EXTRINSIC SEMICONDUCTORS (ESCs)

- **Definition**: A semiconductor doped with a small amount of impurity atoms is called an extrinsic semiconductor.
- The impurity introduced is known as a dopant, and the controlled amount of impurity added into an intrinsic semiconductor (SC) is known as doping.
- The impurities generated are not temperature-dependent but are voltage-dependent and can be controlled.
- Usually, 10^7 atoms are doped in SCs. Doping significantly improves the conductivity of materials.

TYPES OF ESC:

- Depending on the type of impurity, extrinsic semiconductors are of two types:
  - i)P-type SC
  - ii)N-type SC

Common Dopant Elements:

- The common dopant elements for Silicon (Si) and Germanium (Ge) are:

  For P-type semiconductors: Aluminum (Al), Boron (B), and Gallium (Ga).

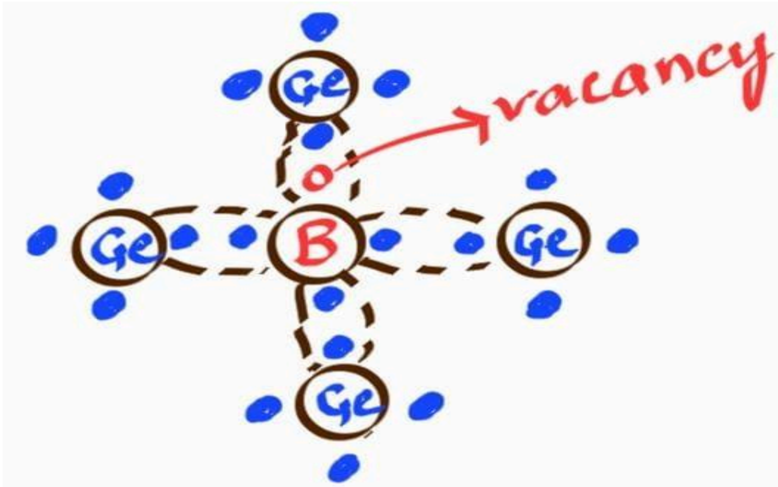
  For N-type semiconductors: Phosphorus (P), Arsenic (As), Antimony (Sb), and Indium (In).

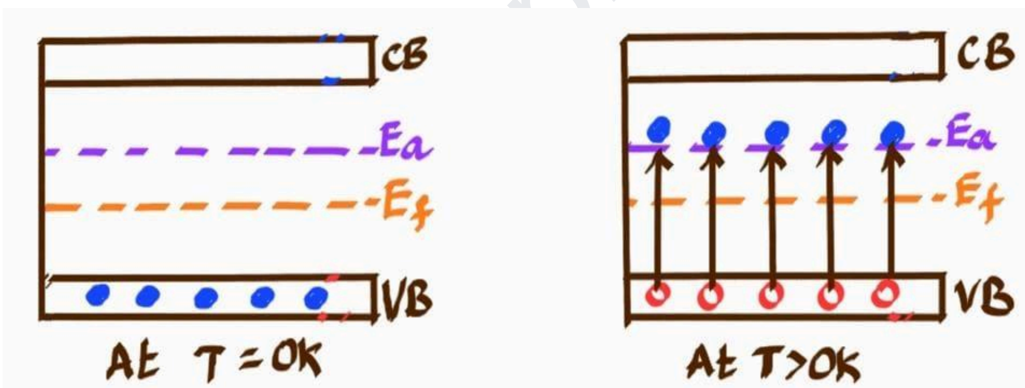
P-Type SC(Acceptor):

- A P-type semiconductor is produced when a pure semiconductor is doped with a trivalent impurity such as Aluminum (Al), Gallium (Ga), Indium (In), Boron (B), etc.
- Since the impurity atom accepts an electron from the Valence Band (VB), it is called an acceptor atom.
- The acceptor impurity atoms produce holes without the simultaneous generation of electrons in the Conduction Band (CB).

Illustration of P-type SC:

- Let us consider Germanium (Ge) as a pure semiconductor, which has 4 valence electrons and can form 4 covalent bonds.
- When a trivalent impurity atom like Boron is added, its 3 valence electrons form 3 covalent bonds with Germanium atoms.
- However, the 4th electron does not have a pair, resulting in a **hole**.
- This means that the hole is ready to accept an electron to fill itself, as shown in a given figure.

- 

- Thus, a small amount of trivalent impurity creates a "majority of holes," which are referred to as P-type SC or Acceptors.
- In a P-type SC, holes are the majority charge carriers, and electrons are the minority charge carriers.
- In a P-type SC, the energy level of this acceptor impurity lies just above the Valence Band (VB). This energy level is called the acceptor level and is represented as **Ea**.
- 

- **At T=0K:**
- The Conduction Band (CB) and acceptor levels are vacant. However, the Valence Band (VB) is full, and the material behaves as an insulator.
- **At T>0K:**
- At low temperatures, electrons from the Valence Band (VB) jump into the acceptor levels, and holes are generated in the VB.In this process, holes are generated without the simultaneous generation of electrons.
- At normal temperature, the acceptor levels are saturated, and a few electrons are excited to the Conduction Band (CB).

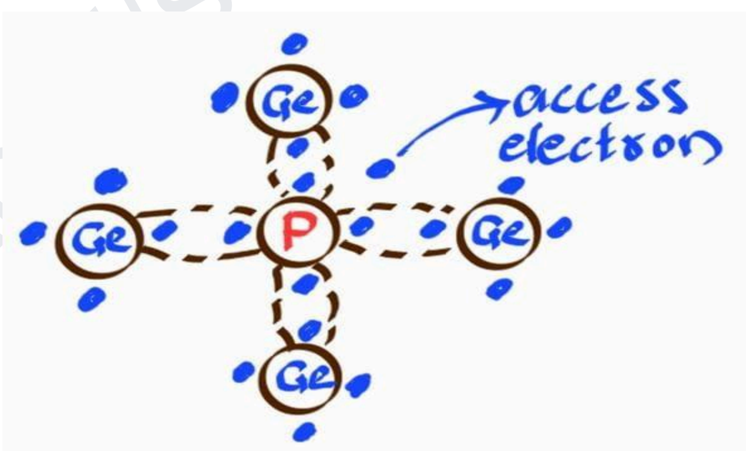
- The Valence Band (VB) now contains holes that have been generated by two different processes, namely:
  (i) Acceptor atom ionization
  (ii) Intrinsic process.
- At sufficiently high temperatures, a large number of electron-hole pairs are generated. The number of holes generated thermally far exceeds the number of holes due to acceptor impurity, and the material behaves as an Intrinsic Semiconductor (ISC).
- The P-type SC has only holes (no electrons) at absolute zero.

N-Type SC(Donor):

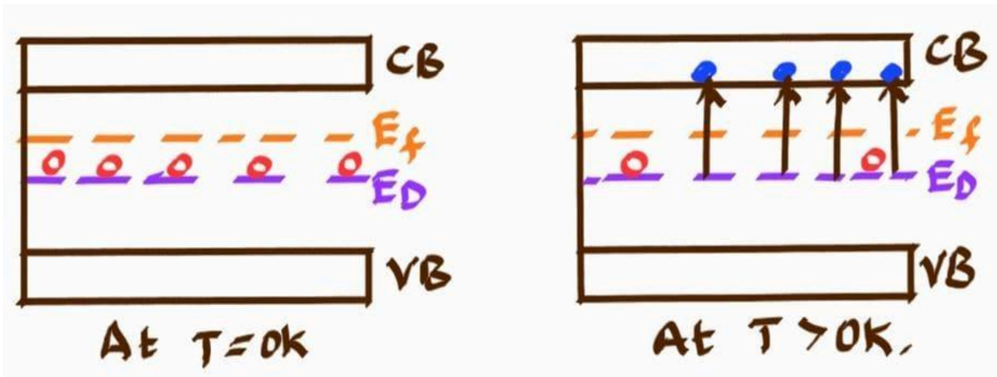
- An N-type semiconductor is produced when a pure semiconductor is doped with a pentavalent impurity such as Phosphorus (P), Antimony (Sb), Arsenic (As), Indium (In), etc.
- The doped atom is called a donor atom and the donor impurity atoms can have one extra electron, which is ready to be donated.

Illustration of N-type SC:

- Let us consider Germanium (Ge) as a pure semiconductor, which has 4 valence electrons and can form 4 covalent bonds.
- When a pentavalent impurity atom like Phosphorus (P) is added to Germanium, the 4 electrons of Phosphorus form bonds with 4 Germanium electrons, leaving one extra electron.
- This extra electron is ready to be donated. Therefore, an electron exists, as shown in the figure.



- In an N-type SC, electrons outnumber holes. Hence, electrons are the majority charge carriers, and holes are the minority charge carriers.

- In an N-type SC, the energy level of this donor impurity lies just below the Conduction Band (CB) of the semiconductor.
- This energy level is called the donor level and is represented by Ed, as shown in the figure.
- 

- **At T=0K:**
- The donor atoms are not ionized and are at the Ed level, which is very near to Ec.
- **At T>0K**:
- When the temperature is raised above 0K, the donor atoms get ionized, and free electrons move to the Conduction Band (CB). The electron concentration in the CB increases with increasing temperature