UNIT IV
SEMICONDUCTOR DEVICES

Semiconductors are materials which have a **conductivity between conductors** (generally metals) and non-conductors or **insulators** (such as ceramics). Semiconductors can be compounds, such as gallium arsenide, or pure elements, such as germanium or silicon. Physics explains the theories, properties and mathematical approach related to semiconductors.

Examples of Semiconductors

Gallium arsenide, germanium and silicon are some of the most **commonly used semiconductors**. Silicon is used in electronic circuit fabrication, and gallium arsenide is used in solar cells, laser diodes, etc.

Holes and Electrons in Semiconductors

Holes and electrons are the types of charge carriers accountable for the flow of current in semiconductors. **Holes** (valence electrons) are the positively charged electric charge carrier, whereas **electrons** are the negatively charged particles. Both electrons and holes are equal in magnitude but opposite in polarity.

Mobility of Electrons and Holes

In a semiconductor, the **mobility of electrons is higher than that of the holes**. It is mainly because of their different band structures and scattering mechanisms.

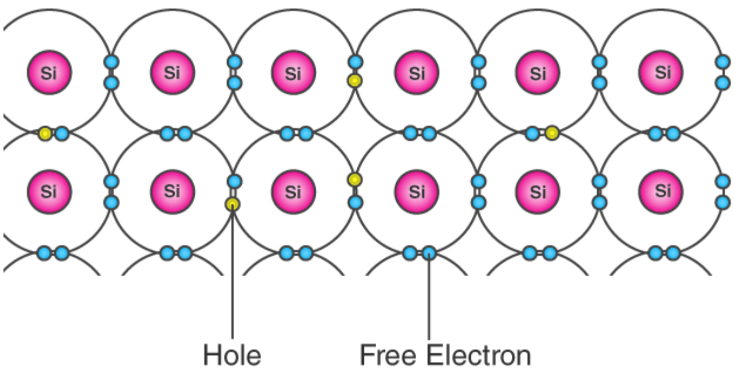
Electrons travel in the conduction band, whereas holes travel in the valence band. When an electric field is applied, holes cannot move as freely as electrons due to their restricted movement. The elevation of electrons from their inner shells to higher shells results in the creation of holes in semiconductors. Since the holes experience stronger atomic force by the nucleus than electrons, holes have lower mobility.

The mobility of a particle in a semiconductor is more, if

- The effective mass of particles is lesser
- The time between scattering events is more

For intrinsic silicon at 300 K, the mobility of electrons is 1500 $cm^2 (V\cdot s)^{-1}$, and the mobility of holes is 475 $cm^2 (V\cdot s)^{-1}$.

The **bond model** of electrons in silicon of valency 4 is shown below. Here, when one of the free electrons (blue dots) leaves the lattice position, it creates a hole (grey dots). This hole thus created takes the opposite charge of the electron and can be imagined as positive charge carriers moving in the lattice.

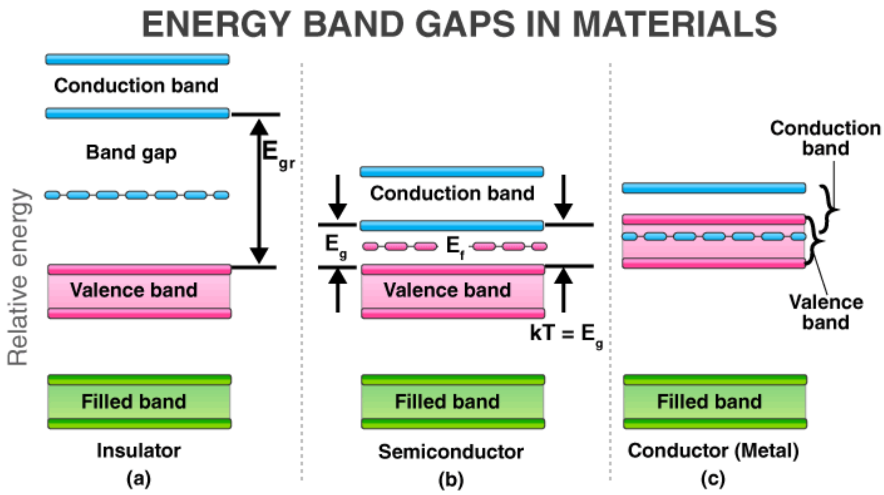


Concept of Electrons and Holes in Semiconductors

Band Theory of Semiconductors

The introduction of band theory happened during the quantum revolution in science. Walter Heitler and Fritz London discovered the energy bands.

We know that the electrons in an atom are present at different energy levels. When we try to assemble a lattice of a solid with N atoms, each level of an atom must split into N levels in the solid. This splitting of sharp and tightly packed energy levels forms **Energy Bands**. The gap between adjacent bands representing a range of energies that possess no electron is called a **Band Gap**.



Energy Band Diagram for Semiconductors, Conductors and Insulators

Conduction Band and Valence Band in Semiconductors

Valence Band

The energy band involving the energy levels of valence electrons is known as the valence band. It is the highest occupied energy band. When compared with insulators, the band gap in semiconductors is smaller. It allows the electrons in the valence band to jump into the conduction band on receiving any external energy.

Conduction Band

It is the lowest, unoccupied band that includes the energy levels of positive (holes) or negative (free electrons) charge carriers. It has conducting electrons resulting in the flow of current. The conduction band possess a high energy level and is generally empty. The conduction band in semiconductors accepts the electrons from the valence band.

Properties of Semiconductors

Semiconductors can conduct electricity under preferable conditions or circumstances. This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

Unlike conductors, the charge carriers in semiconductors arise only because of external energy (thermal agitation). It causes a certain number of valence electrons to cross the energy gap and jump into the conduction band, leaving an equal amount of unoccupied energy states, i.e., holes. The conduction due to electrons and holes is equally important.

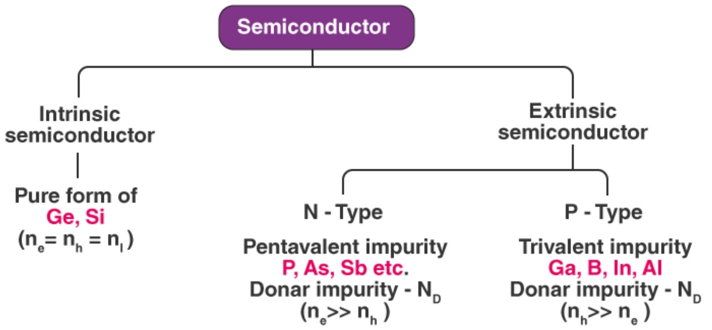
Some Important Properties of Semiconductors

1. Semiconductors act like insulators at zero Kelvin. On increasing the temperature, they work as conductors.
2. Due to their exceptional electrical properties, semiconductors can be modified by doping to make semiconductor devices suitable for energy conversion, switches and amplifiers.
3. Lesser power losses.
4. Semiconductors are smaller in size and possess less weight.
5. Their resistivity is higher than conductors but lesser than insulators.
6. The resistance of semiconductor materials decreases with an increase in temperature and vice-versa.

Types of Semiconductors

Semiconductors can be classified as follows:

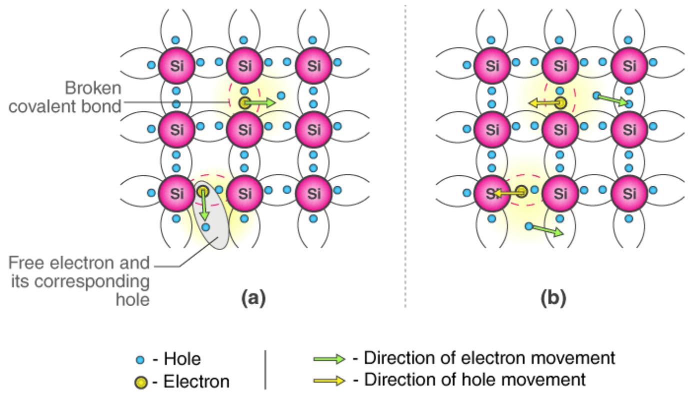
- **Intrinsic Semiconductor**
- **Extrinsic Semiconductor**



Classification of Semiconductors

Intrinsic Semiconductor

An **intrinsic type of semiconductor material** is made to be very pure chemically. It is made up of only a single type of element.



Conduction Mechanism in Case of Intrinsic Semiconductors (a) In the absence of an electric field (b) In the presence of an electric field

Germanium (Ge) and silicon (Si) are the most common types of intrinsic semiconductor elements. They have four valence electrons (tetravalent). They are bound to the atom by a covalent bond at absolute zero temperature.

When the temperature rises due to collisions, few electrons are unbounded and become free to move through the lattice, thus creating an absence in its original position (hole). These free electrons and holes contribute to the conduction of electricity in the semiconductor. The negative and positive charge carriers are equal in number.

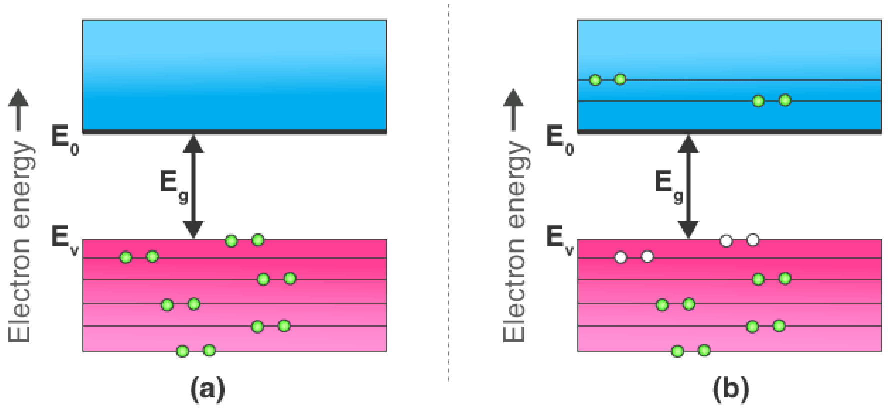
The thermal energy is capable of ionising a few atoms in the lattice, and hence, their conductivity is less.

The Lattice of Pure Silicon Semiconductor at Different Temperatures

- **At absolute zero Kelvin temperature:** At this temperature, the covalent bonds are very strong, there are no free electrons, and the semiconductor behaves as a perfect insulator.
- **Above absolute temperature:** With an increase in temperature, a few valence electrons jump into the conduction band, and hence, it behaves like a poor conductor.

Energy Band Diagram of Intrinsic Semiconductor

The energy band diagram of an intrinsic semiconductor is shown below.



(a) Intrinsic Semiconductor at T = 0 Kelvin, behaves like an insulator (b) At t>0, four thermally generated electron pairs

In intrinsic semiconductors, current flows due to the motion of free electrons, as well as holes. The total current is the sum of the electron current I_e due to thermally generated electrons and the hole current I_h.

Total Current (I) = $I_e + I_h$

For an intrinsic semiconductor, at finite temperature, the probability of electrons existing in a conduction band decreases exponentially with an increasing band gap (E_g).

$n = n_0 e^{-Eg/2.Kb.T}$

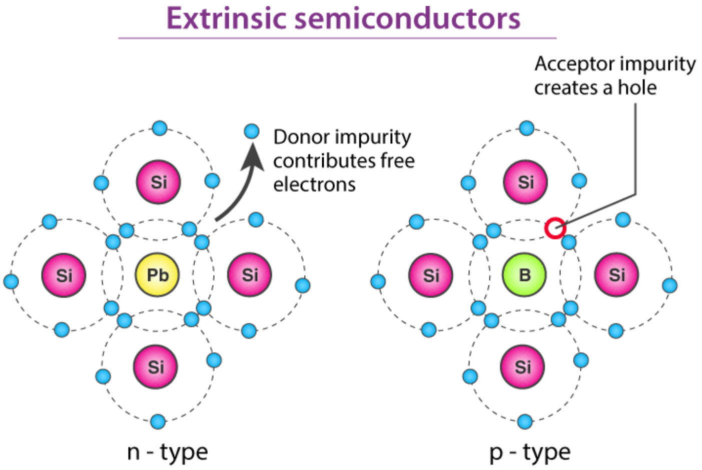
Where,

- Eg = Energy band gap
- K_b = Boltzmann's constants

Extrinsic Semiconductor

The conductivity of semiconductors can be greatly improved by introducing a small number of suitable replacement atoms called IMPURITIES. The process of adding impurity atoms to the pure semiconductor is called DOPING. Usually, only 1 atom in 10^7 is replaced by a dopant atom in the doped semiconductor. An extrinsic semiconductor can be further classified into types:

- **N-type Semiconductor**
- **P-type Semiconductor**



Classification of Extrinsic Semiconductor

N-Type Semiconductor

- Mainly due to electrons
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Electrons and Minority – Holes

When a pure semiconductor (silicon or germanium) is doped by pentavalent impurity (P, As, Sb, Bi), then four electrons out of five valence electrons bond with the four electrons of Ge or Si.

The fifth electron of the dopant is set free. Thus, the impurity atom donates a free electron for conduction in the lattice and is called a "**Donar**".

Since the number of free electrons increases with the addition of an impurity, the negative charge carriers increase. Hence, it is called an n-type semiconductor.

Crystal as a whole is neutral, but the donor atom becomes an immobile positive ion. As conduction is due to a large number of free electrons, the electrons in the n-type semiconductor are the MAJORITY CARRIERS, and holes are the MINORITY CARRIERS.

P-Type Semiconductor

- Mainly due to holes
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Holes and Minority – Electrons

When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga), then the three valence electrons of the impurity bond with three of the four valence electrons of the semiconductor.

This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called “**Acceptors**“.

With an increase in the number of impurities, holes (the positive charge carriers) are increased. Hence, it is called a p-type semiconductor.

Crystal, as a whole, is neutral, but the acceptors become an immobile negative ion. As conduction is due to a large number of holes, the holes in the p-type semiconductor are MAJORITY CARRIERS, and electrons are MINORITY CARRIERS.

Difference between Intrinsic and Extrinsic Semiconductors

Intrinsic Semiconductor	**Extrinsic Semiconductor**
Pure semiconductor	Impure semiconductor
The density of electrons is equal to the density of holes	The density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature, as well as on the amount of impurity
No impurities	Trivalent impurity and pentavalent impurity

Applications of Semiconductors

Let us now understand the uses of semiconductors in daily life. Semiconductors are used in almost all electronic devices. Without them, our life would be much different.

Their reliability, compactness, low cost and controlled conduction of electricity make them ideal to be used for various purposes in a wide range of components and devices. Transistors, diodes, photosensors, microcontrollers, integrated chips and much more are made up of semiconductors.

Uses of Semiconductors in Everyday Life

- Temperature sensors are made with semiconductor devices.
- They are used in 3D printing machines
- Used in microchips and self-driving cars
- Used in calculators, solar plates, computers and other electronic devices.
- Transistors and MOSFET used as a switch in electrical circuits are manufactured using semiconductors.

Industrial Uses of Semiconductors

The physical and chemical properties of semiconductors make them capable of designing technological wonders like microchips, transistors, LEDs, solar cells, etc.

The microprocessor used for controlling the operation of space vehicles, trains, robots, etc., is made up of transistors and other controlling devices, which are manufactured by semiconductor materials.

Importance of Semiconductors

Here, we have discussed some advantages of semiconductors, which make them highly useful everywhere.

- They are highly portable due to their small size
- They require less input power
- Semiconductor devices are shockproof
- They have a longer lifespan
- They are noise-free while operating

History and evolution of Electronics

What is Electronics?

Electronics is the study of flow and control of electrons. Thus the branch of electronics engineering is to study the behavior of an electron when they flow through various materials or devices like resistor, capacitor, semiconductor devices etc under different conditions of applied electric field. The device which controls the flow of electrons is called electronic devices.

History of Electronics:

1. Vacuum tube:

It is also called as electron tube or valve and it was first developed by John Ambrose Fleming in 1904. The vacuum tube is a tube in which gas is removed and thus vacuum is created. The basic working principle of vacuum tubes is thermionic emission. When you heat up a metal the thermal energy makes some electrons loose. The vacuum tube consisted of two electrodes a cathode and an anode placed on either side of the tube. When the cathode is heated up due to thermionic emission the electrons are loosened and while applying positive voltage to the anode, these negatively charged electrons (e-) are attracted towards anode. By creating vacuum that is by removing the gas the path is made clear for the electrons to move from cathode to anode. Thus current is created. It was bulky and used lot of electrical power and because of the heat produced it reduced the life of tube.

Uses:

Vacuum tubes was used in early computers as switch or amplifier.

2. Transistor :

Transistor was invented in 1947 by John Bardeen and Walter Brattain while working under William Shockley at Bell Labs and they were awarded Nobel prize. Transistor is a three terminal semiconductor device used to amplify or regulates current or voltage flow and acts as a switch or gate for electronic signals like faucet controls the flow of water. A voltage or current applied to one pair of transistor's terminals controls the current through another pair of terminals and it can amplify the signal also. Mostly silicon and germanium is used for manufacturing. Transistors are smaller in size than vacuum tubes and consume less and generate almost no heat.

Uses:

The first application of transistor was in Radios in 1950's

3. Integrated circuits's:

Integrated circuits is a set of electronic circuits on one small piece(chip) of semiconductor material normally silicon. Integrated circuits were first developed on September 12th 1958 by Jack Kilby at Texas instrument with five integrated components resistors, capacitors, distributed capacitors and transistors. An integrated circuit can hold transistors, resistors and capacitors . These integrated circuits can perform calculations and store data using either digital or analog technology.

Uses:

IC's found numerous applications from cars (automotive controls), televisions, computers, microwaves, portable devices like laptops, MP3, play stations, cameras, cellular phones to ship equipments, aero planes, space craft's.

Evolution of Integrated Circuit:

SSI- Small Scale Integration(Tens of transistors-1950s)

MSI- Medium Scale Integration (Hundreds of transistors-1960s)

LSI-Large scale integration (Thousands of transistors-1970s)

VLSI- Very Large Scale integration(Tens of thousands of transistors-1980s)

4. Very Large Scale integration (VLSI) :

VLSI began in the 1970s. Before the introduction of VLSI technology most ICs had a limited set of functions. VLSI involves packing more and more logic devices into smaller and smaller areas. In other words it's the process of combining millions of components into a single chip.

Uses:

Used in digital camera, cellphones, computers , automated machines etc

The advantages of VLSI design are

*High speed,

*Low power

*Physically smaller

*Higher reliability

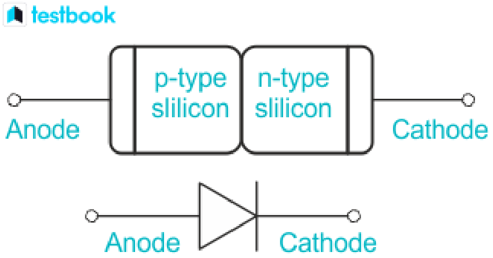
*More functionality.

Characteristics of PN Junction Diode

What is PN Junction Diode?

An interface or a boundary within a semiconductor device, between the P-type and the N-type semiconductor material, is called the PN junction. The P-side, or positive side, of a semiconductor, contains more holes than the N-side, or negative side, which has more electrons. The PN junction in a semiconductor is created by the doping process. A PN junction diode is a semiconductor device that is formed through this method and used in allowing the flow of electric current in one direction and blocking in the opposite.

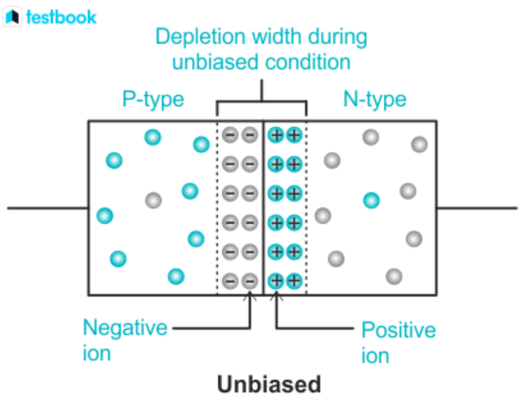
PN Junction Diode Symbol



Let us first discuss the process of doping to get a better understanding of the working principle of the PN junction diode.

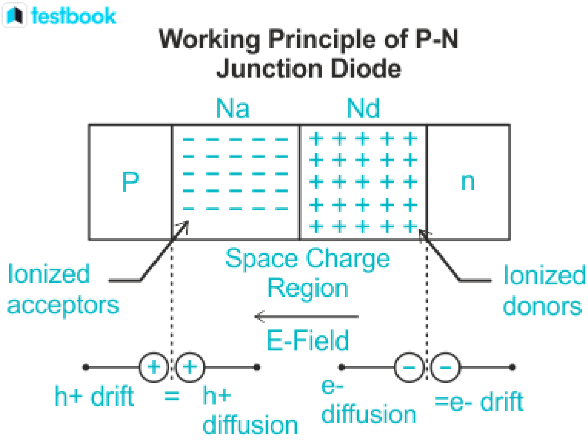
The technique used to increase or decrease the number of holes and electrons in a semiconductor is known as doping

To make N-type semiconductor material, atoms with one additional valence electron than silicon are employed. For this purpose, elements from group V of the periodic table are used. These elements have 5 valence electrons out of which 4 participate in the covalent bond formation with silicon and an additional valence electron is left unbound. As a result, more electrons are introduced to the conduction band, increasing the total amount of electrons in the system.



The elements from the 3rd group of the periodic table are mixed to create a P-type semiconductor. As a result, P-type materials only have three valence electrons to interact with silicon atoms. The total effect is a hole, as there aren't enough electrons to create the four covalent bonds that encircle the atoms and nuclei. The amount of electrons trapped in bonds is larger in P-type materials, thus increasing the number of holes. There is always more of one type of carrier than the other in doped material, and the carrier with the larger concentration is referred to as a 'majority carrier,' while the carrier with the lesser concentration is referred to as a 'minority carrier.' When these two types of semiconductors are joined together, a PN junction type of diode is formed.

Formation of PN Junction Diode



In a PN junction diode, an ionized donor is left behind on the N-side when an electron diffuses from the N-side to the P-side and a layer of positive charge develops on the N-side of the junction. When a hole moves from the P-side to the N-side, an ionized acceptor is left behind on the P-side, causing a layer of negative charges to accumulate on the P-side of the junction. The depletion area is defined as a region of positive and negative charge on each side of the junction. An electric field with a direction from a positive charge to a negative charge develops on either side of the junction.

The electric potential between P and N-regions changes when an external potential is supplied to the PN junction terminals. As a result, the flow of the majority of carriers is altered, allowing electrons and holes to diffuse through the PN junction.

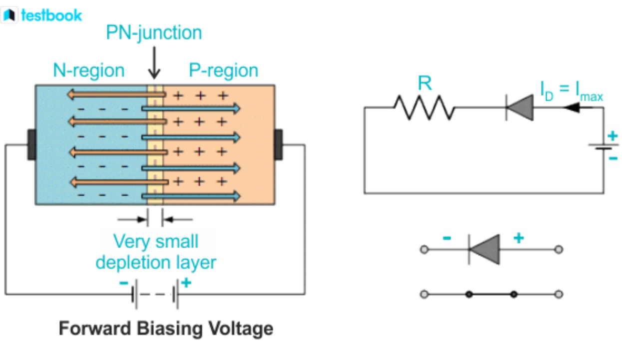
The diode is thought to be in the forward bias state if the applied voltage reduces the width of the depletion layer, and reverse bias if the applied voltage increases the width of the depletion layer. The diode is said to be in the zero bias or unbias state if the breadth of the depletion layer remains unchanged.

Biasing Conditions of PN Junction Diode

Let us understand the working principle of forward and reverse bias conditions of the PN junction in detail.

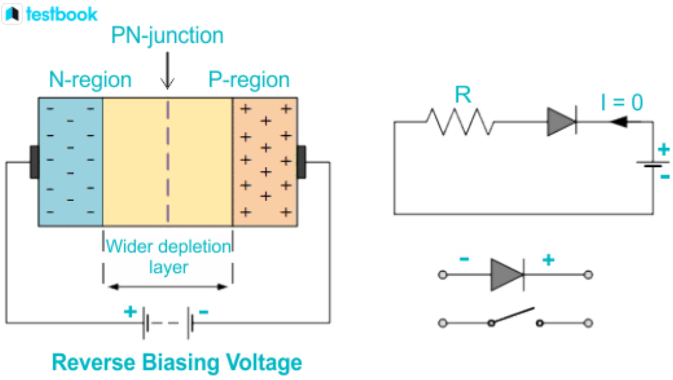
Forward Bias

The PN junction is forward-biased when the P-type is connected to the positive terminal of the battery and the N-type is connected to the negative terminal. In this condition, the applied electric field and the built-in electric field at the PN junction are in opposing directions.



Adding both the electric fields gives a resultant electric field, thus the resulting electric field is found to be smaller than the built-in electric field. As a result, the depletion area becomes thinner and less resistant. When the applied voltage is high, the resistance of the depletion area becomes insignificant. At 0.6 V, the resistance of the depletion zone in silicon becomes absolutely insignificant, allowing current to flow freely over it.

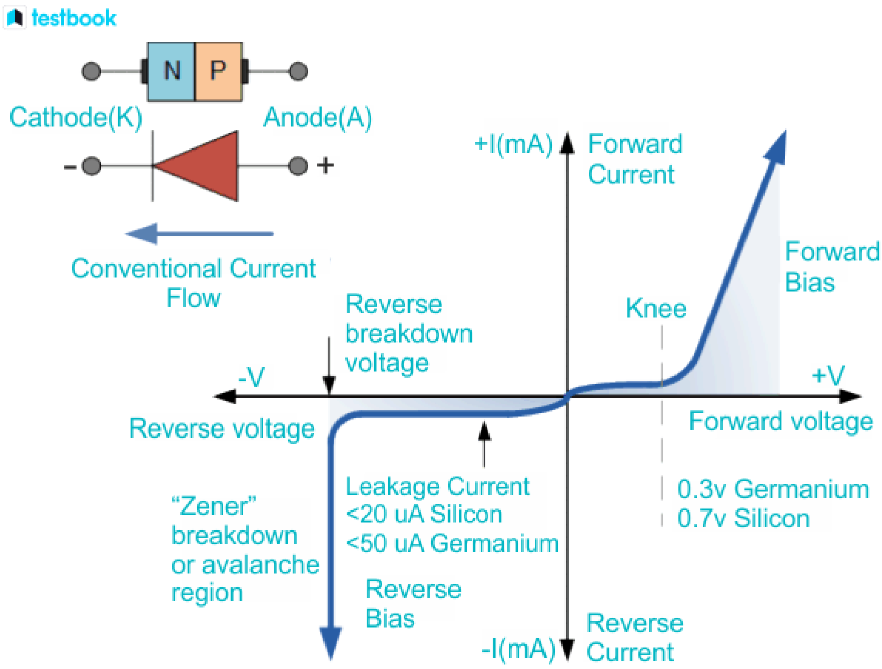
Reverse Bias



The PN junction is reverse biased when the P-type is connected to the negative terminal of the battery and the N-type is connected to the positive side. In this condition, the applied electric field and the built-in electric field are both in the same direction. The resultant electric field and the built-in electric field are also in the same direction, resulting in a more resistive, thicker depletion area. Increasing the applied voltage results in a thicker and more resistant depletion area.

V-**I Characteristics of PN Junction**

The relationship between the voltage across the junction and current through the circuit is known as the volt-ampere (V-I) characteristics of a PN junction or semiconductor diode. Normally, voltage is measured along the x-axis, whereas the current is measured along the y-axis.



The V-I characteristics of the PN junction can be explained in three cases:

- Zero bias or unbias
- Forward bias
- Reverse bias

No movement of holes or electrons occurs at zero bias state as no potential is applied externally which prevents the passage of electric current to flow in the diode.

When the PN junction diode is in the forward bias, the P-type is linked to the positive terminal of the external voltage, while the N-type is connected to the negative terminal. This arrangement of diodes reduces the potential barrier. When the voltage is 0.7 V for silicon diodes and 0.3 V for germanium diodes, the potential barriers diminish, and current flows.

The current grows slowly while the diode is in the forward bias, and the curve formed is non-linear because the voltage supplied to the diode surpasses the potential barrier. Once the diode has broken over the potential barrier, it operates normally, and the curve climbs steeply as the external voltage rises, yielding a linear curve.

When the PN junction diode is in negative bias, the P-type is linked to the negative terminal of the external voltage, while the N-type is connected to the positive terminal which leads to the higher potential barrier. Because minority carriers are present at the junction, a reverse saturation current occurs at first.

Difference between PN Junction Diode & Zener Diode

The differences between PN Junction Diode and Zener Diode are as follows:

PN Junction Diode	**Zener Diode**
The current flows in one direction only	The current can flow in both directions
Depletion layer of the PN junction gets completely damaged in reverse bias	In the Zener diode, the current flows in both the directions even in the reverse bias state
The PN region is lightly doped in a PN junction diode which makes the depletion region wider.	The depletion region is narrower in the Zener diode as the PN junction is doped heavily.
The main application of the PN junction diode is in the process of rectification	Zener diodes are mainly used for voltage regulation purposes.

Properties of PN Junction Diode

Following are some of the common properties of a PN junction diode:

- PN junction diode has the ability to rectify electric current
- It can create a potential barrier and make use of its capacitance properties
- PN junction creates various nonlinear current-voltage characteristics in the semiconductor diode
- The most important property is transforming light energy into electrical energy
- The PN junction diode irradiates when the current flows through it.

Applications of PN Junction Diode

Some of the most exciting applications of PN diodes are as follows

- PN junction diode is utilized as a more triple, voltage doubler, and quadruple in voltage multiplier circuits as well as a switch in various electrical circuits.

- These are used in numerous circuit rectifiers, and varactors for voltage-controlled oscillators.
- While the PN junction diode produces light when biased with a current, hence it is employed in light-emitting diode (LED) and photodiode applications.
- PN junction diodes can also be used for another diode termed a light amplification stimulated emission of radiation.
- In power electronics engineering, it can be employed in solar cells.
- It is employed in the detector as well as the demodulator circuit thus it can be used as a detector for the demodulation circuit.
- They are used as clamps to adjust the reference voltage.
- The voltage across the PN junction diode is used to produce temperature sensors and reference voltages.

Zener Effect

The Zener effect is a type of electrical breakdown that occurs in a reverse-biased PN junction when the electric field enables tunnelling of electrons from the valence to the conduction band of a semiconductor, leading to a large number of free minority carriers which suddenly increase the reverse current. The Zener effect is best-known for its use in the appropriately-named Zener diode.

A normal PN junction diode freely allows current flow if forward biased, but blocks current if it is reverse biased – a useful attribute in rectifier circuits, for example. However, if the reverse voltage applied across such a diode becomes too high, the device will break down and probably suffer permanent damage.

A Zener diode behaves similarly to the extent that it allows forward current, but blocks it if reverse-biased. The difference comes if the reverse voltage reaches the device's critical break-down value, because it begins to conduct in the reverse direction. This is due to an effect known as avalanche breakdown, which occurs in the semiconductor depletion layer; a current starts to flow through the diode to limit the voltage increase.

The voltage value at which the Zener breakdown occurs can be very accurately set by the semiconductor manufacturer's doping stage; this allows Zener diodes to be widely used as voltage reference devices in power supply circuits. The devices are also valuable as voltage limiters, preventing spikes from reaching and damaging electronic equipment.

Zener Diode and its Characteristics

Zener Diode is one of the most important semiconductor diodes used in our daily life. It is a specific diode that works in reverse bias conditions. It allows current to flow from anode to cathode and it also works in the reverse direction. Let's learn about Zener Diodes their function, and their construction, in detail in this article.

Zener Diode

A heavily doped p-n junction diode that works in reverse bias conditions is called a Zener Diode. They are special semiconductor devices that allow the current to flow in both forward and backward directions. For the Zener diode, the voltage drop across the diode is always constant irrespective of the applied voltage. Thus, Zener diodes are used as a voltage regulator.

What is Zener Diode?

A Zener diode can be considered as a highly doped p-n junction diode which is made such that it works in reverse bias condition.

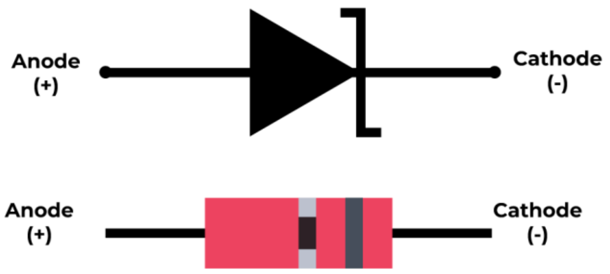
A Zener diode which is also called a Breakdown diode works in reverse bias conditions. An electrical breakdown occurring in the reverse-biased condition of the PN junction diode is called the Zener effect. In this condition when the electric field increases to a high value it enables the tunnelling of electrons from the valence band to the conduction band of a semiconductor, which suddenly increases the reverse current.

Zener Diode Explanation

Zener diode that is also known as a breakdown diode is a heavily doped semiconductor device that has been specially designed to operate in the reverse direction. When the potential reaches the Zener voltage which is also known as Knee voltage and the voltage across the terminal of the Zener diode is reversed, at that point time, the junction breaks down and the current starts flowing in the reverse direction. This effect is known as the Zener effect.

Zener Diode Circuit Diagram

The figure given below is the circuit diagram of the Zener diode. The Zener diode has applications in various electronic devices and it works in reverse biasing conditions. In reverse biasing, the P-type material of the diode is connected with the negative terminal of the power supply, and the n-type material is connected with the positive terminal of the power supply. The diode consists of a very thin depletion region as it is made up of heavily doped semiconductor material.



A Zener diode can be packed in many ways. Some Zener diodes are used where high levels of power dissipation are required. The Zener diode which is the most commonly used is contained within a small glass encapsulation having a band around one end marking the cathode side of the diode.

There are two tags at the end of the bar in the circuit symbol of the Zener diode, one in the upward direction and the other in the lower direction, as shown in the figure given below. In this way, we can easily distinguish between the Zener diode and other diodes.

Zener Diode Working

High-level impurities are added to a Zener diode to make it more conductive and thus the Zener diodes can easily conduct electricity compared to other p-n junction diodes. These impurities reduce the depletion layer of the Zener diode and make it very thin. Thus, this diode also works even if the voltage applied is very small.

In no biassing condition of the Zener diode, all the electrons accumulate in the valence band of the p-type semiconductor material and thus no current flow occurs through the diode.

In reverse bias conditions, if the Zener voltage is equal to the supplied voltage, the diode conducts electricity in the direction of reverse bias. When the Zener voltage equals the supplied voltage the depletion layer vanishes completely.

Zener Diode Working in Reverse Biased

In forward-biased conditions, the Zener Diode works like any normal diode but in the reverse-bias condition, a small leak current flows through the diode. As we keep increasing the reverse voltage it reaches a point where the reverse voltage equals the breakdown voltage. The breakdown voltage is represented as V_z and in this condition the current start flowing in the diode. After the breakdown voltage the current increase drastically unit it reaches a stable value.

In reverse bias condition, two kinds of breakdowns occur for Zener Diode which are,

- Avalanche Breakdown
- Zener Breakdown

Avalanche Breakdown

The phenomenon of Avalanche breakdown occurs both in the ordinary diode and Zener Diode at high reverse voltage. For a high value of reverse voltage, the free electron in the PN junction diode gains energy and acquires high velocity and these high-velocity electrons collide with other atoms and knock electrons from that atoms. This collision continues and new electrons are available for conducting current thus the current increase rapidly in the diode.

This phenomenon of a sudden increase in the current is called the Avalanche breakdown. This phenomenon damages the diode permanently whereas the Zener diode is a specific diode that is made to operate in this reverse voltage area.

If the reverse voltage is greater than 6V the avalanche breakdown happens in the Zener diode.

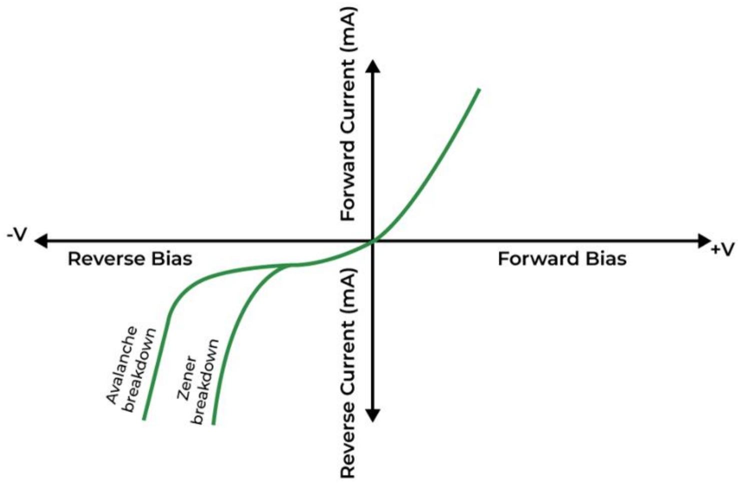
Zener Breakdown

Zener breakdown happens in heavily doped PN junction diodes. In these diodes, if the reverse bias voltages reach closer to Zener Voltage, the electric field gets stronger and is sufficient enough to pull electrons from the valance band. These electrons then gain energy from the electric field and break free from the atom.

Thus, for these diodes in the Zener breakdown region, a slight increase in the voltage causes a sudden increase in the current.

VI Characteristics of Zener Diode

The graph given underneath shows the V-I characteristics of the Zener diode.



Forward Characteristics of Zener Diode

Forward characteristics of the Zener Diode are similar to the forward characteristics of any normal diode. It is clearly evident from the above diagram in the first quadrant that the VI forward characteristics are similar to other P-N junction diodes.

Reverse Characteristics of Zener Diode

In reverse voltage conditions a small amount of current flows through the Zener diode. This current is because of the electrons which are thermally generated in the Zener diode. As we keep increasing the reverse voltage at any particular value of reverse voltage the reverse current increases suddenly at the breakdown point this voltage is called Zener Voltage and is represented as V_Z.

Applications of Zener Diode

Zener diode is a very useful diode. Due to its ability to allow current to flow in reverse bias conditions, it is used widely for various purposes. Some of the common uses of Zener Diode are discussed below,

Zener diode as Voltage Regulator

Zener diode is utilized as a Shunt voltage controller for managing voltage across little loads. The breakdown voltage of Zener diodes will be steady for a wide scope of current. The Zener diode is associated with corresponding to the heap to make it switch predisposition and when the Zener diode surpasses knee voltage, the voltage across the heap will become consistent.

Zener Diode in Over-Voltage Protection

At the point when the info voltage is higher than the Zener breakage voltage, the voltage across the resistor drops bringing about a short-out. This can be kept away from by utilizing the Zener diode.

Zener Diode in Clipping Circuits

Zener diode is utilized for adjusting AC waveform cutting circuits by restricting the pieces of it is possible that one or both the half patterns of an AC waveform.

Zener Diode Specifications

Zener Diode is one other most commonly used diode and some of the specifications of Zener diode are,

- **Zener Voltage:** The voltage at which Zener breakdown occurs in the Zener diode is called as Zener Voltage. It is denoted by V_z generally it ranges from 2.4 volts to 200 volts.
- **Current I_z (max):** The maximum current that the diode can achieve at the Zener Voltage is called max current. It ranges from 200µA to 200 A
- **Current I_z (min):** The minimum current required for the diode to break down is called min current.
- **Power Rating:** The maximum power the Zener diode can dissipate is the power rating of that diode. Power is calculated by taking the product of the breakdown voltage and the value of current at that time.
- **Temperature Stability:** Temperature stability of the Zener diode is greatest at 5V.
- **Voltage Tolerance:** Voltage Tolerance for any Zener diode is normally ±5%
- **Zener Resistance (R_z):** The resistance exhibited by the Zener diode is called Zener Resistance.

Bipolar Junction Transistor

The Bipolar Junction Transistor is a semiconductor device which can be used for switching or amplification

Unlike semiconductor diodes which are made up from two pieces of semiconductor material to form one simple pn-junction. The *bipolar transistor* uses one more layer of semiconductor material to produce a device with properties and characteristics of an amplfier.

If we join together two individual signal diodes back-to-back, this will give us two PN-junctions connected together in series which would share a common *Positve,* (P) or *Negative,* (N) terminal. The fusion of these two diodes produces a three layer, two junction, three terminal device forming the basis of a **Bipolar Junction Transistor**, or **BJT** for short.

Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then bipolar transistors have the ability to operate within three different regions:

- Active Region – the transistor operates as an amplifier and Ic = β*Ib
- Saturation – the transistor is "Fully-ON" operating as a switch and Ic = I(saturation)
- Cut-off – the transistor is "Fully-OFF" operating as a switch and Ic = 0

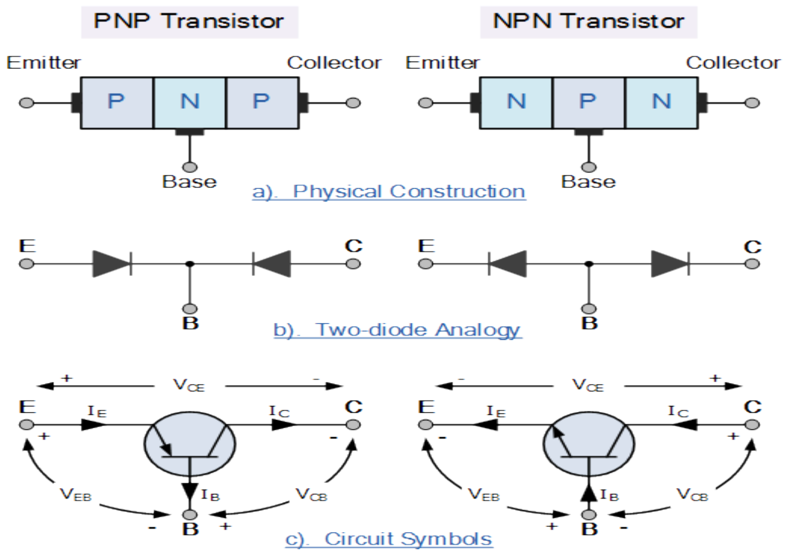
A Typical Bipolar Transistor

The word Transistor is a combination of the two words Transfer Varistor which describes their mode of operation way back in their early days of electronics development. There are two basic types of bipolar transistor construction, PNP and NPN, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.

The **Bipolar Transistor** basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively.

The principle of operation of the two transistor types PNP and NPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.

Bipolar Transistor Construction



The construction and circuit symbols for both the PNP and NPN bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal. The direction of the arrow always points from the positive P-type region to the negative N-type region for both transistor types, exactly the same as for the standard diode symbol.

Common Base (CB) configuration (or) Grounded base configuration

In this circuit arrangement, input is applied between the emitter and base, and output is taken from the collector and base. Here, the base of the transistor is common to both input and output circuits and hence the name common base connection.

In figure (a) the common base npn transistor circuit is shown whereas figure (b) shows the common base pnp transistor circuit.

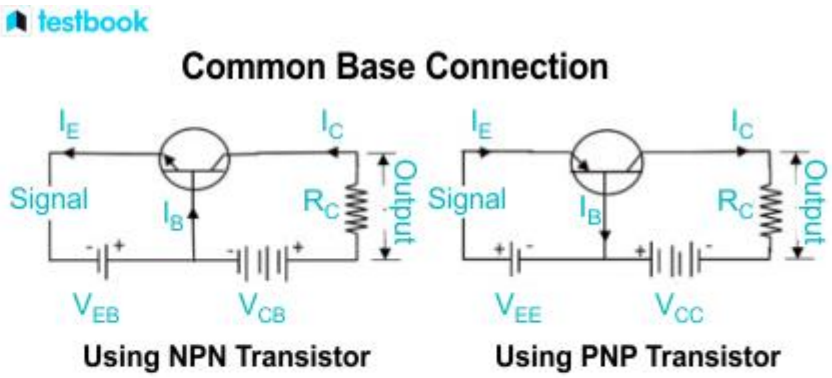


Fig: Common Base Configuration

Input and Output Characteristics of Common Base Configuration

Input Characteristics: It is the curve between input current IE (emitter current) and input voltage VEB (emitter-base voltage) at constant collector-base voltage VCB. The emitter current is taken along Y-axis and the emitter-base voltage is along X-axis. The figure shows the input characteristics of a typical transistor in a common-base configuration.

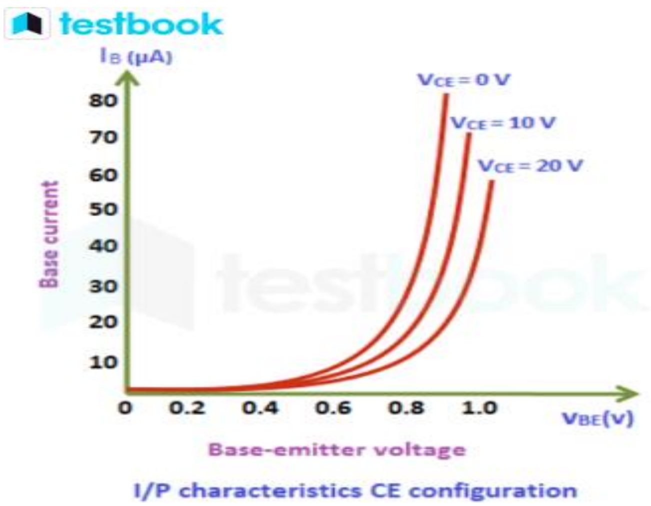


Fig: Input Characteristics of Common Base Configuration

Output Characteristics: It is the curve between collector current IC and collector base voltage, VCB at constant emitter current IE. The collector current is taken along Y-axis and the collector-base voltage magnitude is along X-axis. The figure shows the output characteristics of a typical transistor in a common base configuration.

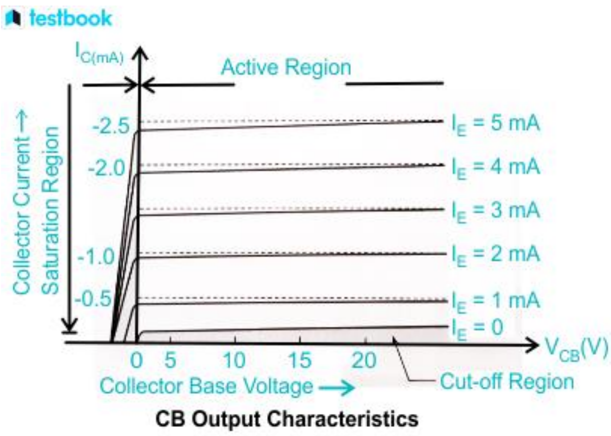


Fig: Output Characteristics of Common Base Configuration

Common Emitter (CE) Configuration

In this circuit arrangement, input is applied between the base and emitter, and output is taken from the collector and emitter. Here, the emitter of the transistor is common to both input and output circuits and hence the name common emitter connection. Figure (a) shows a common emitter npn transistor circuit whereas Figure (b) shows common emitter pnp transistor circuit.

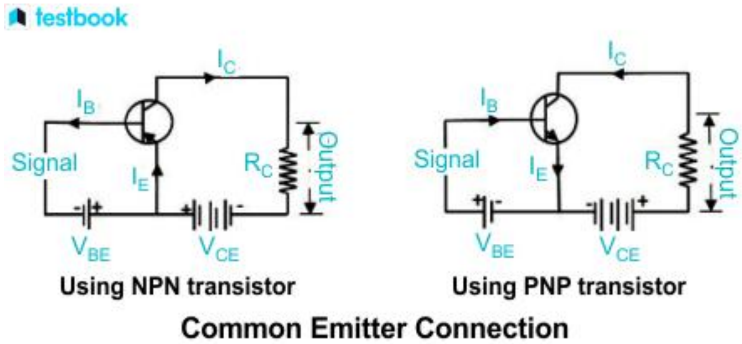


Fig: Common Emitter Configuration

Input and Output Characteristics of Common Emitter Configuration

Input Characteristics: It is the curve between input current IB (base current) and input voltage VBE (base-emitter voltage) at constant collector-emitter voltage, VCE. The base current is taken along Y-axis and base-emitter voltage VBE is taken along X- the axis Figure shows the input characteristics of a typical transistor in a common-emitter configuration.

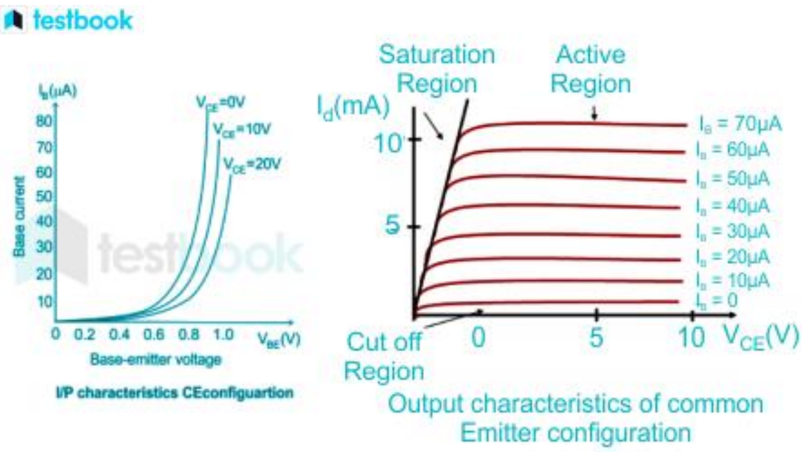


Fig: Input and Output Characteristics of Common Emitter Configuration

Output Characteristics: This characteristic shows the relation between the collector current Ic and collector voltage VCE, for various fixed values of Ig. These characteristics are often called **collector characteristics**. A typical family of output characteristics for an n-p-n transistor in CE configuration is shown in Figure.

Common Collector (CC) Configuration

In this circuit arrangement, input is applied between the base and collector while output is taken between the emitter and collector. Here, the collector of the transistor is common to input and output circuits and hence the name common collector connection. Figure (a) shows a common collector n-p-n transistor circuit where as Figure (b) shows a common collector p-n-p circuit.

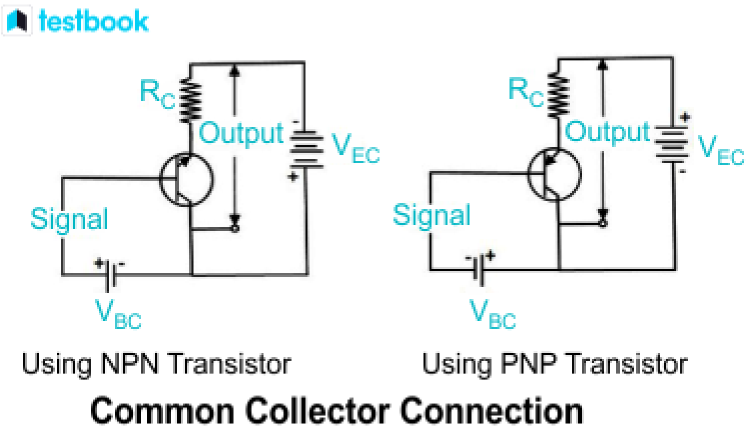


Fig: Common Collector Configuration

Input and Output Characteristics of Common Collector Configuration

Input Characteristics: To determine the input characteristics, VCE is kept at a suitable fixed value. The base-collector voltage VBC is increased in equal steps and the corresponding increase in IB is noted. This is repeated for different fixed values of VCE. The plots of IB verses for different values of VCE shown in Figure are the input characteristics.

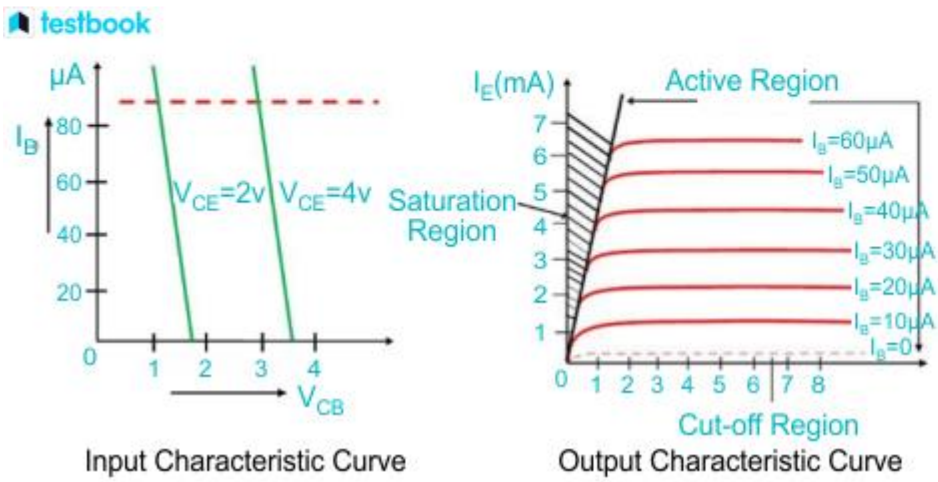
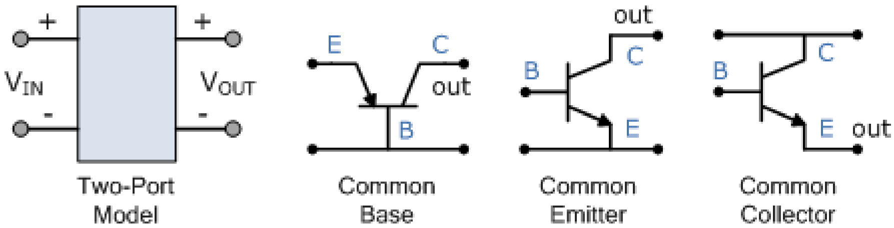


Fig: Input and Output Characteristics of Common Collector Configuration

Output Characteristics: The output characteristics shown in Figure, are the same as those of the common emitter configuration. This characteristics shows the relation between the emitter current IE and collector voltage VCE, for various fixed values of IB. These characteristics are often called **collector**

characteristics. A typical family of output characteristics for an n-p-n and p-n-p transistor in CC configuration is shown in Figure.

Bipolar Transistor Configurations



with the generalised characteristics of the different transistor configurations given in the following table:

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Shift	0^o	180^o	0^o
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium