Introduction

Semiconductors are materials, whose electronic properties are intermediate between those of good conductors and insulators. These intermediate properties are determined by the crystal structure, bonding characteristics, electronic energy bands and also by the fact that unlike metals, semiconductors varies from 10^{-5} to 10^{+4} ohm-m as compared to the values ranging from 10^{-8} to 10^{-6} ohm-m for conductors and from 10^7 to $10^8\ \Omega\,\mathrm{m}$ for insulators. There are elemental semiconductors such as germanium (Ge) and silicon (Si) which belong to the group IV of the periodic table and have resistivity of about 0.6 and 1.5 x 10^3 ohm-m respectively. Besides these, there are certain compound semiconductors such as gallium arsenide (GaAs), indium phosphate (In P), cadmium sulphate (CdS) etc., which are found from the combinations of the elements of group III and V or group II and IV. The resistivity of a semiconductor is a function of temperature. With increase of temperature, the resistivity decreases, so that electrical conductivity increases. Hence the semiconductors have negative temperature co-efficient of resistance.

The band gap of semiconductors varies from 0.2 to 2.5 eV, which is quite small as compared to that of insulators. The band gap of a typical insulator such as diamond is about 6 eV. The conductivity and the effective band gaps of semiconductors can be changed by doping the impurities which strongly affect their electronic and optical properties. These properties determine the wavelength of radiation which can be emitted or absorbed by the semiconductor and hence help to construct devices such as light emitting diodes (LEDs) and lasers.

Origin of Energy Band Formation in Solids

Solids are usually strong and slightly elastic structures. The individual atoms are held together in solids by inter atomic forces or bonds. The bonding is strongly dependent on the electronic structure of the atoms concerned. The attraction between the atoms brings them closer until the individual electron clouds begin to overlap. A strong repulsive force arises according to Pauli's exclusion principle. When the attraction force and the repulsive force between any two atoms are equal, the two atoms occupy a stable position with a minimum potential energy. The spacing between the atoms under this condition is called equilibrium spacing. In solids many atoms are brought together so that the split energy levels form a set of bands of very closely spaced levels with forbidden energy gaps between them as illustrated in the Fig.1

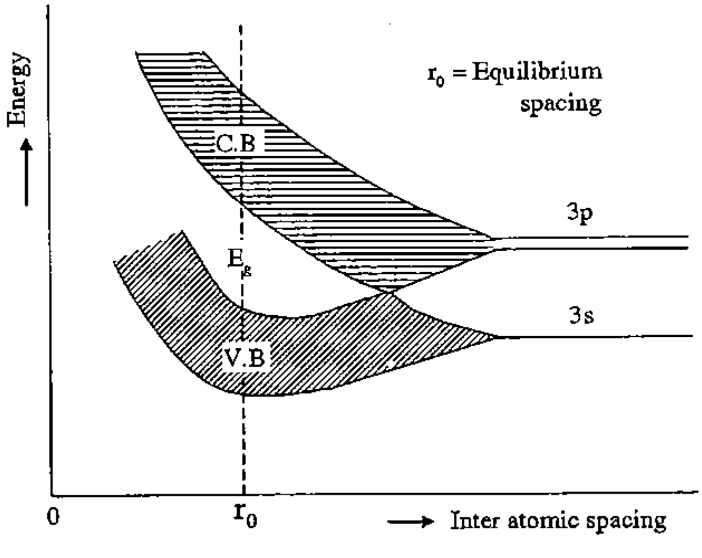
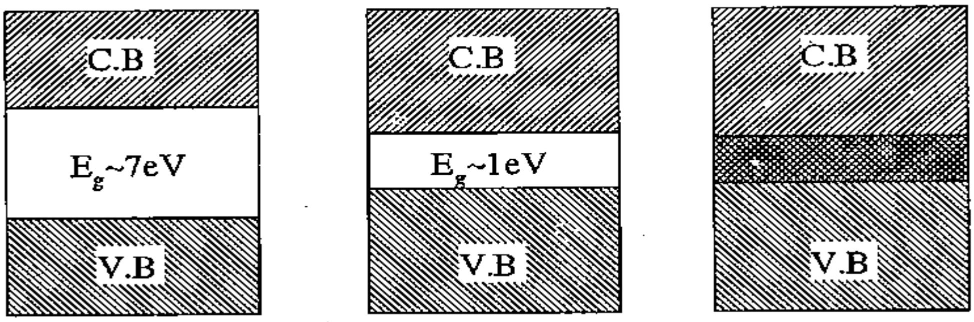


Fig. 1 Spreading of energy levels into energy bands in sodium

The electrons first occupy the lower energy band and are of no importance in determining many of the electrical properties of solids. Instead, the electrons in the higher energy bands of solids are important in determining many of the physical properties of solids. Hence we are interested in those two allowed energy bands called valence and conduction bands. The gap between these two allowed bands is called forbidden energy gap or band gap.

Distinction between Conductors, Semiconductors and Insulators

The electrical properties of solid depend upon its energy band structure and the way in which the energy bands are occupied by the electrons. Depending on the nature of band occupation by electron and on the width of the forbidden band, the solids can be classified as insulators, semiconductors and conductors. The metals are good conductors of electricity while the insulators are bad conductors of electricity. The electrical conductivity of semiconductor lies between that of the metal and the insulator. The energy band theory of solids can explain the electrical conductivity of a solid. The electrons in the innermost shells, which are completely filled, do not take any part in the conduction process. The completely filled bands and the completely empty bands do not contribute to the electrical conduction. The valence band and the conduction band energies are important for the electrical properties of a solid.



(a) Insulators (b) Semiconductors (b) Conductors

Fig.2 Energy band diagram of insulators, semiconductors and conductors

Insulators:

The energy band structure of an insulator is as shown in Fig.2 (a). In insulator, the conduction band is completely empty, the valence band is completely filled and there is a large energy gap, $E_g>2$ eV, between conduction band and valence band. When an electric field is applied, there is no new energy level available to the electron and there is no conduction of electricity. Because of the large band gap, the transition of electron from valence band to conduction band is also not possible. At room temperature, the thermal energy (K_BT) is much less than the band gap energy. The diamond is a perfect insulator having a band gap of 5.5 eV.

Semiconductors:

The energy band diagram of semiconductor is shown in Fig.2 (b). In semiconductors, the conduction and valence bands are partially filled at room temperature. The energy gap between the valence band and the conduction band is small as compared to that of insulator. Due to the small energy gap, some of the valence band electrons make transitions to the conduction band by acquiring thermal energy. These electrons leave an equal number of vacant states or holes in the valence band. These holes behave like positive charge and also contribute to the conduction of electricity. The conductivity is in between that of insulators and conductors. The examples for semiconductors are silicon and germanium having band gap energies are 1.1 eV and 0.62 eV respectively. At absolute zero temperature, all the semiconductors act as insulators. The conductivity of semiconductor increases with increase in temperature and so the semiconductor having a negative temperature coefficient of resistance.

Conductors:

The energy band diagram of a conductor is shown in Fig.2(c). In conductors, the valence band and the conduction band overlap and there is no energy gap between them. At room temperature, the free electrons exist in the conduction band hence conductivity is high. The resistivity increases with increase of temperature as mobility of existing electrons will be reduced due to the collisions; hence the metals have a positive temperature coefficient of resistance. Metals are the best examples for conductors.

Classification of Semiconductors:

The semiconductors are classified as,

1. Intrinsic (or) Pure semiconductors
2. Extrinsic (or) Impure semiconductors

Intrinsic (or) Pure semiconductors

The pure form of a semiconductor is called as intrinsic semiconductor. A pure crystal of silicon or germanium is an intrinsic semiconductor. The electrical conductivity of this type of semiconductor is solely determined by thermally generated carries. In order to understand the electrical conduction in an intrinsic semiconductor, let us consider the case of germanium. The atomic number of germanium is 32, so it has 32 electrons; 2 in the first orbit, 8 in the second orbit, 18 in the third orbit and remaining four in the outermost orbit. Thus the germanium atom has four valence electrons i.e., it is a tetravalent element. Each of the four valence electrons in a germanium atom is shared by the valance electrons of four adjacent germanium atoms and makes four electron pairs as shown. These types of electron pair are known as covalent bonds which provide the bonding force between neighbouring atoms. In this way, the atoms behave as if their outermost orbits were completed with 8 electrons. Thus, free electrons are available to conduct a current through a germanium crystal. A pure germanium crystal is an insulator at absolute temperature.

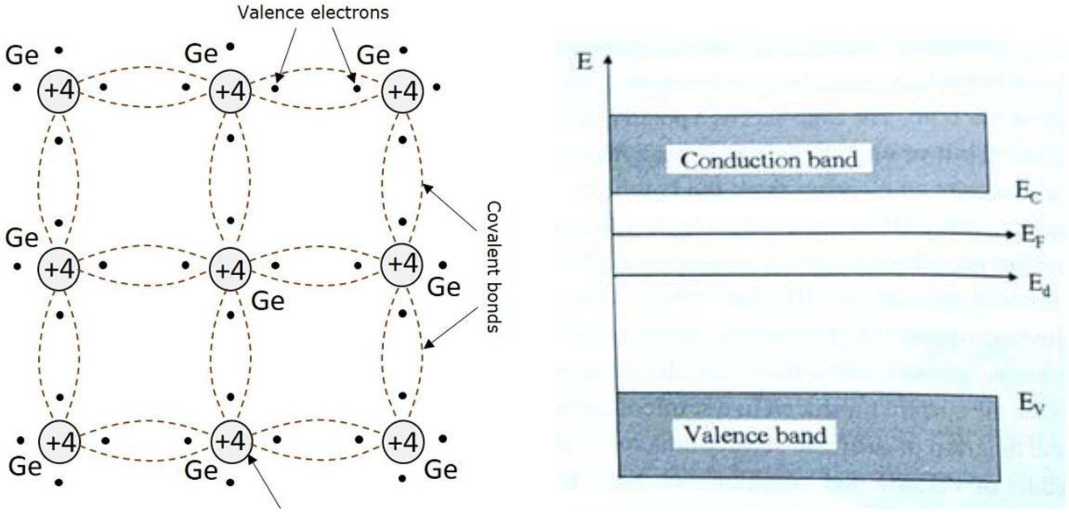


Fig. 3 Bond structure and energy band diagram of intrinsic semiconductor

However, with increase of temperature, a few covalent bonds are broken. When a covenant bond is broken, one electron becomes free and leaves the atom and becomes a positive ion known as hole. The hole acts a positively charged particle, having a charge equal to that of an electron but of opposite sign. Since a hole is a strong centre of attraction for the electron, the hole attracts and electron from the neighbouring atom to fill it. Thus the hole is now shifted to another place from where the electron has migrated. The newly created hole is filled up by a random manner, just like the free electron. On applying an electric field, the holes move in a direction opposite to that of the valence electrons. It constitutes a hole current. It must be noted that in an intrinsic semiconductor, the number of electrons and holes are equal and they are less. Hence the current produced in a semiconductor is not adequate for any useful work. The energy band diagram of intrinsic semiconductor is shown. The Fermi level E_F is at the middle of valence and conduction bands. If E_V and E_C are the energy levels of valence and the Fermi energy is,

$$E_8 = E_C - E_V$$

$$E_F = (E_C + E_V)/2$$

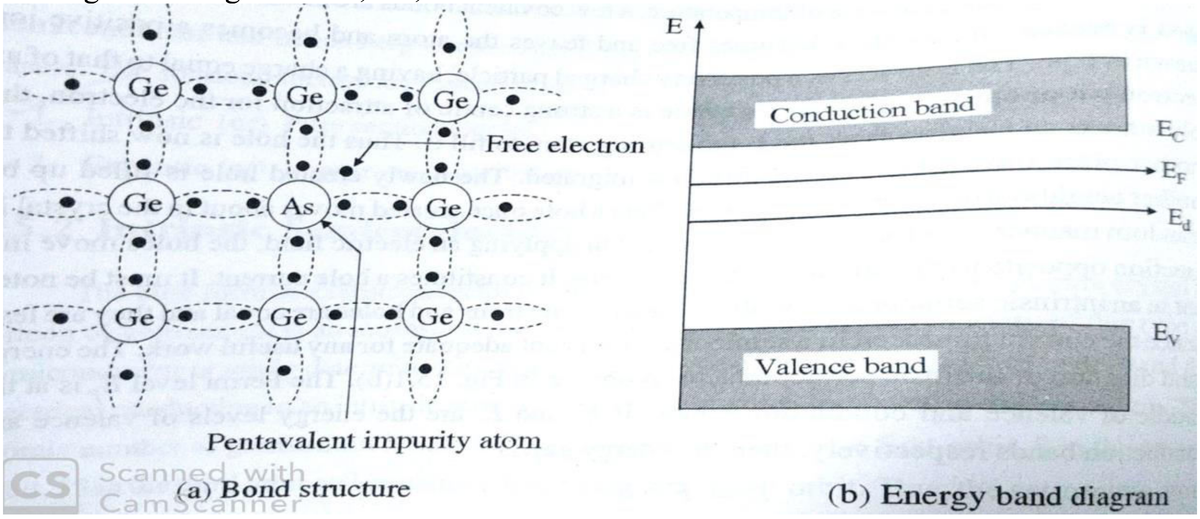
Extrinsic (or) Impure semiconductors

If a small amount of impurity is added to a pure semiconductor, it significantly increases the conducting properties. The process of adding the impurities to a semiconductor is known as doping. Semiconductor doped with impurities is called extrinsic semiconductor. Depending upon the type of impurity added to pure semiconductor (like Ge or Si) the extrinsic semiconductors are further subdivided into two groups

1. n-type semiconductor,
2. P-type semiconductor.

N-type semiconductor

A semiconductor doped with a pentavalent impurity is called n-type semiconductor. Typical examples of pentavalent impurities are arsenic (As, Z=33) and antimony (Sb, Z =51). When these impurities are added to pure germanium crystal, four valence electrons of impurity atom form covalent bonds with the four valence electrons of the neighbouring Ge atoms. The fifth valence electron of impurity atoms has no place to form the covalent bond and remains free to move randomly in the crystal lattice as shown. Thus each impurity atom donates a free electron to the semiconductor. Hence the impurity is called donor impurity. The semiconductor containing donor type impurity is called n-type semiconductor because it has negative charge carriers, i.e., electrons.



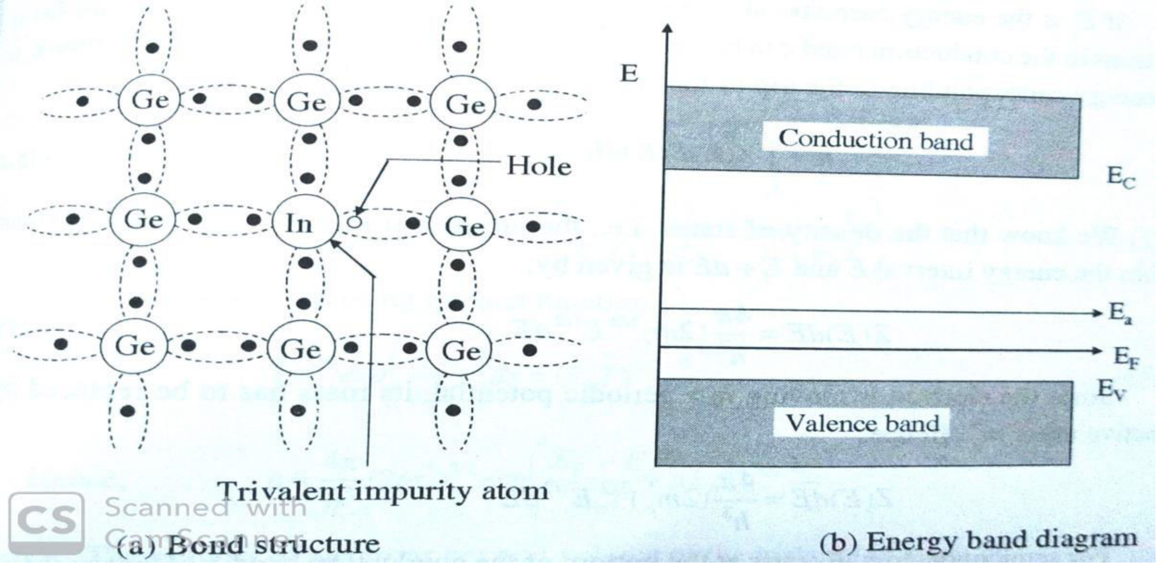
(a) Bond structure (b) Energy band diagram

Fig. 4 Bond structure and energy band diagram of n-type semiconductor

Although each arsenic atom donates one electron, yet doping the crystal with just a trace of impurity provides enough free electrons to move through the crystal structure and act as charge carrier. In the case of germanium, doped with donor impurities the energy required to move an electron from donor impurity to the conduction band is in the order of 0.0127 eV. The energy band diagram for n-type semiconductor is shown. Here E_d represents the energy level corresponding to donor impurities and it lies just below the conduction band. It should be noted that in n-type semiconductors, the electrons are majority charge carriers but there are still present some thermally generated holes which are called the minority charge carriers.

P-type semiconductor

A semiconductor dropped with a trivalent impurity is called P-type semiconductor. Typical examples of trivalent impurities are gallium (Ga, Z=31) and indium (In, Z=49). When a small amount of Indium is added to germanium crystal, three valence electrons of impurity atoms form covalent bonds with three valence electrons from three neighbouring germanium atoms. There is a deficiency of one electron to complete the fourth bond. This electron deficiency is called the hole and it behaves like a positively charged particle as shown. Since there is a strong tendency of semiconductor crystal to form covalent bonds, a hole attracts one electron from a nearby covalent bond. Consequently, a new hole is creaked at the originally occupied place of electron. This hole is again filled by another electron from a nearby bond giving rise to another hole and so on. Thus a hole moves freely throughout the crystal lattice.



(a) Bond structure (b) Energy band diagram

Fig. 5 Bond structure and energy band diagram of p-type semiconductor

An impurity that produces holes inside a semiconductor crystal is called acceptor impurity because it accepts electrons from the nearby germanium atoms. The semiconductor containing acceptor type of impurity is called p-type semiconductor, because the charge carriers are positive holes. The energy band diagram for p-type semiconductor is as shown. Here E_a represents the energy level corresponding to the acceptor impurities. When an intrinsic will be more than the concentration of electrons in conduction band and the Fermi level shifts towards the valence band. The accept level is just above the valence band. It should be noted that in p-type semiconductors, holes are majority charge carriers and electros are the minority charge carriers.

Drift and Diffusion Currents:

The electric current arises due to movement of charge carriers in the material. In semiconductors, the charge carriers are electrons in the conduction band and holes in valence band. Due to thermal agitation they move randomly in all directions and hence the net current in any direction is zero.

When an electric field E is applied across the semiconductor material, every charge carrier experiences a force due to electric field and drifts in the direction of force. Thus a charge carrier acquires an average velocity which is called drift velocity and gives rise to drift current.

The total current due to electrons and holes in the presence of applied electric field is known as drift current.

The electric current density is

$$J = nev_d$$

Here, v_d is the drift velocity.

In steady state the electrons are moving towards the positive terminal of the potential with drift velocity v_d m/s.

The drift velocity is proportional to applied electric field intensity,

$$v_d \propto E$$

$$v_d = \mu E$$

Here, μ is the mobility of electrons.

Thus, the current density is,

$$J = nev_d$$

$$= ne\mu E$$

The corresponding drift current densities due to electrons is,

$$J_{\text{drift}} = ne\mu_e E$$

The corresponding drift current densities due to holes is,

$$J_{\text{drift}} = ne\mu_h E$$

The electrical conductivity of an intrinsic semiconductor due to drift action of electrons and holes is,

$$J_{\text{drift}} = n_i eE(\mu_e + \mu_h)$$

Diffusion current:

The diffusion current is due to the flow of charge carriers when there is non-uniform concentration of charge carriers in semiconductors. The excess carriers move from the region of higher density to the region of higher concentration tending to produce uniform distribution that leads to diffusion current. The diffusion current is proportional to the concentration gradient.

The concentration of carriers dn varies with distance x in a semiconductor constitutes concentration gradient dn/dx.

According to Fick's law the rate at which the carriers diffuse is proportional to the density gradient and the movement is in the direction of negative gradient.

The rate of flow of electrons is across unit area is $-D_n(dn/dx)$

This flow constitutes an electron current density and conventional current is the rate of positive charge.

$$J_n(diffusion) = -e(\text{ rate of flow across unit area})$$

$$= -e(-D_n(dn/dx))$$

$$= eD_n(dn/dx)$$

Similarly, if an excess hole concentration is created in the region, hole diffusion takes place, the corresponding expression for holes in a semiconductor is,

$$J_p(diffusion) = -eD_p(dp/dx)$$

Here, D_p is diffusion constant for holes. For the same type of gradient, the hole and electron currents are in opposite direction. The total current density is,

$$J(diffusion =)J_n(diffusion) + J_p(diffusion)$$

$$= eD_n(dn/dx) - eD_p(dp/dx)$$

Thus, in a semiconductor the total current density is due to drift and diffusion of carriers.

$$J = J_{drift} + J_{diffusion}$$
$$= eE(n\mu_e + p\mu_h) + eD_n(dn/dx) - eD_p(dp/dx)$$
$$= e[(n\mu_e + D_n(dn/dx) + p\mu_h E - D_p(dp/dx))]$$

Einstein's Equation:

The parameters mobility μ and diffusion coefficient $\frac{dn}{dx}$ describes the direct relationship of drift and diffusion are related by Einstein equation. Under equilibrium conditions the drift and diffusion currents due to excess density of electrons are equal. Thus,

$$(dn)e\mu_e E = eD_n \frac{dn}{dx}$$

This is the force on excess carriers restoring to equilibrium. Thus,

$$F = (dn)eE = \left(\frac{eD_n}{\mu_e}\right)\frac{dn}{dx}$$

This force also depends on the thermal energy of excess carries.

According to the kinetic theory of gases, if the molecular concentration of gas increases by (dn), the gas pressure increases by $(dn)k_B T$.

The force corresponding to the pressure gradient is given by,

$$F = k_B T\left(\frac{dn}{dx}\right)$$

By making analogy between the excess carriers in semiconductors and gas molecules in a container, then

$$k_B T\left(\frac{dn}{dx}\right) = \left(\frac{eD_n}{\mu_e}\right)\frac{dn}{dx} \Rightarrow k_B T = \left(\frac{eD_n}{\mu_e}\right) \Rightarrow \frac{D_n}{\mu_e} = \frac{k_B T}{e}$$

This is the relation between diffusion coefficient and mobility of charge carriers and is termed as Einstein relation.

The relation for holes is given by,

$$\frac{D_p}{\mu_h} = \frac{k_B T}{e}$$

$$\frac{D_n}{D_p} = \frac{\mu_e}{\mu_h} \Rightarrow \frac{k_B T}{e}$$

According to Einstein equation, the ratio between the diffusion constants or the mobility of charge carriers is directly proportional to the absolute temperature of the semiconductor. When the temperature increases both mobility and diffusion of charge carriers increased.

Hall Effect: When a slab of metal or semiconductor carrying current is placed in a transverse magnetic field, a potential difference is produced in the direction normal to both current and magnetic field. This phenomenon is called ***Hall Effect*** and the generated voltage is known as ***Hall voltage***. It was discovered by E.H. Hall in 1879.

Consider a slab of conductor in which a current is flowing in the positive X-direction as shown in Fig. Let a magnetic field B is applied along the Z-direction then the electrons experience a Lorentz force is given by, $F_L = BeV_d$ ......(1) here e is charge of the electron and V_d is the drift velocity of the electron.

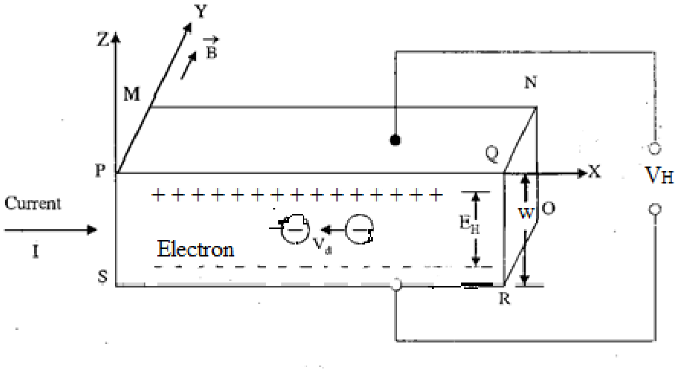


Fig 8. Arrangement of Hall Effect

Applying the Fleming's left hand rule, the force exerted on the electrons is in the negative y-direction. Therefore, the electrons are deflected in downward direction. As a result, the density of electrons increases in the lower end of the material due to which its bottom surface becomes negatively charged. On the other hand, the loss of electron from the upper end causes the top edge of the material to become positively charged. Hence, potential V_L is called a Hall voltage appears between the upper and lower surfaces of the semiconductor which establishes an electric field E_L is called the Hall electric field. The electric field E_H exerts an upward force F_H in the electron is given by,

$$F_H = -eE_H \quad ......(2)$$

Now, as the deflection of electrons continues in the downward direction due to the Lorentz force, it also contributes to the growth of the Hall electric field. At equilibrium position two forces are equal, $F_L = F_H$

Equating (1) and (2)

$$eE_H = eBV_d \Rightarrow E_H = BV_d \quad .....(3)$$

For n-type material the charge carriers are electrons, then the current density is,

$$J = -neV_d \Rightarrow V_d = -\frac{J}{ne} \quad ......(4)$$

Where n is the concentration of charge carries.

Substituting eq (4) in eq (3),

$$eE_H = BV_d$$

$$= -\frac{JB}{ne} \quad ......(5)$$

The Hall Effect is described in terms of the Hall coefficient R and is given by,

$$R_H = -\frac{1}{ne} \quad .....(6)$$

Therefore, substituting the value of R_H from eq (6) in eq (5)

$$E_H = R_H JB$$

$$R_H = \frac{E_H}{JB} \rightarrow -\frac{1}{ne} \quad ......(7)$$

The Hall coefficient can be evaluated by substituting the quantities E_H, J and B. By knowing the Hall coefficient R_H, the carrier density n can be estimated. Since, the charge carriers are holes for p-type material. Hence, the Hall coefficient is,

$$R_H = \frac{E_H}{JB} \rightarrow \frac{1}{pe} \quad ......(8)$$

Here p is the density of holes, The Hall coefficient R_H is inversely proportional to density of charge carriers.

Determination of Hall coefficient:

The Hall electric field per unit current density per unit magnetic induction is called Hall coefficient *(R_H)*. If 'w' is the width of the sample across which Hall voltage V_H is measured.

$$E_H = \frac{V_H}{w} \Rightarrow R_H = \frac{E_H}{JB} \Rightarrow \frac{V_H}{JBw} \Rightarrow V_H = R_H JBw \quad ....(9)$$

If t is the thickness of the sample, then its cross section is wt and current density is,

$$J = \frac{I}{wt} \text{ and } V_H = \frac{R_H IB}{t} \Rightarrow R_H = \frac{V_H t}{Iw} \quad ....(10)$$

The Hall voltage V_H will be opposite for *n*- type and *p* - type semiconductors.

Applications of Hall Effect:

The Hall Effect measurements provide the following information about the solid,

i) The sign of charge carriers can be determined,
ii) The carrier density can be estimated,
iii) The mobility of charge carriers can be measured directly,
iv) It can be used to determine whether the given material is metal, insulator or semiconductor.
v) The magnetic field can be measured by knowing the values of Hall voltage and Hall coefficient

Engineering Applications of Hall Effect:

1. Magnetic Field Sensing

- **Application**: Hall effect sensors are widely used to detect the presence, direction, and strength of magnetic fields.
- **Example**: In **compasses**, **proximity sensors**, and **magnetic field mapping** devices, Hall sensors measure and monitor the magnetic fields in various devices and systems.

2. Current Sensing and Measurement

- **Application**: Hall effect sensors are used to measure **electric current** in a conductor without direct contact. The Hall voltage is proportional to the current flowing through the conductor in the presence of a magnetic field.
- **Example**: Used in **current transducers** for measuring high currents in **power supplies**, **electric motors**, and **battery management systems**.

3. Position and Proximity Sensing

- **Application**: Hall effect sensors are used to detect the **position** or proximity of a magnetic object. These sensors are widely used in systems requiring precise position tracking and switching.
- **Example**: **Rotary encoders** for position sensing in motors and actuators, and **proximity sensors** for detecting the presence of a magnetic object, such as in **automated machinery**.

4. Speed Measurement (Tachometers)

- **Application**: Hall effect sensors are used in **tachometers** to measure rotational speed. By detecting the magnetic field changes from a rotating magnet, they provide an accurate speed measurement.

- **Example**: Used in **vehicles** for wheel speed measurement, in **hard disk drives** for spindle speed monitoring, and in **electric motors** for rotational speed sensing.

5. Magnetic Data Storage Devices

- **Application**: Hall effect sensors are used in **magnetic storage systems** to detect the position and intensity of the magnetic fields stored on magnetic media.
- **Example**: In **hard disk drives (HDDs)**, Hall sensors are used to read data from the magnetic surface, ensuring precise data retrieval and storage.

6. Semiconductor Characterization

- **Application**: The Hall effect is used in semiconductor physics to measure important properties such as **carrier concentration** (electrons or holes), **mobility**, and the **type of charge carriers**.
- **Example**: In the **material characterization** of semiconductors, Hall effect measurements help in the **fabrication of transistors**, **diodes**, and **integrated circuits (ICs)**.

7. Automotive Speed Sensing

- **Application**: Hall sensors are used in **automobiles** to measure the speed of rotating components such as wheels, crankshafts, or drive shafts.
- **Example**: In **anti-lock braking systems (ABS)**, Hall effect sensors monitor wheel speed to detect and prevent wheel lockup during braking, ensuring safety.

8. Hall Effect Magnetic Switches

- **Application**: Hall effect sensors can function as magnetic switches in systems where the presence or absence of a magnetic field triggers an on/off action.
- **Example**: Used in **door/window sensors** for security systems, **smartphones**, and **wearable devices** to detect the opening or closing of magnetic switches.

9. Motion Sensing and Robotics

- **Application**: Hall effect sensors are used to detect motion and determine the position of parts in robotic systems.
- **Example**: Used in **robotic arms** and **linear actuators** for precise position feedback and in **motion control systems** in factories for automation.

10. Medical Imaging (MRI Systems)

- **Application**: Hall sensors are sometimes used in **medical imaging** devices like **MRI machines** for magnetic field detection and mapping.
- **Example**: In **Magnetic Resonance Imaging (MRI)**, Hall effect sensors help monitor and control the magnetic field used to produce images of the inside of the body.

Additional Applications:

- **Magnetic Levitation Systems**: Hall sensors are used to detect and control the position of magnets in **magnetic levitation systems** (such as maglev trains), ensuring stable levitation and movement.
- **Electric Motor Protection**: Hall sensors are used in **motor controllers** to monitor motor current and speed, protecting motors from **over current** or **overvoltage** conditions.
- **Environmental Monitoring**: Hall sensors can also be used in **environmental monitoring systems** to detect and measure magnetic fields in atmospheric studies.

Summary of Engineering & Industrial Applications of Hall effect:

It is used in the following

1. **Magnetic Field Sensing** (Compass, Field Mapping)
2. **Current Sensing** (Power Supplies, Battery Management)

3. **Position and Proximity Sensing** (Rotary Encoders, Proximity Sensors)
4. **Speed Measurement** (Tachometers, Motor Speed Monitoring)
5. **Magnetic Data Storage** (Hard Disk Drives)
6. **Semiconductor Characterization** (Carrier Concentration, Material Research)
7. **Automotive Speed Sensing** (ABS, Vehicle Monitoring)
8. **Magnetic Switches** (Security Sensors, Door/Window Switches)
9. **Motion Sensing and Robotics** (Robotic Systems, Automation)
10. **Medical Imaging (MRI)** (Magnetic Field Detection)

Difference between p-type and n-type semiconductors

S. No	P - TYPE SEMICONDUCTORS	N - TYPE SEMICONDUCTORS
1.	A p-type semiconductor is created when group 3 elements are doped to a complete semiconductor material	A n-type semiconductor is created when group 5 elements are doped to an intrinsic semiconductor
2.	The components like gallium ,boron, indium etc... are doped to form a p type semiconductor , therefore it creates an additional hole ,thus also know as acceptor atom	The components like bismuth , antimony, arsenic etc... are doped to form a n- type semiconductor , therefore it creates an additional electron,thus also know as donor atom.
3.	The majority charge carriers in the case of p-type semiconductors are holes	The majority charge carriers in the case of n-type semiconductors are electrons
4.	The minority carriers in the case of p-type semiconductors are electrons	The minority charge carriers in the case of n-type semiconductors are holes
5.	For a p-type semiconductor, the Fermi level appears closer to the valence band than that of the conduction band	The Fermi level, In case of an n-type semiconductors exists near the conduction band
6.	Here concentration of holes are high	Here concentration of electrons are high
7.	The conductivity is mainly due to the presence of holes	The conductivity is mainly due to the presence of electrons

Difference between intrinsic semiconductor and extrinsic semiconductors

S. No	INTRINSIC SEMICONDUCTOR	EXTRINSIC SEMICONDUCTOR
1.	The pure form of semiconductors is called intrinsic semiconductor	Semiconductor doped with impurities is called extrinsic semiconductor
2.	Electrical conductivity of this type of semiconductor is soley determined by thermally generated carriers	The electrical conductivity of extrinsic semiconductor is determined not only by thermally generated carriers but also due to doping charge carriers
3.	The electrical conductivity of intrinsic semiconductor is very poor	The electrical conductivity of extrinsic semiconductor is high compared to intrinsic semiconductor
4.	With increase in temperature some covalent bonds are broken to form a positive ion know as holes	With increase in temperature excess of charge carriers either electrons or holes are generated in extrinsic semiconductor
5.	The number of electrons in the conduction band is equal to the number of holes in the valence band	The number of electrons and holes are not equal in extrinsic semiconductor and depends on type of the semiconductor
6.	On applying an electric field , the holes move in a direction opposite to that of the valence	On applying the electric field , excess of electrons move in the direction of electric field and holes move in the

	electrons and electrons move in the same direction	opposite direction
7.	The Fermi level of intrinsic semiconductor is at the middle of valence and conduction bands	In extrinsic semiconductor , Fermi level shifts either towards conduction band or valence band
8.	The current producer in an intrinsic semiconductor is not adequate for any useful work	Due to the excess of charge carriers the current produced in a semiconductor is useful for work
9.	Examples:- pure crystalline form of silicon and germanium	Examples:- doped crystalline form of gallium arsenide, gallium phosphide etc...

Q. No		***Assignment Questions on Unit-5***	**Marks**	**CO**	**RBT**
1	A	Describe the origin of energy band formation in solids with neat diagram	7	CO5	Understand
	B	A copper strip 2.0 cm wide and 1.0 mm thick is placed in a magnetic field with B=1.5 wb/m^2. If a current of 200A is set up in the strip, Calculate Hall voltage that appears across the strip. Assume $R_H = 6\times10^{-7}\ \mathrm{m^3/C}$	3	CO5	Apply
2	A	Explain how the materials are classified into conductors, semiconductors and insulators with help of energy band diagrams.	7	CO5	Understand
	B	The carrier density of a specimen is $1.86\times10^{22}/\mathrm{m^3}$ Its resistivity is $8.93\times10^{-3}\ \Omega\mathrm{m}$ .find the hall coefficient and mobility of charge carriers	3	CO5	Apply
3	A	Outline the importance of Hall effect to determine the nature of semiconductor material?	7	CO5	Understand
	B	Calculate the drift velocity of the carriers from a hall effect set up when current of 0.50 A flows through a metal strip with thickness 0.5 mm and width 10 mm. The hall voltage is 0.20 mV when a magnetic field 5000 Gauss is used.	3	CO5	Apply
4	A	What is Drift current? Deduce the expression for it in a semiconductor.	7	CO5	Understand
	B	An electric field of 100V/m is applied to a sample of n-type semiconductor whose Hall coefficient is -0.0125m^3/C. Determine the current density in the sample, assuming $\mu_e = 0.6\mathrm{m^2/V.s.}$	3	CO5	Apply
5	A	Derive the expression for Diffusion current in a semiconductor?	7	CO5	Understand
	B	The hall coefficient of silicon is found to be $-7.35\times10^{-5}\ \mathrm{m^3C^{-1}}$ in the range of temperatures from 100 K to 400 K. Calculate the density of the charge.	3	CO5	Apply
6	A	Obtain the relation between the parameters μ and D from Einstein relations	7	CO5	Understand
	B	In a Hall coefficient experiment, a current of 0.25 A is sent through a metal strip having thickness 0.2mm and width 5mm.The Hall voltage is found to be 0.15mV when a magnetic field of 2000 gauss is used. Find the carrier concentration?	3	CO5	Apply
7	A	Distinguish between intrinsic and extrinsic semiconductors.	7	CO5	Understand
	B	At 300K, find the diffusion coefficient of electrons in silicon if mobility is 0.21 m^2/V-s	3	CO5	Apply
8	A	Differentiate the P-type and N-type Semiconductors	7	CO5	Understand
	B	In a Hall coefficient experiment, a current of 0.25 A is sent through a metal strip having thickness 0.2mm and width 5mm.The Hall voltage is found to be 0.15mV when a magnetic field of 2000 gauss is used. Calculate the carrier concentration?	3	CO5	Apply
9	A	Describe the Engineering applications of Hall Effect	7	CO5	Understand
	B	Calculate the number of donor atoms per m^{3}of n-type material having resistivity of $0.25\,\Omega\text{-}\mathrm{m}$ .The mobility of electrons is $0.30\ \mathrm{m^2/V-s}$	3	CO5	Apply
10	A	Compare the Semiconductors with Insulators and Conductors	7	CO5	Understand
	B	The R_H of a specimen is $3.66\times10^{-4}\ \mathrm{m^3/C}$. Its resistivity is $8.93\times10^{-3}\ \Omega-\mathrm{m}$ Find μ and n	3	CO5	Apply