University of Babylon
College of Material Engineering
Department of Methlogical Engineering

Class: 3^{rd}
Subject: Electronic and Magnetic Materials
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Content

Impurities of Semiconductors

- An elemental or compound semiconductor that was not contaminated by the introduction of impurities is called an **intrinsic semiconductor**. At an absolute zero temperature, intrinsic semiconductors form stable covalent bonds that have valence shells completely filled with electrons.
- These covalent bonds are very strong, so that each electron is held very strongly to the atoms sharing it. Thus, there are no free electrons available, and no electrical conduction is possible.
- As the temperature is raised to relatively high temperatures, the valence bonds sometimes break, and electrons are released. The free electrons behave in the same way as free electrons in a metal; therefore, electrical conduction is now possible when an electric field is applied.

- If an impurity, such as phosphorus or boron, is introduced into the crystal structure of an intrinsic semiconductor, its chemical state is altered to where the semiconductor will have an excess or deficiency of electrons, depending on the impurity type used.
- The process of adding a small quantity of impurities to an intrinsic semiconductor is called **doping**. As an example, consider an intrinsic silicon crystal structure with its covalent bonds, shown as a two-dimensional sketch in Fig.1. Each atom is surrounded by four other atoms, with which it shares one pair of electrons, to form four covalent bonds. If the silicon crystal (Group IV) is doped with a controlled quantity of an impurity (dopant), such as phosphorus (Group V), the newly formed covalent bonds (Fig.2) have an excess of electrons that are free to move from atom to atom when a voltage is applied across the semiconductor.

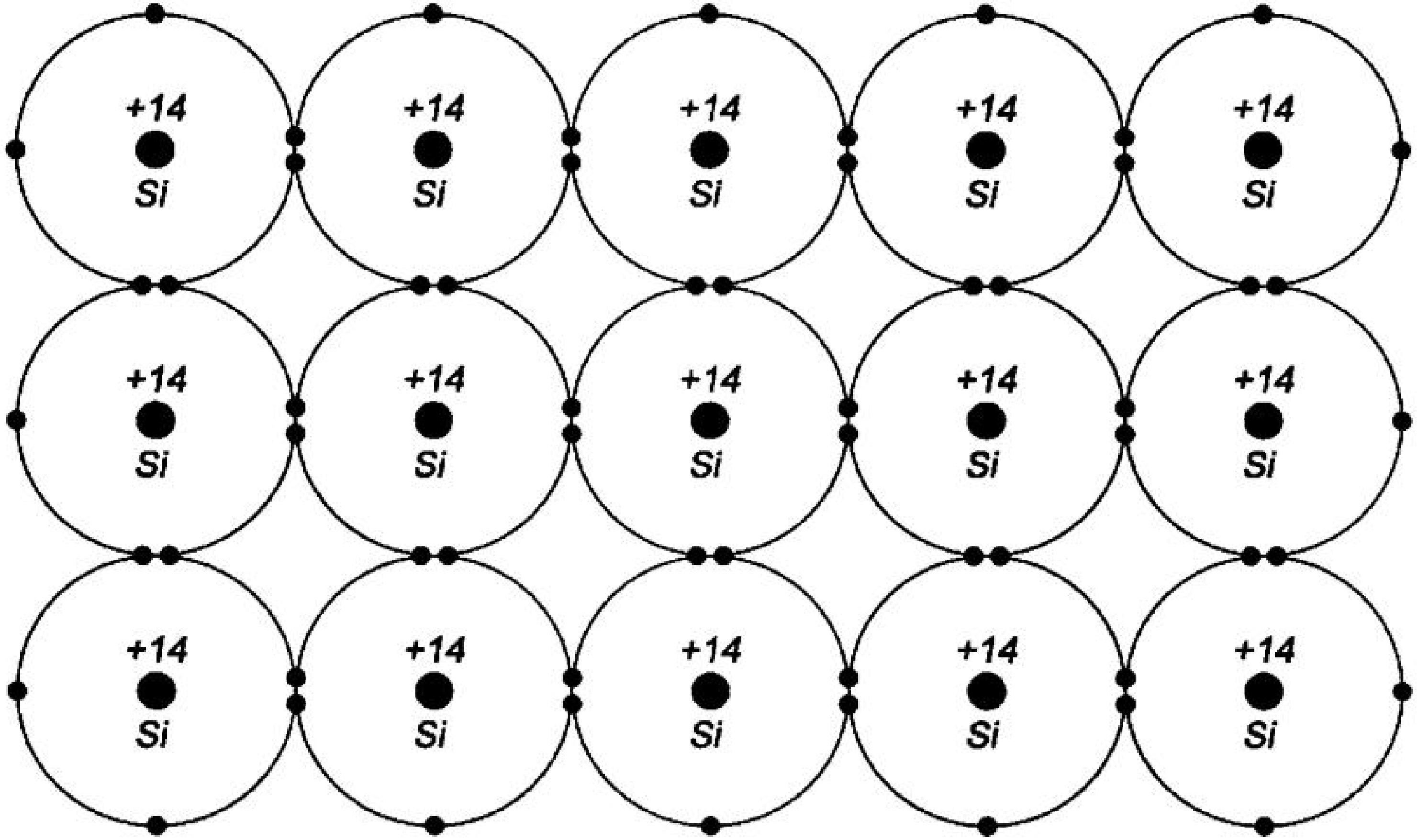
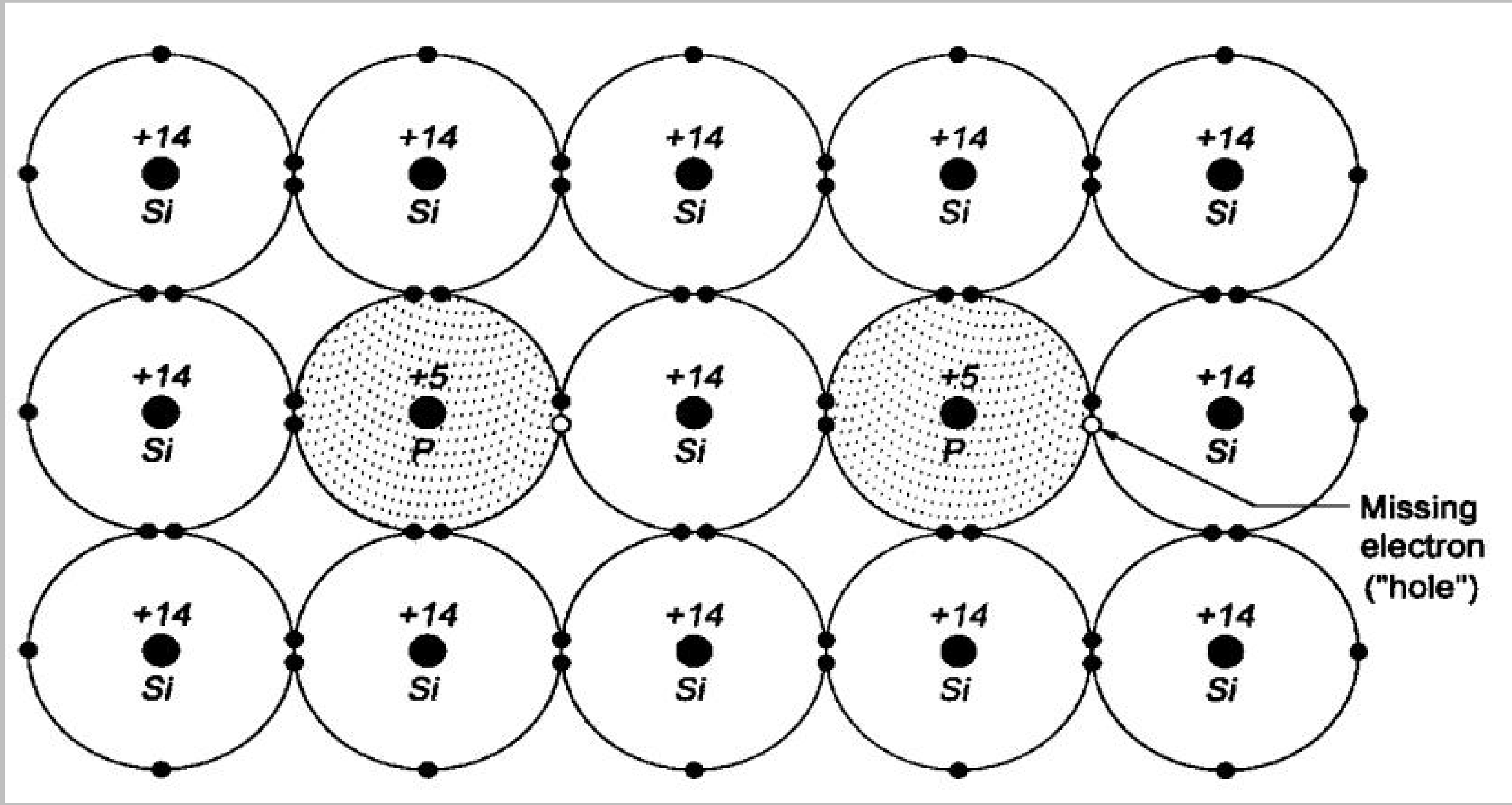


Fig.1: Two-dimensional representation of an intrinsic silicon crystal (only valenceelectrons are shown).

Fig.2: Two-dimensional representation of silicon crystal doped with phosphorus to create a n-type semiconductor (only valence electrons are shown).



The material thus altered is called an n-type (n for negative) semiconductor. Another semiconductor type, called p-type (p for positive), can be formed by doping the silicon crystal with a dopant from Group III, such as boron. The resultant combination (Fig.3) has a deficiency of electrons and thus creates “holes,” or electron vacancies, in the positively charged atoms.

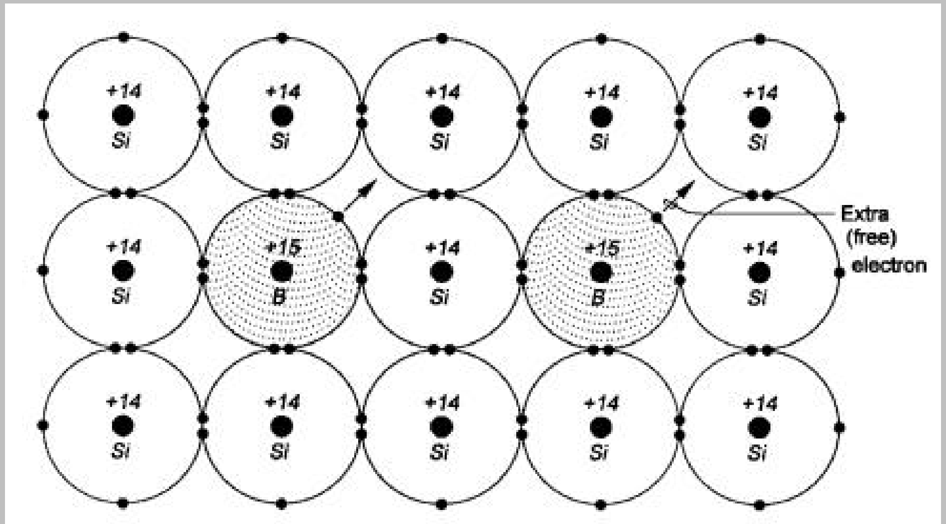
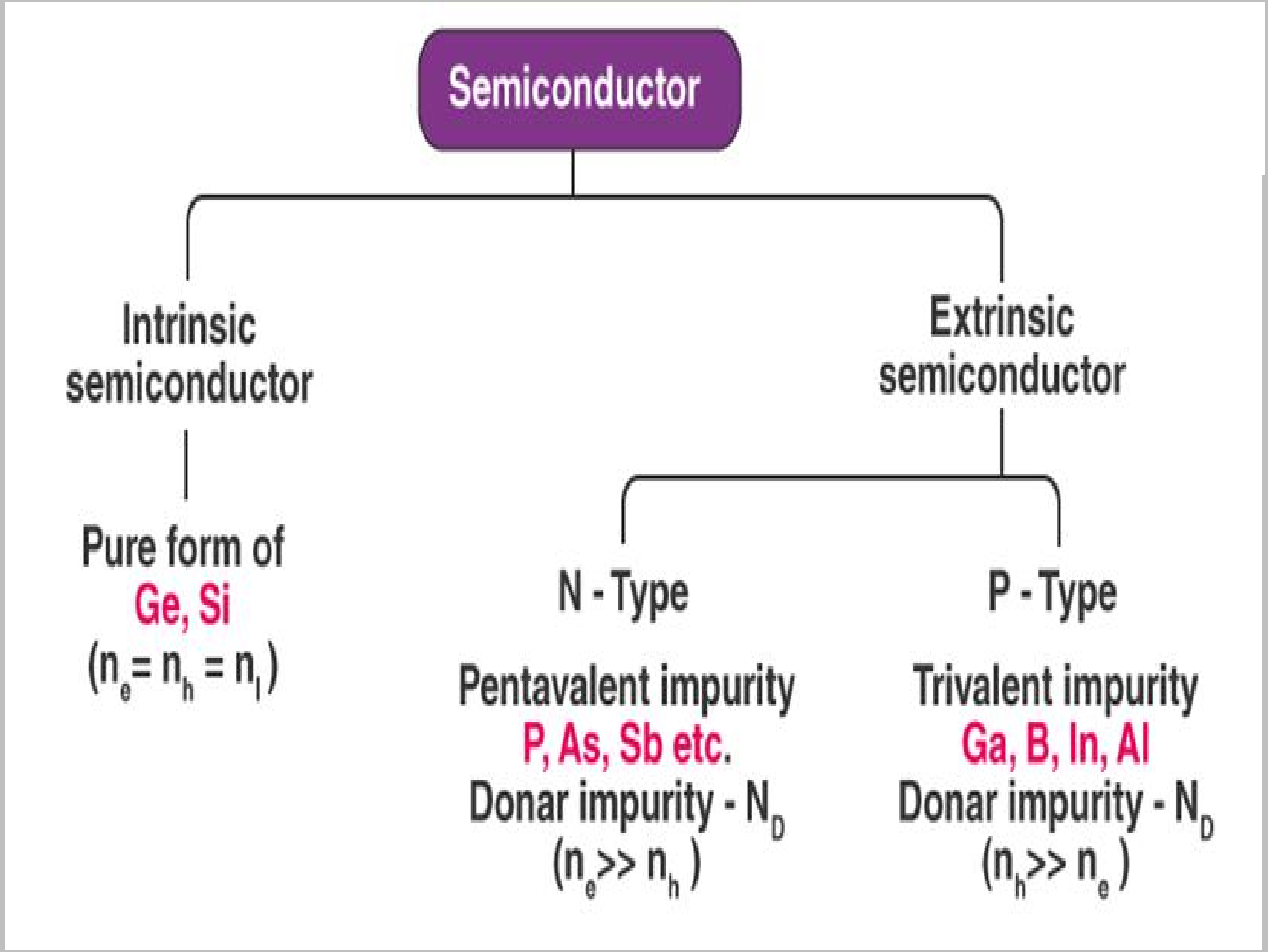


Fig.3: Two-dimensional representation of silicon crystal doped with boron to create an p-type semiconductor (only valence electrons are shown).

Types of Semiconductors

Semiconductors can be classified as follows:

- Intrinsic Semiconductor
- Extrinsic Semiconductor



Intrinsic Semiconductor

An intrinsic type of semiconductor material is made to be very pure chemically. It is made up of only a single type of element.

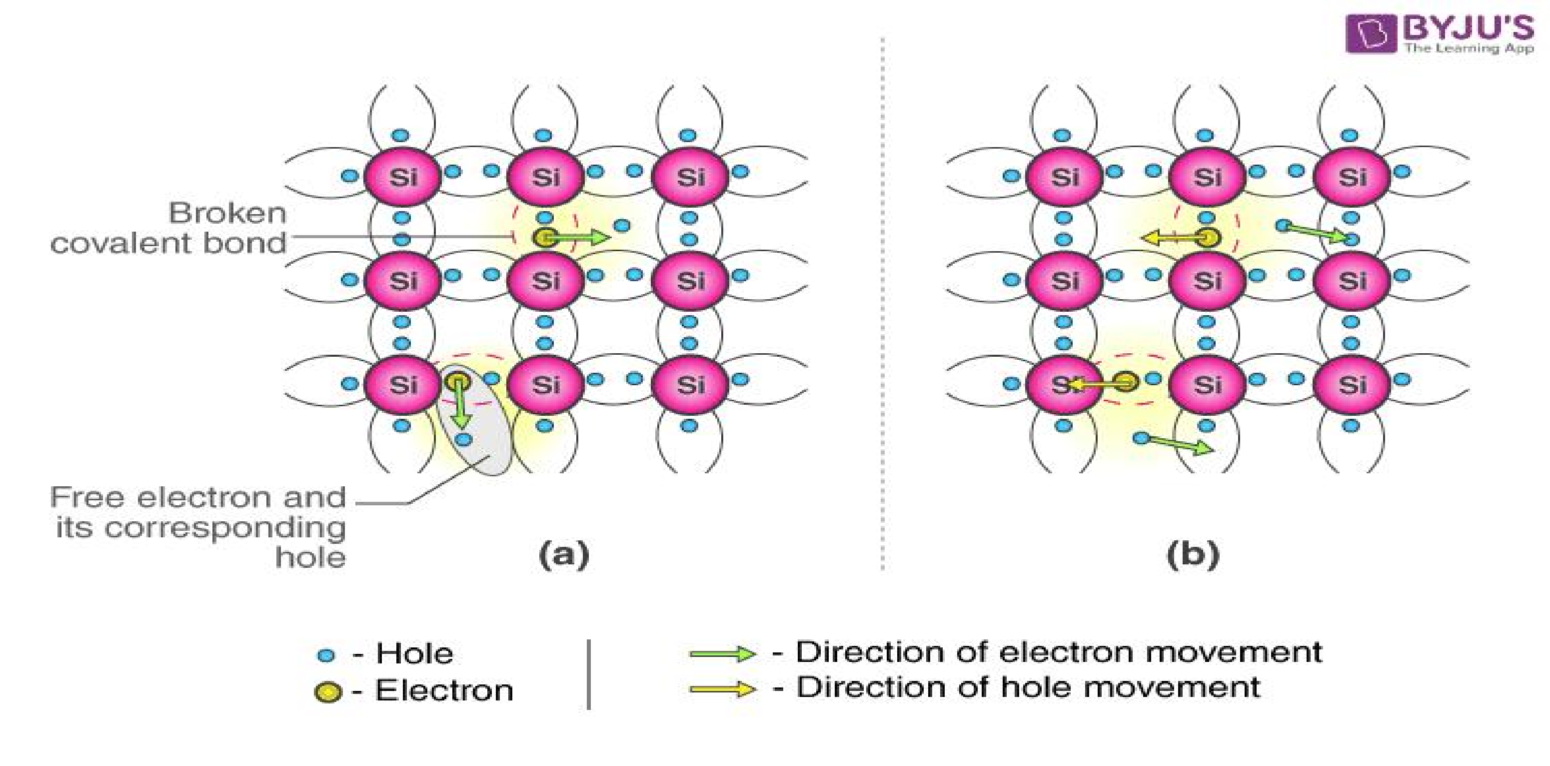


Fig.4: Conduction Mechanism in Case of Intrinsic Semiconductors (a) In the absence of an electric field (b) In the presence of an electric field

- Germanium (Ge) and silicon (Si) are the most common types of intrinsic semiconductor elements. They have four valence electrons (tetravalent). They are bound to the atom by a covalent bond at absolute zero temperature.
- When the temperature rises due to collisions, few electrons are unbounded and become free to move through the lattice, thus creating an absence in its original position (hole). These free electrons and holes contribute to the conduction of electricity in the semiconductor. The negative and positive charge carriers are equal in number.
- The thermal energy is capable of ionising a few atoms in the lattice, and hence, their conductivity is less.

Energy Band Diagram of Intrinsic Semiconductor

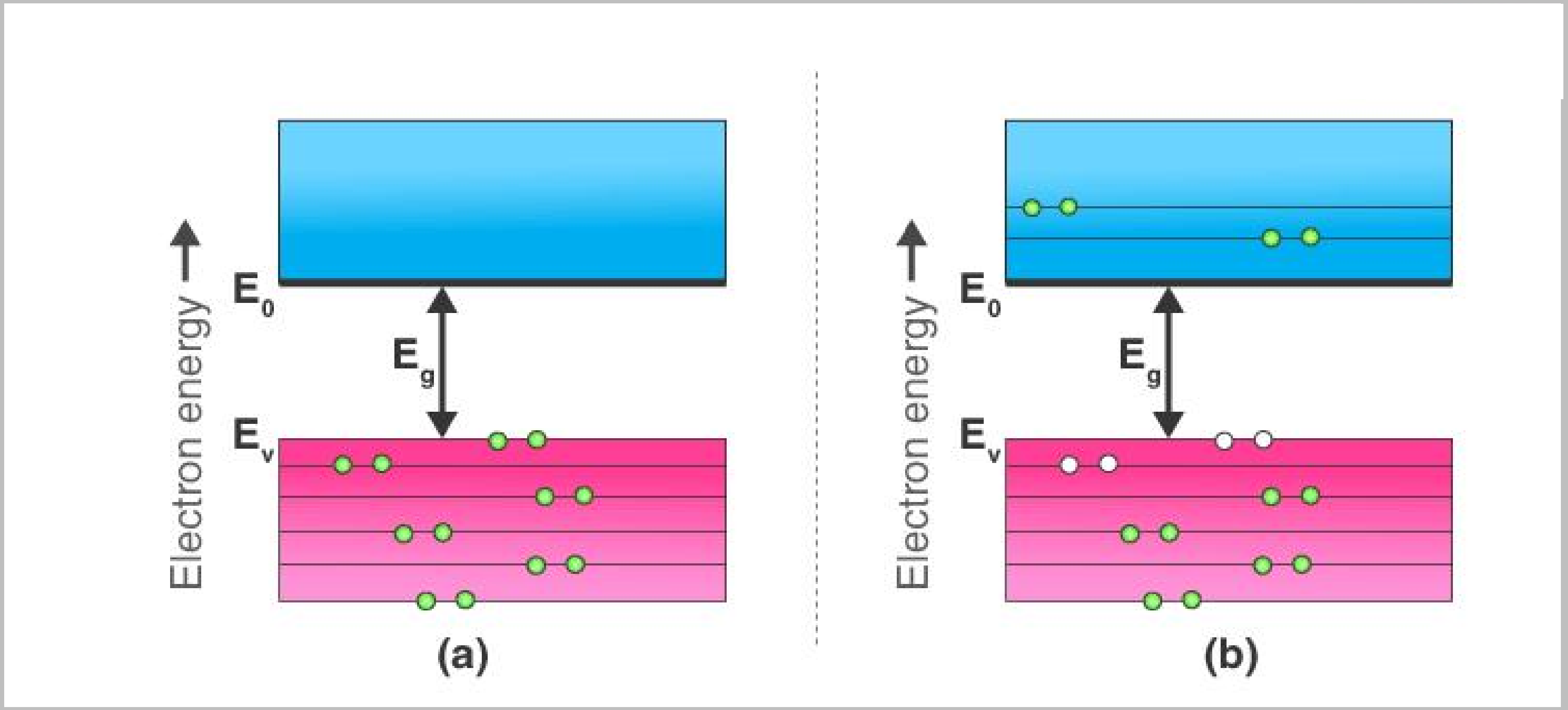


Fig.5: (a) Intrinsic Semiconductor at T = 0 Kelvin, behaves like an insulator (b) At t>0, four thermally generated electron pairs

In intrinsic semiconductors, current flows due to the motion of free electrons, as well as holes. The total current is the sum of the electron current I_e due to thermally generated electrons and the hole current I_h.

$$\text{Total Current (I)} = I_e + I_h$$

For an intrinsic semiconductor, at finite temperature, the probability of electrons existing in a conduction band decreases exponentially with an increasing band gap (E_g).

$$n = n_\circ \exp\left(-\frac{E_g}{2K_bT}\right)$$

Where,

Eg = Energy band gap

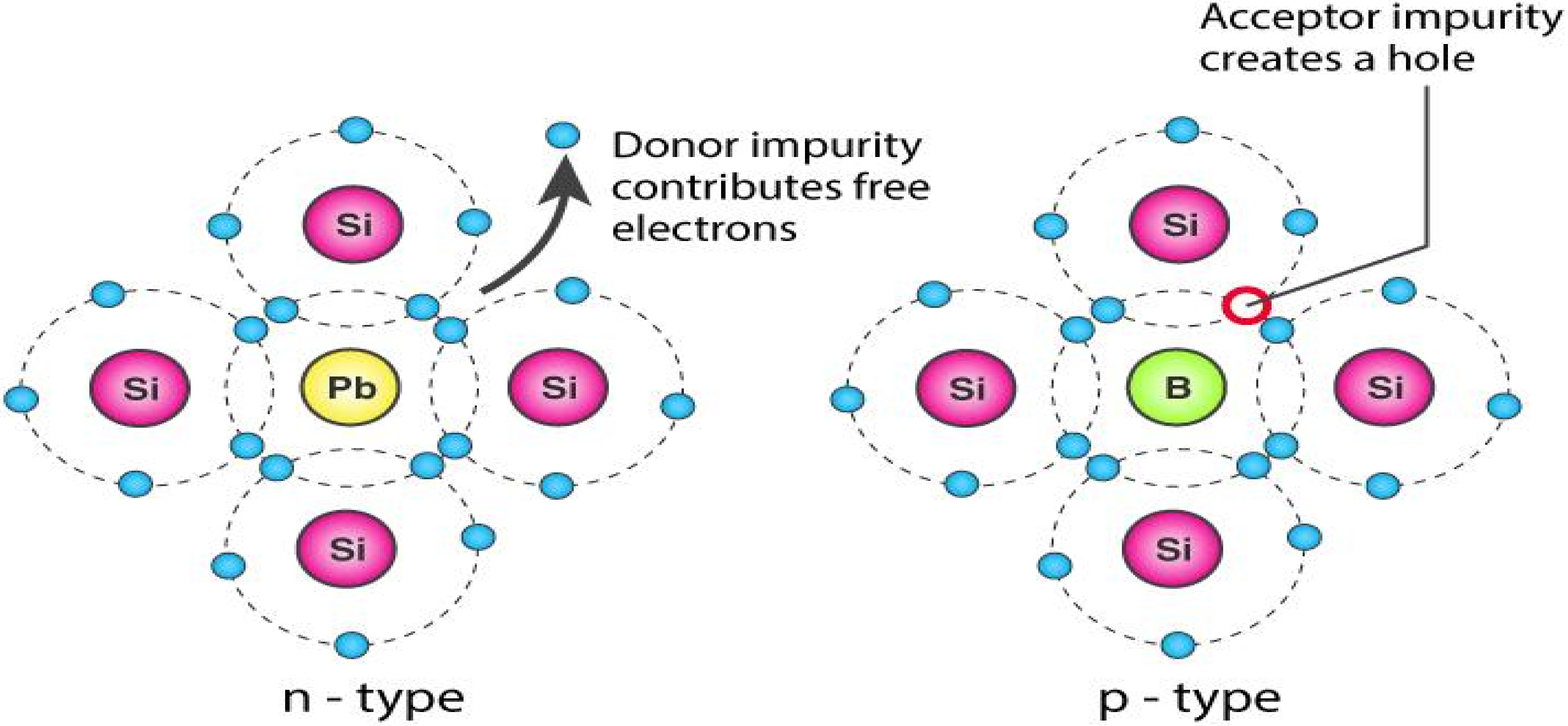
K_b = Boltzmann’s constants

Extrinsic Semiconductor

The conductivity of semiconductors can be greatly improved by introducing a small number of suitable replacement atoms called Impurities. The process of adding impurity atoms to the pure semiconductor is called Doping. Usually, only 1 atom in 107 is replaced by a dopant atom in the doped semiconductor. An extrinsic semiconductor can be further classified into types:

- N-type Semiconductor
- P-type Semiconductor

Extrinsic semiconductors



N-Type Semiconductor

When a pure semiconductor (silicon or germanium) is doped by pentavalent impurity (P, As, Sb, Bi), then four electrons out of five valence electrons bond with the four electrons of Ge or Si. The fifth electron of the dopant is set free. Thus, the impurity atom donates a free electron for conduction in the lattice and is called a "**Donar**". Since the number of free electrons increases with the addition of an impurity, the negative charge carriers increase. Hence, it is called an n-type semiconductor. Crystal as a whole is neutral, but the donor atom becomes an immobile positive ion. As conduction is due to a large number of free electrons, the electrons in the n-type semiconductor are the Majority Carriers, and holes are the Minority Carriers.

$$I = I_e \; and \; N_e \gg N_h$$

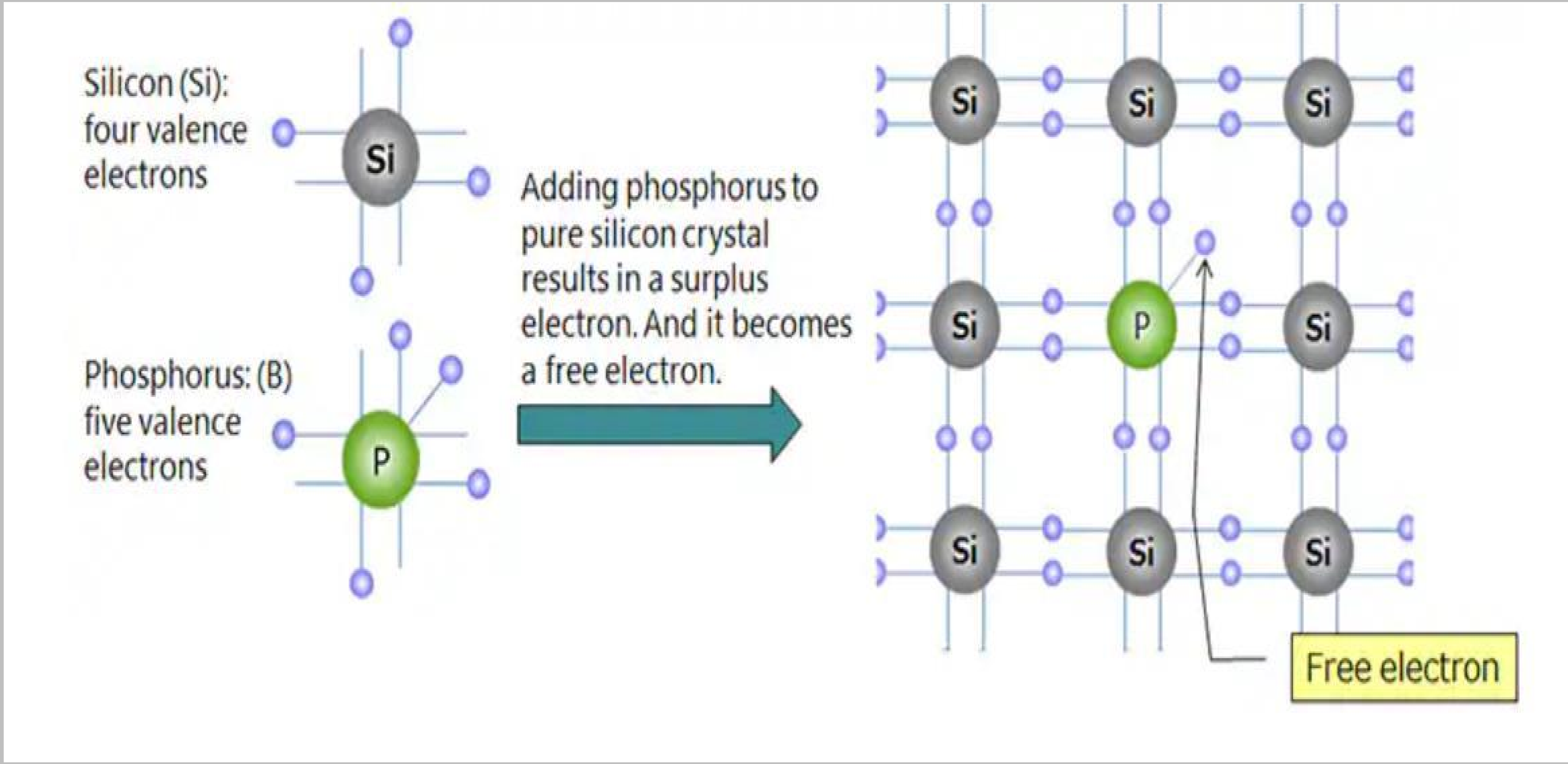
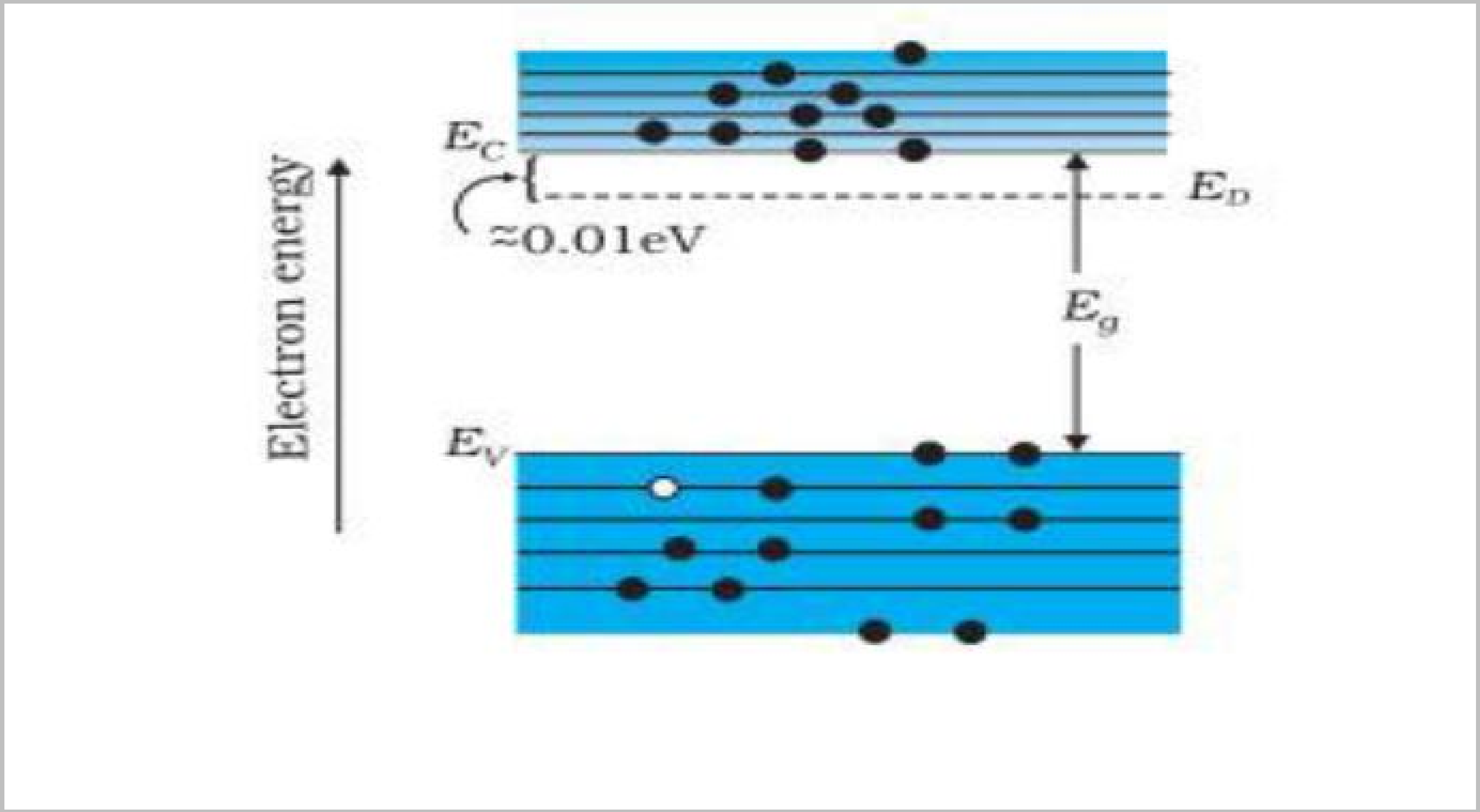

Silicon (Si):
four valence
electrons
Si
Phosphorus: (B)
five valence
electrons
P
Adding phosphorus to
pure silicon crystal
results in a surplus
electron. And it becomes
a free electron.
Si
Si
Si
Si
P
Si
Si
Si
Si
Free electron

Fig.6: Energy level diagram of an n-type semiconductors

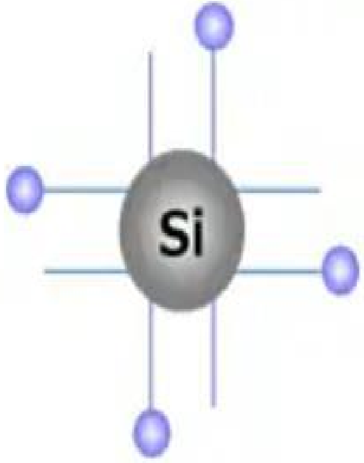


P-Type Semiconductor

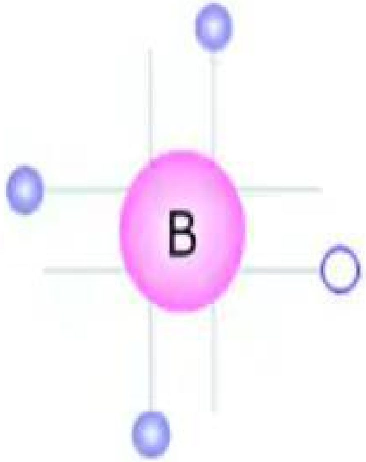
When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga), then the three valence electrons of the impurity bond with three of the four valence electrons of the semiconductor. This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called "**Acceptors**". With an increase in the number of impurities, holes (the positive charge carriers) are increased. Hence, it is called a p-type semiconductor. Crystal, as a whole, is neutral, but the acceptors become an immobile negative ion. As conduction is due to a large number of holes, the holes in the p-type semiconductor are Majority Carriers, and electrons are Minority Carriers.

$$I = I_h \ and \ N_h \gg N_e$$

Silicon (Si): Four valence electrons



Boron (B): Three valence electrons



Adding boron to pure silicon crystal results in lack of an electron. And it becomes a hole.

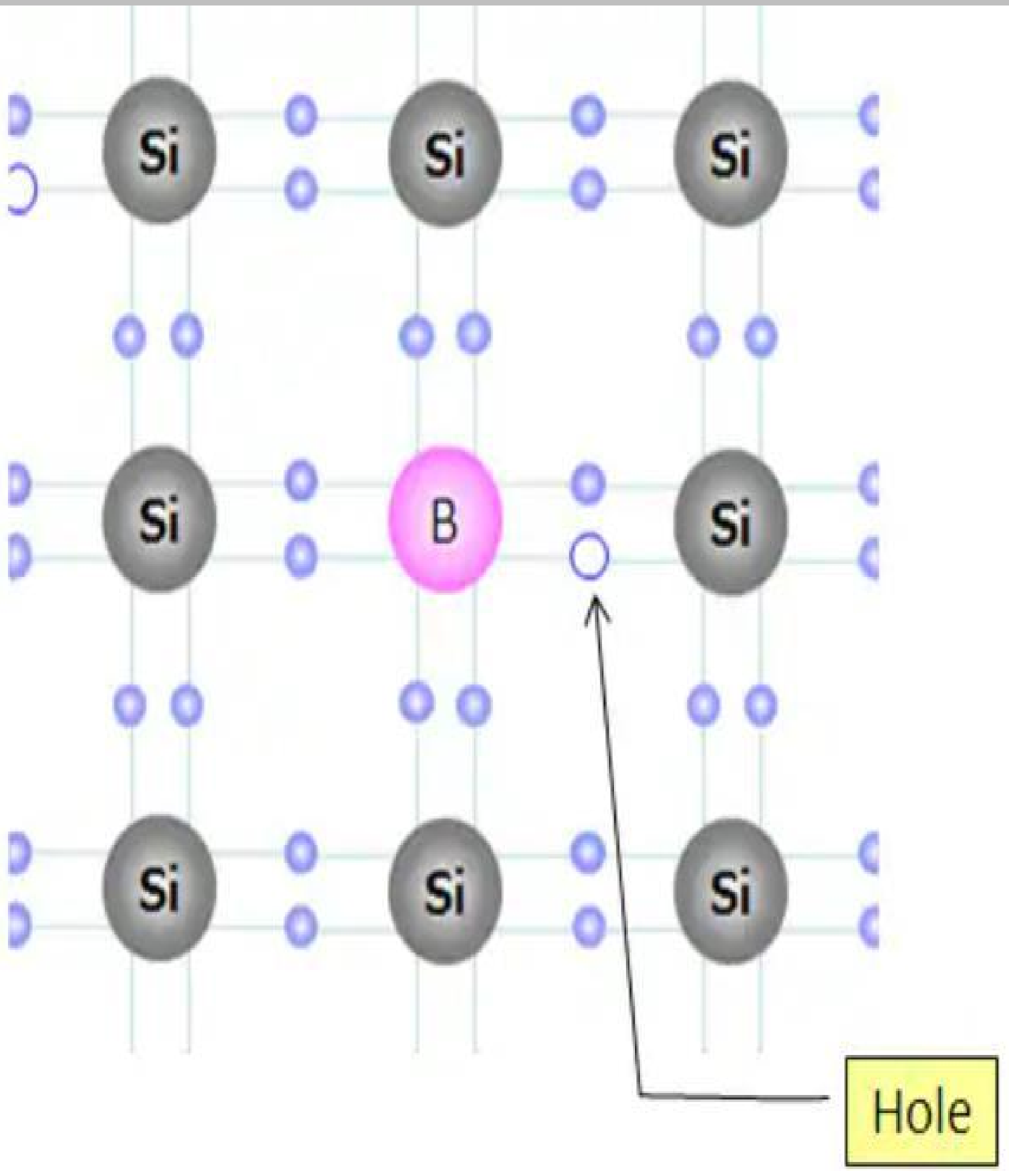
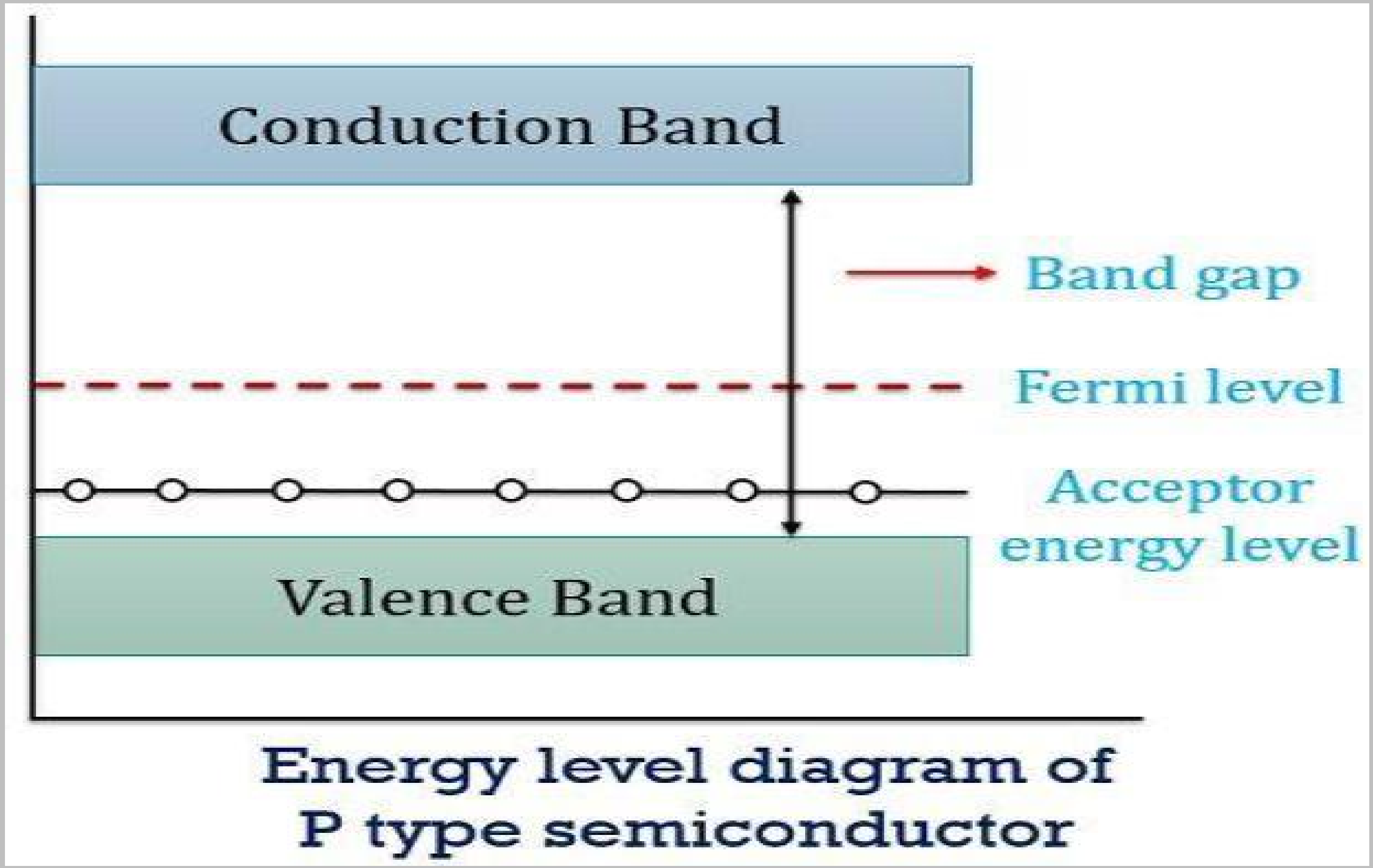
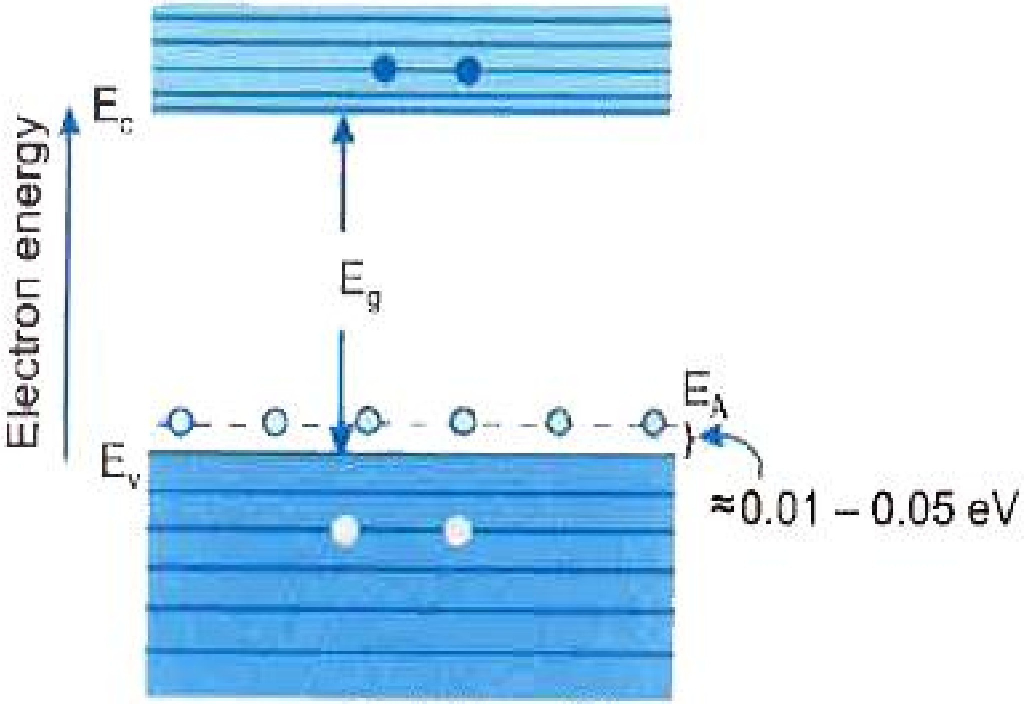


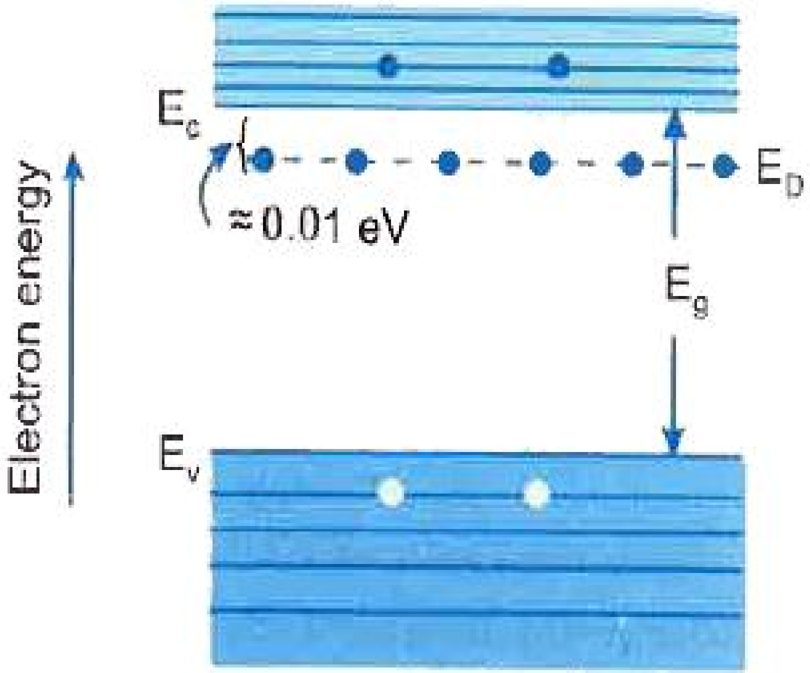
Fig.7: Energy level diagram of an p-type semiconductors



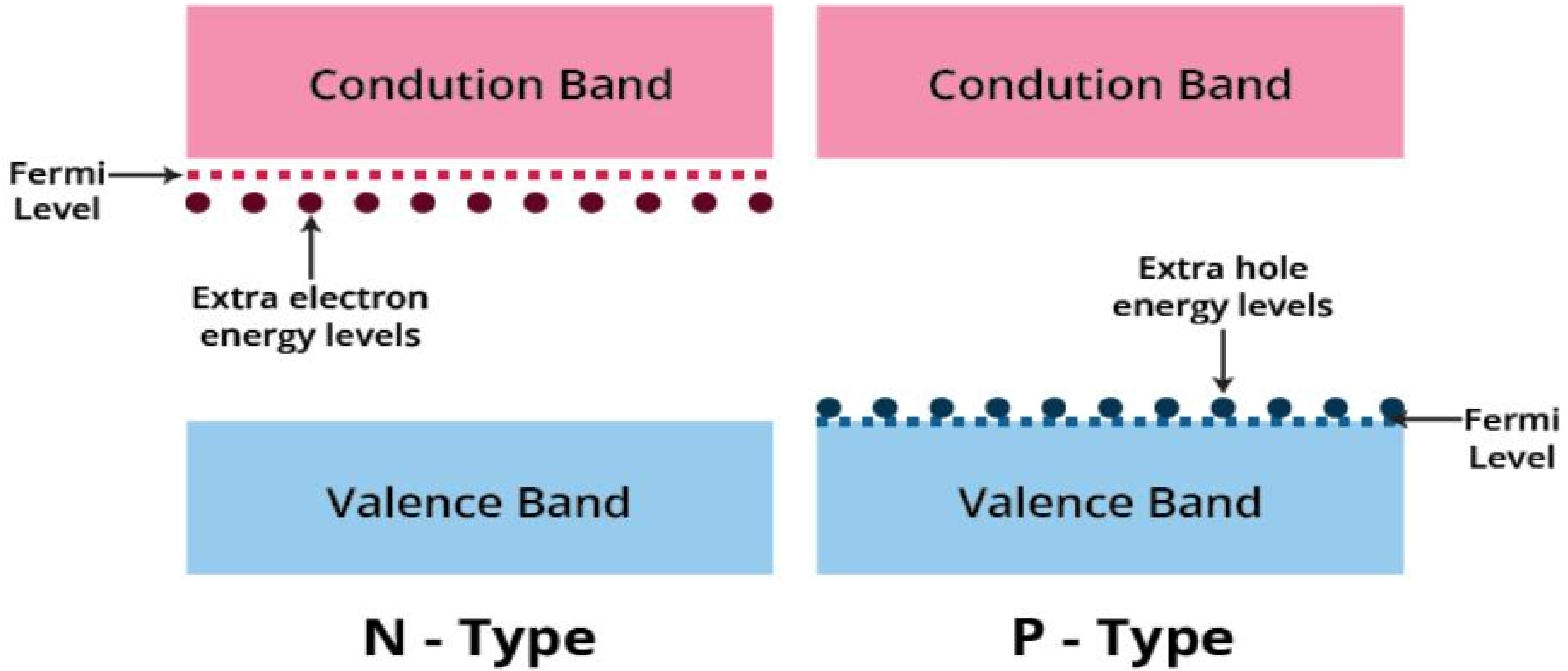
p-type semiconductor

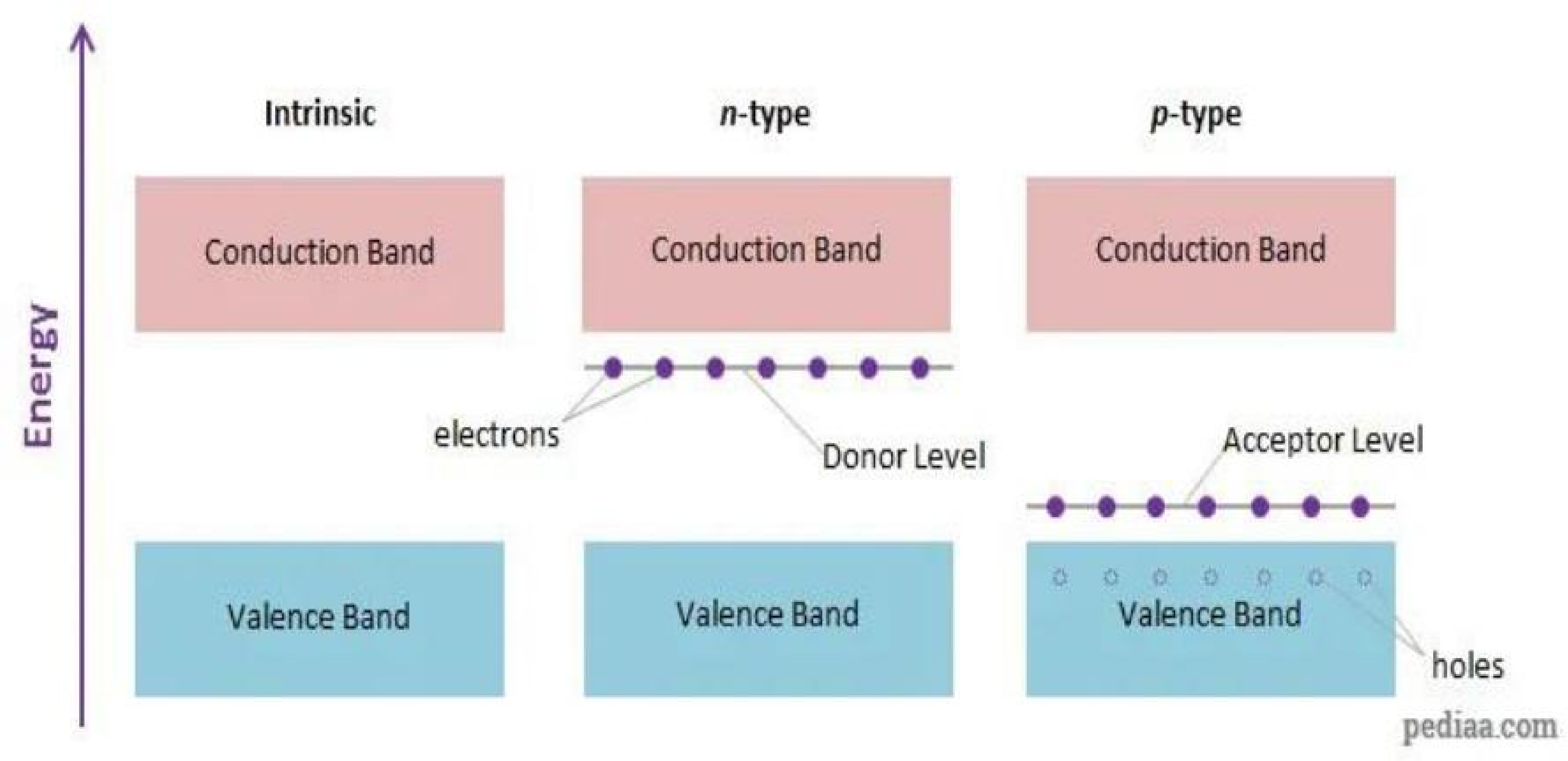


n-type semiconductor



p-type semiconductor	*n-type semiconductor*
1. It is formed by doping with a trivalent impurity.	1. It is formed by doping with a pentavalent impurity.
2. Here $n_h >> n_e$	2. Here $n_e >> n_h$


Condution Band
Condution Band
Fermi
Level
Extra electron
energy levels
Extra hole
energy levels
Fermi
Level
Valence Band
Valence Band
N - Type
P - Type


Energy
Intrinsic
n-type
p-type
Conduction Band
Conduction Band
Conduction Band
electrons
Donor Level
Acceptor Level
Valence Band
Valence Band
Valence Band
holes
pediaa.com

Difference between Intrinsic and Extrinsic Semiconductors

Intrinsic Semiconductor	Extrinsic Semiconductor
Pure semiconductor	Impure semiconductor
The density of electrons is equal to the density of holes	The density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature, as well as on the amount of impurity
No impurities	Trivalent impurity and pentavalent impurity

Applications of Semiconductors

Let us now understand the uses of semiconductors in daily life. Semiconductors are used in almost all electronic devices. Without them, our life would be much different.

Their reliability, compactness, low cost and controlled conduction of electricity make them ideal to be used for various purposes in a wide range of components and devices. Transistors, diodes, photosensors, microcontrollers, integrated chips and much more are made up of semiconductors.

Uses of Semiconductors in Everyday Life

1. Temperature sensors are made with semiconductor devices.
2. They are used in 3D printing machines
3. Used in microchips and self-driving cars
4. Used in calculators, solar plates, computers and other electronic devices.
5. Transistors and MOSFET used as a switch in electrical circuits are manufactured using semiconductors.

Industrial Uses of Semiconductors

- The physical and chemical properties of semiconductors make them capable of designing technological wonders like microchips, transistors, LEDs, solar cells, etc.
- The microprocessor used for controlling the operation of space vehicles, trains, robots, etc., is made up of transistors and other controlling devices, which are manufactured by semiconductor materials.

Importance of Semiconductors

Here, we have discussed some advantages of semiconductors, which make them highly useful everywhere.

1. They are highly portable due to their small size
2. They require less input power
3. Semiconductor devices are shockproof
4. They have a longer lifespan
5. They are noise-free while operating


Thank you