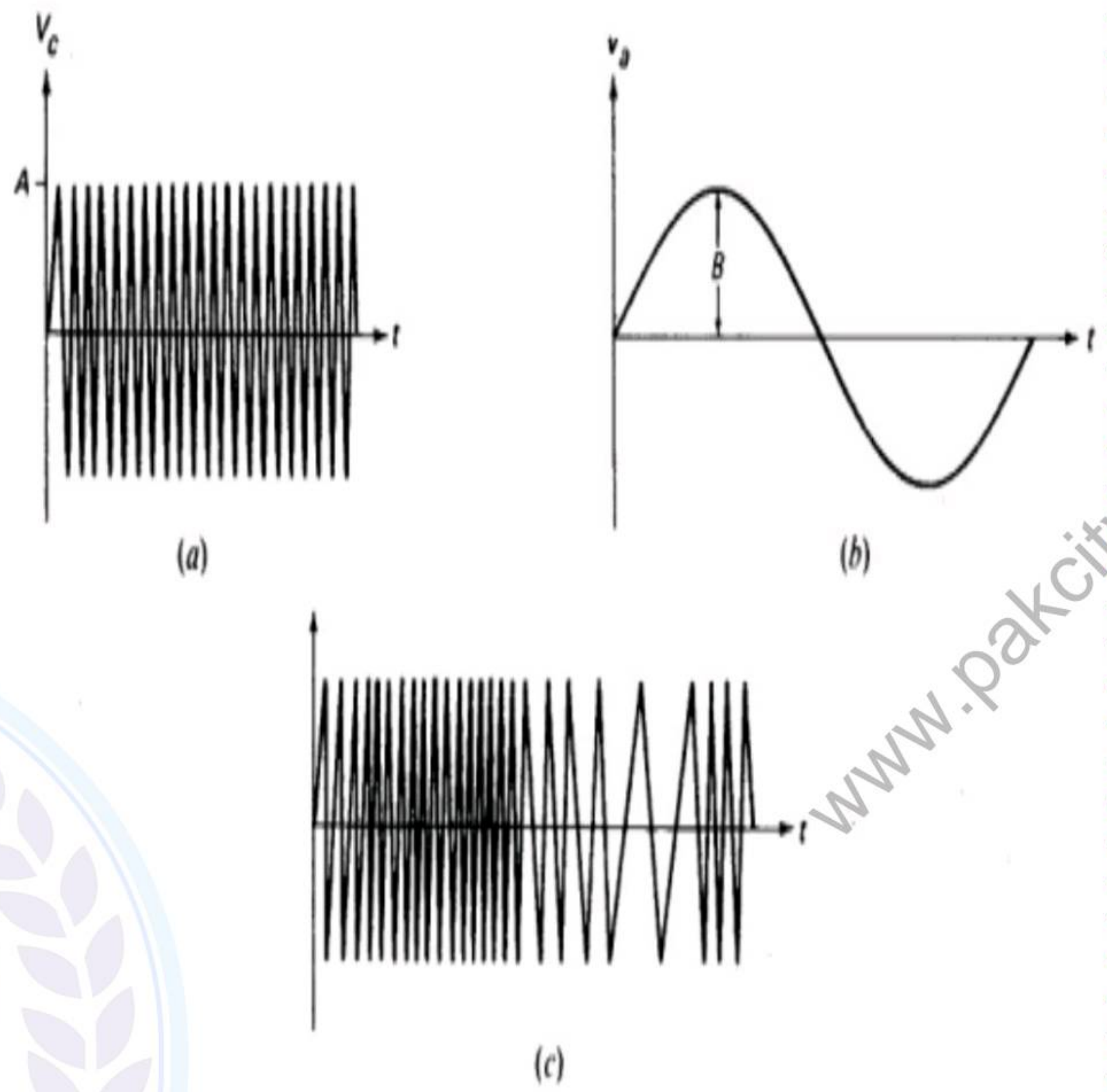
Frequency Modulation:

A type of modulation in which in which a carrier wave is made to carry the information in a signal (audio or visual) by fluctuation in the frequency of the carrier wave. The variation in the frequency of the carrier signal is proportional to the frequency of the modulating signal while the amplitude of the carrier remains constant.



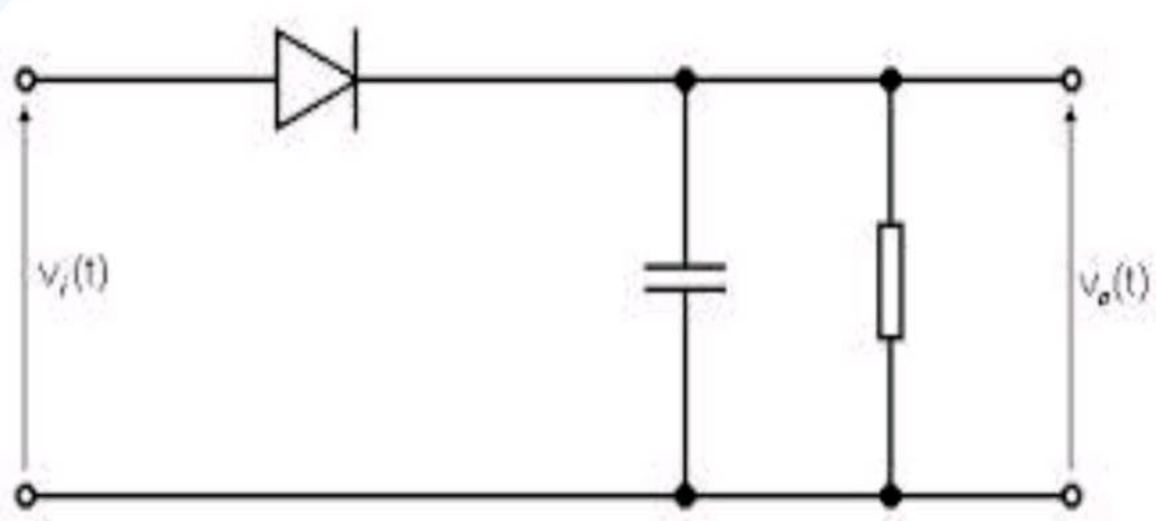
Application:

Frequency modulation is used in variety of telecommunication application such as

- Transmitting Audio signals in television transmission.
- Commercial FM radio.
- Cellular communication.

Reception of Electromagnetic signals:

Electromagnetic waves carrying the modulated carrier signal are received at the receiving end with help of an antenna and then Demodulated to obtain the message signal.

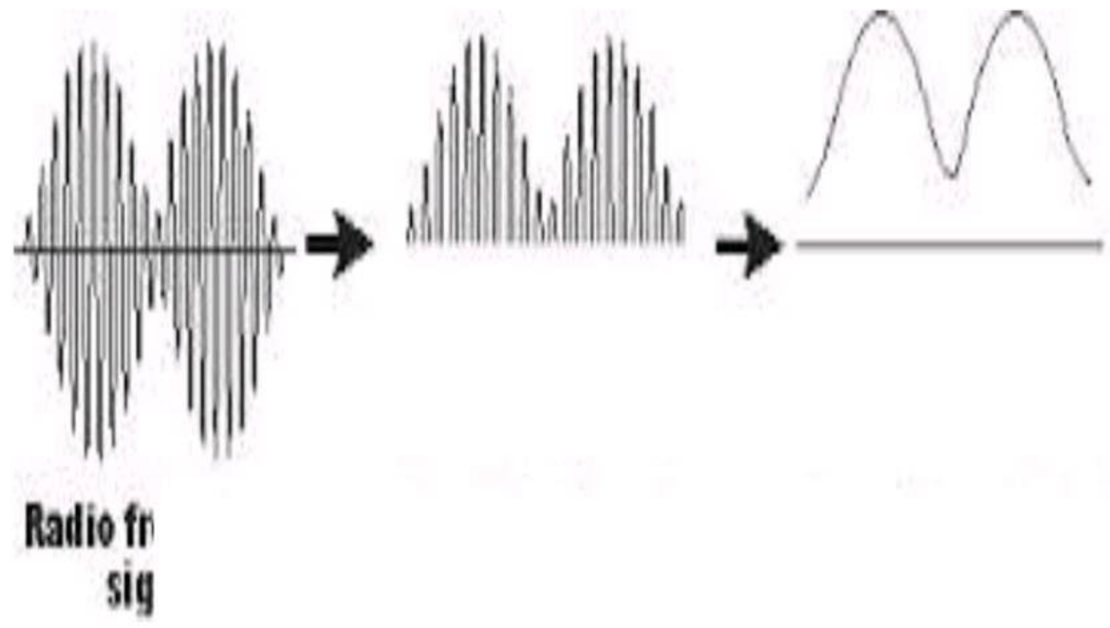


Demodulation:

Signal processing process use to extract out the message from the modulated carrier signal is called demodulation.

Demodulator:

The circuit used to demodulate the Modulated carrier signal is called Demodulator.



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Band Theory of Solids:

- According to band theory in a substance there is large number of atoms packed closely.
- In normal condition electrons in the outer most shell of a bonded to atoms and are called Valence electrons.
- The range of energy values that a valence electron in a crystalline solid can acquire is called Valence band. Electron in a valence band is not free to move in a crystalline structure.
- If electrons in the conduction band acquire enough energy it can come out of the influence of their atomic nucleus and become free electron.
- The range of energy values that an electron in a crystalline solid acquires and become free to move throughout the crystalline structure is called conduction band. Electron in a conduction band is free to move in crystalline structure.
- The range of energy values that does not belongs to either valence, or conduction band. This is the amount of energy required by a valence electron to jump from valence band to conduction band. This band of energy is called forbidden energy gap or band gap or energy gap.
- Electrical conductivity of solids varies with temperature.

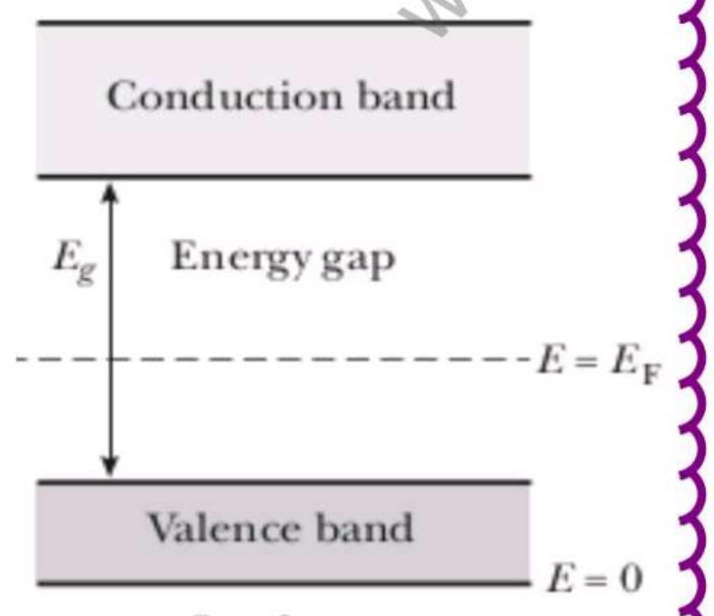
Types of Solid material

There are following three types of solids on the basis of their electrical conductivity

1. Insulators.
2. Conductor.
3. Semiconductors

Insulators:

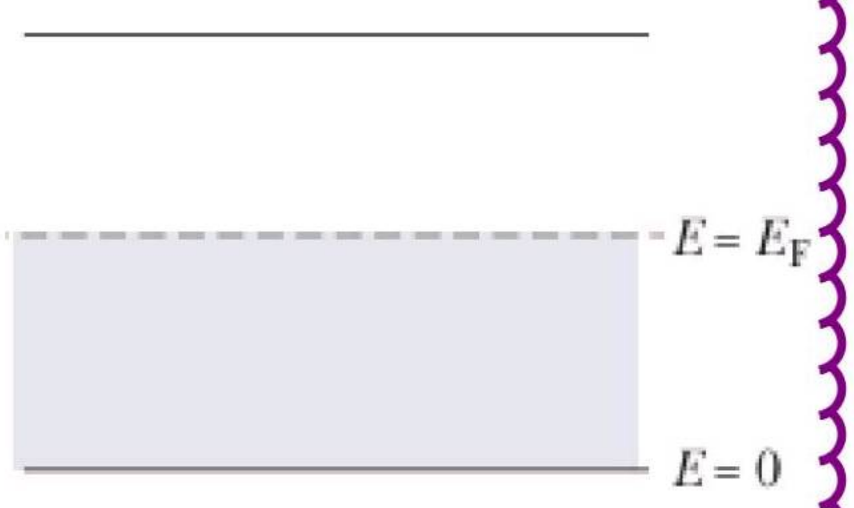
Materials which do not conduct electricity are called insulators. In insulator there is a large band gap between the valance and conduction band and the probability of an electron to exist in conduction band is zero. There for at any temperature their electrical conductivity is zero.



Insulator

Conductors:

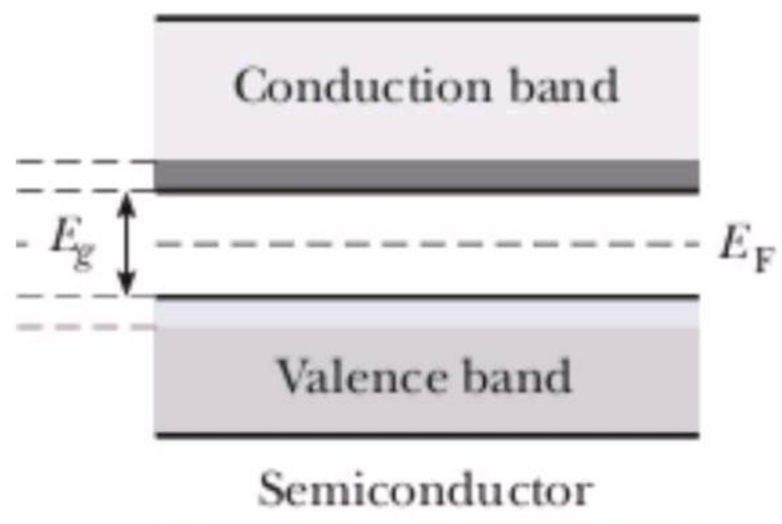
Materials which conduct electricity are called Conductors. In conductors there is no band gap between the valance and conduction band (both band over laps each other) and the probability of an electron to exist in conduction always 100%. Therefore, at any temperature they are able to conduct electricity. Conductors have positive temperature coefficient there for their electrical conductivity decreases with increase in temperature.



Metal

Semiconductors:

Materials which have electrical conductivity lying between conductors and insulators are called semiconductors. In conductors there is no band gap between the valance and conduction band (both band over laps each other) and the probability of an electron to exist in conduction always 100%. Therefore, at any temperature they are able to conduct electricity. Conductors have positive temperature coefficient there for their electrical conductivity decreases with increase in temperature.



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Types of Semiconductors

There are following two types of Semiconductors.

I. Intrinsic Semiconductors.
II. Extrinsic Semiconductors.

Intrinsic Semiconductors:

Intrinsic semiconductors are pure and naturally occurring semiconductors. Elements of group IV-A in periodic table Such as germanium and silicon are example of elemental semiconductors. Binary compound of group V-A and VI-A such as GaAs, GaP, IAs and CdS are example of Compound semiconductors.

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Extrinsic Semiconductor:

These are artificially prepared semiconductor material having impurities added to them in order to increase their electrical conductivity. They are prepared by the process of doping and also called Doped semiconductors.

Doping:

Doping can be defined as:

"The process of adding impurities to the semiconductor crystal structure to increase their electrical conductivity is called Doping."

Types of Doping:

There are following two types of Semiconductor Doping.

1) Donor Doping.
2) Acceptor Doping.

Donor Doping:

When elements of group V-A are used as doping impurity the doping is called Donor Doping.

Explanation:

Elements of group V-A has 5 valance electrons present in the outer most shell there for when they are added to the crystal structure of intrinsic semiconductors such as pure silicon or germanium four of them form covalent bonds with nearby atoms 5th electron remain unbounded providing an excess electron to the semiconductor for the electrical conduction.

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Acceptor Doping:

When elements of group III- A are used as doping impurity the doping is called Acceptor Doping.

Explanation:

Elements of group III-A has three valance electrons present in the outer most shell there for when they are added to the crystal structure of intrinsic semiconductors such as pure silicon or germanium they Accept one of the electrons from a host atom and form four covalent bonds with nearby atoms leaving a covalent bond between host atoms incomplete providing a deficiency of electron (Hole) in semiconductor for the electrical conduction.

Effect of Temperature on Semiconductors:

Semiconductor materials have negative temperature coefficient i-e Conduction of semiconductors increases with increase in temperature. But there is temperature range in which the conduction of semiconductor decreases. Actually, at zero Kelvin temperature all semiconductors (whether they are intrinsic or extrinsic) act as insulator this is due to the fact that at this temperature there is no ionized impurity or broken covalent band.

Explanation:

As the temperature is increased impurities start to ionize. As the temperature increases more the thermal energy is sufficient for bond breaking thus hole electron pairs are produced and conductivity increases after that increase in temperature causes the lattice vibration to increase and probability of electron to strike the nuclei and lose energy is increased which causes the conductivity to decrease at further increase in temperature the drift velocity of electron becomes sufficiently high so that the electrons can follow so fast and there probability of striking the nuclei decreases so much and then conductivity continuo to increase.

PN-Junction:

The region separating two different type of extrinsic semiconductor (p-type and n-type) in a single crystal structure is called PN-junction.

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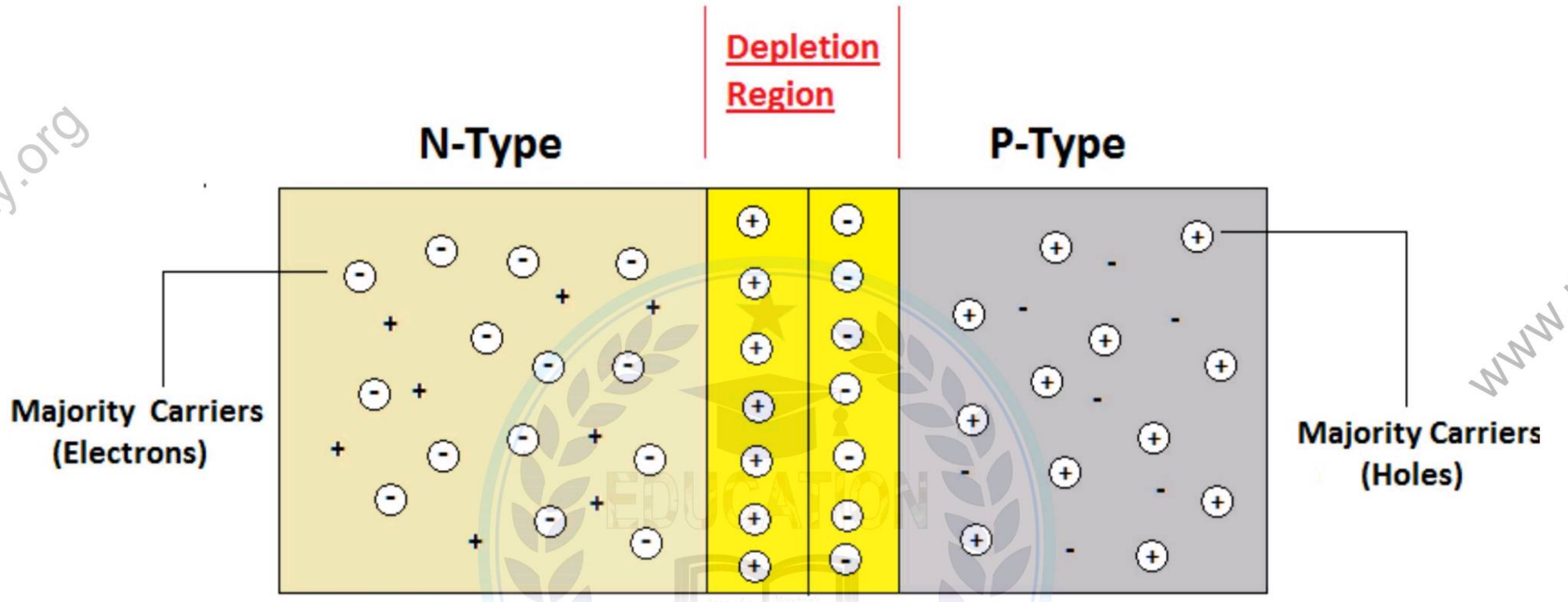
Formation of Potential Barrier:

When the PN junction is formed, the N-type region loses free electrons as they diffuse across the Junction. This creates a layer of positive charges (penta-valent ions) near the junction. As these electrons move across the junction, these electrons combine with holes in the p-region loses. This creates a layer of negative charges (trivalent ions) near the junction. These two layers of positive and negative charges form the depletion region. A point is reached where the total negative charge in the depletion region repels any further diffusion of electrons (negatively charged particles) into the p region (like charges repel) and the diffusion stops. In other words, the depletion region acts as a barrier to the further movement of electrons across the junction.



Silicon Crystal Doped with N-Type & P-Type Impurities

Semiconductor Diode:

It is the simplest and only semiconductor passive device it consists of a single PN-junction.

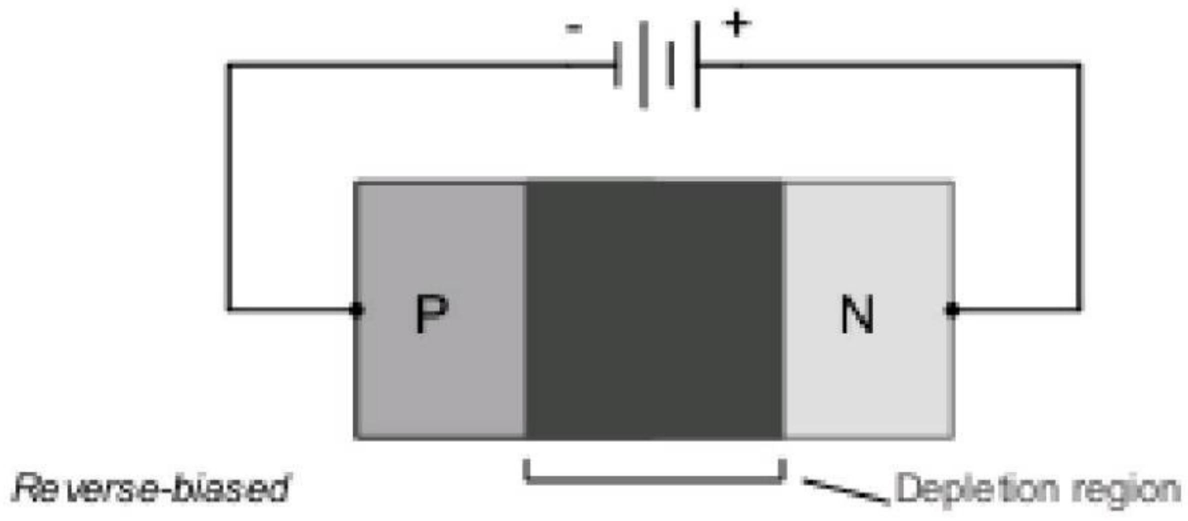
Diodes mode of operation:

There are two modes of diode operation.

- Forward Biased mode
- Reverse Biased mode

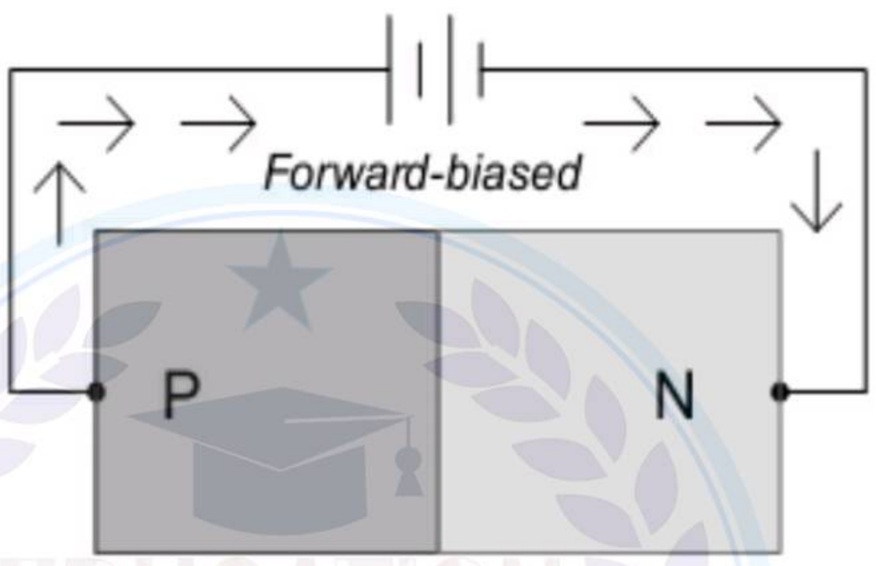
Forward Biased Mode:

The diodes mode of operation in which the potential difference applied across the diode is opposite to the built –in potential is called Forward Biased Mode.



Reverse Biased Mode:

The diodes mode of operation in which the potential difference applied across the diode is in same direction to the built –in potential is called Reverse Biased Mode.



Rectifier:

It is an electronic circuit that converts A.C voltage (or Current) into D.C voltage (or Current). There are two basic types of Rectifiers.

- Half Wave rectifier
- Full Wave rectifier

Half Wave Rectifier:

It consists of a single semiconductor diode attached in series with A.C source. It utilizes half of the Ac Signal voltage and converts in to D.C voltage.

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Working:

- During the positive half cycle of A.C signal the diode is forward biased and current flow through the circuit.
- The current passes through the Load resistor and voltage is developed across it.
- During the Negative half cycle of A.C signal the diode is reversed biased and no current flow through the circuit.
- Since there is no current in the circuit there will be no voltage developed across the Load resistor
- The output wave form is shown in figure.

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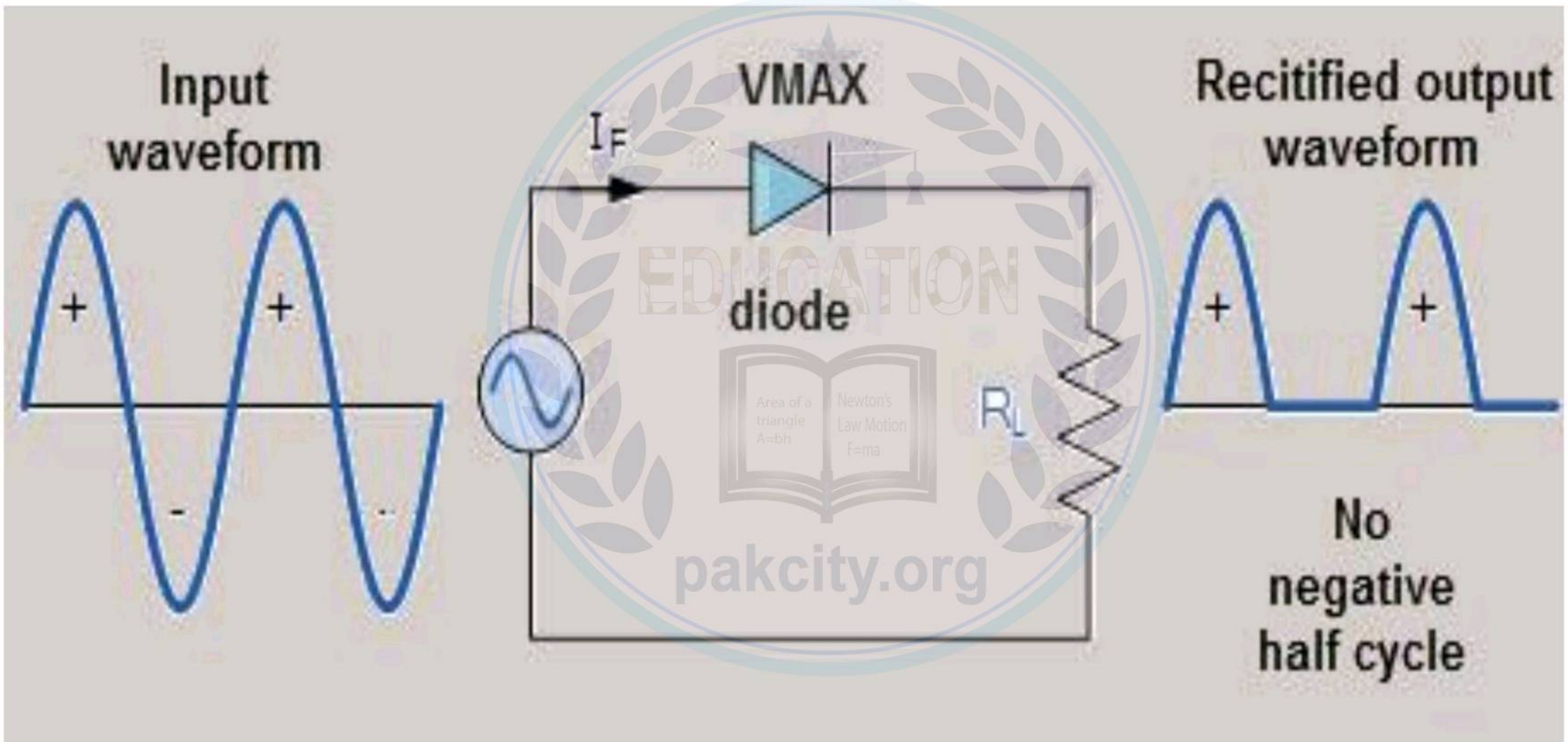
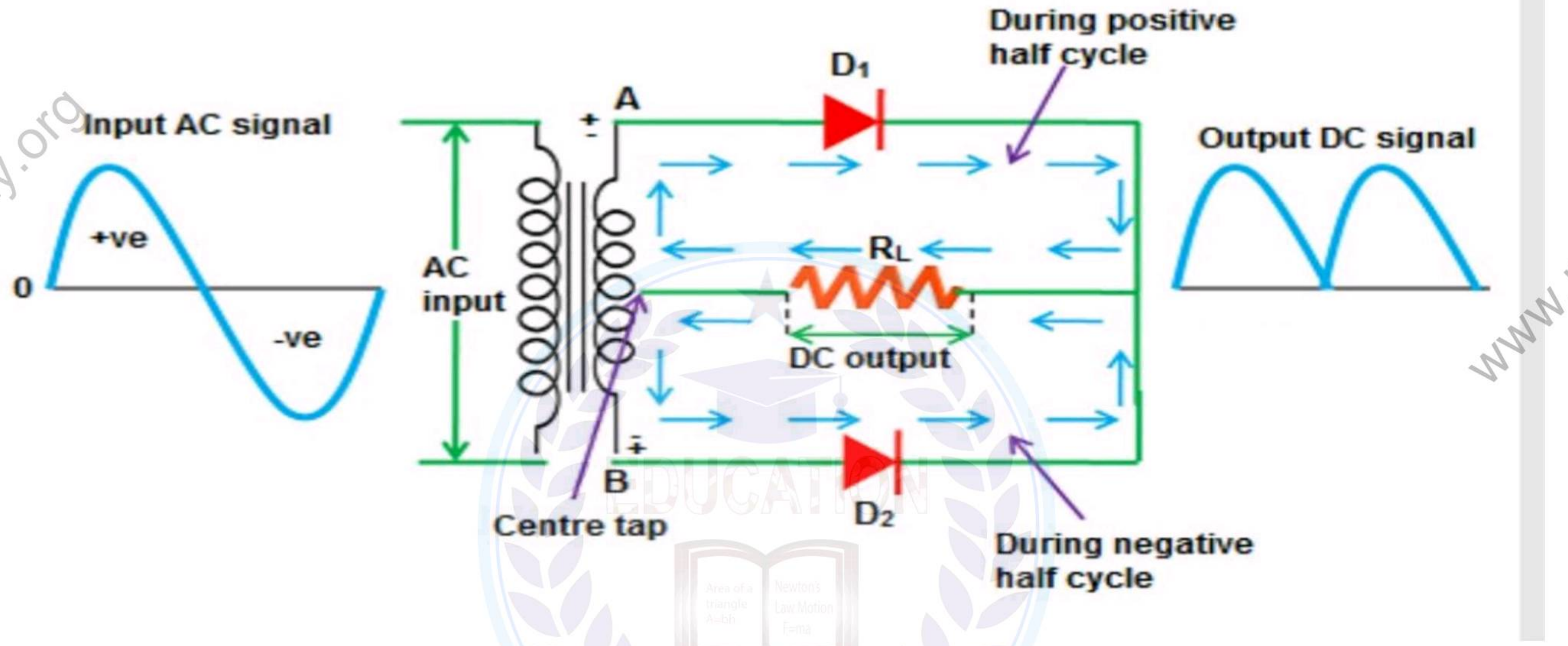


Full Wave Rectifier:

It consists of two semiconductor diodes attached with A.C source coupled through a center tapped transformer. It utilizes full A.C Signal voltage and converts in to D.C voltage.

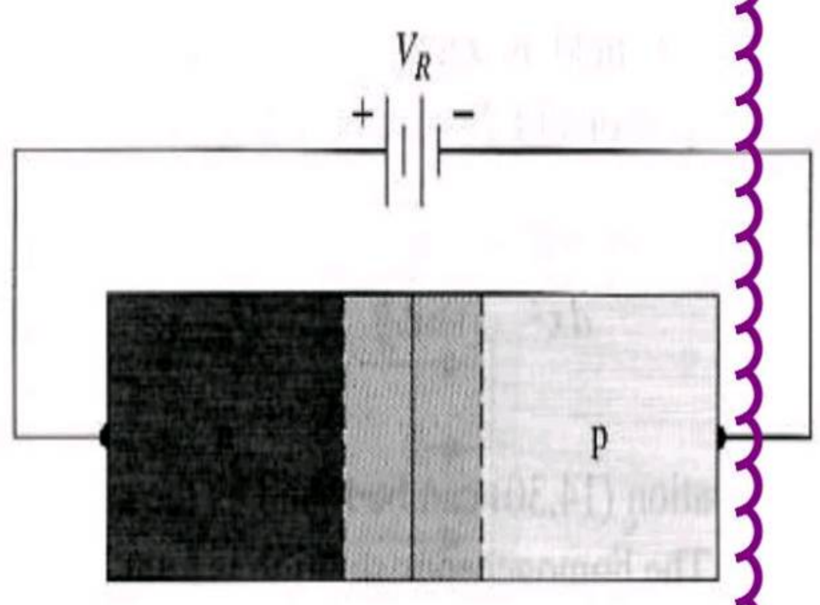
Working:

- During the positive half cycle of A.C signal the diode(D_1) is forward biased and current flow through the circuit.
- The current passes through the Load resistor and voltage is developed across it.
- During the positive half cycle of A.C signal the diode(D_2) is forward biased and current flow through the circuit.
- The current passes through the Load resistor and voltage is developed across it.
- The output wave form is shown in figure.



Photodiode:

Photodiode is an optoelectronic device that conducts electrical current when illuminated with light (or other electromagnetic radiation depending on material in manufacturing).



Construction:

Photodiode is a simple PN junction (normally made up of compound semiconductors) encapsulate in glass or plastic. Encapsulating material is painted black except the region which has to be illuminated with light.

Working:

Photodiodes are used in reverse biased mode when there is no light falling on the photodiode there is only a reverse leakage current flowing across the junction called the *Dark current* $(\mathbf{I_o})$. When photodiode is exposed to light, the light falling on the PN junction creates hole-electron pair within the junction, which are swept out of the junction due to built-in potential and added to the already flowing dark current. This additional current is known as *Short circuit current*$(\mathbf{I_s})$. Total current $(\mathbf{I})$ flowing when photodiode is exposed to light can be represent mathematically as:

$$\boxed{\mathbf{I} = \mathbf{I_o} + \mathbf{I_s}}$$

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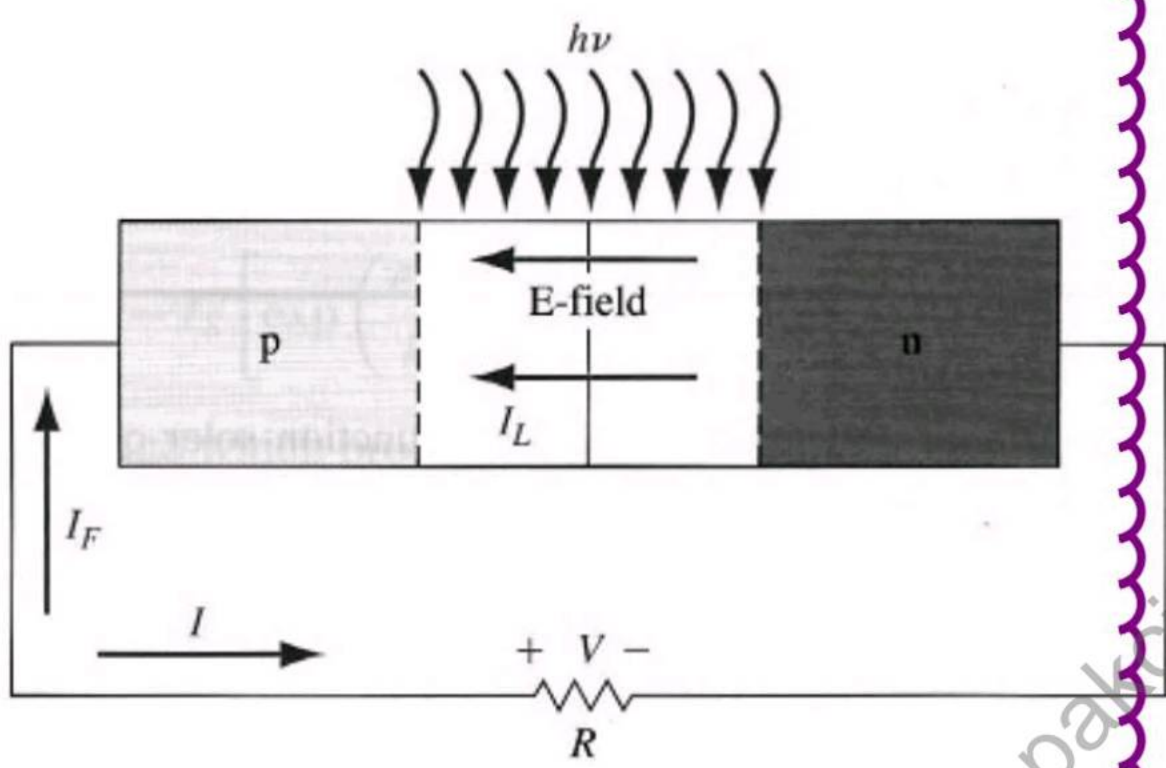
Applications:

Photo diode is used in variety of applications such as proximity sensors, Light operated switches, remote controlled systems etc.

SOLAR CELLS:

Solar cells are semiconductor devices used to convert light energy in to electrical energy, when exposed to light. The efficiency of solar cells is from 14% to 45%.



Construction:

Solar cell is simply a PN junction. Selenium and silicon are the widely used materials for the manufacturing of solar cells. Although, GaAs, IAs and CdS are also used among other.

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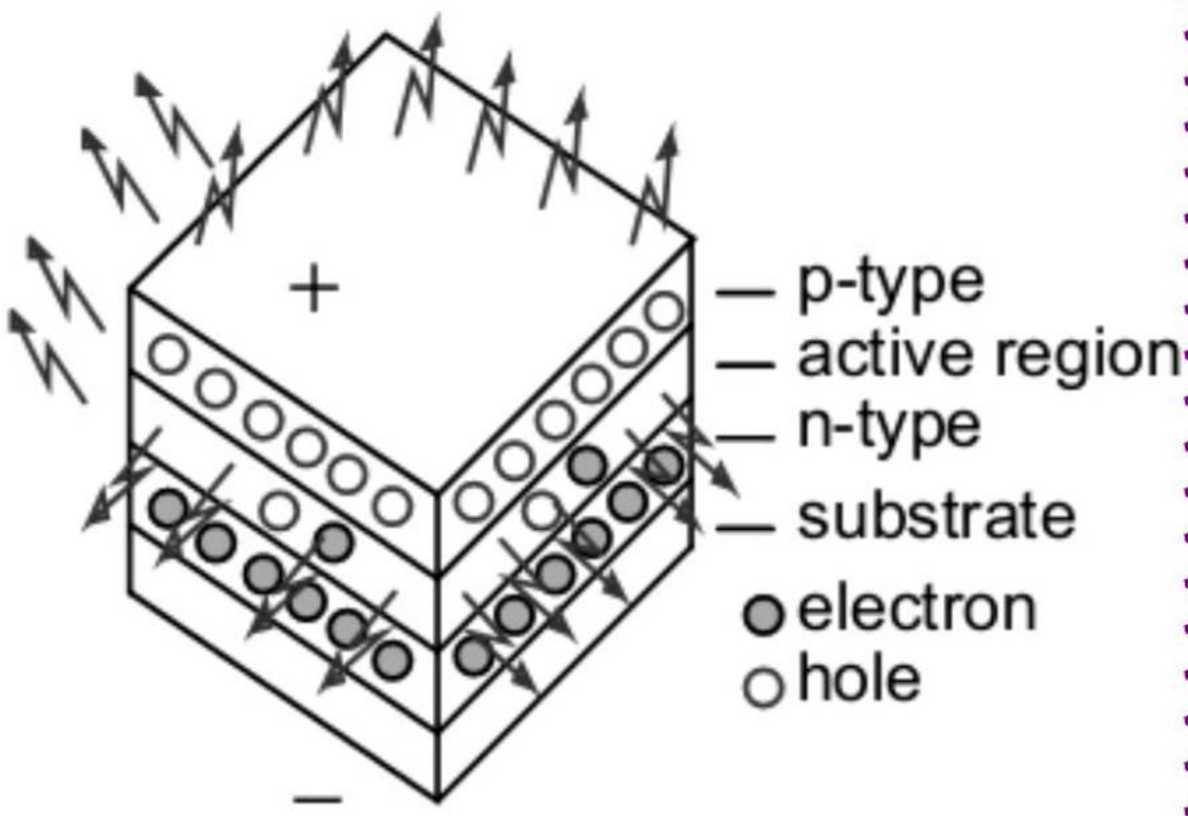
Working:

Solar cells are used without any biasing voltage. When light is allowed to fall on PN-junction hole-electron pairs are produce within the depletion region which are then swept out of the region by built-in potential in direction opposite to the direction of conventional forward current in PN-junction current

LIGHT EMITTING DIODE (LED):

Light emitting diodes are special purpose diodes. These diodes have property that when forward biased they radiate energy in the form of light.



Construction:

Light emitting diode is a simple PN junction. Material such as Germanium or silicon radiates energy mostly in the form of heat there for they cannot be used for manufacturing of light emitting diode. On the other hand other semiconductor materials such as GaAs, GaP, and GaAsP etc. radiate most energy in the form of light.

Working:

The basic operation of the light-emitting diode (LED) is as follows. When the device is forward-biased, electrons cross the PN junction from the n-type material and recombine with holes in the p-type material. These free electrons are in the conduction band and at a higher energy than the holes in the valence band. When recombination takes place, the recombining electrons release energy in the form of heat and light.

Application:

LEDs are use primary as power on indicators for many appliances. They are also used for alpha numeric display as Seven segment am sixteen segment forms.

Transistor:

Transistor is an active semiconductor device (a semiconductor device that can induce gain into a circuit). The word transistor is combination of two words i-e transfer and resistor.

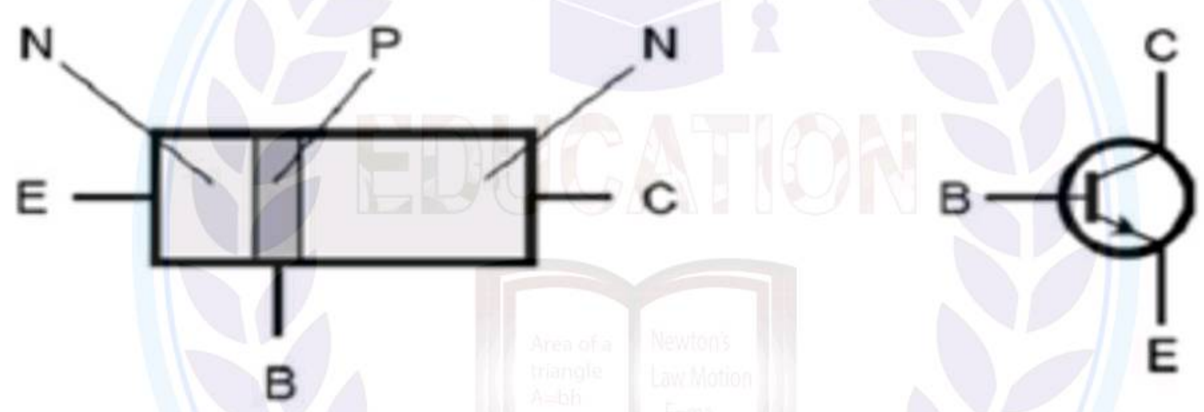
Types of Transistors:

There are two types of transistor

1) NPN
2) PNP

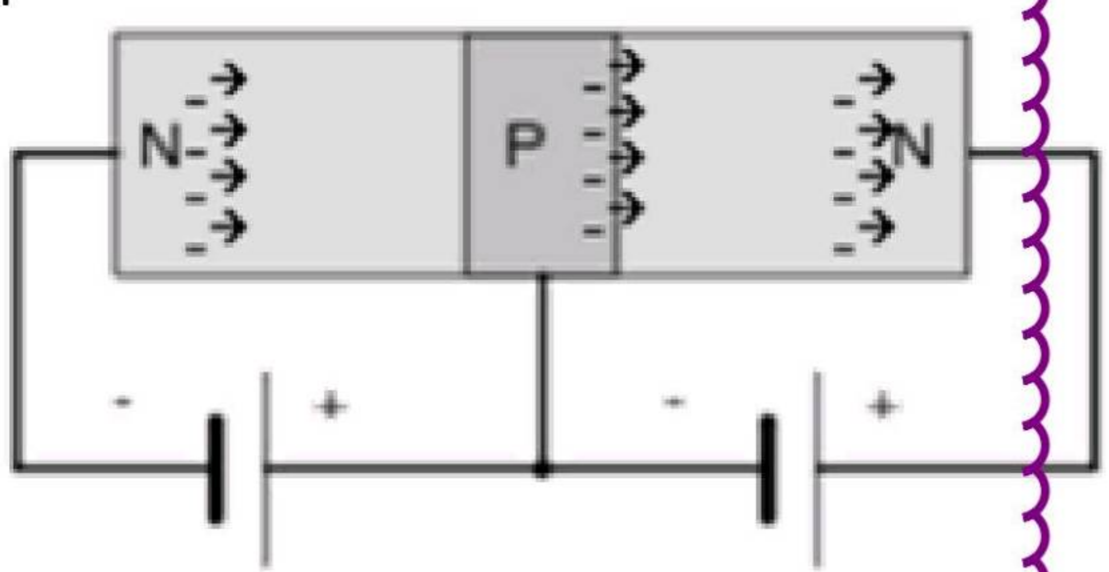
NPN-Transistor:

NPN transistor is made by fabricating a single crystal in which a P- type material is fabricated between two layers of N-type material.
Following figure, the crystal structure and schematic symbols for NPN-transistor



Working Of NPN-Transistor:

- The emitter base junction is forward biased & base collector junction is reversed biased.



- The forward bias causes the electrons in the n-type emitter to flow towards the base which constituent current(I_E).
- These electrons cross into the p-type base, they try to combine with holes but the base is lightly doped and is very thin.
- Therefore, only few electrons combine with holes and the remaining electrons cross into the collector and generate collector current(I_C).

- In this way almost, the entire emitter current flows in the collector circuit. From the above description it is clear that:

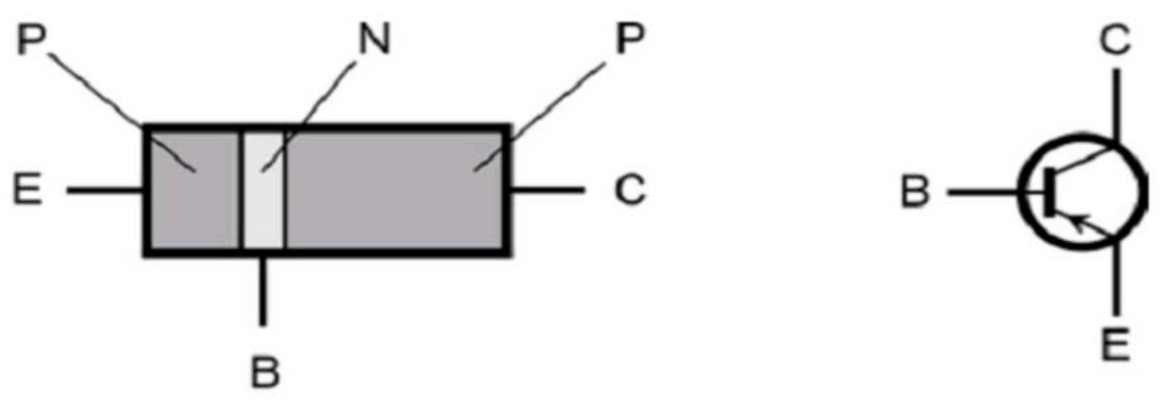
$$I_E = I_B + I_c$$

- Thus, there are two current paths through a transistor. One is the base-emitter path or input and the other is the collector-emitter path or output.

$$\alpha = \frac{I_C}{I_E}$$

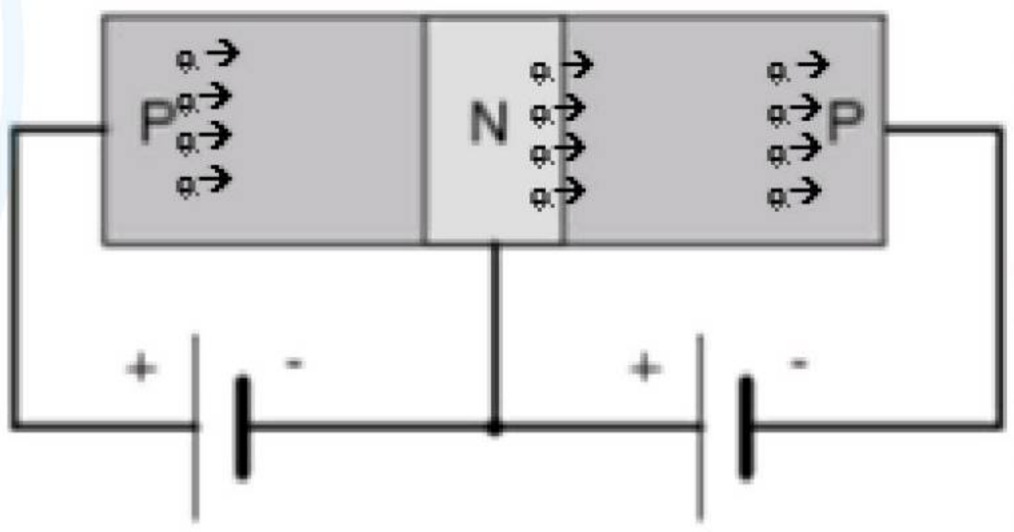
PNP-Transistor:

PNP transistor is made by fabricating a single crystal in which an N- type material is fabricated between two layers of P-type material.
Following figure, the crystal structure and schematic symbols for PNP-transistor



Working Of PNP-Transistor:

- The emitter base junction is forward biased & base collector junction is reversed biased.
- The forward bias causes the holes in the p-type emitter to flow towards the base which constituent $I_E$current.
- These holes cross into the n-type base, they try to combine with electrons but the base is lightly doped and is very thin.
- Therefore, only few holes combine with electrons and the remaining holes cross into the collector and generate collector current I_c.



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$$\alpha = \frac{I_C}{I_E}$$

Characteristics Curves:

The characteristic contains two curves i.e.

Input Characteristics:

It gives the relationship between input voltage & input current

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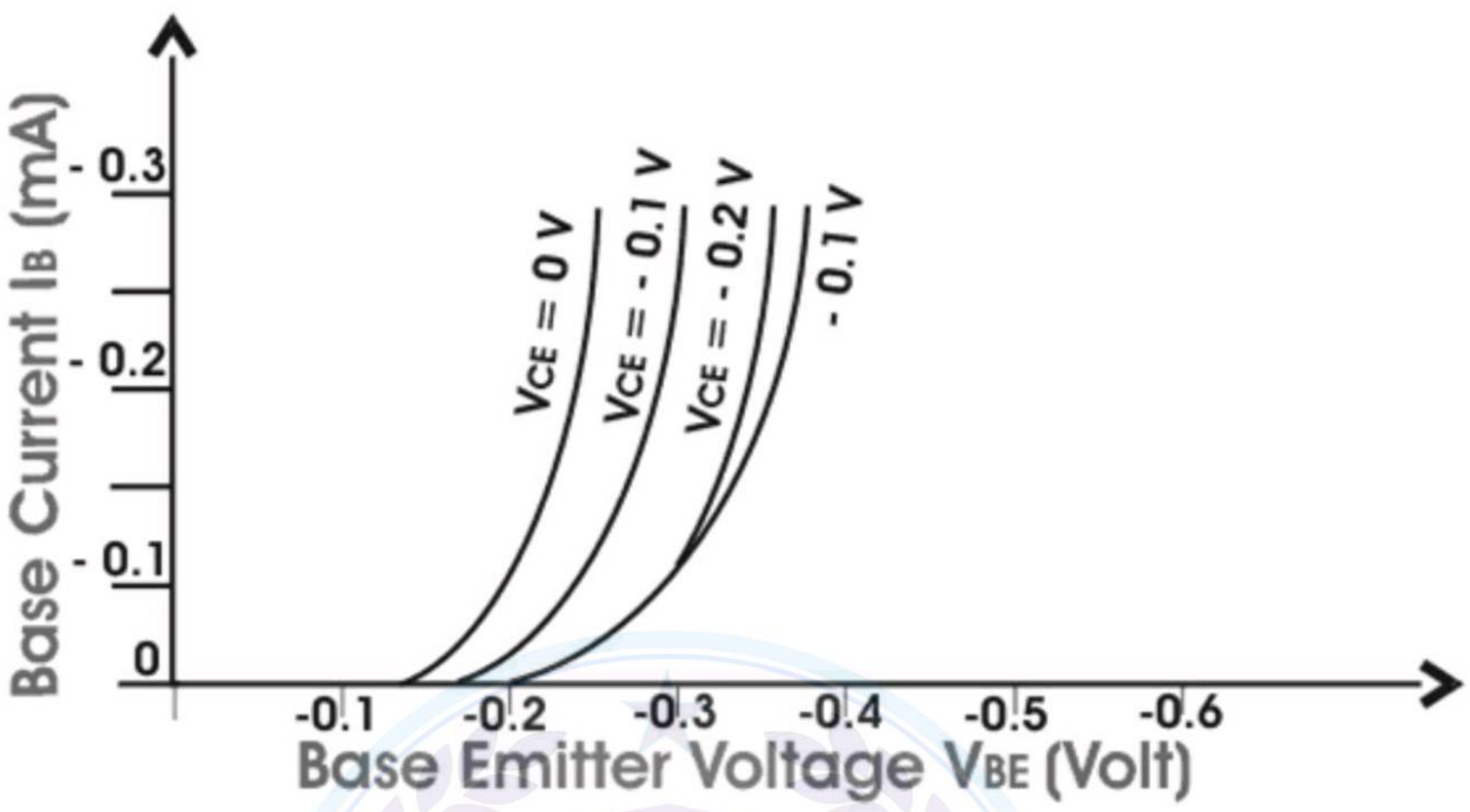
- I_B (Base Current) is the input current, V_{BE} (Base – Emitter Voltage) is the input voltage for CE (Common Emitter) mode. So, the input characteristics for CE mode will be the relation between I_B and V_{BE} with V_{CE} as parameter.
- The typical CE input characteristics are similar to that of a forward biased of p – n diode. But as V_{CB} increases the base width decreases
- The characteristics curves are represented as,



Output Characteristics:

It gives the relationship between voltage & current in output circuit.

- Output characteristics for CE mode is the curve or graph between collector current (I_C) and collector – emitter voltage (V_{CE}) when the base current I_B is the parameter.
- CE transistor has also three regions named

1. **Active region:**
   The active region has collector region reverse biased and the emitter junction forward biased.
2. **Cut-off regions:**
   For cut-off region the emitter junction is slightly reverse biased and the collector current is not totally cut-off.
3. **Saturation region:**
   For saturation region both the collector and the emitter junction are forward biased.

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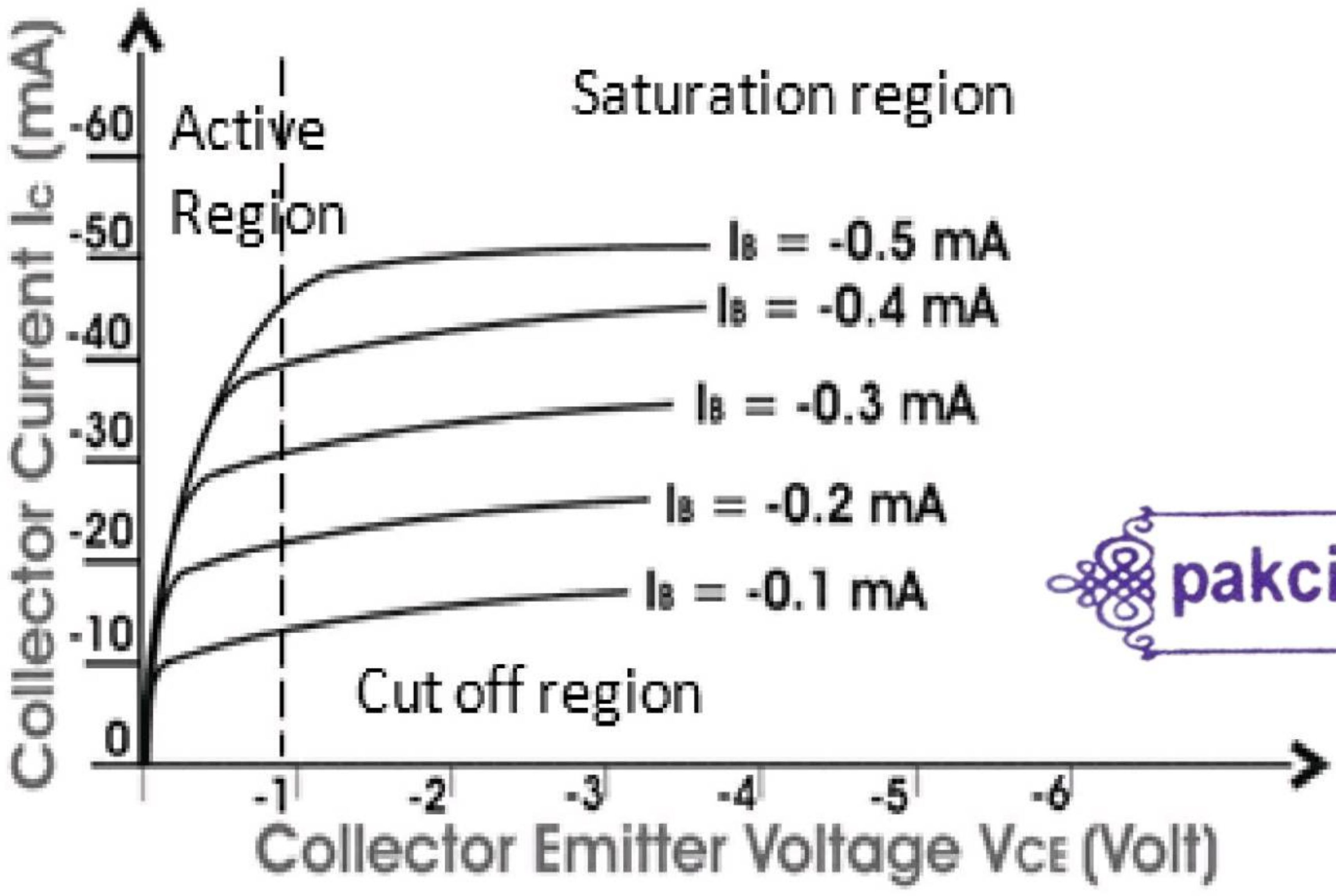
- The characteristics curves is represented as:



AMPLIFIER:

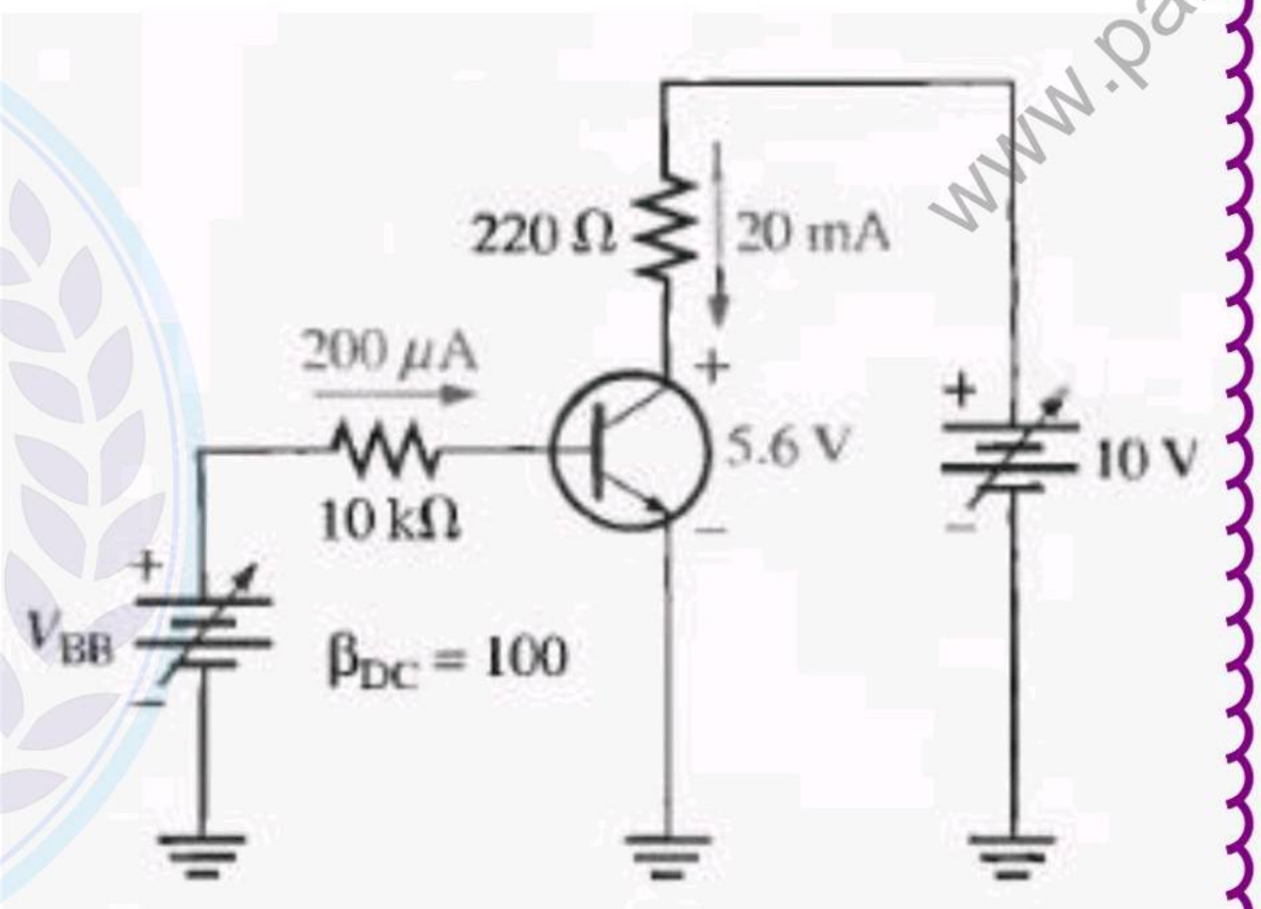
Amplifier is a circuit or device that can raises the strength of a weak signal. The factor by which an amplifier increases the strength of a weak signal is called gain of an amplifier.

Transistor as an Amplifier:

A transistor can be used to amplify a weak signal. The transistor has following relation between base and collector current.

$$I_C = \alpha I_B$$

Where α is called the gain of the transistor.



Now if we apply a small voltage across the base emitter junction, this voltage allows a small base current to flow inside the base region resulting in large collector current to flow in collector. Now, if we connect a large resistance R_C at collector. Collector current will cause a large voltage to build across $\mathbf{R_C}$. Hence, small voltage applied at BE junction is converted into large voltage across $\mathbf{R_C}$.