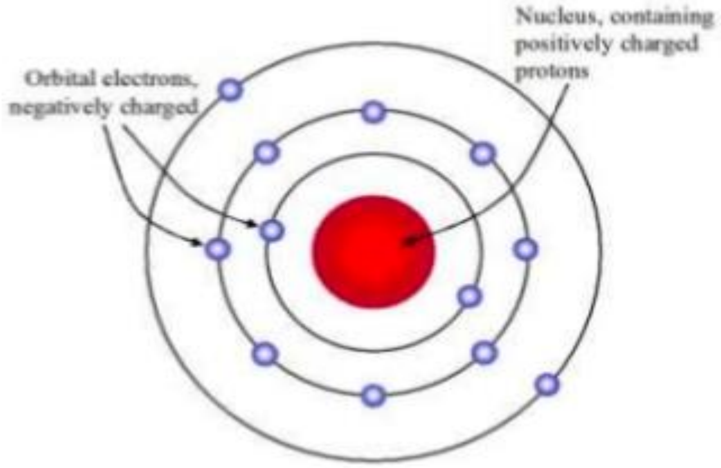
# Semiconductor (1)

PH-122

# Energy levels in atom

- In isolated atoms the electrons are arranged in energy levels.



Valence shells:

- An atom can be represented by valence shell and core .
- Outer most shell is called valence shell.
- Electrons in this shell have higher energy and weakly bound to the atom because force of attraction between positively charged nucleus and electron (negatively charged) decreases with increasing distance from the nucleus.
- Electrons in this shell are called valence electrons.

Ionization:

if valence electron in an atom gets enough energy called ionization energy, it can escape from valence shell. The process of losing an electron is called ionization and in result atom has positive charge called positive ion.

- The escaped valence electron ➔ free electron
- when atom gets extra electron is called negative ion.

# Bands in solid

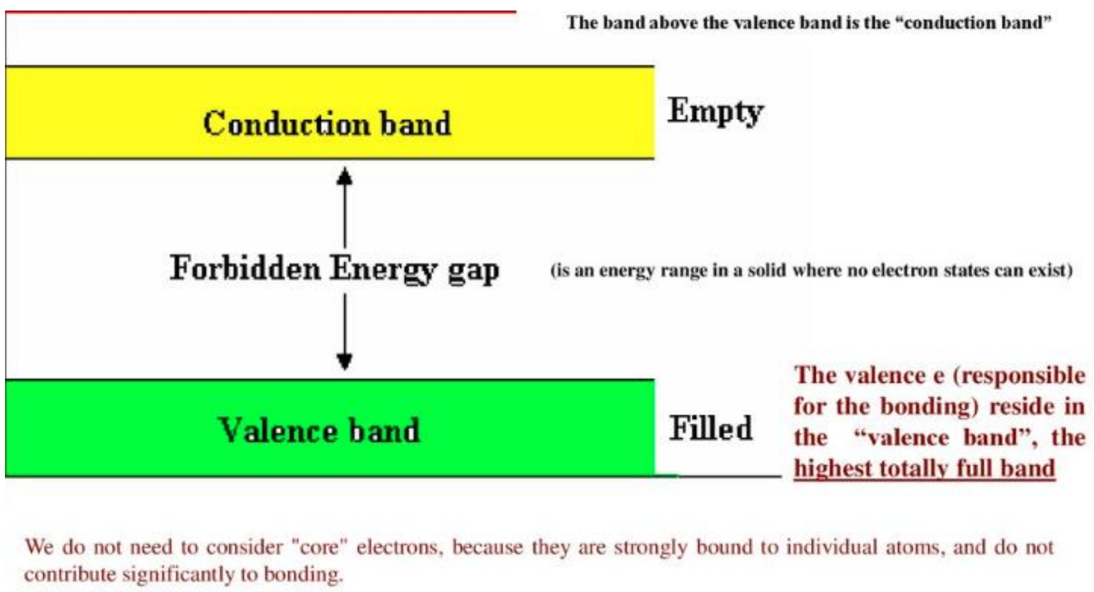
Instead of having discrete energies as in the case of free atoms, the available energy states form bands in solids.

The following are the important energy band in solids:

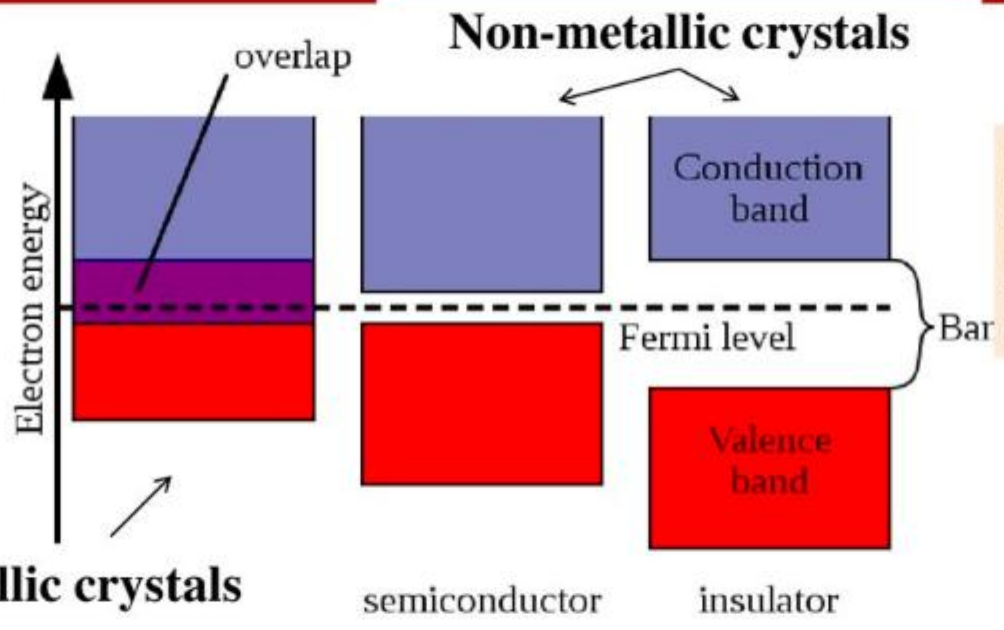
- Valence band
- Conduction band
- Forbidden energy gap or Forbidden band

# Bands in solids

- Valance band: The band of energy occupied by the valance electrons is called valence band. The electrons in the outermost orbit of an atom are known as valance electrons. This band may be completely or partial filled. Electron can be move from one valance band to the conduction band by the application of external energy.
- Conduction band The band of energy occupied by the conduction electrons is called conduction band. This is the uppermost band and all electrons in the conduction band are free electrons. The conduction band is empty for insulator and partially filled for conductors.
- Forbidden Energy Gap or Forbidden band The gap between the valance band and conduction band on energy level diagram known as forbidden band or energy gap. Electron are never found in the gap. Electrons may jump from back and forth from the bottom of valance band to the top of the conduction band. But they never come to rest in the forbidden band.



## Non-metallic crystals




- The large gap between the vb and cb requires high energy to remove an e.
  Thus, insulators do not conduct.

**Width of the gap?**

- e may move to a higher level energy state with little or no additional energy imparted

- heat energy gives some e enough energy to get across the gap and get into the conduction band.

# Energy gaps (room temperature)

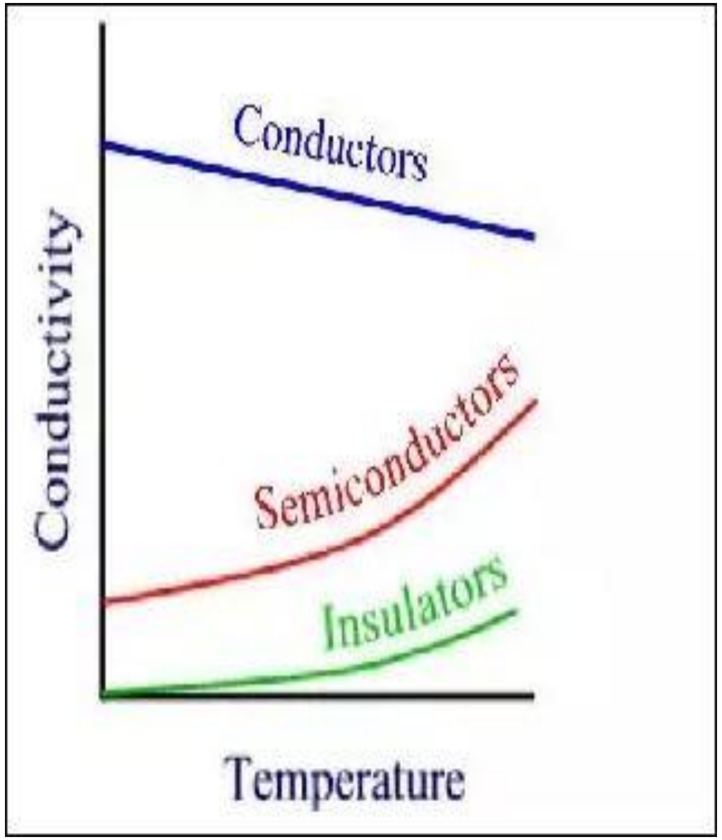
| Material | *Eg (eV)* | Observed electrical behaviour |
|---|---|---|
| $SiO_2$ | 9.0 | Insulator |
| Diamond | 5.5 | Insulator |
| GaAs | 1.42 | Semiconductor |
| Silicon | 1.12 | Semiconductor |
| Germanium | 0.66 | Semiconductor |
| Cu | 0 | Metal |
| Ag | 0 | Metal |

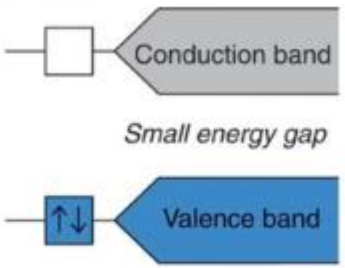
**The distinction between semiconductors and insulators is a matter of convention.** In general, a material with a band gap < 3 eV is regarded as a semiconductor. A material with a band gap > 3 eV will commonly be regarded as an insulator.

- **Effect of temperature on conductor, semiconductor :**
- In **conductors**, atoms vibrate about their equilibrium position
- Temperature increases, amplitude of vibration larger
- Chance of collision with free electrons higher
- Resistance higher, value of current lower
- Temperature coefficient of resistance is positive
- In **semiconductor:**
- At low temperature , pure semiconductors like insulators
- At high temperature, no. of conduction electrons increases
- ( resistance decreases and more current )
- Number of carriers in semiconductor material increases.
- Temperature coefficient of resistance is negative.
- Energy band gap is nearly 1eV.
- In **insulator:**
- At high temperature, more conductivity and less resistivity due to free electrons. Temperature coefficient of resistance is negative
- Energy band gap of 6eV.

Graph between conductivity and temperature

- Conductivity of conductor decreases as we increase the temperature
- Conductivity of semiconductor increases when temperature increases
- In insulator conducting property increases with an increase in temperature






chnology

# Semiconductors

- The band structure o similar to that of insulators

- The width of the forbidden gap  much smaller than for insulators.

- If  T increases, the vibration of the crystal lattice also increases. At $T_{room}$ electrons in the vb have energy to jump to the cb

So electrons in the cb can carry charge in a crystal and current flow becomes possible.

## Semiconductors

### Intrinsic Semiconductors

Pure semiconductors in which its properties are solely based off of the material itself.

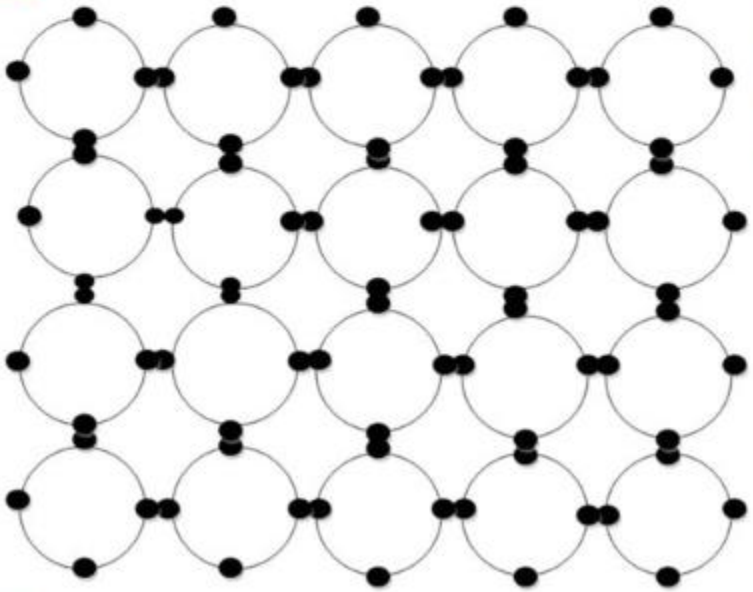
### Extrinsic Semiconductors

Impure semiconductors that have been "doped" in order to enhance its conductivity.

A "dopant" atom is added to the lattice in order to draw electrons from the valence band.

# Semiconductor Structure

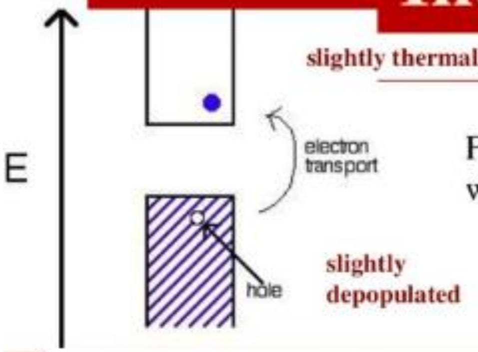
**All intrinsic semiconductors** are group 14 elements. They have 4 valence electrons available for bonding in their outermost shell..



Si has four v e, and uses them to make 4 covalent bonds to neighboring Si atoms. None of electrons are available to carry a current.

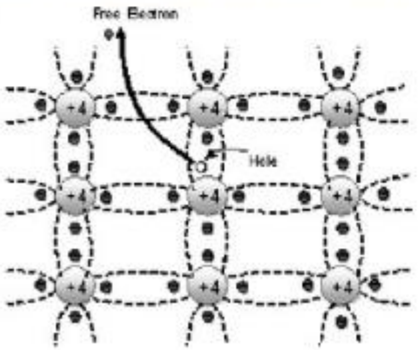

The excited electrons leave the chemical bond and become "free" or conduction electrons

# Intrinsic Semiconductors




For every electron that jumps into the conduction band, the missing electron will generate a **hole** that can move freely in the valence band

hole = empty electron state – A hole can also move and thus conduct current: it acts as a "positive electron"




Without "help" the total number of "carriers" (e and h) is limited.

- For most materials, this is not that much, and leads to very high resistance and few useful applications.
- We need to add carriers by modifying the crystal = "**doping the crystal**".

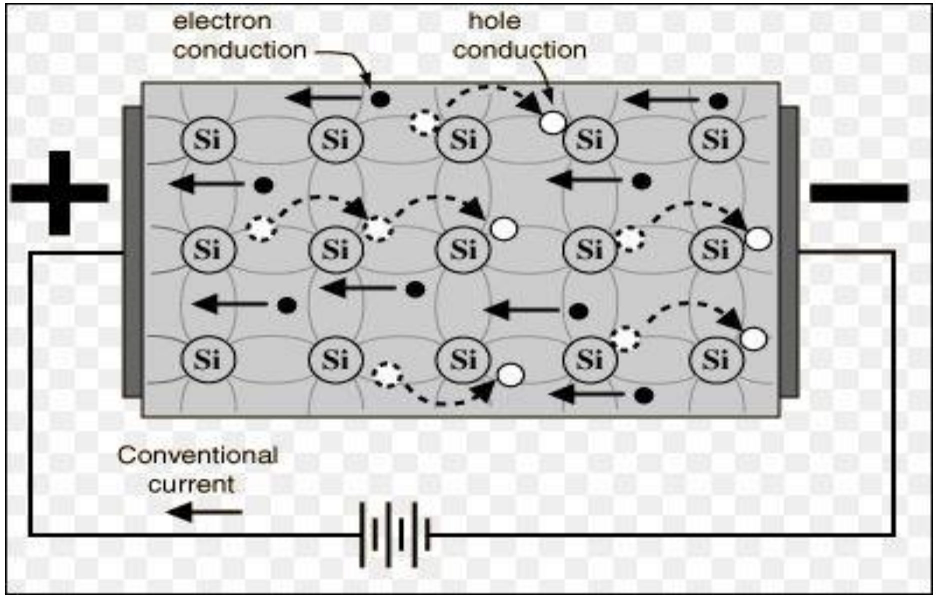
- **Hole:** Hole or vacant place is created in valence band, when valence electron jumps into the conduction band by external energy a vacancy is left in valence band within the crystal.
- **Conduction electron**: After the absorption of enough energy, valence electron jumps into conduction band and become free electron. This free electron is called conduction electron.
- **Electron- Hole pair**: when electron jumps into conduction band leaving hole in valence band, this process is called electron hole pair.
- **Recombination Process:** It happens when conduction electron loses energy and falls back into a hole in valence band.

**<u>Conduction in semiconductor:</u>**

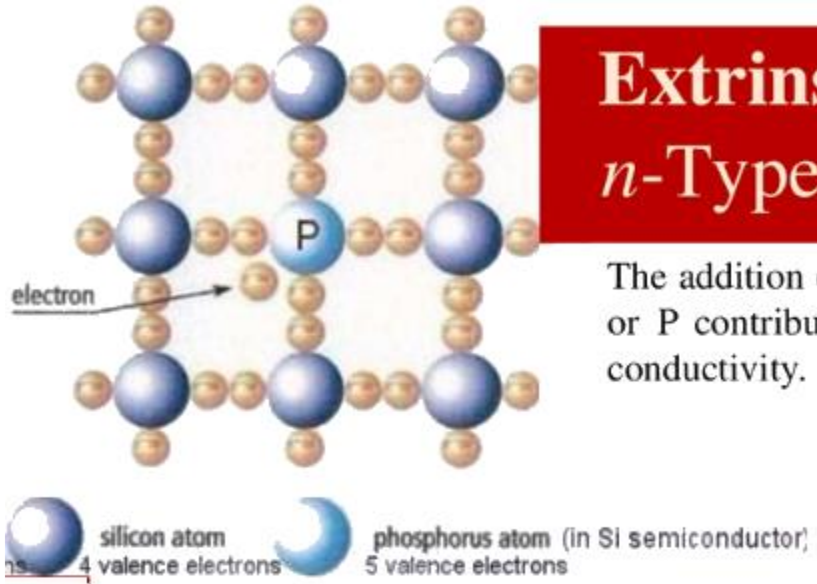
**<u>(i) Electron current: (Ie) I</u>**n intrinsic semiconductor when voltage is applied as shown in figure, free electrons in conduction band move to the positive plate of the battery. This movement produces current in semiconductor and is called electron current.

**<u>(ii) Hole current (Ih):</u>**

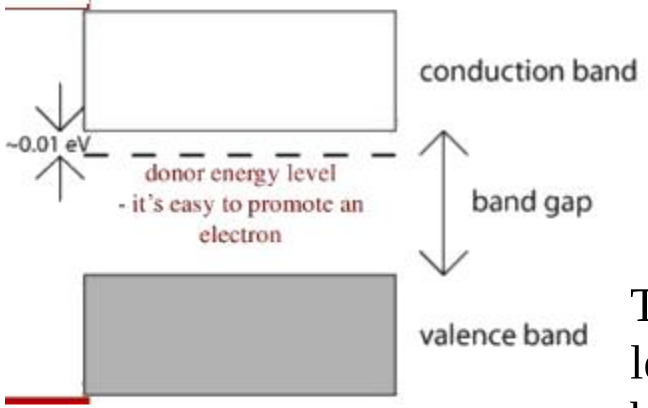
- Current due to the movement of hole in valence band.
- Electrons in valence band also attracted towards positive plate of the battery, so the holes appear to move towards negative plate.



# Extrinsic Semiconductors
## *n*-Type Semiconductor




The addition of **pentavalent impurities** such as Sb, As or P contributes free electrons, greatly increasing the conductivity.

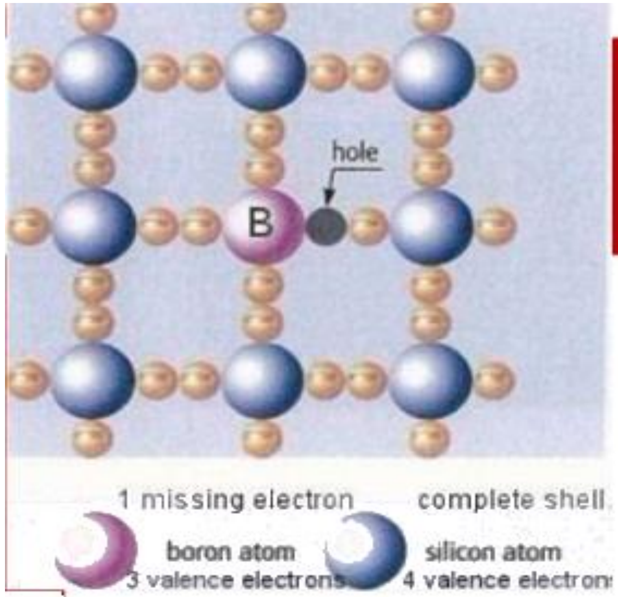



The promoted electrons become charge carriers that contribute to the conductivity.

The addition of donor [impurities]() contributes electron energy levels high in the semiconductor [band gap]() so that electrons can be easily excited into the conduction band

# Extrinsic Semiconductors

## *p*-Type Semiconductor

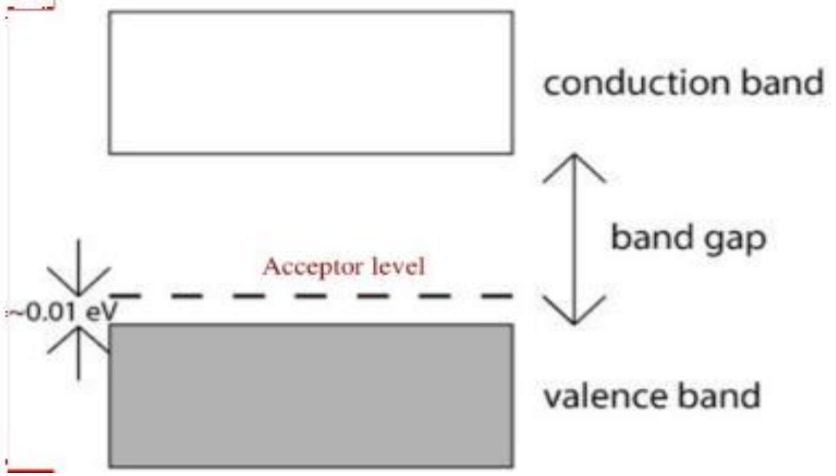



Dopants from the IIIA group such as $B^{+3}$

The impurity is 1e short of the required amount of electrons needed to establish covalent bonds with 4 neighbours.

This arrangement leaves a **hole** in that covalent bond.

**majority carriers = holes**




For each promotion of an electron into acceptor levels, a hole is left in the valance band.

Holes become the charge carriers and contribute to the conductivity of the semiconductor.

The addition of acceptor impurities contributes hole levels low in the semiconductor band gap so that electrons can be easily excited from the valence band into these levels, leaving mobile holes in the valence band.