PARISHRAM

2026

Lecture - 01

easy
Theory

Semiconductor

Electronics

PHYSICS | **Lecture : 01**

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Topics *to be covered*

1. Band Theory

Unit–IX	**Electronic Devices**	7
	Chapter–14: Semiconductor Electronics: Materials, Devices and Simple Circuits	

Unit IX: **Electronic Devices**

Chapter–14: Semiconductor Electronics: Materials, Devices and Simple Circuits

Energy bands in conductors, semiconductors and insulators (qualitative ideas only) Intrinsic and extrinsic semiconductors- p and n type, p-n junction

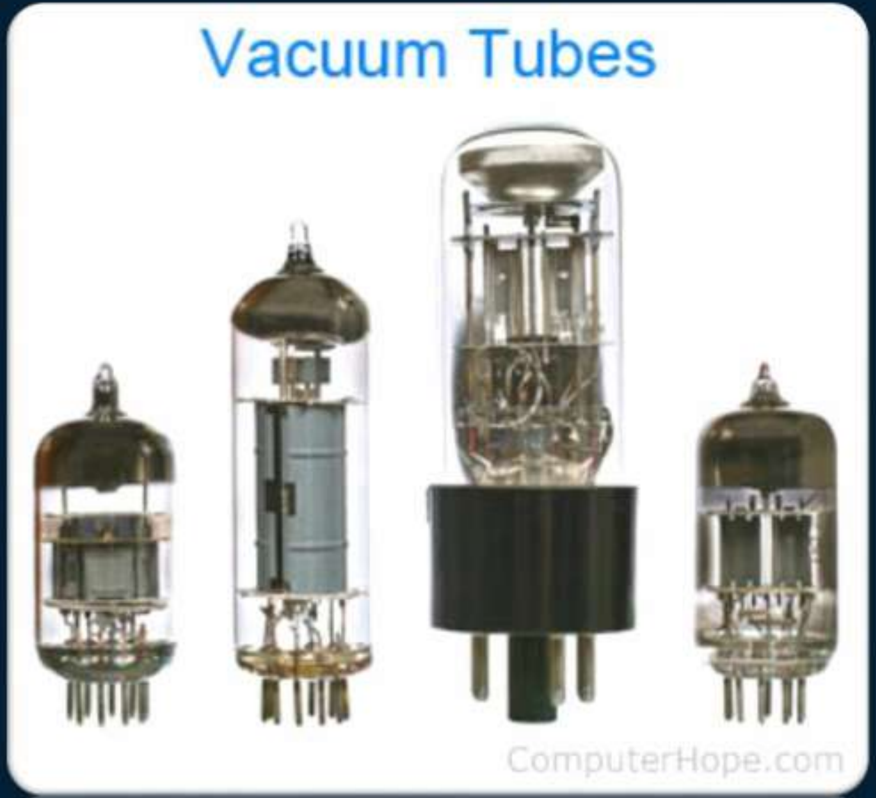
Semiconductor diode - I-V characteristics in forward and reverse bias, application of junction diode -diode as a rectifier.

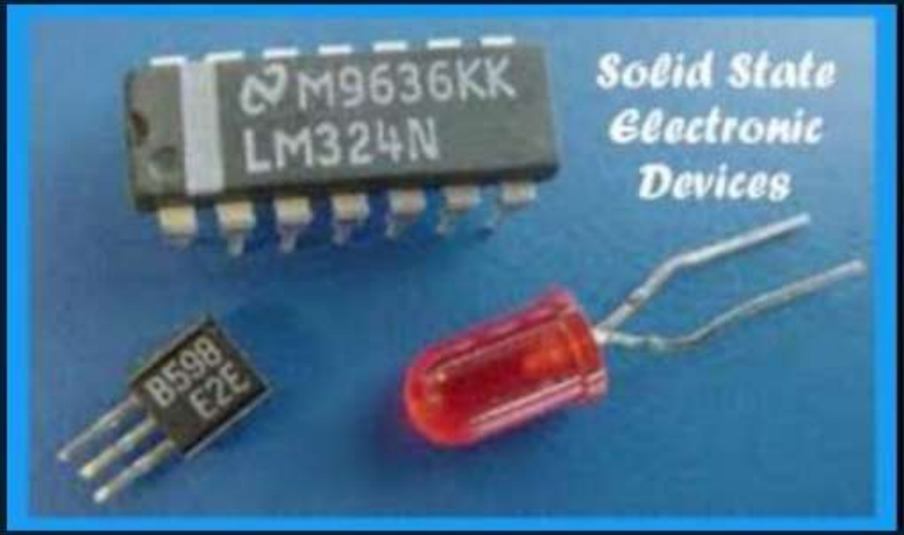
Types of Electronic Devices

We can control the flow of electrons.
(Less e^-)

The electronic devices are of two types

1. **Vacuum tubes:** These include vacuum diodes, triode and pentode.
2. **Solid-state electronic devices:** In such devices, the charge carriers flow through solid-state semiconductors.

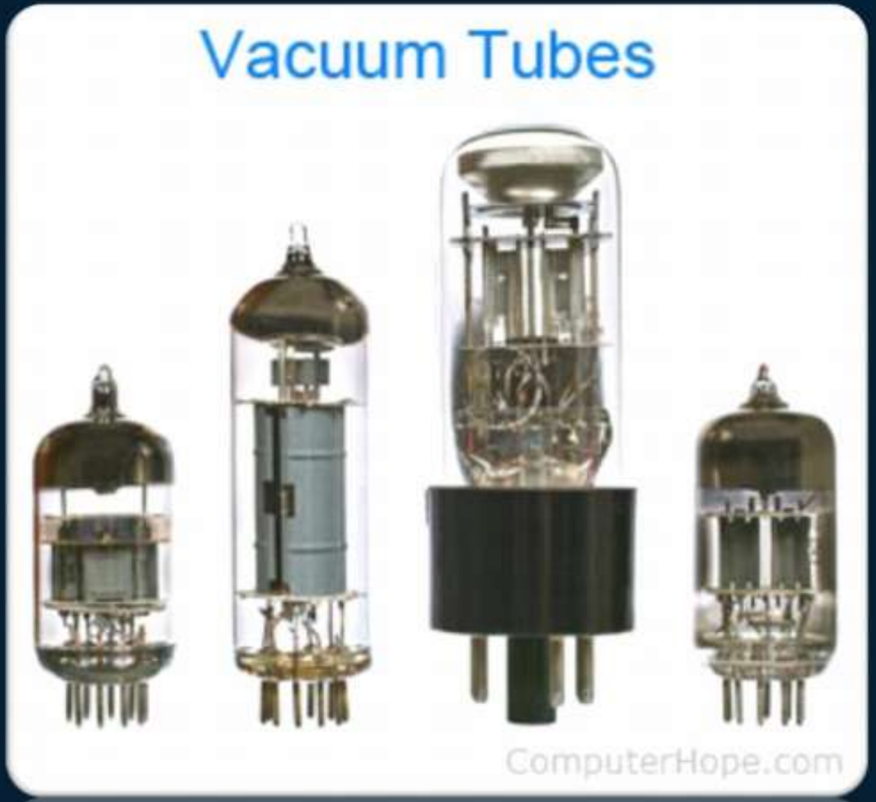




1. Vacuum Tubes

Important features of vacuum tubes:

- In vacuum tubes, electrons are obtained from a heated cathode and the flow of electrons is controlled by varying the voltage between its different electrodes.
- A vacuum is necessary in the interelectrode region so that the electrons may not lose their energy on colliding with air molecules in their path.
- As the electrons can flow only in one direction (from cathode to anode), so vacuum tubes are also known as vacuum valves.
- Bulky and consumes high power & operate at high voltages (= 100V).
- They have limited life and low reliability.

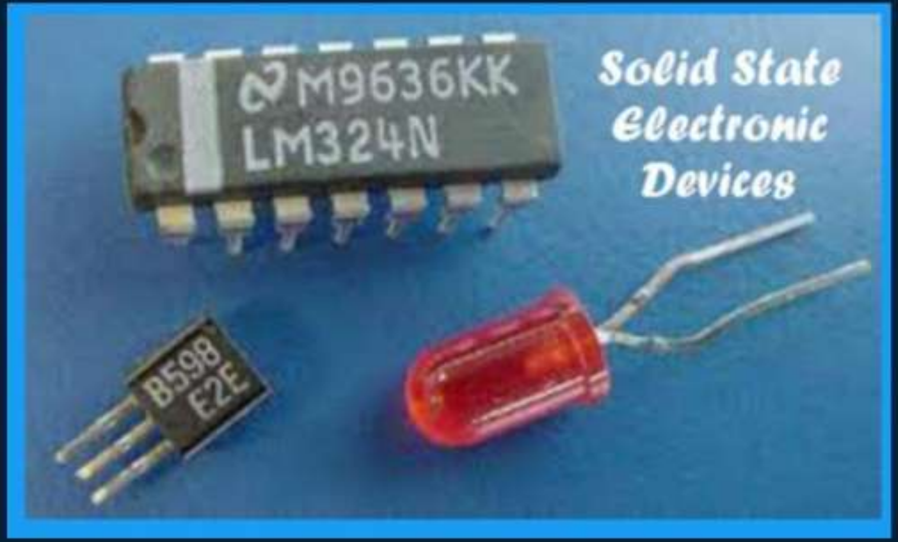


2. Solid State Devices

In 1930's, it was first realised that some solid-state semiconductors and their junctions offer the possibility of controlling the number and direction of flow of charge carriers through them.

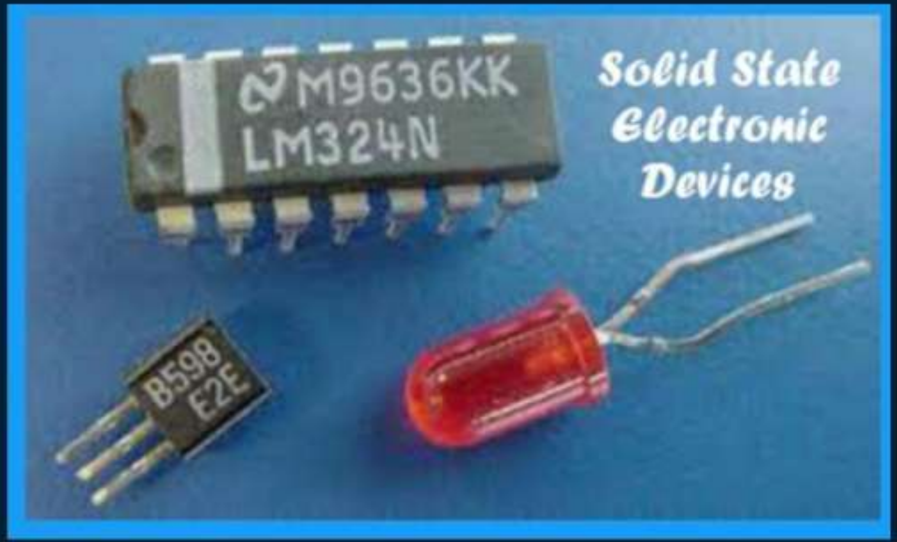
Semiconductors are the basic materials used in the present solid electronic devices like junction diode (a 2-electrode device), transistor (a 3-electrode device) and integrated circuits (ICs).

Transistor discovery in 1948.



Important features of semiconductor devices:

- In a semiconductor device, simple excitations like light, heat or small applied voltage can change the number of charge carriers.
- The charge carriers flow in the solid itself, no vacuum needed for the flow of charges as required in vacuum tubes.
- Semiconductor devices are small in size, consume low power and operate at low voltages.
- It does not require any cathode heating for the production of charge carriers. So it starts operating as soon as it is switched on.
- They have long life and high reliability.



Impact of Solid State Devices

Evan the Cathode Ray Tubes (CRT) used in television and computer monitors which work on the principle of vacuum tubes are being replaced by Liquid Crystal Display (LCD) monitors with supporting solid state electronics.

The miniaturization of various electronic gadgets become possible with the use of semiconductor devices and a continuation of this process led to the discovery of integrated circuits. (IC)

Classification of Solid on the basis of their Conductivity

$\boxed{\sigma = \frac{1}{\rho}}$

On the basis of the relative values of electrical conductivity (σ) or resistivity $\left(\rho = \frac{1}{\sigma}\right)$, the solids are broadly classified as:

1. **Metals** (Low resistivity or high conductivity).

   $\rho = 10^{-2} - 10^{-8}\ \Omega\ m$

   $\sigma = 10^{2} - 10^{8}\ Sm^{-1}$

   $\rho \downarrow \downarrow$

2. **Insulators** (high resistivity or low conductivity)

   $\rho = 10^{11} - 10^{19}\ \Omega m$

   $\sigma = 10^{-11} - 10^{-19}\ Sm^{-1}$

   $\rho \uparrow$

3. **Semiconductors** (resistivity or conductivity intermediate to metals and insulators)

   $\rho = 10^{-5} - 10^{6}\ \Omega m$

   $\sigma = 10^{5} - 10^{-6}\ Sm^{-1}$

   $\rho -$

Note: These values are indicative of magnitude & could well go outside the ranges as well.

Semiconductors

Conductor $T\uparrow \rho\uparrow R\uparrow$

$\alpha \to +$, high $i\downarrow$

$\alpha \to -$, high

$\rho\uparrow$

1. Semiconductors have a much higher resistivity than metals.

$T\uparrow \rho\downarrow R\downarrow i\uparrow$

2. Semiconductors have a temperature coefficient of resistivity (α) that is both negative and high. That is, the resistivity of semiconductors decreases rapidly with temperature, while that of metals increases.
3. Semiconductors have a considerably lower number density n of charge carriers (charge carriers per unit volume) than metals.

$$n\downarrow = \frac{N}{V}\downarrow$$

Classification of Semiconductors

Classification on the basis of their Chemical composition

1. Elemental semiconductors: Si (Silicon) and Ge (Germanium)
2. Compound semiconductors:

   Examples are:

   (i) Inorganic: CdS (Cadmium sulfide), GaAs (Gallium arsenide), CdSe (Cadmium selenide), InP (Indium phosphide) etc.

   (ii) Organic: Polypyrrole, polythiophene, etc.

Note: Most of the currently available semiconductor devices are based on elemental semiconductors Si or Ge and compound inorganic semiconductors.

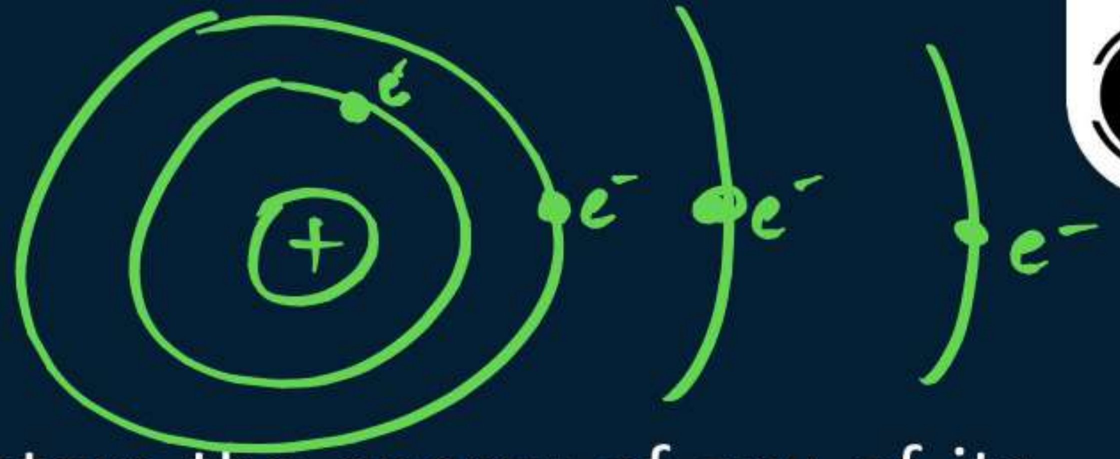
Classification of Semiconductors

Classification on the basis of the source & the nature of charge carriers

1. **Intrinsic semiconductors:** The pure semiconductors (impurity less than 1 part in
10
10[illegible]) are called intrinsic semiconductors.

2. **Extrinsic semiconductors:** The semiconductors obtained by adding or doping the pure semiconductor with small amounts of certain specific impurity atoms having valency different from that of the host atoms.

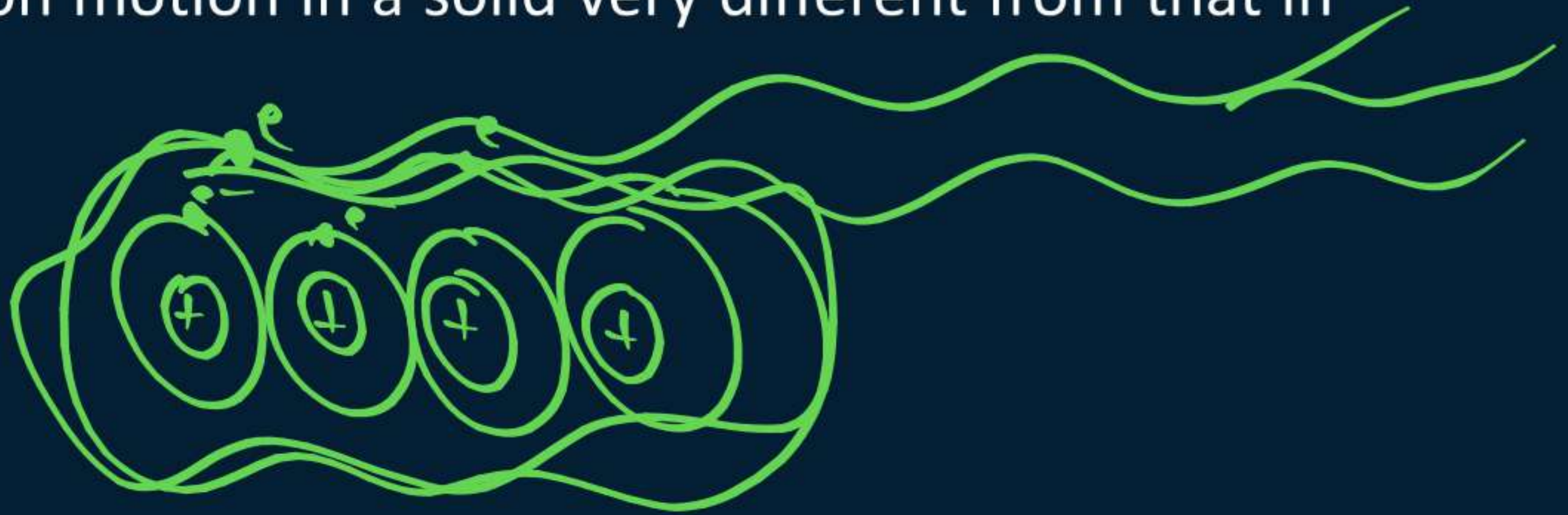
Energy Bands in Solids



According to the Bohr atomic model, in an isolated atom the energy of any of its electrons is decided by the orbit in which it revolves.

But when the atoms come together to form a solid they are close to each other. So the outer orbits of electrons from neighbouring atoms would come very close or could even overlap.

This would make the nature of electron motion in a solid very different from that in an isolated atom



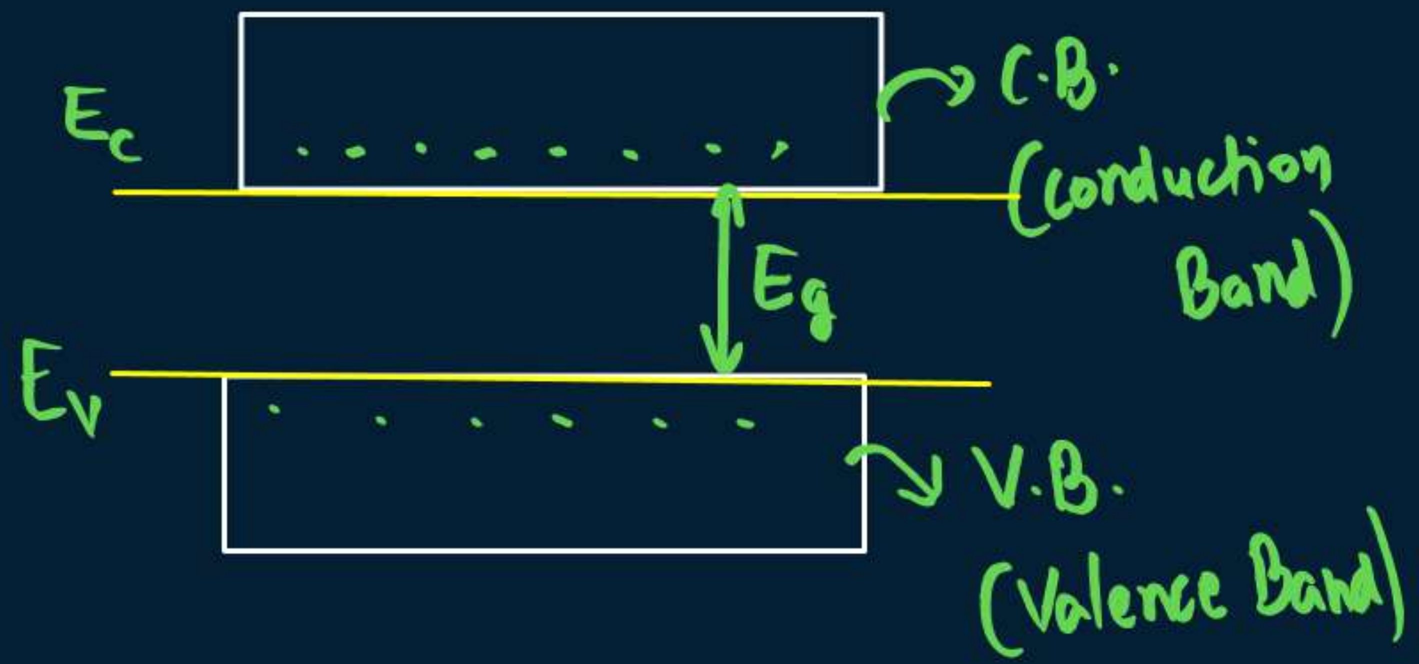
Energy Bands in Solids

- Inside the crystal each electron has a **unique position** and no two electrons see exactly the same pattern of surrounding charges.
- Because of this, each electron will have a different energy level.
- These different energy levels with continuous energy variation form what are called energy bands.

Energy Bands in Solids

- Positions of energy bands in a semiconductor at 0 K are shown in Fig.
- The lowest energy level in the **conduction band** is shown as Ec and highest energy level in the **valence band** is shown as Ev.
- The separation between top of valence band and bottom of conduction band is called **energy band gap (Energy gap Eg)**

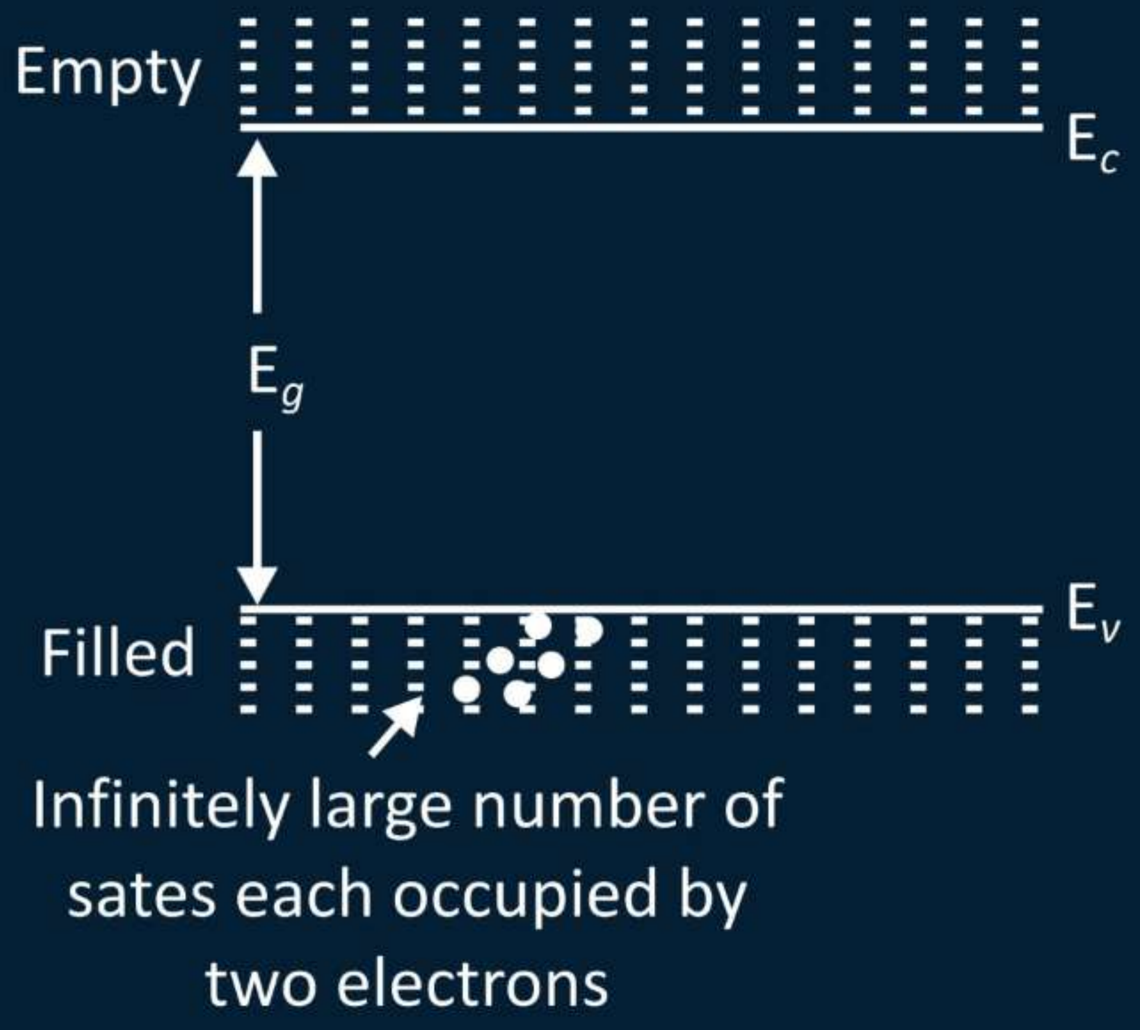
0K



Difference between Valence band, Conduction Band and Energy Band gap

1. **Valence band:** In the energy band diagram of semiconductors, the valence band is a lower band belonging to valence electrons of the given crystal. This band may be partially or completely filled with electrons.

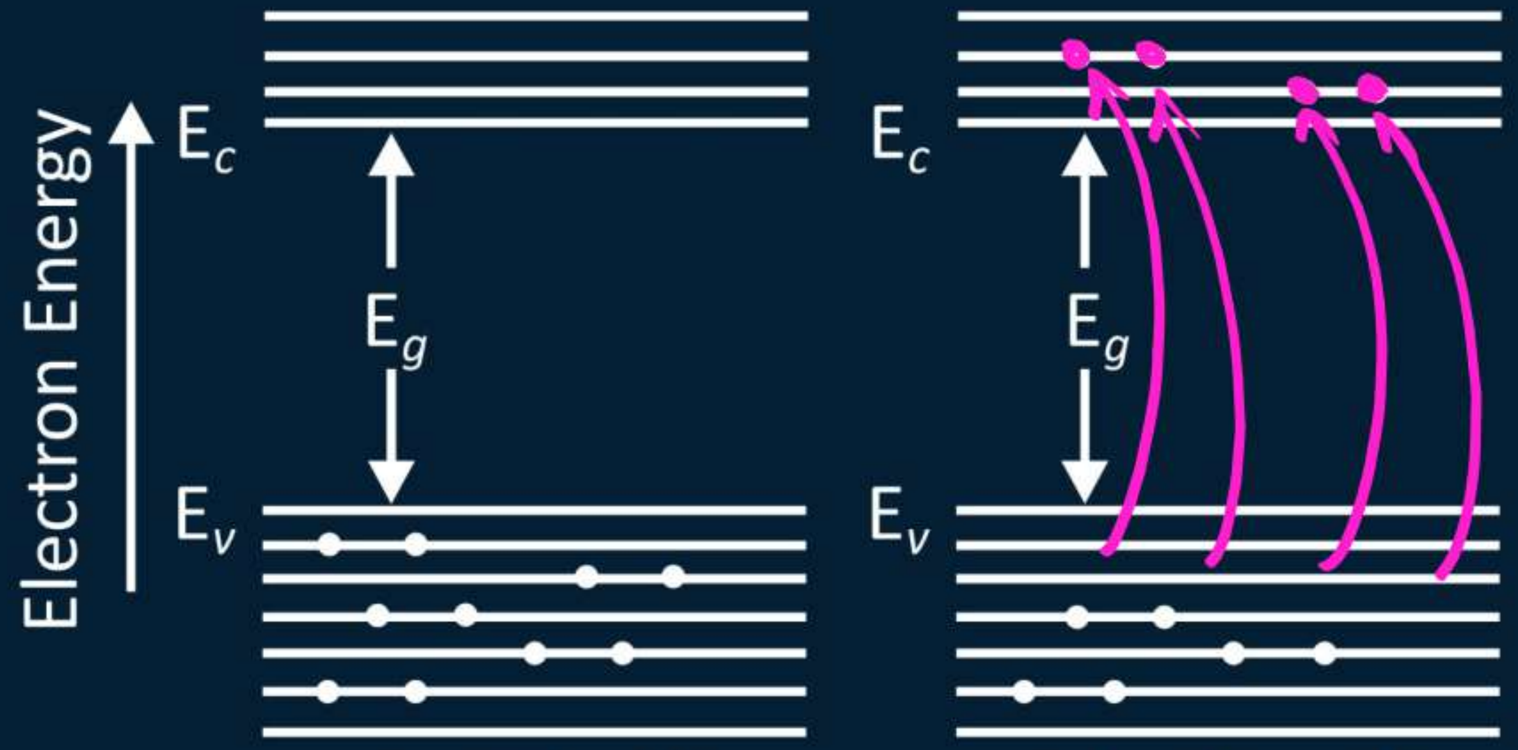
- This band is never empty.
- In this band electrons are not capable of gaining energy from external electric field. Therefore, the electrons in this band do not contribute to the electric current.



2. **Conduction band:** In the energy band diagram of semiconductors, the conduction band is an upper band in which the electrons are not present at $\boxed{0\text{ K}}$. ✓

25°C At room temperature, this band is either empty or partially filled with electrons.

In this band, electrons can gain energy from external electric field and contribute to the electric current.



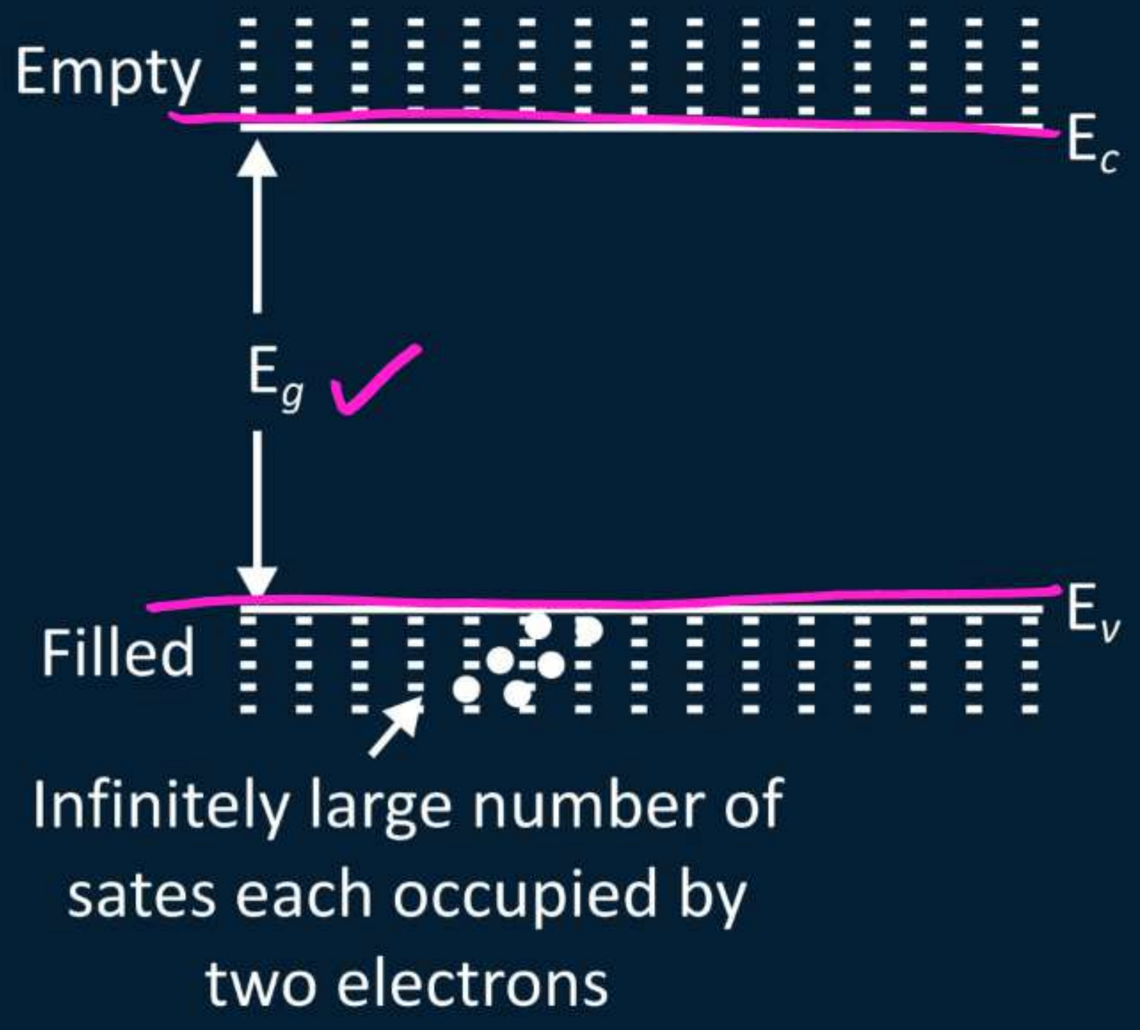
(i) at T = 0K
(behaves like insulator)

(ii) at T > 0K

3. **Energy band gap (i.e. energy gap):** In the energy band diagram, energy band gap is the separation between highest energy level of valence band and lowest energy level in conduction band. Electrons are not found in this band. This band is completely empty.

The minimum energy required for shifting electrons from valence band to conduction band is called energy band gap (Eg).

$$\boxed{E_g = E_c - E_v}$$



Distinction b/w Metals, Insulators and Semiconductors on the basis of Band Theory

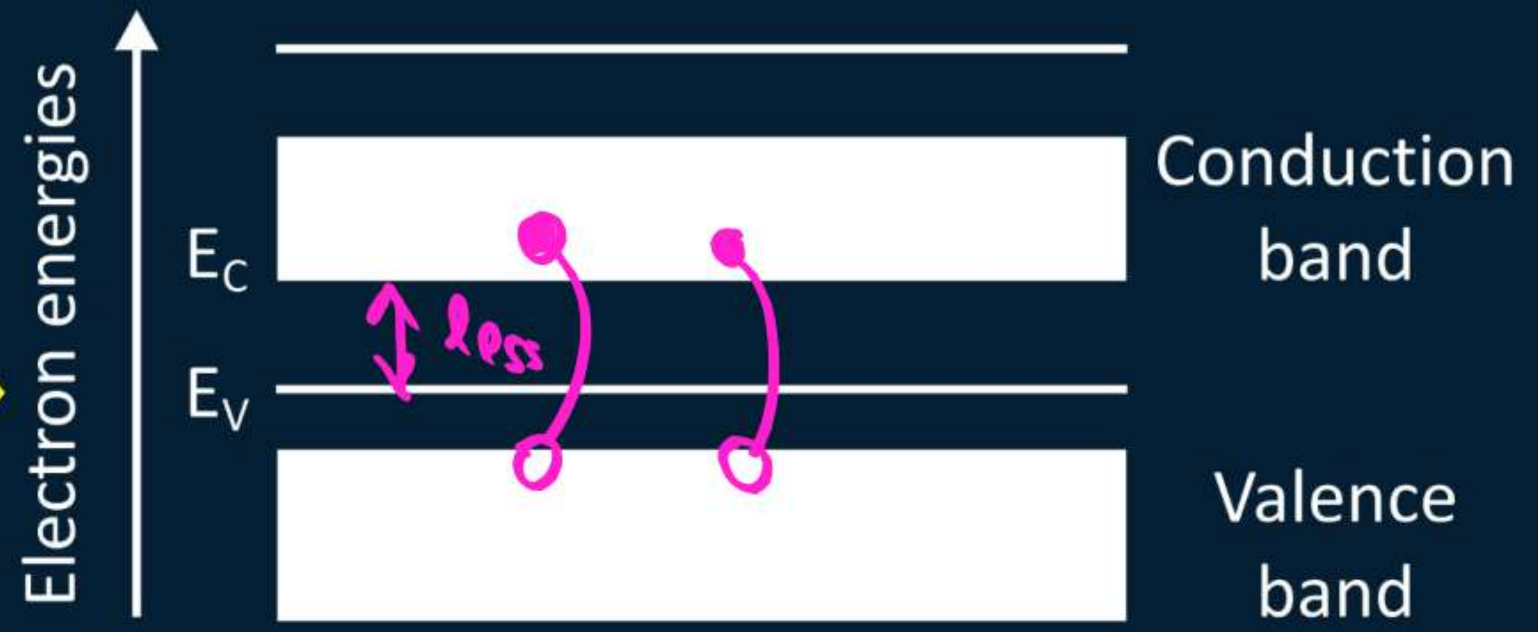
METALS

There are two cases:

Case I: When the conduction band is partially filled and the Valance band is partially empty.

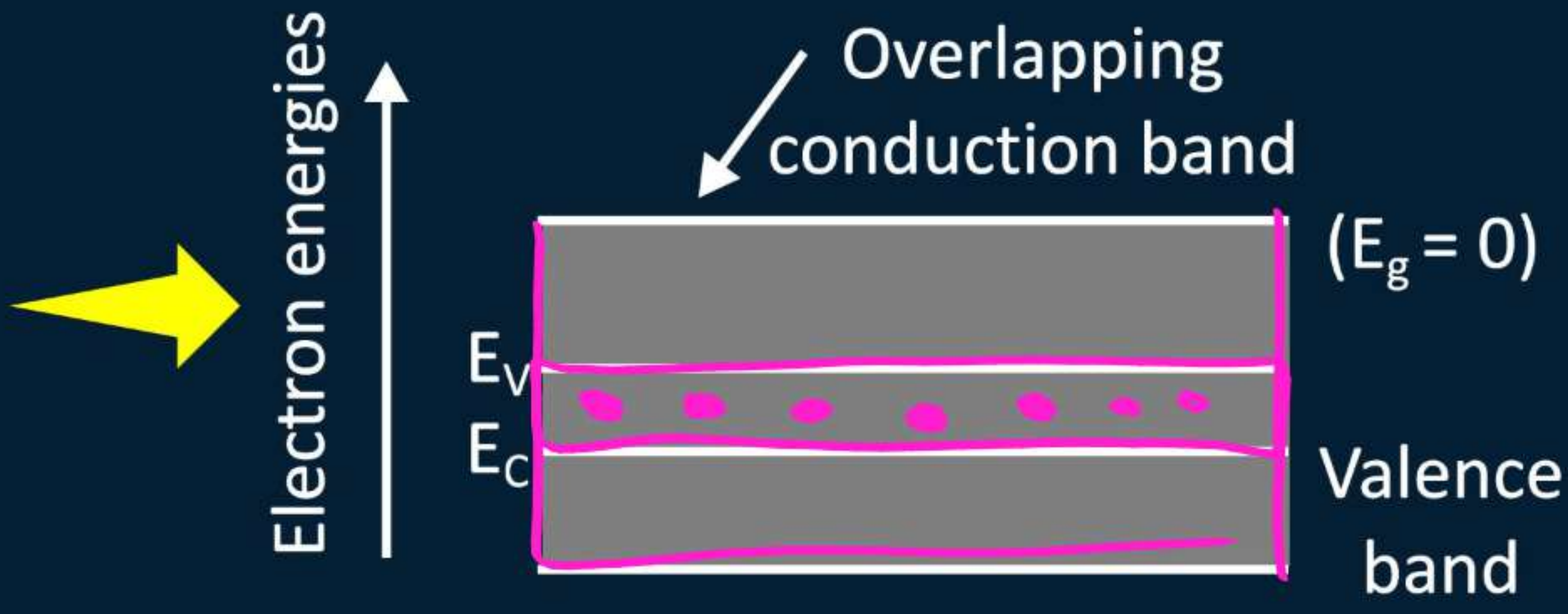
(When the valence band is partially empty, electrons from its lower level can move to higher level making conduction possible. Therefore, the resistance of such materials is low or the conductivity is high)

$\rho \downarrow \sigma \uparrow$



Case II: When the conduction bands overlaps with valence band.

(When there is overlap electrons from valence band can easily move into the conduction band. This situation makes a large number of electrons available for electrical conduction)



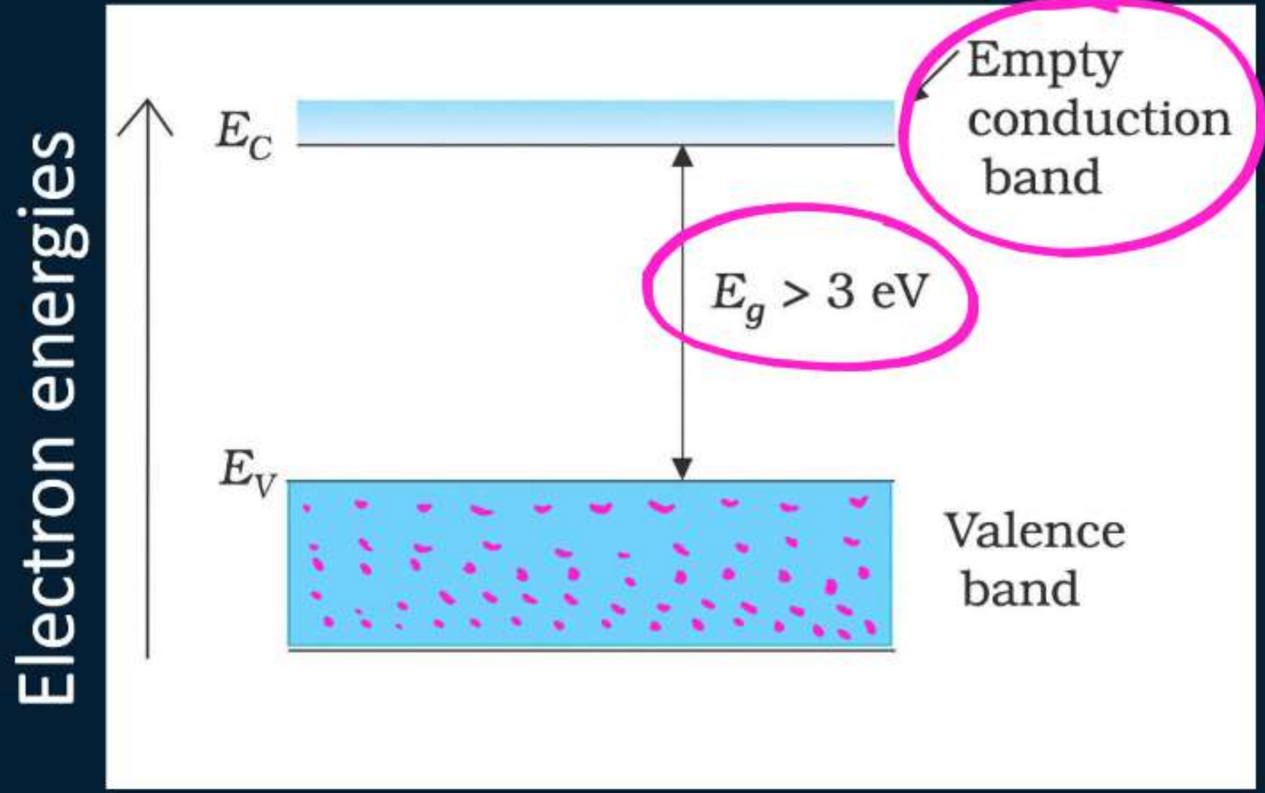
Insulators on the basis of Band Theory

INSULATORS

In this case, as shown in Fig., a large band gap Eg exists ($Eg > 3\ eV$). There are no electrons in the conduction band, and therefore no electrical conduction is possible.

Note that the energy gap is so large that electrons cannot be excited from the valence band to the conduction band by thermal excitation. This is the case of insulators.

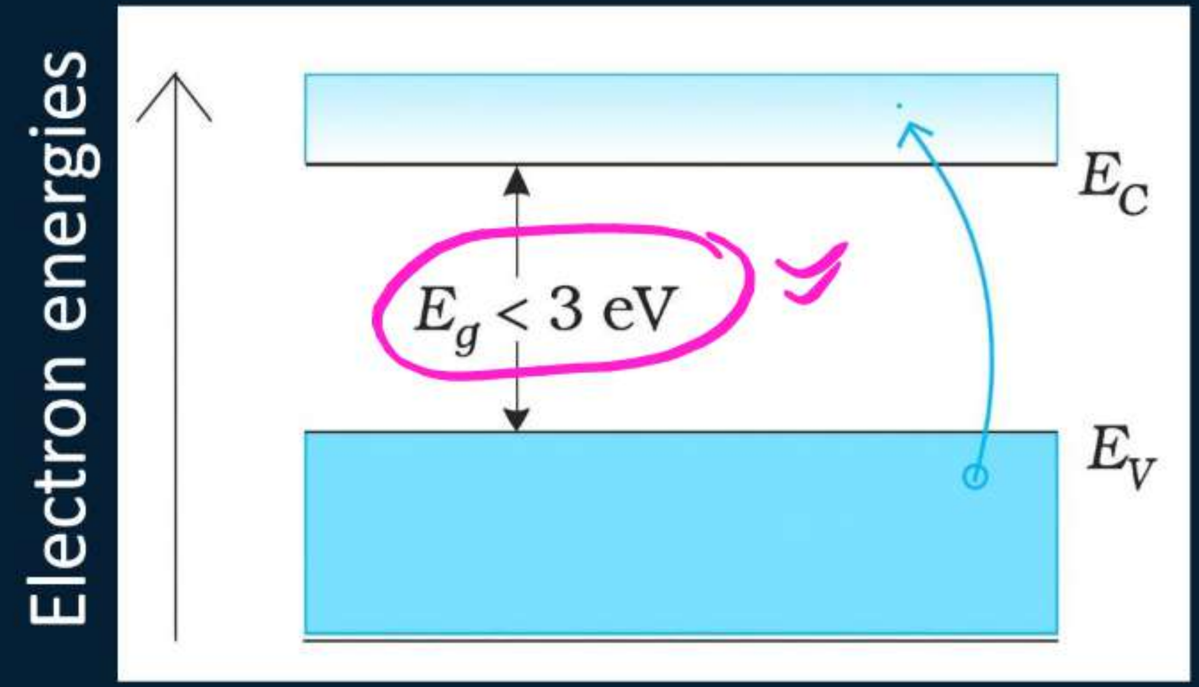
For example, in case of diamond, the energy gap is of 6 eV.



Semiconductors on the basis of Band Theory

SEMICONDUCTORS

This situation is shown in Fig.. Here a finite but small band gap (Eg < 3 eV) exists. Because of the small band gap, at room temperature some electrons from valence band can acquire enough energy to cross the energy gap and enter the conduction band. These electrons (though small in numbers) can move in the conduction band. Hence, the resistance of semiconductors is not as high as that of the insulators.



For example

the energy gap for $\boxed{\text{germanium is of 0.72 eV}}$ & for $\boxed{\text{silicon it is of 1.1 eV.}}$ At zero kelvin temperature, electrons are not able to cross even this small energy gap and hence the conduction band remains totally empty.

Therefore, the semiconductor at zero kelvin behaves as insulator

Classification of Semiconductors

Classification on the basis of the source and the nature of charge carriers

1. **Intrinsic semiconductors**: The pure semiconductors (impurity less than 1 part in 1010) are called intrinsic semiconductors.
2. **Extrinsic semiconductors**: The semiconductors obtained by adding or doping the pure semiconductor with small amounts of certain specific impurity atoms having valency different from that of the host atoms.

Intrinsic Semiconductors

The term intrinsic semiconductor refers to a pure semiconductor whose conductivity is due to the presence of intrinsic charge carriers **(electrons and holes)** and not due to any impurity or foreign atoms.

Example: Ge or Si

⇒ **Charge carriers**

(i) electrons

(ii) holes

Explanation of Semiconductor

Valence bond model

Covalent

Energy bond model

Valence Bond Model for Intrinsic Semiconductors

Si → 4e⁻
Ge → 4e⁻
} Sharing

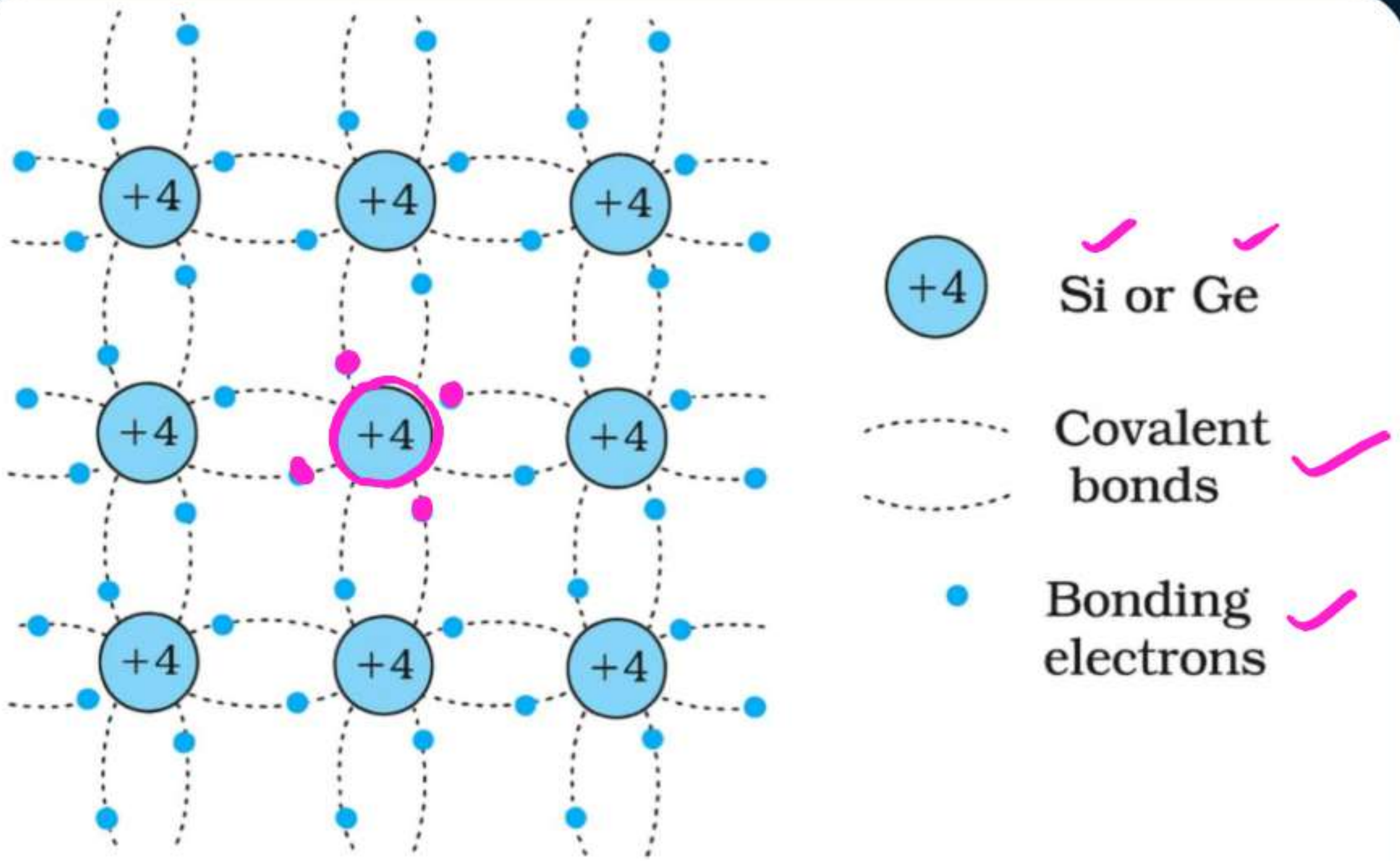
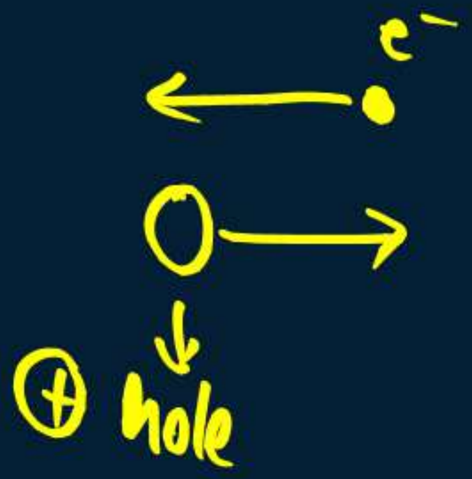
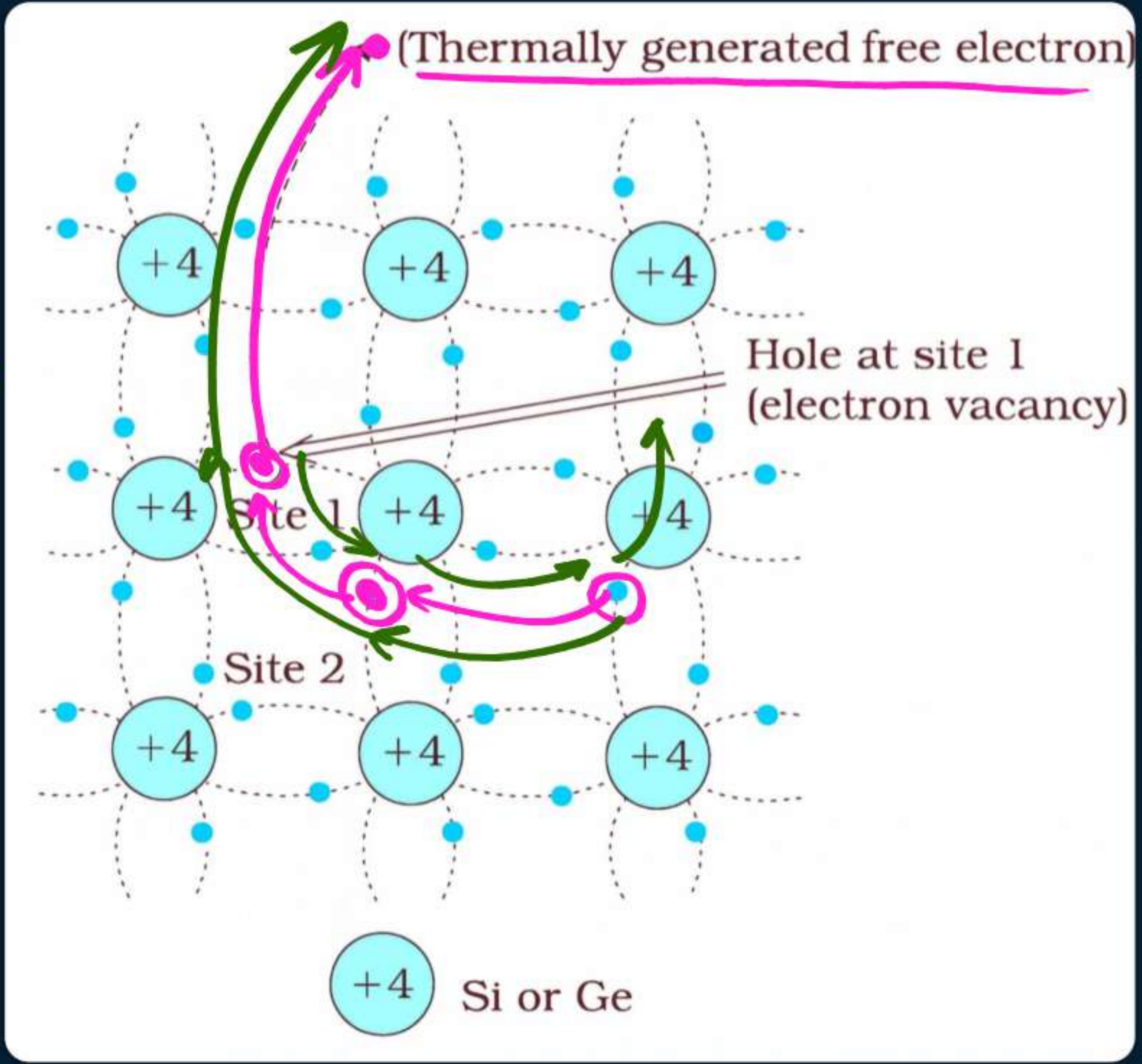


FIGURE Schematic two-dimensional representation of Si or Ge structure showing covalent bonds at low temperature (all bonds intact). +4 symbol indicates inner cores of Si or Ge.

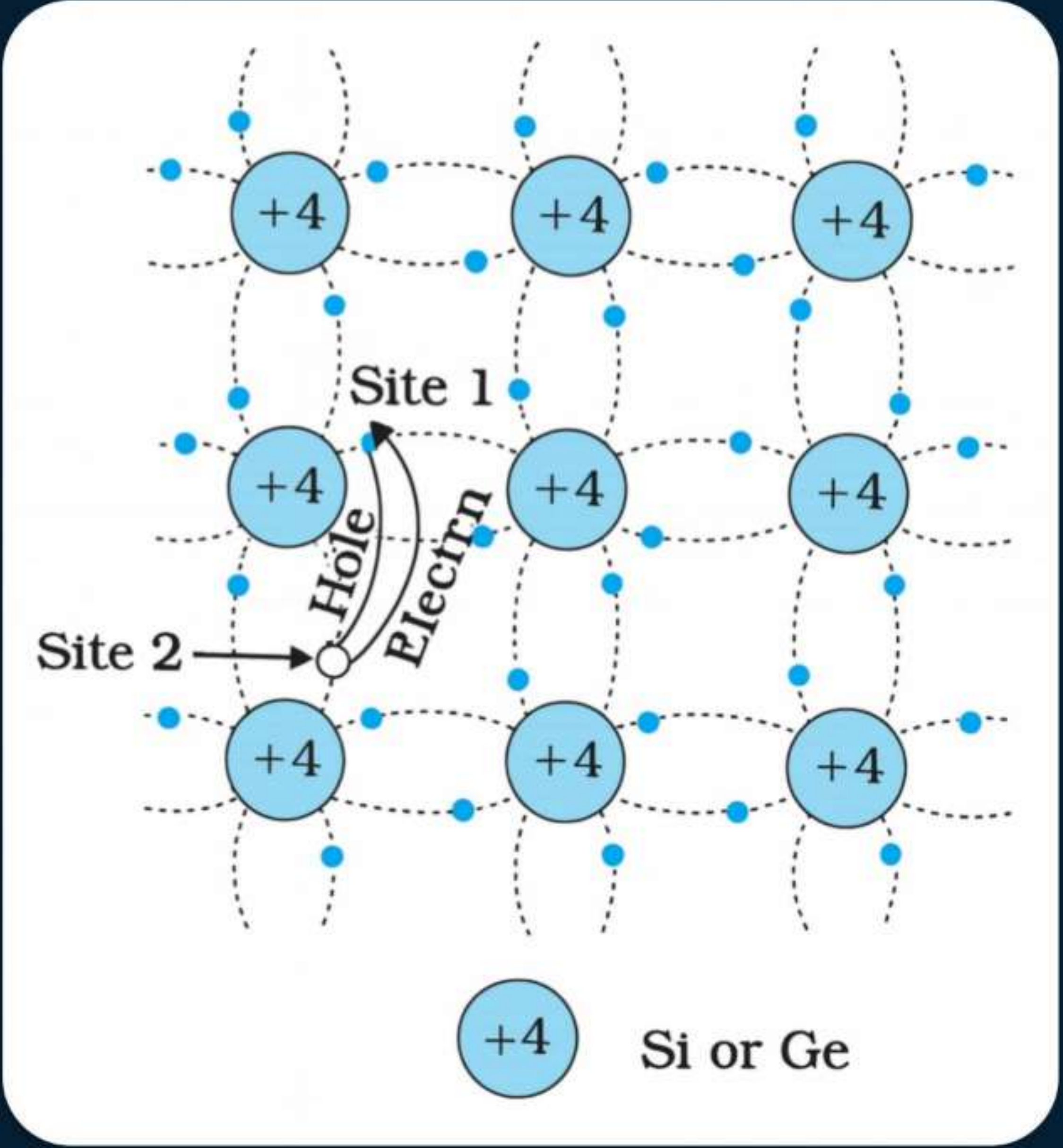
Valence Bond Model for Intrinsic Semiconductors

The neighbourhood, from which the free electron (with charge $-q$) has come out leaves a vacancy with an effective charge ($+q$). This vacancy with the effective positive electronic charge is called a **hole.** The hole behaves as an apparent free particle with effective positive charge.





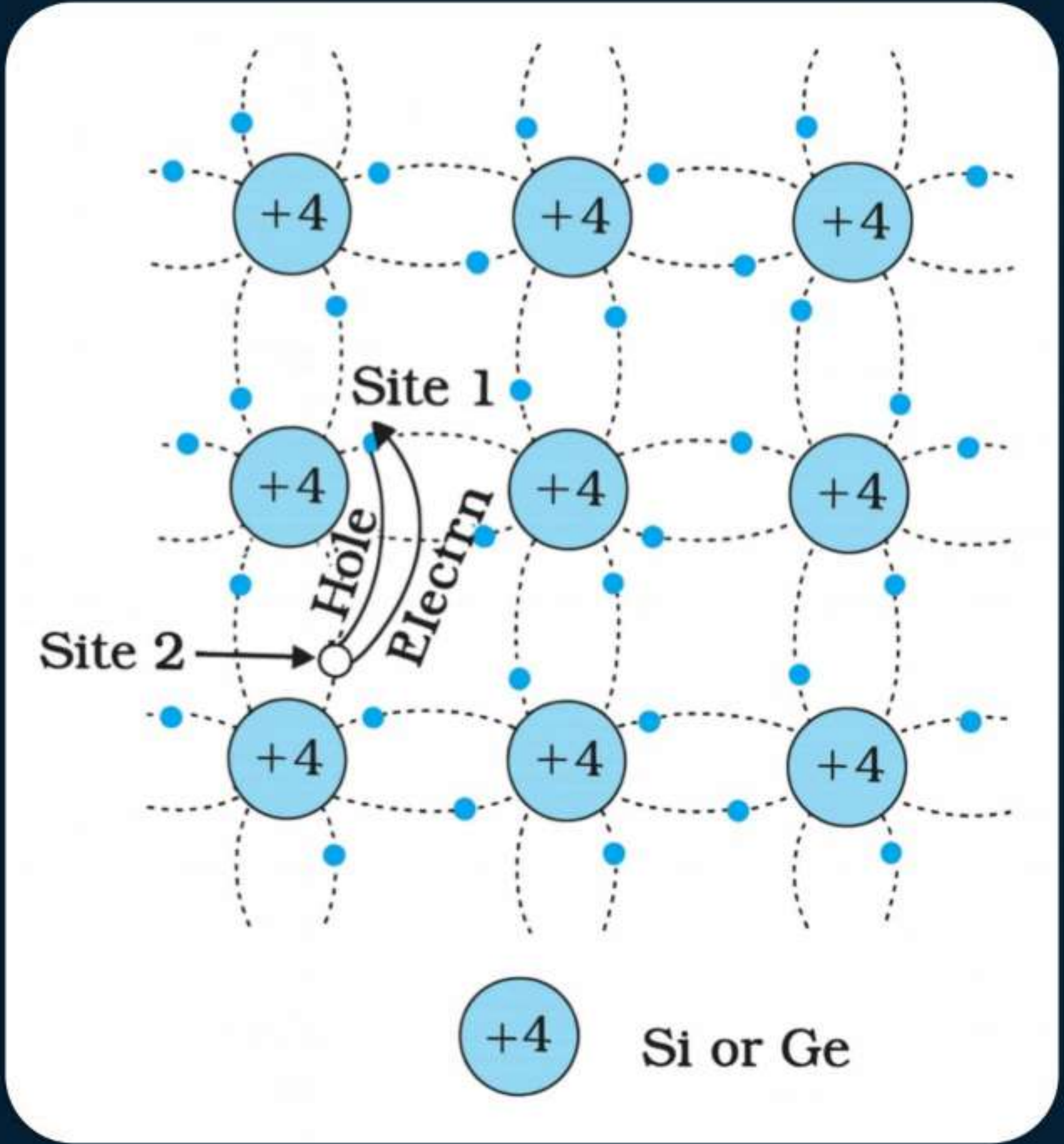
Movement of Holes



Total Current in Intrinsic Semiconductor

$$\boxed{n_e = n_h = n_i}$$

$$\boxed{I_{total} = I_e + I_h}$$



No. of free electrons (ne) at Absolute Temperature T

$$n_e = Ce^{-E_g/2kT}$$

K = Boltzman constant

E_g = Ionization energy

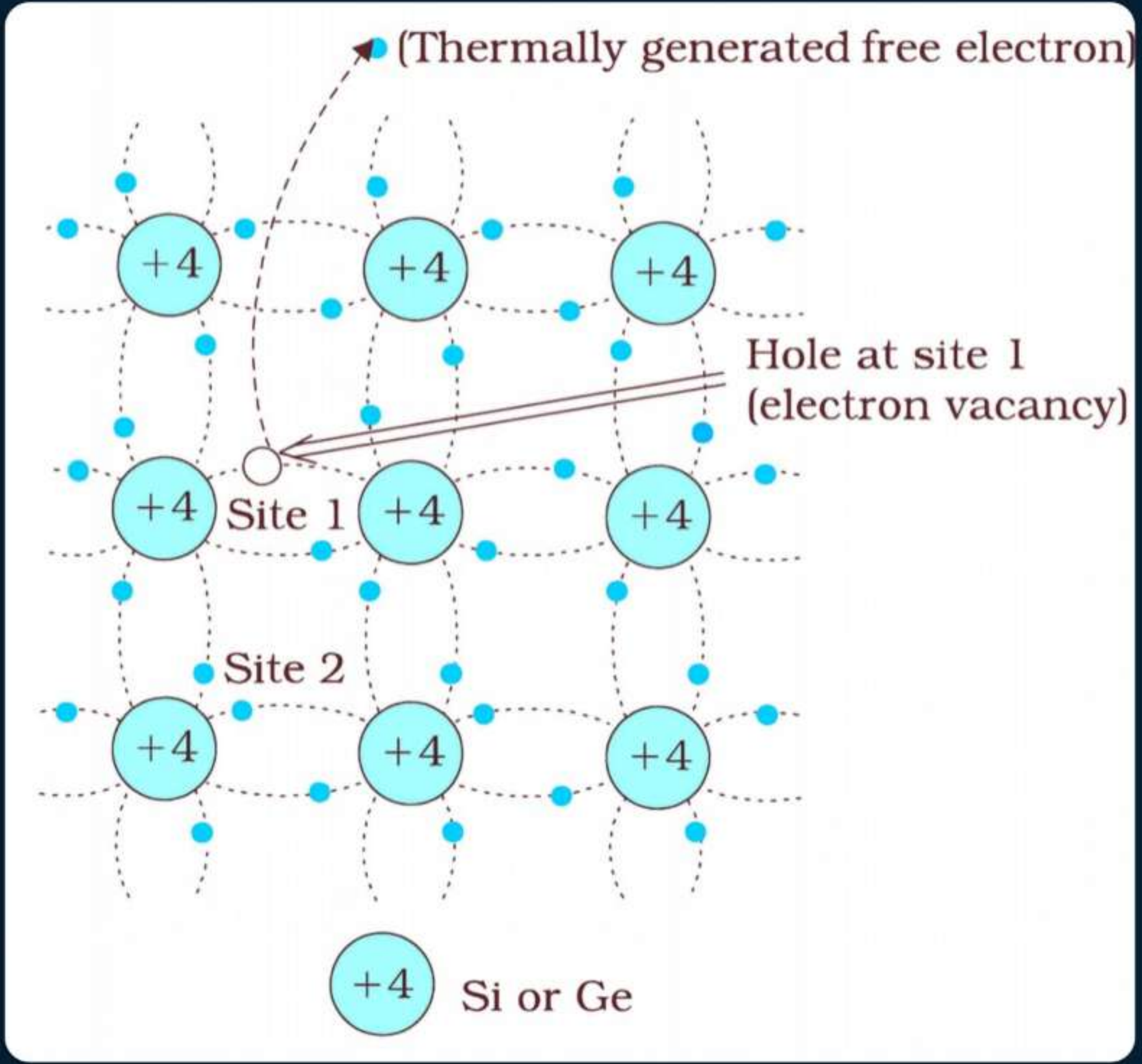
T = Absolute temperature

$n_e = n_h = n_i$

n_e = no. density of free electrons

n_h = no. density of holes

n_i = intrinsic charge carrier concentration

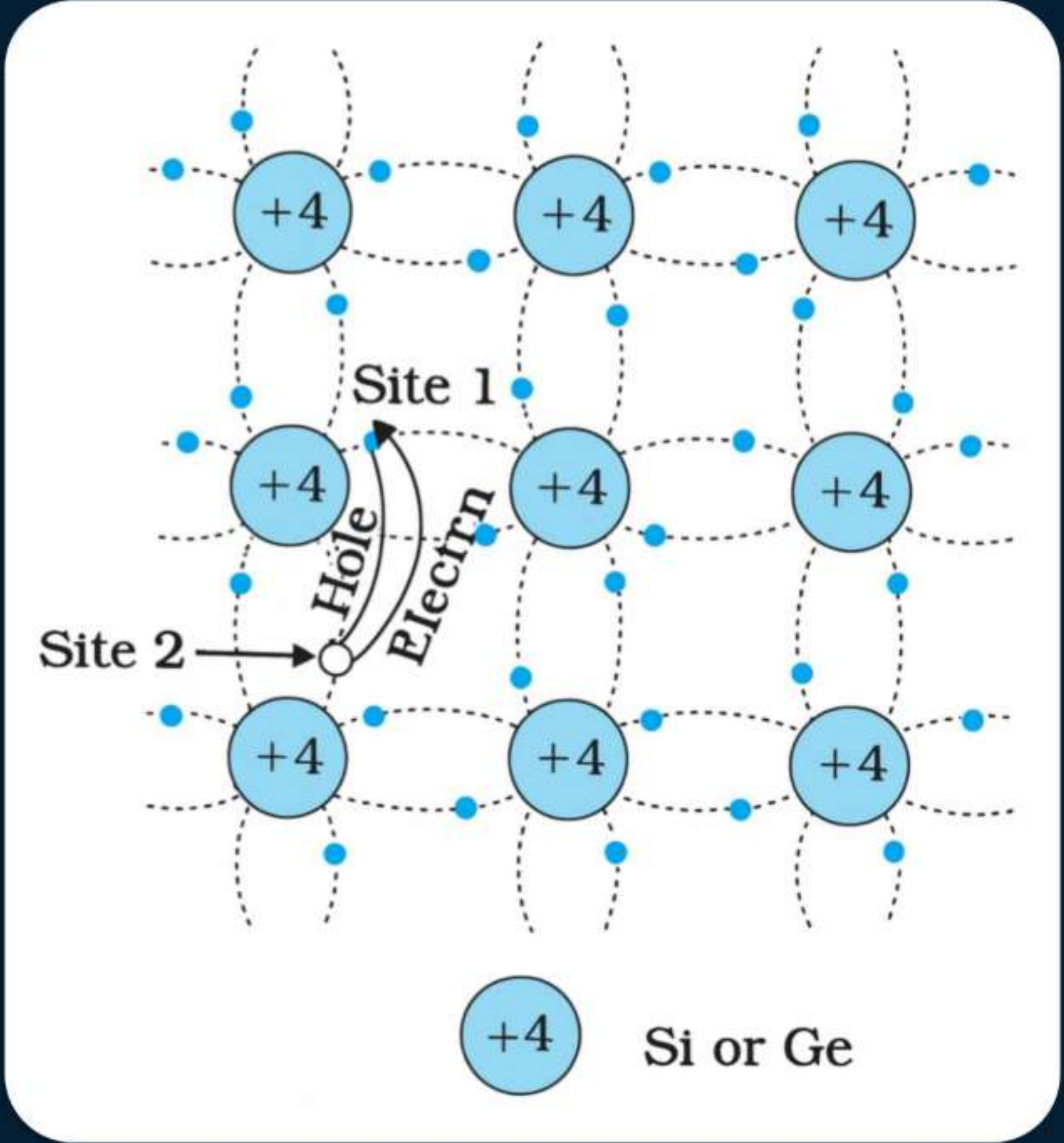


Holes

The vacancy or absence of an electron in the bond of a covalently bonded crystal is called a hole.

Remember that the motion of hole is only a convenient way of describing the actual motion of bound electrons,

whenever there is an empty bond anywhere in the crystal. Under the action of an electric field, these holes move towards negative potential giving the hole current, I_h.



Holes

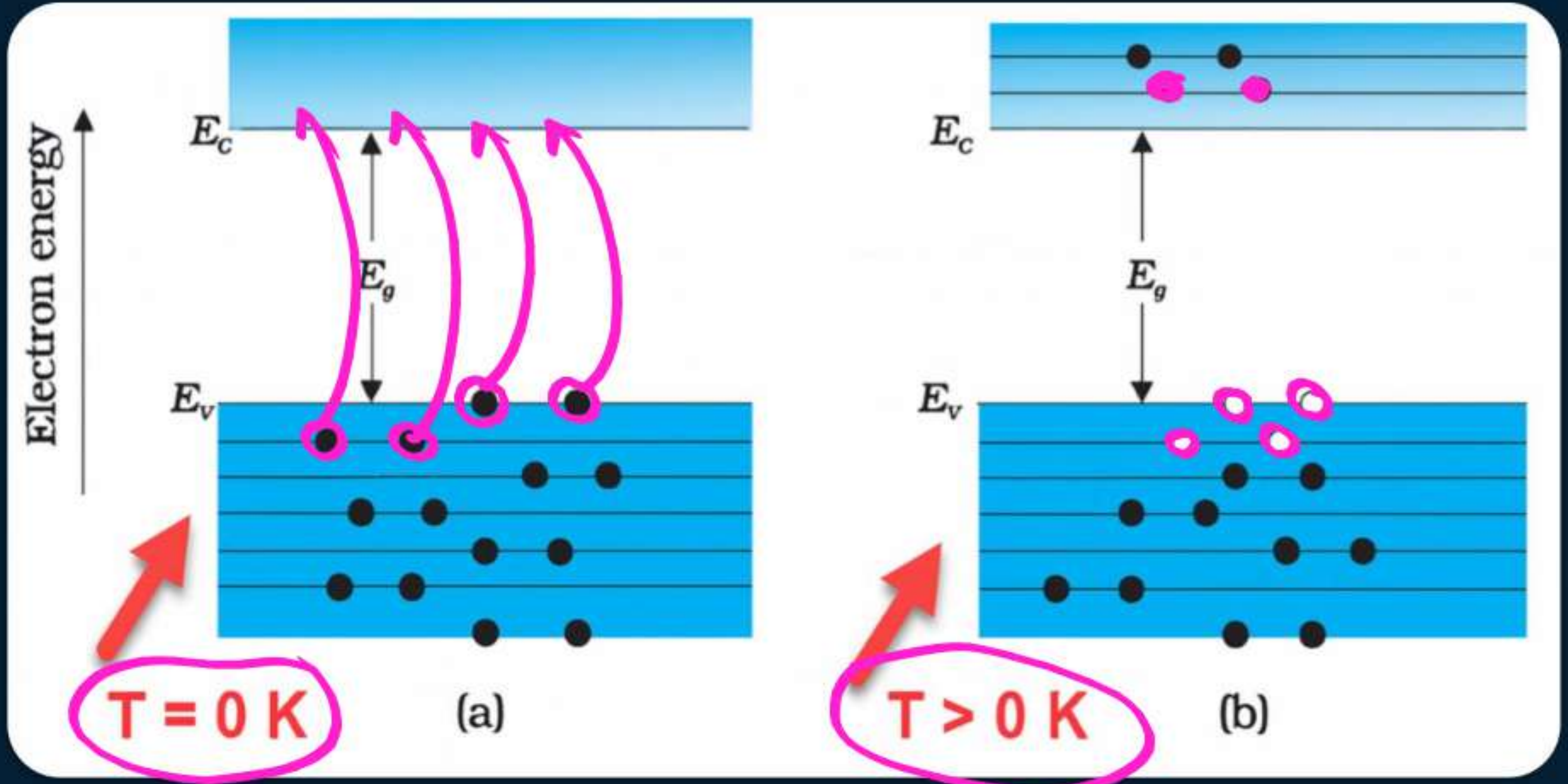
Characteristics of holes:

- A hole is just a vacancy created by removal of an electron from a covalent bond of semiconductor.
- It has the same mass as the removed electron.
- It is associated with the positive charge of magnitude *e*.
- The energy of hole is higher, the farther below it is from

Intrinsic Semi-Conductors on Energy Band Theory

An intrinsic semiconductor will behave like an insulator at T = 0 K as shown in Fig. (a).

It is the thermal energy at higher temperatures (T > 0K), which excites some electrons from the valence band to the conduction band. These thermally excited electrons at T > 0 K, partially occupy the conduction band.



Therefore, the energy-band diagram of an intrinsic semiconductor will be as shown in Fig. (b). Here, some electrons are shown in the conduction band. These have come from the valence band leaving equal number of holes there.

Intrinsic Semi-Conductors

$\rightarrow$ Ge
$\rightarrow$ Si

Important points (Intrinsic Semi- Conductors)

1. In an intrinsic semiconductor
   (i) there are two types of current carriers (i.e., free electrons and holes)
   (ii) number of electrons is equal to number of holes.

$$n_e = n_h$$

2. An intrinsic semiconductor is electrical neutral as a whole.
3. In a semiconductor the total current is due to the movement of both the free electrons and holes, whereas in a metal conductor the current is due to flow of electrons only.

Limitations of Intrinsic (pure) Semi-Conductors

Limitations of developing pure semiconductor

1. Intrinsic semiconductors have low intrinsic charge carrier concentration (of hole and electrons) as $10^6\ m^{-3}$. So they have low electrical conductivity.
2. As intrinsic charge carriers are always thermally generated, so flexibility is not available to control their number.
3. For intrinsic semiconductors, $\boxed{n_e = n_h}$. They cannot have predominant hole or electron conduction. This puts a limit to the usefulness of such materials.

$n_e = n_h$

Need to improve intrinsic Semiconductors

Looking into the Limitations of an Intrinsic Semiconductors, no important electronic devices can be developed using their conductivity.

Hence there is a necessity of improving their conductivity. This can be done by making use of impurities.

Extrinsic Semi - Conductors

Semiconductors

Intrinsic Semiconductors
(Pure Semiconductors)
Ex. Si, Ge etc

Extrinsic Semiconductors
(Impure Semiconductors)
Doped Semiconductor

Tri → 3 – 'Al'
Tetra – 4 – 'Si'
Penta – 5 – 'P'

p-type Semiconductors
Tetravalent Si or Ge +
Trivalent Valency 3 like
Indium (In) , Boron (B), Aluminium (Al)

n-type Semiconductors
Tetravalent Si or Ge +
Pentavalent Valency 5 like
Arsenic (As), Antimony (Sb), Phosphorous (P)

Doping

Dopant

Doped

Doping

The dopant has to be such that it does not distort the original pure semiconductor lattice. It occupies only a very few of the original semiconductor atom sites in the crystal. A necessary condition to attain this is that the sizes of the dopant and the semiconductor atoms should be nearly the same.	The deliberate addition of a desirable impurity is called doping and the impurity atoms are called dopants. Such a material is also called a doped semiconductor. 13 14 15 Al Si P	When a small amount, say, a few parts per million (ppm), of a suitable impurity is added to the pure semiconductor, the conductivity of the semiconductor is increased manifold. Such materials are known as extrinsic semiconductors or impurity semiconductors.

Extrinsic Semi-Conductors

A doped semiconductor or a semiconductor with suitable impurity atom added to it, is called extrinsic semiconductor.

There are two types of dopants used in doping the tetravalent Si or Ge:

i. Pentavalent (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.

ii. Trivalent (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.

Imp points: Extrinsic Semi-Conductors

13	14	15
B	C	N
Al	$\boxed{\text{Si}}$	P
Ga	$\boxed{\text{Ge}}$	As
In	Sn	Sb
Tl	Pb	Bi

Extrinsic semi conductors are of two types:

i. *n*-type semiconductors

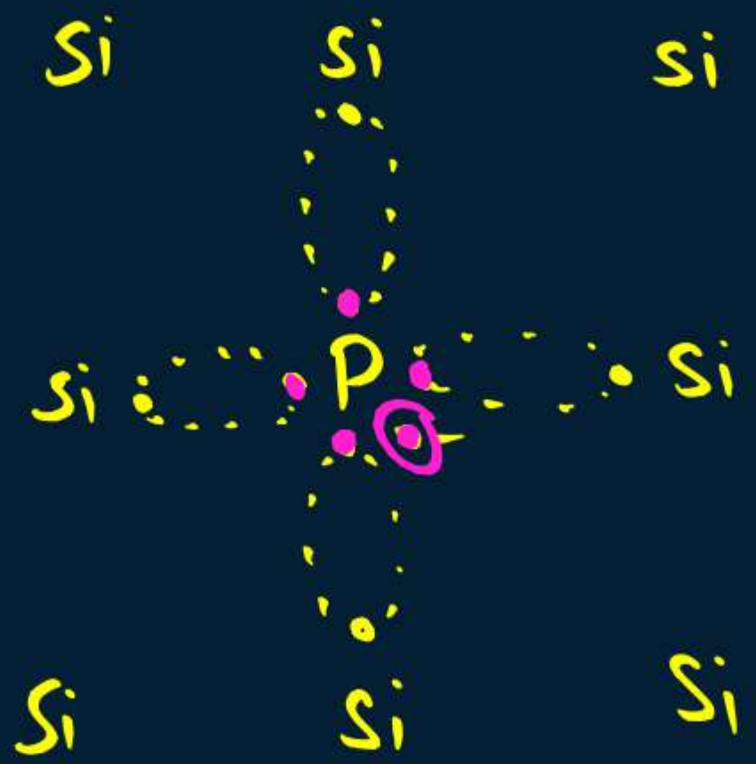
ii. *p*-type semiconductors

Si or Ge belongs to the fourth group in the Periodic table and, therefore, we choose the dopant element from nearby fifth or third group, expecting and taking care that the size of the dopant atom is nearly the same as that of Si or Ge.

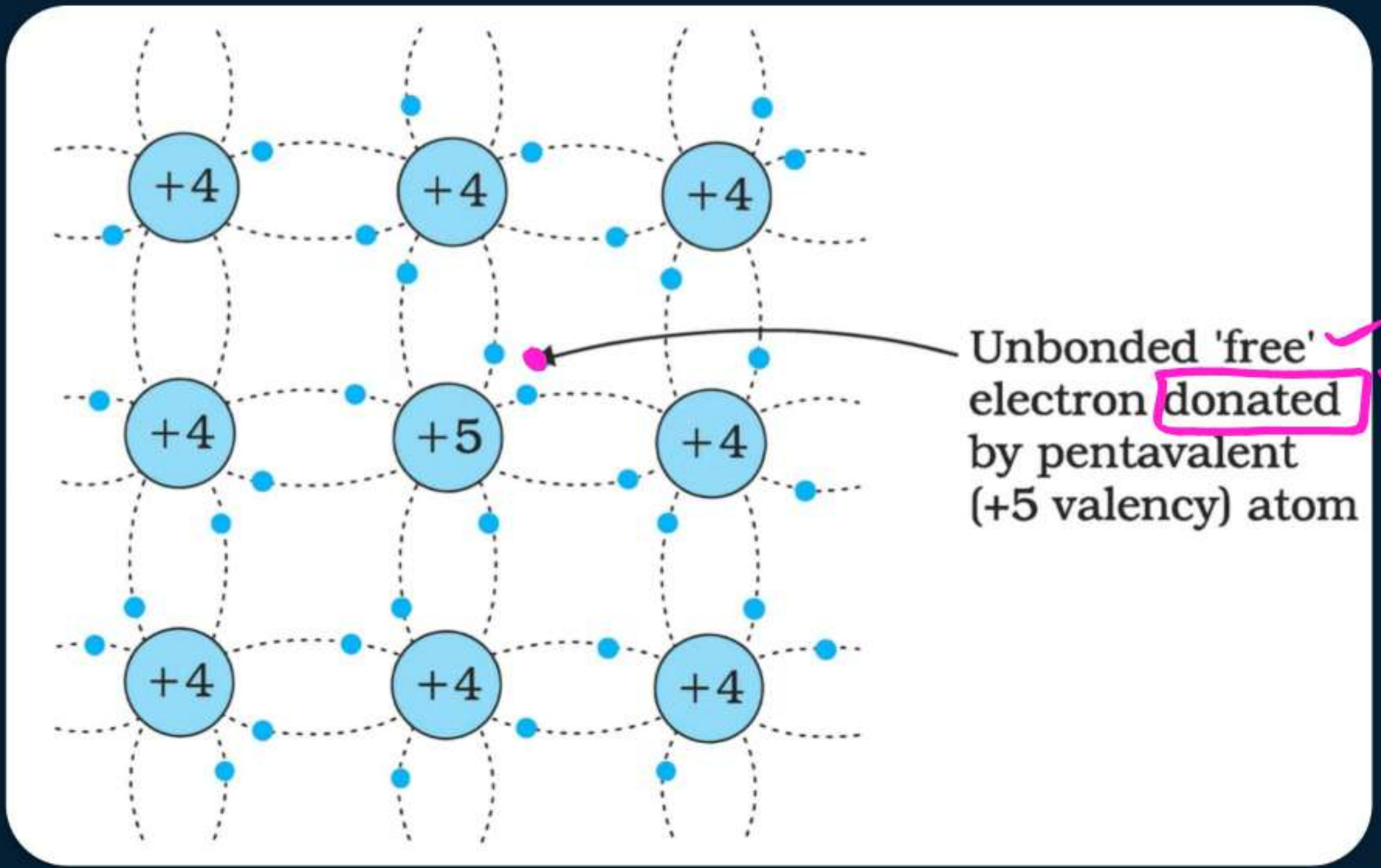
Interestingly, the pentavalent and trivalent dopants in Si or Ge give two entirely different types of semiconductors as discussed below.

Extrinsic Semi-Conductors: n-type (Valence Bond explanation)

(i) n-type semiconductor. (Valence Bond explanation)

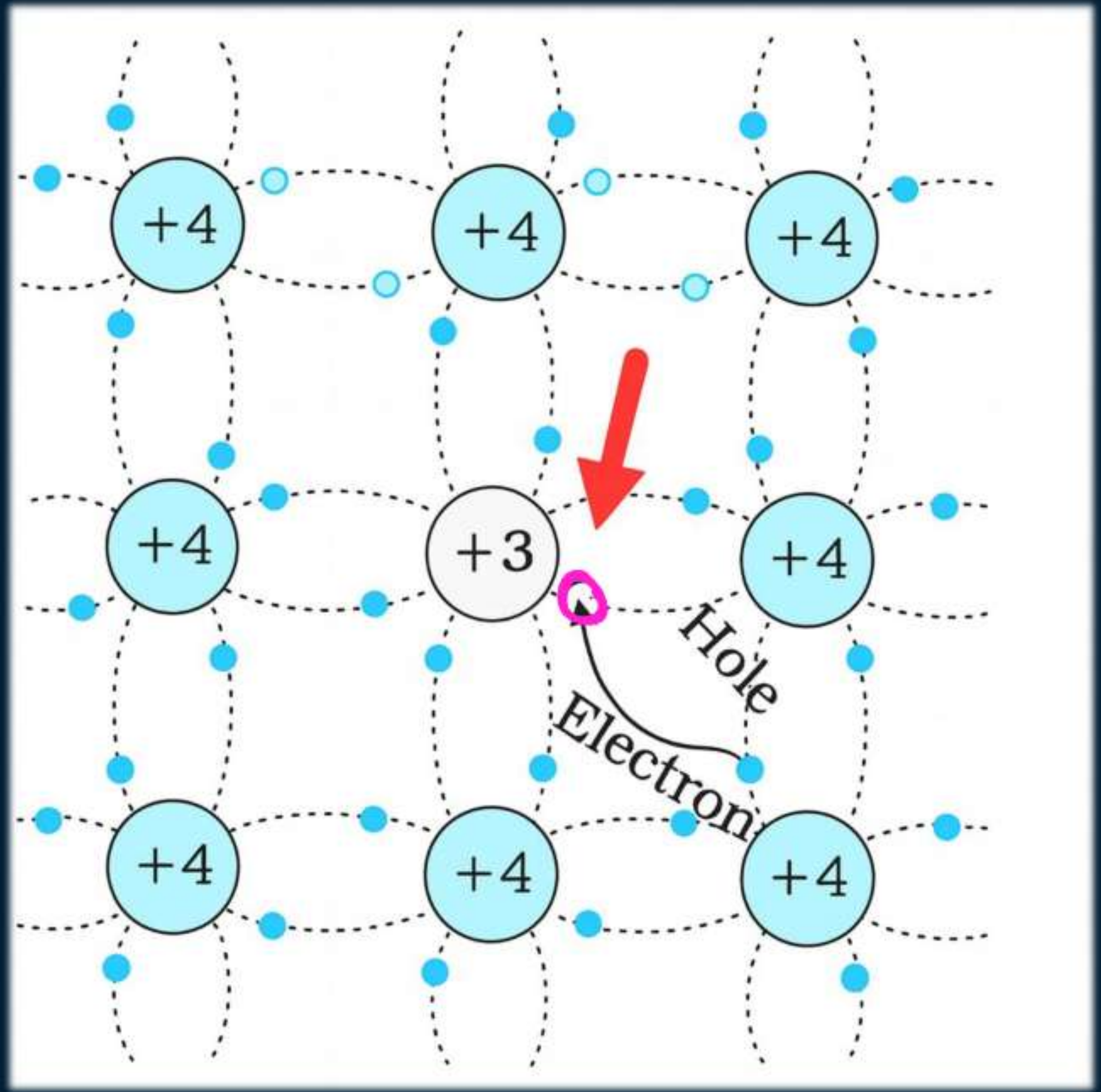


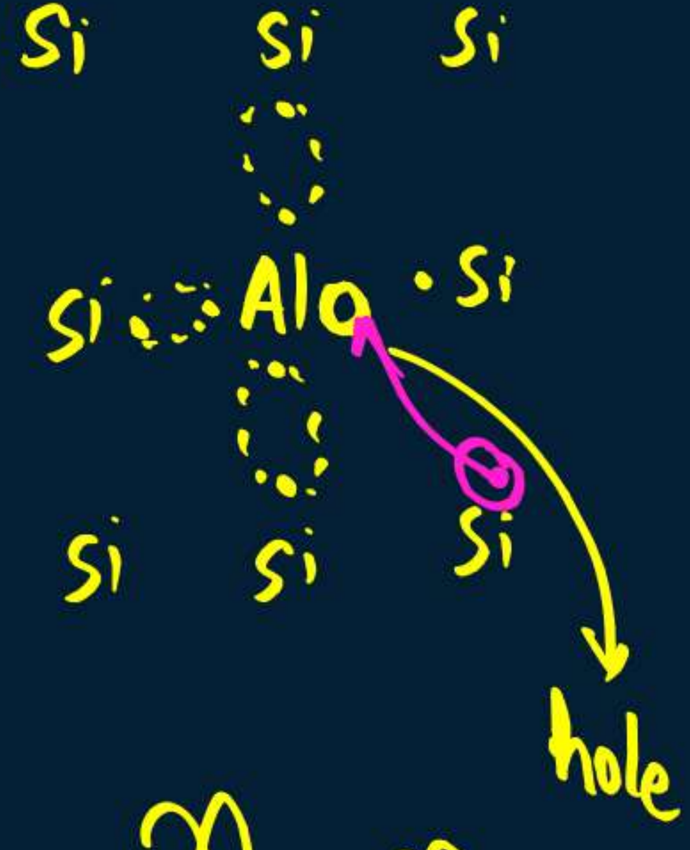
$$n_e > n_h$$



Extrinsic Semi-Conductors: p-type (Valence Bond explanation)

(ii) p-type Semiconductor. (Valence Bond Explanation)



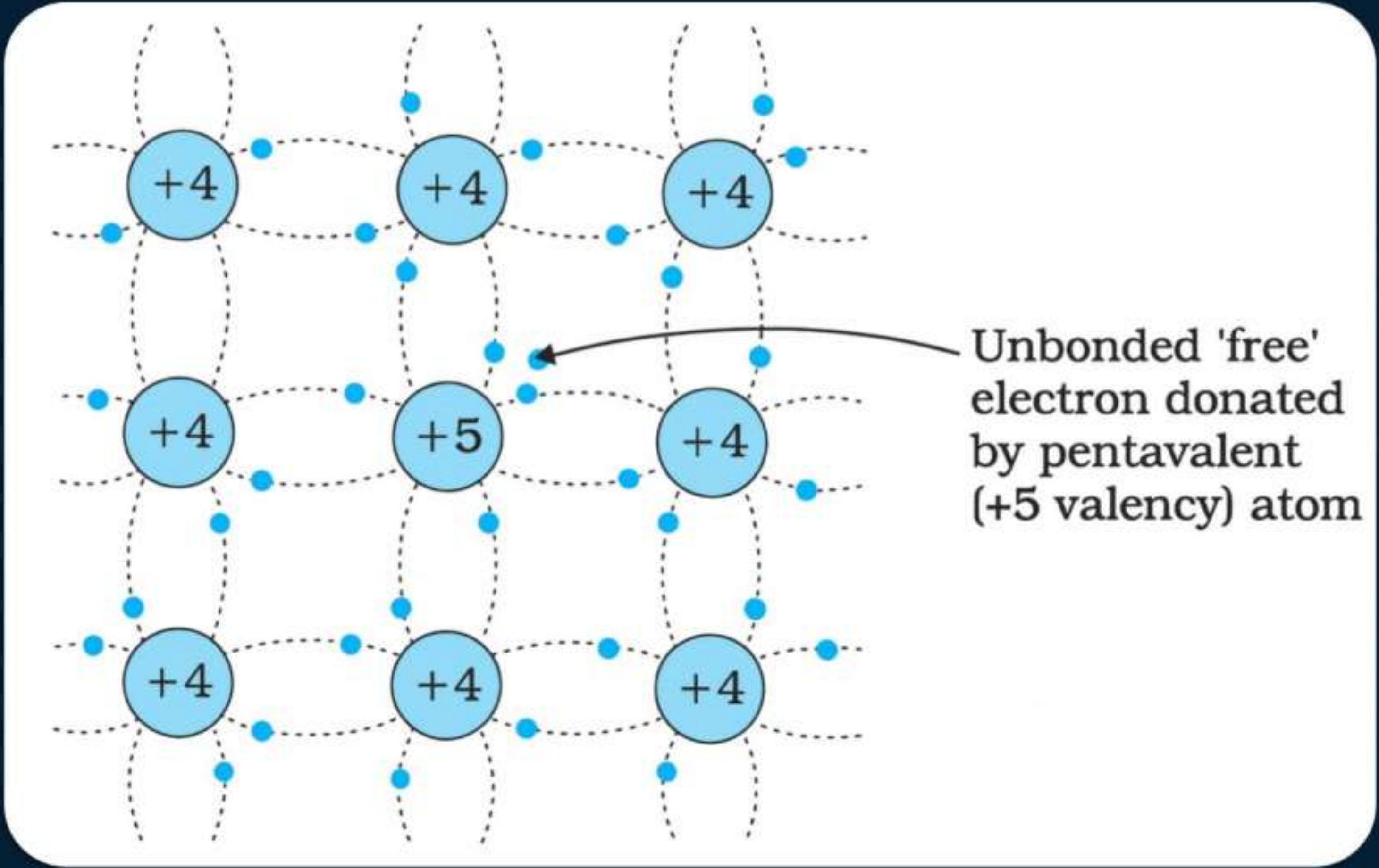


$n_h > n_e$

Extrinsic Semi-Conductors: (*n*-type Valence Bond explanation)

It has been found that energy required is 0.01 ev for germanium and 0.05 ev for silicon, to separate this electron from its atom.

This is in contrast to the energy required to jump the forbidden band (about 0.72 ev for germanium and about 1.1 ev for silicon) at room temperature in the intrinsic semiconductor.



⇒ Hence in *n*-type semiconductor,

- electrons are majority carriers and holes are minority carriers.

$n_e >> n_h$

Extrinsic Semi-Conductors: (n-type Valence Bond explanation)

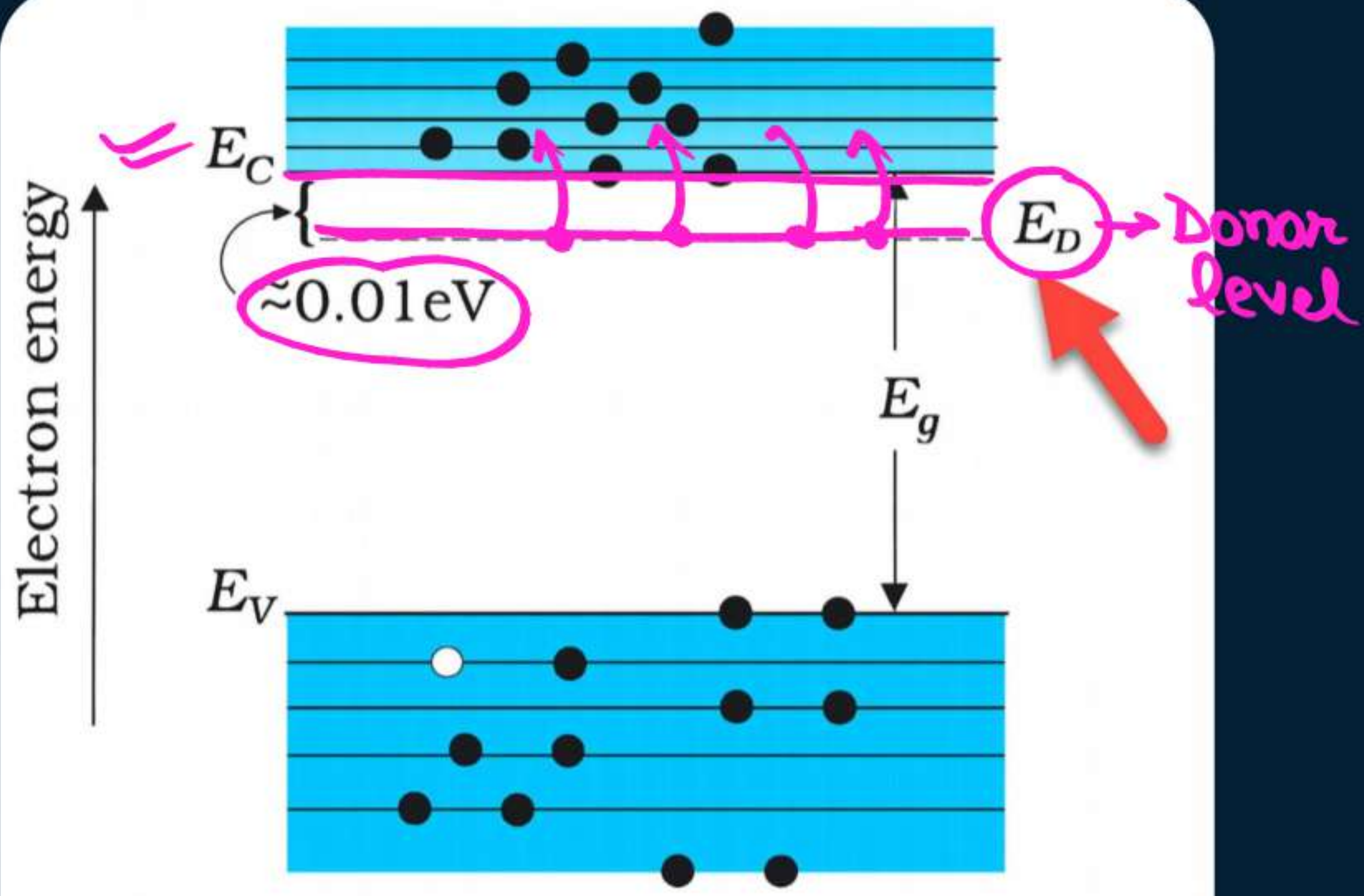
The semiconductor's energy band structure is affected by doping.

In the case of extrinsic semiconductors, additional energy states due to donor impurities (ED) also exist.

In the energy band diagram of n-type Si semiconductor, the donor energy level ED is slightly below the bottom EC of the conduction band and electrons from this level move into the conduction band with very small supply of energy.

Hence a very small energy supplied can excite the electrons from donor levels to conduction band.

Due to it, the conductivity of semiconductor is remarkably improved.



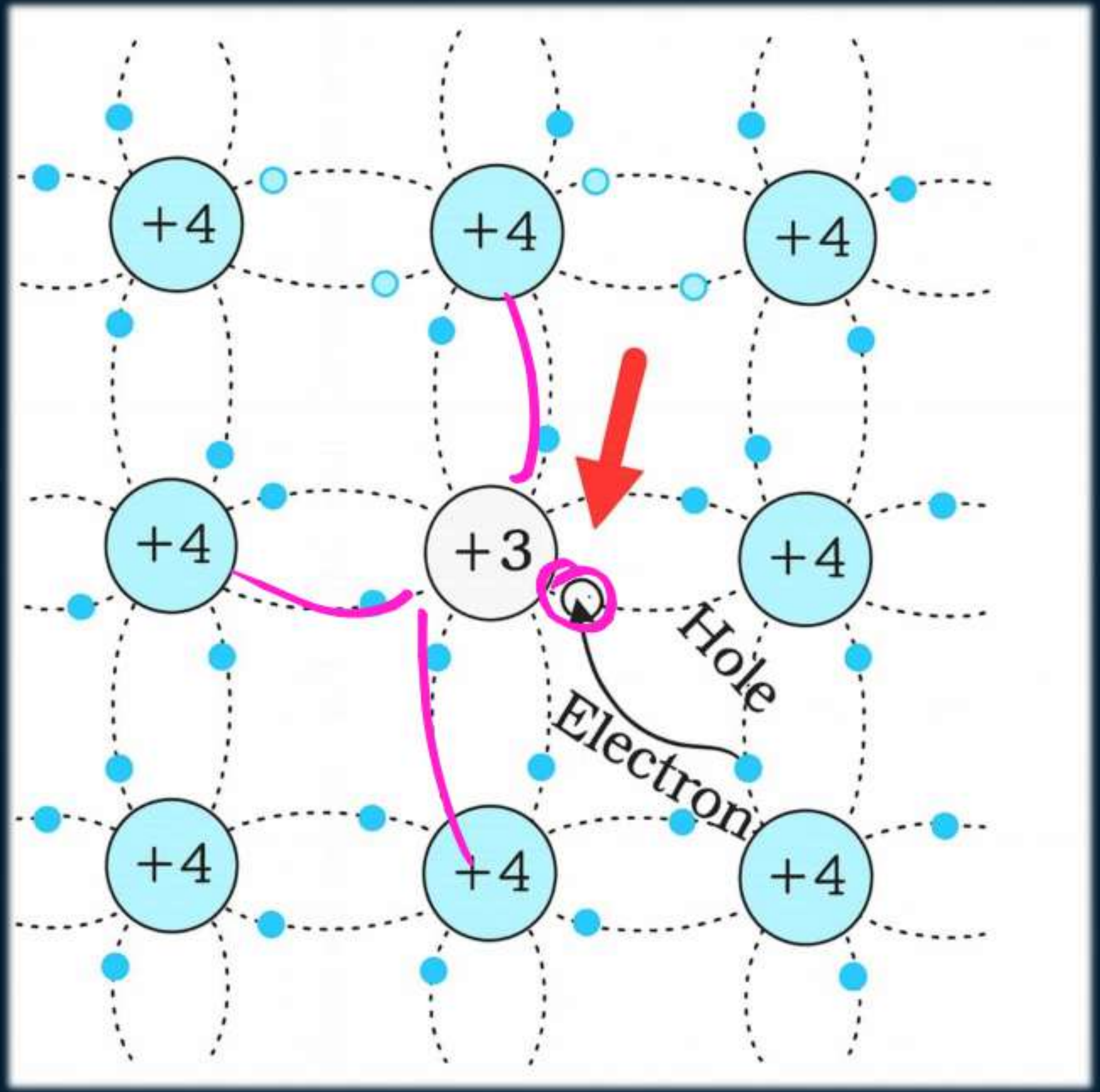
(a) $T > 0K$
one thermally generated electron-hole pair + 9 electrons from donor atoms

Extrinsic Semi-Conductors (p-type, Valence Bond explanation)

- In the p-type semiconductor,
- Electrons are minority carriers and
- holes are majority carriers.

In p-type

$n_h >> n_e$

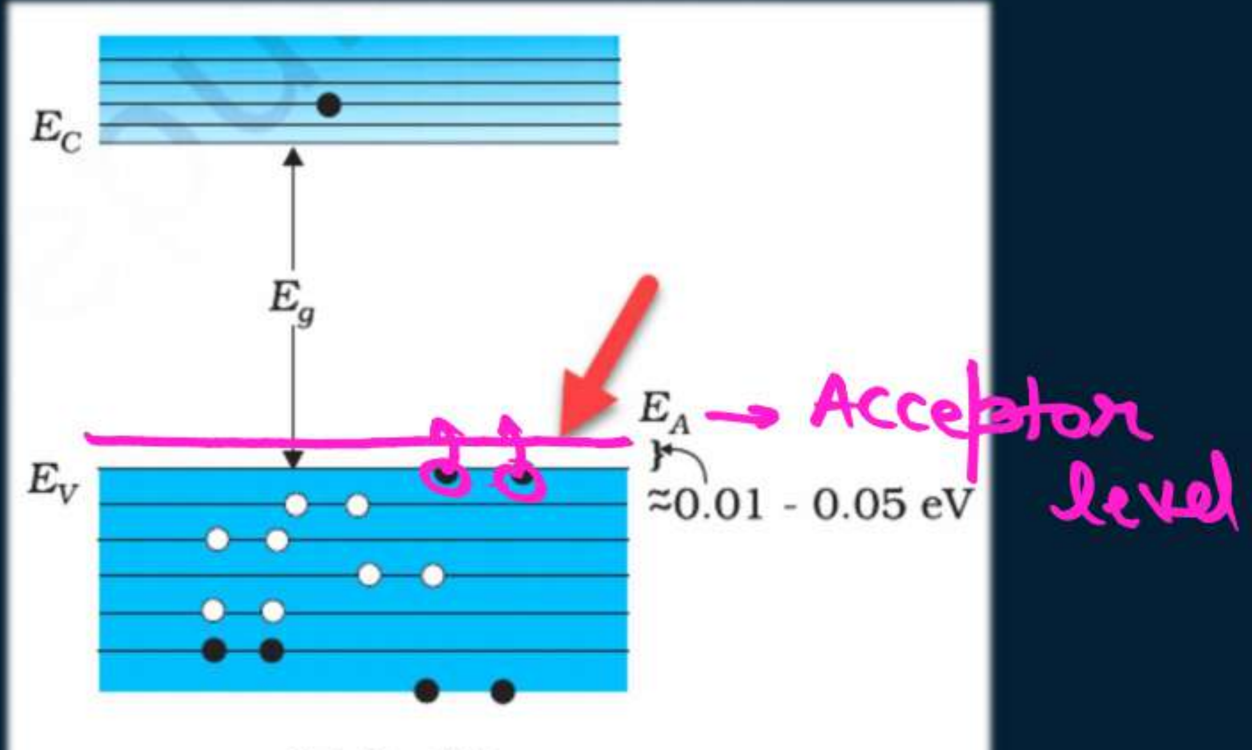


Extrinsic Semi-Conductors (p-type, Energy Band explanation)

❖ The semiconductor's energy band structure is affected by doping.

❖ In the case of extrinsic semiconductors, additional energy states due to acceptor impurities (E_A) also exist.

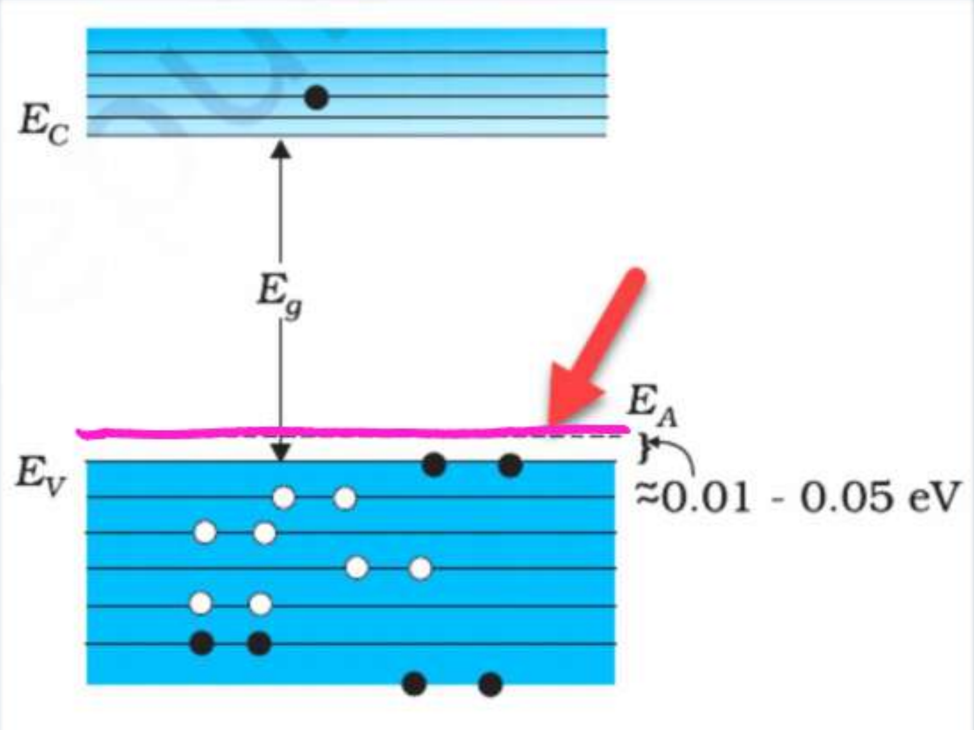
❖ The acceptor energy level E_A is slightly above the top E_V of the valence band as shown in Fig. (b).



(b) $T > 0K$

Extrinsic Semi-Conductors (p-type, Energy Band explanation)

- With very small supply of energy an electron from the valence band can jump to the level E_A and ionise the acceptor negatively.
- Alternately, we can also say that with very small supply of energy the hole from level E_A sinks down into the valence band.



(b) $T > 0K$

$n_e >> n_h \rightarrow n\text{-type}$
$n_h >> n_e \rightarrow p\text{-type}$

Points to be Noted

1. **In a doped semiconductor**

The number density of electrons and holes are not equal. **Under thermal equilibrium**, the product of the free negative and positive concentrations is a constant quanatity, independent of the amount of donor and acceptor impurity doping. This relationship is known as "**mass-action law**" and is given by

$$\boxed{n_e \times n_h = n_i^2}$$

Where ne, nh are the number density of electrons and holes respectively and n_i, is number density of intrinsic carriers (i.e. electrons or holes) in a pure semiconductor.

Points to be Noted

$n_e \approx N_d >> n_h$

2. **In n-type semiconductor**

The number density of electrons is nearly equal to the number density of donor Atoms N_d and is very large as compared to number density of holes. Hence

$$n_e \approx N_d \gg n_h$$

3. **In p-type semiconductor**

The number density of holes is nearly equal to the number density of acceptor atoms N_a and is very large as compared to number density of electrons. Hence

$$n_h \approx N_a \gg n_e$$

$n_h \approx N_a >> n_e$

Points to be Noted

"skip"

4. **The number density of intrisnic current carrier (n_i)** of a semiconductor varies with temperature T K according to relation

$$n_i = n_0 e^{-Eg/(2kT)}$$

where n_0 is a constant, k is the Boltzmann constant and E_g is the energy gap of the given semiconductor.

5. **Both n-type and p-type semiconductors are neutral.**

n-type

p-type → **Neutral**

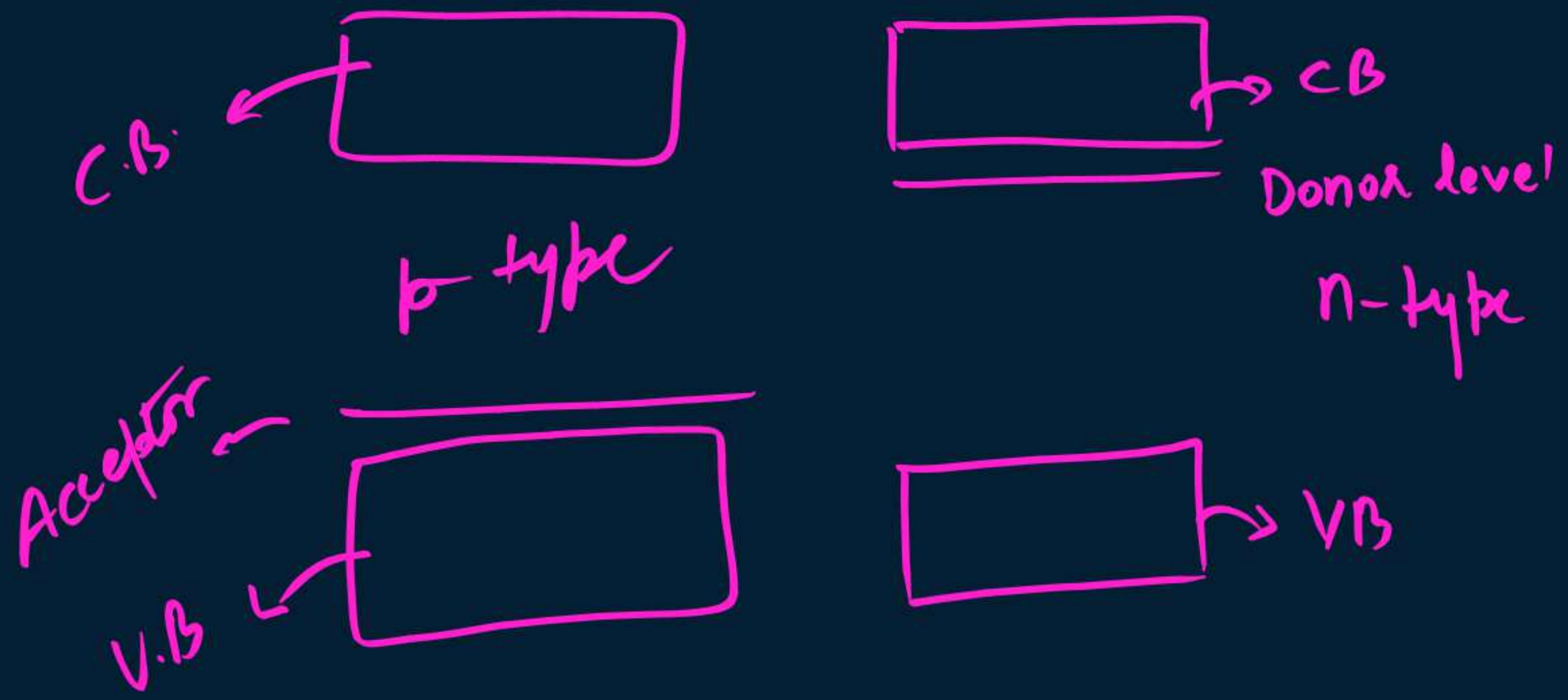
Points to be Noted

Donor-level

6. The fermilevel in **n-type** semiconductor lies in the forbidden energy gap near the conduction band.

Acceptor level

7. The fermilevel in **p-type** semiconductor lies in the forbidden energy gap near the valence band.



QUESTION

H.W.

Suppose a pure Si crystal has 5×10^{28} atoms m^{-3}. It is doped by 1 ppm concentration of pentavalent As. Calculate the number of electrons and holes. Given that $n_i = 1.5 \times 10^{16}\ m^{-3}$.

$$\boxed{n_h \times n_e = n_i^2}$$

H.W.

Difference between Intrinsic & Extrinsic Semiconductors

	INTRINSIC SEMICONDUCTORS	EXTRINSIC SEMICONDUCTORS
1.	These are pure semiconducting tetravalent crystals.	These are semiconducting tetravalent crystals doped with impurity atoms of group III or V.
2.	Their electrical conductivity is low.	Their electrical conductivity is high.
3.	There is no permitted energy state in between valance and conduction bands.	There is permitted energy state of the impurity atom between valance and conduction bands.
4.	The number of free electrons in the conduction band is equal to the number of holes in valance band.	The electrons are majority charge carriers in n-type while holes are majority charge carriers in p-type.
5.	Their electrical conductivity depends on temperature.	Their electrical conductivity depends on temperature as well as on dopant concentration.

Difference between n-type & p-type Semiconductors

	n-type SEMICONDUCTORS	p-type SEMICONDUCTORS
1.	These are extrinsic semiconductors obtained by doping impurity atoms of group V to Ge or Si crystal.	These are extrinsic semiconductors obtained by doping impurity atoms of group III to Ge or Si crystal.
2.	The impurity atoms added provide free electrons and are called donors.	The impurity atoms added create vacancies of electrons (or holes) and are called acceptors.
3.	The donor impurity level lies just below the conduction band.	The acceptor impurity level lies just above the valance band.
4.	The electrons are majority charge carriers while holes are minority charge carriers.	The holes are majority charge carriers while electrons are minority charge carriers.
5.	$n_e >> n_h$ or $n >> p$	$n_e << n_h$ or $n << p$

Homework

Notes ✓

Revision

PARISHRAM

2026

Lecture - 02

Semiconductor

Electronics

PHYSICS Lecture : 02

BY - RAKSHAK SIR

Topics *to be covered*

1 - p-n Junction diode

- diode as rectifier

QUESTION

$$\boxed{n_e \times n_h = n_i^2}$$

Suppose a pure Si crystal has 5×10^{28} atoms m^{-3}. It is doped by 1 ppm concentration of pentavalent As. Calculate the number of electrons and holes. Given that $n_i = 1.5 \times 10^{16}\ m^{-3}$.

$n_e = ?$ $n_h = ?$

$$n_i = 1.5 \times 10^{16}\ m^{-3}$$

$$n_e \times n_h = n_i^2$$

$$5\times 10^{22} \times n_h = (1.5 \times 10^{16})^2$$

$$n_h = \frac{1.5 \times \cancel{1.5}^{0.3} \times 10^{\cancel{32}\,10}}{\cancel{5}_{1} \times \cancel{10^{22}}} = 0.45 \times 10^{10}$$

$$\boxed{n_h = 4.5 \times 10^{9}\ m^{-3}}$$

$$N_D \approx n_e$$

$$\boxed{n_e = 5 \times 10^{22}\ m^{-3}}$$

10^6 atoms $\longrightarrow$ 1 impure atom

1 atom $\longrightarrow$ $\frac{1}{10^6}$ impure atom

5×10^{28} atoms $\longrightarrow$ $5 \times 10^{\cancel{28}\,22} \times \frac{1}{\cancel{10^6}}$ impure atoms

5×10^{22} impure atoms

Difference between Intrinsic & Extrinsic Semiconductors

	INTRINSIC SEMICONDUCTORS	EXTRINSIC SEMICONDUCTORS
1.	These are pure semiconducting tetravalent crystals.	These are semiconducting tetravalent crystals doped with impurity atoms of group III or V.
2.	Their electrical conductivity is low.	Their electrical conductivity is high.
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$n_e = n_h$ 4.	The number of free electrons in the conduction band is equal to the number of holes in valance band.	The electrons are majority charge carriers in n-type while holes are majority charge carriers in p-type.
5.	Their electrical conductivity depends on temperature.	Their electrical conductivity depends on temperature as well as on dopant concentration.

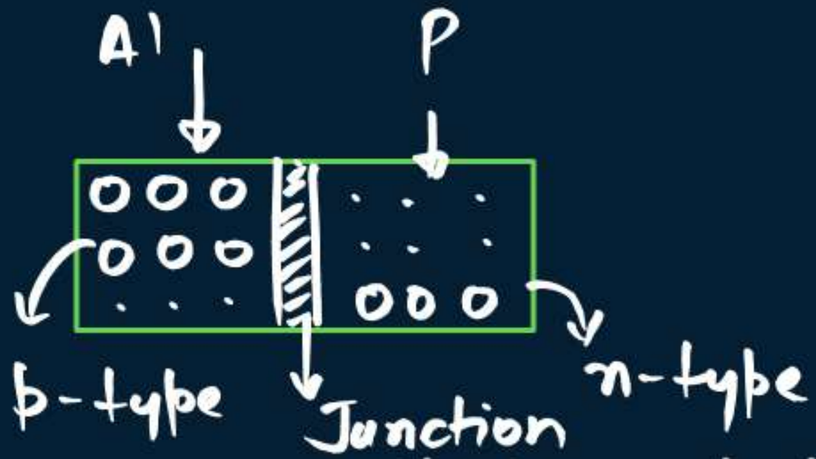
$n_h >> n_e$: p-type

$n_e >> n_h$: n-type

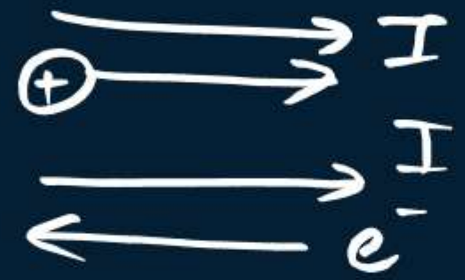
Difference between n-type s.c. v/s p-type s.c.

	n-type SEMICONDUCTORS	p-type SEMICONDUCTORS
1.	These are extrinsic semiconductors obtained by doping impurity atoms of group V to Ge or Si crystal.	These are extrinsic semiconductors obtained by doping impurity atoms of group III to Ge or Si crystal.
2.	The impurity atoms added provide free electrons and are called donors.	The impurity atoms added create vacancies of electrons (or holes) and are called acceptors.
3.	The donor impurity level lies just below the conduction band.	The acceptor impurity level lies just above the valance band.
4.	The electrons are majority charge carriers while holes are minority charge carriers.	The holes are majority charge carriers while electrons are minority charge carriers.
5.	$(n_e >> n_h)$ or $(n >> p)$	$(n_e << n_h)$ or $n << p$

p-n Junction



It is a single crystal of Ge or Si doped in such a manner that one half portion of it acts as p-type semiconductor and other half as n-type semiconductor.



Formation of p-n junction

Two important processes involved during formation of p-n junction are

1. **Diffusion (diffusion current $(p \rightarrow n)$)**
2. **Drift (Drift Current $(n \rightarrow p)$)**

- The small region in the vicinity of the junction which is depleted of free charge carriers and has only immobile ions is called **depletion region**.
- The accumulation of negative charges in the p–region and positive charges in the n–region sets up a potential difference across the junction. This acts as a barrier and is called **barrier potential (V_B)**.

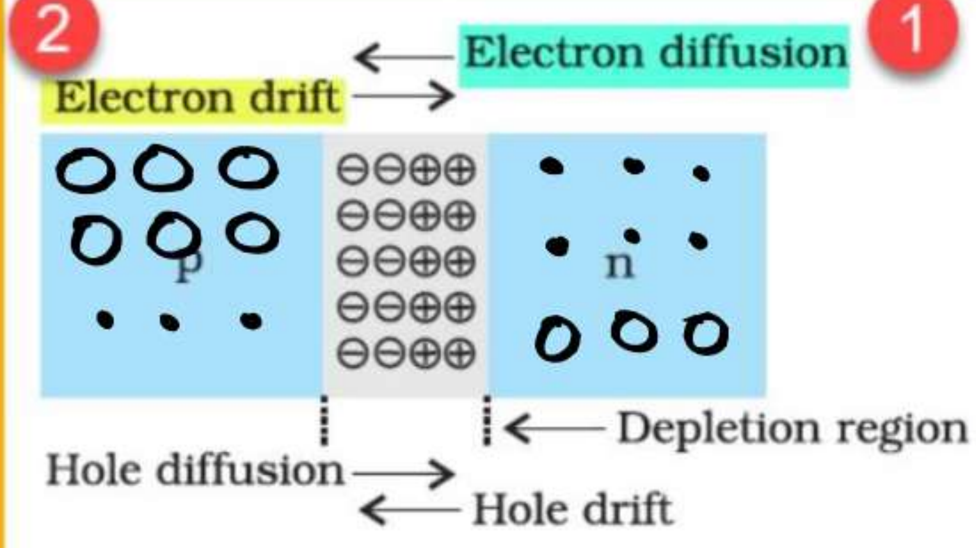


FIGURE p-n junction formation process.

holes : $p \rightarrow n$ } Majority charge move
e^- : $p \leftarrow n$

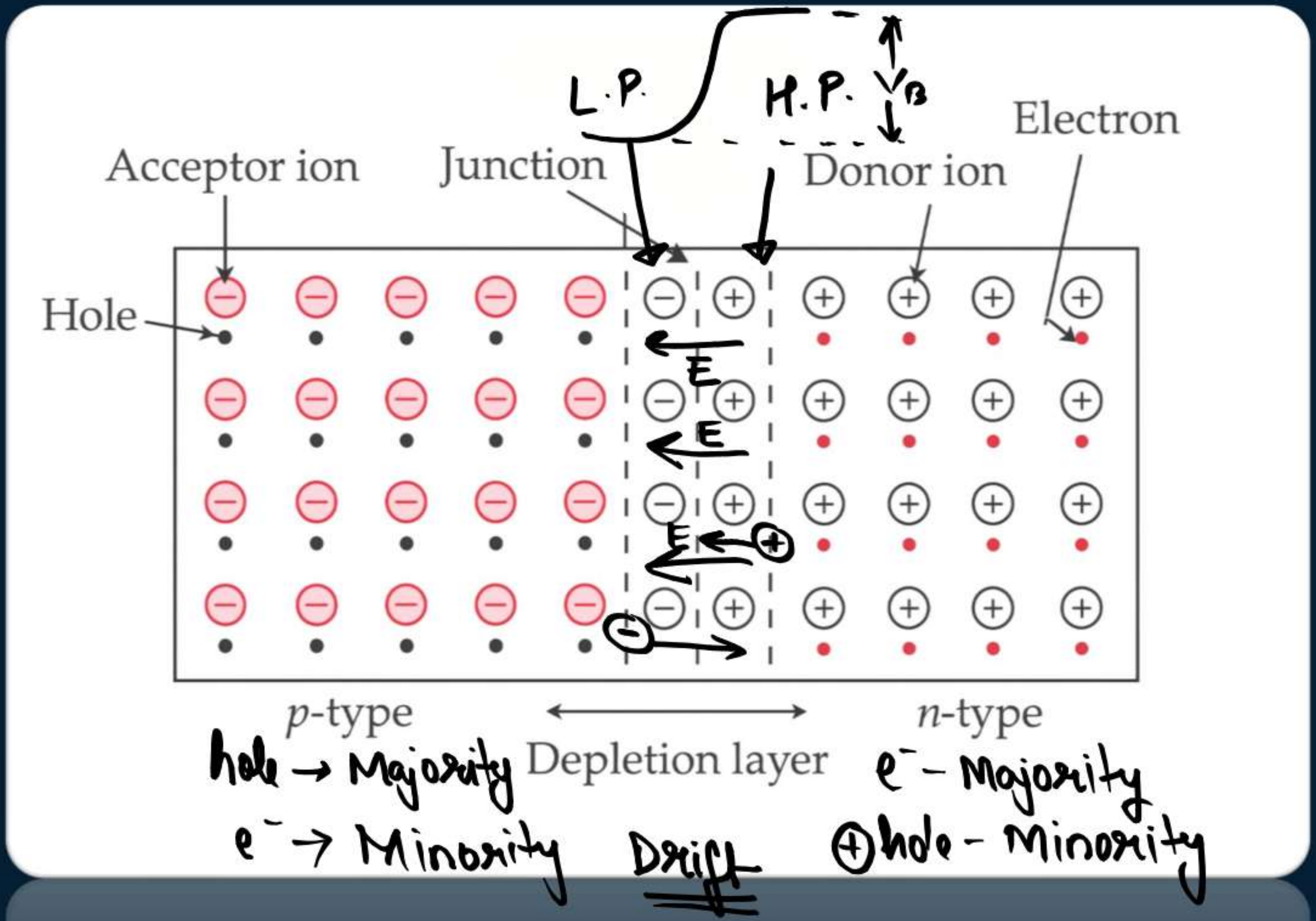
$(p \rightarrow n)$ diffusion current

Y.K.B.

$\longrightarrow E$

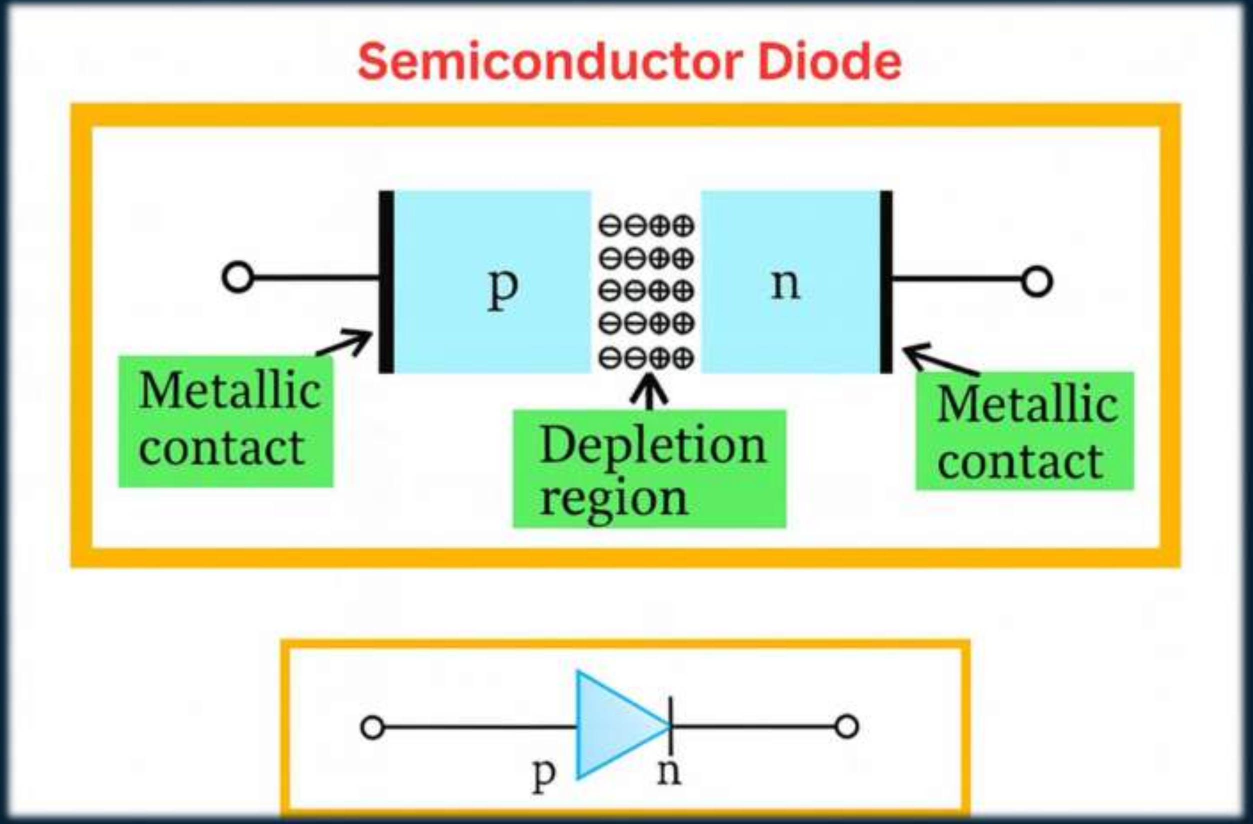
$+q \rightarrow$

$\leftarrow -q$



p-n Junction (Semiconductor Diode, Symbol)

Semiconductor Diode



Circuit Symbol for a p–n Junction

p-n Junction (depletion Layer and barrier potential)

The barrier potential V_B depends on

(i) the nature of the semiconductor

(ii) temperature

(iii) amount of doping

At room temp (300K) The value of V_B is 0.3 V for Ge and 0.7 V for Si.

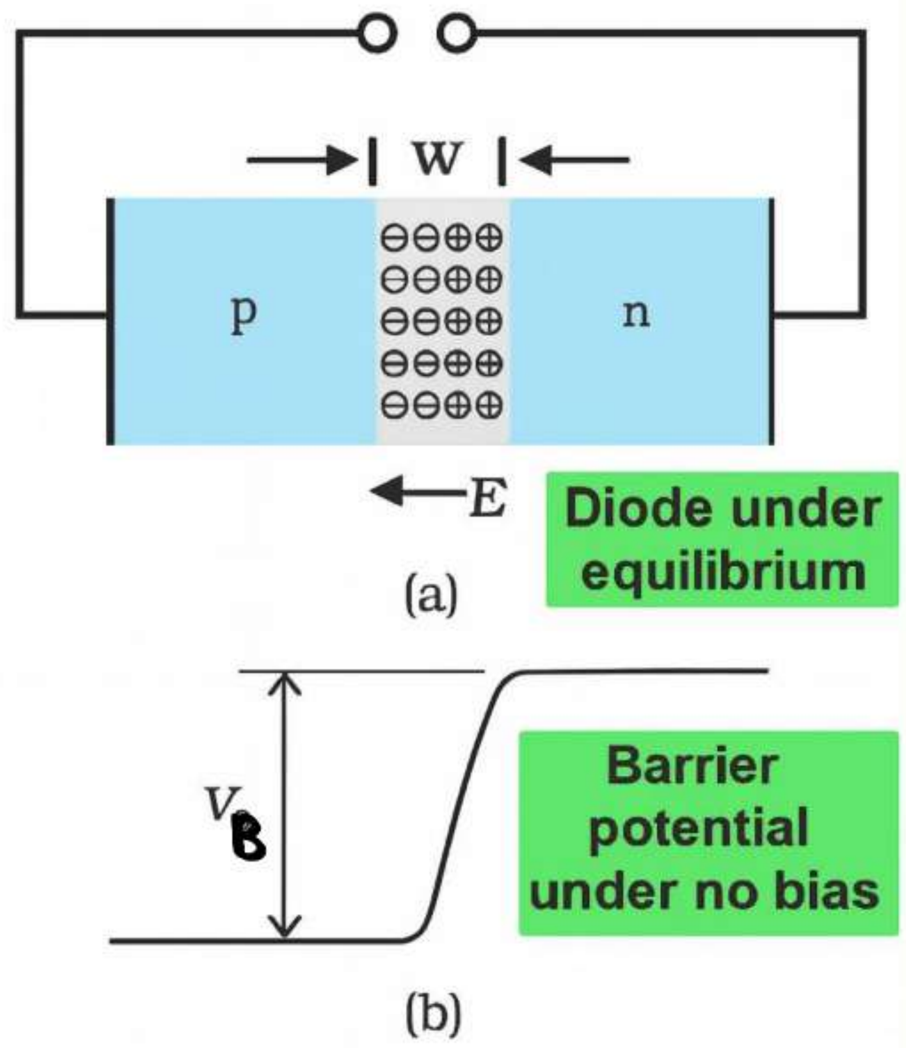
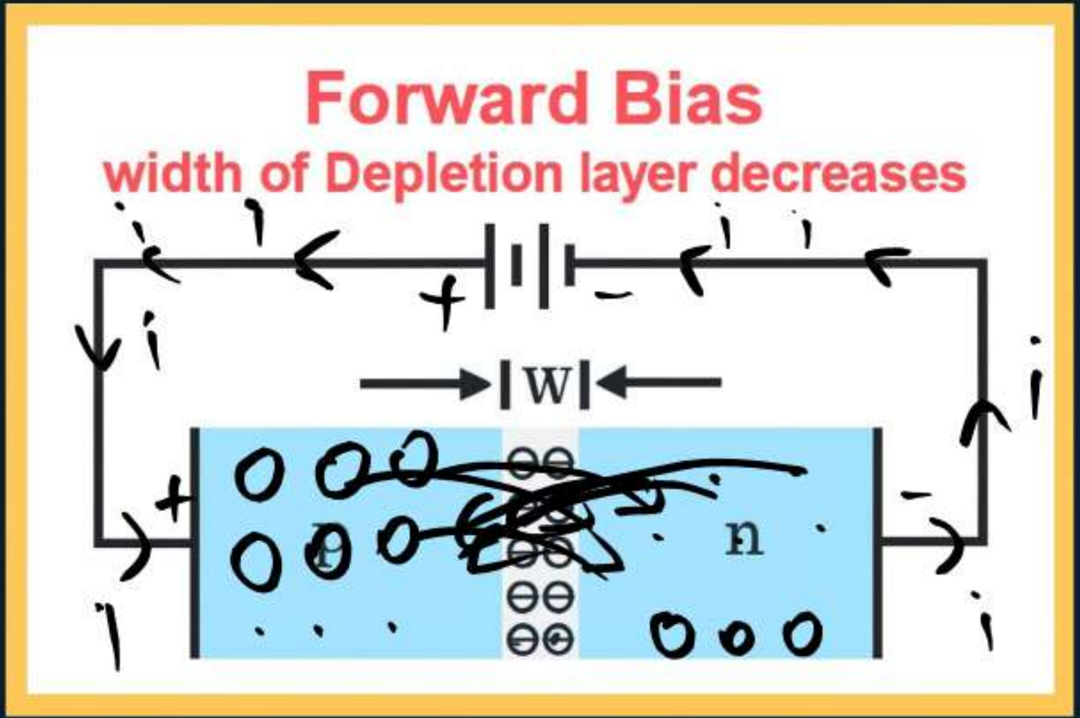


FIGURE (a) Diode under equilibrium (V = 0), (b) Barrier potential under no bias.

Working of a p-n junction (Forward Bias)

Forward Biasing: → Battery Connect

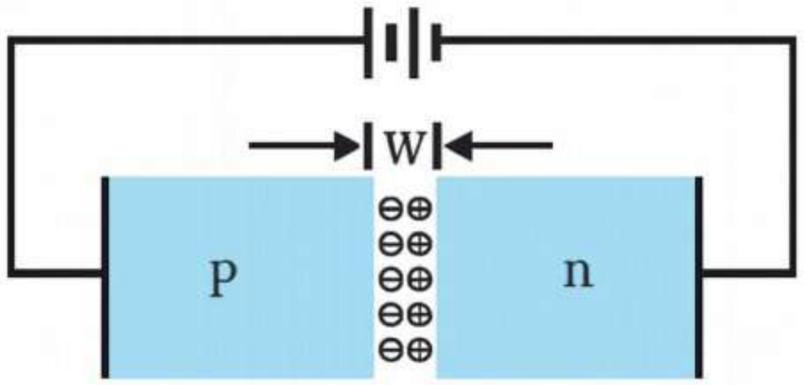
If the positive terminal of a battery is connected to the p-side and the negative terminal to the n-side, then the p-n junction is said to be forward biased.

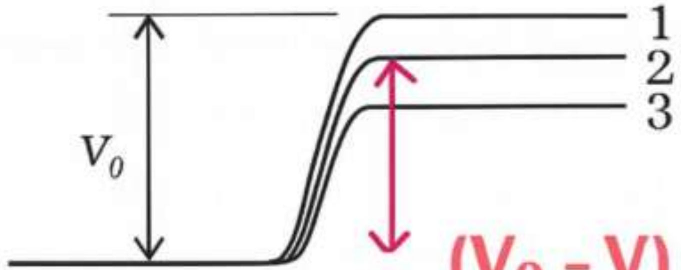


Forward biasing of a p-n junction

1. Barrier potential decreases $(V_0 - V)$ or $(V_B - V)$
2. Width of depletion layer decreases.
3. Effective resistance across p-n junction decreases.
4. Current in mA.

diffusion current support
majority carriers





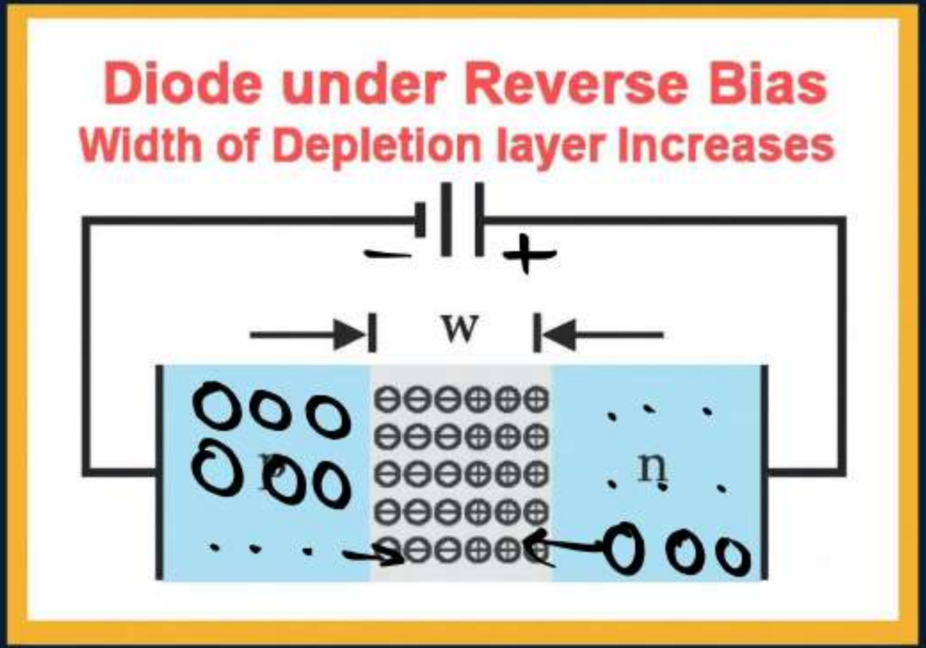
(b)

Barrier potential (1) without battery. (2) Low battery voltage. and (3) High voltage battery.

Working of a p-n junction (Reverse Bias)

Reverse Biasing:

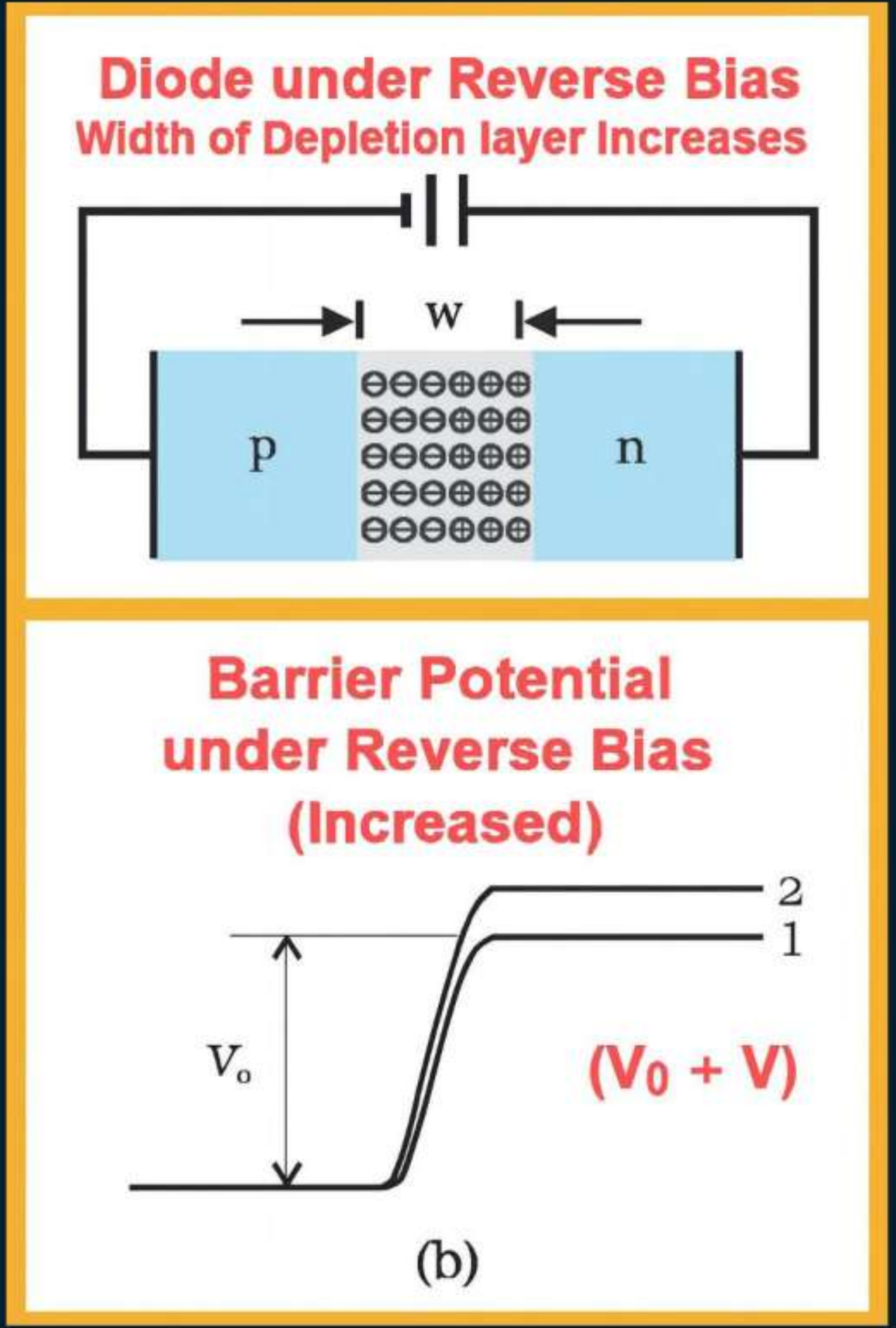
If the positive terminal of a battery is connected to the n-side and the negative terminal to the p-side, then the p-n junction is said to be reverse biased.



Reverse biasing of p-n Junction

1. Potential barrier increases $(V_0 + V)$ or $(V_B - V)$
2. Increasing the width of depletion layer.
3. Resistance across p-n junction very large.
4. No current due to majority charge carrier. $(I_{diff} = 0)$
5. Very small current (μA) due to minority charges.

I_{drift} ko support



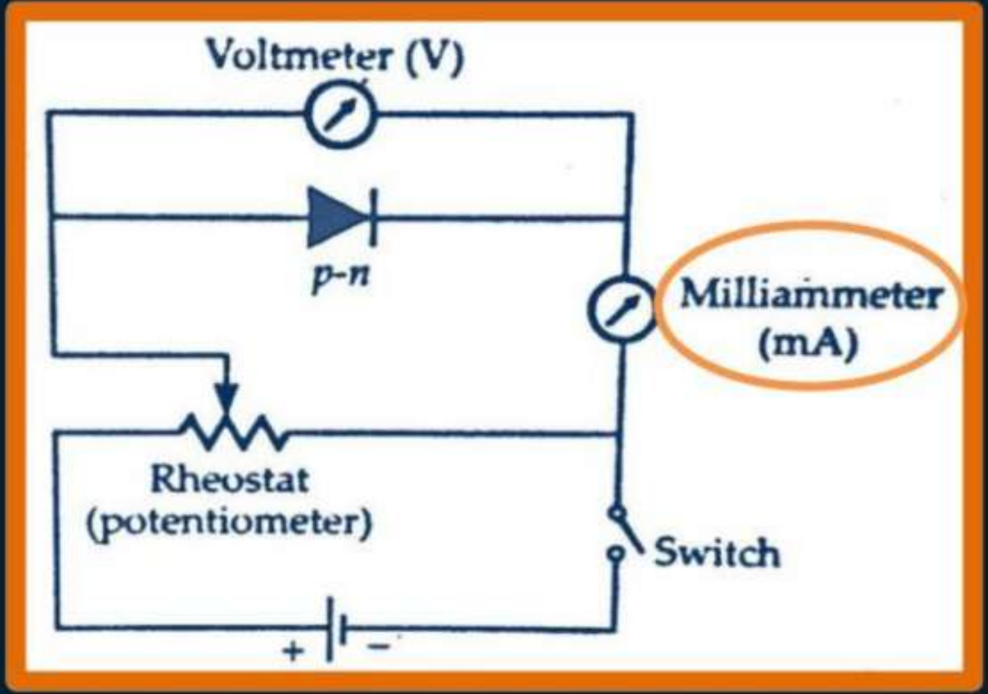
V-I characteristic of a p-n Junction Diode

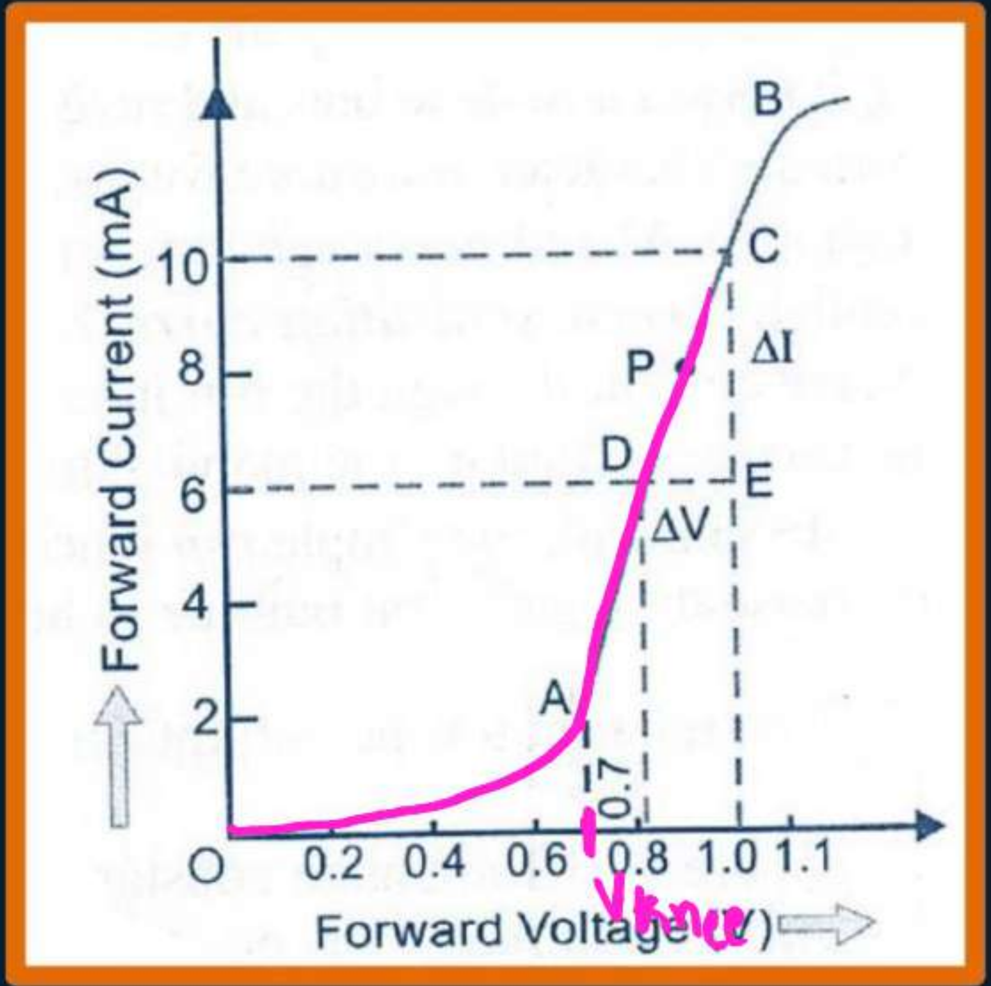
These are the graphical relations between voltage applied to p-n junction and the current through the p-n junction (both when it is forward and reverse biased) is called the **voltage-current or V-I characteristics of a p-n junction**.

V-I characteristic of a p-n Junction Diode

Forward Bias Characteristic

These are the graphical relations between forward bias voltage applied to p-n junction and the forward current through the p-n junction.



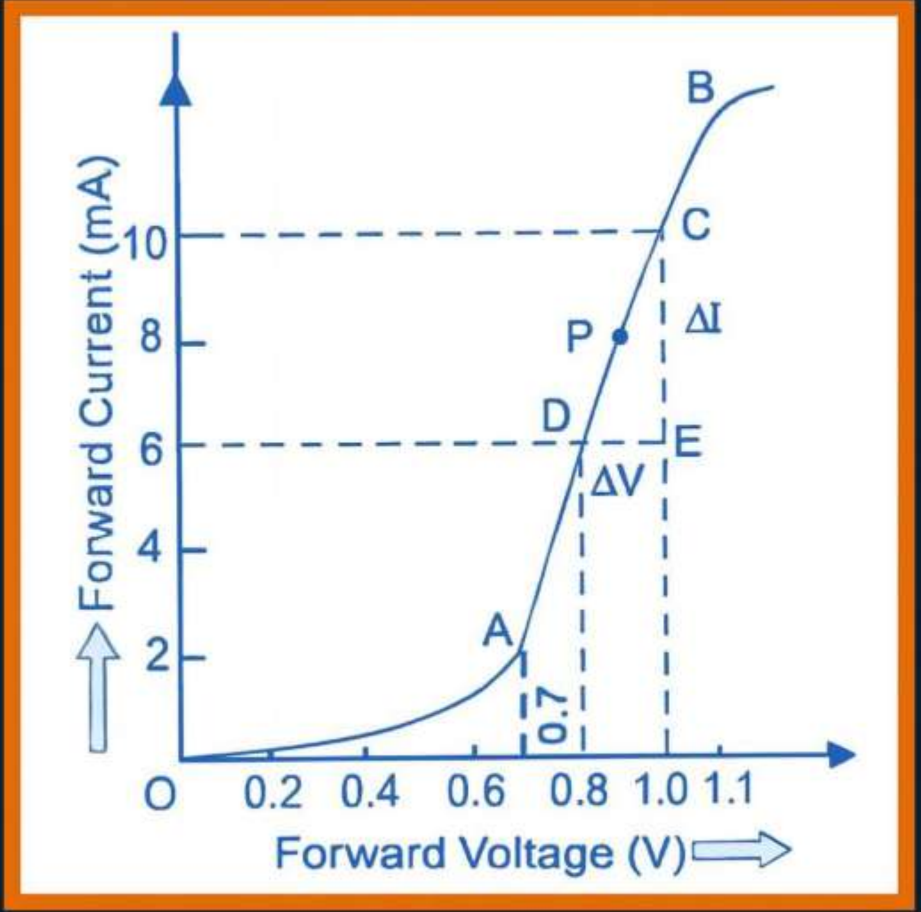


V-I characteristic of a p-n Junction Diode

Forward Bias Characteristic

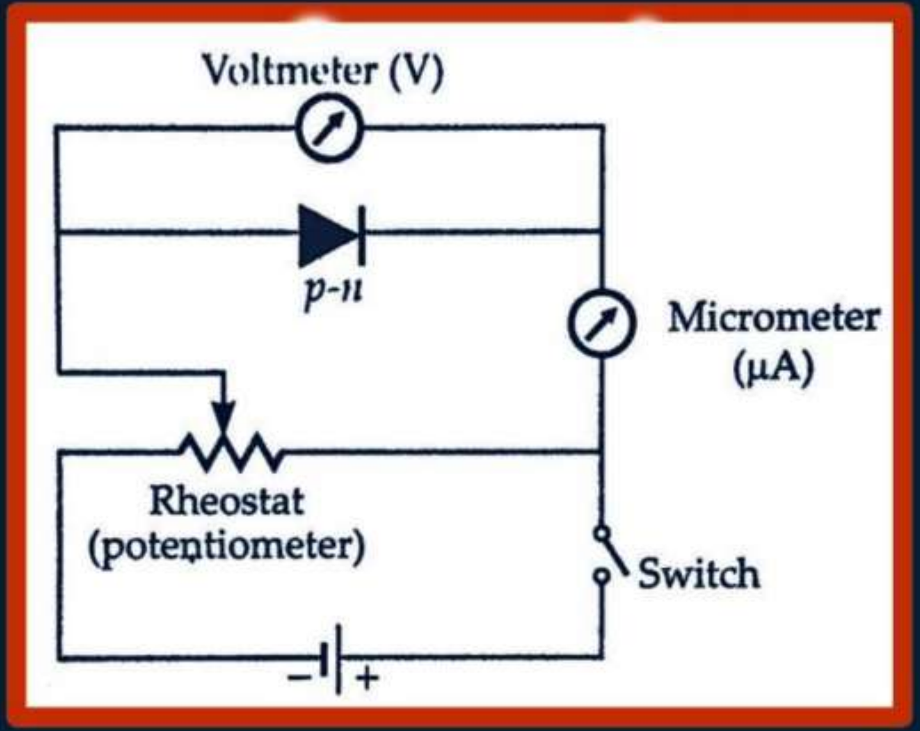
Important Features of graph:

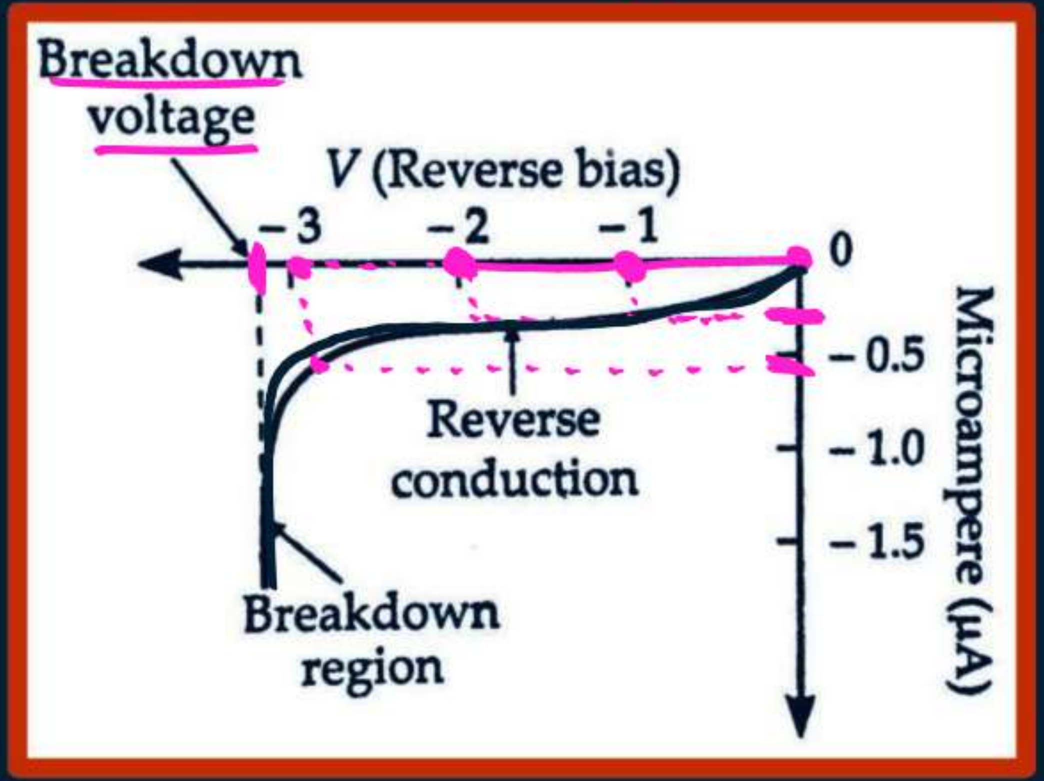
1. The V-I graph is not a straight line (does not obey Ohm's law)
2. Initially current increases very slowly, till the voltage crosses a certain value, called threshold-voltage/cut-in voltage or knee voltage. (ex. 0.3 V for Ge diode and 0.7 V for Si diode)
3. After the cut-in voltage, diode current increase rapidly (exponentially). Here majority charge carriers feel negligible resistance at the junction.

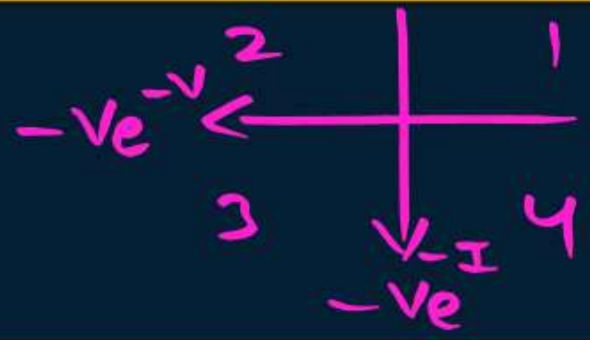


V-I characteristic of a p-n Junction Diode

Reverse Bias Characteristic





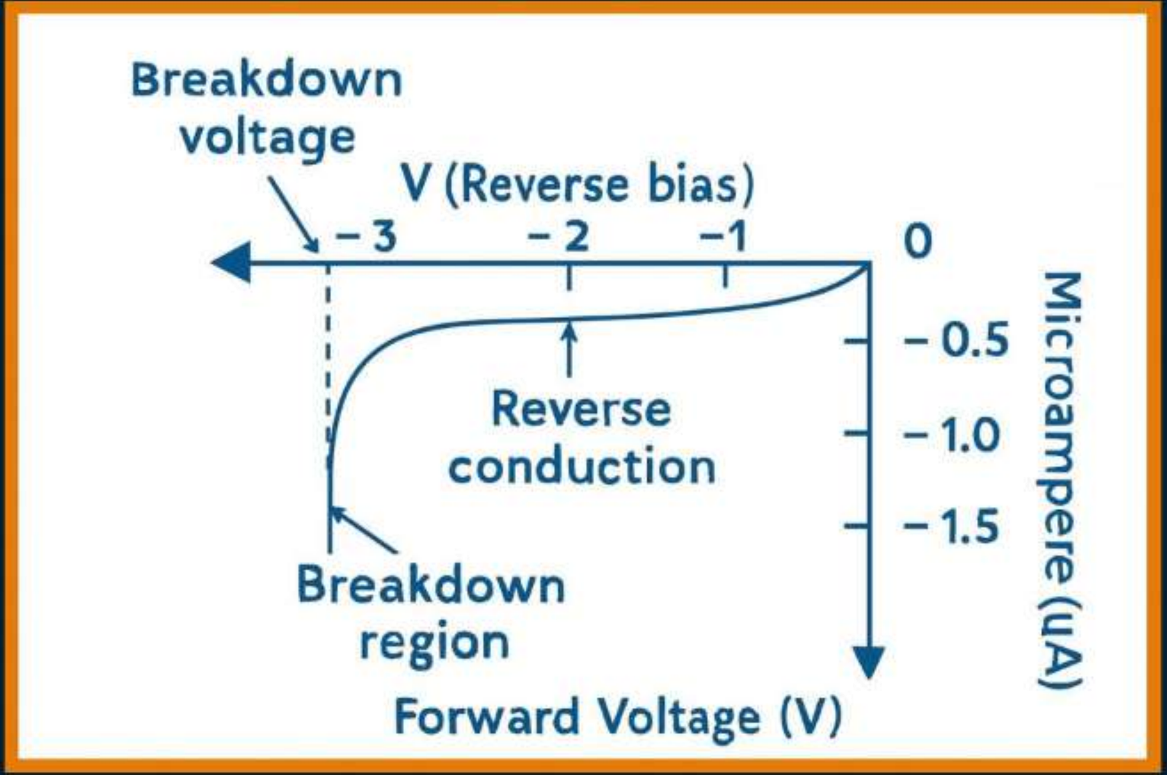


V-I characteristic of a p-n Junction Diode

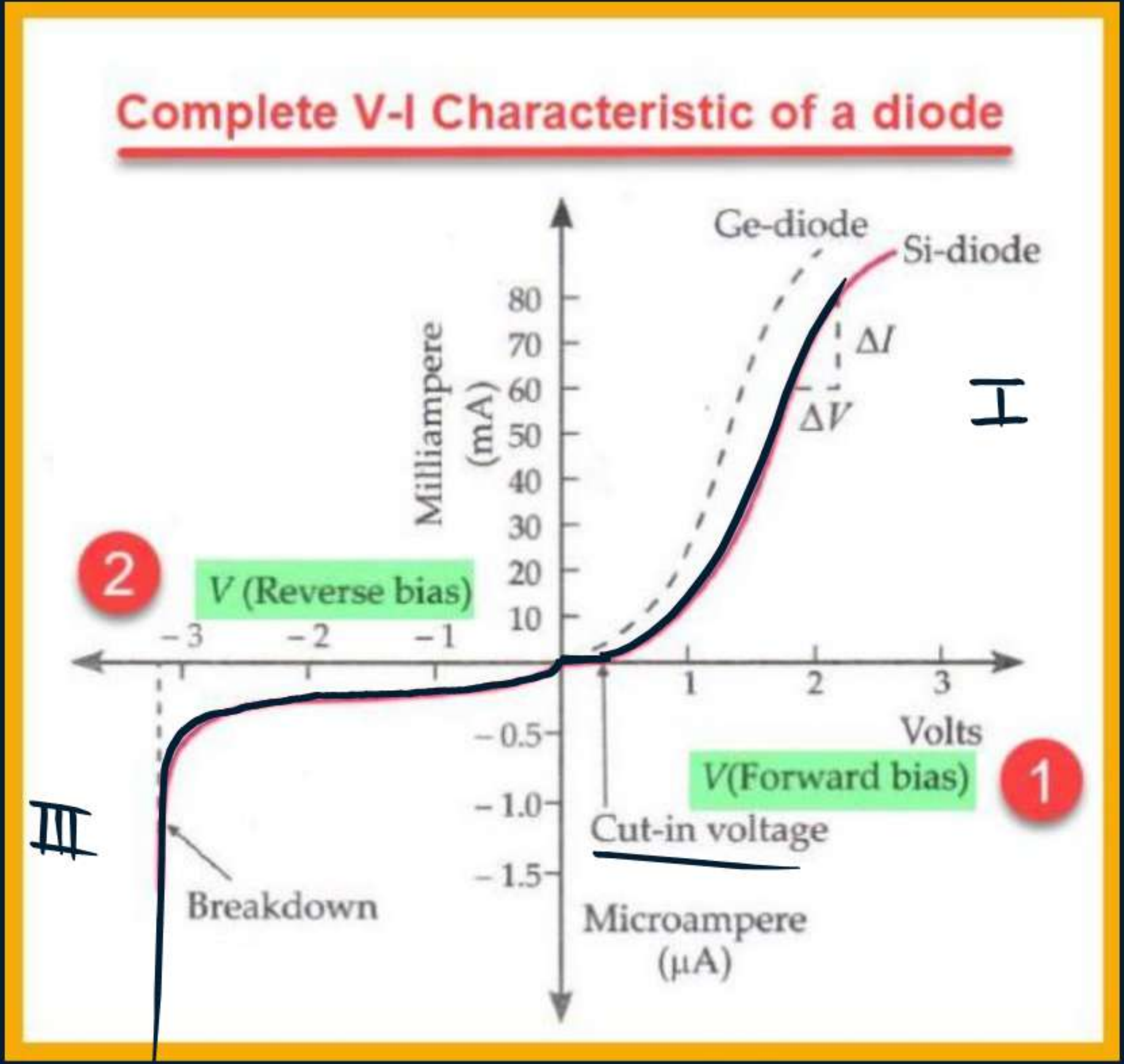
Reverse Bias Characteristic

Important Features of graph:

1. Reverse bias voltage produces a very small current few μA which almost remains constant with bias. This small current is called reverse saturation current. It is due to drift of minority charge carriers.
2. When reverse voltage reaches sufficiently high value, the reverse current suddenly increases to a large value. This voltage is called Zener breakdown voltage of the diode. (this property is used to convert a.c. to d.c., called rectification)



Complete V-I Characteristic of a Junction Diode



Important Point in p-n junction

Imp. Point to note that the p-n junction diode primerly allows the flow of current only in one direction (forward bias).

The forward bias resistance is low as compared to the reverse bias resistance. This property is used for rectification of ac voltages.

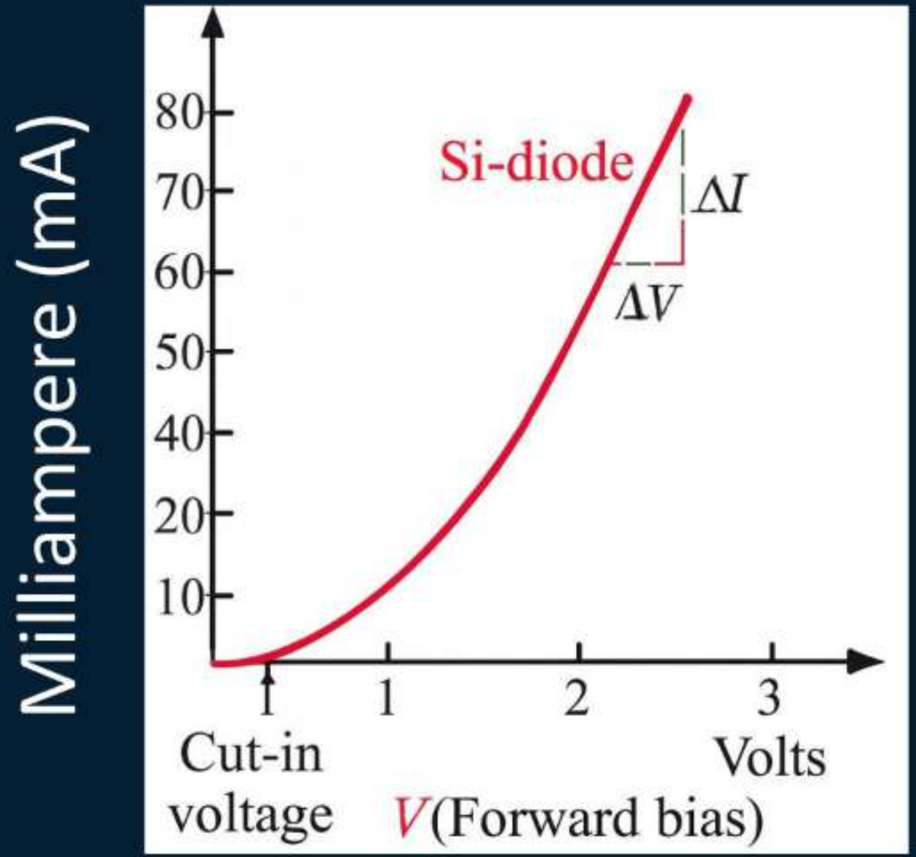
$V = IR$

Dynamic Resistance of a Junction Diode

For diodes, we define a quantity called dynamic resistance as the ratio of small change in voltage ΔV to a small change in current ΔI:

$$\boxed{r_d = \frac{\Delta V}{\Delta I}}$$

$$r_d = \frac{\text{small change in applied voltage } (\Delta V)}{\text{corresponding change in current } (\Delta I)} = \frac{\Delta V}{\Delta I}$$



Above the threshold voltage (cut-in voltage), the diode characteristic is linear. In the linear region diode characteristic is linear. In the linear region

Junction Diode as a Rectifier

Rectifier

Rectifier is a device which is used for converting alternating current/voltage into direct current/voltage.

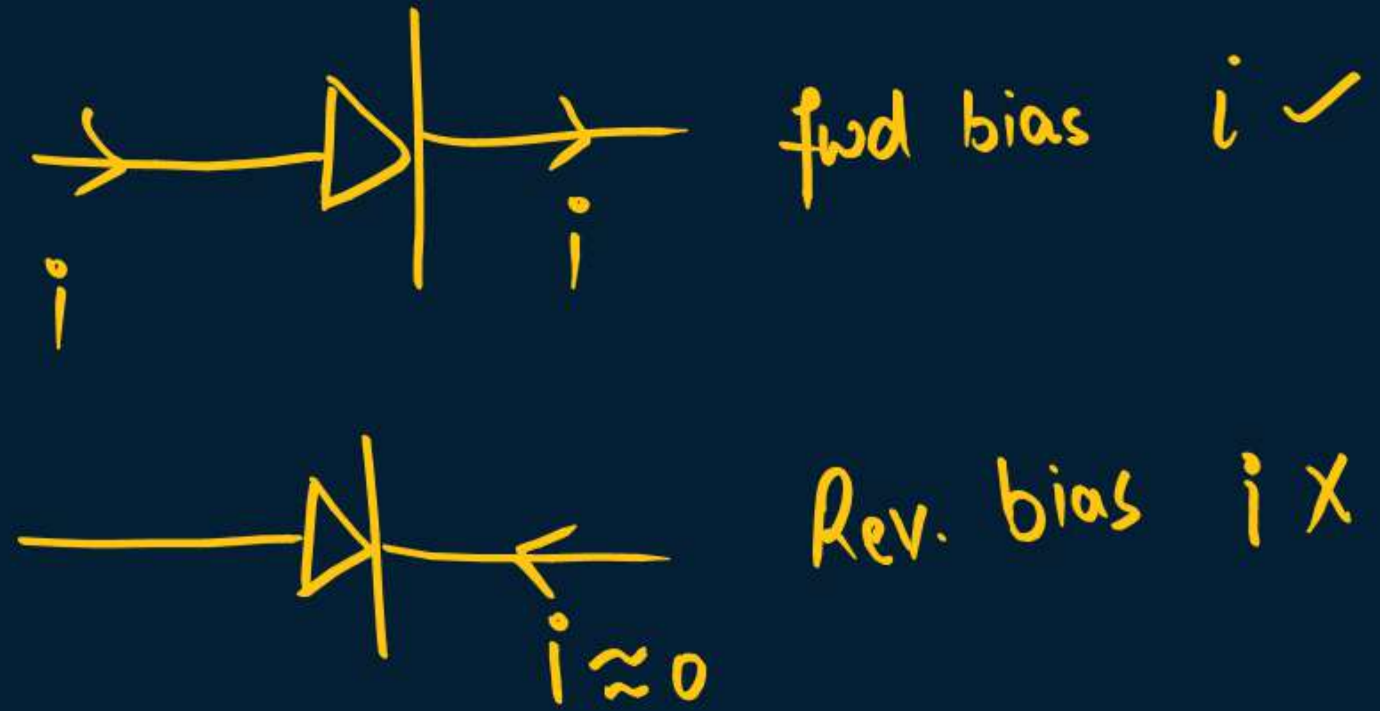
A.C. → D.C.

Junction Diode as a Rectifier

Principle: When a p-n junction diode is forward biased, it offers less resistance and a current flows through it; but when it is reverse biased, it offers high resistance and almost no current flows through it. This unidirectional property of a diode enables it to be used as a rectifier.

The p-n junctions can be used as

- ❖ A half-wave rectifier ✓
- ❖ A full-wave rectifier ✓

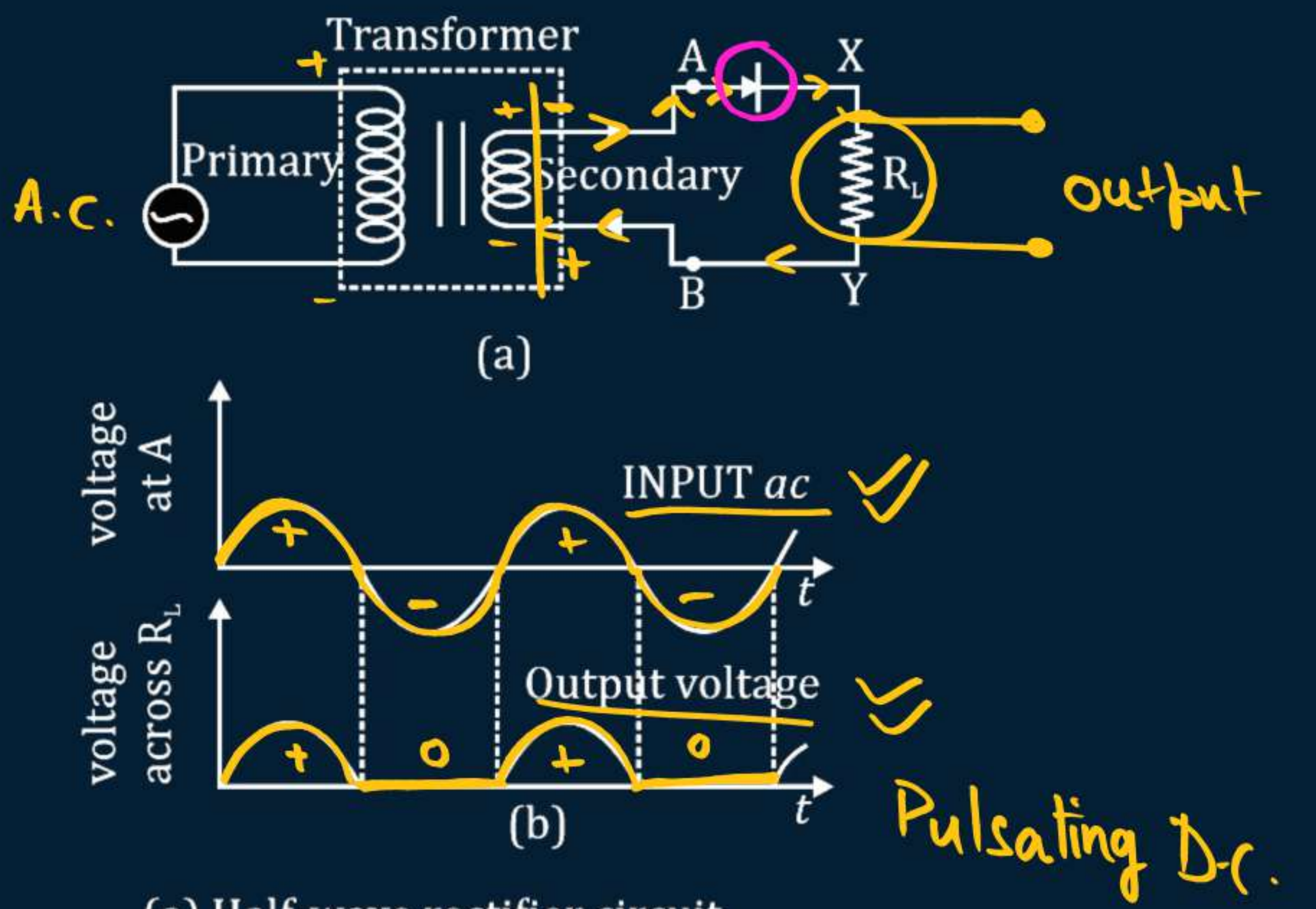


Junction Diode as a Half Wave Rectifier

Half Wave Rectifier

Output freq. = Input freq.

Half-wave rectifier Circuit

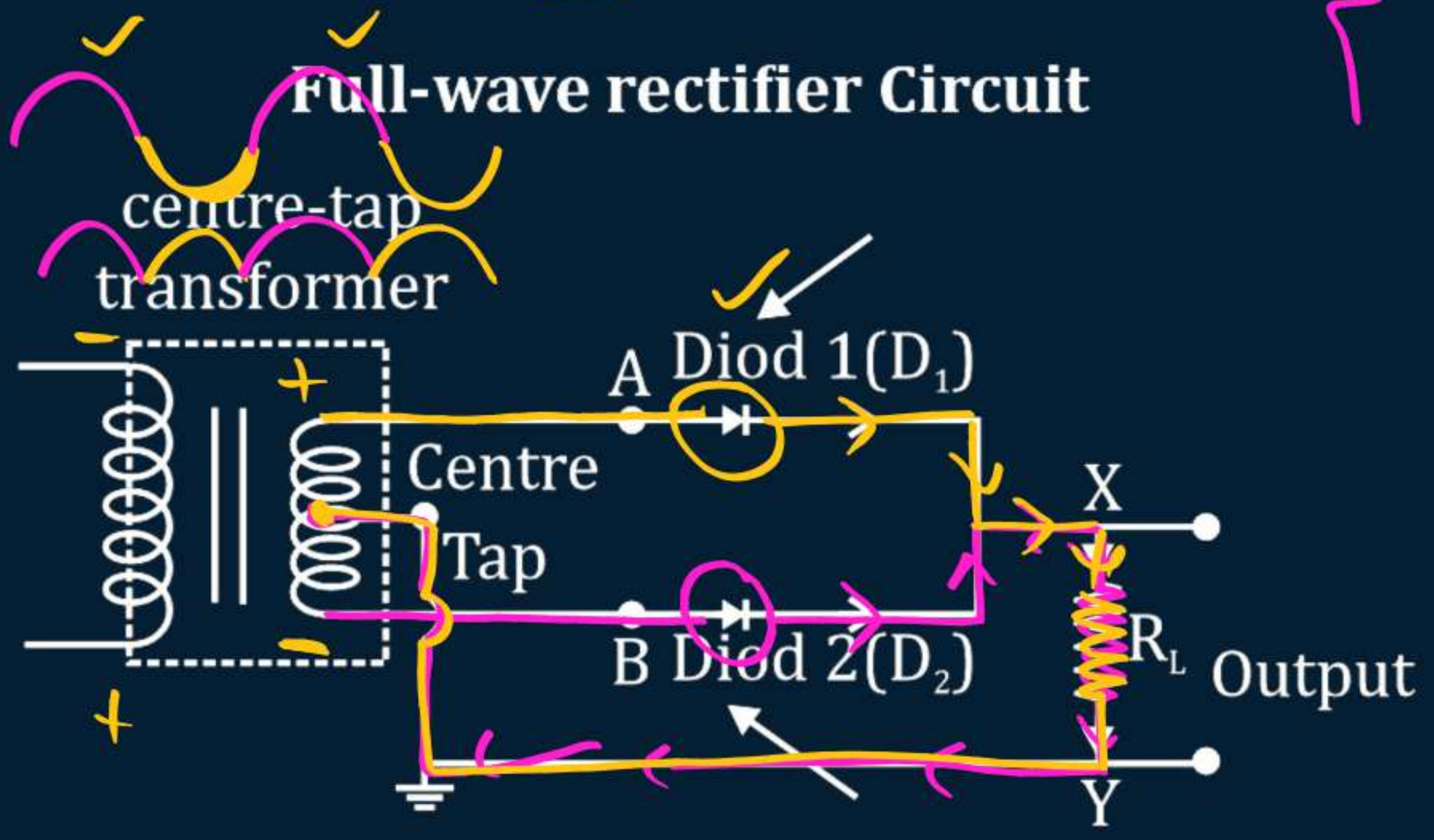


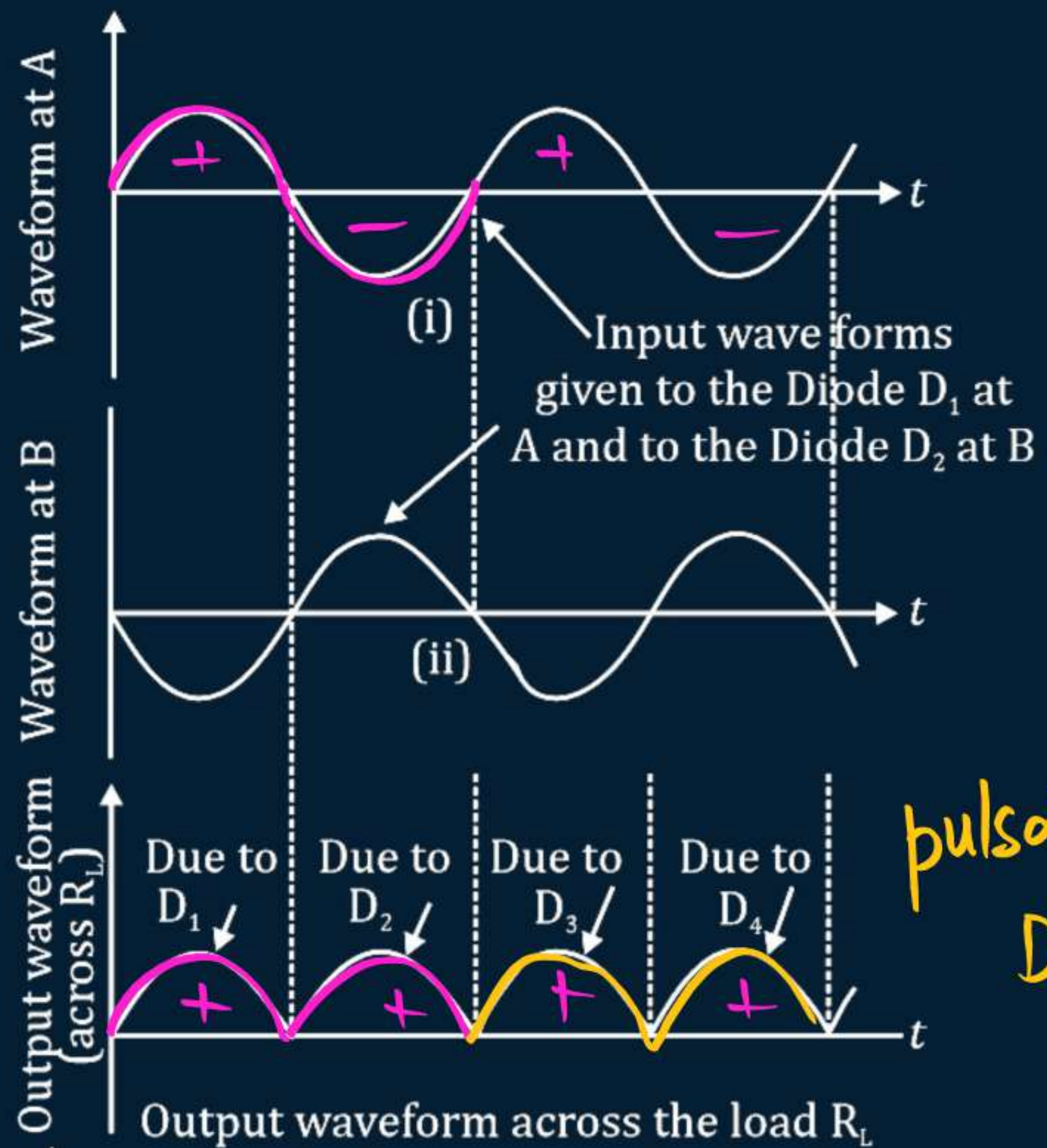
(a) Half-wave rectifier circuit
(b) Input ac voltage and output voltage waveforms from the rectifier circuit.

Junction Diode as a Full Wave Rectifier

Full Wave Rectifier

Output freq. = 2 × Input freq.





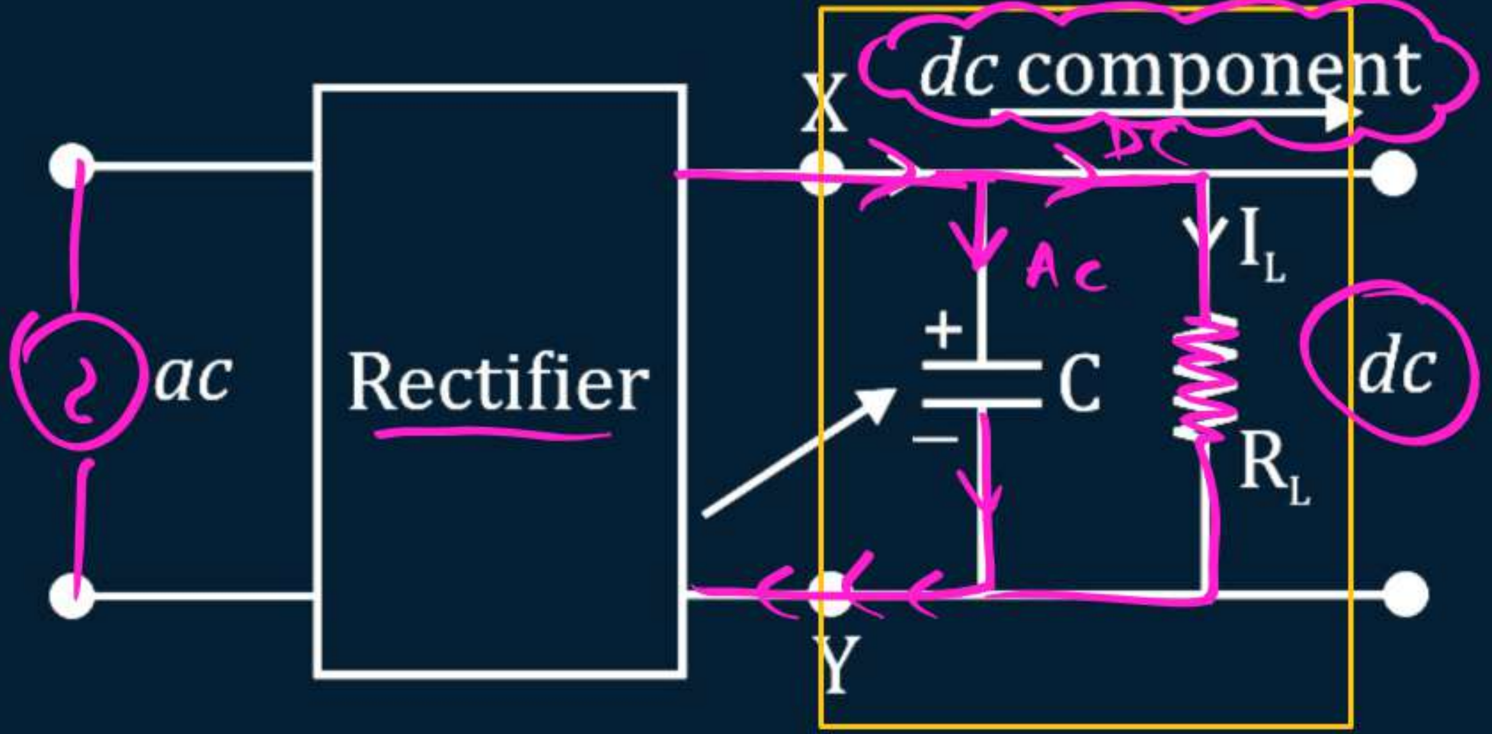
Output waveform across the load R_L connected in Full-wave rectifier Circuit

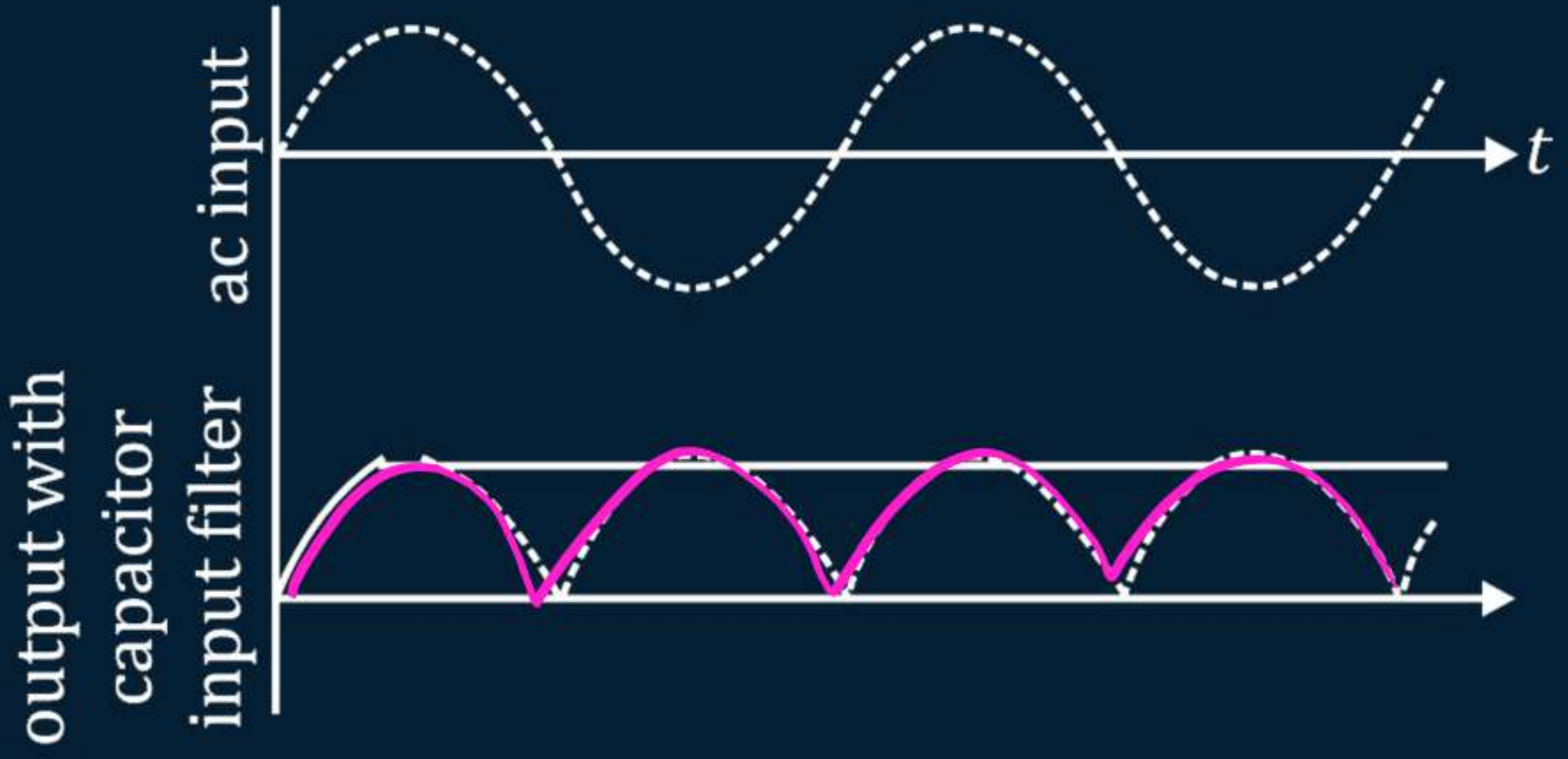
pulsating D.C.

Capacitor Filter Circuit

Capacitor Blocks DC
passes AC

Full-wave rectifier with Capacitor filter





Homework

→ Notes

→ Revision

→ Kal practice session → S.C.E.

PARISHRAM

2026

Semiconductor

Electronics

PHYSICS | Lecture : 3

BY - RAKSHAK SIR

Topics *to be covered*

A Practice Session → PYQ

QUESTION

$$\boxed{n_i^2 = n_h \times n_e}$$

A pure Si crystal having 5×10^{28} atoms m^{-3} is dopped with 1 ppm concentration of antimony. If the concentration of holes in the doped crystal is found to be $4.5 \times 10^{9}\ m^{-3}$, the concentration (in m^{-3}) of intrinsic charge carriers in Si crystal is about **[Delhi Set 1-2024]**

→ Pure ← 15^{th} group (Pentavalent)

↳ e^- extra : n-type

B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb → Antimony
Tl	Pb	Bi

$$N_d \approx n_e = 5 \times 10^{22}\ m^{-3}$$

$$n_h = 4.5 \times 10^{9}\ m^{-3}$$

$$n_i = ?$$

10^6 atoms → 1 impure atom

1 atom → $\frac{1}{10^6}$ impure atoms

5×10^{28} atoms → $\frac{5 \times 10^{28}}{10^6}$ impure atoms

5×10^{22}

$$n_i^2 = n_h \times n_e$$

$$n_i = \sqrt{4.5 \times 10^9 \times 5 \times 10^{22}}$$

SOLUTION

- The relation $np = n_i^2$ always holds for semiconductors in thermal equilibrium.
- In an $\mathbf{n}$-type semiconductor, electrons are majority carriers and $n \approx N_D$.
- Using the known hole concentration, we can easily find n_i.
- The obtained value $(\sim 10^{16}\ \mathrm{m}^{-3})$ matches the known intrinsic carrier concentration for silicon at room temperature, validating our calculation.
- Final Answer (Class 12 Board Format):

$$n_i = 1.5 \times 10^{16}\ \mathrm{m}^{-3}$$

QUESTION

During the formation of a p-n junction: [Delhi Set 1-2023]

(1) Diffusion ($p \to n$) : Majority

(2) Drift ($n \to p$) : Minority

(3) Barrier potential

↳ $\vec{E}$

(4) Depletion Region : Neutral Area

SOLUTION

During the formation of a p-n junction:

1. Diffusion of majority carriers:
   - Electrons move from $\mathbf{n} \rightarrow \mathbf{p}$ region.
   - Holes move from $\mathbf{p} \rightarrow \mathbf{n}$ region.

   (Reason: concentration gradient across the freshly joined crystal.)

2. Recombination near the junction:

   The diffusing electrons and holes recombine close to the junction, so free carriers are removed from this region.

3. Depletion (space-charge) region forms:
    - On the n-side, donor atoms left behind become immobile + ions.
    - On the p-side, acceptor atoms left behind become immobile - ions.

    This ionized region is depleted of free carriers → depletion layer.
4. Built-in electric field and potential barrier:
    - Electric field E sets up from $\mathrm{n} \rightarrow \mathrm{p}$ (from + donor ions to - acceptor ions).
    - Hence the p-side is at higher potential than the n-side.
    - A potential barrier $\mathrm{V_b}$ develops ($\approx 0.7\ \mathrm{V}$ for Si, $\approx 0.3\ \mathrm{V}$ for Ge) which opposes further diffusion.
5. Equilibrium condition:

    The diffusion current (due to majority carriers) is exactly balanced by the drift current (due to the builtin field acting on minority carriers). No net current flows at equilibrium.

    One-line summary: Electrons $\mathrm{n} \rightarrow \mathrm{p}$ and holes $\mathrm{p} \rightarrow \mathrm{n}$ diffuse and recombine, creating a depletion region with an internal field $(\mathrm{n} \rightarrow \mathrm{p})$ and a potential barrier (p at higher potential); at equilibrium, diffusion current = drift current.

QUESTION

$T\uparrow \ \rho\downarrow \ R\downarrow \ \sigma\uparrow$

Assertion (A): The resistance of an intrinsic semiconductor decreases with increase in its temperature. T

Reason (R): The number of conduction electrons as well as hole increase in an intrinsic semiconductor with rise in its temperature. T **[Delhi Set 1-2023]**

SOLUTION

Assertion (A) is True — Resistance decreases with increase in temperature.

Reason (R) is True — Number of conduction electrons and holes increases with temperature.

Reason correctly explains Assertion.

QUESTION

In an extrinsic semiconductor, the number density of holes is 4×10^{20} m^{-3}. If the number density of intrinsic carriers is 1.2×10^{15} m^{3}, the number density of electrons in it is

[Outside Delhi Set 1-2023]

$$n_i^2 = n_h \times n_e$$

$$n_h = 4 \times 10^{20}\, m^{-3}$$

$$n_i = 1.2 \times 10^{15}\, m^{-3}$$

$$n_e = ?$$

SOLUTION

- The relation $np = n_i^2$ is the mass action law for semiconductors.
- In an extrinsic semiconductor, one type of carrier (here holes) is in majority, and the other (electrons) can be found using this relation.
- Since p is very large compared to n_i, the minority carrier concentration (electrons) is very small.
- Final Board-style Answer:

$$n = 3.6 \times 10^9 \ \mathrm{m}^{-3}$$

Hence, the number density of electrons in the extrinsic semiconductor is $3.6 \times 10^9 \ \mathrm{m}^{-3}$.

QUESTION

Pieces of copper and of silicon are initially at room temperature. Both are heated to temperature T. The conductivity of

[Outside Delhi Set 1-2023]

$\alpha +$ $T\uparrow \rho\uparrow$

$T\uparrow$ → Conductor (Cu) → $\sigma\downarrow \rho\uparrow$

→ Semiconductor (Si) → $\sigma\uparrow \rho\downarrow$

$\alpha -$ $T\uparrow \rho\downarrow$

$$\rho = \rho_0(1+\alpha(\Delta T))$$

$$R = R_0(1+\alpha(\Delta T))$$

SOLUTION

(1) Copper (a metal):

- In metals, the number of free electrons (charge carriers) is almost constant — it does not depend much on temperature.
- When temperature increases, lattice vibrations increase, causing more collisions between electrons and atoms.
- This increases the resistivity and hence decreases conductivity.

So, for copper: conductivity decreases with rise in temperature.So, for copper: con ductivity decreases with rise in temperature.

(2) Silicon (a semiconductor):

- In semiconductors, the number of charge carriers (electrons and holes) depends strongly on temperature.
- As temperature increases, more covalent bonds break, creating more electron–hole pairs.
- Therefore, the number of free charge carriers increases rapidly, leading to an increase in conductivity.
- So, for silicon: conductivity increases with rise in temperature.

So, for silicon: conductivity increases with rise in temperature.

QUESTION

The formation of depletion region in a p-n junction diode is due to

[Outside Delhi Set 1-2023]

SOLUTION

The depletion region in a p–n junction diode is formed due to the diffusion and subsequent recombination of charge carriers (electrons and holes) across the junction, leaving behind immobile ions that create a region depleted of mobile charge carriers.

QUESTION

Which of the following has negative temperature coefficient of resistivity?

[(Term 1) Paper 2021-22]

$\downarrow$

Semiconductor

SOLUTION

Because with increase in temperature, the number of charge carriers (electrons and holes) increases, leading to decrease in resistivity.

$T\uparrow$ Covalent Bond break

$\downarrow$

New hole - e^- pair

$\downarrow$

$\sigma\uparrow$ $\rho\downarrow$

QUESTION

V-I

(a) Explain the characteristics of a p-n junction diode that makes it suitable for its use as a rectifier.

(b) With the help of a circuit diagram, explain the working of a full wave rectifier.

[Delhi Set 1-2024]

SOLUTION

(a) Characteristics of a p-n junction diode that make it suitable as a rectifier

1. Unidirectional Conduction:

- A p-n junction diode conducts current only in one direction - when it is forward biased.
- In reverse bias, the current is almost zero (only a small leakage current flows).
- This property allows the diode to convert alternating current (AC) into direct current (DC).

2. Forward Bias Characteristics:

- In forward bias, when the applied voltage exceeds the barrier potential ($\approx 0.7\ \mathrm{V}$ for Si, $\approx 0.3\ \mathrm{V}$ for Ge), the diode conducts heavily.
- The forward current increases exponentially with applied voltage.

3. Reverse Bias Characteristics:

- In reverse bias, only a small leakage current flows until the breakdown voltage is reached.
- This helps the diode block current in the opposite direction.

Hence, due to its unidirectional property, a p-n junction diode is used as a rectifier to convert AC into DC.

SOLUTION

(b) Working of a Full-Wave Rectifier

```
                |------|>|------|
      ~         |      D1       |---- +ve output
  AC -----( )                   |
  Supply        |      D2       |
                |------|<|------|---- -ve output
                       |
                       |
                   (Load RL)
                       |
                      GND
```

QUESTION

Explain the following, giving reasons:

(a) A doped semiconductor is electrically neutral.

(b) In a p-n junction under equilibrium, there is no net current. $i_{diff} = i_{drift}$

(c) In a diode, the reverse current is practically not dependent on the applied voltage.

[Delhi Set 1-2024]

$Al \begin{cases} \to 13e^{+} \\ \to 13p^{+} \end{cases}$ $P \begin{cases} \to 15e^{-} \\ \to 15p^{+} \end{cases}$ $Si \begin{cases} \to 14e^{-} \\ \to 14p^{+} \end{cases}$

SOLUTION

(a) A doped semiconductor is electrically neutral.

- When a pure semiconductor is doped with pentavalent (n-type) or trivalent (p-type) impurities, equal numbers of positive (nuclei/ions) and negative (electrons) charges are introduced.
- The impurity atoms replace silicon (or germanium) atoms in the lattice but do not create any net charge.
- The total number of positive charges = total number of negative charges.

(b) In a p–n junction under equilibrium, there is no net current.

- At equilibrium, two types of currents exist:
  1. Diffusion current: Due to movement of majority carriers (electrons and holes) across the junction.
  2. Drift current: Due to movement of minority carriers under the influence of the electric field in the depletion region.
- These two currents are equal in magnitude but opposite in direction, so they cancel each other.

(c) In a diode, the reverse current is practically not dependent on the applied voltage.

- In reverse bias, the majority carriers are blocked, and only minority carriers contribute to the current.
- The number of minority carriers depends on temperature, not on reverse voltage.
- Thus, increasing the reverse voltage slightly widens the depletion region but does not significantly change the minority carrier current.

QUESTION

(a) Draw the circuit arrangement for studying V-I characteristics of a p-n junction diode in (i) forward biasing and (ii) reverse biasing. Draw the typical V-I characteristics of a silicon diode. Describe briefly the following terms: (i) minority carrier injection in forward biasing and (ii) breakdown voltage in reverse biasing.

OR

(b) Name two important processes involved in the formation of a p-n junction diode. With the help of a circuit diagram, explain the working of junction diode as a full wave rectifier. Draw its input and output waveforms. State the characteristic property of a

[Delhi Set 1-2023]

SOLUTION

(a) (i) Circuit arrangement for forward biasing

Circuit Diagram:

- The p-side of the diode is connected to the positive terminal of the battery.
- The n-side is connected to the negative terminal through a resistor, ammeter, and variable resistor.
- A voltmeter is connected across the diode.

```
(+)
|—— Ammeter —— Diode (p→n) —— Variable Resistor —— (–)
              |—— Voltmeter ——|
```

When voltage is applied in this direction, the potential barrier decreases.Once the applied voltage exceeds the barrier potential (≈0.7 V for Si), the diode conducts heavily.

The forward current rises sharply beyond this voltage.

(a) (ii) Circuit arrangement for reverse biasing

Circuit Diagram:

- In this biasing, the potential barrier increases and only a small reverse saturation current flows due to minority carriers.
- When reverse voltage exceeds a certain limit, the diode breaks down and current increases sharply.

(+) — Ammeter — |<| — Variable Resistor — (–)
|—— Voltmeter ——|

(a) (iii) Typical V–I Characteristics of a Silicon Diode

Forward Bias:

- Current is almost zero until the applied voltage reaches about 0.7 V (the threshold voltage).Beyond this, current increases rapidly.

Reverse Bias:

- Current remains very small (reverse saturation current) until breakdown voltage is reached, after which it rises suddenly.

(a) (iv) Explanation of Terms

Minority Carrier Injection (in Forward Bias):

- Electrons from the n-side cross the junction into the p-side, where they act as minority carriers.
- Similarly, holes from the p-side cross into the n-side and act as minority carriers.

This process is called minority carrier injection.

Breakdown Voltage (in Reverse Bias):

- It is the minimum reverse voltage at which the reverse current increases sharply.
- This occurs due to avalanche breakdown or Zener breakdown mechanisms.

Beyond this voltage, the diode conducts a large current even in reverse direction.

(b) (i) Two important processes involved in the formation of a p–n junction diode:

1. Diffusion:

- When a p-type and n-type semiconductor are joined together, electrons from the n-side diffuse into the p-side, and holes from the p-side diffuse into the n-side due to concentration gradient.
- This movement of majority carriers leads to recombination near the junction.

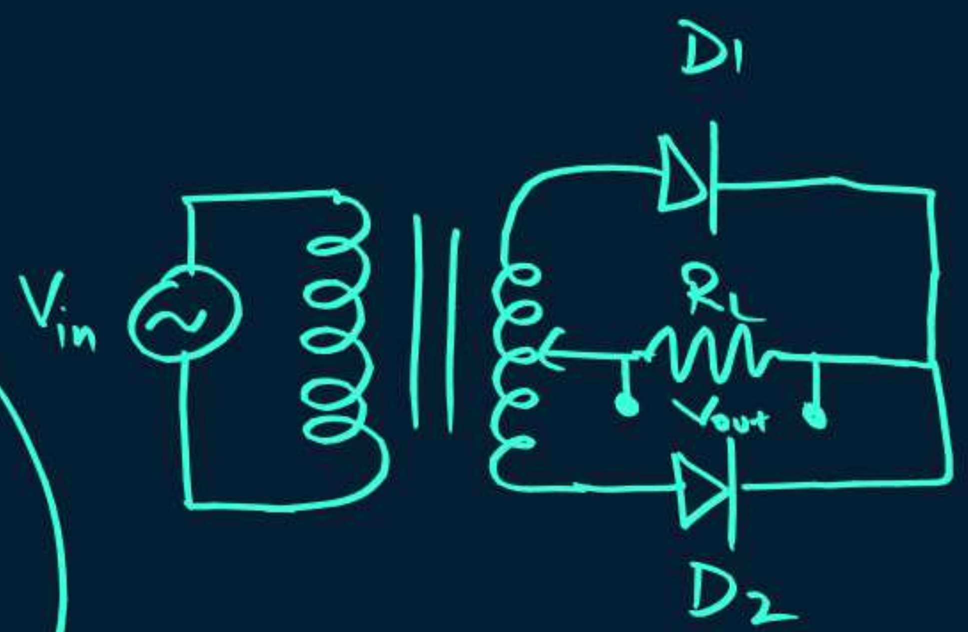
2. Drift:

- As electrons and holes recombine, immobile ions are left behind, creating an electric field (from n to p).
- This field opposes further diffusion, leading to a balance between diffusion and drift currents.

(b) (ii) Working of p–n Junction Diode as a Full-Wave Rectifier

Circuit Diagram:

```
|------|>|------|
  ~     |      D1        |---- + Output
AC -----( )              |
Supply   |       D2       |
        |------|<|------|---- - Output
               |
           (Load RL)
               |
              GND
```



Centre-tap full wave rectifier

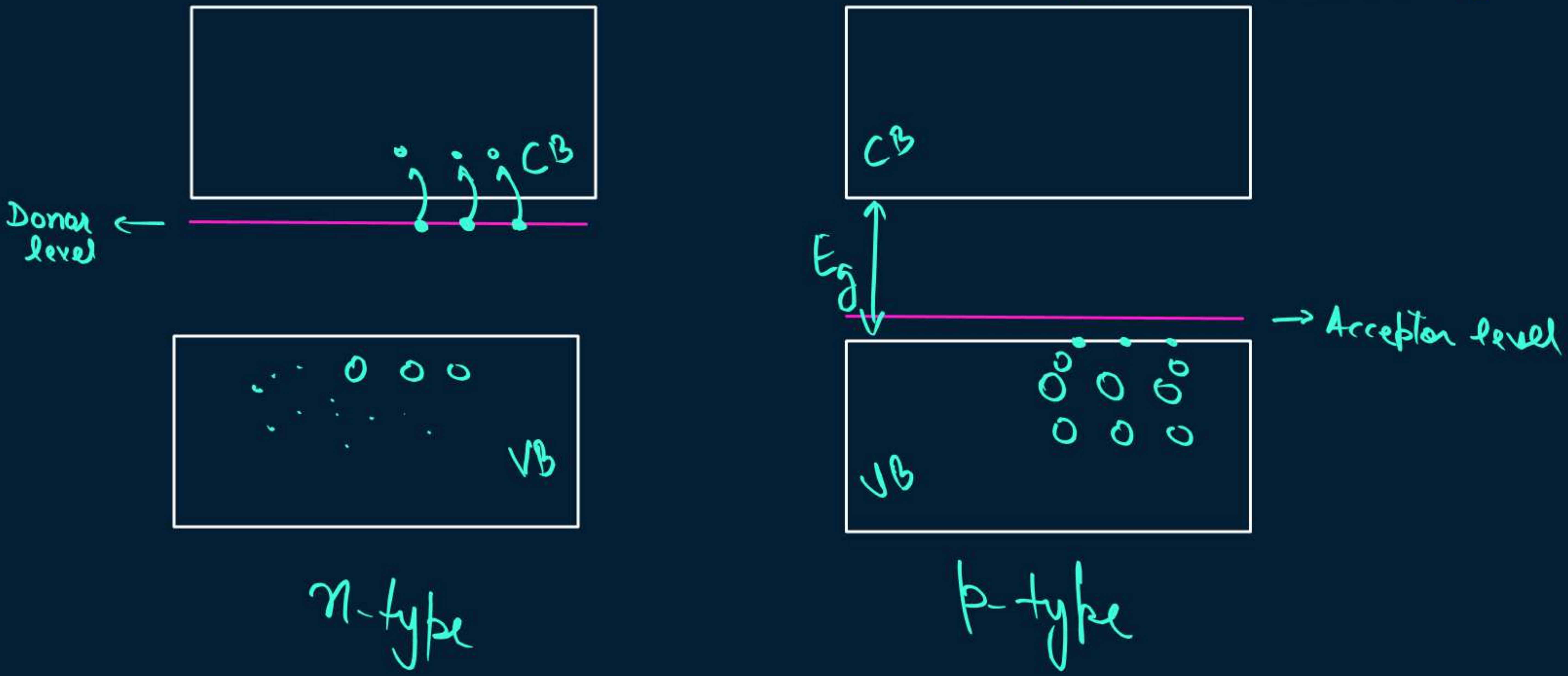
(b) **Explanation:**

1. During the positive half-cycle of AC input:
   - The upper end of the secondary coil becomes positive.
   - Diode D_1 is forward biased → conducts current.
   - Diode D_2 is reverse biased → does not conduct.
   - Current flows through the load resistor R_L in one direction.
2. During the negative half-cycle of AC input:
   - The polarity of the secondary coil reverses.
   - D_2 becomes forward biased and conducts, while D_1 is reverse biased.
   - Current through R_L again flows in the same direction.

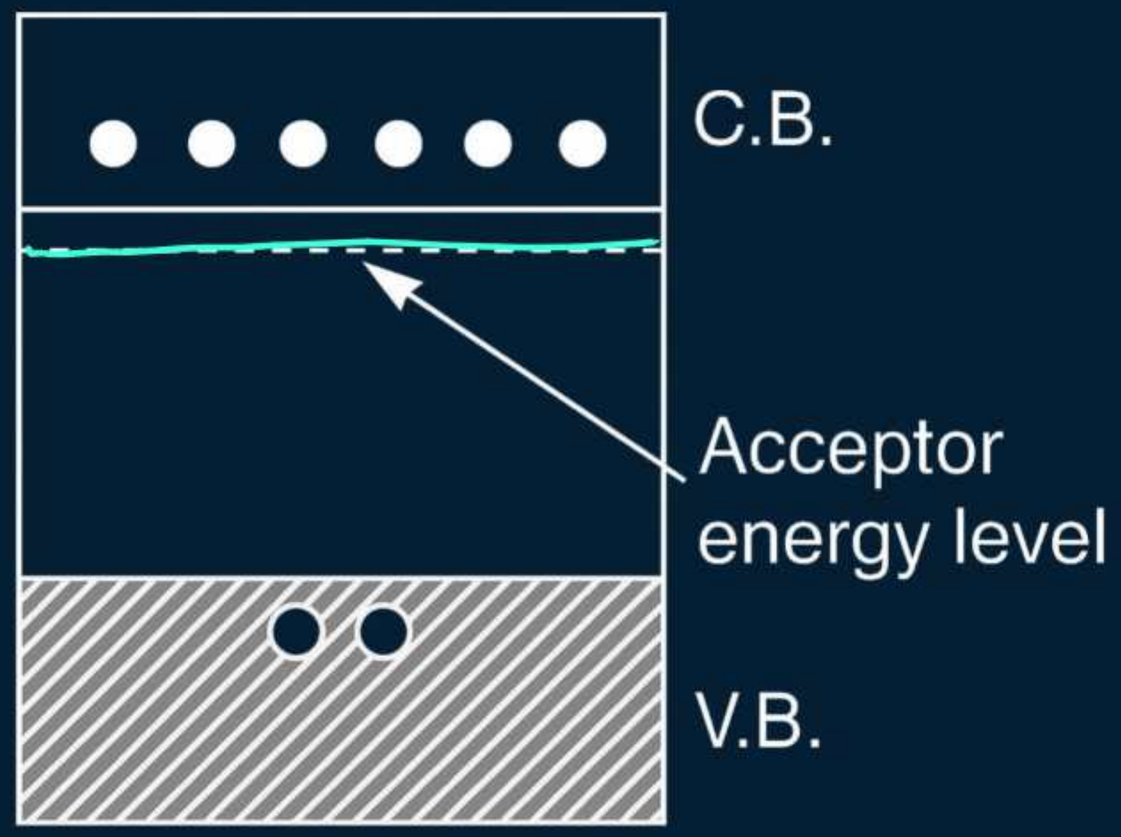
QUESTION

Draw energy band diagram for an n-type and p-type semiconductor at $T > 0$ K.

[Outside Delhi Set 1-2023]



SOLUTION



p-type semiconductor

QUESTION

Answer the following giving reasons:

(i) A p-n junction diode is damaged by a strong current.

(ii) Impurities are added in intrinsic semiconductors. [Outside Delhi Set 1-2023]

SOLUTION

$i\uparrow$

(i) A strong current damages a p-n junction diode because it increases the semiconductor's temperature as more power passes through it and some of that energy is converted to heat. The semiconductor then conducts more current as the temperature rises a little further, which raises the temperature even further. Higher temperature results in more current, which increases the temperature. In what is referred to as a thermal runaway, this cycle keeps repeating. The semiconductor (p-n junction) is ultimately destroyed.

(ii) To improve a semiconductor's electrical conductivity, impurities are added. Doping is the process of introducing impurities into semiconductors to improve their electrical conductivity; these impurities are referred to as ~~intrinsic semiconductors.~~

Dopants

Homework

→ Atoms & Nuclei → Read

→ Numerical

NDA

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