Unit IX => Electronic Devices.

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Chapter => 14

SEMICONDUCTOR DEVICES AND DIGITAL CIRCUITS

ENERGY BANDS IN SOLIDS :->

In a single isolated atom the electrons in each orbit have definite energy associated with it but in case of the solids all the atoms are close to each other and hence the energy level of the outermost orbit electrons are affected by neighbouring atoms.
When two single and isolated atoms are brought close to each other, then the outermost orbit electrons of the two atoms interact with each other i.e., the electrons in the outermost orbit of one atom experiences and attractive force from the nearest atomic nucleus due to which the energy levels of the electrons are modified.

'The electrons in the same orbit exhibit different energy levels. ~~But~~ The grouping of these different energy levels is called Energy Band.'

The energy levels of the inner orbit electrons are not much affected by the presence of neighbouring atoms.

DIFFERENT ENERGY BANDS IN SOLIDS

(a) Valence Band (b) Conduction Band (c) Forbidden Band/ Forbidden Gap.

VALENCE BAND => It is the energy band formed by grouping the range of energy levels of the valence electrons.

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(b) CONDUCTION BAND ⇒ It is the energy band formed by ~~stx~~ grouping the range of energy levels of the free electrons. Generally this band is empty.
The energy levels of this band are higher than that of valence band. On supplying the energy to the electron in the valence band, they may jump from valence band to conduction band.

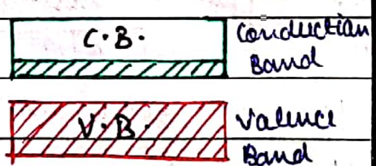
(c) FORBIDDEN BAND ⇒ This energy band is present b/w valence band and conduction band. In solids electrons can not stay in this band because there is no allowed energy state in this region. This band decides electrical conductivity of a solid.

Imp # CLASSIFICATION OF MATERIALS ON THE BASIS OF ENERGY BANDS

Materials

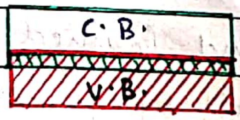
Conductors

Case I



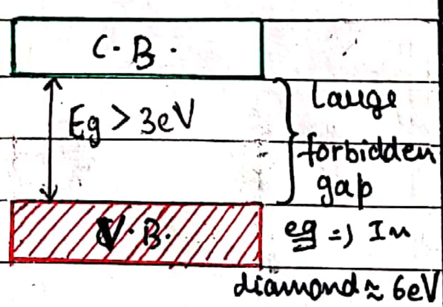
C.B is partially filled and V.B. is completely filled. There is negligible gap b/w them.
ex ⇒ Na.

Case II



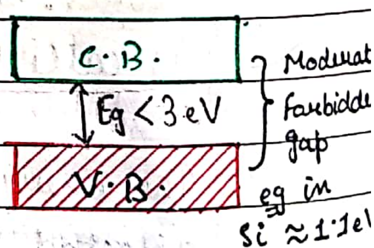
V.B. is completely filled and C.B is empty but V.B. overlaps with C.B. eg ⇒ Zn

Insulators



Valence Band is completely filled and conduction band is ~~a~~ ~~too~~ empty and there is a large forbidden gap between them.
eg ⇒ In diamond ≈ 6eV

Semi-conductors



Valence band is completely filled and conduction Band is empty and there is a moderate forbidden gap.
For eg in Si ≈ 1.1e

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CURRENT CARRIERS IN SEMI-CONDUCTORS

In a pure semi-conductor each atom behaves as if there are 8 electrons in its valence shell (due to the formation of covalent bonds) and therefore the entire material behaves as insulator at low temperature.

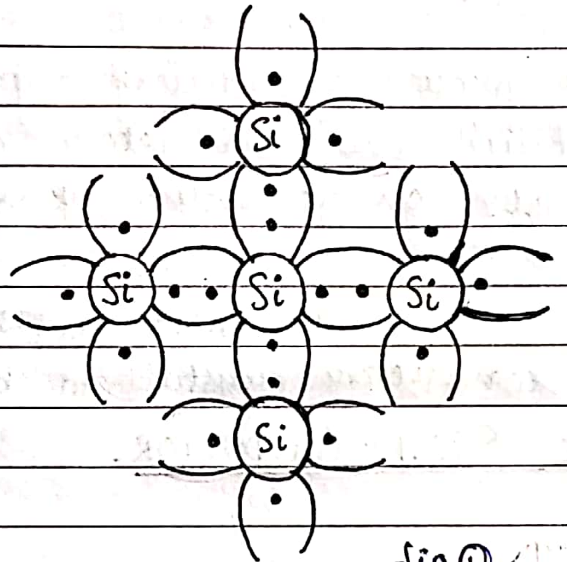

fig ①

at temperature much below room temperature

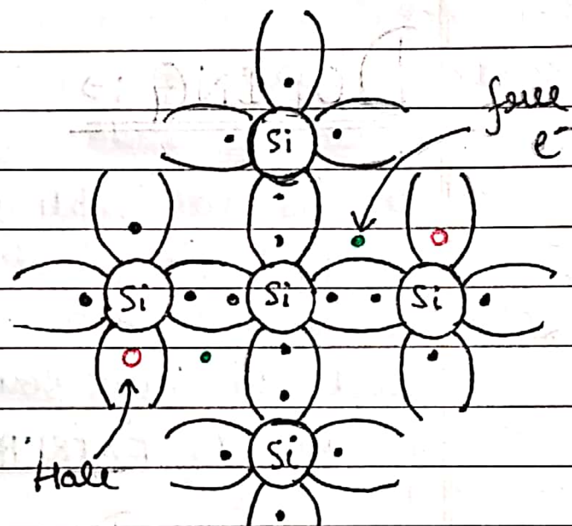

fig ②

At room temperature

At room temperature, due to the thermal agitation, electrons from a few covalent bonds come out creating a vacancy known as a Hole.
This whale can be filled by some other electron in a covalent bond and now the hole is created at the place from where the electron had moved. Thus, the movement of electron and hole are in opposite direction.
The atom which leaves the electron (or where the hole is created) becomes a +ve ion which is immobile.

Thus, at room temperature a pure semi-conductor will have electrons and holes wandering in random directions. These electrons and holes are called INTRINSIC CARRIERS and such a semi-conductor is called **INTRINSIC SEMI-CONDUCTORS.**

In INTRINSIC SEMI-CONDUCTORS :-

$$n_e = n_h = n_i$$

- n_e → no. density of free e^-s
- n_h → no. density of holes
- n_i → no. density of intrinsic carriers

DOPING :-

'The process of adding impurity to a pure semi-conductor crystal so as to improve its conductivity is known as DOPING.'

The impurity atoms added are known as DOPANTS and the new semi-conductor crystal so obtained is known as EXTRINSIC SEMI-CONDUCTOR.

Types of DOPANTS :-

Dopants are classified in two categories :-

DOPANTS → Pentavalent Dopants, Trivalent Dopants

Pentavalent Dopants

- Have 5 valence electrons
- eg ⇒ Phosphorus, antimony, Arsenic.
- Also known as Donor Impurity Atom.
- On adding this impurity to a semi conductor we get n-type extrinsic semi-conductor.

Trivalent Dopants

- Have 3 valence electrons
- eg ⇒ Gallium, Indium, Aluminium, Boron.
- Also known as Acceptor Impurity Atom.
- On adding this impurity to a semi conductor we get p-type extrinsic semi-conductor.

NOTE: Doping does not disturb the overall charge neutrality of the semiconductor.

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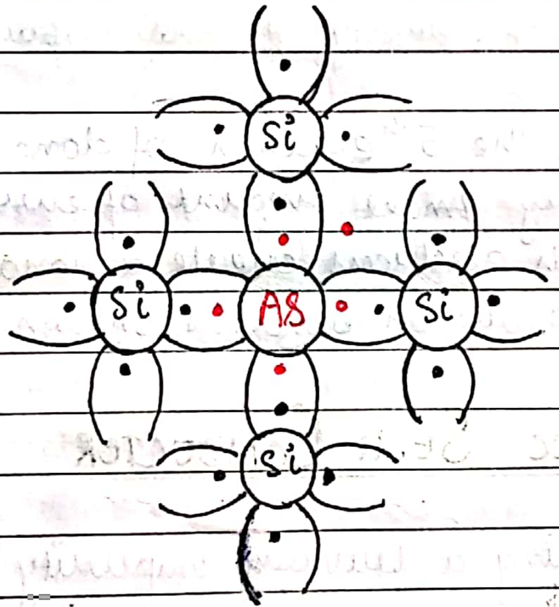
NOTE:⇒ Even the small Doping $(1:10^6)$ can drastically increase the conductivity of a semi-conductor.

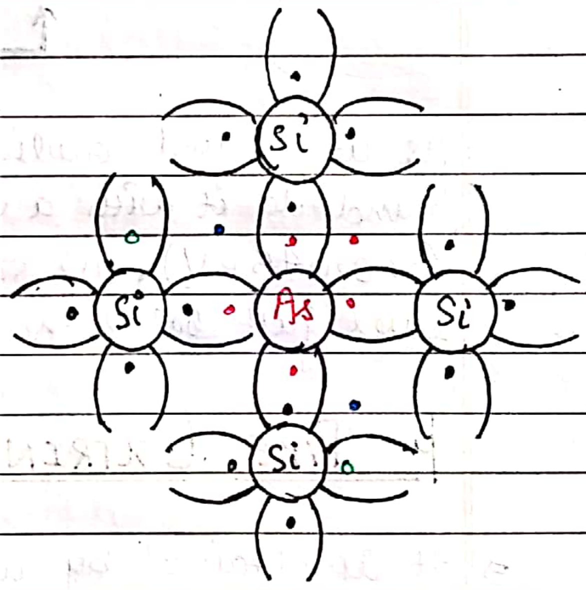
n- TYPE EXTRINSIC SEMICONDUCTOR

It is obtained by adding pentavalent impurity (donor impurity) atoms to a pure semi-conductor.
Consider a pentavalent impurity arsenic is added to a silicon crystal in a small ratio $(1:10^6)$. The 4 electrons out of the 5 valence electrons of arsenic atom take the part in covalent bonding with 4 silicon atoms surrounding it. The 5th electron is set free.



fig(1)

At temperature much below room temperature



fig(2)

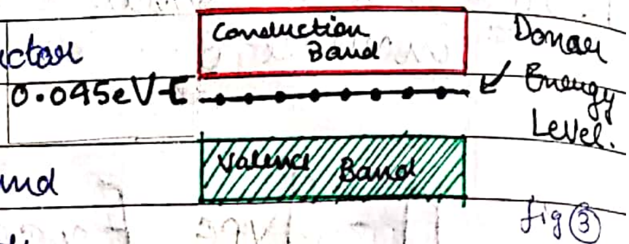
At Room Temperature

⇒ The extra free electrons created in the crystal will be as many as number of pentavalent impurity atoms added.

⇒ The 5th electron of Arsenic atom is bound to the Donor atom with a small amount of energy of order ≈ 0.045 eV. as shown in fig.

⇒ The conduction band has more e's (than holes in valence band) as these e's have been contributed by thermal excitation and donor impurities.

⇒ In n-type extrinsic semi-conductor we have a large no. of free electrons (majority carriers) and a small no. of holes (minority carriers).



Modified Energy Band Diagram

⇒ If n_e is the no. density of the electrons and n_h be the no. density of holes, then

$$n_e n_h = n_i^2$$

n_i ⇒ no. density of intrinsic carriers.

Also, $n_e \approx N_d >> n_h$

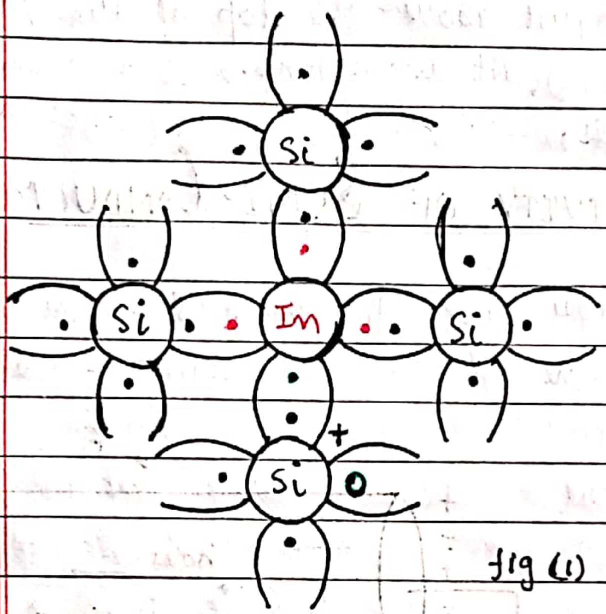
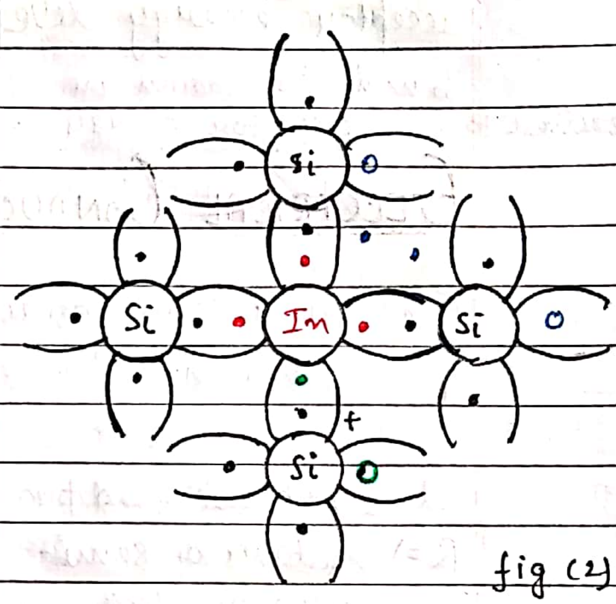
N_d → no. density of donor impurity atom

As we stated earlier, the 5^{th} electron of donor atom is bound to it with a very small amount of energy ($\approx 0.045\,eV$), all such electrons create a donor energy level just below the conduction band as shown in fig(3)

p-TYPE EXTRINSIC SEMI-CONDUCTOR

⇒ It is obtained by adding a trivalent impurity to an intrinsic/pure semi-conductor.

Consider an example in which silicon is doped with a trivalent impurity Indium (In).

 	
at a temperature much below room temperature.	at room temperature.

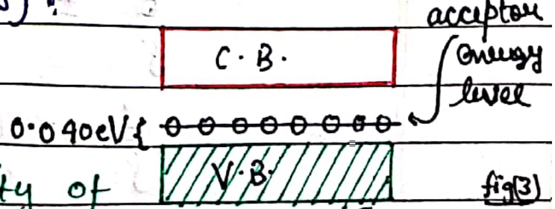
Indium atom can share one electron each with the other 3 silicon atoms surrounding it. In an attempt to have 8 electrons, the Indium atoms robs 1 of the electron from nearby Silicon atom but a hole is created in the covalent bond from which the electron has been robbed and hence for every trivalent impurity atoms added, an extra hole will be created.

At some higher temperature (say room temperature) some electrons will come out from the covalent bonds (as shown in fig(2)) creating a hole at their places.

Clearly, in p-type extrinsic semi-conductor there are large no. of holes (majority carriers) and small no. of electrons (minority carriers).

$$n_h \approx N_a >> n_e$$

N_a → no. density of acceptor impurity atoms.



Modified Energy Band Diagram

⇒ Each acceptor impurity creates a hole ... filled by an e^- of Si–Si covalent bond, i.e., a very small amount of energy ($\approx 0.01\,eV - 0.05\,eV$) is required by an e^- of the valence band to move into this hole. Thus,

⇒ In the p-type extrinsic semiconductor, the holes create an acceptor energy level just above the top of the valence band as shown in fig (3). At room temp., e^-'s of valence band get excited to these acceptor energy levels, leaving behind an equal no. of holes in the valence band.

ELECTRICAL CONDUCTIVITY OF SEMI-CONDUCTOR

Consider a semiconductor block of length 'l' and area of cross section 'A' is connected to a battery of voltage 'V'.

Let E ⇒ Electric field produced

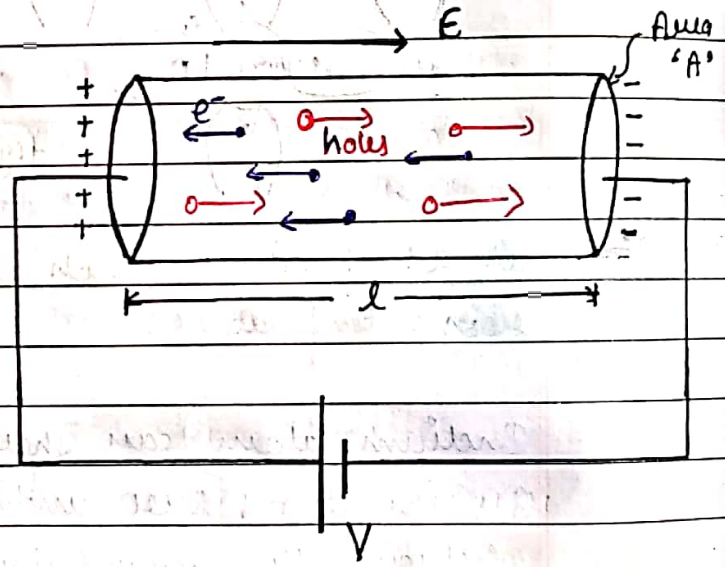
R ⇒ Resistance of semi-conductor block

ρ ⇒ Resistivity of semi-conductor block

I_e ⇒ electron current

I_h ⇒ hole current

I ⇒ Total current



Clearly $I = I_e + I_h$

$$I = n_e e A v_e + n_h e A v_h \qquad [\text{as } I = neAv_d]$$

$$\therefore \frac{V}{R} = eA\left[n_e v_e + n_h v_h\right] \qquad \left(\text{as } I = \frac{V}{R}\right)$$

$$\frac{V}{\rho \frac{l}{A}} = eA\left[n_e v_e + n_h v_h\right] \qquad \left(\text{as } R = \rho\frac{l}{A}\right)$$

$$\frac{V}{l}\frac{\cancel{A}}{\rho} = e\cancel{A}\left[n_e v_e + n_h v_h\right] \qquad \left(\text{as } \frac{V}{l} = E\right)$$

$$\frac{E}{\rho} = e\left[n_e v_e + n_h v_h\right]$$

$$\frac{1}{\rho} = e\left[n_e\frac{v_e}{E} + n_h\frac{v_h}{E}\right]$$

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conductivity

$$\sigma = e\left[n_e \mu_e + n_h \mu_h\right] \quad \left(\text{as } \frac{v_e}{E} = \mu\right)$$

electron mobility — hole mobility

⇒ At low temperature pure semi-conductor behaves as an insulator. It becomes slightly conducting at room temperature.

⇒ Even small doping can drastically change the conductivity of intrinsic semi-conductors.

⇒ Electron mobility is higher than the Hole mobility in the semiconductors.

⇒ Unlike conductors, the electrical resistivity of semi conductor decreases with the increase in temperature.

⇒ If the light of energy greater than forbidden energy gap is incident on intrinsic semi-conductor, the electrons from valence band moves to conduction band. This phenomenon is called Photo Conductivity which is used in Light Depending Resistors [LDR].

Q ⇒ Pure Silicon at 300K has equal electron and hole concentration of $1.5 \times 10^{16}/m^3$. Doping by Indium increases the hole concentration to $4.5 \times 10^{22}/m^3$. Calculate the electron concentration in the doped silicon.

Soln ⇒ $n_i = 1.5 \times 10^{16}\ m^{-3}$ $\quad n_h = 4.5 \times 10^{22}\ m^{-3}$

as $n_i^2 = n_e \cdot n_h$

$$n_e = \frac{n_i^2}{n_h} = \frac{1.5 \times 10^{16} \times 1.5 \times 10^{16}}{4.5 \times 10^{22}}$$

$$= 0.5 \times 10^{10}$$

$$n_e = 5 \times 10^{9}\ m^{-3}$$

conductivity

$$\sigma = e[n_e \mu_e + n_h \mu_h] \quad \left(\frac{v_d}{E} = \mu\right)$$

μ_e: electron mobility; μ_h: hole mobility

Difference b/w INTRINSIC AND EXTRINSIC Semiconductors

	INTRINSIC Semiconductors	EXTRINSIC Semiconductors
(1)	These are pure semi-conducting tetravalent crystals.	These are semi-conducting tetravalent crystals doped with impurity of group III or V.
(2)	Their electrical conductivity is low.	Their electrical conductivity is high.
(3)	There is no permitted energy state b/w valence and conduction bands.	There is permitted energy state of the impurity atom b/w valence & conduction bands.
(4)	The no. of free electrons in the conduction band is equal to the no. of holes in valence band.	The e^-s are majority charge carriers in n-type semiconductor while holes are majority charge carriers in p-type semiconductors.
(5)	Their electrical conductivity depends on temperature.	Their electrical conductivity depends on temp. as well as on dopant concentration.

by an e^- of Si–Si covalent bond, i.e., a very small ... of energy ($\approx 0.01\,eV - 0.05\,eV$) is required by an e^- of the valence band to move into this hole. Thus,

⇒ In the p-type extrinsic semiconductor, the holes create an acceptor energy level just above the top of the valence band as shown in fig (3). At room temp., e^-s of valence band get excited to these acceptor energy level, leaving behind an equal no. of holes ...

Difference b/w n-Type AND p-Type Semi-Conductors.

	n-Type Semi Conductor	p-Type Semiconductors
(1)	These are extrinsic semi-conductors obtained by doping impurity atoms of group V to Ge or Si crystal	These are extrinsic semi-conductors 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 valence 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)	The free electron density is much greater than hole density, i.e., $n_e >> n_h$.	The hole density is much greater than free electron density, i.e., $n_h >> n_e$.

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p-n JUNCTION :->

A single piece of semi-conductor material (either silicon or Germanium) with one portion doped with pentavalent impurity and the other with trivalent impurity behaves as p-n Junction. The boundary dividing the 2 portions is called Junction.

FORMATION OF p-n JUNCTION :->

Smaller quantity of Trivalent impurity, say indium (In) is fused to a thin waffer (a thin slice) of n-type Germanium / silicon semiconductor. This process produces p-type Germanium / silicon just below the surface of contact. This p-type semi-conductor along with n-type semiconductor waffer forms a p-n Junction.

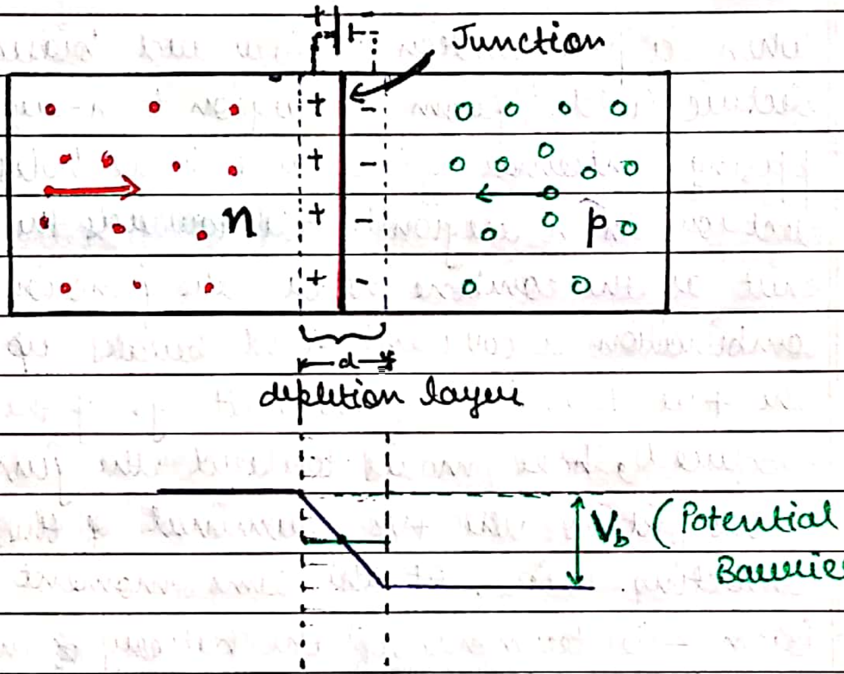
Depletion Layer and Potential Barrier in p-n Junction

'The region around the junction having no mobile charge carriers is known as Depletion Layer or Depletion Zone or Space Charge Region.'

When p-n Junction is formed electrons diffuse through the junction from n-region to p-region and combine with the holes and hence get neutralised. Similarly, holes diffuse through the junction from p-region to n-region and combine with the electrons and hence get neutralised. Due to this -ve ions in p-region and +ve ions in n-region are produced which remain fixed at their positions in the crystal lattice. These ions form -ve and +ve charge regions near the junction. This region is devoid of the mobile charge carriers which is known as Depletion Region.

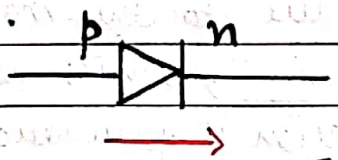
'The potential difference set up across the junction due to the formation of charged regions which opposes the diffusion of the charge carriers further is known as Potential Barrier.'

Its Value is nearly 0.7 V for Silicon and 0.3V for Germanium.



Semi Conductor Diode or (p-n Junction Diode)

A p-n junction having metallic contacts at both the ends is called a semi conductor diode or p-n Junction Diode.



Biasing of p-n Junction Diode

'The process of connecting a diode to a battery is called Biasing.' or 'Applying external voltage to a p-n junction diode is called Biasing.'

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A diode can be given biasing in following 2 ways:-
(1) FORWARD BIASING (2) REVERSE BIASING

p-n Junction Diode under forward Biasing:-

'A p-n junction diode is said to be forward biased when its p-section is connected to +ve and n-section is connected to -ve terminal of the cell / battery.'

When a p-n junction is forward biased then external / applied electric field (from p-region to n-region) dominates over opposing internal field and hence holes in p-region and electrons in n region move towards the junction and ceases to exist as the combine near the junction. For each such combination a covalent bond breaks up in the p-region near the +ve terminal of the battery. Of the hole and electron so produced, hole moves toward the junction, and electron moves enters the +ve terminal of the battery through connecting wire. At the same moment an electron is released from -ve terminal of the battery ~~of~~ and enters the n-region to replace the electron lost by combining with a hole at the junction. Thus, the motion of majority carriers (holes in p-region and electrons in n-region) constitute a current across the junction, called forward current. (In addition to this large current there is a small reverse current due to the motion of minority carriers, called reverse current, which is almost negligible). Thus, when a p-n junction is forward biased

(a) the effective potential barrier reduces.
(b) thickness of depletion layer decreases.
(c) The junction resistance becomes very low ~~an~~
(d) A large ~~forward~~ current (when potential barrier is broken) flows through the diode.

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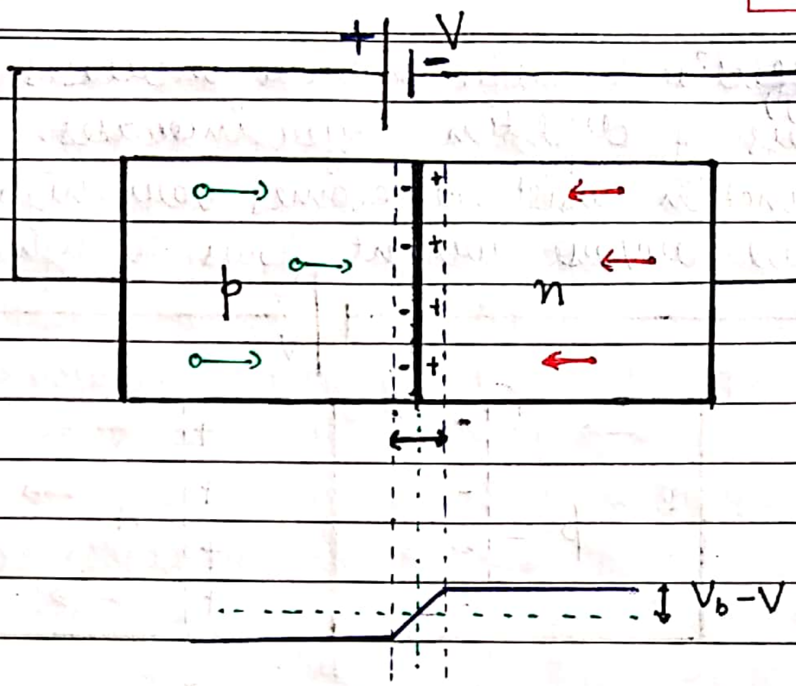

p-n Junction Diode Under Reverse Biasing :-

'A p-n junction diode is said to be reverse biased when its p-section is connected to -ve and n-section is connected to +ve terminal of the cell/battery.'

When a p-n junction is reverse biased then external/applied electric field (from n region to p-region) ~~aids~~ supports the opposing internal field and hence holes in p-region and electrons in n-region move away from the junction and hence cannot combine near the junction. Thus, there is almost no current due to the flow of majority carriers. However there is a very small reverse current (≈ few μA) flows across the junction due to few thermally agitated minority carriers (electrons in p-region and holes in n-region) which move across the junction under the applied electric field. The reverse current is temperature dependent and increases with the temperature of the diode. Thus when a p-n junction is reverse biased :-

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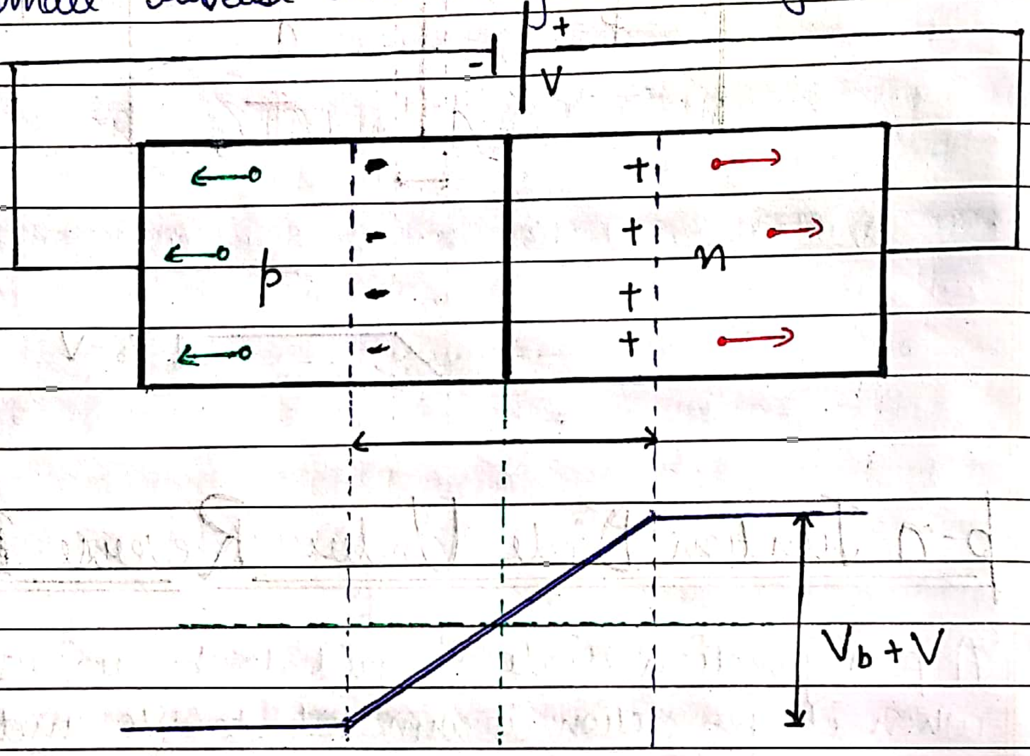
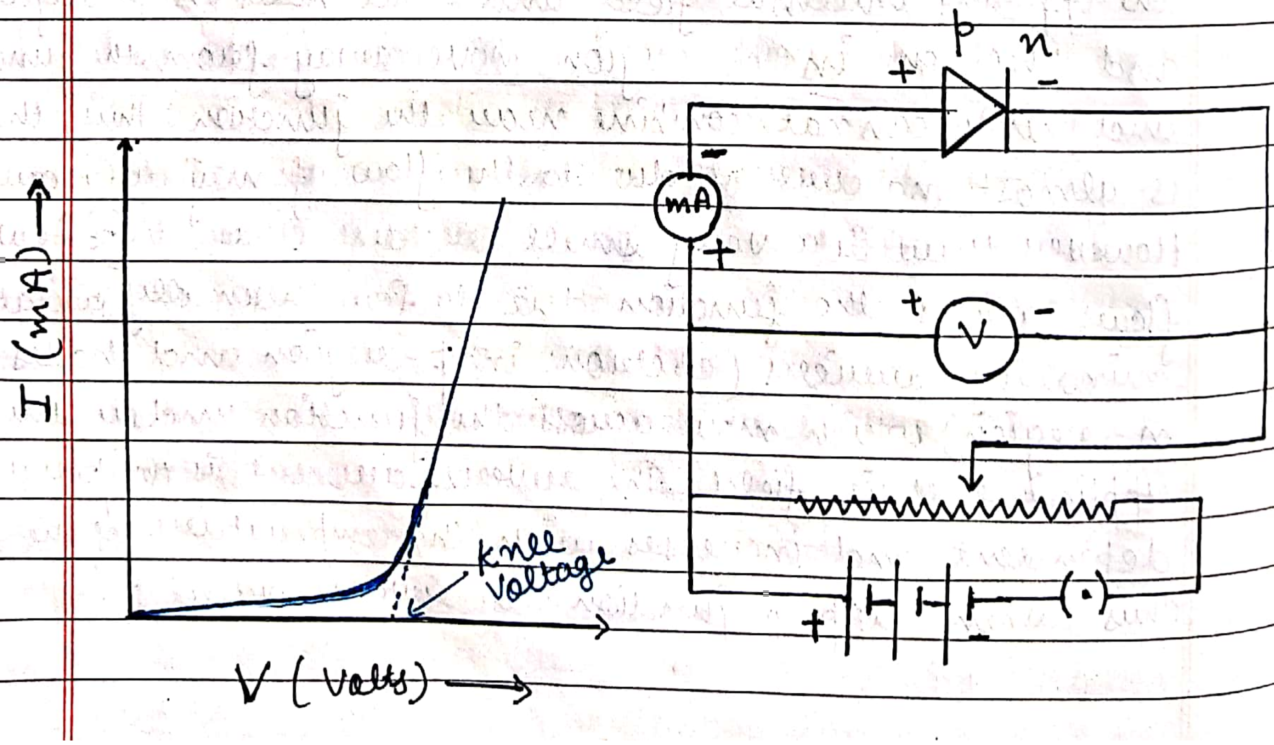
(a) the effective potential barrier increases.
(b) thickness of depletion layer increases.
(c) the junction resistance becomes very high
(d) a small reverse current flows through the diode.



V-I CHARACTERISTICS OF p-n JUNCTION DIODE

(A) Forward Bias Characteristics :->



knee Voltage (cut in Voltage)

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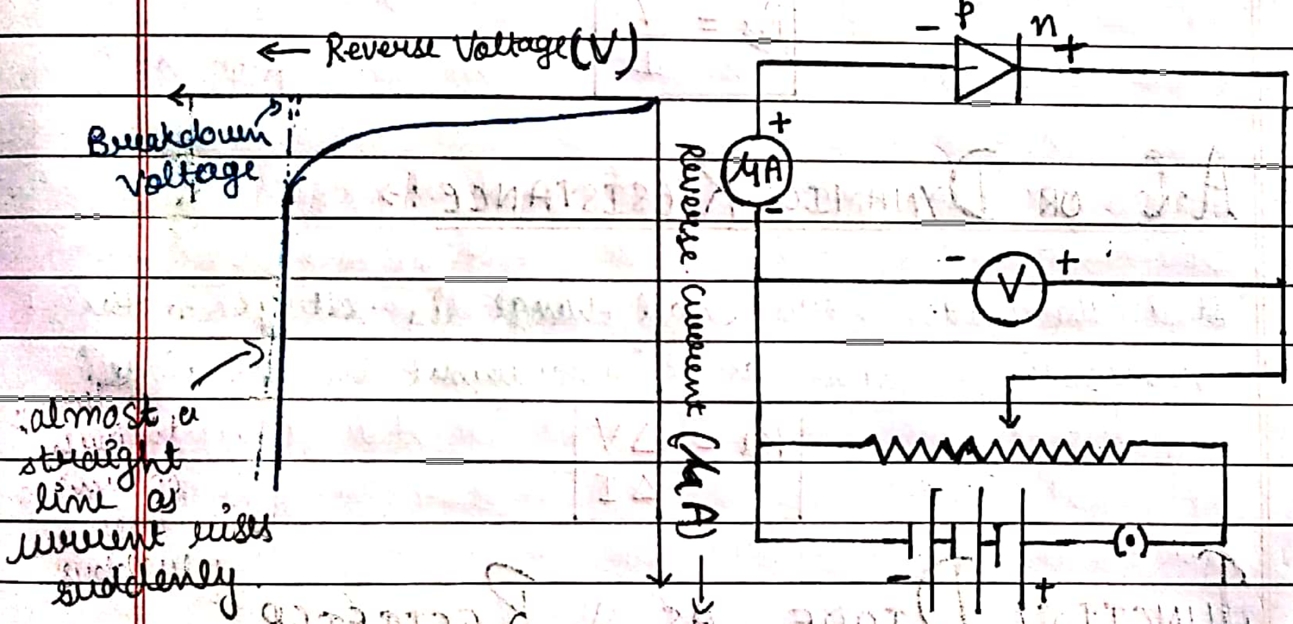
These are the graphs showing the variations of current with the applied voltage when the diode is forward biased. The circuit diagram to study these characteristics and the characteristics so obtained are shown in the fig.
The current for the diode increases slowly in the begining but when the applied voltage is above a certain voltage (called knee voltage or threshold voltage) the current increases rapidly. (for Si ≈ 0.7V and Ge ≈ 0.3V)

(B) Reverse Bias Characteristics



These are the graphs showing the variation of current with the applied voltage when diode is reverse biased. The circuit diagram to study these characteristics and the characteristics so obtained are shown in the fig.

When the diode is reversed biased there is a small current due to the minority carriers which attain a maximum or saturation value immediately and is independent of the applied reverse voltage. It depends upon the temperature of the diode.

Imp → As the reverse voltage is increased to a certain critical value called Breakdown or Zener Voltage, large

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amount of covalent bonds in both the regions are broken due to which large electron-hole pairs are produced which diffuse through the junction and hence there is a sudden rise in the reverse current.

D.C. OR STATIC RESISTANCE :→

It is the ratio of dc voltage across the diode to the direct current flowing through it, i.e.,

$$R_s = \frac{V}{I}$$

A.C. OR DYNAMIC RESISTANCE :→

'It is the ratio of the small change in voltage to the corresponding small change in current in the diode.'

$$R_d = \frac{\Delta V}{\Delta I}$$

Imp #
JUNCTION DIODE AS A RECTIFIER

'A device which converts ac power into dc power is known as Rectifier and the process of conversion of a.c power into dc power is known as Rectification.

PRINCIPLE :→ 'A junction diode offers low resistance and hence conducts when forward biased and offers high resistance and hence does not conducts when reverse biased.'

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TYPES :→ There are 2 types of rectifiers :→

(1) **HALF WAVE RECTIFIER** ⇒ It rectifies only half of the ac input cycle.

(2) **FULL WAVE RECTIFIER** ⇒ It rectifies the complete ac input cycle.

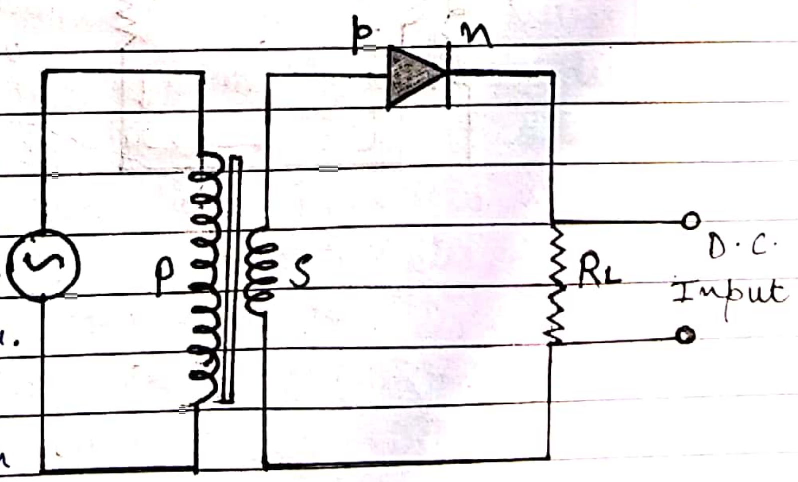
Junction Diode as a Half Wave Rectifier

A Half Wave Rectifier rectifies only half of the ac input cycle.

PRINCIPLE :→ 'A junction diode offers low resistance and hence conducts when forward biased and offers high resistance and hence does not conducts when reverse biased.' When ac input is applied to the diode, the diode will be on forward and reverse biasing for alternate +ve half and −ve half cycles of ac input. The diode will conduct only for those half cycles for which it is forward biased.

Circuit Diagram :→ The circuit for the half wave rectifier is shown in the fig. below

The ac input signal to be rectified is fed to the Primary (P) coil of step down transformer. The secondary (S) coil is connected to junction diode through load resistance (R_L).



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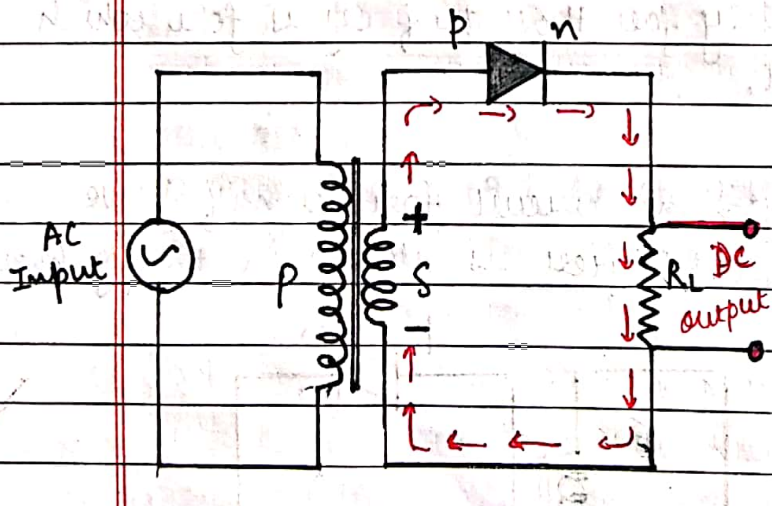
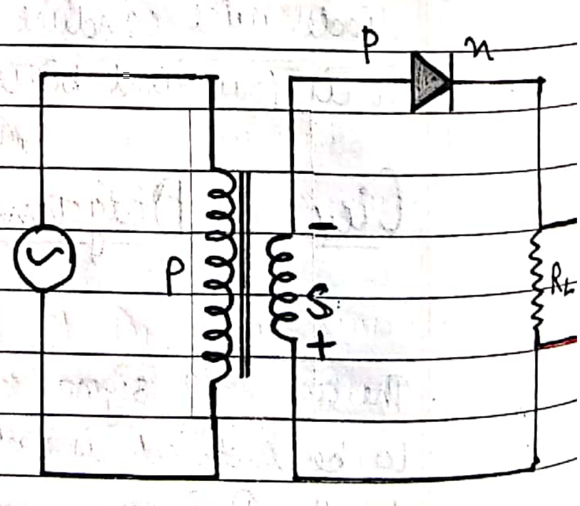
The dc output signal is obtained across the load resistance R_L.

WORKING :-) When the +ve half cycle of ac input signal flows through the primary coil (P) an induced emf is set up in the secondary coil (S). [due to mutual induction]. Let the direction of induced emf is such that the upper end of the secondary coil becomes +ve and lower end becomes -ve, then this takes the diode on forward bias and hence the diode conducts. Thus, the output is obtained across R_L which varies as per the input half cycle.

When -ve half cycle of ac input flows through the primary, again an induced emf is set up across secondary. Let now the direction of induced emf is such that the upper end of the secondary becomes -ve and lower end becomes +ve which takes the diode on Reverse Bias. Therefore, the diode does not conduct and no output is obtained across R_L.

The Input and corresponding output voltages are shown in the fig below :-)





No output obtained.

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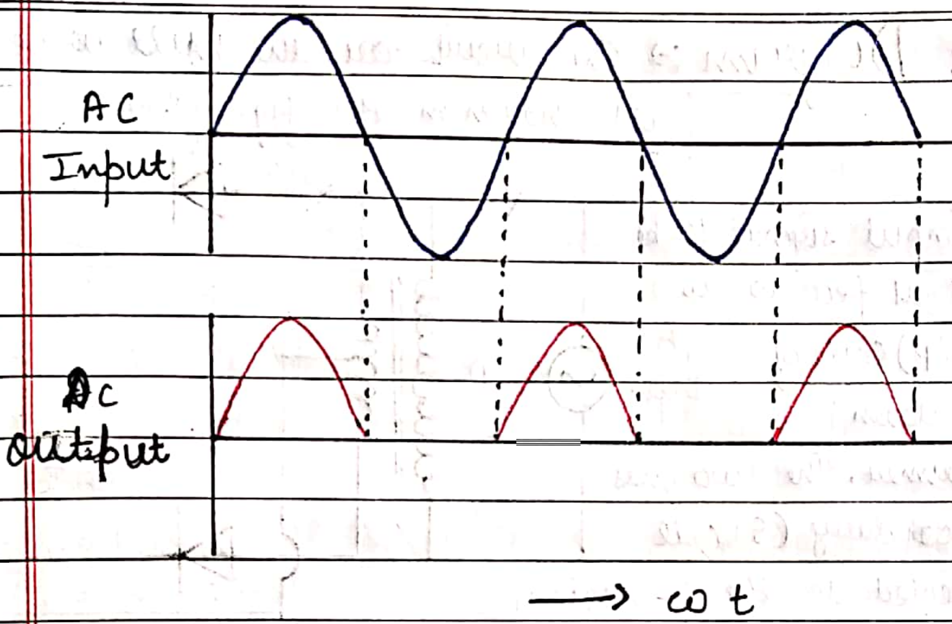


DISADVANTAGES OF HALF WAVE RECTIFIER

(1) Output signal is discontinuous.
(2) Efficiency is less.
(3) output is fluctuating or pulsating which contains a.c. components or ripples. Also output d.c. voltage

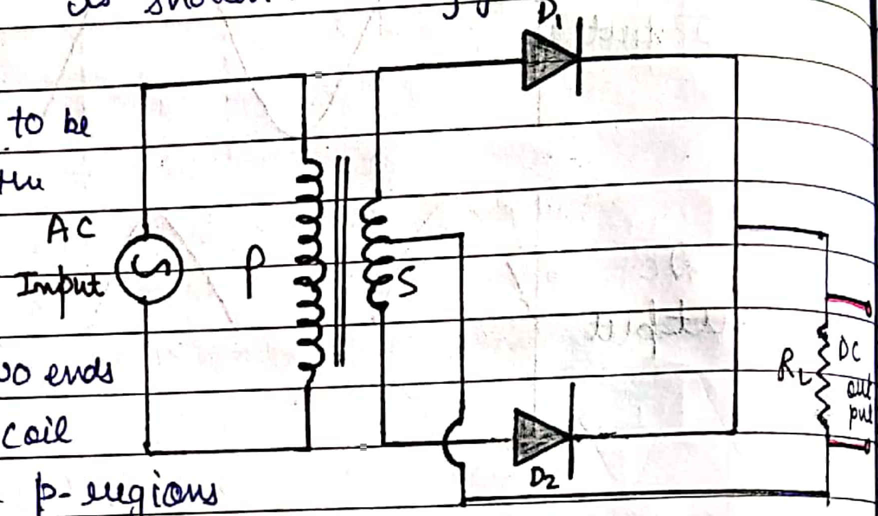
$$V_{dc} = I_{dc} \times R_L = \frac{I_0}{\pi} \times R_L$$

Junction Diode as a Full Wave Rectifier

Full wave Rectifier rectifies the complete ac input cycle.

PRINCIPLE: → 'An ideal junction diode offers low (zero) resistance and hence conducts when forward biased and offers high (∞) resistance and hence does not conducts when reverse biased.' Here two diodes D_1 and D_2 are connected in such a way that, for those half cycles for which D_1 is forward biased and hence conducts, D_2 will be at reverse bias and hence does not conducts and, for which D_2 is forward biased and hence conducts, D_1 will be at reverse bias and hence does not conducts.

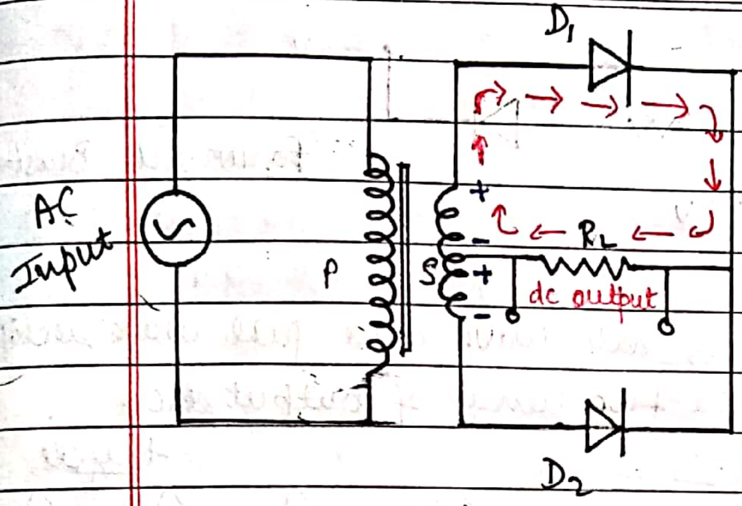
Circuit Diagram :- The circuit for the full wave rectifier is shown in the fig. below.



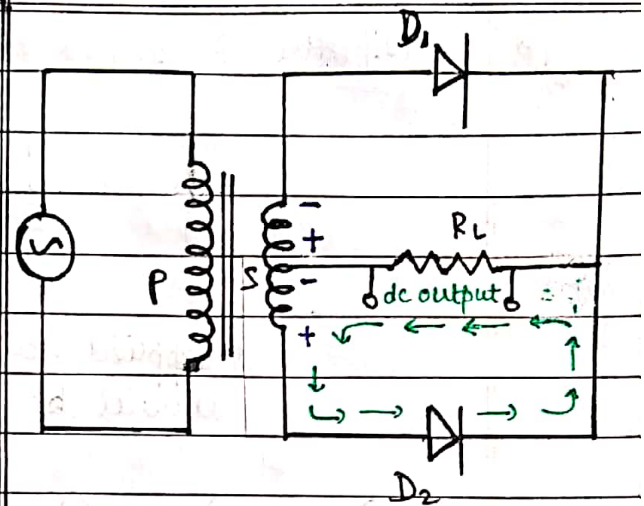
The ac input signal to be rectified is fed to the Primary (P) coil of the step down transformer. The two ends of the secondary (S) coil are connected to the p-regions of the junction diode D_1 and D_2. The load resistance (R_L) is connected b/w common point of n-sides of the diodes and the central tapping of the secondary coil. The dc output signal is obtained across the load resistance.

WORKING :- When the +ve half cycle of ac input signal flows through primary coil of the step down transformer, an emf is induced across the secondary coil of the transformer. Let the direction of induced emf is such that the upper end of the secondary is +ve and lower end is -ve, then D_1 gets forward and D_2 gets reverse biased and hence only the diode D_1 conducts. Thus, an output is obtained across R_L through D_1.

When the -ve half cycle of ac input comes D_1 is at reverse bias and D_2 is at forward bias and hence D_2 conducts. Thus, the output is obtained across R_L through D_2.

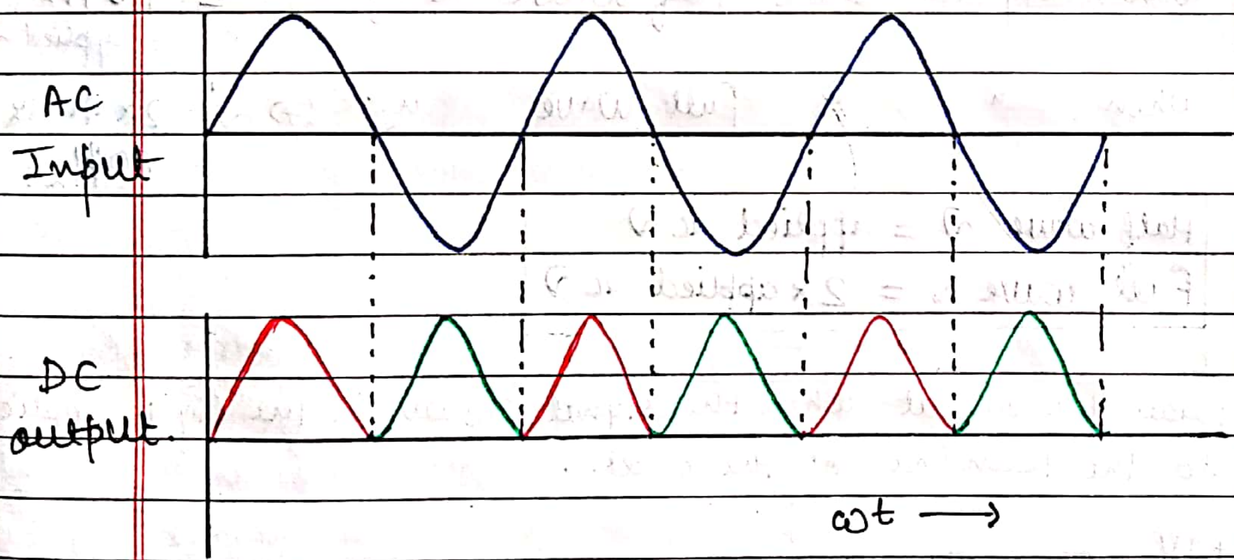


when +ve half cycle flows.
D_1 ⇒ current flows.
D_2 ⇒ current does not flow.



when −ve half cycle flows.
D_1 ⇒ current does not flow
D_2 ⇒ current flows.

The input and corresponding output voltages are shown in the fig. below :-



Disadvantages of Full Wave Rectifier

(1) Output is fluctuating or pulsating which contains ac components or ripples also.

(2) Additional filter circuit is required to get smooth dc output.

SPECIAL PURPOSE p-n JUNCTION DIODE :→

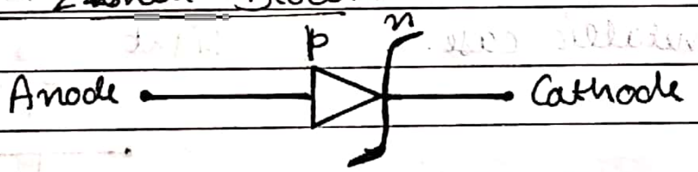
Accept rectification junction diodes can be manufactured for some other purposes also like voltage regulation, light conduction, light emission, solar generation, etc.

* (A) ZENER DIODE :→

'A properly doped p-n junction diode which works in the breakdown region without being damaged is called ZENER OR BREAKDOWN DIODE.'

It is designed to operate under reverse bias in the breakdown region and mainly used as voltage regulator.

Symbol of Zener Diode :→



It is fabricated in such a way that both n and p regions of the diode are heavily doped. As a result of this the thickness of the depletion region is very small and thus a strong electric field is set up across the junction.

OPTOELECTRONIC JUNCTION DEVICES :→

'An optoelectronic Junction device is a junction diode which conducts when light is incident on it.'

Charge carriers in such a devices are generated by photons. Junction diode conducts when electric field is applied across the junction of the diode. However some special junction diodes can also conduct when charge carriers are generated by exposing the junction diode of suitable frequency.

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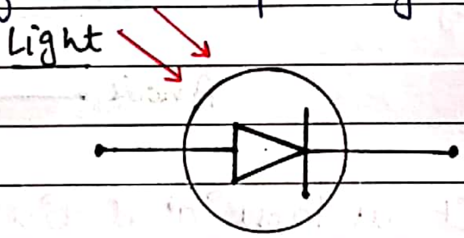
(B) **PHOTO DIODE** :- 'It is reversed biased p-n junction made from photo sensitive semi-conductor.'

In photo-diode, the reverse current varies linearly with the light flux when diode is illuminated with the light.

For operating a photo diode reverse bias is kept below the breakdown voltage. Conductivity of photo diode changes with the absorption of light around depletion layer.

Construction :- A reverse bias p-n junction diode is enclosed in transparent envelope. Light is allowed to fall on the transparent surface facing the diode. All other faces of the envelope may be enclosed in a metallic case.



Action and V-I Characteristics of Photo Diode

The circuit diagram to study V-I characteristics of a photo diode is shown below:-

When photo diode is reverse bias, a constant current I_d flows due to the thermally generated minority carriers known as DARK CURRENT. When the reverse biased junction is illuminated, the no. of newly created electron-hole pairs is proportional to the no. of incident photons. Now, the total reverse current $I = I_d + I_s$ where I_s is the short circuit current which is proportional to the light intensity.

The photo generated charge carriers increases the conductivity of the semiconductor.

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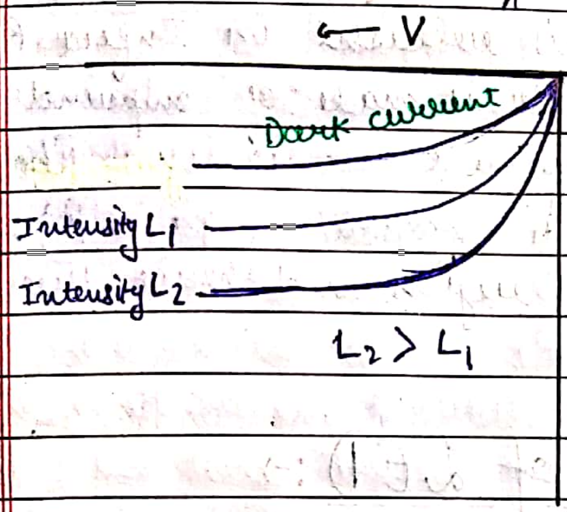
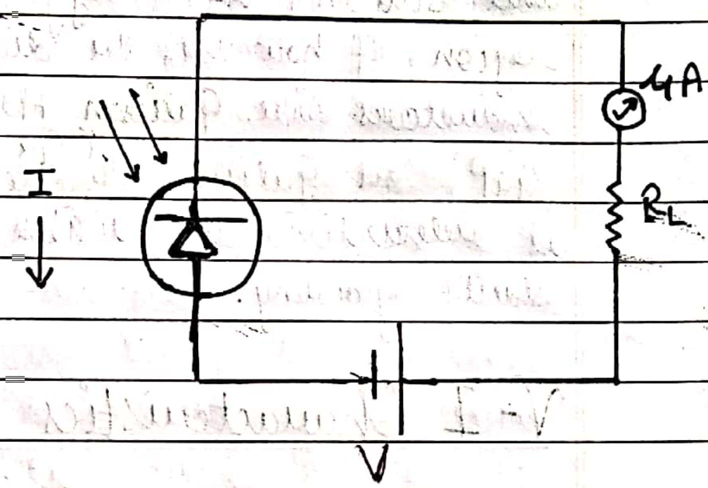
The V-I characteristic of photo diode is shown in the fig. below.



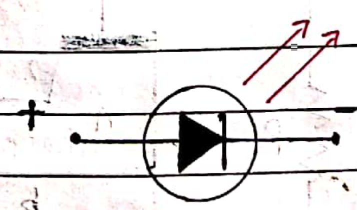


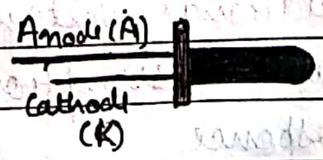
Uses of Photo Diode :-

(1) Used as photo detectors to detect intensity of radiation.
(2) Used as light operated switches.
(3) Used in optical communication equipments.
(4) Used in Logic circuits.
(5) Used as optical demodulators.
(6) Used to count the objects interrupting the light beam.

(C) LIGHT EMITTING DIODES :- [LED]

'A special heavily doped p-n junction diode which emit spontaneous radiations when forward biased is known as Light emitting Diode (LED).'
It converts electrical energy into light energy.



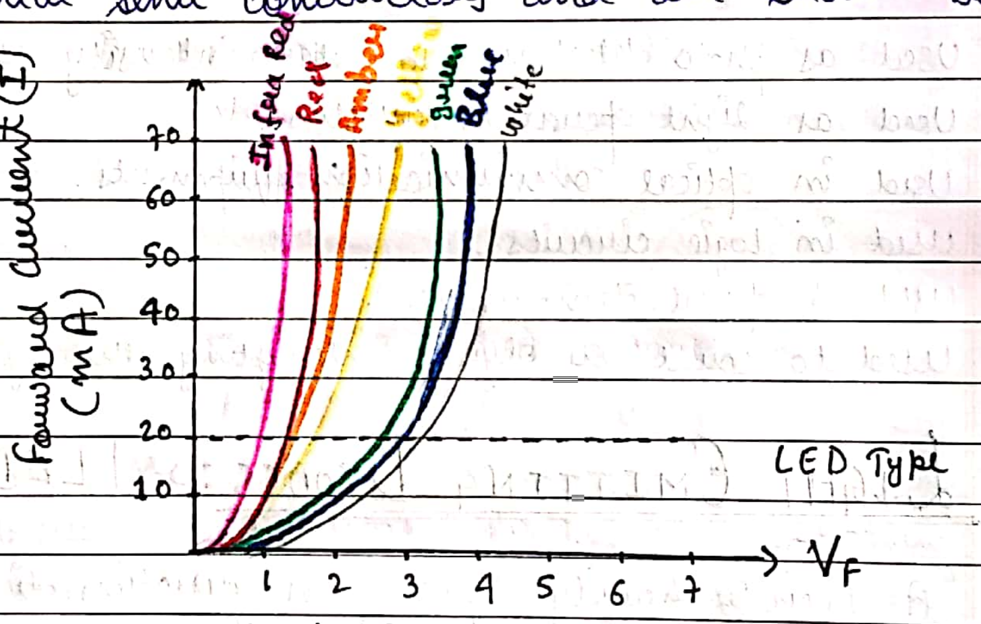


When junction diode is forward biased, the electrons and holes recombine at the junction and energy is released in the form of electromagnetic radiation.

In case of elemental semi conductors like Germanium and Silicon, the energy is released in Infra Red region. If however, the diode is made of compound semi-conductors like Galium Arsenide (GaAs) or Galium Phosphide (GaP) or Galium Arsenide Phosphide (GaAsP), the energy is released in the visible region and hence the diode starts glowing.

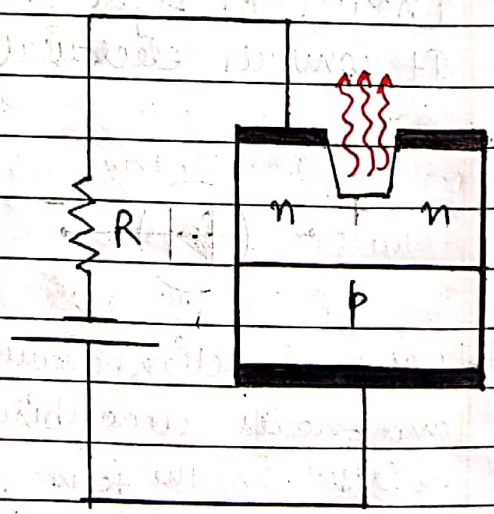
V-I Characteristics of LED :-

V-I characteristics of LED are same as that of elemental semi conductors and are shown below.



Advantages of LED :-

(1) Easy to manufacture.
(2) Low cost.
(3) Low operational voltage.
(4) Low power consumption.
(5) Quick responce
(6) Longer life



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Uses of LED :→

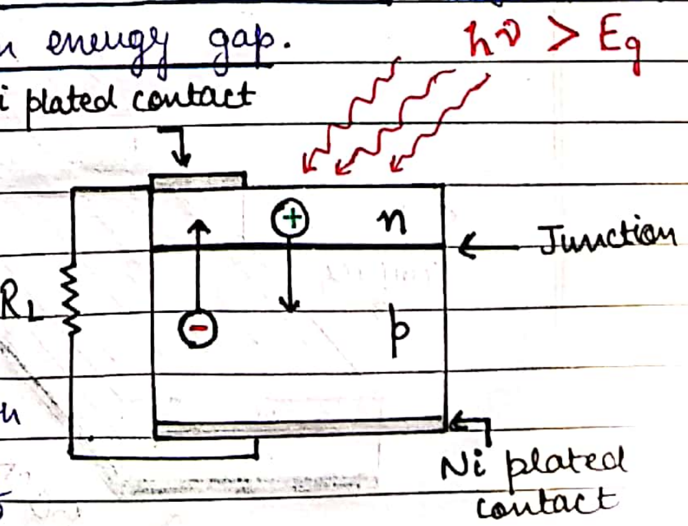
(1) In optical communication.
(2) As indicator lamps.
(3) As digital displays.
(4) In remote control units.
(5) As night lamps, flash lamps and torch lamps.
(6) In decoration purposes.

(D) SOLAR CELL / PHOTO VOLTAIC DEVICE :→

A special p-n junction diode which converts solar energy (sunlight) directly into electrical energy is known as a Solar Cell.

CONSTRUCTION :→ A simple solar cell consists of a p-n junction diode of which n region is very thin (0.3 micrometer) and p-region is thick (300 micro meter). Junction surface of these diodes is kept large so that a large amount of radiations may fall on it. Nickel plated contacts are connected through a load resistance as shown in the fig.

Material used to manufacture a solar cell should have low cost, easy availability, desirable conductivity, high optical absorption and low forbidden energy gap.



⇒ **Action :→**

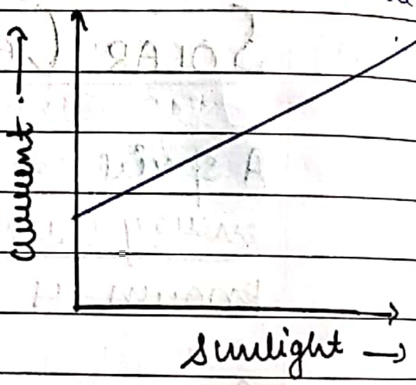
($h\nu > E_g$)

(1) When light falls on the solar cell, the e⁻s - holes pair are generated in both n-region and p-region of the diode.

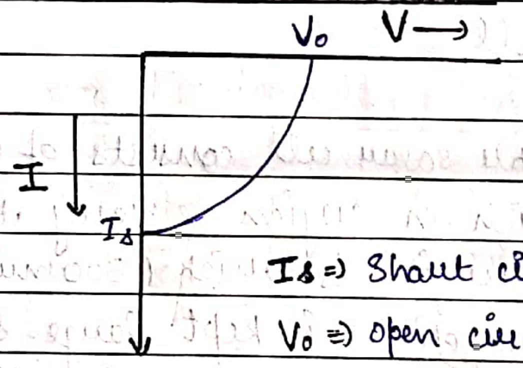
(2) Electrons diffuse from p-region to n-region and holes from n-region to p-region due to the electric field across the depletion layer. Thus, e^-'s and holes are seperated out.

(3) The collection of electrons and holes from both the sides of p-n junction will give rise to an open circuit voltage.

(4) When external resistance R_L is connected across the junction diode, electric current flows through the circuit. The current in the circuit increases with the intensity of the sunlight.



V-I Characteristics :-



I_s ⇒ Short circuit current.

V_0 ⇒ open circuit voltage.

Uses :-

(1) In street lights.

(2) In solar heaters.

(3) To supply power to satellite and space vehicles.

(4) In some gadgets like watches, calculators, etc.