Concept of Semiconductor

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Syllabus: Basic Electronics
Module 1: Concepts of Semiconductors

- Basic ideas of electronics, charged particles, review of atomic energy levels, elementary concepts of energy bands in crystals, conduction band and valence band, distinction between metal, semiconductor and insulator, Fermi-Dirac Distribution and definition of Fermi level, intrinsic and extrinsic semiconductors, concepts of majority and minority carries in semiconductors, current flow in semiconductors.

Categories of Solids:

There are three categories of solids, based on their **conducting properties**:

- ❑ Conductors (silver, copper, aluminum etc.)
- ❑ Semiconductors (Germanium, silicon, boron etc.)
- ❑ Insulators (glass, quartz, rubber etc.)

Electrical Resistivity and Conductivity of Selected Materials at 293 K.

Reviewing the previous table reveals that:

The electrical conductivity at room temperature is quite different for each of these three kinds of solids

Metals and alloys have the highest conductivities followed by **semiconductors** and then by **insulators.**

Table 11.1 Electrical Resistivity and Conductivity of Selected Materials at 293 K

Material	Resistivity ($\Omega \cdot m$)	Conductivity ($\Omega^{-1} \cdot m^{-1}$)
Metals		
Silver	1.59×10^{-8}	6.29×10^{7}
Copper	1.72×10^{-8}	5.81×10^{7}
Gold	2.44×10^{-8}	4.10×10^{7}
Aluminum	2.82×10^{-8}	3.55×10^{7}
Tungsten	5.6×10^{-8}	1.8×10^{7}
Platinum	1.1×10^{-7}	9.1×10^{6}
Lead	2.2×10^{-7}	4.5×10^{6}
Alloys		
Constantan	4.9×10^{-7}	2.0×10^{6}
Nichrome	1.5×10^{-6}	6.7×10^{5}
Semiconductors		
Carbon	3.5×10^{-5}	2.9×10^{4}
Germanium	0.46	2.2
Silicon	640	1.6×10^{-3}
Insulators		
Wood	10^{8}–10^{11}	10^{-8}–10^{-11}
Rubber	10^{13}	10^{-13}
Amber	5×10^{14}	2×10^{-15}
Glass	10^{10}–10^{14}	10^{-10}–10^{-14}
Quartz (fused)	7.5×10^{17}	1.3×10^{-18}

Resistivity vs. Temperature:

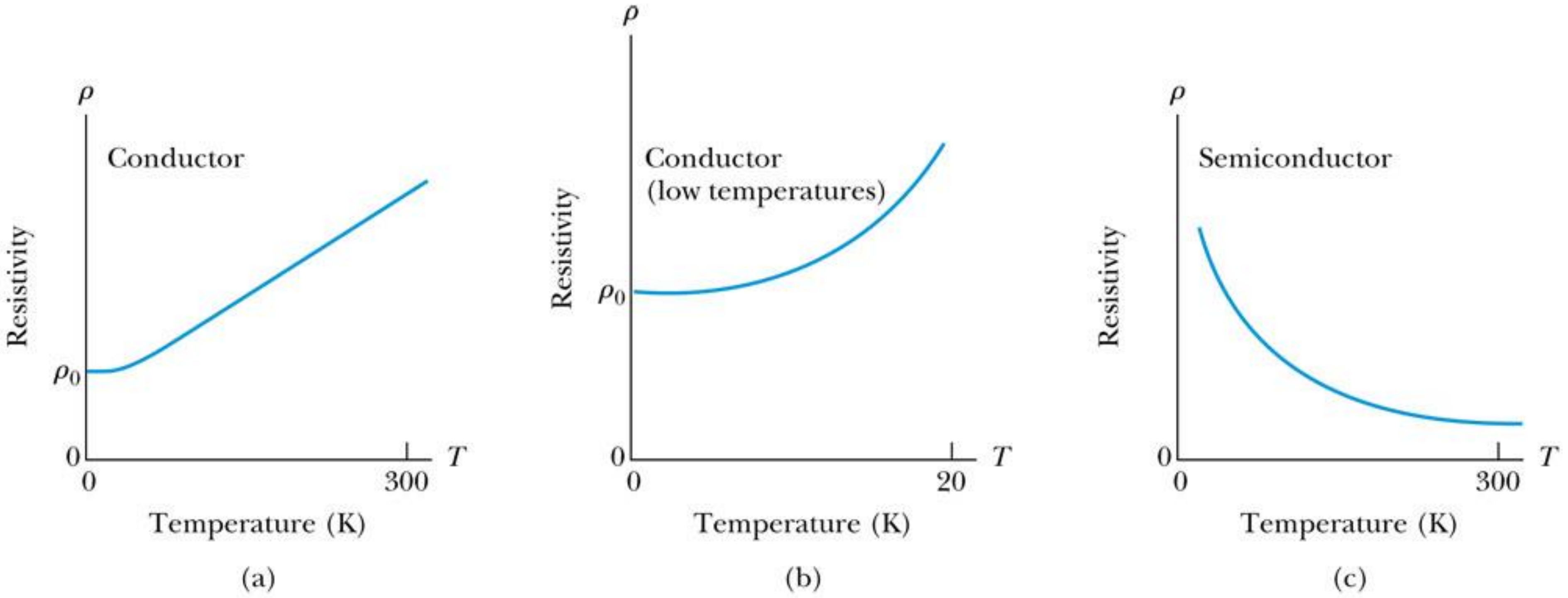


Figure : (a) Resistivity versus temperature for a typical conductor. Notice the linear rise in resistivity with increasing temperature at all but very low temperatures. (b) Resistivity versus temperature for a typical conductor at very low temperatures. Notice that the curve flattens and approaches a nonzero resistance as $T \to 0$. (c) Resistivity versus temperature for a typical semiconductor. The resistivity increases dramatically as $T \to 0$.

Different type of semiconductor materials:

Elemental Semiconductor Materials: Group IV elements Crabon (C), Silicon (Si), Germanium (Ge), Tin (Sn) and lead (Pb)

Element	*Atomic Number*	*Electronic Configuration*
Carbon (C)	6	$1s^2\ 2s^2\ 2p^2$
Silicon (Si)	14	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$
Germanium (Ge)	32	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^2$
Tin (Sn)	50	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 5s^2\ 5p^2$
Lead (Pb)	82	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 4f^{14}\ 5s^2\ 5p^6\ 5d^{10}\ 6s^2\ 6p^2$

Fig: Electronic configuration of group IV A

Compound semiconductor materials: Most of the compound semiconductor materials are formed from the combinations of group III and group V elements.

Elemental Semiconductors	Silicon Si Germanium Ge
Compound Semiconductors	Aluminium phosphide AlP Aluminium arsenide AlAs Gallium phosphide GaP Gallium arsenide GaAs Indium phosphide InP

Fig. List of some semiconductor materials

III	*IV*	*V*
B	C	
Al	Si	P
Ga	Ge	As
In		Sb

Fig. A portion of periodic table

Energy band theory of Crystal:

- In order to account for *decreasing* resistivity with increasing temperature as well as other properties of semiconductors, a new theory known as the **band theory** is introduced.
- The essential feature of the band theory is that the allowed energy states for electrons are nearly continuous over certain ranges, called **energy bands**, with forbidden energy gaps between the bands.

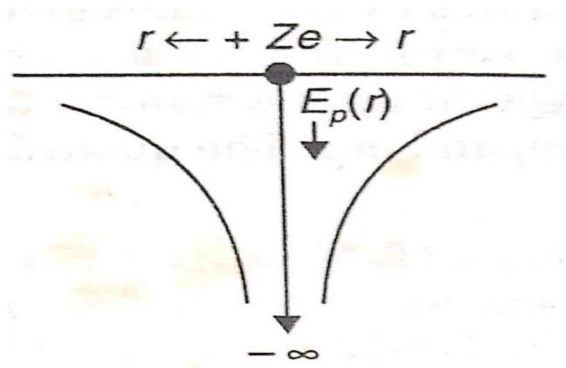


Fig. Potential energy of an electron with its distance

At a distance r from the nucleus, the electrostatic potential due to the nuclear charge is $V(r) = \frac{Ze}{4\pi\varepsilon r}$ where Z is the atomic number, the atomic nucleus has a positive

Potential energy of an electron $E\ (r) = -eV(r) = -\frac{Ze^2}{4\pi\varepsilon r}$

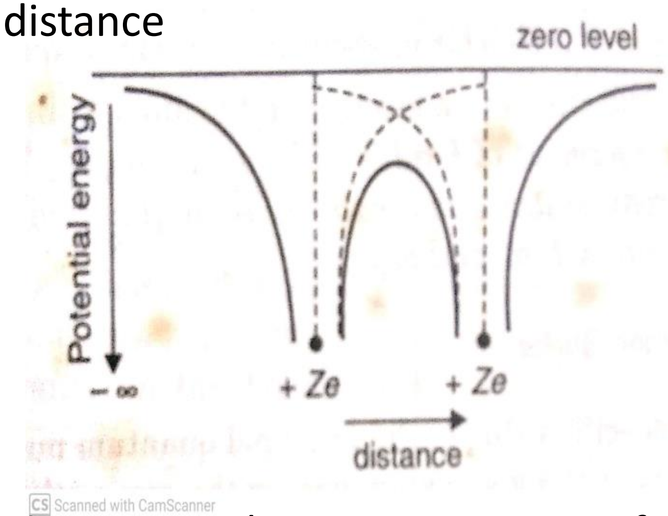


Fig. Potential energy variation of an electron with its distance between two identical nuclei.

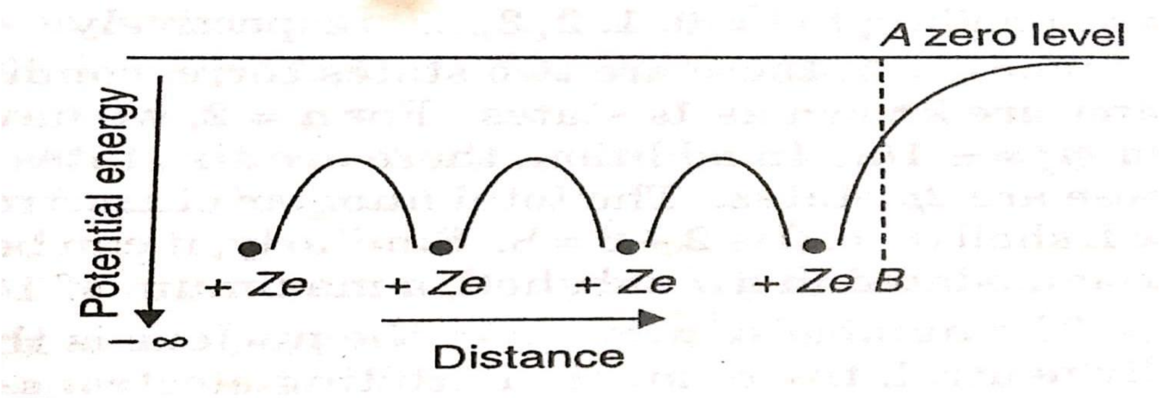


Fig. Potential energy of an electron along a row of atoms in a crystal.

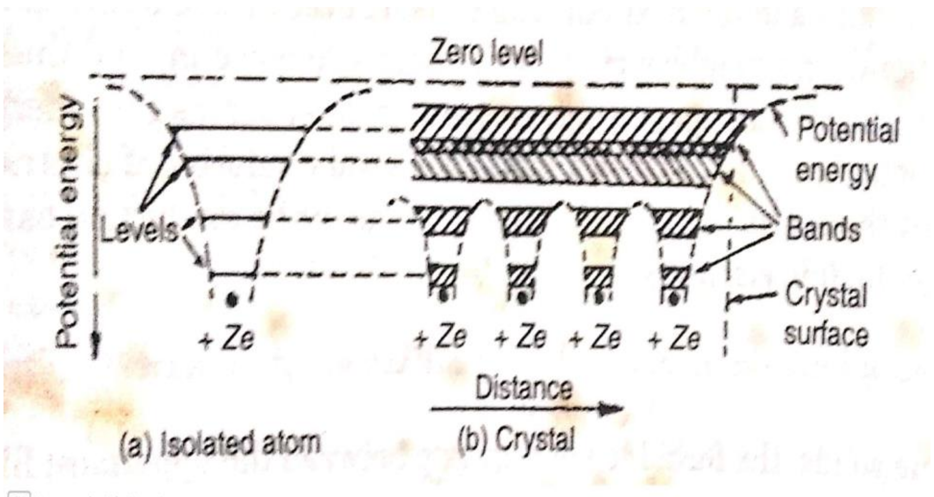


Fig.: Splitting of energy levels of isolated atoms into energy bands as these atoms are brought close together to produce a crystal

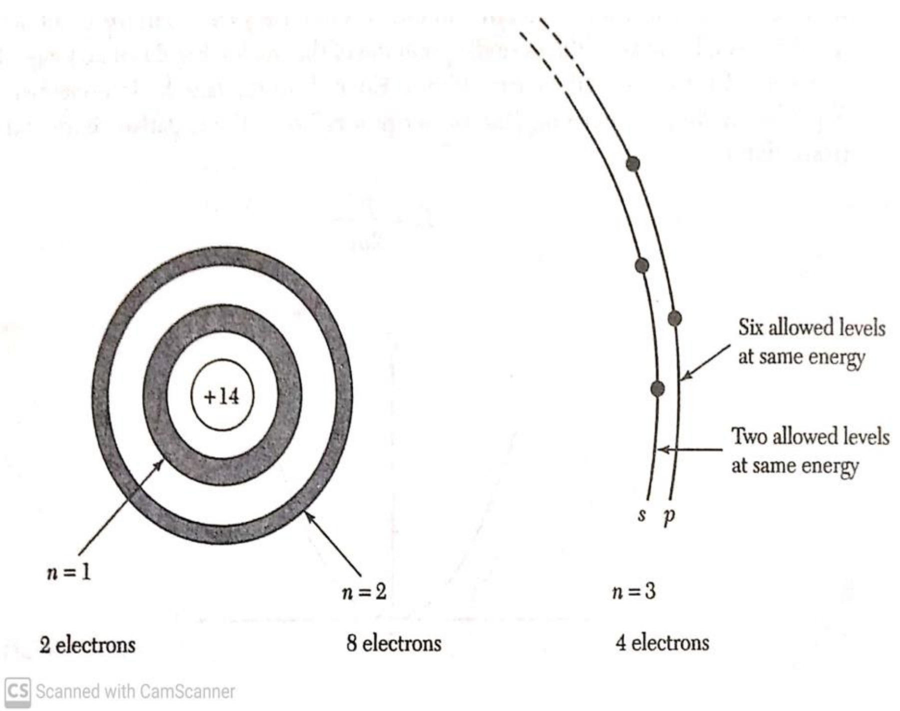


Fig.: isolated silicon atom

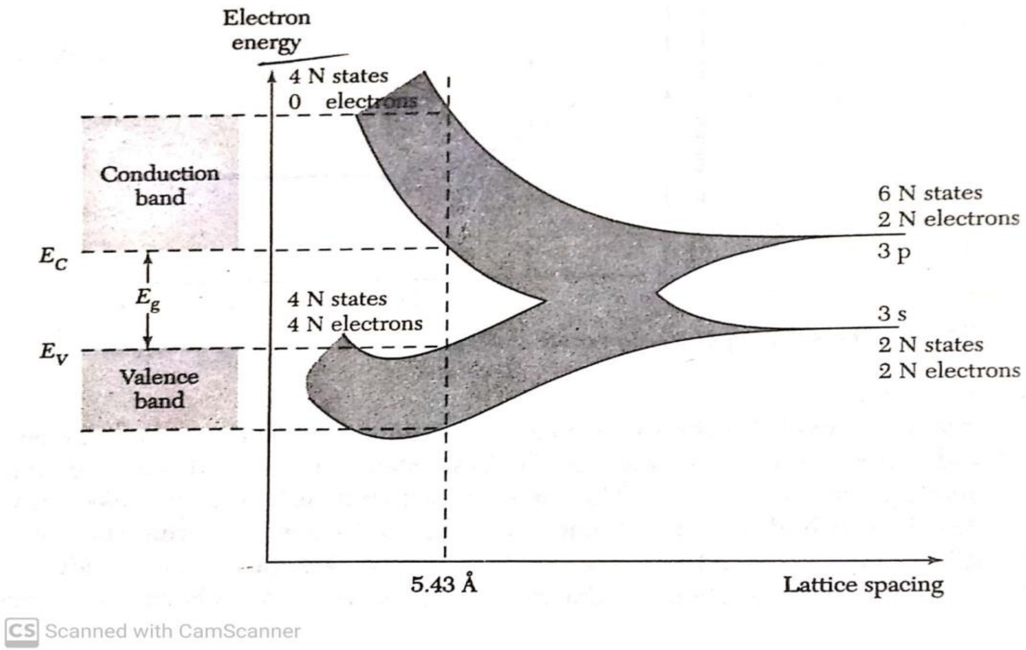
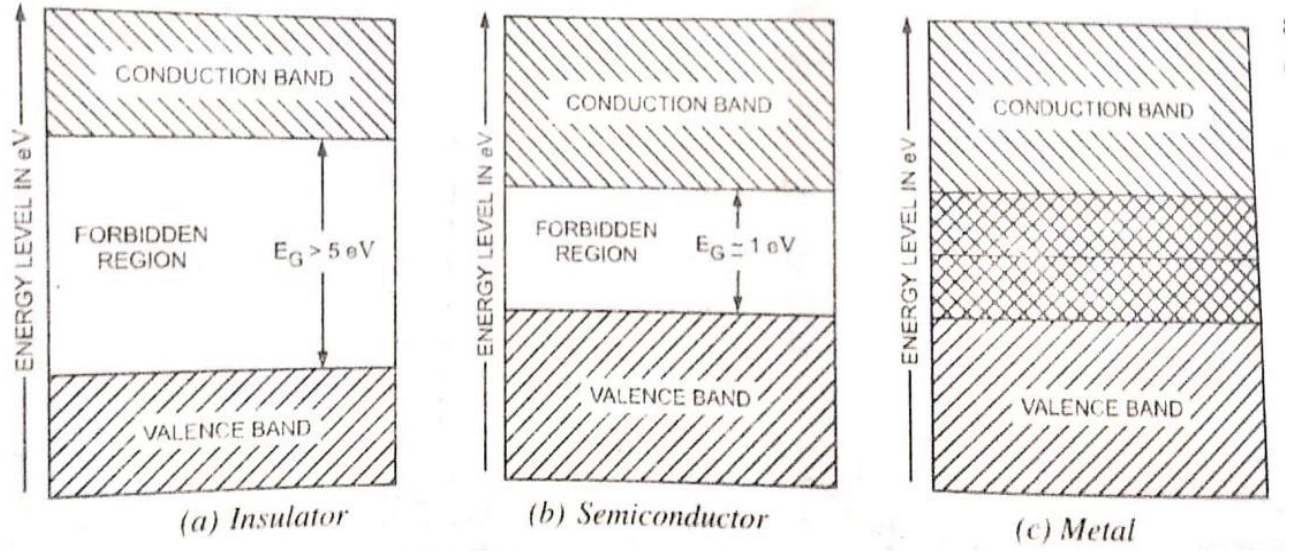


Fig. formation of energy band

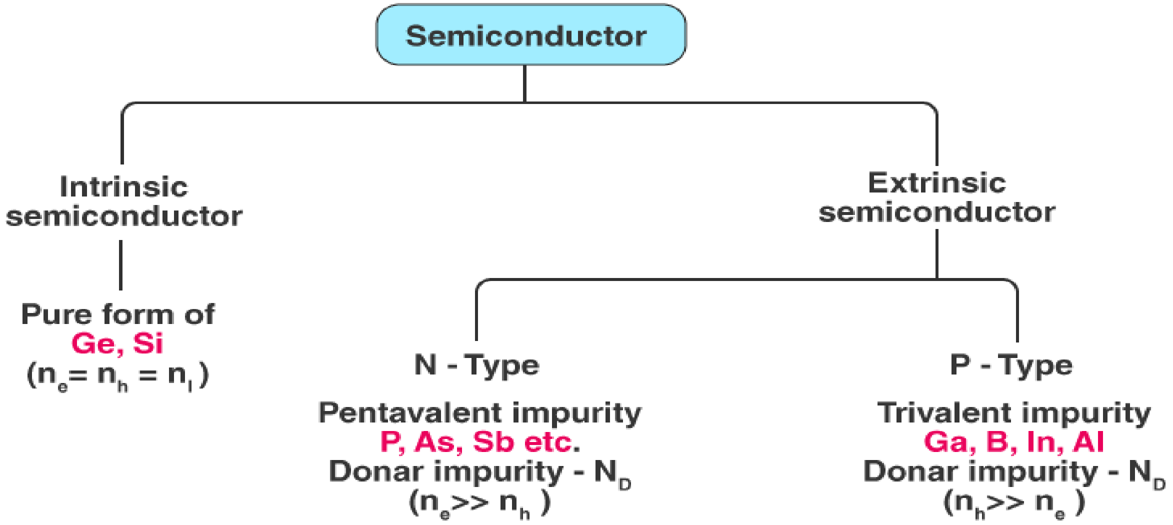
Conduction in metal insulator and semiconductor:



- ❑ Insulator are characterized by a large bandgap.
- ❑ For metal conduction bad either partially filled or overlaps the valance band so there is no bandgap

Material	Energy gap (eV)	
	0K	300K
Si	1.17	1.11
Ge	0.74	0.66
InSb	0.23	0.17
InAs	0.43	0.36
InP	1.42	1.27
GaP	2.32	2.25
GaAs	1.52	1.43
GaSb	0.81	0.68
CdSe	1.84	1.74
CdTe	1.61	1.44
ZnO	3.44	3.2
ZnS	3.91	3.6

Classification of semiconductor



Intrinsic semiconductor: An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.

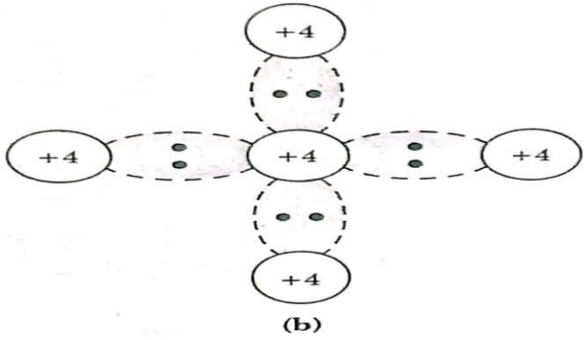


Fig.:Two dimensional representation

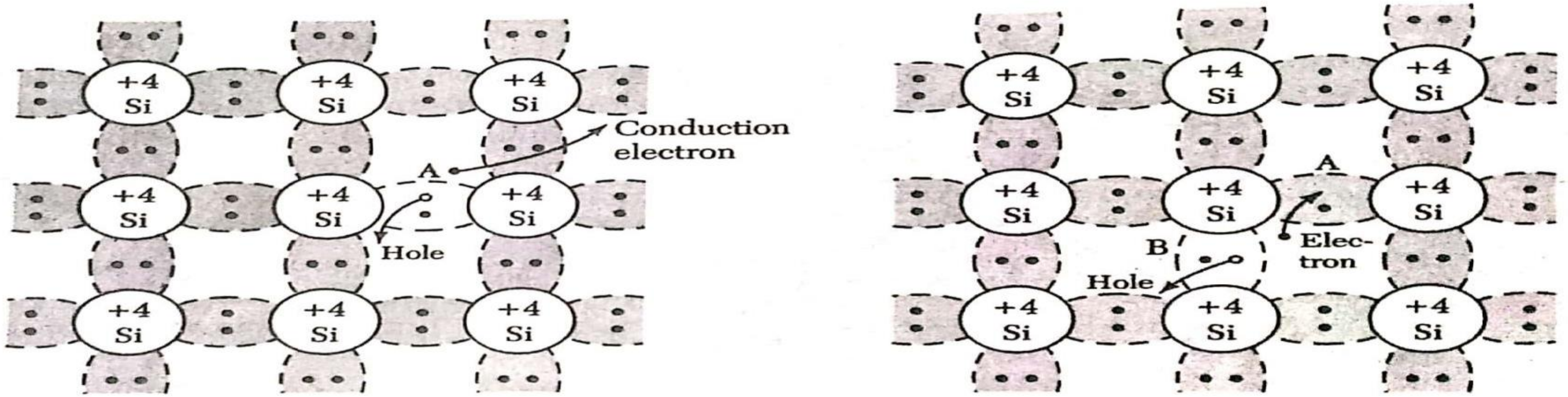
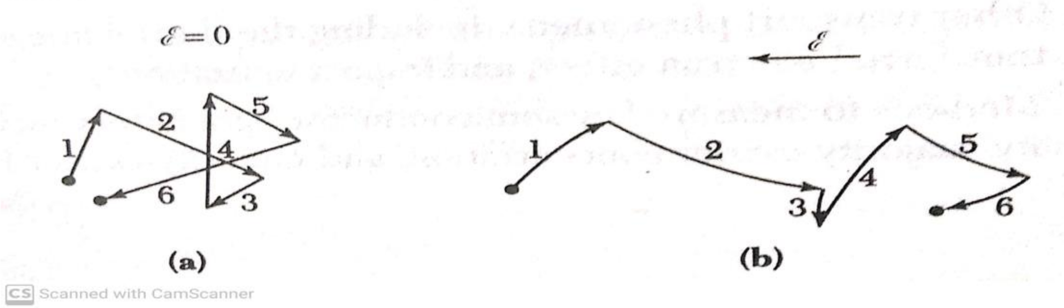


Fig. Basic bond representation of intrinsic silicon

- Energy require to break the covalent bond is 1.1 eV for Si and 0.72 eV for Ge.
- When electrons move into the conduction band, they leave behind vacancies in the valence band. These vacancies are called **holes**. Because holes represent the absence of negative charges, it is useful to think of them as **positive charges.**
- Whereas the ***electrons move in a direction opposite*** to the applied electric field, ***the holes move in the direction of the electric field*.**
- In intrinsic semiconductor, there is a balance between the number of electrons in the conduction band and the number of holes in the valence band.

Drift current:

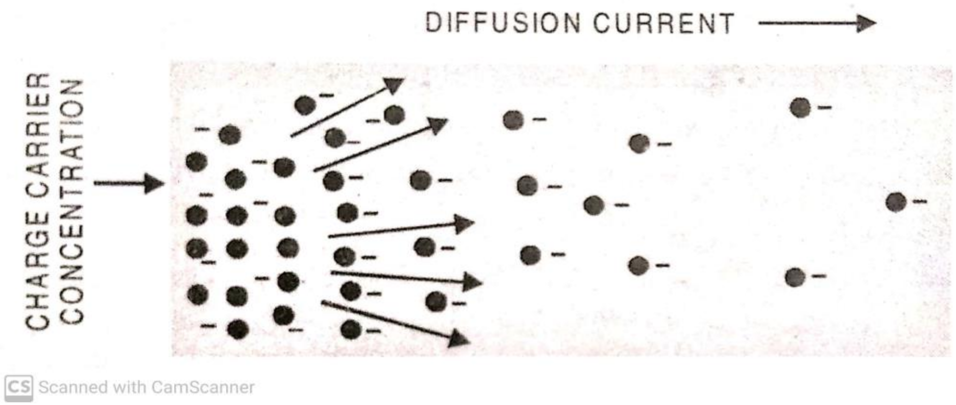


a) Random thermal motion
b) Combine motion due to random thermal motion and applied electric field.

Drift current can be defined as the charge carrier's moves in a semiconductor because of the electric field. Once the voltage is applied to a semiconductor, then electrons move toward the +Ve terminal of a battery whereas the holes travel toward the –Ve terminal of a battery.

Diffusion current:

The diffusion current can be defined as the flow of charge carriers within a semiconductor travels from a higher concentration region to a lower concentration region. A higher concentration region is nothing but where the number of electrons present in the semiconductor. Similarly, a lower concentration region is where the less number of electrons present in the semiconductor. The process of diffusion mainly occurs when a semiconductor is doped non-uniformly.



Mass Action law:

It states that, under thermal equilibrium the product of the free electron concentration n and the free hole concentration p is equal to a constant square of intrinsic carrier concentration n_i The intrinsic carrier concentration is a function of temperature. The equation for the mass action law for semiconductor

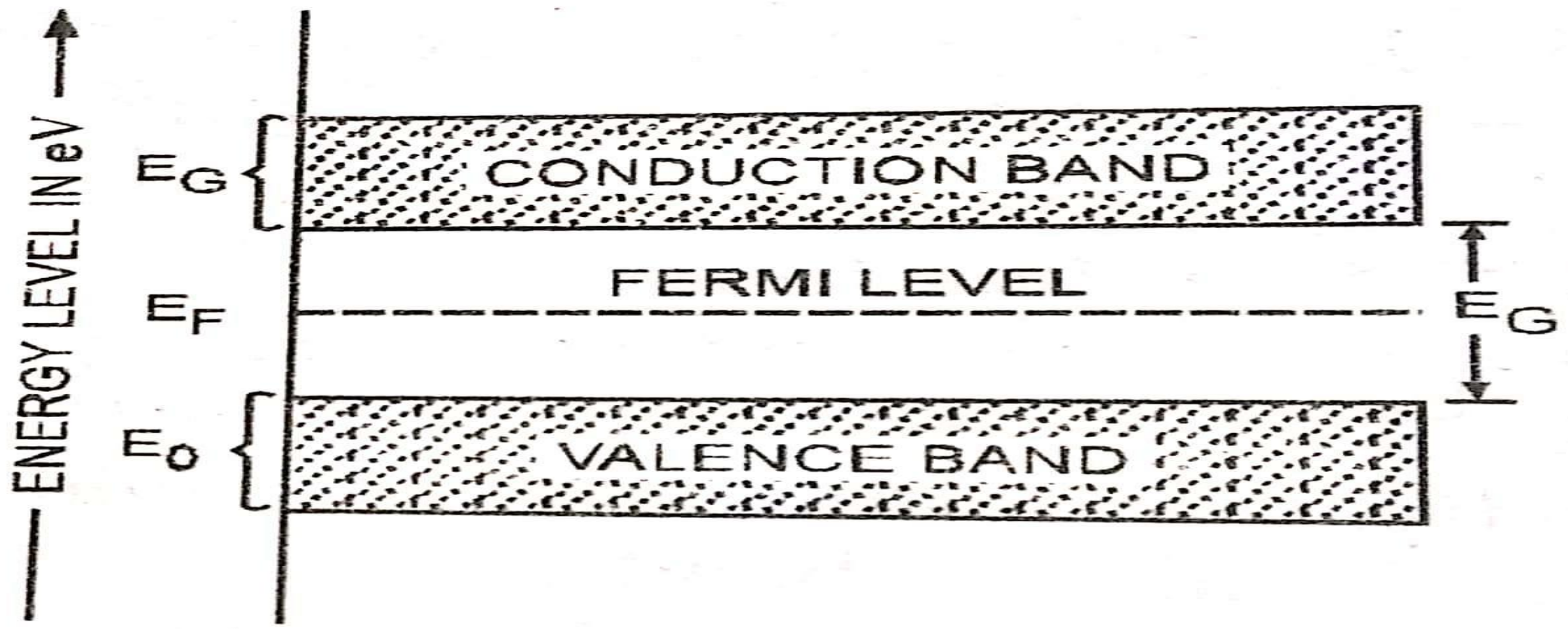
$$np = n_i^2$$

Position of fermi level:

- The probability that an electron occupies an electronic state with energy E is given by the Fermi-Dirac distribution function, $f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$

Where k= Boltzmann constant, T= absolute temperature in kelvin E_F =energy of fermi level

- At absolute zero temperature, the probability of an electron occupying a state in the conduction band is zero, valance band being totally full.
- It can be the highest occupied energy level at T=0K lies near the middle of the band gap for an intrinsic semiconductor.



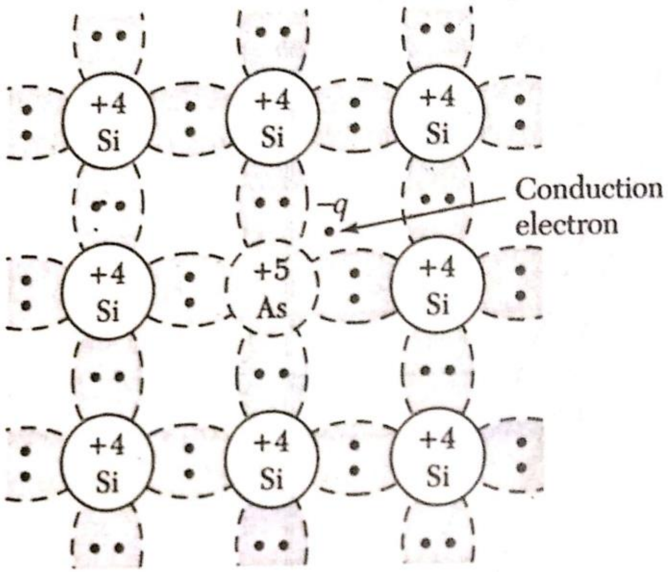
Extrinsic semiconductor:

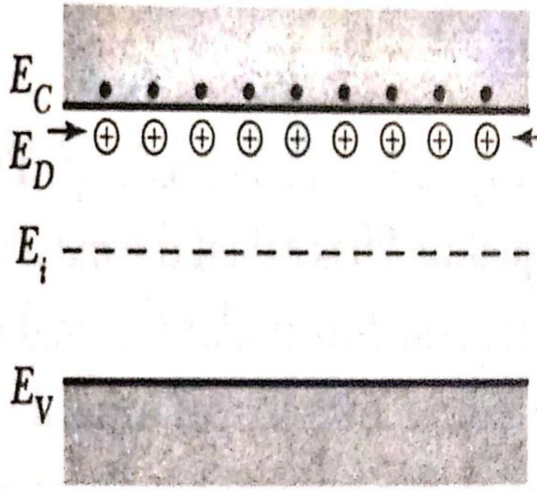
- It is possible to fine-tune a semiconductor's properties by adding (the process is called doping) a small amount of another material, called a *dopant*, to the semiconductor creating what is a called an **impurity semiconductor.**
- The effect is that adding only a small amount of impurity greatly increases the electrical conductivity.

N-type semiconductor:

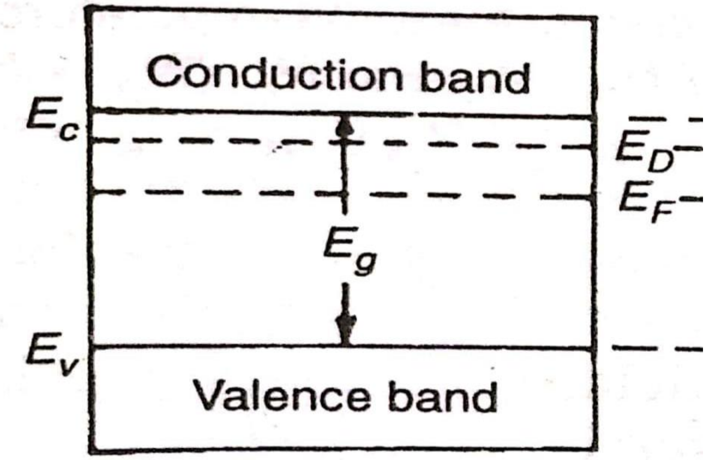
The addition of small amount of pentavalent impurity (As, Sb, Bi, P) to a pure semiconductor, the semiconductor is known as an ***n*-type** semiconductor.

- Majority carrier electron, minority carrier hole
- The energy levels just below the conduction band are called **donor levels**.
- Distance of new allowable energy level is 0.05 eV for Si and 0.01 of Ge





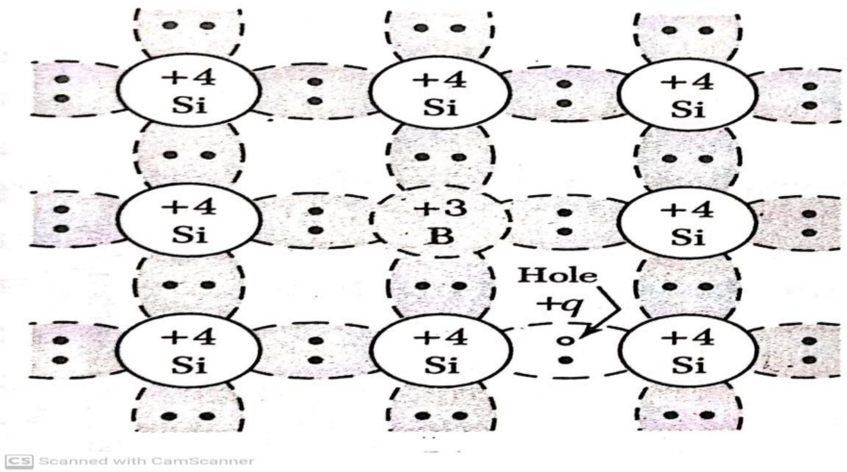
Donor ions

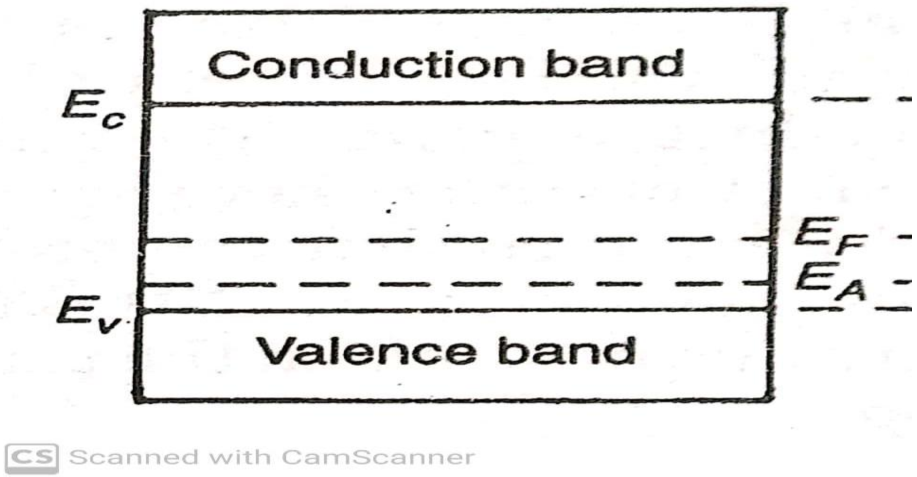


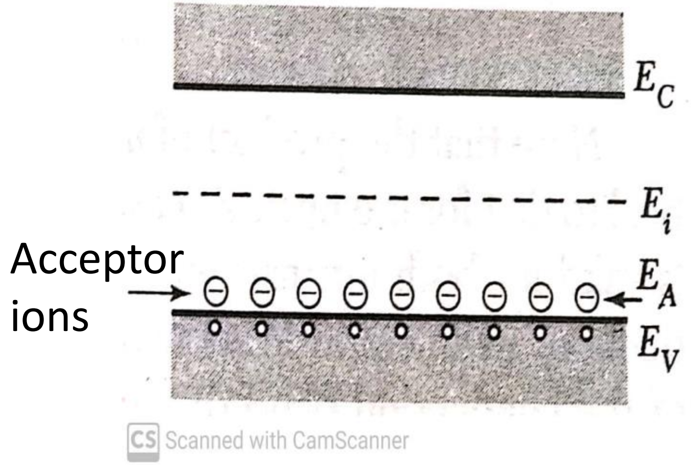
Band representation of n-type semiconductor

P-type semiconductor:

The addition of small amount of trivalent impurity (B, Ga, In, Al) to a pure semiconductor, the semiconductor is known as an ***p*-type** semiconductor.







- ❑ Majority carrier Hole, minority carrier electron
- ❑ The energy levels just above the valance band are called **acceptor levels**.
- ❑ Distance of new allowable energy level is 0.05 eV for Si and 0.01 of Ge

Thank You