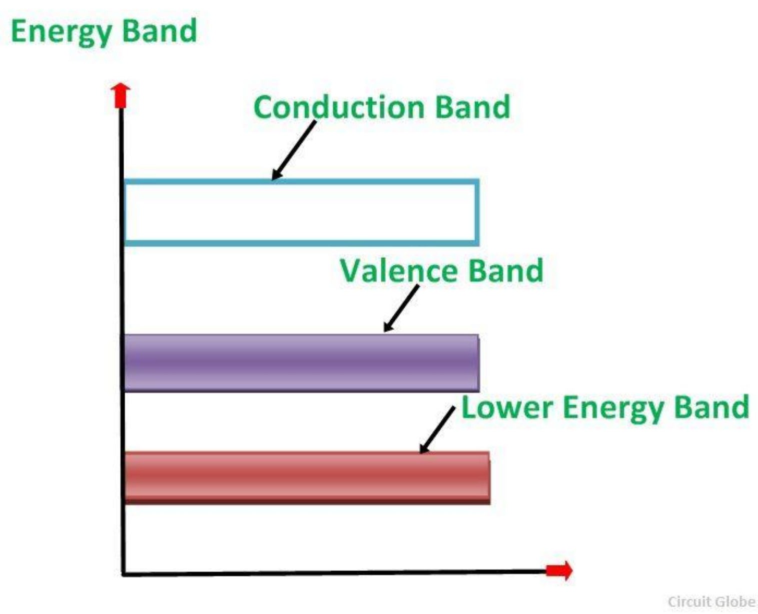
## Intrinsic Semiconductor and Extrinsic Semiconductor

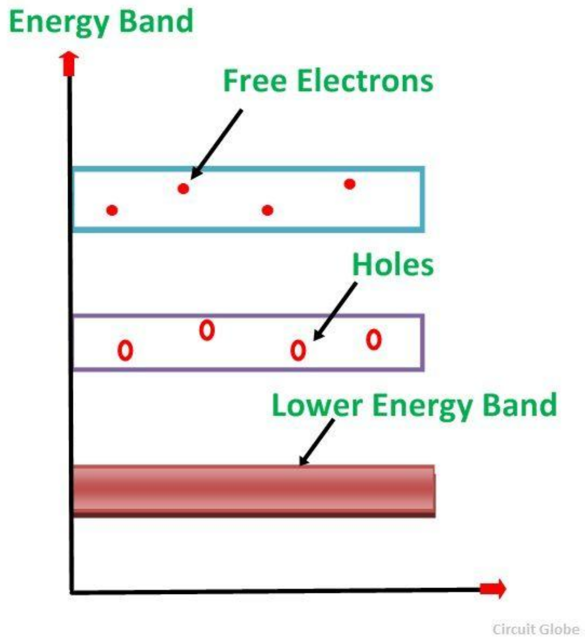
The semiconductor is divided into two types. One is **Intrinsic Semiconductor** and other is an **Extrinsic semiconductor**. The pure form of the semiconductor is known as the intrinsic semiconductor and the semiconductor in which intentionally impurities is added for making it conductive is known as the extrinsic semiconductor.The conductivity of the intrinsic semiconductor become zero at room temperature while the extrinsic semiconductor is very little conductive at room temperature. The detailed explanation of the two types of the semiconductor is given below.

## Intrinsic Semiconductor

An extremely pure semiconductor is called as Intrinsic Semiconductor. On the basis of the energy band phenomenon, an intrinsic semiconductor at absolute zero temperature is shown below.




Its valence band is completely filled and the conduction band is completely empty. When the temperature is raised and some heat energy is supplied to it, some of the valence electrons are lifted to conduction band leaving behind holes in the valence band as shown below.




The electrons reaching at the conduction band move randomly. The holes created in the crystal also free to move anywhere. This behavior of the semiconductor shows that they have a negative temperature coefficient of resistance. This means that with the increase in temperature, the resistivity of the material decreases and the conductivity increases.

## Extrinsic Semiconductor

A semiconductor to which an impurity at controlled rate is added to make it conductive is known as an extrinsic Semiconductor.

An intrinsic semiconductor is capable to conduct a little current even at room temperature, but it is not useful for the preparation of various electronic devices. Thus, to make it conductive a small amount of suitable impurity is added to the material.

## Doping

The process by which an impurity is added to a semiconductor is known as Doping. The amount and type of impurity which is to be added to a material has to be closely controlled during the preparation of extrinsic semiconductor. Generally, one impurity atom is added to a $10^8$ atoms of a semiconductor.

The purpose of adding impurity in the semiconductor crystal is to increase the number of free electrons or holes to make it conductive. If a Pentavalent impurity, having five valence electrons is added to a pure semiconductor a large number of free electrons will exist.

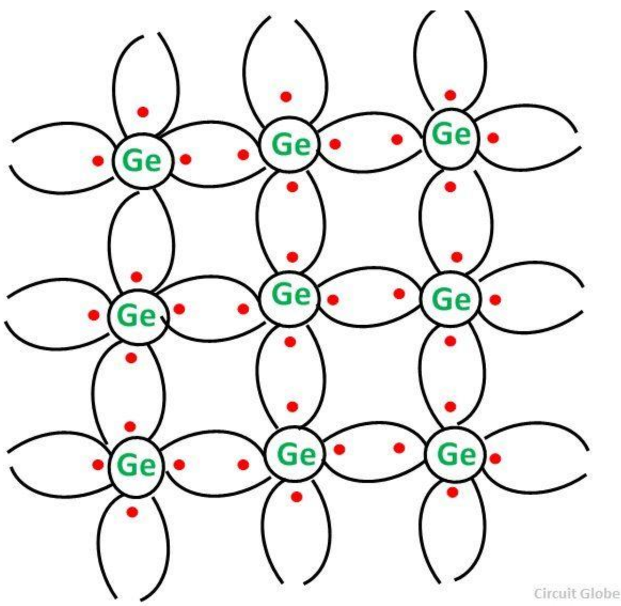
If a trivalent impurity having three valence electrons is added, a large number of holes will exist in the semiconductor.

Depending upon the type of impurity added the extrinsic semiconductor may be classified as **n type semiconductor** and **p type semiconductor**.

## n Type Semiconductor

When a small amount of **Pentavalent impurity** is added to a pure semiconductor providing a large number of free electrons in it, the extrinsic semiconductor thus formed is known as **n-Type Semiconductor.** The conduction in the n-type semiconductor is because of the free electrons denoted by the pentavalent impurity atoms. These electrons are the excess free electrons with regards to the number of free electrons required to fill the covalent bonds in the semiconductors.

The addition of Pentavalent impurities such as arsenic and antimony provides a large number of free electrons in the semiconductor crystal. Such impurities which produce n-type semiconductors are known as **Donor Impurities**. They are called a donor impurity because each atom of them donates one free electron crystal.

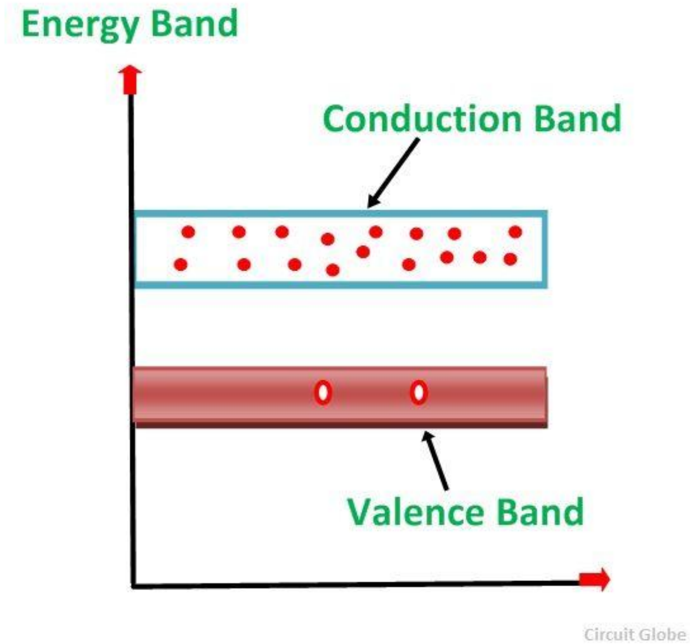



When a few Pentavalent impurities such as **Arsenic** whose atomic number is **33**, which is categorised as **2, 8, 15** and **5**. It has five valence electrons, which is added to germanium crystal. Each atom of the impurity fits in four germanium atoms as shown in the figure above.

Hence, each Arsenic atom provides one free electron in the Germanium crystal. Since an extremely small amount of arsenic, impurity has a large number of atoms; it provides millions of free electrons for conduction.

### Energy Diagram of n-Type Semiconductor

The Energy diagram of the n-type semiconductor is shown in the figure below.



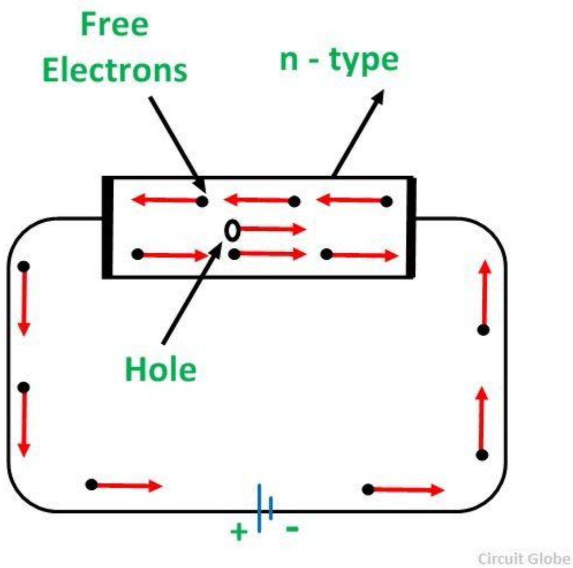

A large number of free electrons are available in the conduction band because of the addition of the Pentavalent impurity. These electrons are free electrons which did not fit in the covalent bonds of the crystal.However, a minute quantity of free electrons is available in the conduction band forming hole- electron pairs.

**The following points are important in the n-type semiconductor.**

- The addition of Pentavalent impurity results in a large number of free electrons.
- When thermal energy at room temperature is imparted to the semiconductor, a hole-electron pair is generated and as a result, a minute quantity of free electrons are available. These electrons leave behind holes in the valence band.
- Here n stands for negative material as the number of free electrons provided by the Pentavalent impurity is greater than the number of holes.

### Conduction Through n-Type Semiconductor

In the n-type semiconductor, a large number of free electrons are available in the conduction band which are donated by the impurity atoms. The figure below shows the conduction process of an n-type semiconductor.



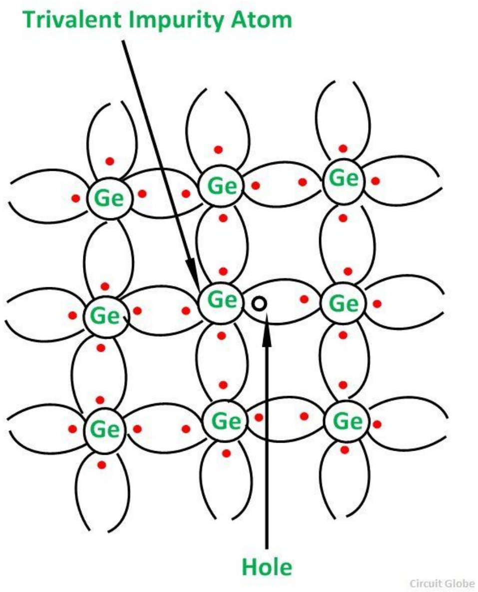

When a potential difference is applied across this type of semiconductor, the free electrons are directed towards the positive terminals. It carries an electric current. As the flow of current through the crystal is constituted by free electrons which are carriers of negative charge, therefore, this type of conductivity is known as **negative** or **n-type conductivity.**

The electron-hole pairs are formed at room temperature. These holes which are available in small quantity in valence band also consists of a small amount of current. For practical purposes, this current is neglected.

## p Type Semiconductor

The extrinsic **p-Type Semiconductor** is formed when a **trivalent impurity** is added to a pure semiconductor in a small amount, and as a result, a large number of holes are created in it. A large number of holes are provided in the semiconductor material by the addition of trivalent impurities like **Gallium** and **Indium.** Such type of impurities which produces p-type semiconductor are known as an **Acceptor Impurities** because each atom of them create one hole which can accept one electron.

A trivalent impurity like gallium, having three valence electrons is added to germanium crystal in a small amount. Each atom of the impurity fits in the germanium crystal in such a way that its three valence electrons form covalent bonds with the three surrounding germanium atoms as shown in the figure below.

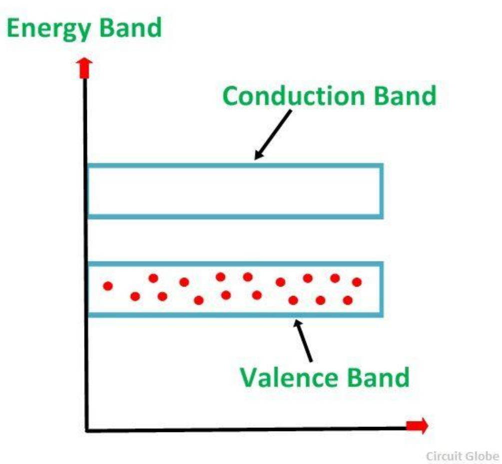



In the **fourth covalent bonds**, only the germanium atom contributes one valence electron, while gallium atom has no valence bonds. Hence, the fourth covalent bond is incomplete, having one electron short. This missing electron is known as a **Hole**. Thus, each gallium atom provides one hole in the germanium crystal.

As an extremely small amount of Gallium impurity has a large number of atoms, therefore, it provides millions of holes in the semiconductor.

## Energy Band Diagram of p-Type Semiconductor

The energy band diagram of a p-Type Semiconductor is shown below.

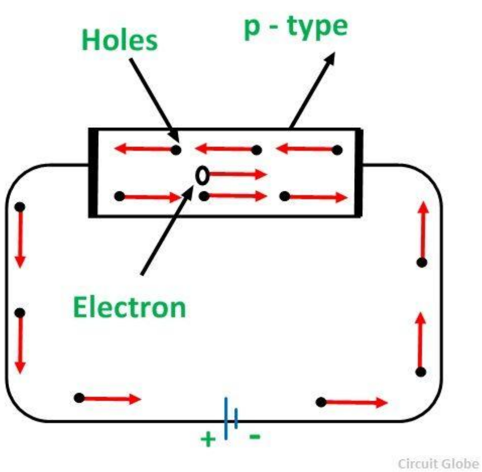


A large number of holes or vacant space in the covalent bond is created in the crystal with the addition of the trivalent impurity. A small or minute quantity of free electrons is also available in the conduction band.

They are produced when thermal energy at room temperature is imparted to the germanium crystal forming electron-hole pairs. But the holes are more in number as compared to the electrons in the conduction band. It is because of the predominance of holes over electrons that the material is called as a p-type semiconductor. The word "p" stands for the positive material.

**Conduction Through p Type Semiconductor**

In p type semiconductor large number of holes are created by the trivalent impurity. When a potential difference is applied across this type of semiconductor as shown in the figure below.




The holes are available in the valence band are directed towards the negative terminal. As the current flow through the crystal is by holes, which are carrier of positive charge, therefore, this type of conductivity is known as **positive** or **p type conductivity**. In a p type conductivity the valence electrons move from one covalent to another.

The conductivity of n type semiconductor is nearly double to that of p type semiconductor. The electrons available in the conduction band of the n type semiconductor are much more movable than holes available in the valence band in a p type semiconductor. The mobility of holes is poor as they are more bound to the nucleus.

Even at the room temperature the electron hole pairs are formed. These free electrons which are available in minute quantity also carry a little amount of current in the p type semiconductors.

## Conductivity of Semiconductors

For intrinsic semiconductors (no impurities), the number of electrons will be equal to the number of holes ($n_e = n_h$ ).

From mass action law for intrinsic Semiconductors

$$n_e = n_h = n_i$$

where $n_i$ indicates intrinsic concentration this is a fix value for for a intrinsic semiconductor

Thus, the conductivity for an intrinsic semiconductor exist due to both electrons and holes can be calculated:

$\sigma = q(\mu_e n_e + \mu_h n_h)$ ---- [1]

Above Expression give conductivity of Extrinsic Semiconductors

where

$\mu_e$ = indicate mobility of electrons

$\mu_h$ = indicate mobility of holes

$q$ = magnitude of charge

And since( $n_e = n_h = n_i$ )the conductivity for an intrinsic semiconductor is given by

$$\sigma = q n_i(\mu_e + \mu_h)$$

**n-type semiconductor**

$n_e >> n_h$

so neglecting $\mu_h$ $n_h$ in euation [1]

so $\sigma_n = q\ \mu_e n_e$ (conductivity of n-type semiconductor)

where $\sigma_n$ is the conductivity of n-type semiconductor

**p-type semiconductor**

$n_h >> n_e$

so neglecting $\mu_e$ $n_e$ in euation [1]

so $\sigma_p = q\ \mu_h n_h$ (conductivity of p-type semiconductor)

where $\sigma_p$ is the conductivity of p-type semiconductor.

Link for Video Lecture Introduction to Semiconductor:

https://www.youtube.com/watch?v=BlyHqABrZjA&list=PLNsppmbLKJ8KeEIxy81OlC-AGIWJAG8gL&index=28