Electronics

in which we study charges

CHAPTER 1

SEMICONDUCTOR DIODES

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Q.1 Distinguish among conductors, insulators and semiconductors on qualitative and quantitative basis? *(Pu.2011,Uos.2012,Gcuf.2012)*

CONDUCTORS

The materials having large number of free electrons are **called conductors**. The conductors conduct current when potential difference is applied. Copper and aluminium are good examples of conductors.

The electrons in the outermost orbit of an atom are **called valence electrons**. The maximum number of valence electron can be 8. The material is usually metal and conductor when valence electrons of an atom are less than 4.

The valence electrons of a conductor which are loosely attached to the nucleus of an atom are **called free electrons.** The free electrons moving randomly and continuously in a conductor are **called conduction electrons**. The part of atom without free electrons **is called positively charged ionic core**. These ionic cores are assumed to be fixed in conductor.

On quantitative basis, each atom of a typical conductor may contribute one electron. On average such conductor has 10^{23} conduction electrons per cm^3. The resistivity of conductors is very small and is of the order of $10^{-8}\ \Omega$–m. The resistivity of copper is $1.68 \times 10^{-8}\ \Omega$–m and resistivity of aluminium is $2.65 \times 10^{-8}\ \Omega$–m.

The temperature coefficient of resistance ($\alpha = \dfrac{R_T - R_0}{R_0\,\Delta T}$) of conductors is always positive because resistance increases with increase in temperature.

INSULATORS

The materials having no free electrons at ordinary temperature are **called insulators**. The insulators do not conduct current when potential difference is applied. Glass and plastic are good examples of insulators. The material is usually called insulator and non–metallic when valence electrons of an atom are more than 4. The insulators have no ionic cores because electrons are tightly bound.

On quantitative basis, a typical insulator has one conduction electron per cm^3 at room temperature. The resistivity of insulators is very high and is of the order of 10^{11} Ω–m to1016 Ω–m. The resistivity of glass is $9.0 \times 10^{11}\ \Omega$–m. The insulators have no temperature coefficient of resistance at room temperature.

EMICONDUCTORS

The partial conductors are **called semiconductors.** The semiconductors have few e electrons and holes at room temperature and practically do not conduct current due to tential difference. The semiconductor material has both metallic and non–metallic operties when number of valence electrons of an atom is 4. Silicon and germanium are od examples of semiconductors.

The charge carriers are free electrons and holes in semiconductors. The positively arged ionic cores are assumed to be fixed.

On quantitative basis, a typical semiconductor has 10^{13} conduction electrons per n^3 at room temperature. The density of charge carriers can be changed by introducing all impurities.

The resistivity of semiconductors has intermediate values between conductors and sulators and is of the order of 0.5 Ω–m to 10^{-4} Ω–m. The resistivity of germanium is Ω–m and resistivity of silicon at room temperature is $3.0 \times 10^{+3}$ Ω–m. The nperature coefficient of resistance of semiconductors is generally negative because sistance of semiconductors decreases with increase in temperature.

2 Describe band theory in solids and state how conductors, insulators and semiconductors are distinguished using concept of energy bands?
(Pu.2006,2007,2015,Uos.2014,Gcuf.2014)

AND THEORY IN SOLIDS

The electrons of an isolated atom are bound to the nucleus and only have **allowed ergy levels**. Each energy level of an isolated atom splits into **sub-levels called energy states** under the action of other atoms when many atoms are brought close together to m a solid. These closely spaced energy states are **called energy bands**. There is a ge of energy states between two allowed energy bands which are not occupied by the ctrons. These are called **forbidden energy states** and its range is called forbidden ergy gap.

There are many energy bands in solids but **valence-band, conduction-band** and **ergy gap** between them are more important because they are involved in electrical nduction.

LENCE BAND

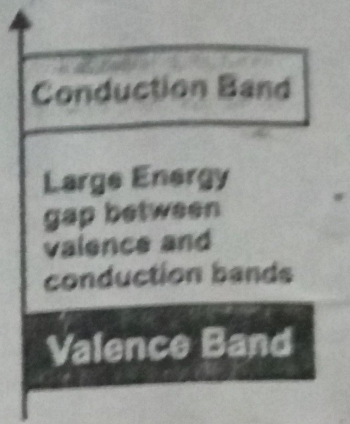
The electrons in outermost orbit of an atom are known as valence electrons and ergy band occupying these valence electrons is called valence–band. The ence–band may be completely filled or partially filled with electrons of highest energy d can not be empty. The valence–band of inert gases is completely filled whereas other terials have partially filled.

ONDUCTION BAND

The valence electrons which are loosely bound to the nucleus of an atom are known free electrons. These free electrons are responsible of electrical conductivity of the terial so **called conduction electrons.** The energy band occupying conduction ctrons is called conduction–band. The conduction energy band may be empty or tially filled and never be completely filled. Any electron leaving the valence–band is ommodated by conduction-band.

⟹ The energy bands below the valence–band are completely filled and do not part in conduction process. That is why valence–band and conduction-band are invo in electrical conductivity of solid materials. The conduction properties of solids de upon energy gap between valence–band and conduction–band.

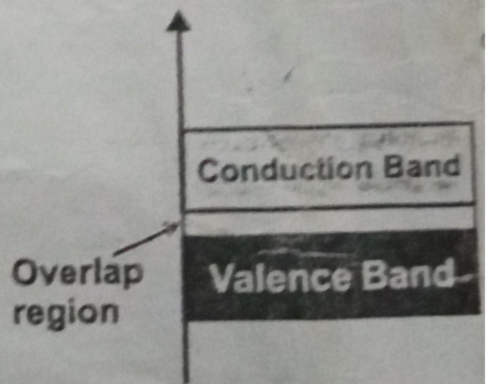
INSULATORS



The materials with full–valence band and empty conduction-band are called insulators. The energy gap between valence–band and conduction–band in insulators is very large (≈15eV). The electrical conductivity of insulators is very small because high electric field is required to push electrons from valence–band to the conduction–band.

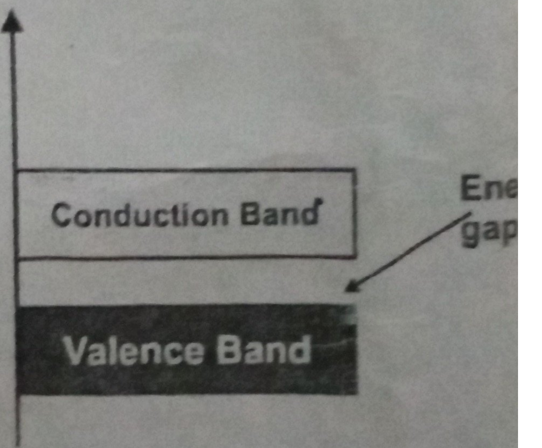
⟹ The valence electrons of the insulators do not have enough energy to cross from valence–band to the conduction–band at room temperature. However, w temperature is raised some of valence electrons may acquire enough energy to cross to the conduction–band. This decreases the resistance of an insulator. Hence tempera co-efficient of resistance of insulators is negative.

CONDUCTORS:-



Those materials in which valence–band and conduction–band overlap upon each other are called conductors. The valence–band and conduction– band both become partially filled due to overlapping. The electric current flows through conductors when a slight Pd is applied at the end of conductor because free electrons can easily move.

SEMICONDUCTORS:-



The materials having almost full valence–band and almost empty conduction–band with small energy gap (≈ 1 eV) between them are called semiconductors. The semiconductor behaves as insulator at 0K because conduction–band has no electrons and valence–band is completely filled. The electrical conductivity of a semiconductor increases with rise in temperature because some electrons cross over from valence–band to the conduction–band.

How do you account for the fact that resistivity of metals increases with increase in temperature but that of semiconductors decreases. *(Pu.2002,2013)*

ISTIVITY OF CONDUCTORS (METALS)

The resistivity of conductors increases with increase in temperature because ation of ionic cores increases. These vibrations offer greater resistance to flow of electrons. The conductivity of conductors(metals) decreases with increase in perature because both are reciprocal to each other. The conductors have positive perature coefficient of resistivity.

SISTIVITY OF SEMICONDUCTORS

The resistivity of semiconductors decreases with increase in temperature because re electrons acquire enough energy to be excited across the energy gap from nce–band to conduction–band. The increase of electrons in conduction band reases the resistivity and increases the conductivity. The semiconductors have ative temperature coefficient of resistivity.

4 What are the advantages of making solid state devices? *(Pu.2010)*

VANTAGES OF MAKING SOLID STATE DEVICES

The solid state crystalline materials such as germanium or silicon having electrical ductivity greater than insulators but less than good conductors are called iconductors. Transistors, semiconductor diodes, integrated circuits and rectifier are mples of solid state semiconductor devices.

The semiconductor materials are used in computers, radios, television receivers and ecassette recorders etc. The semiconductor devices perform many control functions. ey may be used as rectifiers, amplifiers, detectors, oscillators and switching elements.

There is a little chance of vibrations because semiconductors are solid materials. e semiconductors require little power and radiate little heat. They do not need warm up e and operate as soon as power is applied. The semiconductors have small size so upy small spaces.

The conductivity of germanium and silicon may be increased by adding impurities. changes the properties of semiconductors dramatically and has many applications in ctronics.

5 What are intrinsic semiconductors? Why silicon is used widely in electronic devices? *(Pu.2009,2010,2013)*

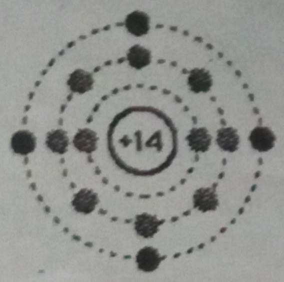
TRINSIC SEMICONDUCTORS

The naturally pure, undoped and crystalline structured semiconductor materials are lled **intrinsic semiconductors**. The silicon and germanium are examples of miconductor materials. Both belongs to group IV of periodic table.

SILICON

Silicon is a non–metallic element occurring in the earth's crust in the form of silica and silicates. The silica also occurs in the skeletons of some microscopic animals and stems of some plants. It is used to make photocells for camera and exposures meters. Silica is also used in making glass and ceramics. Silicon has both an amorphous and a crystalline allotrope. It is used in combination with other materials such as glass, semiconductor devices, concrete, brick, refractory, pottery, and silicones.

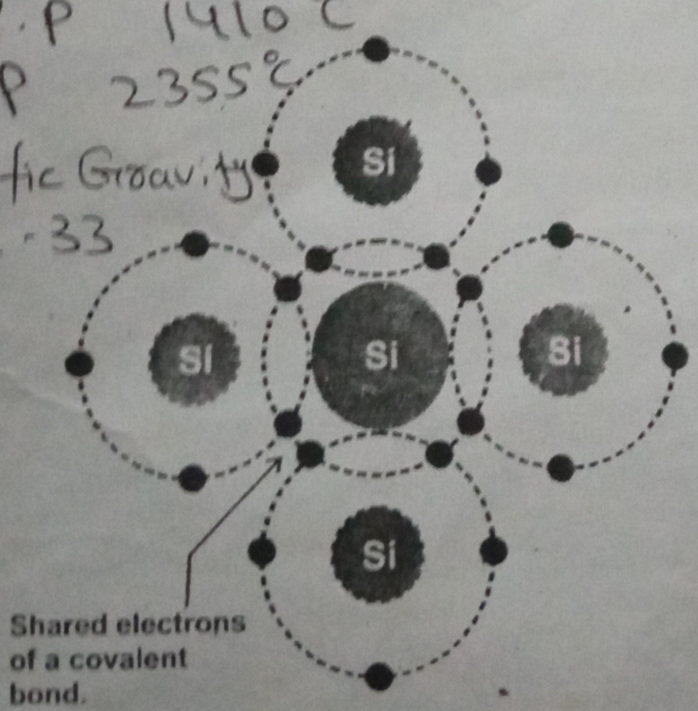
The chemical symbol of silicon is Si. Its atomic number is 14. The atom of silicon has 14 electrons orbiting around the nucleus. The silicon belongs to forth group on periodic table and has four valence electrons. Its crystal contains groups of four atoms arranged as a triangular pyramid. Its resistivity is 1500 Ω–m. The electron configuration of silicon is $1s^2 2s^2 2p^6 3s^2 3p^2$.

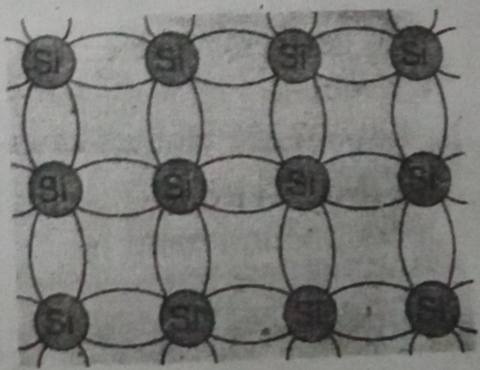


Silicon

The silicon atoms form covalent bonds and can crystallize into a regular lattice. The illustration below is a simplified sketch. The actual crystal structure of silicon is a diamond lattice. This crystal is called an intrinsic semiconductor. It can conduct a small amount of current is called intrinsic semiconductor current.

M.P 1410°C
B.P 2355°C
Sapacific Gravity
2.33





Some electrons are excited across the band gap into the conduction band in an intrinsic semiconductor like silicon at temperatures above 0K; they leave behind electron vacancies called holes in the regular silicon lattice. These electrons and holes can move across the material when electric field is applied.

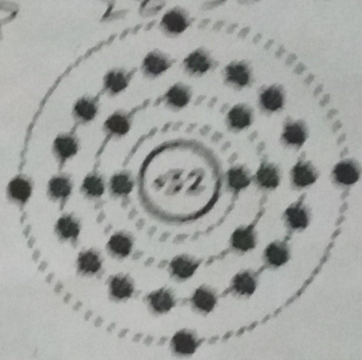
ERMANIUM

Germanium is a brittle, crystalline, gray-white metallic element. It is widely used as semiconductor, alloying agent, catalyst and optical glasses. Germanium is obtained as a y product in zinc refining.

M.P 937.4 °C
B.P 2830 °C

Specific Gravity 5.323

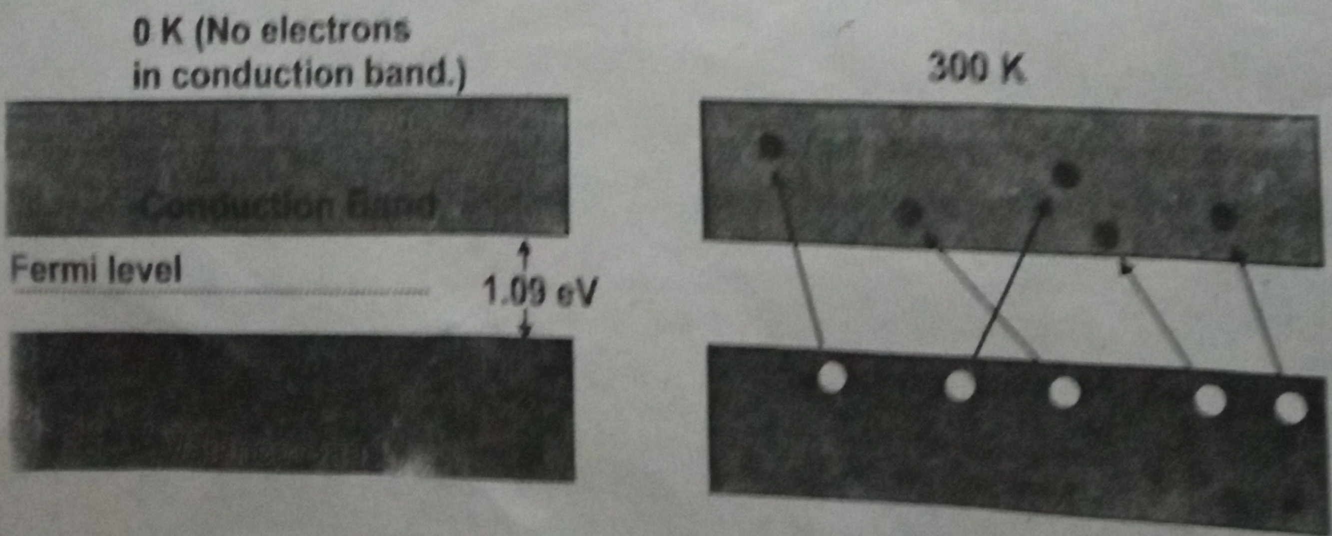
The chemical symbol of germanium is e. Its atomic number is 32. The germanium om has 32 electrons orbiting around the ucleus. The germanium belongs to forth roup on periodic table so has four valence ectrons. Its resistivity is 0.6 Ω–m. The ectron configuration of germanium is $1s^2$ $2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$.



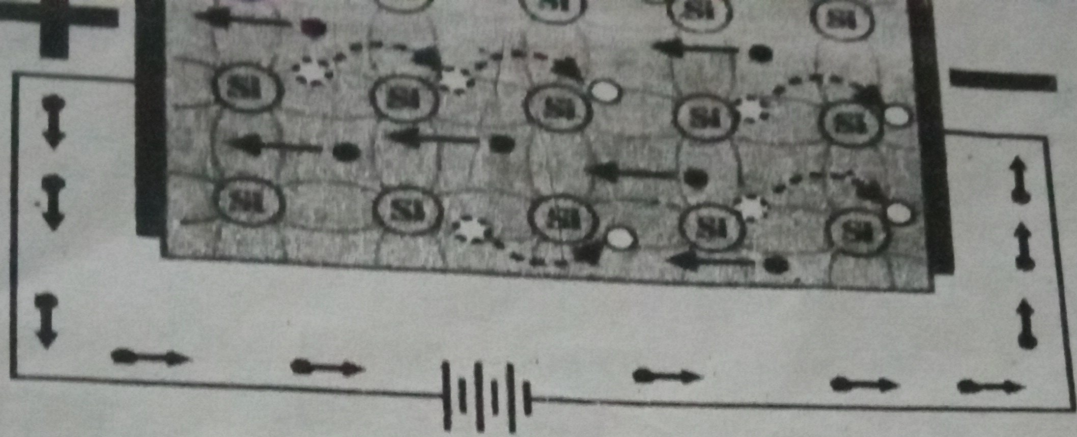
Germanium

/HY SILICON IS WIDELY USED IN SEMICONDUCTORS

The pure silicon or germanium may be used as intrinsic semiconductor in solid ate electronic devices, The energy gap for silicon at 0K is 1.09 eV. The silicon has ur valence electrons.



The energy gap of germanium is 0.72 eV. The germanium has four valence ctrons.



The current flow in an intrinsic semiconductor is called intrinsic semiconductor current. It is strongly influenced by density of free electron and is highly temperature dependent.

Q.8 What is meant by doping? Name the majority charge carriers in n–type and p–type. How n–type and p–type semiconductors are prepared? *(Pu.2001,2002,2004,2006,2008,2010,2013,Uos.2011)*

DOPING OF SEMICONDUCTORS

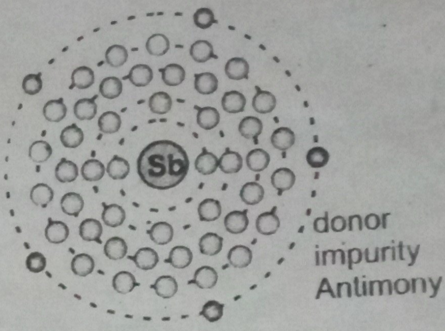
The addition of a small percentage of impurity into intrinsic semiconductors such as germanium or silicon is **called doping**. The new materials formed after doping are called **extrinsic semiconductors.** The doping increases the density of charge carriers (free electrons or holes) and conductivity of intrinsic semiconductors.

The extrinsic semiconductors have two types **called n–type and p–type**. All electronic devices are based on extrinsic semiconductors.

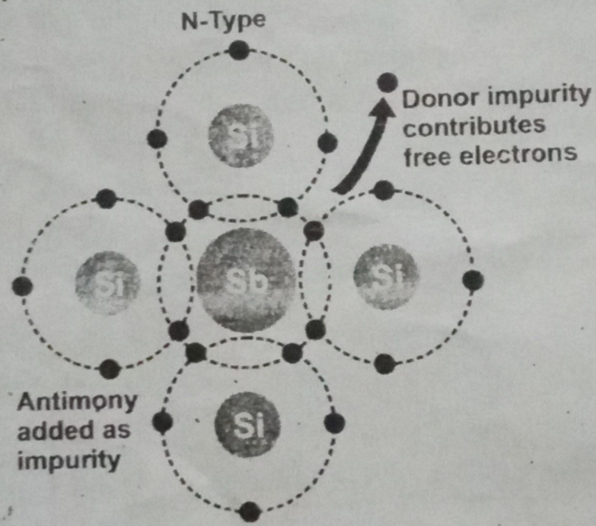
N-TYPE SEMICONDUCTORS

The materials formed after addition of pentavalent impurity such as antimony, arsenic or phosphorous into intrinsic semiconductors is **called n–type materials.**

The atom of pentavalent impurity such as antimony has 5–valence electrons as shown in fig.



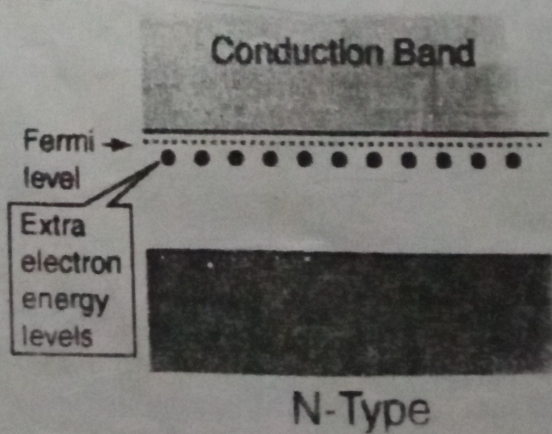
The pentavalent impurity when added in pure Si or Ge occupies the central position and four of its valence electrons form covalent bond with four valence electrons of intrinsic semiconductor.



→ The fifth electron of impurity atom remains unbound and acts as charge carrier. The impurity atom is **called donor atom** because it has donated a free electron. It means addition of donor atoms increases the density of free electrons in the conduction–band and greatly increases the conductivity of the intrinsic semiconductor.

⇒ The free electrons in conduction–band in n–type material are **called majority charge carriers** The holes produced due to breakage of covalent bonds in n–type material are **called minority charge carriers.**

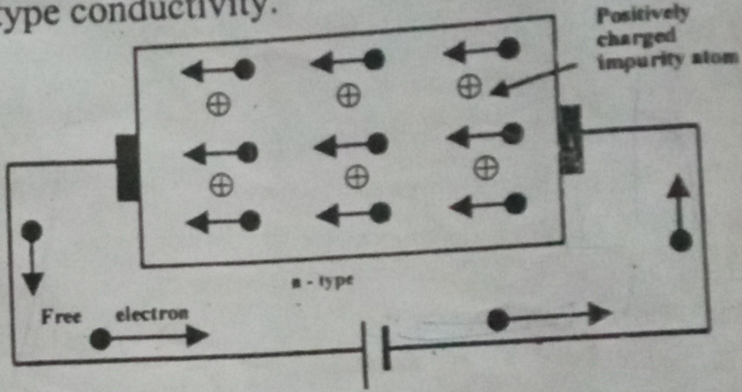
The extra energy level added by the impurities in n–type material near the top of the band gap is **called Fermi level**. This Fermi level makes the excitation of free electrons into the conduction band easy.



The positively charged donor ionic cores remain fixed at their lattice sites at ro[illegible] temperature. That is why they are not called charge carriers. The n–type material [illegible] net charge.

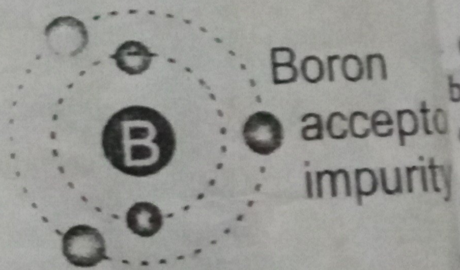
N-TYPE CONDUCTIVITY

The flow of current in n–type semiconductor when connected to a battery is [illegible] movement of free electrons which are directed towards the positive terminal of batt[illegible] called n–type or electron type conductivity.



P-TYPE SEMICONDUCTORS

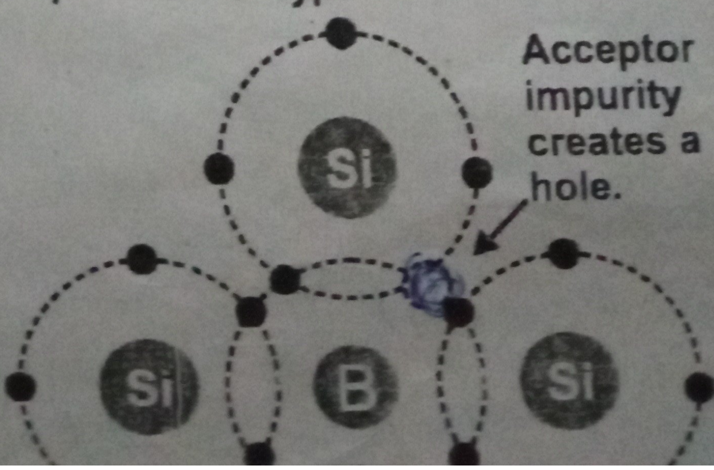
The materials formed after doping of trivalent impurity such as boron, aluminium or gallium into intrinsic semiconductors is **called p–type materials.**



The atom of trivalent impurity such as boron has 3–valence electrons as shown in fig.

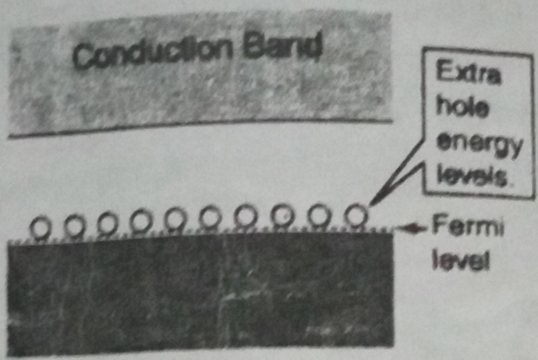
The impurity atom when doped with pure Si or Ge occupies the central positi[illegible] three valence electrons form covalent bond with three valence electrons of in[illegible] semiconductor. A vacancy is formed at the position of fourth covalent bond as sh[illegible] fig. This vacancy is **called hole**. It acts as charge carrier.

P-Type



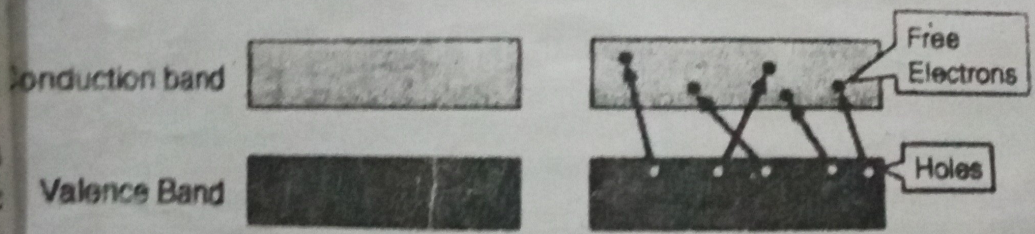
e impurity atom is **called acceptor atom** because it can accept an electron to e covalent bond. It means addition of acceptor atoms increases the density of he density of holes greatly increases the conductivity of the intrinsic luctor.

e holes in valence-band are **called majority charge carriers** while electrons l due to breakage of covalent bonds are **called minority charge carriers** in aterial.



P-Type

extra energy level called Fermi level is created by the impurities near the f the band gap in p–type materials. In this way free electrons can be easily to the conduction band.



negatively charged acceptor ionic cores remain fixed at their lattice sites at perature. That is why they are not called charge carriers. The p–type material charge.

ONDUCTIVITY

low of current due to movement p–type semiconductors is called ole type conductivity. The holes impurity are shifted from one ond to another when Pd is he p–type semiconductor. The sitively charged therefore they towards the negative terminal d establish hole current.