ANALOG ELECTRONICS

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Unit Name	Hours	Marks
1 Semiconductors and Diodes	7	**20**
2 Transistors and MOSFETs	12	35
3 Optoelectronic devices	6	15
4 Rectifiers, filters and regulators	7	20
5 Amplifiers and Oscillators	11	30
6 OP-AMP and Timers	9	25

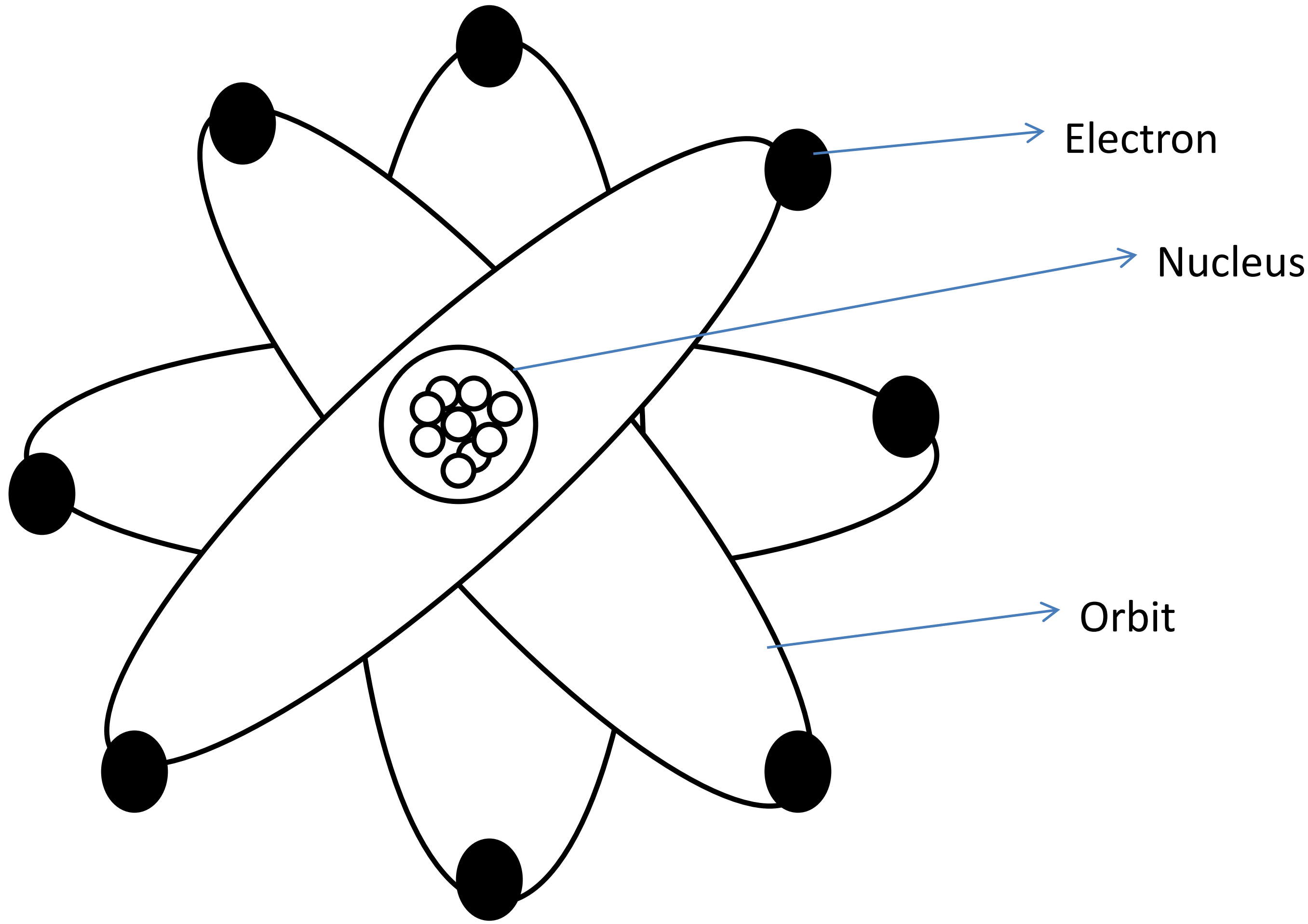
Unit –I

Semiconductors and Diodes:

Electrons- free and valence. Conductors, Insulators, and Semiconductors- definition &energy band diagrams.Properties of semiconductors. Meaning of Hole current, electron-hole pairs, recombination, doping, acceptor and donor impurities.
Intrinsic and Extrinsic, N and P type semiconductors.
Diode- formation, depletion region, VI Characteristics, ratings, types and applications. Zener diode- reverse bias characteristics, voltage regulation, shunt voltage regulator, and applications. Varistor and Thermistor working and applications.

ATOM

Atom is the smallest particle of an element consisting of positively charged nucleus around which electrons revolve in different orbits called as shells.



Charge of a electron is 1.602*10^-19 C
Mass of an electron is 9.1*10^-31 kg

Valence Electrons : The electrons in the outermost orbit of an atom is known as valence electrons.

These are loosely bound to the nucleus and can be easily dislodged from the orbit by applying certain external force like heat, light etc.

Conductors, Insulators and Semiconductors:

Conductors:

The materials which allows electric current to flow through them easily are called conductors.

Ex: silver, copper and gold

Insulators:

The materials which do not allow the electric current to flow through them are called as insulators.

Ex: Glass, plastic, rubber

Semiconductor:

The materials whose conductivity lies between conductors and insulators are called as semiconductors.

Ex: silicon, germanium

Types of Semiconductor:

There are two types of semiconductor

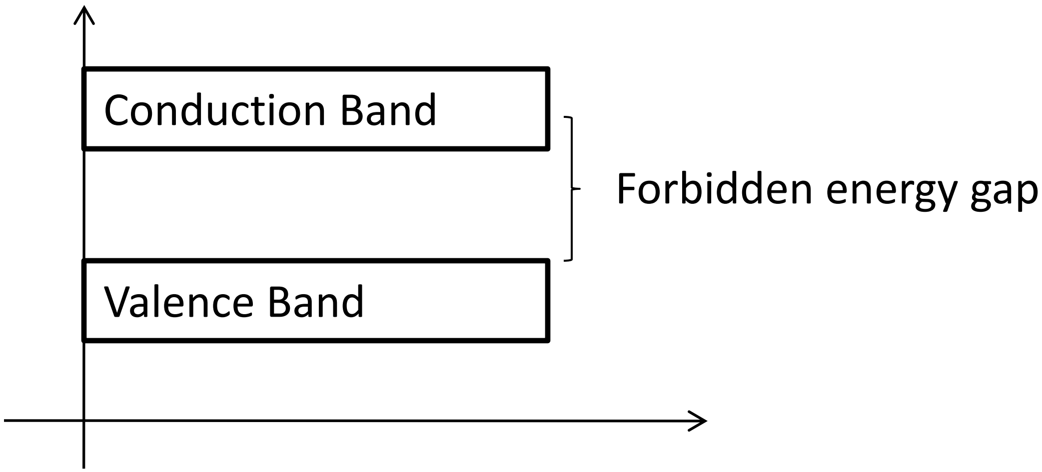
1. Intrinsic semiconductor
2. Extrinsic semiconductor

Energy Bands:

The range of energies possessed by an electron in a solid is called energy band.

Important bands in solid are

1. Valence Band
2. Conduction Band
3. Forbidden energy gap



1. Valence Band:

The range of energies possessed by valence electrons is known as valence band.

In a normal atom valence band has highest energy.

2. Conduction band:

The range of energies possessed by conduction band electrons is known as conduction band.

3. Forbidden energy gap:

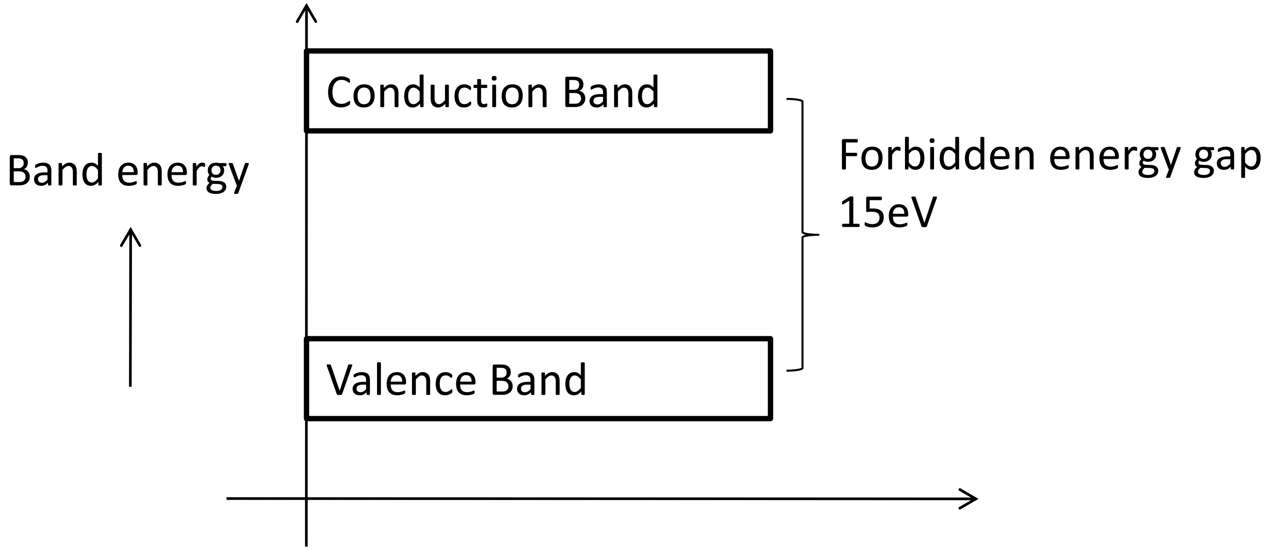
The separation between conduction band and valence band is known as forbidden energy gap.

No electrons can stay in forbidden energy gap.

Energy band diagram in solids

1.Insulators:

In terms of energy band, the valence electrons is full and the conduction band is empty. The energy gap between valence and conduction band is very large as shown in the fig below.

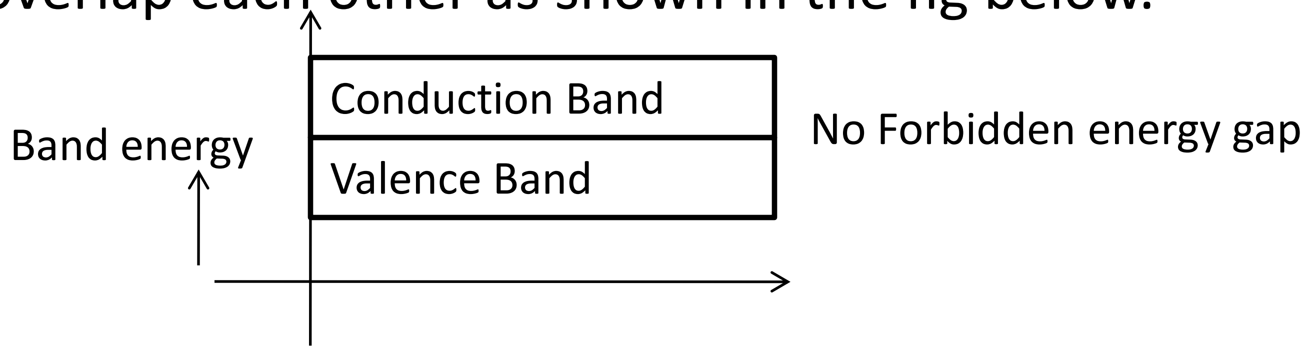


Therefore very high electric field is required to push the electrons from valence band to the conduction band . For this reason the electrical conductivity of such materials is extremely small.

Property: Insulators are having negative temperature coefficient of resistance

2. Conductors:

In terms of energy band the valence band and conduction band overlap each other as shown in the fig below.

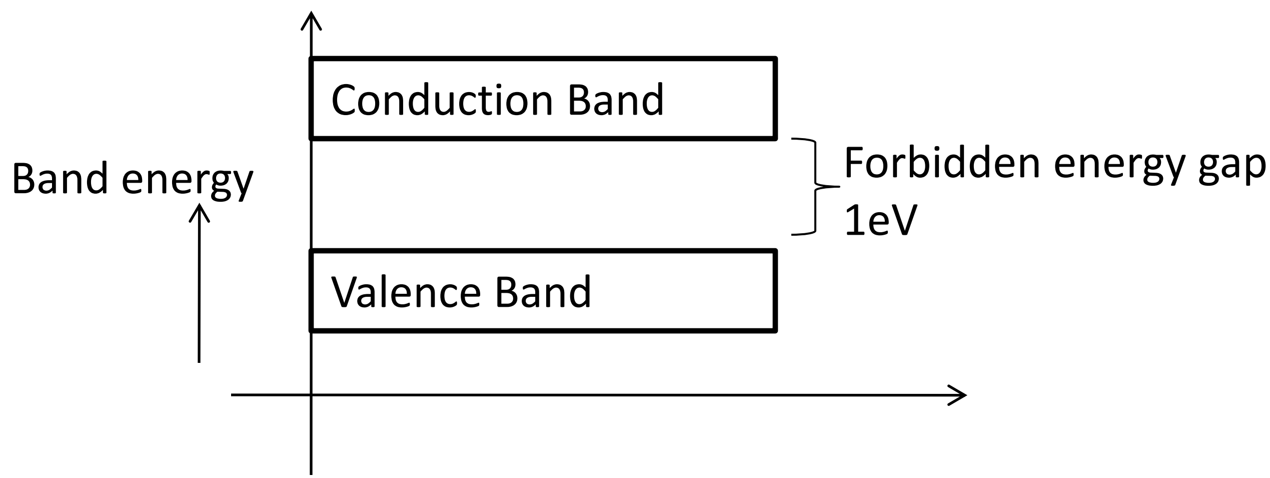


A slight electric field across the conductor causes the electrons to move from valence band to conduction band. There is no energy gap in the conductors

Property: Conductors are having positive temperature coefficient of resistance

3. Semiconductors:

In terms of energy band the valence band is almost filled and the conduction band is empty. The energy gap between the conduction band and the valence band is very small as shown in the fig below.



Therefore comparatively smaller electric field is required to push the electrons from valence band to conduction band at low temperature.

Properties of Semiconductor:

1. The resistivity of semiconductor is less than that of insulator and more than that of conductor.
2. Semiconductor is having negative temperature coefficient of resistance.
3. When a suitable impurity is added to a semiconductor, its current conducting property changes appreciably.
4. Semiconductors are crystalline structure
5. Semiconductors are good conductor at high temperature and insulator at low temperature.

Important definition:

1. Hole: When an electron jumps from valence band to conduction band it leaves a vacancy(empty) in valence band called as hole.

2. Hole Current: Holes are positively charged, movement of holes constitute a current called hole current.

3. Electron current: The movement of free electrons constitute a current called electron current.

4. Recombination: The merging of free electrons and holes is called recombination.

5. Electron hole pair: The electron hole pair is the fundamental unit of generation and recombination corresponding to the electron transition between the valence band and conduction band.

6. Doping: The process of adding impurities to a pure semiconductor is called doping.

7. Acceptor Impurity: The impurity atom which accepts the electrons from the valence band are known as acceptor impurity.

8. Donor impurity: The impurity atom which donates the electrons are called donor impurity.

Comparison between Intrinsic and Extrinsic semiconductor:

Intrinsic Semiconductor	**Extrinsic Semiconductor**
1. Purest form without any impurity	1. Impurity is added hence not pure
2. Naturally available	2. Obtain by the process called doping
3. Conductivity is very low	3. Conductivity is high and can be control by doping
4. Number of electrons and holes are equal	4. Either the electrons or holes are more in number
5. Practically not used for manufacturing device Ex: pure silicon and pure germanium	5. Used for manufacturing for electronic devices. Ex: n type, p type

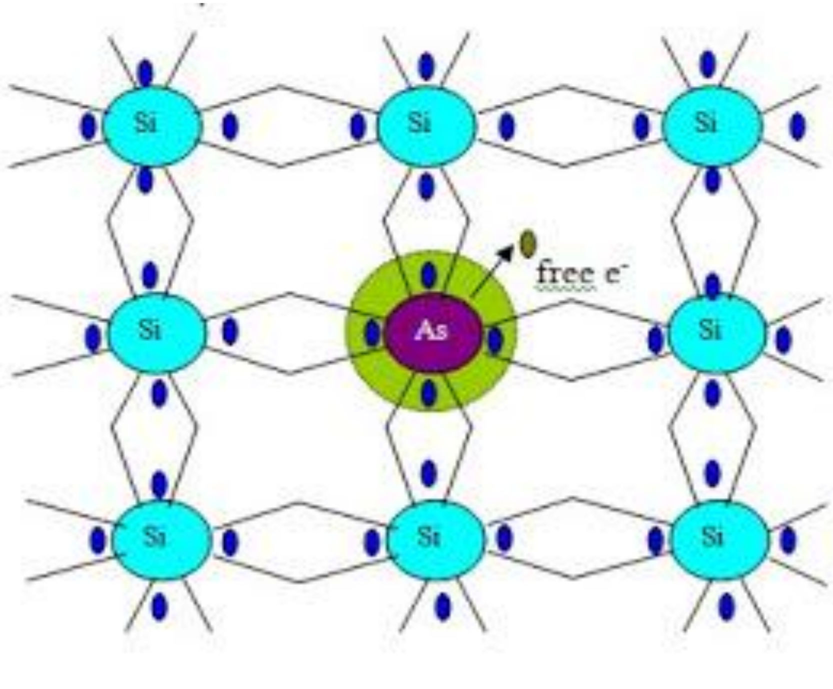
Types of extrinsic semiconductor:

There are two types of extrinsic semiconductor

1. N type semiconductor
2. P type semiconductor

1.N type semiconductor:

When a small amount of penta valent impurity is added to a pure semiconductor is known as n type semiconductor.

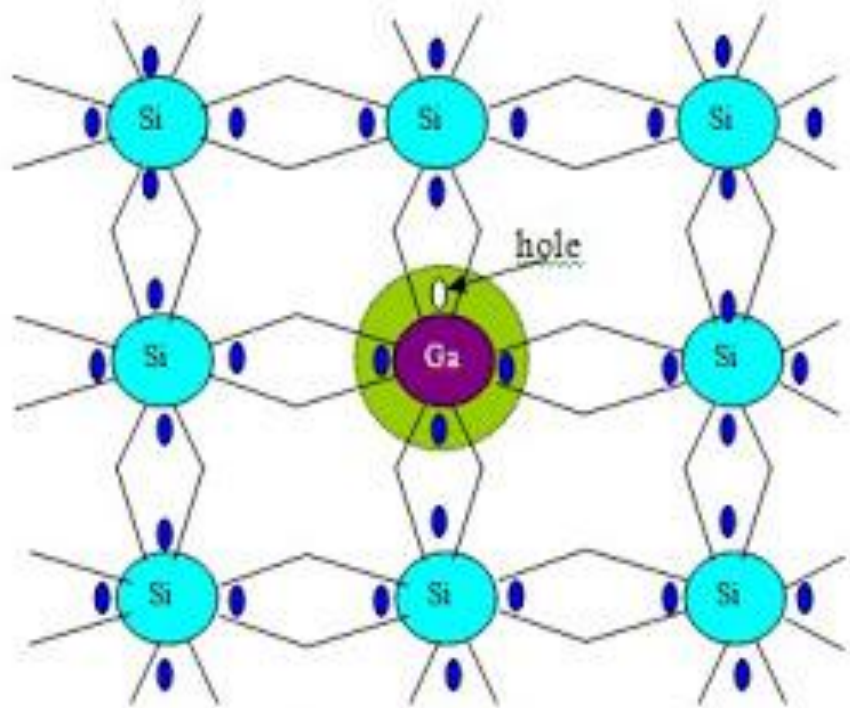


n-type semiconductor

1. Consider a pure silicon crystal consisting of 4 valence electrons.
2. When a small amount of penta valent impurity like arsenic, bismuth, phosphorous is added to a silicon crystal a large number of free electrons becomes available in the crystal.
3. The arsenic penta valent atom has 5 valence electrons . Arsenic atom fits in the silicon crystal in such a way that 4 atoms of arsenic forms covalent bond with 4 valence electrons of silicon atom.
4. The 5^{th} valence electron of arsenic finds no place in covalent bond and thus becomes free as shown in the figure above.
5. In N type the majority charge carriers are free electrons

1. <u>P type semiconductor</u>:

When a small amount of trivalent impurity is added to a pure semiconductor is known as p type semiconductor.

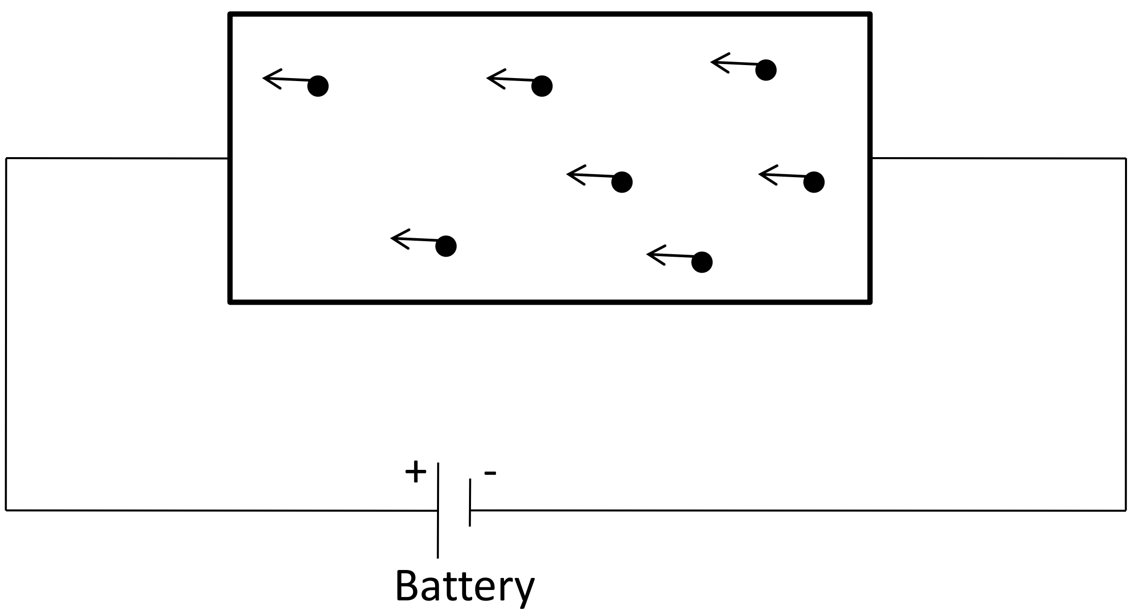


p-type semiconductor

1. Consider a pure silicon crystal, when a small amount of trivalent impurity like indium, gallium, boron is added to a silicon crystal there exists a large number of holes in the crystal.
2. Gallium is a trivalent atom it has 3 valence electrons fits into the silicon crystal by forming 3 covalent bonds with three electrons of silicon atom which is shown in the figure.
3. The fourth bond is incomplete being shortage of one electron which creates a hole.
4. Therefore for each gallium atom added one hole is created.
5. In p type semiconductor the majority charge carriers are holes.

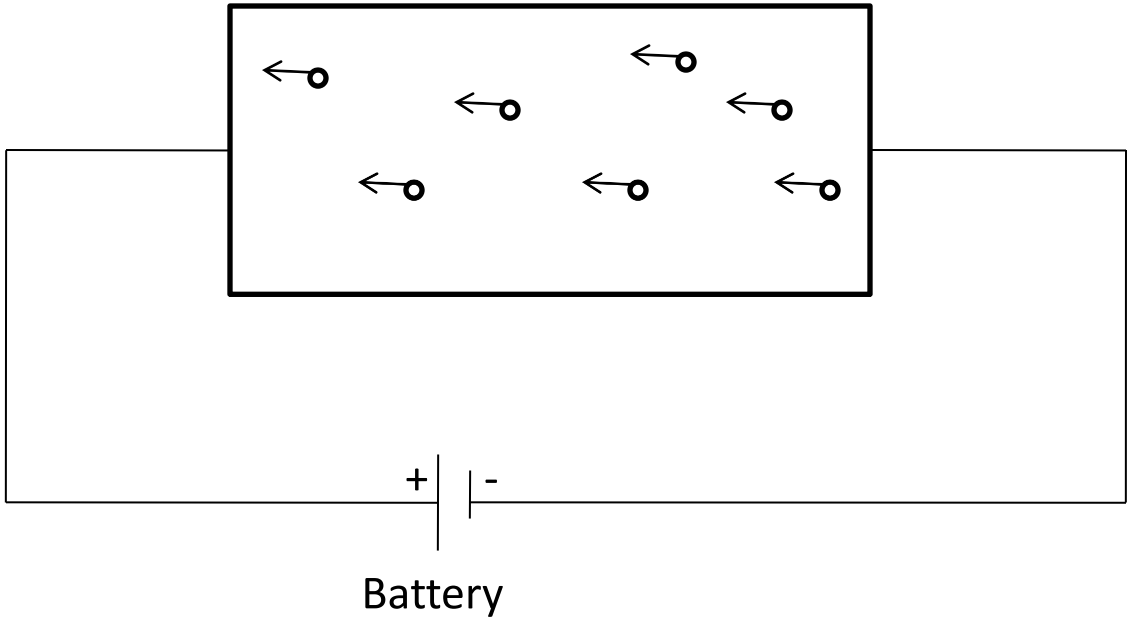
Conduction in n type material:

If the voltage is applied, the current is the mainly because of free electrons which are obtained by adding a pentavalent impurity to a pure semiconductor. The free electrons are large in number hence the electrons are the majority charge carriers while there is a small current due to less number of holes hence holes are minority charge carriers.



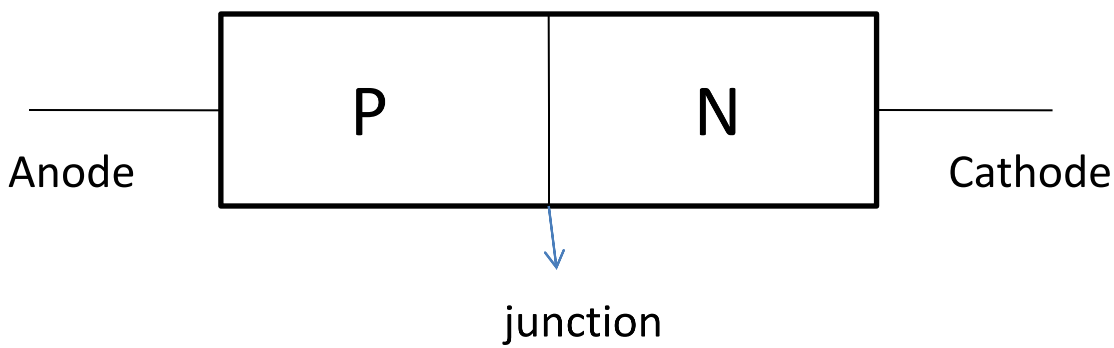
Conduction in p type material:

If the voltage is applied, the holes which are large in number by adding a trivalent impurity to a pure semiconductor. The holes are majority charge carriers and electrons are less in number they are minority charge carriers.



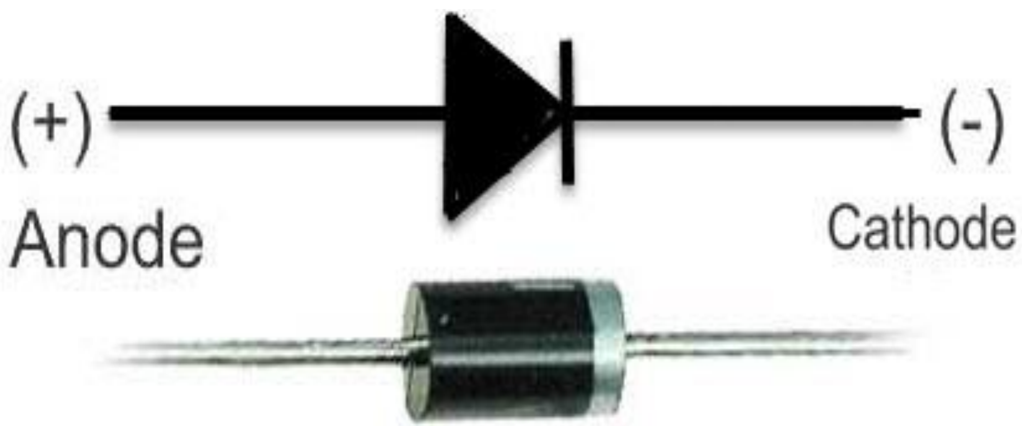
Diode/ p n junction:

When a p type semiconductor is suitably joined to n type semiconductor. The contact surface is called pn junction.



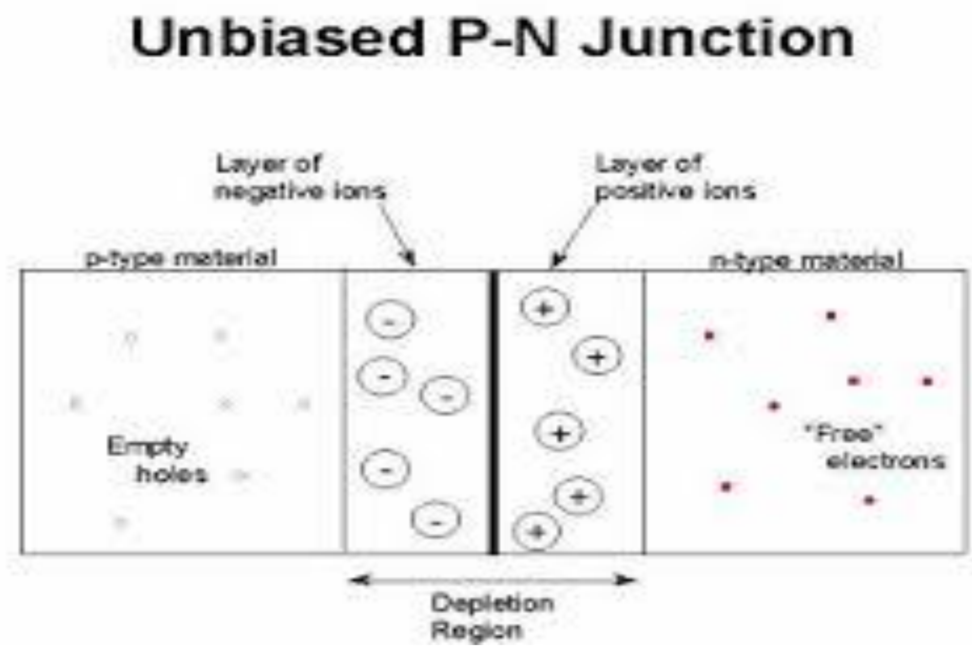
It is a two terminal device consisting of pn junction formed by either germanium or silicon. The pn junction has two terminals called electrode, one form p region and another form n region. Since there are two electrodes it is called diode.

The p region acts as anode while the n region acts as a cathode. The arrow head in a symbol indicates the direction of current. The pn junction allows the current flow in only one direction.



Symbol of diode

Formation of depletion region in unbiased diode:



1.At the instant of pn junction formation, the free electrons near the junction in the n region begins to move across the junction into the p region where they combine with the holes near the junction.

2.The resulting n region losses free electrons as they diffuse into the junction, this creates a layer of positive charge near the junction.

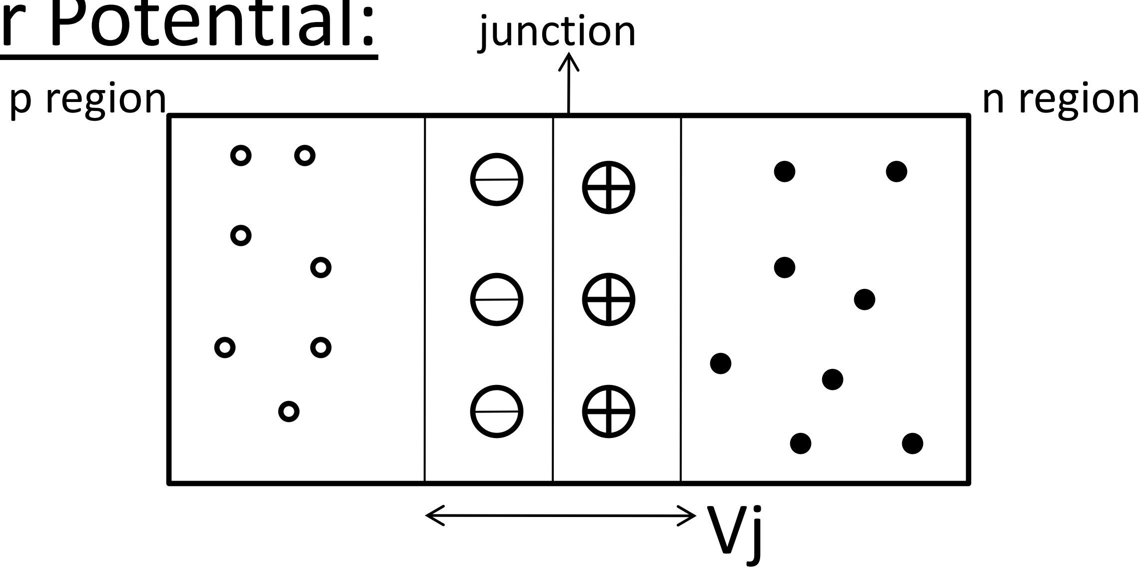
3. Similarly the holes from the p region move across the n region and combine with the holes.

4. The result is that there is a layer of negative charge near the junction. These two layers of positive and negative charge forms the depletion region.

5.Once the pn junction is formed and depletion layer is created, the diffusion of free electrons and holes stops.

6. In other words the depletion layer acts as a barrier to the further movement of free electrons and holes across the junction.

Barrier Potential:



Due to immobile positive ions on n side and negative ions on p side, there exists an electric field across the junction which creates potential difference in the depletion region which acts as a barrier this is called barrier potential, junction potential, built in potential, cut in potential of pn junction.

It is denoted by Vj

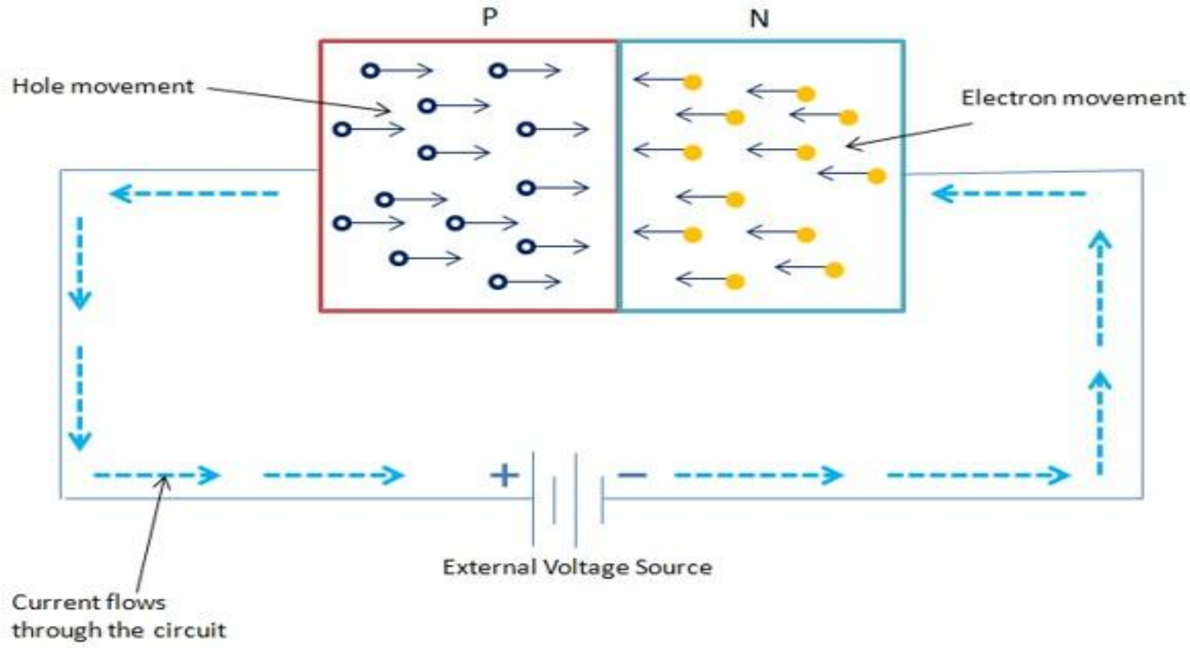
Biasing of pn junction:

The bias refers to the use of DC voltage(external DC voltage)to establish certain operating condition for an electronic devices.

There are two types of biasing.

1. Forward Biasing
2. Reverse Biasing

Forward Biasing:



1. When external DC voltage is applied to the junction, in such a direction that it cancels the potential barrier and thus permitting current flow is called forward biasing.

2. To apply the forward bias connect positive terminal of the battery to the p type semiconductor and negative terminal of the battery to the n type semiconductor as shown in the fig.

3. The applied voltage establish an electric field which acts against the field due to potential barrier.

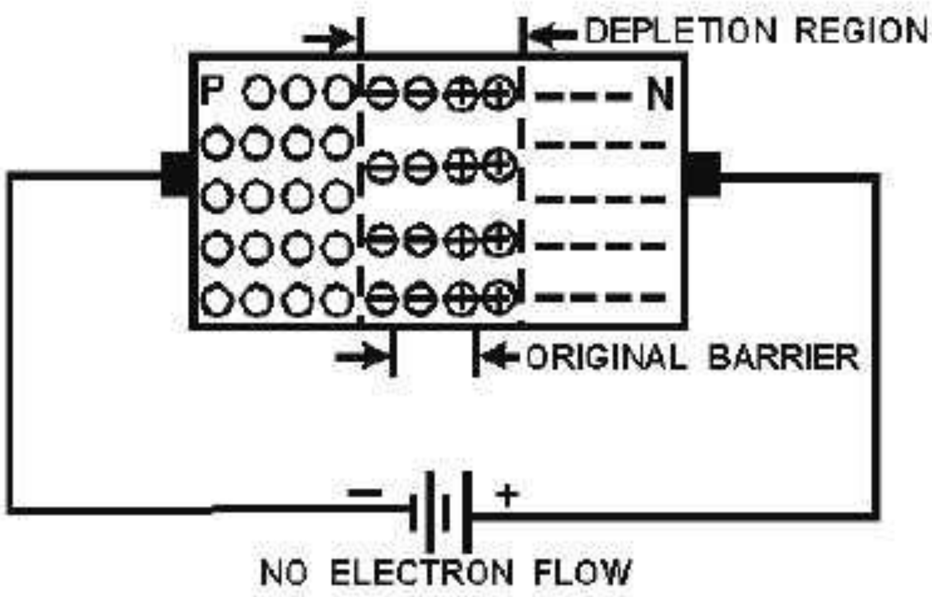
4. Therefore the negative of the battery pushes the free electrons against the barrier from n region to p region.

5. Due to this the width of the depletion region reduces and barrier potential also reduces as applied voltage is increased.

6. At a particular value the junction becomes very narrow and charge carriers can easily cross the junction.

7. This large number of majority charge carriers constitute a current called forward current

Reverse Biasing:



1.When an external DC voltage is applied to the junction in such a direction that potential barrier is increased it is called reverse biasing.

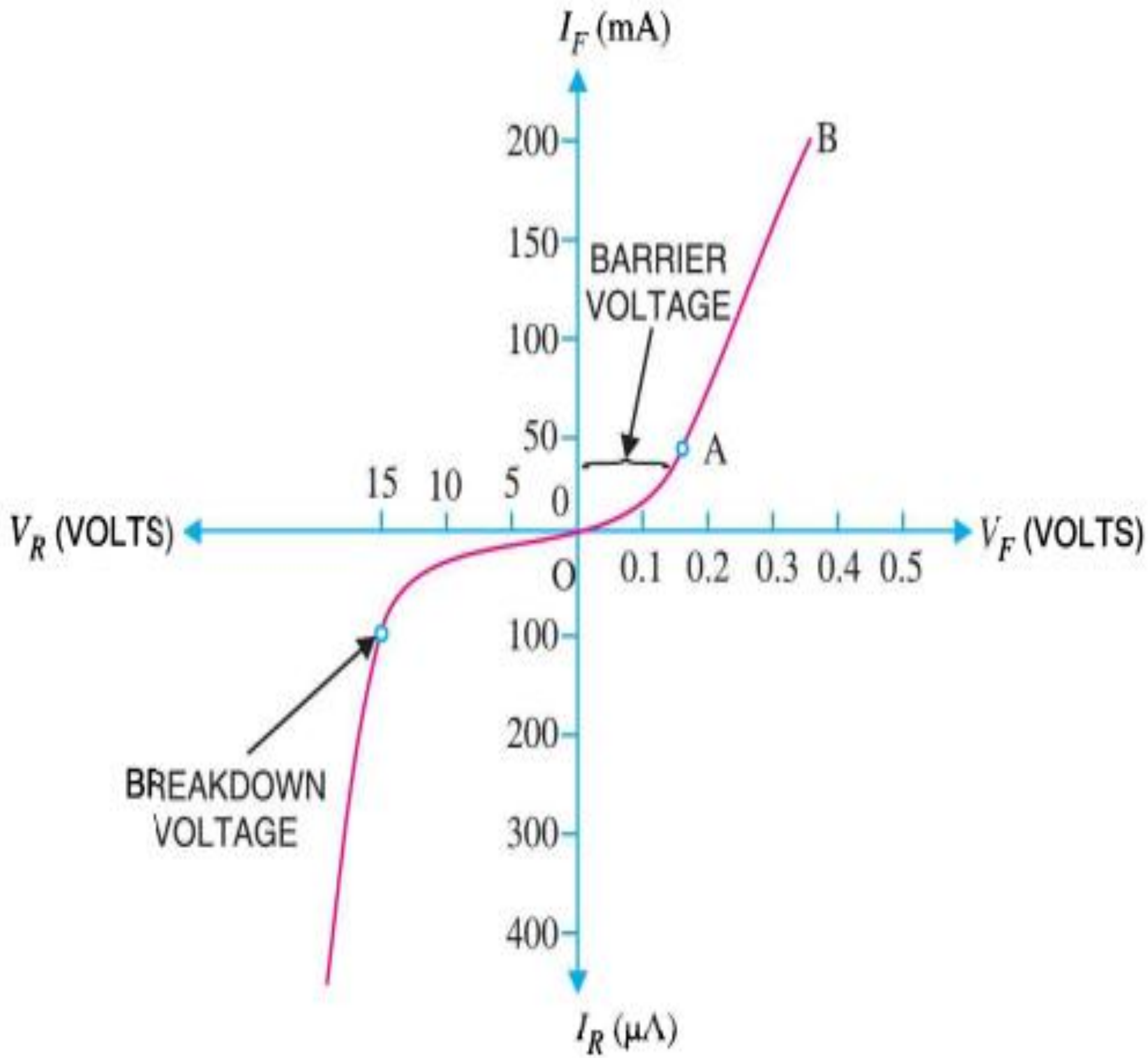
2.To apply reverse bias connect negative terminal of the battery to the p type and positive terminal of the battery to the n type semiconductor as shown in the fig.

3. In this case the holes are attracted by the negative battery terminal and electrons are attracted by the positive terminal so that both holes and electrons move away from each other.

4. Since there is no electron hole combination hence no current flows and the junction is having high resistance.

5. In the reverse bias condition the width of the depletion region is increased because the majority charge carriers are pulled away from the junction.

VI characteristics of Diode:



Forward Bias characteristics:

1. When the diode is forward biased and applied voltage is increased from zero hardly small current flows through the device in the beginning.
2. It is so because the external voltage is being opposed by internal barrier voltage, whose value is 0.7V for silicon and 0.3V for germanium.
3. As soon as VB is neutralized, the current through the diode increases rapidly with the increase in the applied barrier voltage.

Reverse Bias characteristics:

1. When the diode is reverse biased, majority charge carriers are blocked and only a small current flows through the diode as reverse voltage increases from zero.
2. The reverse current very quickly reaches its maximum value which is known as leakage current.

Ratings of diode:

1. Reverse current: The constant current flowing through the diode when it is reverse biased is called reverse saturation current of diode.

2. Reverse breakdown voltage: When the reverse voltage is increased at a certain value the breakdown of the diode occurs and reverse current increases very sharply, the voltage is called reverse breakdown voltage. The diode gets damaged in this condition.

3. Knee voltage: A small forward voltage applied to a forward biased diode at which current starts increasing exponentially (rapidly) is called Knee voltage

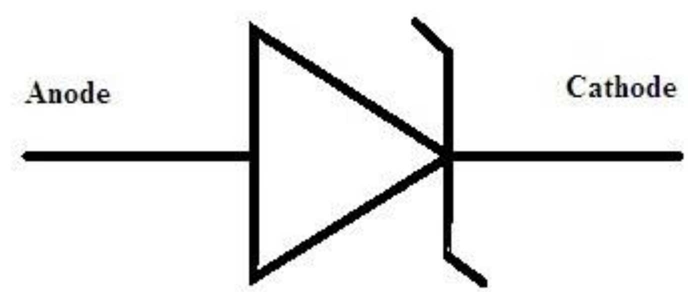
4. Maximum forward current: The maximum current that a forward bias diode can withstand before burning out due to high junction temperature is called maximum forward current.

5. Peak inverse voltage(PIV): The maximum voltage applied to the diode in the reverse direction without breakdown of the diode is called peak inverse voltage of the diode.

6. Maximum power rating(MPR): The maximum power that the diode can dissipate safely without increasing the junction temperature above its limiting value is called maximum power rating of the diode

Zener Diode:

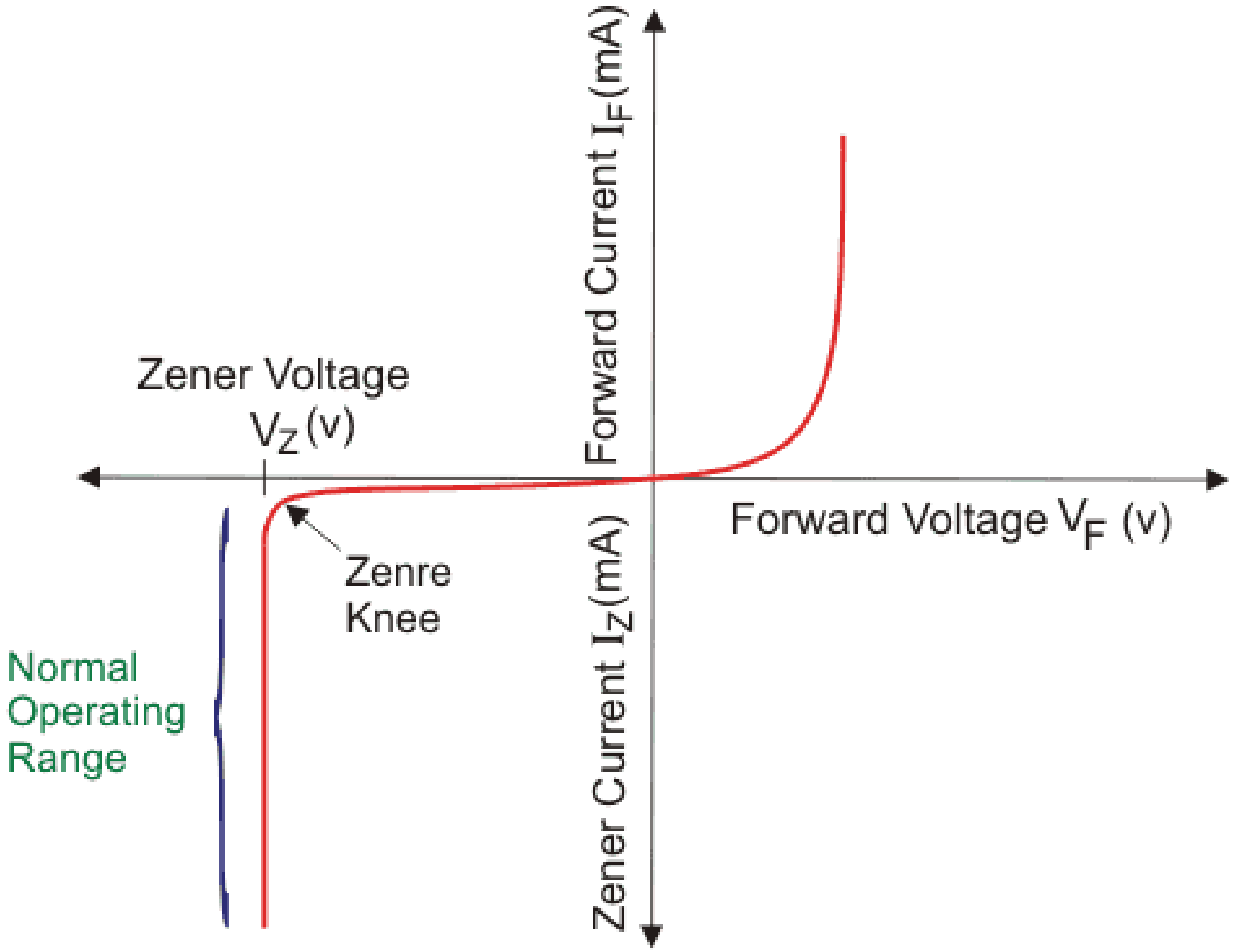
A zener diode is a heavily doped silicon pn junction semiconductor device which is operated I its reverse breakdown region.



Symbol of zener diode

The zener diode is fabricated with precise breakdown voltage by controlling the doping level during manufacturing.

VI characteristics of zener diode:



1. In the forward biased condition the normal diode and zener diode operates in similar manner.

2. But the zener diode is designed to operate in reverse breakdown region. Hence its reverse VI characteristic is important.

3. When the reverse voltage is applied to the zener diode, initially small current flows, which is its reverse saturation current.

4. At a certain reverse voltage, the reverse breakdown occurs and current in the zener diode increases rapidly. The sharp change in the zener current is called knee or zener knee of the reverse characteristics.

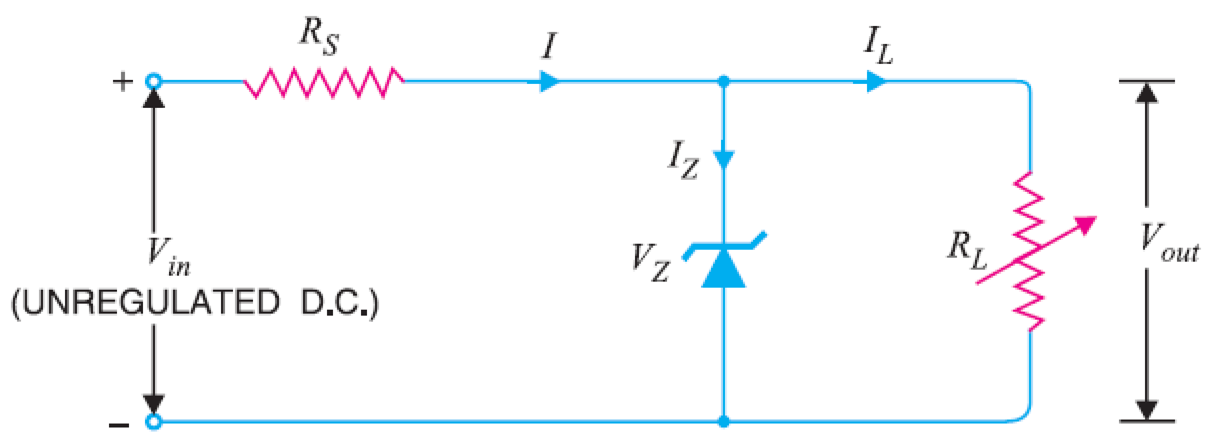
5. The reverse biased voltage at which the breakdown occurs is called zener breakdown voltage, denoted by Vz.

6. For zener diode two currents are specified. The Izmin is the minimum current through the zener diode to maintain it in reverse breakdown and Izmax is the maximum current which the zener diode can take safely maintaining its reverse breakdown operation.

7. The voltage across zener diode Vz is constant till current through the zener diode is between Izmin and Izmax.

Zener diode as a shunt voltage regulator:

A zener diode is mainly used in voltage regulation. A regulator is a device which maintaining the output voltage constant irrespective of change in supply voltage and load.



The zener diode has a characteristics that as long as current through a diode is between Izmin and Izmax the voltage across it is constant and equal to zener voltage.

As zener diode is connected in shunt with the load resistance, the output voltage is equal to zener voltage.

The value of R can be obtained mathematically as

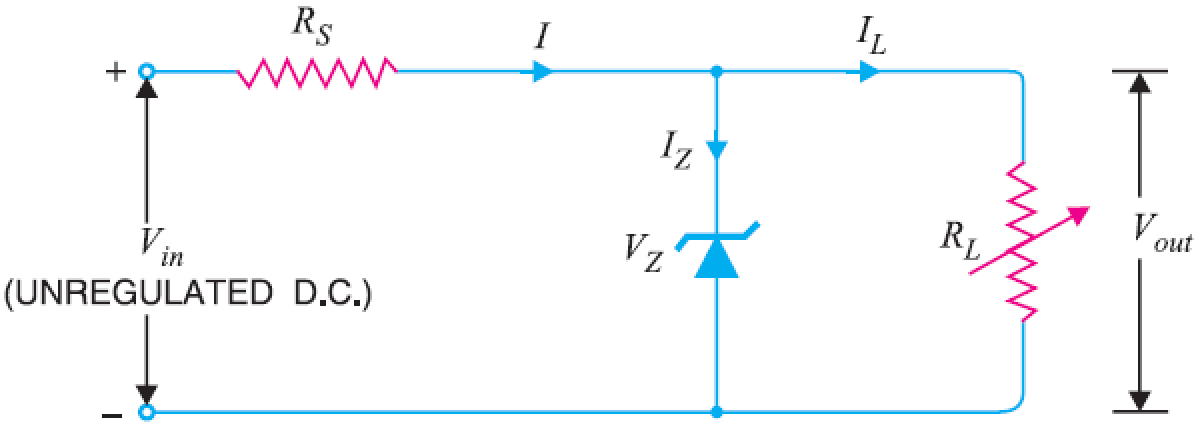
$$R = \frac{Vin - Vz}{Iin}$$

$$Iin = \frac{Vin - Vz}{R}$$

The relation between the currents is given by

$$Iin = Iz + Il$$

Case 1: Regulation with varying input voltage.



The fig shows the zener regulator under varying input voltage condition.

It can be seen that the output voltage Vo=Vz is constant.

Therefore

$$Il = \frac{Vo}{Rl} = \frac{Vz}{Rl} = \text{constant}$$

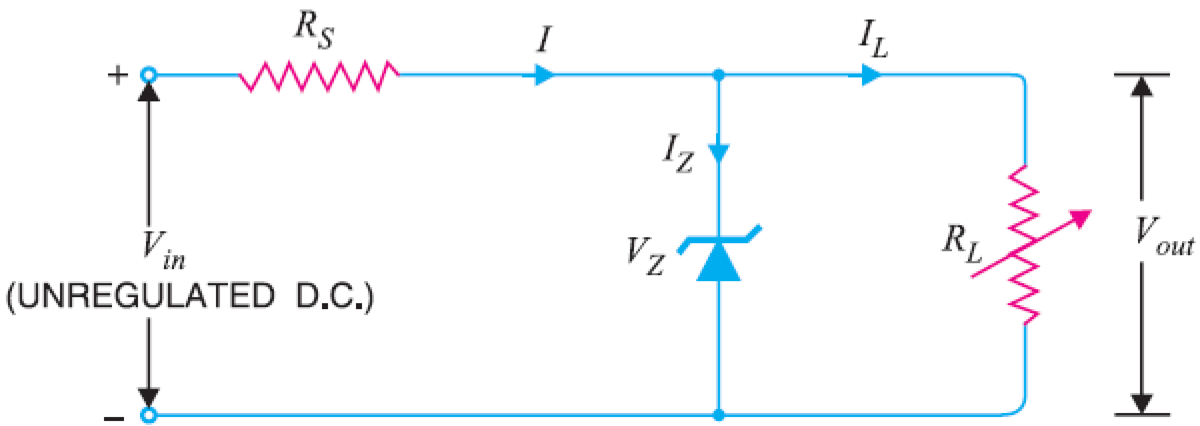
and $$Iin = Iz + Il$$

Now Vin increases, then the total current Iin increases. But Il is constant as Vz is constant. Hence the current Iz increases to keep Il constant.

But as long as Iz is between Izmin and Izmax the Vz that is the output voltage Vo is constant.

Similarly if Vin decreases then the current Iin decreases to keep Il constant Iz decreases.

Case 2: Regulation with varying load.



The figure shows a zener regulator under varying load condition and constant input voltage.

The input voltage is constant while the load resistance Rl is variable.

As Vin is constant and Vo=Vz is constant the current Iin is constant.
Therefore

$$Iin = \frac{Vin - Vz}{R} = \text{Constant}$$

Therefore $$Iin = Iz + Il$$

Now if Rl decreases so Il increases, to keep Iin constant Iz decreases. But as long as it is between Izmin and Izmax output voltage Vo will be constant.

Similarly if Rl increases Il decreases, to keep Iin constant.

Applications of Zener diode:

1. As a voltage regulator.
2. As a voltage clipper circuits.
3. For controlling the output amplitude.
4. As a reference voltage in comparator circuit.
5. Used in calibration instrument.

Varistors:

Varistors are the variable resistors, these are voltage dependent resistors(VDR), these are used to protect the circuit from high voltage transient by rapidly changing the resistance value from high to low. This action of varistor clamps the voltage to a safe value.

A high energy voltage transient is an abnormal short leaving disturbance in the circuit, which is produced by switching operation or a sudden fault in an electrical equipment or lightening strokes.

A transient change in voltage in a circuit from 120 to 170 V, the current suddenly jumps from 100mA to 400mA it means a 300%increase in current in the circuit. This sudden increase in current may damage the circuit. The varistor protects the circuit from destruction by dissipating the energy in the form of heat.

Applications of Varistors:

1.Protection of circuit.
2.Transient separation in inductive and transformer switch circuits.

Thermistors:

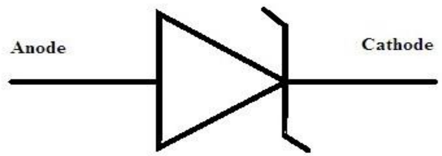
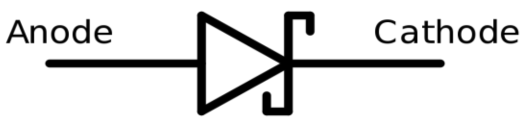
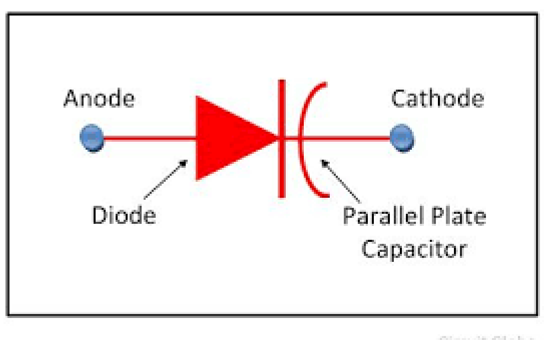
Temperature sensitive resistors are called as thermistor. It is used to detect very small changes in temperature. The variation in temperature are converted to an appreciable variation in resistance in this device.

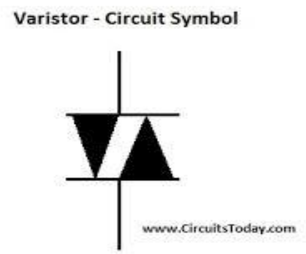
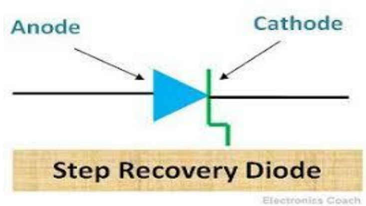
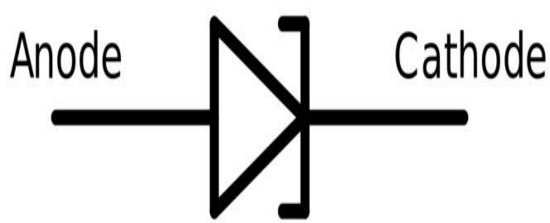
Thermistors with both negative temperature coefficient and positive temperature coefficient are available.
For NTC thermistors has a resistance of 10kΩ to 100kΩ are available.

Applications:

1. Temperature measurement and control
2. Time delay circuit
3. Liquid level management.

Diode types and its application:

Sl.no	Diode	Symbol	Application
1	Zener diode		Voltage regulator, voltage clipper, calibration instrument
2.	Schottky diode		High frequency applications as digital computes, switch mode power supply, radar system.
3.	Varactor diode		Used as a voltage variable capacitance, television receiver, FM modulator, automatic frequency control devices.

Sl.no	Diode	Symbol	Application
4.	Varistor diode		Protection of circuit from transient spikes, protection from impulse voltage.
5.	Step recovery diode		Frequency multiplier circuit, pulse generator.
6.	Tunnel diode		Pulse and digital circuits, pulse generator and amplifier.