

# CONDUCTORS, INSULATORS AND SEMICONDUCTORS

---

## BAND THEORY

---

In an atom, the electrons in inner shells are tightly bound to the nucleus while the electrons in the outermost shell (i.e the valence electron) are loosely bound to the nucleus.

During the formation of a solid, a large number of atoms are brought very close together; the energy levels of these valence electrons are affected most.

The energies of inner shell electrons are not affected much.

The band formed by a series of energy levels containing the valence electrons is called the **Valence Band (VB)**.

- It is highest occupied energy band.
- It may be completely filled or partially filled with electrons.

The next higher permitted energy band is called the **Conduction Band (CB)**.

- It may also be defined as the lowest unfilled permitted energy band.
- It may be empty or partially filled with electrons.
- The electrons can move freely in the conduction band and hence the electrons in conduction band are called conduction electrons.

The energy gap between the **VB** and **CB** is called the **Forbidden Energy Gap or Forbidden Band**.

- This band is formed by a series of non-permitted energy levels above the top of valence band and below the bottom of the conduction band.

- It is denoted by  $E_g$  and is the amount of energy to be supplied to the electron in **VB** to get excited into the **CB**.
- When an electron gains sufficient energy, it is ejected from the valence band. Because of this, a covalent bond is broken and a vacancy for electron, called Hole, is generated.
- It is supposed to behave as a positive charge.
- This Hole can travel to the adjacent atom by acquiring an electron from an atom.
- When an electron is captured by a Hole, the covalent bond is again re-established.
- Thus conduction electrons are found in and above freely in the conduction band. The Holes exist in and move in the valence band.

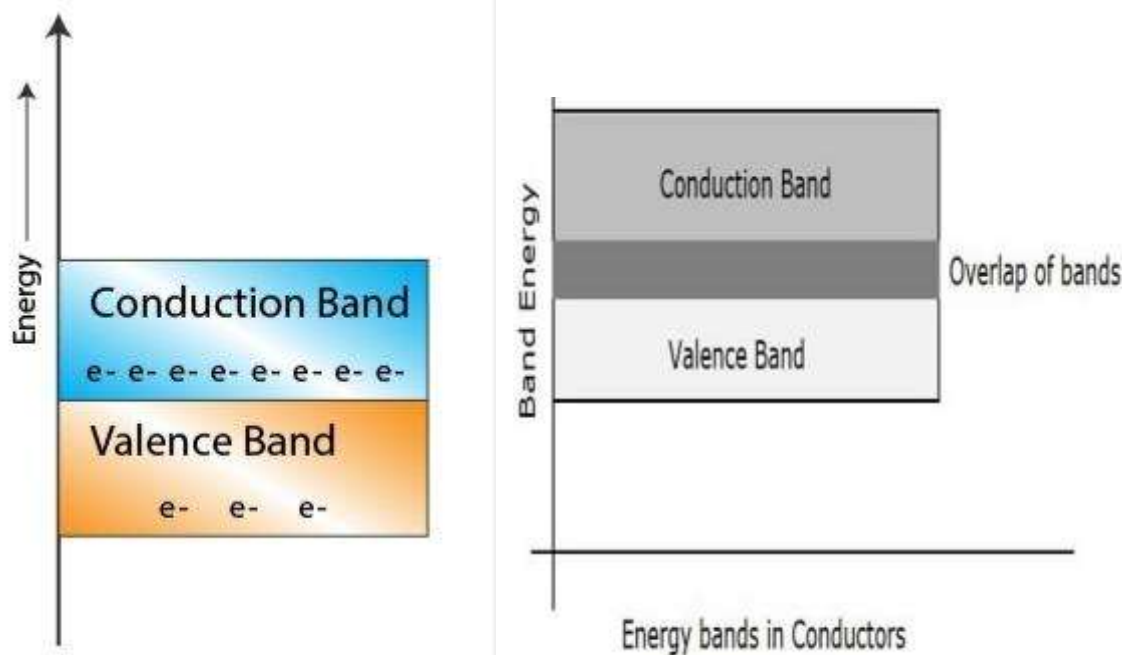
### Distinction between Metal, Insulator and Semiconductor

- There are many energy bands in solids as there are energy levels in parent atom.
- The electrical conduction properties of solids are concerned, only the valence band and conduction band energies of the electron are considered.
- Completely filled bands and completely empty bands do not contribute to electrical conduction.
- The electrons in the innermost filled shell do not take part in conduction process.
- The electrons in conduction band are free and move easily under an electric field.
- The electrons in valence band are attached to the lattice and are not free to move
- If they acquire sufficient energy to cross the forbidden gap  $E_g$ , they occupy the conduction band states are available for conduction.
- On the basis of the band theory, solids are classified into three categories;
  - Insulator
  - Semiconductor
  - Conductor

# WHAT ARE CONDUCTORS?

In electrical engineering, a conductor (or **electrical conductor**) is defined as an object or type of material that allows the flow of charge in one or more directions. Materials made of metal are common electrical conductors, as metals have a high conductance and low resistance.

Electrical conductors allow electrons to flow between the atoms of that material with drift velocity in the conduction band. **Electrical conductors** may be metals, metal alloy, electrolyte, or some non-metals like graphite and a conductive polymer. These materials allow electricity (i.e. the flow of charge) to pass through them easily.

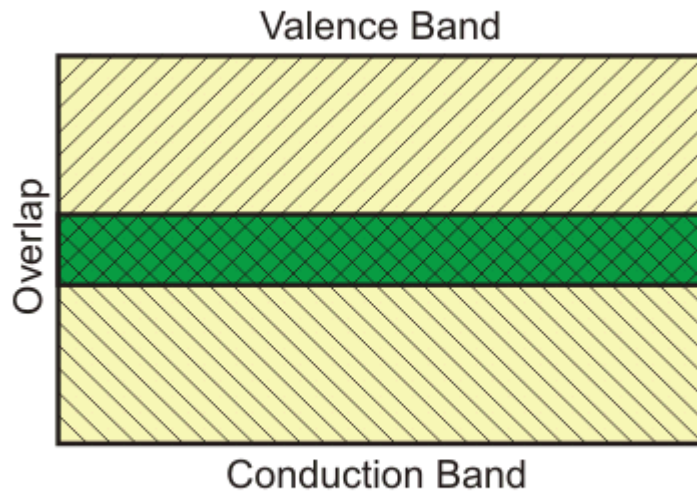


## How Does a Conductor Conduct Current?

The substance of the **electrical conductor** atom must have no energy gap between its valence band and conduction band.

The outer electrons in the valence band are loosely attached to the atom. When an electron gets excited due to electromotive force or thermal effect, it moves from its valence band to the conduction band.

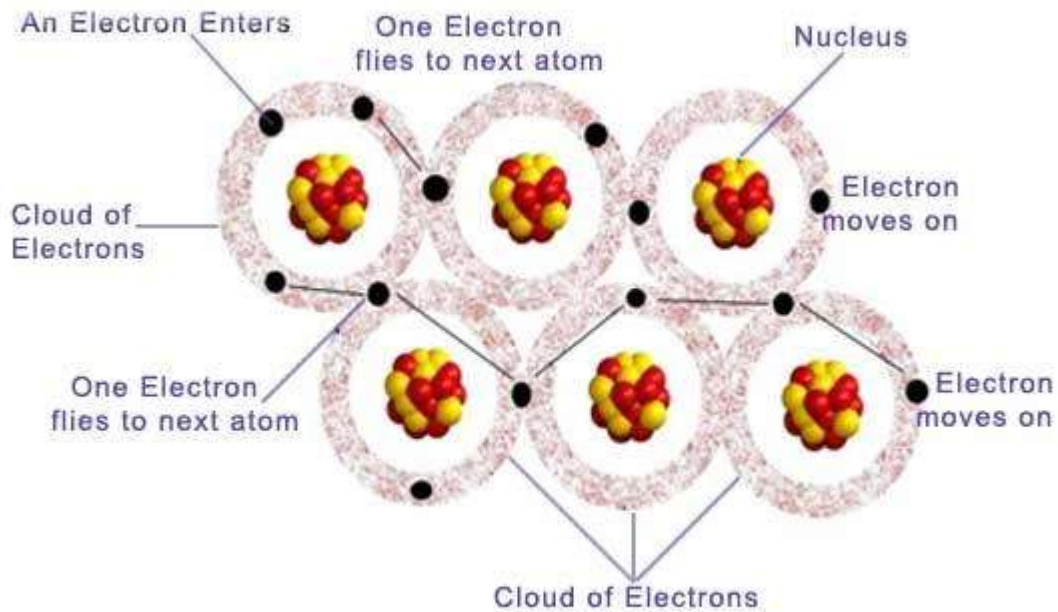
The conduction band is the band where this electron gets its freedom to move anywhere in the conductor. The conductor is formed of atoms. Thus as a whole, the conduction band is in the abundance of electrons.



### Energy Band Diagram of Conductor

In other words, it can be said that the metallic bonds are present in the conductors. These metallic bonds are based on the structure of positive metal ions. These structures are surrounded by an electron cloud.

When a potential difference occurs in the conductor across two points, the electrons get sufficient energy to flow from lower potency to higher potency in this conduction band against a small resistance offered by this conductor material. Electricity or current flows in the opposite direction of the flow of the electrons.



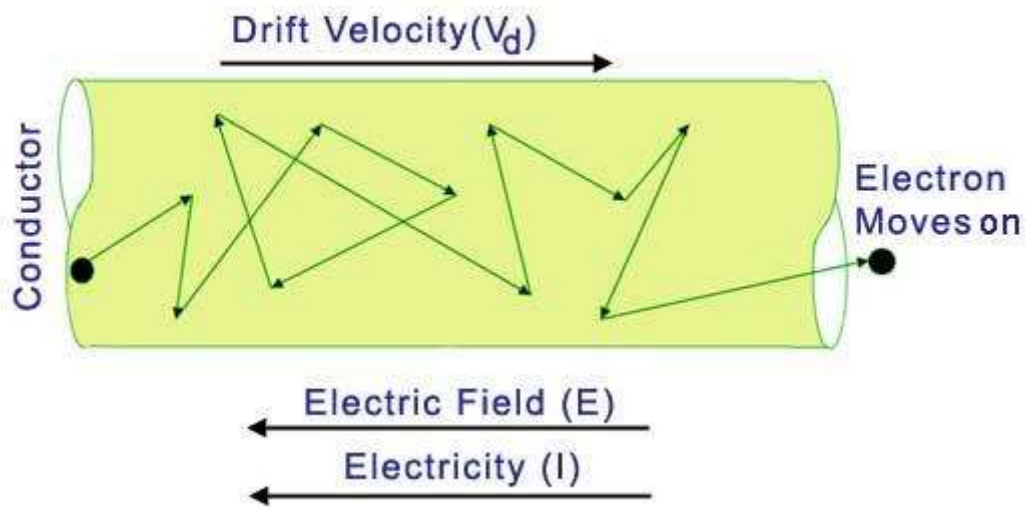
## Drifting of an Electron from Atom to Atom

### How an Electron Flows through a Conductor?

Electrons do not move or flow in a straight line. In a conductor, the electrons are in to and fro motion or random velocity i.e. is called Drift Velocity ( $V_d$ ) or average velocity. Due to this Drift Velocity, the electrons get collisions every moment with atoms or another electron in the conduction band of the conductor.

Drift velocity is quite small, as there are so many free electrons. We can estimate the density of free electrons in a conductor, thus we can calculate the drift velocity for a given current. The larger the density, the lower the velocity required for a given current.

In the Conductor, the flow of the electrons is against the Electric Field (E).



## Properties of Electrical Conductor

The main properties of electrical conductors are as follows:

1. A conductor always allows the free movement of electrons or ions.
2. The electric field inside a conductor must be zero to permit the electrons or ions to move through the conductor.
3. Charge density inside a conductor is zero i.e. the positive and negative charges cancel inside a conductor.
4. As no charge inside the conductor, only free charges can exist only on the surface of a conductor.
5. The electric field is perpendicular to the surface of that conductor.

## Type of Conductors

Electrical conductors can be classified based on their Ohmic Response. They are:

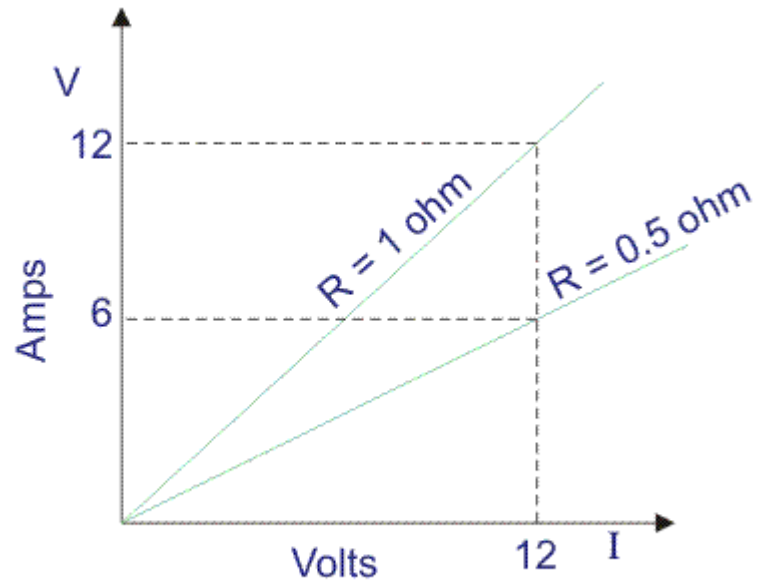
### Ohmic Conductors

This type of conductors always follow Ohm's Law ( $V \propto I$ )

V vs. I graph gives a straight line always.

Example

Aluminum, Silver, Copper etc.



**V - I Characteristics of Ohmic Conductor**

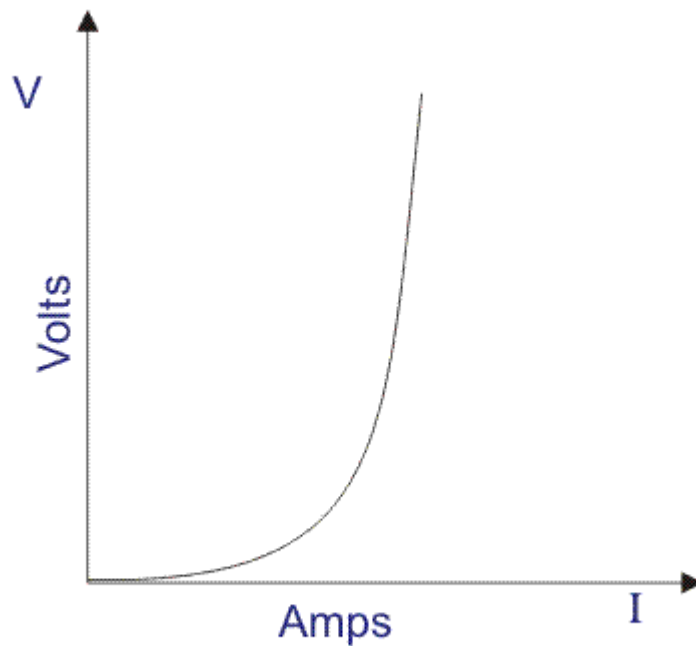
### Non-Ohmic Conductors

This type of conductors never follow Ohm's Law ( $V \propto I$ )

V vs. I graph does not give a straight line i.e. nonlinear graph.

Example

LDR ([Light Dependent Resistor](#)), [Diode](#), Filament of Bulb, [Thermistors](#), etc.



## V -I Characteristics of Non-Ohmic Conductor

The examples of conductors are given below

### Solid Conductor

Metallic Conductor: Silver, Copper, Aluminum, Gold, etc.

1. Non Metallic Conductor: Graphite
2. Alloy Conductor: Brass, Bronze, etc.

### Liquid Conductor

Metallic Conductor: Mercury

1. Non Metallic Conductor: Saline Water, Acid Solution, etc.

NB:

Copper Conductor is the most common material used for electrical wiring.

1. Gold Conductor is used for high-quality surface-to-surface contacts.
2. Silver is the best conductor on the Conductors list.
3. Impure Water is listed in the Conductor List but it has less conductivity.

## What is the Charge of a Conductor During Carrying Electricity?

A current-carrying conductor at any instance has zero charge. This is because at any instance number of electrons (at drift velocity) is equal to the number of protons in this conductor. So the net charge is zero.



Suppose a conductor is connected across a [battery](#), i.e. positive end and negative end are connected with a conductor. Now electrons flow through the conductor from the negative end to the positive end of the battery. This flow of electrons is possible until this battery has EMF producing capability through a chemical reaction inside.

### Is A Conductor Positively or Negatively Charged?

Just think that here the **conductor** is the media through which charges can be passed from one electrode to another electrode of the battery. The electrons get rid of the negative side of the battery and enter the conduction band of the conductor where already plenty of valence electrons of conductor atoms are available.

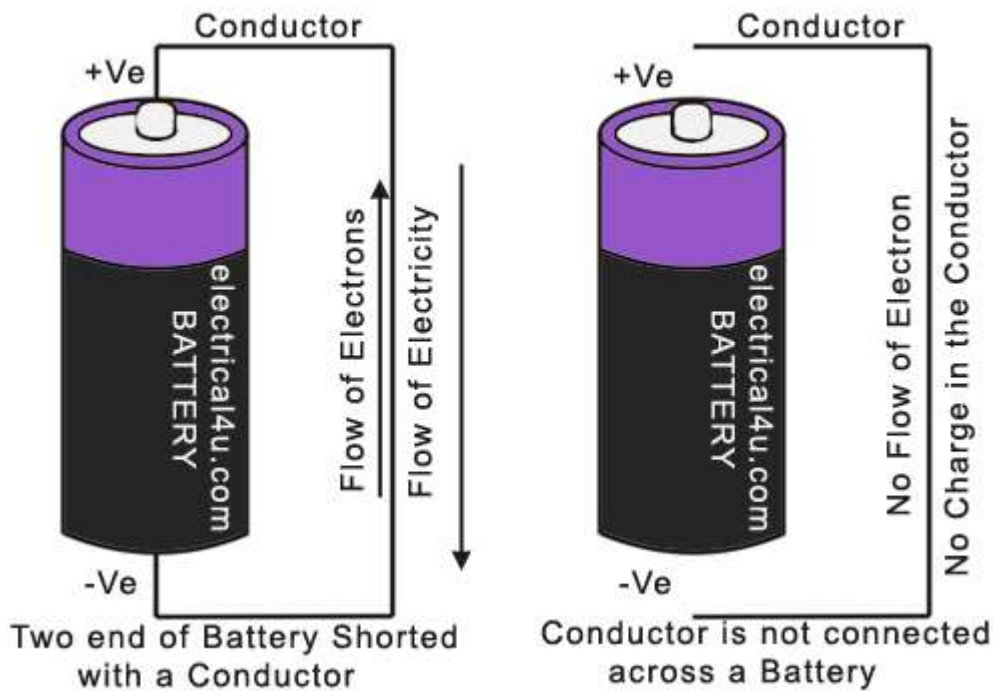
The free electrons start the journey in drift motion (towards the positive electrode of the battery) from atom to atom in the conduction band.

At any instance, each atom holds zero charge because drift electrons from adjacent atoms fill its valence band electron gaps and it happens continuously i.e. total number of electrons equal to the number of protons in the conductor at any moment. Now the rate of change of charge (q) with respect to time (t) is called current (I),

$$i.e. I = \frac{dq}{dt},$$

This rate of change of charge with respect to time occurs. Convention-wise, Current (I) flows in the opposite direction of electron flow.

When you remove the conductor from the [battery](#), this conductor does not hold any charged particle, but EMF remains present across the battery electrodes with positive and negative polarity with no flow of electrons.



## EFFECT OF TEMPERARURE ON CONDUCTORS

The more effect of temperature, the more vibration in the conductor molecules. This impedes the electrons to flow, i.e. the electrons get obstruction to flow smoothly through the conductor. Thus, conductivity decreases gradually with increasing the temperature.

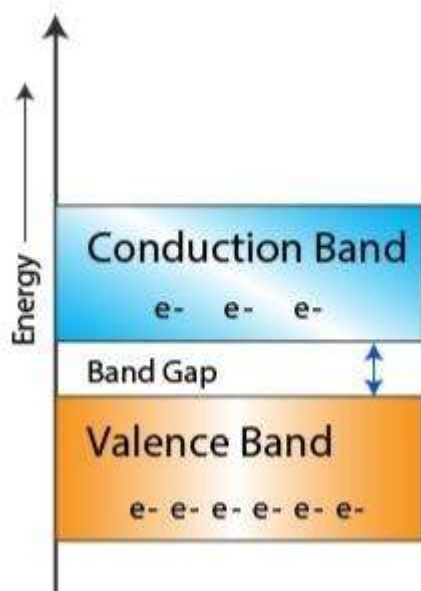
Again, raise of temperature break some bonds in the conductor molecules and release some electrons. These electrons are less in number. As a whole, it can be said that increase in the temperature opposition against the drifting electron increases in the conductor.

## SEMICONDUCTORS

In semiconductors, the gap between valence band and conduction band is smaller. Ex: Ga, As, Si, Ge

At room temperature there is sufficient energy available for electrons to make a transition from valence band to conduction band. This allows some conduction to take place

Conductivity increases with increase in temperature as more electrons will have enough energy to move into conduction band



### Some important properties of semiconductor

- Semiconductor acts like insulator at 0K and conductor at high temperatures.
- Their resistivity is higher than conductors but lesser than insulators
- It's temperature coefficient of resistivity is negative
- Resistivity:  $10^{-5}$  to  $10^6$  ohm m
- Conductivity:  $10^5$  to  $10^{-6}$  mho/m
- Resistance decrease with increase in temperature

### Advantages of semiconductors

- shock proof
- Longer life span
- Highly portable
- Noise free while operating

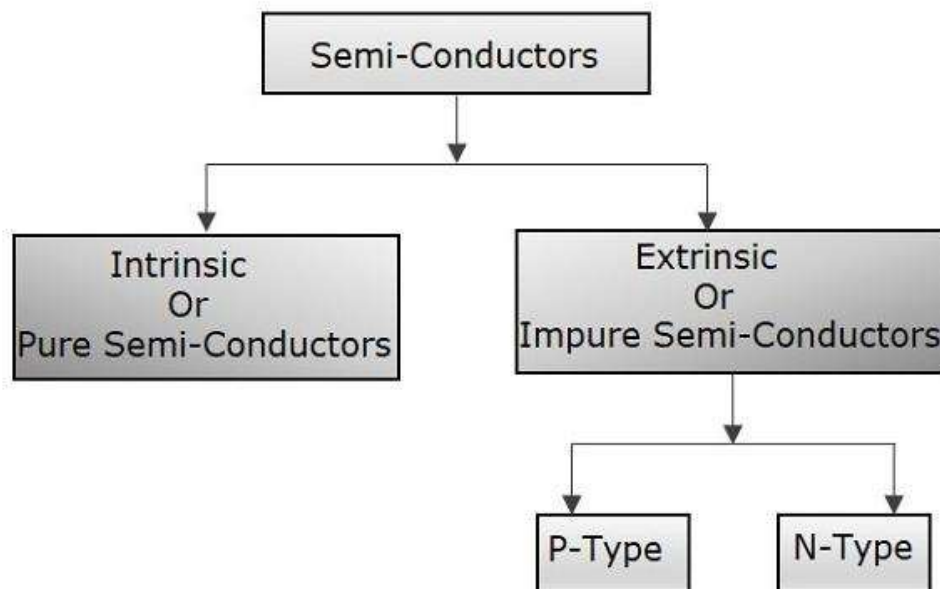
A Semiconductor in its extremely pure form is said to be an intrinsic semiconductor. The properties of this pure semiconductor are as follows –

The electrons and holes are solely created by thermal excitation.

The number of free electrons is equal to the number of holes.

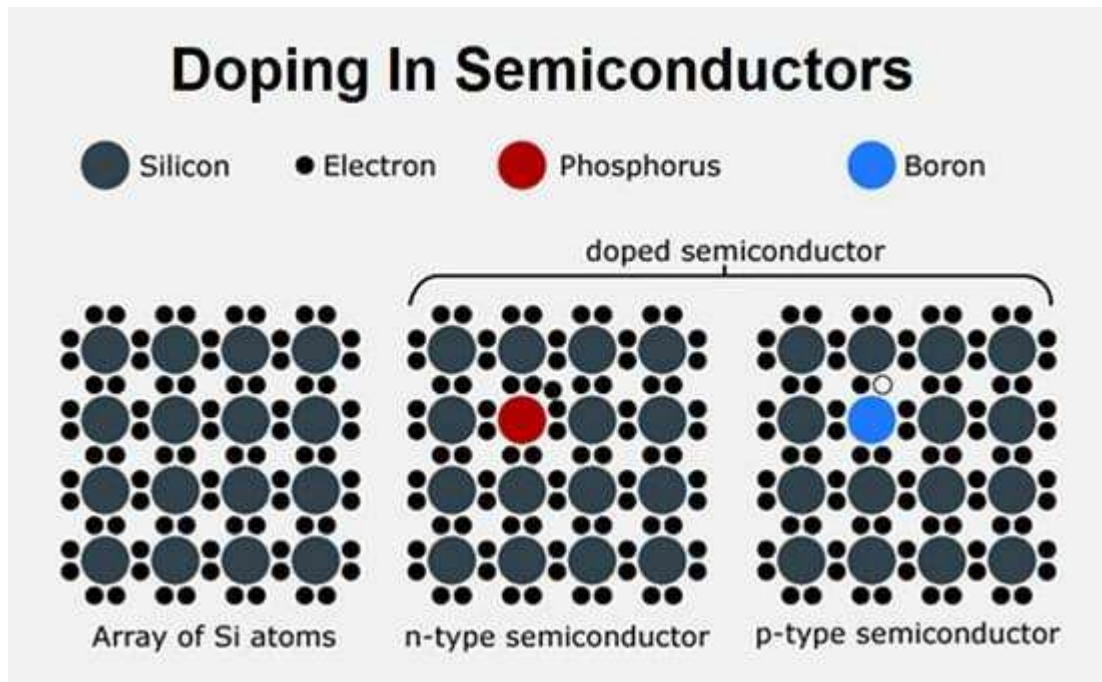
The conduction capability is small at room temperature.

In order to increase the conduction capability of intrinsic semiconductor, it is better to add some impurities. This process of adding impurities is called as Doping. Now, this doped intrinsic semiconductor is called as an Extrinsic Semiconductor.



## DOPING

Doping is adding very small amounts of group 3 or group 5 elements to a group 4 semiconductor such as silicon. Adding a group 5 element causes the material to contain electrons that are free to move around (just like in a metal). Because electrons are negatively charged particles these semiconductors known as n-type semiconductors.



Adding a group 3 element causes the material to contain 'holes'. These are gaps in the covalent bonds between atoms that will move around and act just like positively charged particles (hence these semiconductors being known as p-type).

The process of adding impurities to the semiconductor materials is termed as doping. The impurities added, are generally pentavalent and trivalent impurities.

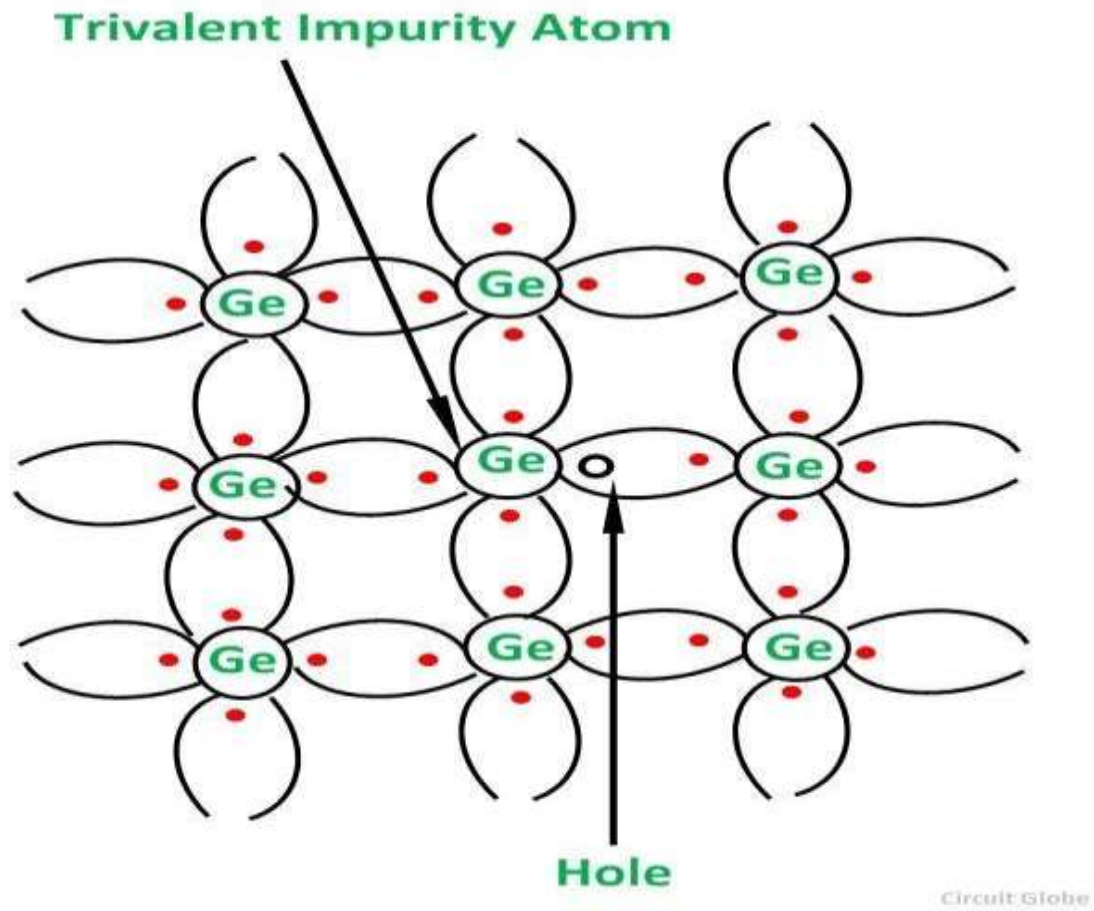
## Pentavalent Impurities

The pentavalent impurities are the ones which has five valence electrons in the outer most orbit. Example: Bismuth, Antimony, Arsenic, Phosphorus

The pentavalent atom is called as a donor atom because it donates one electron to the conduction band of pure semiconductor atom.

## Trivalent Impurities

The trivalent impurities are the ones which has three valence electrons in the outer most orbit. Example: Gallium, Indium, Aluminum, Boron

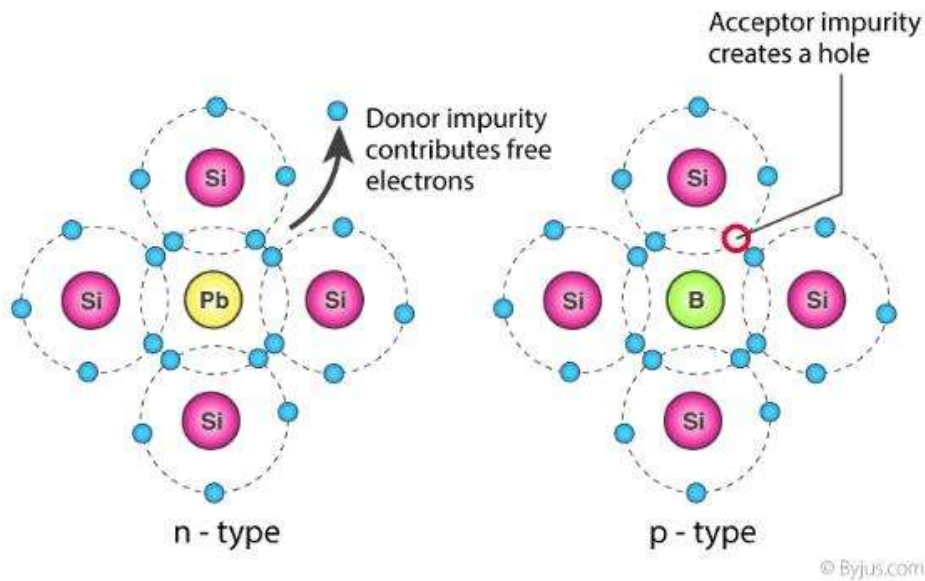


The trivalent atom is called as an acceptor atom because it accepts one electron from the semiconductor atom.

## Extrinsic Semiconductor

An impure semiconductor, which is formed by doping a pure semiconductor is called as an extrinsic semiconductor. There are two types of extrinsic semiconductors depending upon the type of impurity added. They are N-type extrinsic semiconductor and P-Type extrinsic semiconductor.

## EXTRINSIC SEMICONDUCTORS



### N-Type Extrinsic Semiconductor

A small amount of pentavalent impurity is added to a pure semiconductor to result in N-type extrinsic semiconductor. The added impurity has 5 valence electrons.

For example, if Arsenic atom is added to the germanium atom, four of the valence electrons get attached with the Ge atoms while one electron remains as a free electron. This is as shown in the following figure.

All of these free electrons constitute electron current. Hence, the impurity when added to pure semiconductor, provides electrons for conduction.

In N-type extrinsic semiconductor, as the conduction takes place through electrons, the electrons are majority carriers and the holes are minority carriers.

As there is no addition of positive or negative charges, the electrons are electrically neutral.

When an electric field is applied to an N-type semiconductor, to which a pentavalent impurity is added, the free electrons travel towards positive electrode. This is called as negative or N-type conductivity.

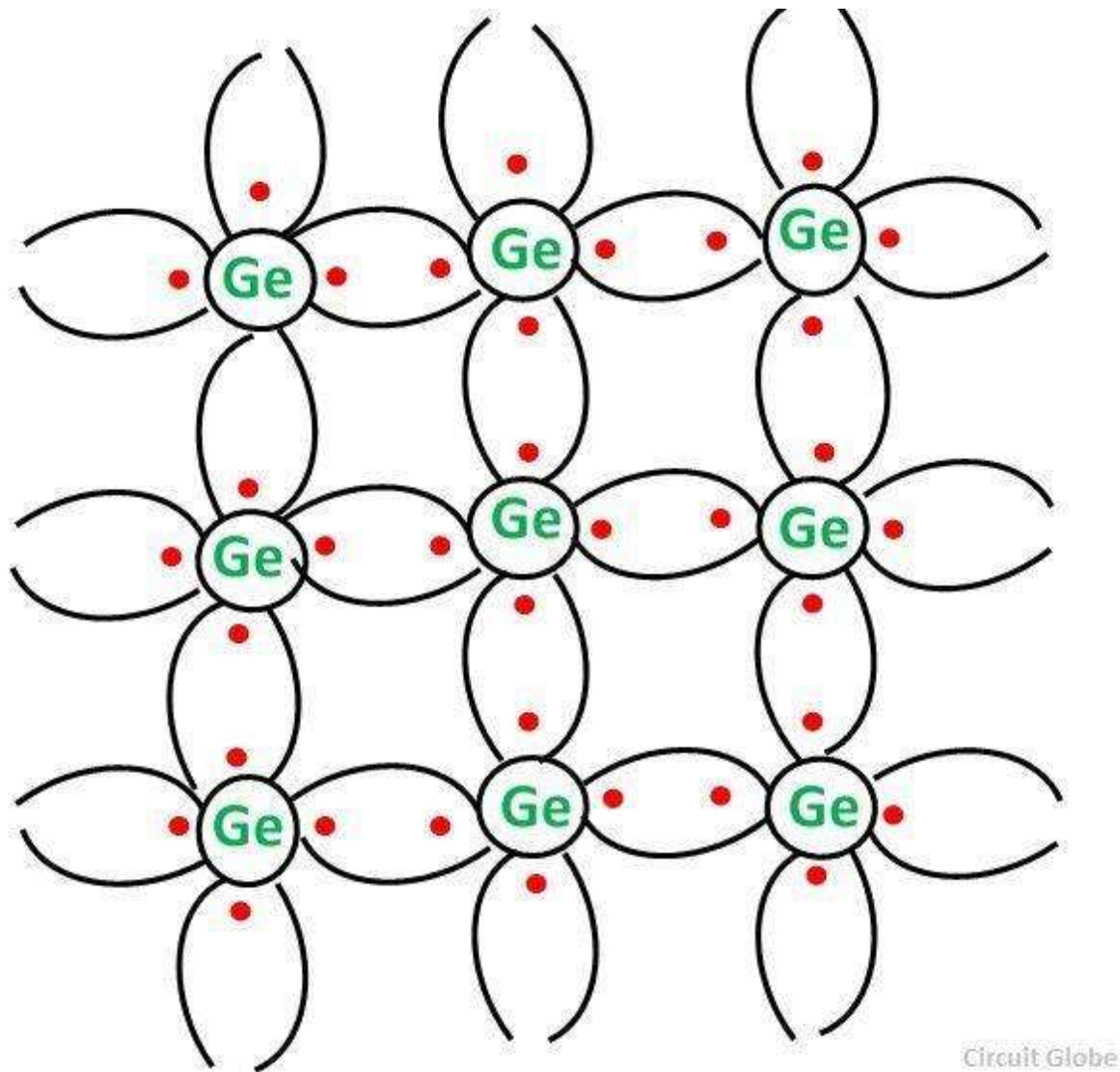
### P-Type Extrinsic Semiconductor



A small amount of trivalent impurity is added to a pure semiconductor to result in P-type extrinsic semiconductor. The added impurity

has 3 valence electrons. For example, if Boron atom is added to the germanium atom, three of the valence electrons get attached with

the Ge atoms, to form three covalent bonds. But, one more electron in germanium remains without forming any bond. As there is no electron in boron remaining to form a covalent bond, the space is treated as a hole. This is as shown in the following figure.



The boron impurity when added in a small amount, provides a number of holes which helps in the conduction. All of these holes constitute hole current.



In P-type extrinsic semiconductor, as the conduction takes place through holes, the holes are majority carriers while the electrons are minority carriers.

The impurity added here provides holes which are called as acceptors, because they accept electrons from the germanium atoms.

As the number of mobile holes remains equal to the number of acceptors, the P-type semiconductor remains electrically neutral. When an electric field is applied to a P-type semiconductor, to which a trivalent impurity is added, the holes travel towards negative electrode, but with a slow pace than electrons. This is called as P-type conductivity.

In this P-type conductivity, the valence electrons move from one covalent bond to another, unlike N-type.

## INTRINSIC SEMICONDUCTOR

A semiconductor which is pure and contains no impurity is known as intrinsic semiconductor. In an intrinsic semiconductor, the number of free electrons and holes are equal. Ex: pure Si and Ge

The diagram, titled "INTRINSIC SEMICONDUCTORS", illustrates a silicon crystal lattice. It features a 4x4 grid of silicon atoms, each represented by a pink circle labeled "Si". Each atom is connected to its four neighbors by covalent bonds, shown as pairs of curved lines. Several atoms have a small blue dot with an arrow pointing away from it, labeled "Free electron". Other atoms have a small yellow circle with a blue dot inside, labeled "Hole". A legend on the right side of the diagram identifies these symbols: a blue dot with an arrow for "Free electron" and a yellow circle with a blue dot for "Hole". The diagram is set against a white background with a purple header bar. On the left side, there are three social media icons: a green WhatsApp icon, a purple share icon, and an orange phone icon. The BYJU'S logo is in the top right corner, and the copyright notice "© Byjus.com" is in the bottom right corner.

Electrons and Holes configuration in a Silicon atom

## USES OF SEMICONDUCTORS

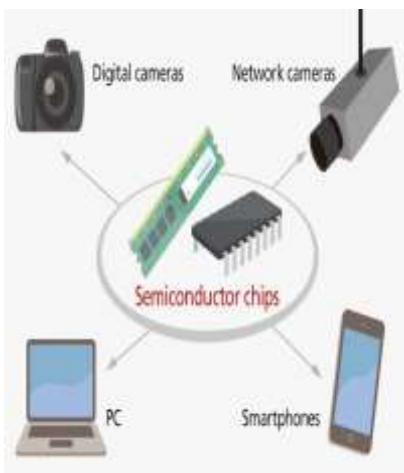
Semiconductor, any of a class of crystalline solids intermediate in electrical conductivity between a conductor and an insulator.

Semiconductors are employed in the manufacture of various kinds of electronic devices, including diodes, transistors, and integrated circuits.

Such devices have found wide application because of their compactness, reliability, power efficiency, and low cost. As discrete

components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers. They have a wide range of current- and voltage-handling capabilities and, more important, lend themselves to integration into complex but readily

manufacturable microelectronic circuits. They are, and will be in the foreseeable future, the key elements for the majority of electronic systems, serving communications, signal processing, computing, and control applications in both the consumer and industrial markets.



# What Are Insulators?

---

Insulators are materials that inhibit the flow of electrical current. The opposite of conductors, which allow electric particles to flow freely, insulators are implemented in household items and electrical circuits as protection. Thermal insulation is similar, but it constricts the flow of heat rather than electricity.

## Insulators

Insulators possess a high resistivity and low conductivity. Their atoms have tightly bound electrons that do not move throughout the material. Because the electrons are static and not freely roaming, a current cannot easily pass. In addition to protecting loss of current, insulators make an electrical current more efficient by concentrating the flow.

## The Properties of Insulators

An insulator is a material which is a poor conductor of electricity or heat. Some common insulators include wood, plastic, glass, porcelain and Styrofoam; Styrofoam and plastic see wide use in household applications. Floors, roofs and basements often get urethane foam insulation, as it reduces heating costs by retaining heat in homes. A number of properties limit an insulator's ability to conduct heat and electricit

Insulators are poor conductors of heat and electricity, due to tight binding of electrons in their atoms and molecules. Examples include air, rubber, Teflon, Styrofoam, cloth and fiberglass.

## High Resistance

The ability to impede electric current from passing through is known as electrical resistance; this property is measured in units called ohms. When 1 volt produces 1 ampere of current in an object, the resistance is 1 ohm. An ohm is a very small unit of resistance; a conductor might have a resistance of an ohm or two, whereas insulators have ohm measurements in the billions. All materials except superconductors have some resistance; conductors have low resistance, while insulators have high resistance levels.

## Breakdown Voltage

All insulators will conduct heat and electricity if subjected to extremely high voltages. At very high voltages, the material's composition will lose its insulating abilities; the voltage at which this change occurs is known as the breakdown voltage, also known as dielectric strength. As an example, consider air, normally an excellent insulator. Lightning passes through air because its very high voltage overwhelms, or breaks down, air's ability to insulate. Different insulators have different breakdown voltages, and are used for different purposes. For example, plastic may be used as an insulator in households where the voltage is not very high, but it cannot be used for industrial purposes. Ceramic is one of the best insulators in such applications, as it has a very high breakdown voltage.

## Atomic Structure of Insulators

In insulators, the valence (outer) electrons are tightly held together. When the movement of electrons is restricted, no current can flow, making substances with this property – for example, non-metals such as glass, wood and plastic – excellent insulators. This also impedes the flow of heat. The reason most liquids and aqueous solutions are not good electrical insulators is that they contain ions which allow electric current to flow; the same applies to wet plastic and wood.

## Air Permeability

Air permeability, the ability of a material to allow air to flow through its pores, is a necessary property for some heat or thermal insulators. Good insulators have a high air permeability, since air itself is a good insulator. Examples include cloth, such as an oven mitt, and the fiberglass used in home heat insulation.

## Porcelain Insulator



Porcelain is the most commonly used material for overhead insulators in the present day. The porcelain is aluminum silicate. The aluminum silicate is mixed with plastic kaolin, feldspar, and quartz to obtain final hard and glazed **porcelain insulator** material.

Porcelain is the most commonly used material for overhead insulators in the present day. The porcelain is aluminum silicate. The aluminum silicate is mixed with plastic kaolin, feldspar, and quartz to obtain final hard and glazed **porcelain insulator** material.

The surface of the insulator should be glazed enough so that water should not be traced on it. Porcelain also should be free from porosity since porosity is the main cause of deterioration of its dielectric property. It must also be free from any impurity and air bubble inside the material which may affect the insulator properties.

Property	Value(Approximate)
Dielectric Strength	60 kV / cm
Compressive Strength	70,000 Kg / cm <sup>2</sup>
Tensile Strength	500 Kg / cm <sup>2</sup>

### *Properties of Porcelain Insulator*

### Glass Insulator



**Glass Insulator (Disc)**

Nowadays **glass insulators** have become popular in transmission and distribution systems. Annealed tough glass is used for the insulating purpose. Glass insulator has numbers of advantages over conventional porcelain insulator

### *Advantages of Glass Insulator*

1. It has a very high dielectric strength compared to porcelain.
2. Its resistivity is also very high.
3. It has a low coefficient of thermal expansion.
4. It has a higher tensile strength compared to porcelain insulator.
5. As it is transparent in nature the is not heated up in sunlight as porcelain.
6. The impurities and air bubbles can be easily detected inside the glass insulator body because of its transparency.
7. Glass has a very long service life because the mechanical and electrical properties of glass do not be affected by aging.
8. After all, glass is cheaper than porcelain.

### *Disadvantages of Glass Insulator*

1. Moisture can easily be condensed on the glass surface and hence air dust will be deposited on the wet glass surface which will provide a path to the leakage current of the system.
2. For higher voltage glass can not be cast in irregular shapes since due to irregular cooling internal strains are caused.

### *Properties of Glass Insulator*

Property	Value(Approximate)
Dielectric Strength	140 kV / cm
Compressive Strength	10,000 Kg / cm <sup>2</sup>
Tensile Strength	35,000 Kg / cm <sup>2</sup>



**Polymer Insulator**  
(Suspension)

## Polymer Insulator

A **polymer insulator** has two parts, one is glass fiber reinforced epoxy resin rod-shaped core and the other is silicone rubber or EPDM (Ethylene Propylene Diene Monomer) made weather sheds. The rod-shaped core is covered by weather sheds. Weather sheds protect the insulator core from the outside environment. As it is made of two parts, core and weather sheds, **polymer insulator** is also called a **composite insulator**. The rod-shaped core is fixed with Hop dip galvanized cast steel made end fittings on both sides.

## Advantages of Polymer Insulator

1. It is very lightweight compared to porcelain and glass insulator.

2. As the **composite insulator** is flexible the chance of breakage becomes minimum.
3. Because of lighter in weight and smaller in size, this insulator has lower installation costs.
4. It has a higher tensile strength compared to a porcelain insulator.
5. Its performance is better, particularly in polluted areas.
6. Due to lighter weight polymer insulator imposes less load to the supporting structure.
7. Less cleaning is required due to the hydrophobic nature of the insulator.

### *Disadvantages of Polymer Insulator*

1. Moisture may enter in the core if there is any unwanted gap between core and weather sheds. This may cause the electrical failure of the insulator.
2. Over crimping in end fittings may result in cracks in the core which leads to mechanical failure of polymer insulator.

In addition to this, some other disadvantages might be experienced. Let us give a practical example where many difficulties are faced in maintaining a distribution network in Victoria Australia due to polymeric insulators.

There are many Cockatoos, Galahs, and Parrots in that area of Australia, which loves to chew on polymeric strain insulators. Here, the 22 kV network has many polymeric strain insulators installed, and now after a few years of installing polymeric strain insulators, the authority is now replacing many of them back with Glass disc insulators.

Another disadvantage is that they have had post type polymeric insulators melt and bend in bush fire areas. They have a concrete pole and a steel cross arm that survives a bush fire, however, the polymers in some cases fail. This would not be the case with glass or porcelain insulators.

They have also had polymeric insulators fail in areas close to the ocean coastline where there are high salt levels in the air.

1. Subject to bird attack by Parrots, Cockatoos, and Galahs.
2. Not resilient to bushfire temperatures.
3. Not recommended for a location near surf beaches due to salt spray.

The information is contributed by Robert Lancaster of Australian Electricity Supply Industry

### **Uses of insulators**

- Prevent passage of high voltage in circuit
- Reduces cost of energy



- Protects from electric shock or electrocution
- Allows sound proofing of appliances
- Improves process performance



### **Applications of insulators**

Used in Coating of electric wires.

Used in Circuit boards.

Used in high voltage appliances.

Coating for electric poles on streets.

Used to prevent electric shocks.



THE END