

Chapter-1

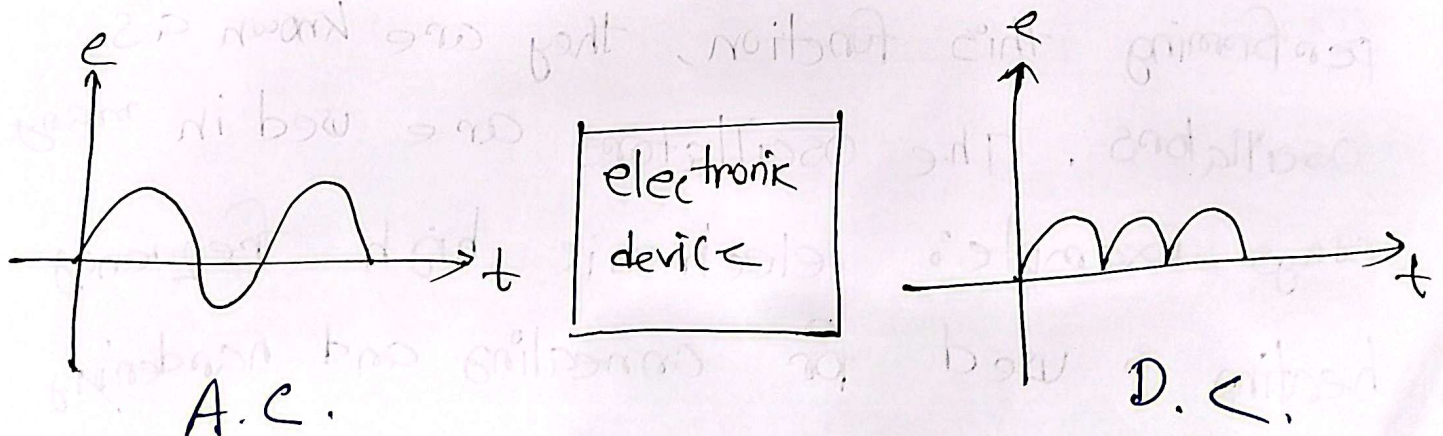
Introduction

☐ what is ~~electronci~~ electronics? Mention some applications of electronics?

⇒ Electronics: The branch of engineering which deals with current conduction through a vacuum or gas or semiconductor is known as electronics.

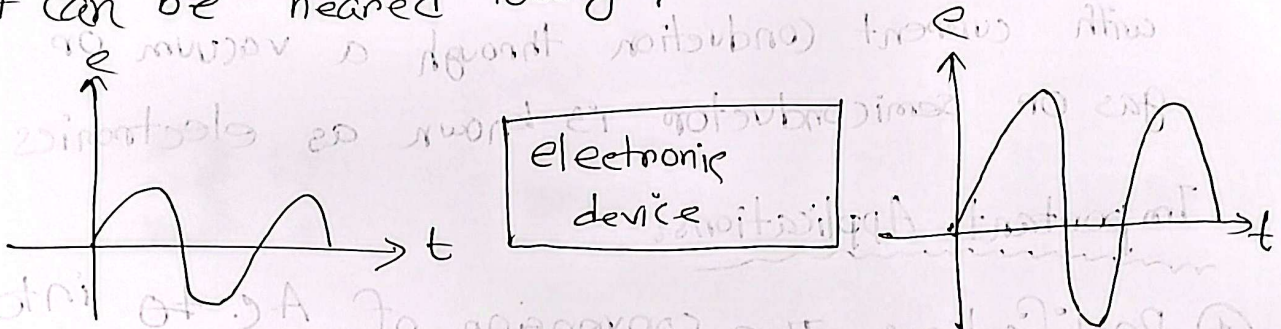
Important Applications:

① Rectification: The conversion of A.C. to D.C. is called rectification. Electronic devices can convert A.C. power into D.C. power with very high efficiency. This D.C. supply can be used for charging storage batteries, field supply of D.C. generators, electroplating, etc.



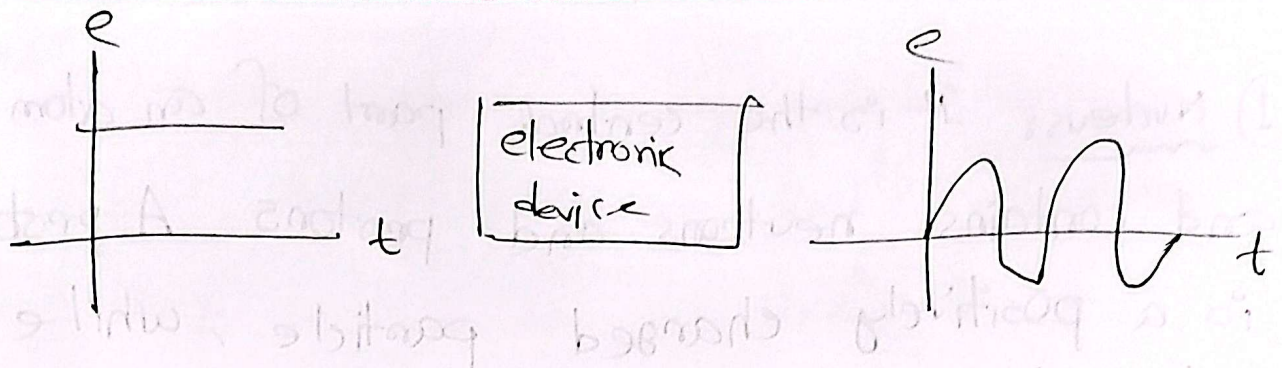
② Amplification: The process of raising the strength of a weak signal is known as amplification.

Example: An amplifier is used in a radio-set where the weak signal is amplified so that it can be heard loudly.



③ Control: Speed of a motor, voltage across a refrigerator etc. can be automatically controlled with the help of such devices.

④ Generations: Electronic devices can convert D.C. power into A.C. power of any frequency. When performing this function, they are known as oscillators. The oscillators are used in many ways. Example: electronic high frequency heating is used for annealing and hardening.



⑥ Conversion of light into electricity: This conversion of light into electricity is known as photo-electricity. Photo-electric devices are used in Burglar alarms, sound recording on motion pictures etc.

⑦ Conversion of electricity into light: This valuable property is utilized in television and radar.

⌚ Atomic Structure

⌚ With an example, explain atomic structure.

⇒ All the materials are composed of very small particles called atoms. An atom consists of a central nucleus of positive charge around which negatively charged particles called electrons revolve.

① Nucleus: It is the central part of an atom and contains neutrons and protons. A proton is a positively charged particle, while the neutron has the same mass of the proton, but has no charge. The sum of neutrons and protons called atomic weight.

$$\text{atomic weight} = \text{no. of protons} + \text{no. of neutrons}$$

② Extra nucleus: It is the outer part of an atom and contains electrons only. An electron is negatively charged particle.

The charge of an electron is equal but opposite to the proton. The number of electrons or protons in an atom is called atomic number.

$$\text{atomic number} = \text{no. of protons or electrons in an atom}$$

Num. of electrons in any orbit $= 2n^2$

First orbit contains $= 2 \times 1^2 = 2$ electrons

Second " $= 2 \times 2^2 = 8$;

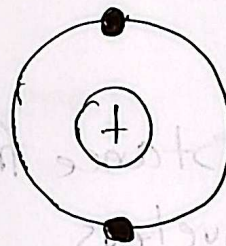
Structure of Helium atom:

Atomic no $= 2$

Mass no $= 4$

electrons $= 2$

neutrons $= 4 - 2 = 2$



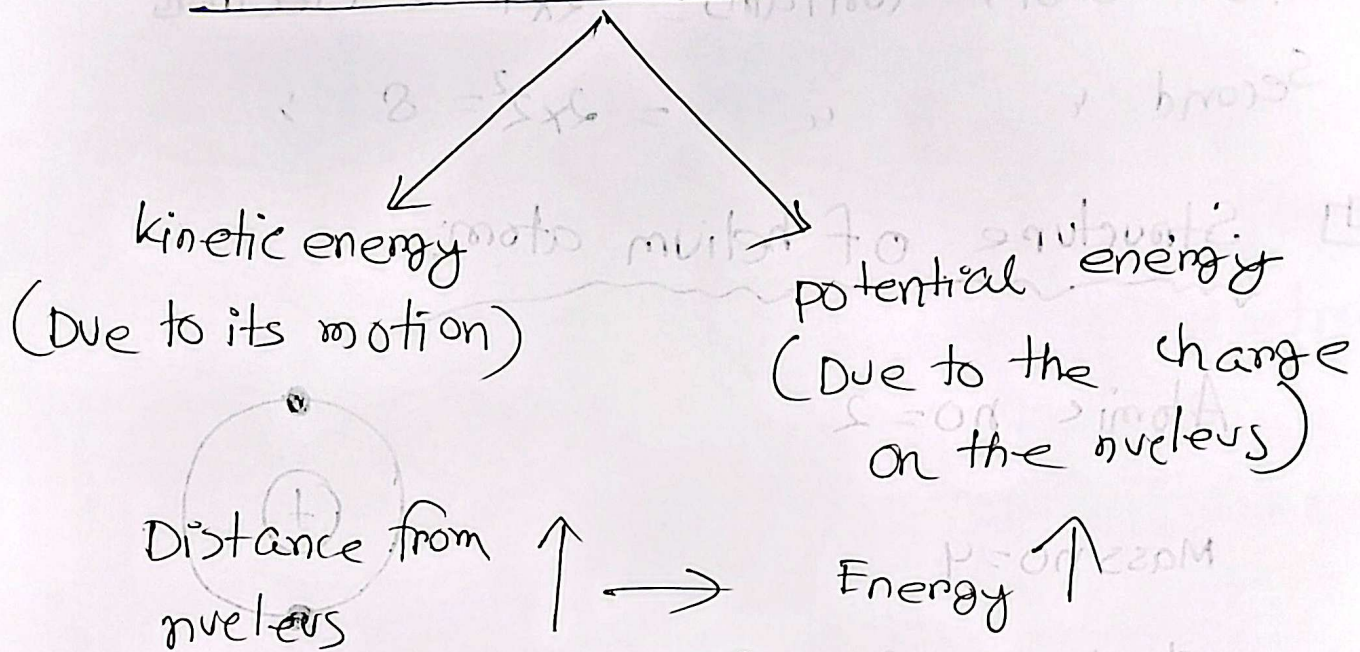
Electron:

Charge, $e = 1.602 \times 10^{-19} \text{ C}$

Mass, $m = 9 \times 10^{-31} \text{ kg}$

radius $= 1.9 \times 10^{-15} \text{ meters}$

□ Energy of an Electron:



□ Valence Electrons The electrons in the outermost orbit of an atom are known as valence electrons.

NO of valence electrons Materials

- | | |
|-----------------|--------------------------------------|
| i) less than 4 | → metal, conductor
(Na, Mg, Al) |
| ii) more " 4 | → non-metal, insulator
(N, S, Ne) |
| iii) equal to 4 | → semi-conductor.
(C, Si, Ge) |
- 1
2
3
4
5
6
7
8

Free electrons: The valence electrons, which are very loosely attached to the nucleus are known as free electrons.

Conductor:

→ substance which has larger number of free electrons.

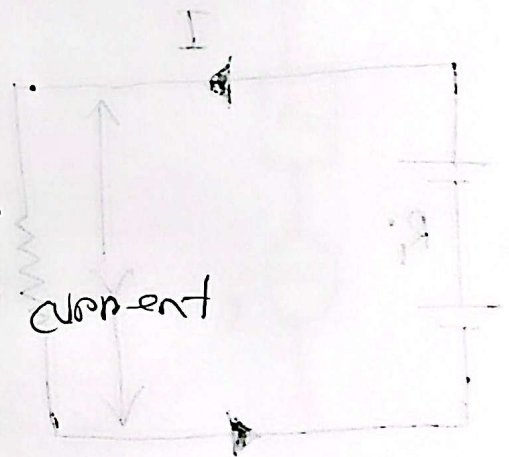
→ produce electric current.

Insulator:

→ NO free electron
→ Does not conduct current

Semiconductors:

→ has very few free electrons.
→ partially conducts no current
practically

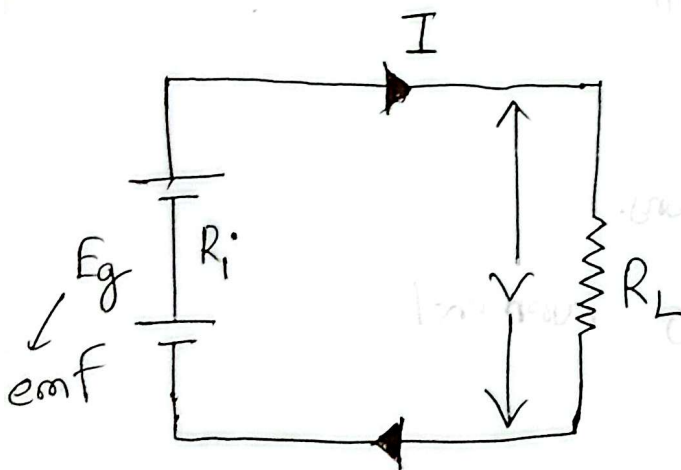


Voltage Sources

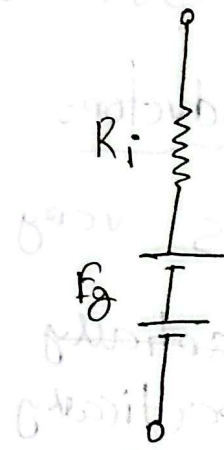
i) Direct Voltage Source: A device which produces direct voltage ~~source~~ output continuously is called a direct voltage source. Examples: cells, d.c. generator

Characteristics:

- ① Maintain the same polarity (positive & negative terminals remain same)
- ② Current flows in one direction (+ to -)



(i)



(ii)

Load current,
$$I = \frac{E_g}{R_L + R_i}$$

Terminal voltage,
$$V = (E_g - IR_i) \text{ or } IR_L$$

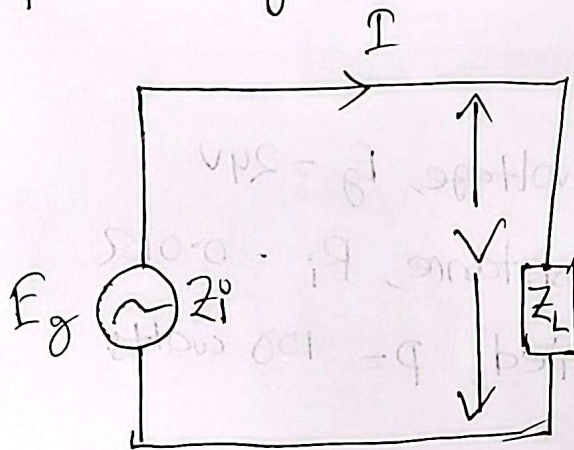
$R_i \rightarrow$ Internal resistance

$R_L \rightarrow$ Load resistor

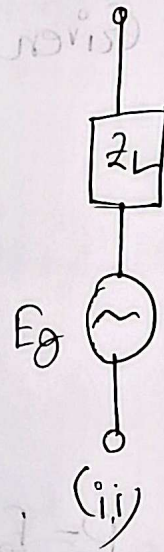
Alternating Voltage source: A device which produces alternating voltage output continuously is known as alternating voltage source. e.g. A.c. generator.

Characteristics:

- ① Reverse the polarity of the output voltage.
- ② Current flows through the circuit that periodically reverses in direction.



(i)



(ii)

$$\text{Load current, } I(\text{r.m.s.}) = \frac{E_g}{Z_L + Z_i}$$

$$\text{Terminal voltage, } V_i = (E_g - IZ_i) \text{ or } IZ_L$$

Z_i = internal impedance

Z_L = Load Impedance

Impedance: Impedance is the total opposition a circuit presents to the flow of A.C.

Constant Voltage Source: $\rightarrow$ has very low internal impedance as compared with external load impedance

Constant Current Source $\rightarrow$ has very high internal impedance as compared with external load impedance.

Exm: 1.1:

Given that,

Generated voltage, $E_g = 24V$

Internal resistance, $R_i = 0.01\Omega$

Power supplied, $P = 100 \text{ watts}$

(i)

$$P = E_g \times I$$
$$\Rightarrow I = \frac{P}{E_g} = \frac{100}{24} = 4.17A$$

$$\therefore \text{Voltage drop in } R_i = IR_i = 4.17 \times 0.01$$
$$= 0.0417V$$

(Ans)

(ii)

Terminal voltage, $V = E_g - IR_i$
 $= 24 - 0.0417$
 $= 23.96 \text{ V (Ans)}$

Exm:-1.2:-

Generated voltage, $E_g = 500 \text{ V}$

Internal resistance, $R_i = 1000 \Omega$

When, $R_L = 10 \Omega$

i) Load current, $I = \frac{500}{1000 + 10} = 0.495 \text{ A}$

when, $R_L = 50 \Omega$

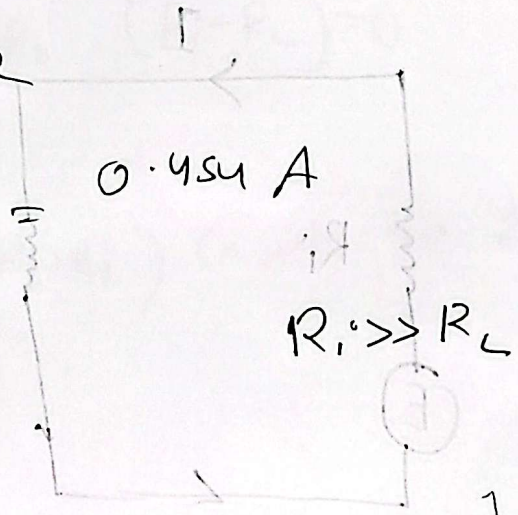
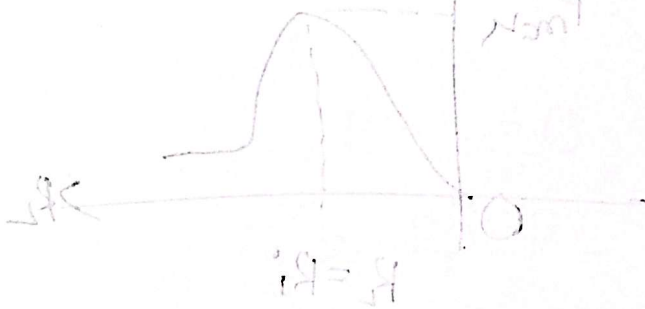
$I = \frac{500}{1000 + 50} = 0.476 \text{ A}$

When, $R_L = 100 \Omega$

$I = \frac{500}{1000 + 100}$

0.454 A

$R_i \gg R_L$



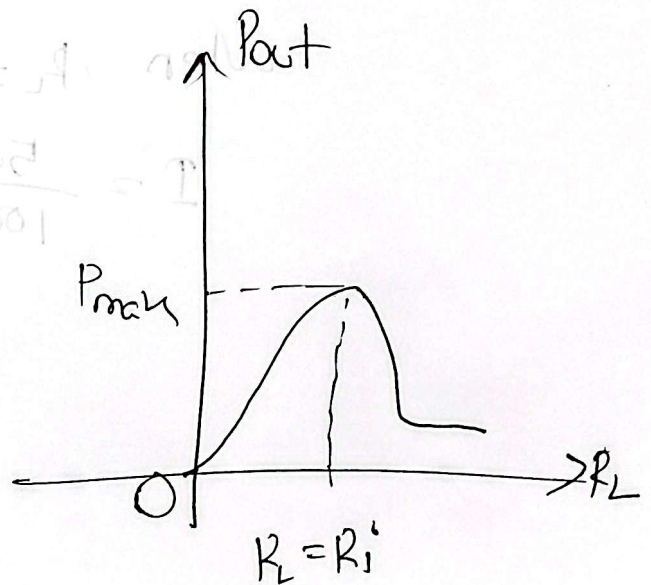
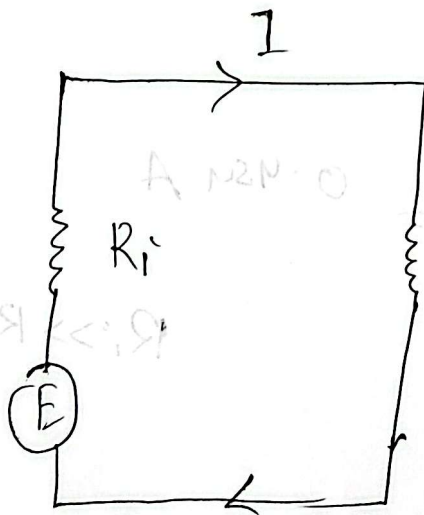
Maximum Power transfer theorem:

It states that, "Maximum power is transferred from a source to a load when the load resistance is ~~max~~ equal to the internal resistance of the source."

To prove this theorem mathematically, consider a voltage source of generated voltage E and internal resistance R_i and load resistance R_L .
The current I :

$$I = \frac{E}{R_i + R_L}$$

Power delivered to the load, $P = I^2 R_L = \left(\frac{E}{R_i + R_L} \right)^2 \times R_L$ — (1)



Now,

E & R_i are constant. Therefore, P depends upon R_L .

Now differentiate the eqn. (1) w.r.t. R_L and set the result equal to zero.

Thus,

$$\frac{dP}{dR_L} = 0$$

$$\Rightarrow E^2 \left[\frac{(R_L + R_i)^2 - 2R_L(R_L + R_i)}{(R_L + R_i)^4} \right] = 0$$

$$\Rightarrow (R_L + R_i)^2 - 2R_L(R_L + R_i) = 0$$

$$\Rightarrow (R_L + R_i)(R_L + R_i - 2R_L) = 0$$

$$\Rightarrow (R_L + R_i)(\cancel{R_L + R_i} - 2R_L) = 0$$

$$\Rightarrow \text{Since } (R_L + R_i) \text{ can't be zero.}$$

$$R_i - R_L = 0$$

$$\Rightarrow R_i = R_L$$

(proved)

Chapter-4

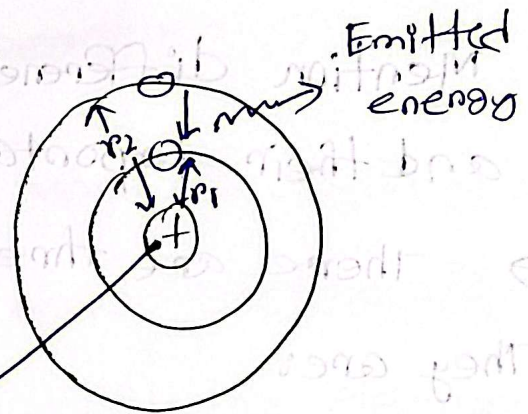
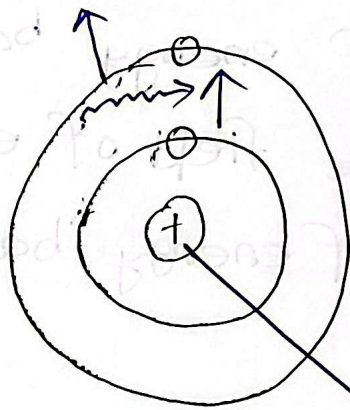
Atomic structure

☐ Bohr's Atomic Model in 1913, ^{Neils Bohr} gave explanation of atomic structure. According to Bohr:

- (i) An atom consists of a positively charged nucleus ~~an~~ around which negatively charged electrons revolve in different circular orbits.
- (ii) The electron can revolve around the nucleus only in certain permitted orbits.
- (iii) The electrons in each permitted orbit have a certain fixed amount of energy. The larger the orbit, the greater is the energy of electron.
- (iv) If an electron is given additional energy, it is lifted to the higher orbit. The atom is said to be in a state of excitation.

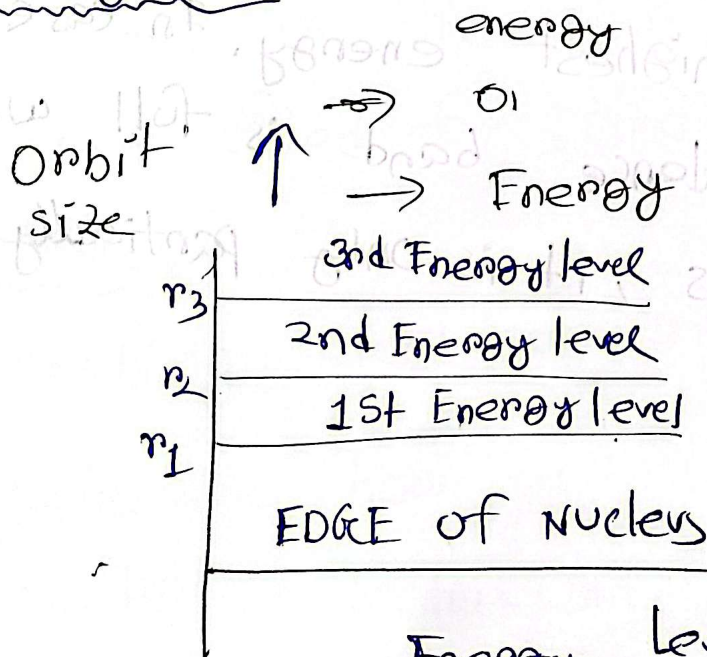
This state does not last long, because the electron soon falls back to the original lower orbit. As it falls, it gives back the acquired energy in the form of heat, light or other radiations.

absorbed energy



positively charged nucleus.

Energy Levels → Each orbit has fixed amount of energy



Energy Level Diagram.

Energy Bands:

The range of energies possessed by an electron in a solid is known as energy band.

→ Energy levels of an isolated atom are converted into corresponding bands when the atom is in a solid.

▣ Mention different types of energy bands and their importance in the field of electronics.

⇒ There are three types of energy bands.

They are:

1. Valence band: The range of energies possessed by valence electrons is known as valence band. In a normal atom, valence band has the electrons of highest energy. In case of inert gases, the valence band is full whereas for other materials, it is only partially filled.

Importance:

- ① It controls electricity flow.
 - ② It determines the material type that is conductor, semiconductor or insulator.
 - ③ Used in electrical devices like transistors, diodes, LEDs etc.
 - ④ Changes with temperature.
- (ii) Conduction Band: The range of energies possessed by conduction band electrons is known as conduction band. All the electrons in conduction band are free electrons. Generally, Insulator have empty conduction band and on the other hand it is partially filled for conductors.

Importance:

- ① Enabling electrical conduction in materials.
- ② Determines how well a material can conduct electricity.

(3) Used in Solar cells.

(i) As Temperature rises, increasing a material's conductivity.

(ii) Forbidden Energy Gap: The energy difference between valence band and conduction band is known as Forbidden energy gap.

→ No electron of a solid can stay in a forbidden energy gap.

→ In insulator this gap is large, while in conductors the gap is non-existent.

Importance:

(1) Its size determines the material type.

Small → conductor

Moderate → semiconductor

Large → insulator

(2) controls electrical conductivity.

③ essential in semiconductor devices, like transistors, diodes etc.

④ Increasing temperature reduces the band gap.

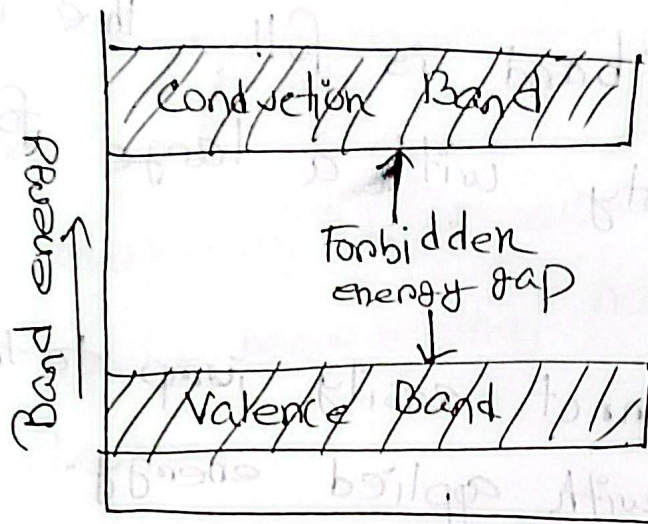


Fig: Energy Band.

☐ Classify Solids considering energy bands and energy gaps.

⇒ Solids are classified into three categories based on their energy bands and energy gap.

1. Conductor

2. Insulator

3. Semiconductor.

1. Insulators

Definition: Materials that do not conduct electricity because they have no free electrons.

Energy band structures

→ The valence band is full, the conduction band is empty with a large forbidden energy gap.

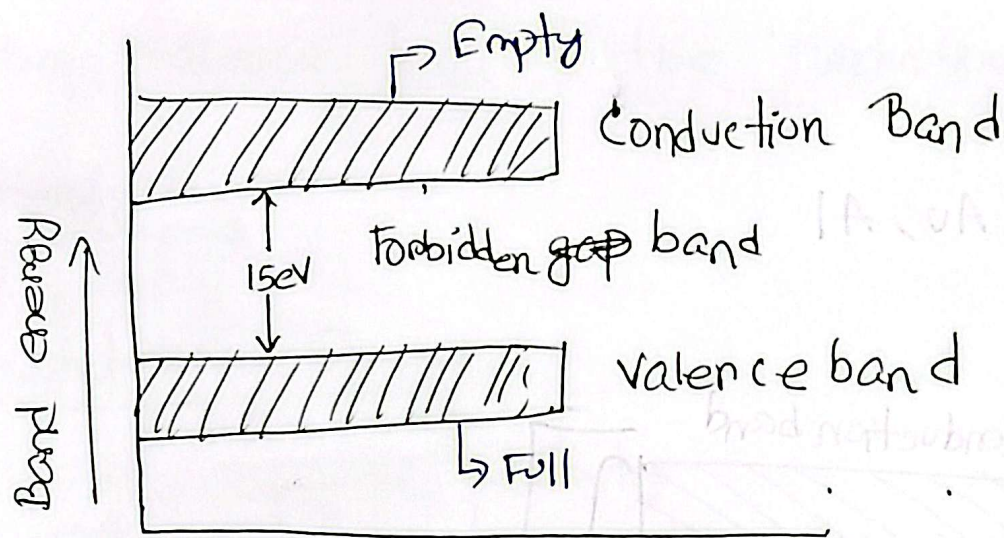
→ Electrons cannot easily jump to the conduction band, even with applied energy.

Energy gap:

→ The energy gap between valence band and conduction band is very large ($\approx 15 \text{ eV}$).

Examples:

→ Glass, Rubber, plastic, Diamond etc.



2. Conductors:

Definition: Materials that allow electricity to flow easily because they have large number of free electrons.

Energy band structures:

→ The valence band and the conduction band overlap each other.

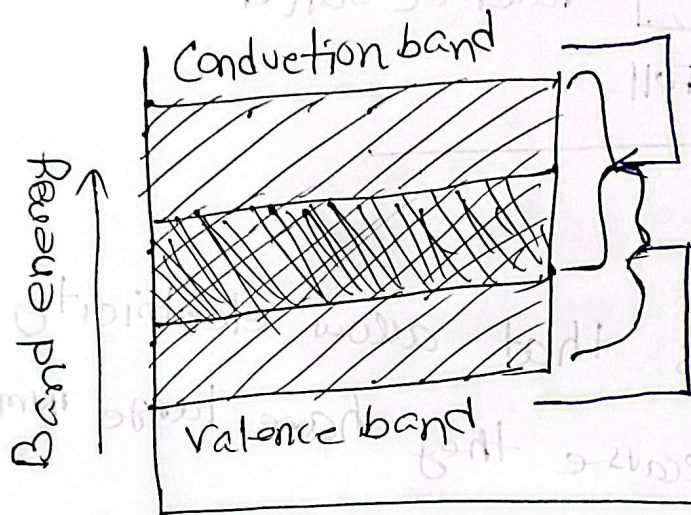
→ Since there is no forbidden energy gap, electrons move freely.

Energy gap:

→ 0eV.

Examples:

→ Cu, Ag, Au, Al



3. Semiconductors:

Definition: Semiconductors are those substances whose electrical conductivity lies in between conductors and insulators.

Energy band structure:

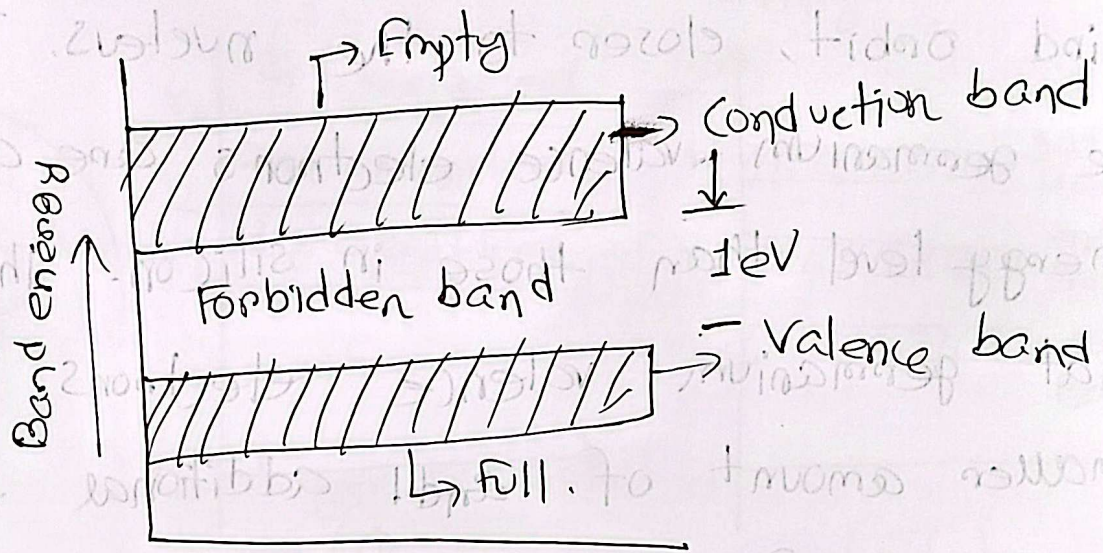
→ The valence band is full, the conduction band is empty but a small forbidden energy gap exists.

→ Electron need external energy to jump from

the valence band to the conduction band.

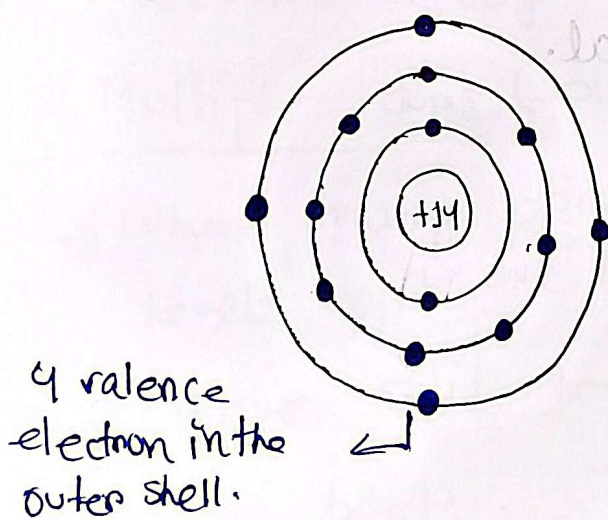
Energy Gap $\approx 1\text{eV}$

Examples: Si, Ge,

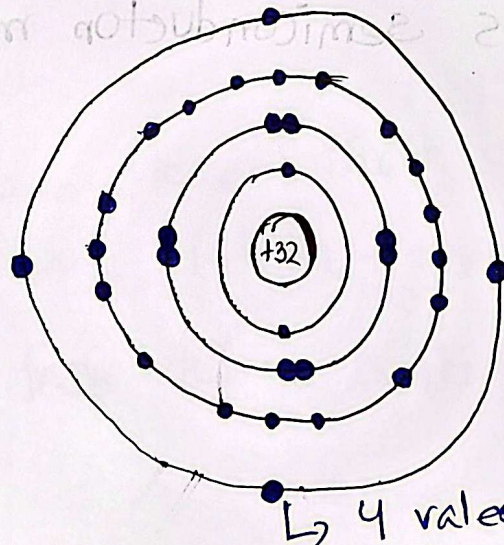


Why Silicon is widely used as Semiconductor material?

⇒ Silicon is widely used as semiconductor material.

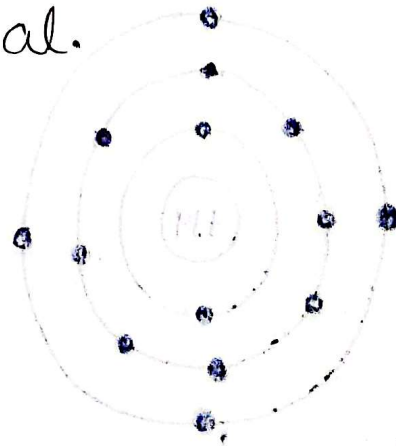
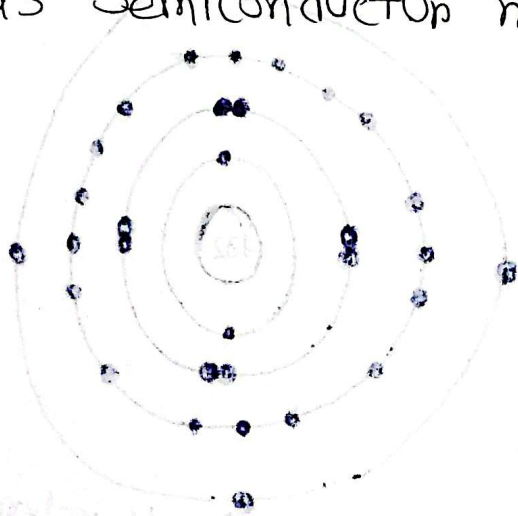


(i) Silicon atom



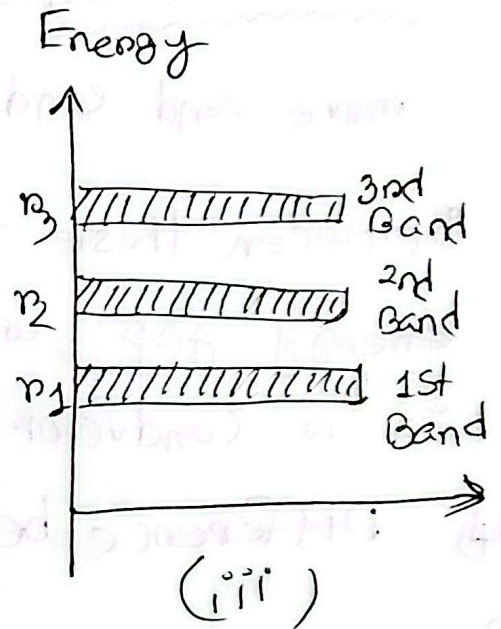
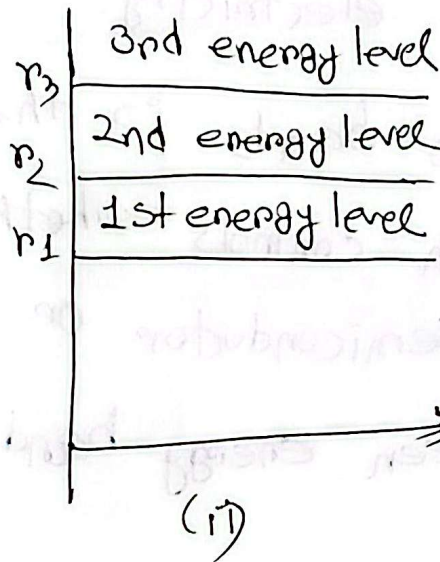
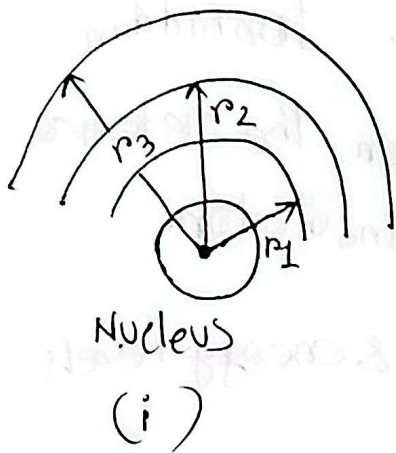
(ii) Germanium atom.

From the atomic structure of germanium and silicon we can see the valence electrons in germanium are in the fourth orbit while the valence electrons in silicon are in the third orbit, closer to the nucleus. Therefore, the germanium valence electrons are at higher energy level than those in silicon. This means that germanium valence electrons require smaller amount of ~~and~~ additional energy to escape from the atom and become free electron. This property makes germanium more unstable at high temperature. This is the basic reason why silicon is widely used as semiconductor material.



4) Explain the concept of energy bands in solid.

⇒ The range of energies possessed by an electron in a solid is known as energy band.



Formation of energy bands:

1. Isolated atoms: In a single isolated atom, electrons occupy specific energy levels.
2. Multiple atoms: (solid)
 - ⇒ When many atoms come close, their energy levels split due to quantum interactions.
 - ⇒ These split levels form continuous energy bands.

3. Two Main Energy bands Form.

* Valence Band: Contains electrons tightly bound to atoms.

* Conduction Band: contains free electrons that move and conduct electricity.

Between these two bands is the forbidden energy gap, which controls whether the material is a conductor, semiconductor or insulator.

↳ Difference between energy band & energy levels

⇒

Energy Bands	Energy levels
① Exists in a solid with many atoms.	① Exists in a single atom.
② Has continuous energy range.	② Discrete energy values
③ Determines electrical conductivity of solids.	③ Defines electron configuration in atoms
④ Form Formation: Due to overlapping energy levels	④ Due to electrons in an isolated atom.

of many atoms in a solid.

⑤ Example: Energy bands in silicon, with VB & CB.

⑤ Examples Energy levels

in a ~~hydrog~~ hydrogen atom.

$n = 1, 2, 3, \dots$

Chapter 5

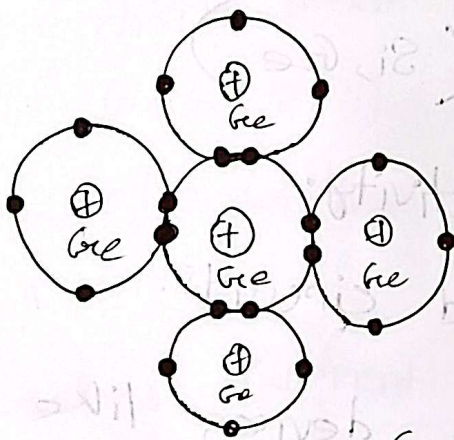
☐ Semiconductors A semiconductor is a substance which has resistivity (10^{-4} to $0.5 \Omega m$) in between conductor & insulator. For example: Ge, Si, C.

☐ Properties of semiconductors

- ① The resistivity of a semiconductor is less than an insulator but more than a conductor.
- ② The energy band gap is small (0.1 eV to 3 eV)
- ③ As temperature increases, conductivity increases
- ④ Semiconductors have negative temperature co-efficient of resistance. For example, Ge is actually an insulator at low temperatures but it becomes a good conductor at high temperatures.
- ⑤ Some semiconductors generate electricity when exposed to light.

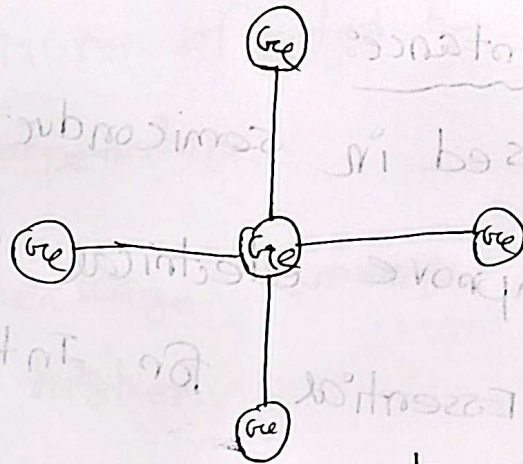
Bonds in Semiconductors

In semiconductors, bonds are formed by sharing of valence electrons. Such bonds are called co-valent bonds.



covalent bonds among Ge atoms

(i)



Bonding diagram

(ii)

- i) Co-valent bonds are formed by sharing of valence electrons
- ii) In the formation of covalent bond, valence electrons are associated with particular atoms. For this reason, valence electrons in a semiconductor are not free.

Q1 What is Crystal? why it is important in electronics?

→ A substance in which the atoms or molecules are arranged in an orderly pattern is known as a crystal. All semiconductors have crystalline structure.

Importance:

1. Used in semiconductors (Si , Ge)
2. Improve electrical conductivity.
3. Essential for Integrated Circuits.
4. Used in Piezo electric devices like Quartz (SiO_2)
5. Used in LED, Laser Technology like (GaAs)
6. Essential for solar panels like (monocrystalline & polycrystalline Silicon).

⌚ Difference between Si & Ge energy bands.

⇒

Silicon	Germanium
① Band gap energy 1.1 eV ② Electrical conductivity lower than Ge. ③ Less affected by temperature ④ Leakage current — lower ⑤ more stable at high temp. ⑥ More abundant and cheaper	① 0.7 eV ② Higher than Si ③ More affected by temperature ④ Leakage current higher. ⑤ Less stable at high temperature ⑥ Less abundant and more expensive.

Effect of temperature on Semiconductors

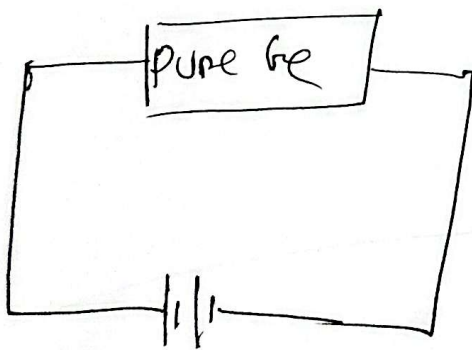
i) At absolute zero:

→ At absolute zero temperature, all the electrons are tightly held by the semiconductor atoms.

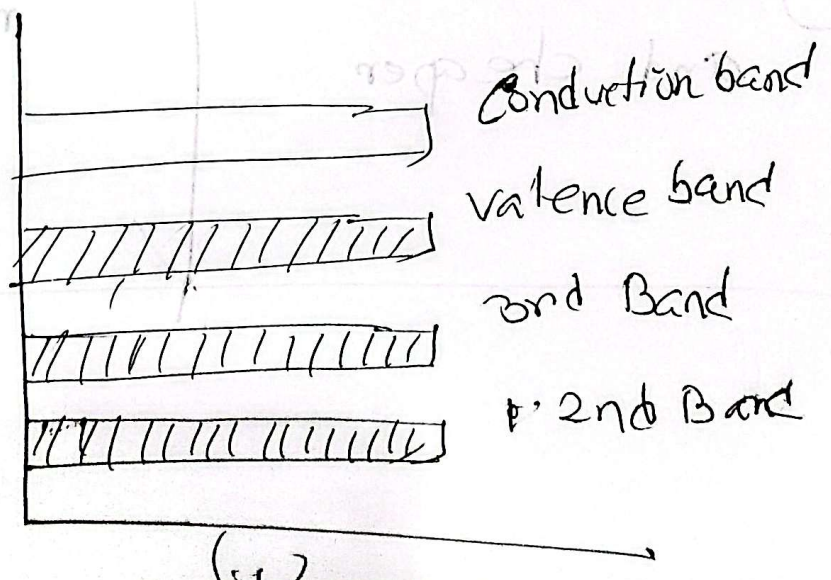
→ The inner orbit electrons are bound, whereas the valence electrons are engaged in co-valent bonding.

→ At this temperature, the co-valent bonds are very strong and there are no free electrons.

→ Therefore the semiconductor crystal behaves as a perfect insulator.



(i)



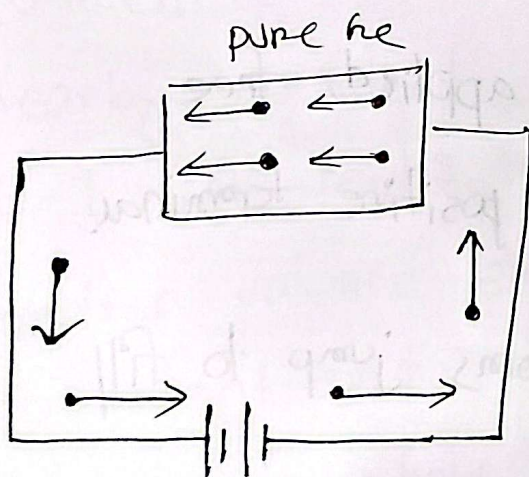
ii) Above absolute zero.

→ When the temperature is raised, some of the covalent bonds in the semiconductor break due to the thermal energy supplied.

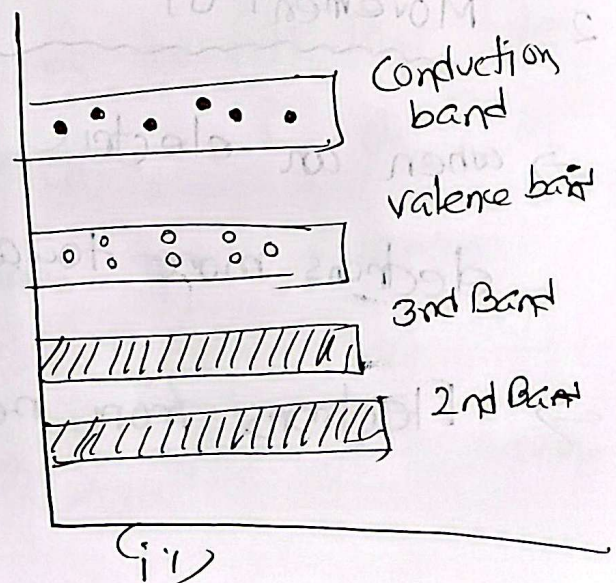
→ The breaking of bonds sets ~~with~~ those electrons free which are engaged in the ~~information~~ of these bonds.

→ The result is that a few free electrons exist in the semiconductor.

→ These free electrons can constitute a tiny electric current if ~~pot~~ potential difference is applied across the semiconductor crystal.



(i)



(ii)

 What is hole current? How it is formed?

⇒ Hole current is the electric current created by the movement of holes in semiconductor.

Formation:

1. Electron-Hole Pair Generation:

→ In a semiconductor, some electrons gain energy and move from the valence band to the conduction band.

→ The place where the electron was removed in the valence band is called a hole.

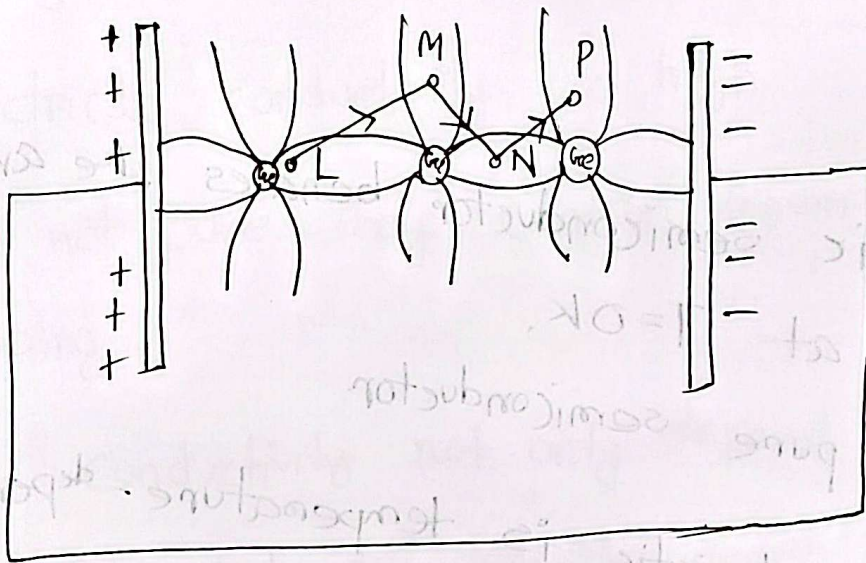
2. Movement of holes:

→ When an electric field is applied, free electrons move towards the positive terminal.

→ Electrons from nearby atoms jump to fill.

the holes, creating new holes in different positions.

→ This movement of holes in the opposite direction of electron flow is called hole current.



Here we can see a hole is created in the covalent at L and a valence electron from nearby covalent bond comes to fill the hole at L. This results in the creation of hole at M. Another valence electron comes from nearby covalent bond and fill the hole and thus created a hole at N. Thus the hole having

a positive charge has moved from L to N towards the negative terminal. This creates hole current.

4 Intrinsic Semiconductors A semiconductor in an extremely pure form is known as an intrinsic semiconductor.

Properties:

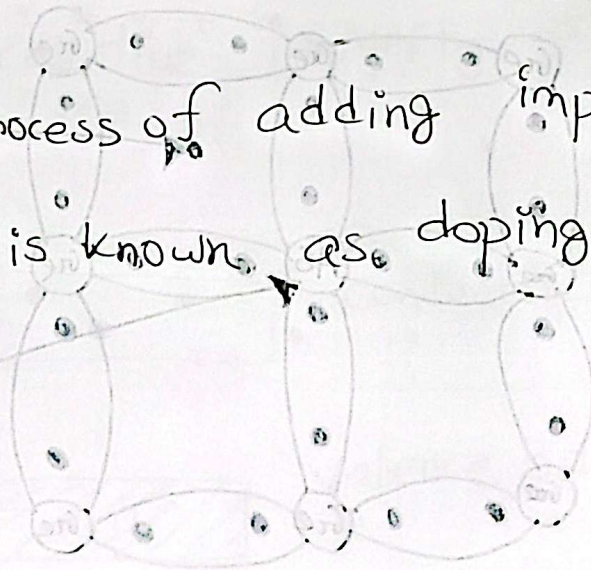
1. An intrinsic semiconductor behaves like an insulator at $T = 0K$.
2. It is a pure semiconductor.
3. Its characteristic is temperature-dependent.
4. Electrical conductivity is comparatively low.
5. The density of electrons is equal to the density of holes.

Extrinsic Semiconductor: Extrinsic semiconductors are semiconductors that are doped with specific impurities.

Properties:

1. The density of electrons is not equal to the density of holes.
2. Electrical conductivity is high.
3. It's not pure, they contain impurity through doping.
4. The conductivity not only depend on the temperature but also on the amount of impurity.

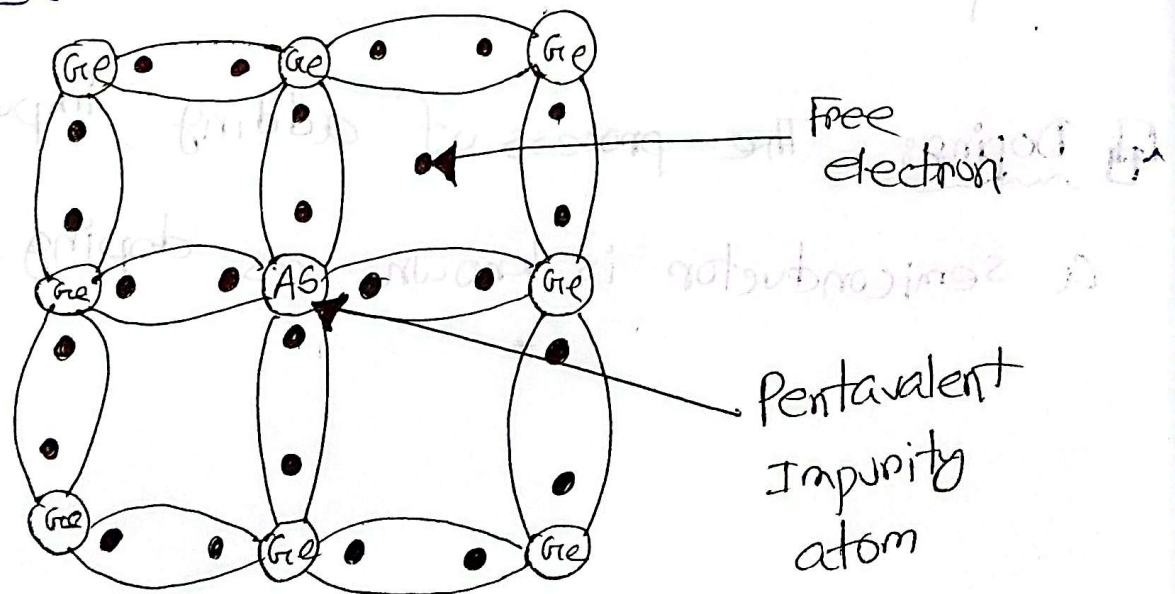
Doping: The process of adding impurities to a semiconductor is known as doping.



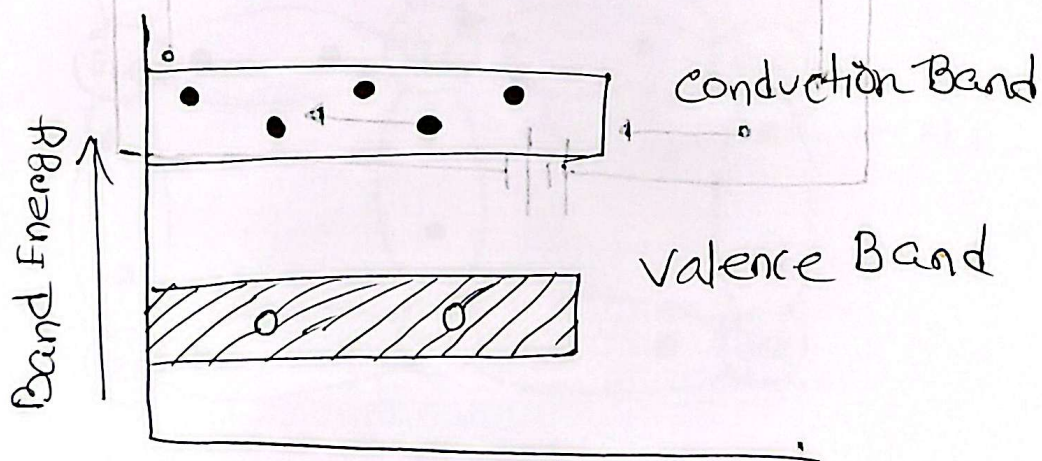
n-type Semiconductors When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as n-type semiconductor. The addition of pentavalent impurity provides a large number of free electrons in the semiconductor crystal.

Examples: Arsenic and Antimony
n-type semiconductor are known as donor impurities because they donate or provide free electrons to the semiconductor.

Formation of n-type semiconductors

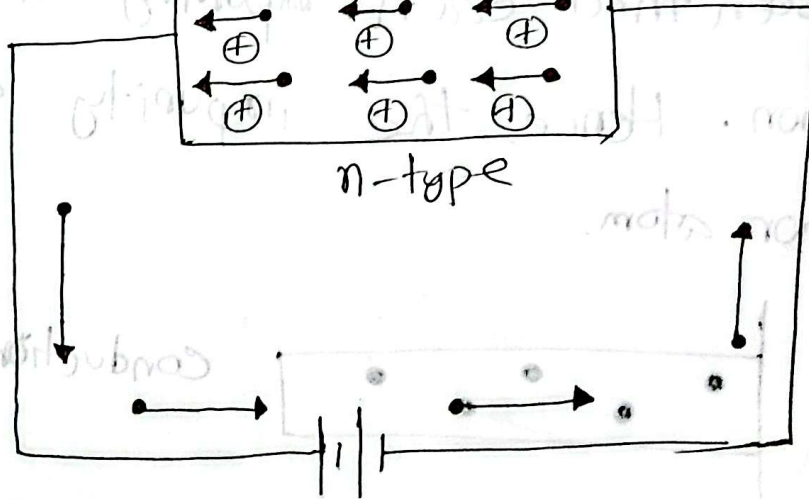
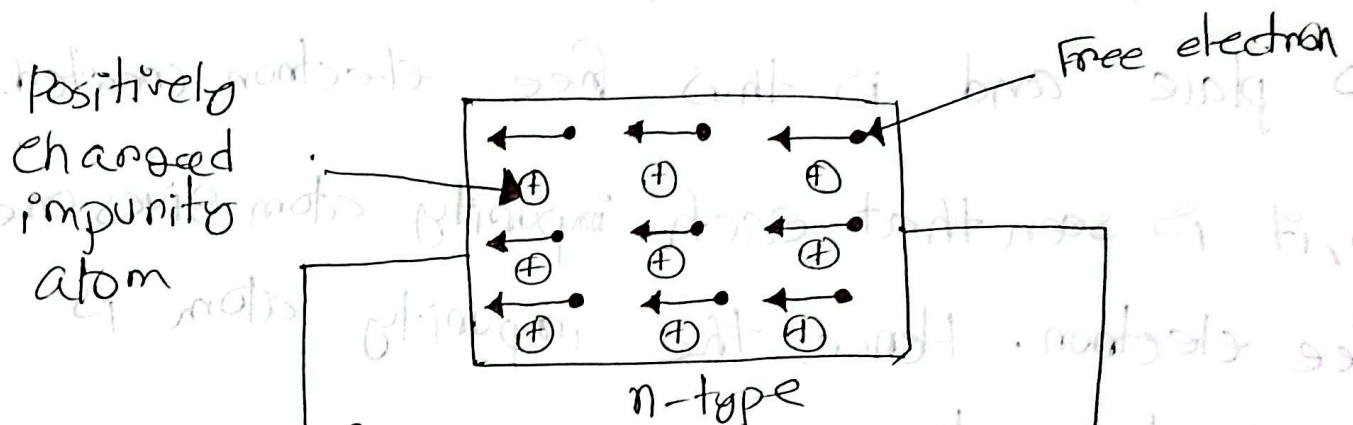


Consider a pure germanium crystal. We know that, Germanium atom has four valence electrons. When a small pentavalent impurity like arsenic is added to Ge crystal, a large number of free electrons become available in the crystal. Arsenic has five valence electrons. An arsenic atom fits in the Ge crystal in such a way that its four valence electrons form covalent bonds with Ge atoms. The fifth valence electron of arsenic finds no place and is thus free. Electron created. So, it is seen that each impurity atom gives one free electron. Hence, the impurity atom is called donor atom.



From the figure we can see the energy band description of n-type semiconductor. The addition of pentavalent impurity has produced a number of conduction band electrons i.e. free electrons.

Conductivity: The current conduction in an n-type semiconductor is predominantly by free electrons i.e. negative charges and is called n-type or electron type conductivity.



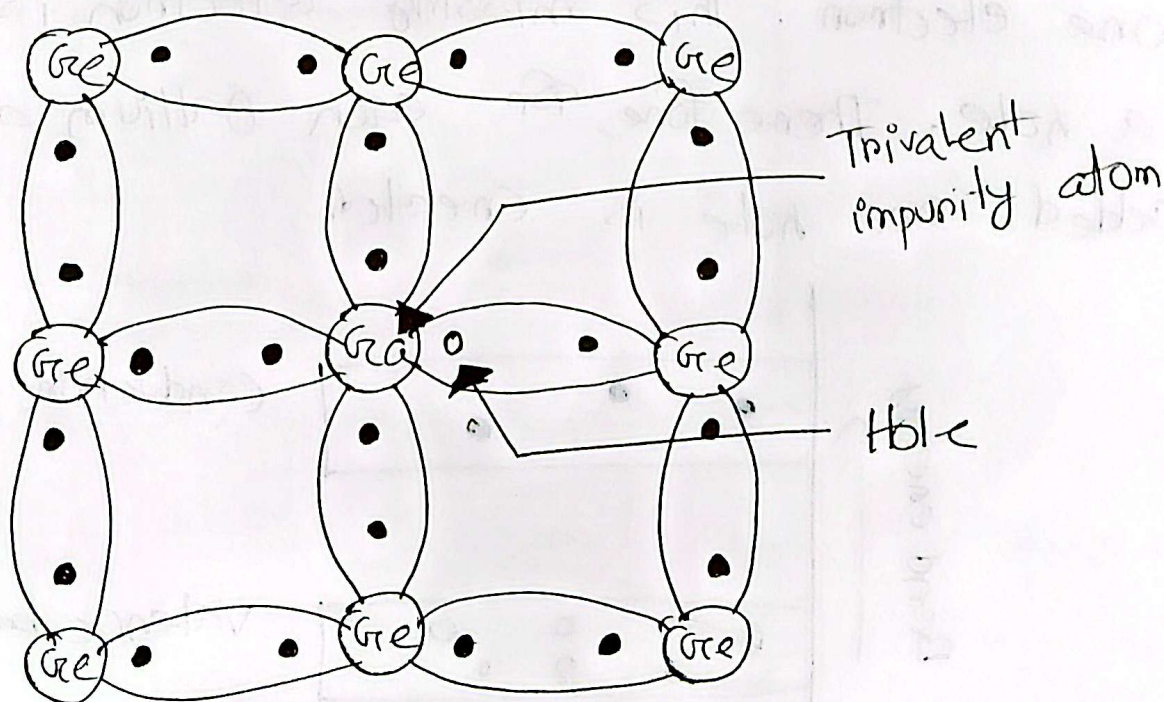
□ P-type Semiconductors when a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor.

The addition of trivalent impurity provides a large number of holes in the semiconductor.

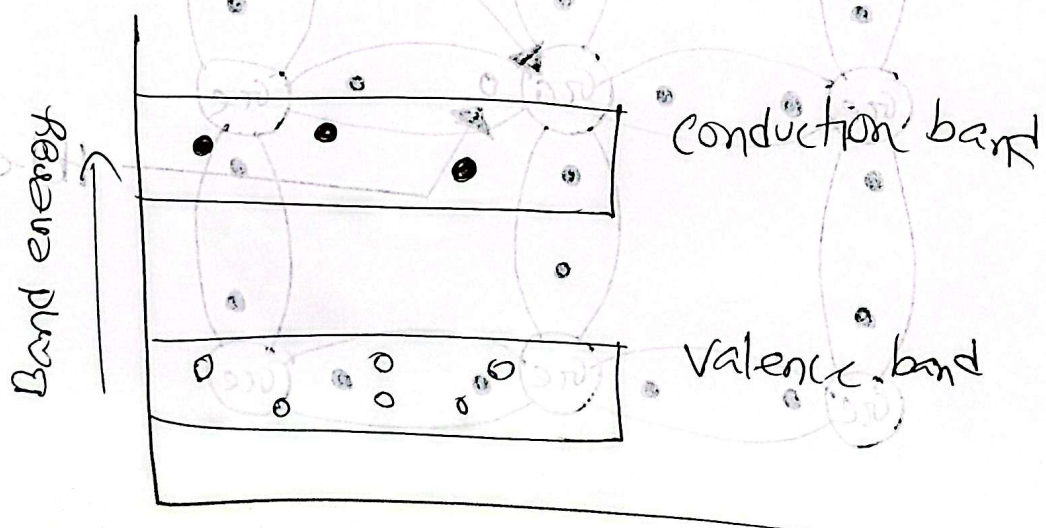
Examples: Gallium & Indium.

p-type semiconductors are known as acceptor impurities because the holes created can accept the electrons.

Formation of p-type semiconductor:



Consider a pure Ge crystal. When a small amount of trivalent impurity like gallium is added to germanium crystal, there exists a large number of holes in the crystal. Gallium has three valence electrons. Each atom of gallium fits into the Ge crystal but now only three co-valent bonds can be formed. So, it is seen that the fourth electron of germanium atom does not form any co-valent bond. For this reason, fourth bond is incomplete, being short of one electron. This missing electron is called a hole. Therefore, for each gallium atom added, one hole is created.



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Majority and Minority Carriers

Due to the effect of impurity, n-type material has a large number of free electrons whereas p-type material has a large number of holes. However, it may be noticed that even at room temperature, some of the covalent bonds break, thus releasing an equal number of free electrons and holes.

In n-type material has a large number of free electrons and a small number of holes.

Here,

Majority carriers $\rightarrow$ Free electrons

Minority carriers $\rightarrow$ Holes.

In p-type material has a large number of holes and a small number of free electrons.

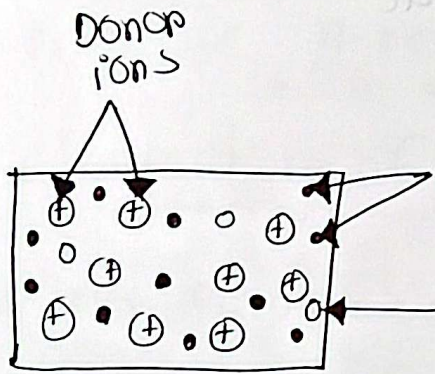
Here,

majority

carriers $\rightarrow$ holes

minority

carriers $\rightarrow$ free electrons



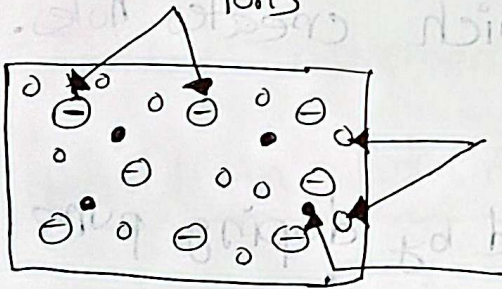
Majority carriers
(electrons)

Minority carriers
(holes)

n-type

(i)

Acceptor
ions



Majority carriers (holes)

Minority carriers (electrons)

p-type

(ii)

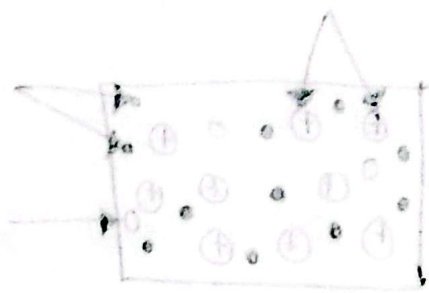
Formation of pn junctions

When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called pn junction.

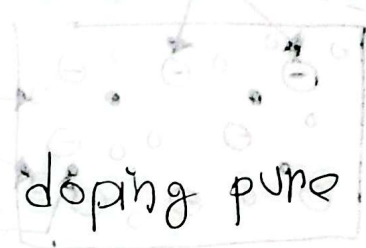
Step-by step:

1. Doping Process:

* p-type semiconductor: Formed by doping pure Silicon (Si) or Germanium (Ge) with a trivalent impurity (e.g. Boron (B)), which creates holes. (positive charge carriers).



* n-type semiconductor: Formed by doping pure Si or Ge with a pentavalent impurity (e.g. Phosphorus (P)), which creates free electrons (negative charge carriers).



2. Diffusion of charge carriers

* when p-type and n-type materials are

joined, electrons from the n-region diffuse into the p-region and recombine with holes.

* Similarly, holes from the p-region diffuse into the n-region and recombine with electrons.

3. Formation of the Depletion Region:

* As recombination occurs near the junction, a charge-free region forms, called the depletion region.

* This region acts as a barrier, preventing further movement of electrons and holes.

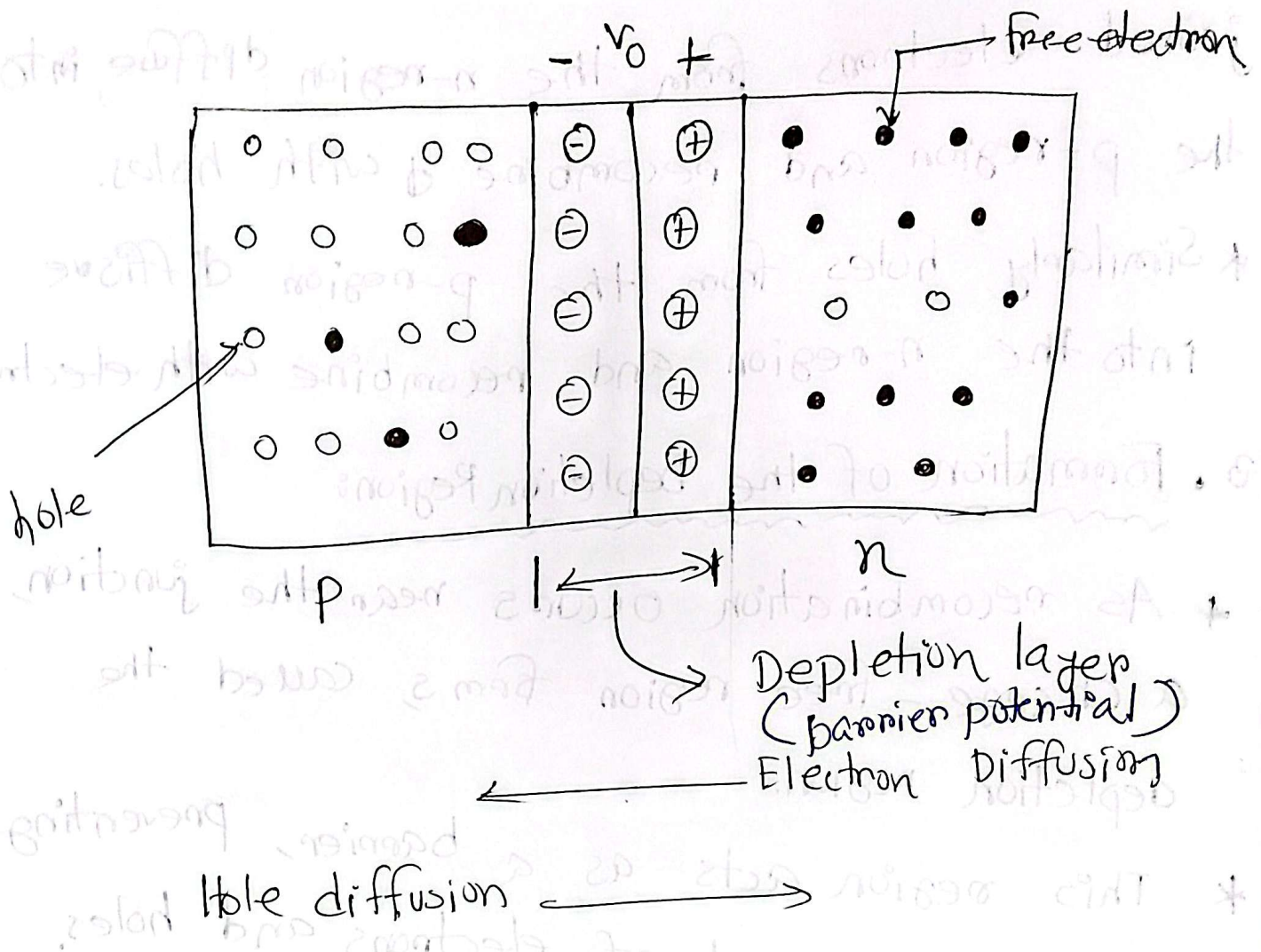
4. Built-in Potential Formation:

* Due to the separation of positive and negative charges, an electric field is created across the junction.

* This results in a built-in potential barrier.

* Silicon $\approx 0.7V$

* Germanium $\approx 0.3V$



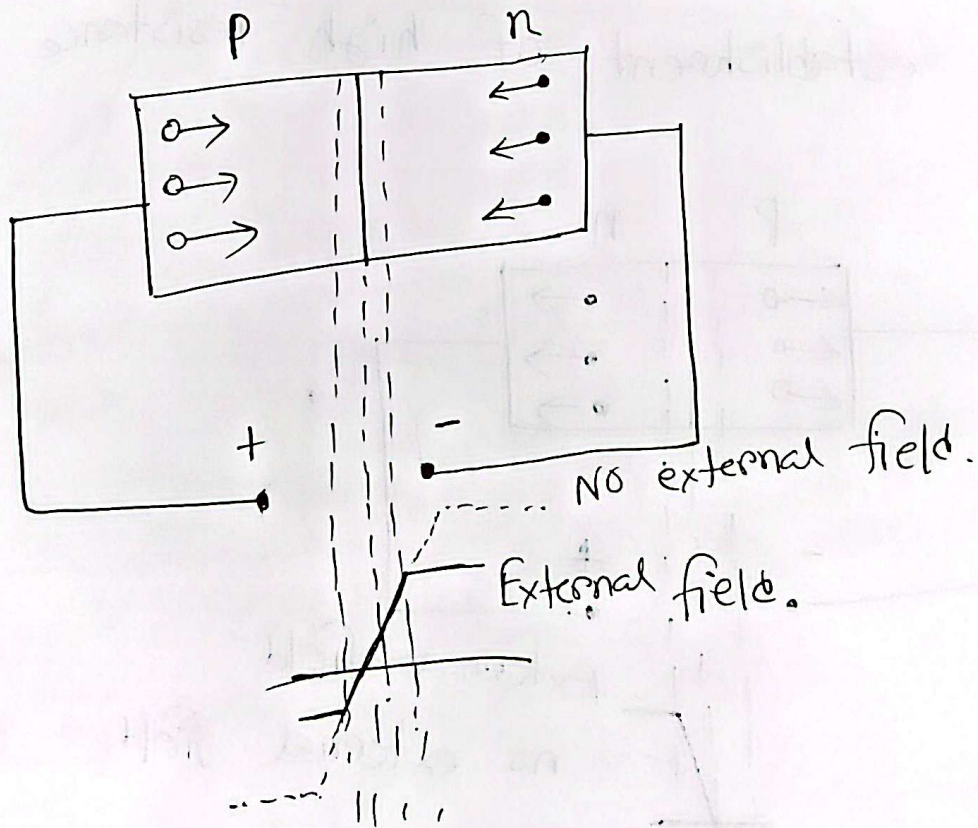
Biasing a pn Junction

There are two type of bias junction condition in pn junction.

1. Forward biasing: when an external d.c. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called "forward biasing".

Effects:

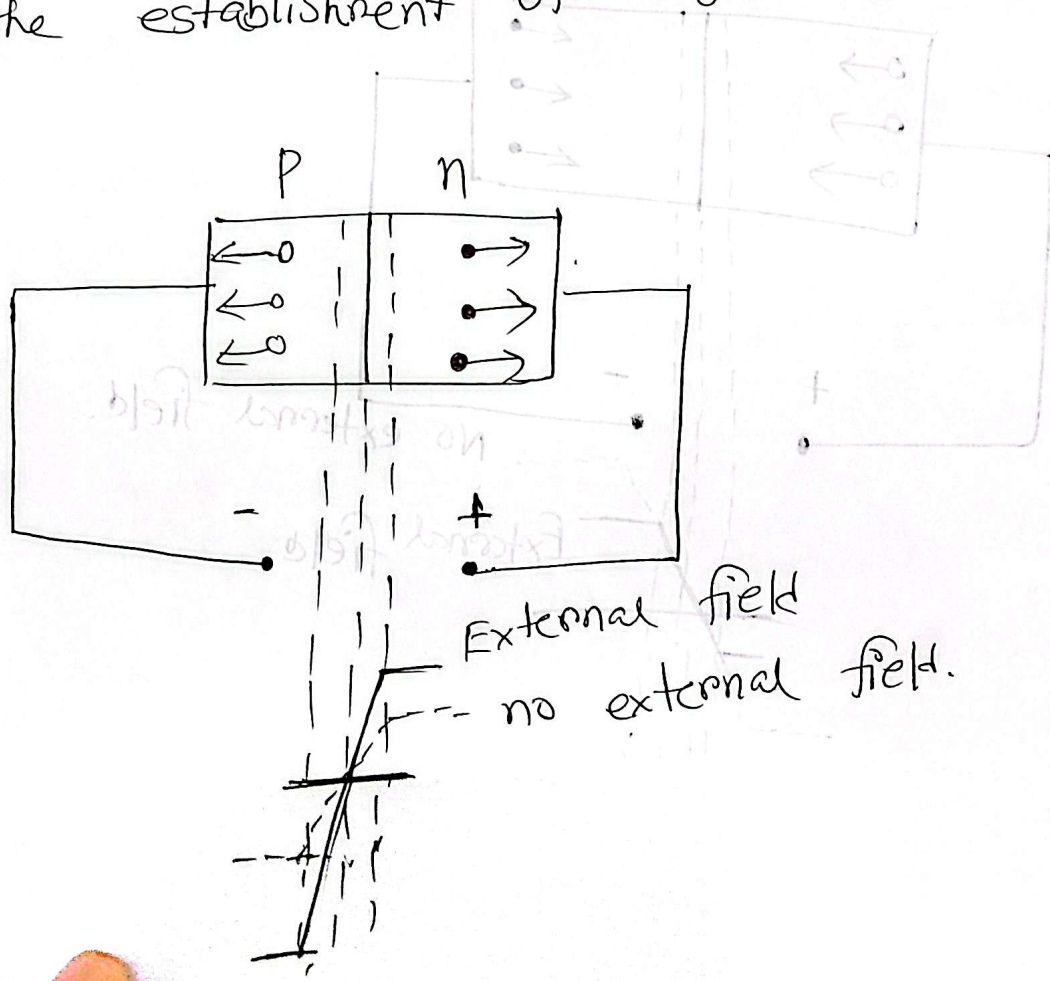
1. The external voltage reduces the potential barrier ($\sim 0.7V$ for Si, $\sim 0.3V$ for Ge)
2. The junction offers low resistance to current flow.
3. The current flows in the circuit due to the establish of low resistance path.
4. The magnitude of current depends upon the applied forward voltage.



2. Reverse biasing when the external d.e. voltage applied to the junction is in such a direction that potential barrier is increased it is called reverse biasing.

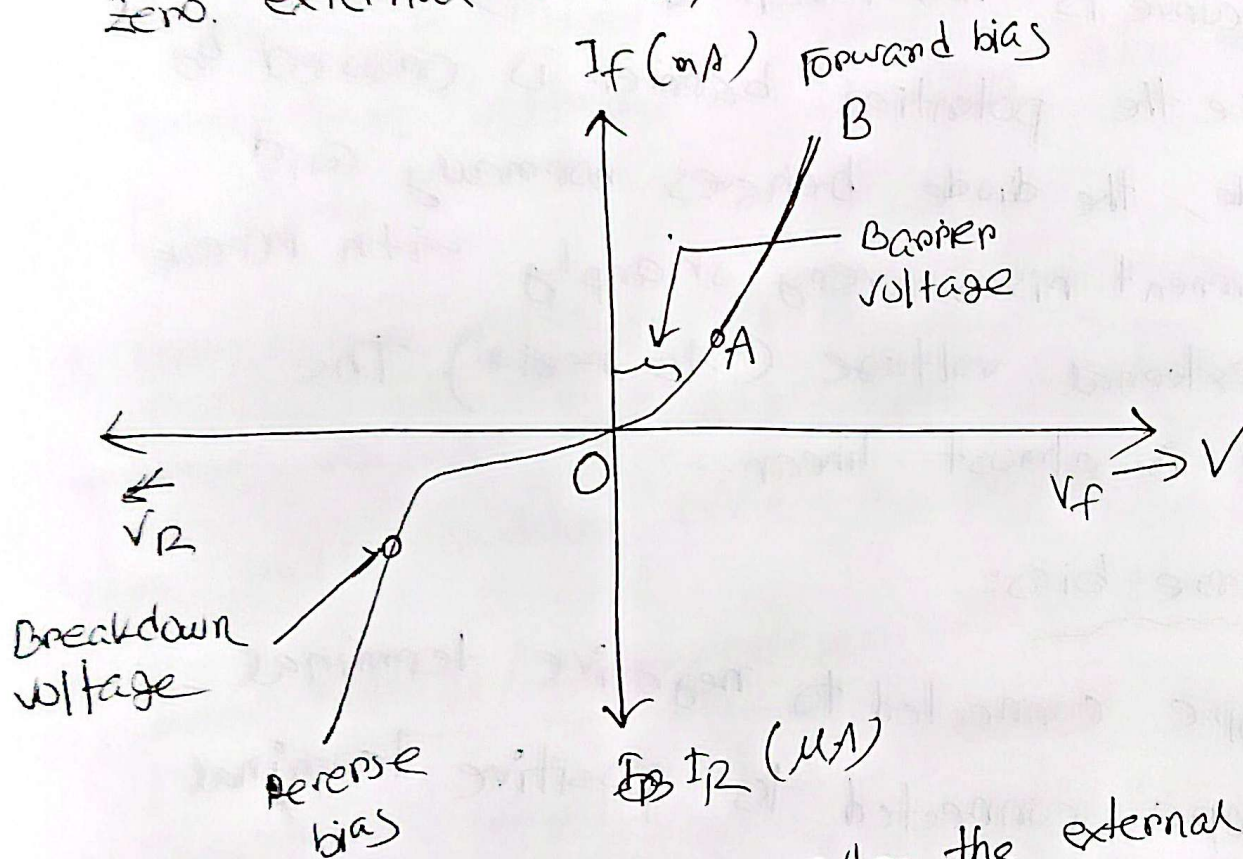
Effects:

1. The potential barrier is increased.
2. The junction offers very high resistance to current flow.
3. NO current flows in the circuit due to the establishment of high resistance path.



V-I characteristics of pn junction:

The V-I characteristics of a pn junction (also called a crystal or semiconductor diode) describe how current flows through the junction under different applied voltages. This depends on zero, external voltage, forward & reverse bias.



- i) zero external voltage when the external voltage is zero, the circuit current is zero as indicated by point O.

ii) Forward Bias

- p-type connected to positive terminal, n-type connected to negative terminal.
- the potential barrier is reduced
- The current increases very slowly and the curve is non-linear (OA region)
- Once the potential barrier is crossed by the diode, the diode behaves normally and the current rises very sharply with increase in external voltage (AB region). The curve is almost linear.

iii) Reverse bias

- p-type connected to negative terminal -
- n-type connected to positive terminal.
- the potential barrier is increased.
- The resistance also increased.
- A very small current (μA) flows in the circuit, this is called reverse

Saturation current and is due to the minority carriers.

→ If the applied voltage increases rapidly there is increased kinetic energy due to minority ^{charge} carriers which affect the majority charges. In this stage the voltage is called breakdown voltage. This may also destroy the diode.

Breakdown Voltage It is the minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current.

Knee Voltage / Barrier Voltage It is the forward voltage at which the current through the junction starts to increase rapidly.

for Si pn junction, potential barrier is 0.7V

for Ge pn junction, potential barrier is 0.3V.

Limitations of pn junctions

Every pn junction has limiting values of maximum forward current, peak inverse voltage and maximum power rating.

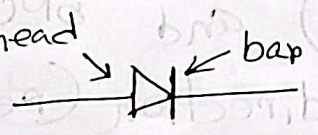
- ① Maximum forward current: It is the highest forward current that a pn junction can conduct without damage. If exceeded, the junction will be destroyed due to overheating.
- ② Peak Inverse ^{voltage} current: It is the maximum reverse voltage ~~than~~ that can be applied to the pn junction without damage. If the reverse voltage ~~across~~ exceeds PIV, the junction will be destroyed due to overheating.
- ③ Maximum power rating: It is the maximum power that can be dissipated at the junction without damaging it. The power dissipated at the junction is equal to the product of junction current and the voltage across the junction. $P = V_f \times I_f$

Chapter 6

Semiconductor Diode

□ Crystal diode: A pn junction is known as a semiconductor di or crystal diode.

Properties:

1. Allows current in one direction.
2. represented by :
 of the diode symbol
3. If the arrowhead is positive w.r.t. bar of the symbol, the diode is forward biased.
4. If the arrowhead of diode is negative w.r.t. bar of the diode, the diode is reverse biased.
5. Red marks denotes arrow and blue marks indicates bar.
6. Used for converting AC to DC
7. Small and Lightweight.
8. Needs a small voltage to work.

Q What is Rectifier? Explain, how crystal diode can be used as rectifier?

⇒ A rectifier is an electrical circuit that converts AC into DC.

How a crystal diode is used as a Rectifier

A crystal diode can be used as a rectifier because it allows current to flow in only one direction (forward bias) and blocks current in the opposite direction (reverse bias). This property makes it useful for rectification.

Types of rectifiers using a Crystal Diode:

1. Half-wave Rectifier:

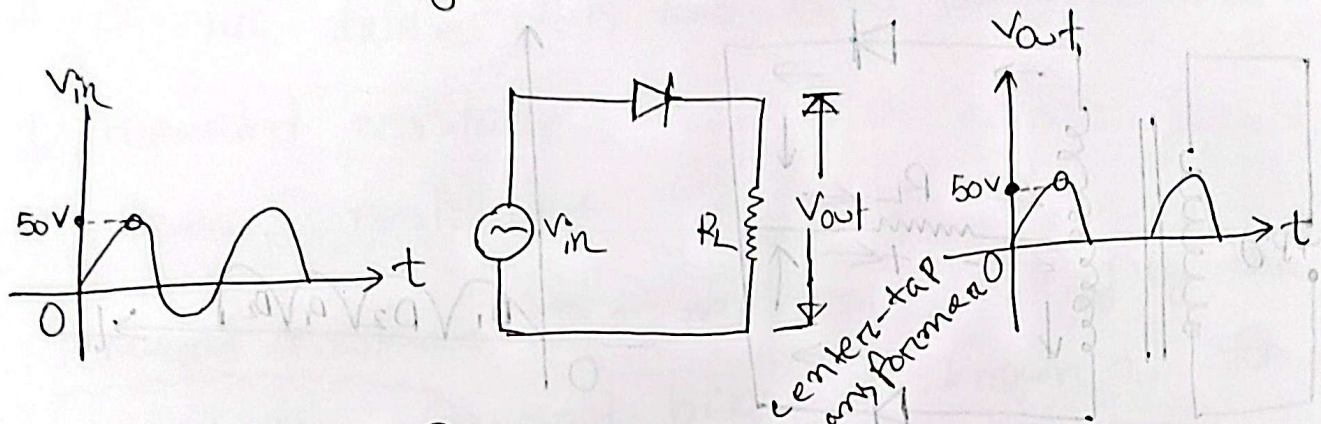
* Circuit: Uses one diode to pass only one half of the AC cycle.

* Working:

→ During the positive half-cycle, the diode is forward biased and current flows.

→ During the negative half-cycle, the diode is reverse biased, and the current is blocked.

* Output: A pulsating DC voltage. (only positive half cycles).



2. Full-wave Rectifier:

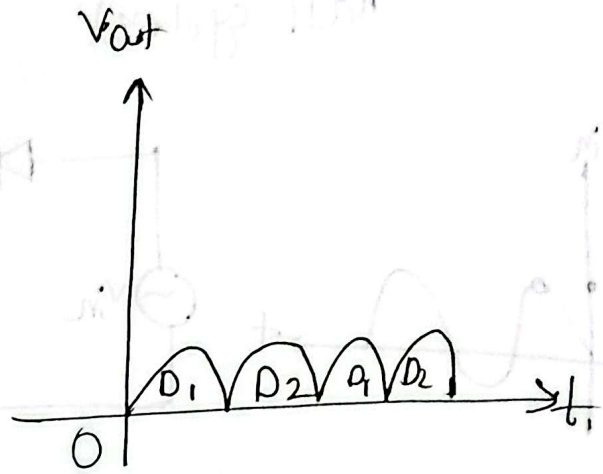
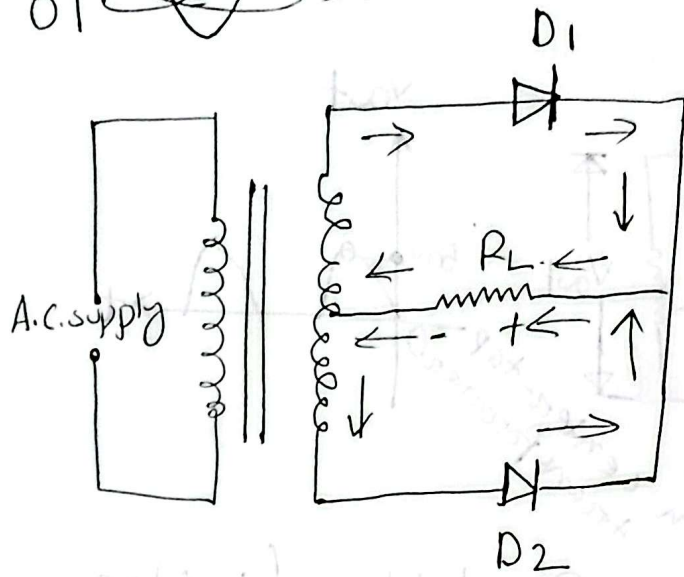
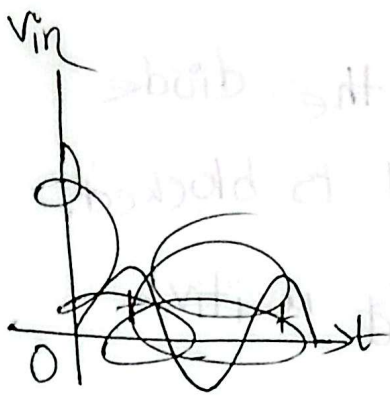
* Circuit: Uses two diodes or four diodes. (bridge rectifier)
 with center-tap transformer

* Working:

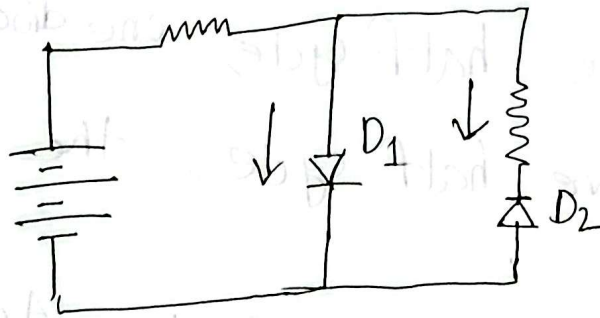
→ During the positive half-cycle, one diode conducts.
→ During the negative half-cycle, the other diode conducts.

→ This allows both halves of the AC cycle to be converted into DC.

* Output: A smoother DC voltage compared to a half-wave rectifier.



Exm: 6.1 → Find whether the diodes are forward or reverse biased.



Soln: → The conventional current coming out of a battery flows in the branch circuits. In diode D_1 , the conventional current flows in the direction of arrowhead and this is forward biased. In diode D_2 , the conventional

current flows thro in the ~~direction~~ opposite to arrowhead and this is reverse biased.

Resistance of crystal diode

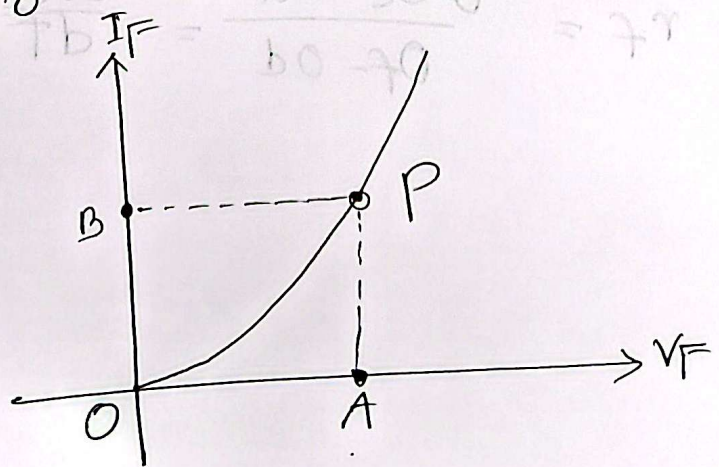
A crystal diode has two types of resistance :

1. Forward resistance.
2. Reverse resistance.

1. Forward resistance The resistance offered by the diode to the forward bias is known as forward resistance. There are two types, d.c. forward resistance & a.c. forward resistance.

* d.c. or static forward resistance: It is the opposition offered by the diode to the direct current. It is the ratio of d.c. voltage across the diode to the current flowing through it.

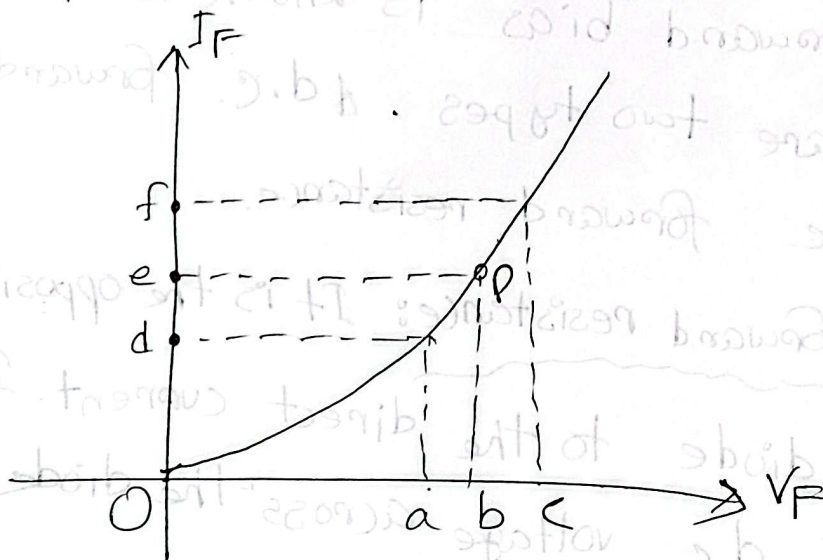
$$R_f = \frac{V}{I}$$



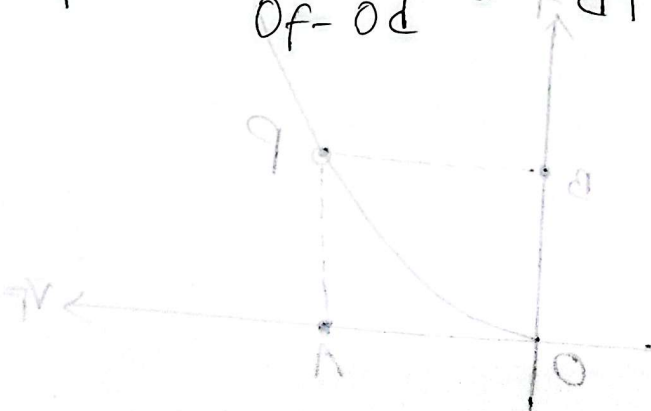
$$R_f = \frac{OA}{OB}$$

* A.c. or dynamic forward resistance It is the opposition offered by the diode to the changing forward current. It is measured by the ratio of change in voltage across diode to the resulting change in current through it.

$$r_f = \frac{\text{change in } \Delta V}{\Delta I}$$



$$r_f = \frac{I_{Fe} - I_{Fd}}{V_{Fe} - V_{Fd}} = \frac{ae}{df}$$



2. Reverse resistance: The resistance offered by the diode to the reverse bias is known as reverse resistance. It can be d.c. reverse resistance or a.c. reverse resistance depending upon whether the reverse bias is direct or changing voltage. ^{Ideally,} the reverse resistance of a diode is infinite. In practice, the reverse resistance is not infinite because a small leakage current exist. The reverse resistance is very large compared to forward resistance. In Ge diodes, the ratio of reverse to forward is 40000:1 while for silicon this ratio is 1000000:1.

Exm: 6.2:

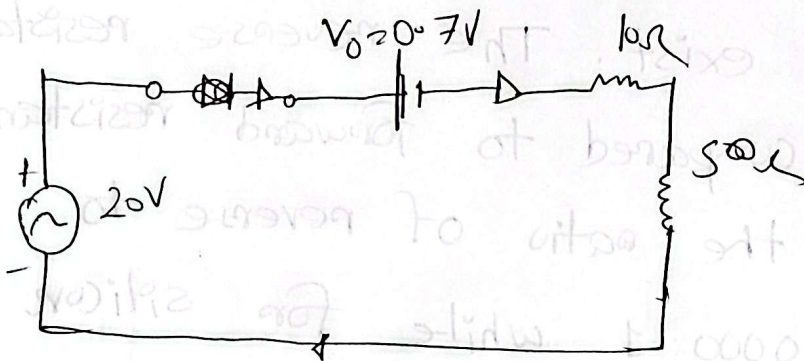
peak input voltage, $= 20V$

Forward resistance, $r_f = 10\Omega$

Load " , $R_L = 500\Omega$

Potential barrier voltage, $V_0 = 0.7V$ (Si)

The diode will conduct during the positive half-cycles of a.c. input voltage only.



- i) ~~peak current~~ when $V_{in} = V_F = 20V$ the input voltage reaches the positive peak. the peak current through the diode will occur.

$$V_F = V_0 + (I_F)_{peak} (r_f + R_L) \quad \text{--- ①}$$

$$\begin{aligned} \therefore (I_F)_{peak} &= \frac{V_F - V_0}{r_f + R_L} = \frac{20 - 0.7}{10 + 500} \\ &= \frac{19.3}{510} A \\ &= 37.8 \text{ mA (Ans)} \end{aligned}$$

ii) peak_n^{output} voltage $= (I_f)_{\text{peak}} \times R_L$
 $= 37.8 \text{ mA} \times 500 \Omega = 18.9 \text{ V}$ Ans.

Ideal diode, For an ideal diode, put $V_0 = 0$ and $r_f = 0$ in eqn. (1)

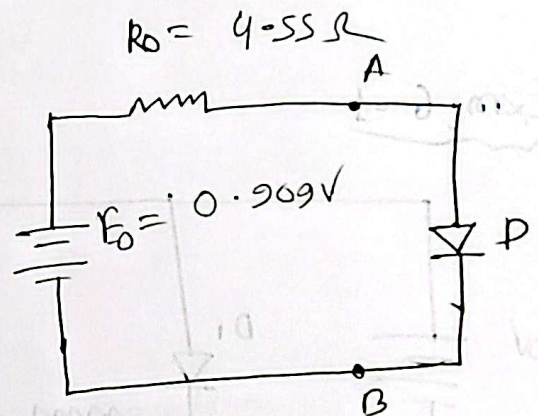
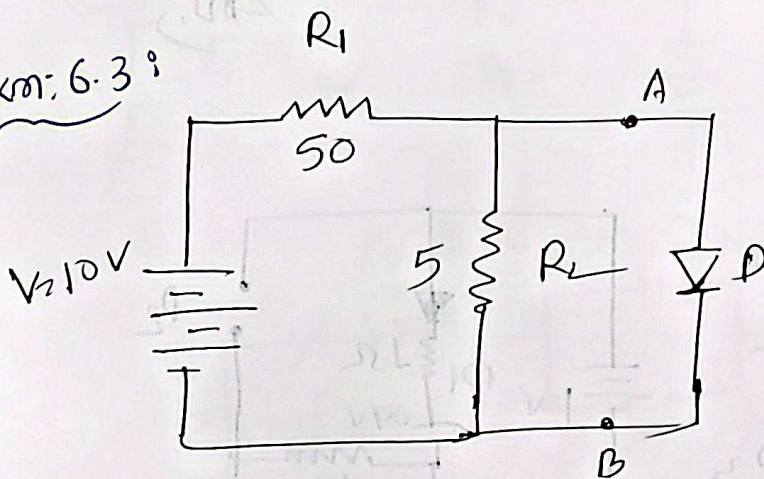
Now,

$$V_F = (I_f)_{\text{peak}} \times R_L$$

$$\Rightarrow (I_f)_{\text{peak}} = \frac{V_F}{R_L} = \frac{20}{500} = 40 \text{ mA}$$

Peak output voltage $= (I_f)_{\text{peak}} \times R_L$
 $= 2 \text{ W}$ Ans.

Exm: 6.3:



We shall use thevenin's theorem to find current.

E_0 = thevenin's voltage

= open circuited voltage across AB with diode removed

$$= \frac{R_2}{R_1 + R_2} \times V = \frac{5}{55} \times 10 = 0.909 \text{ V}$$

R_0 = thevenin's resistance

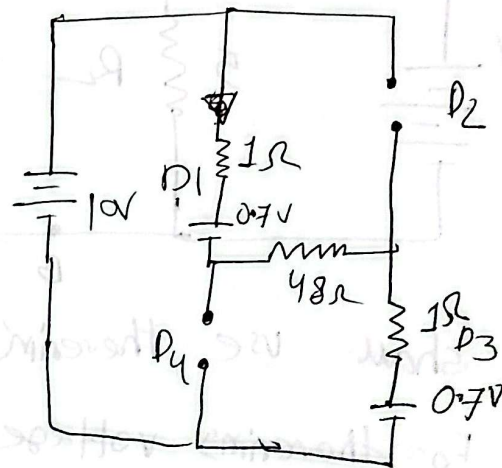
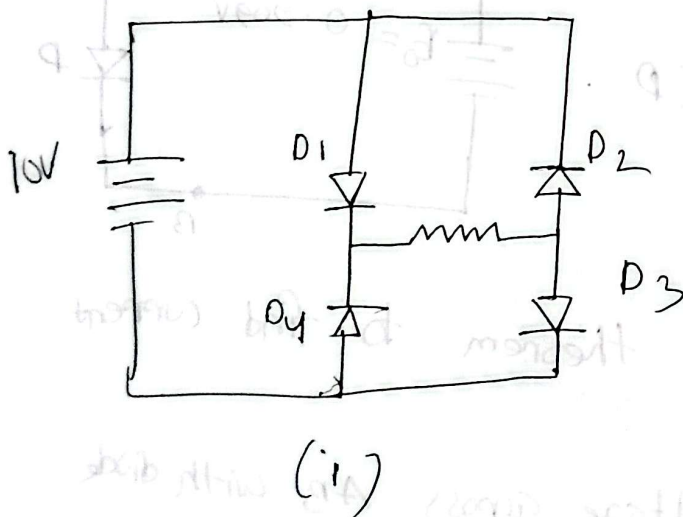
= resistance at terminals AB with diode removed and battery replaced by a short circuit.

$$\frac{R_2 \times R_1}{R_1 + R_2} = \frac{50 \times 5}{55} = 4.55 \Omega$$

Since the diode is ideal, it has zero resistance

$$\therefore \text{Current, } I = \frac{E_0}{R_0} = \frac{0.999}{4.55} = 0.2 \text{ A} = 200 \text{ mA}$$

Exm: 6.4



Diodes D_1 and D_3 are forward biased
and D_2 and D_4 are reverse biased.

we can consider the branches containing diodes,

D_2 and D_4 as open.

Now,

$$V_0 = 0.7 \text{ V}$$

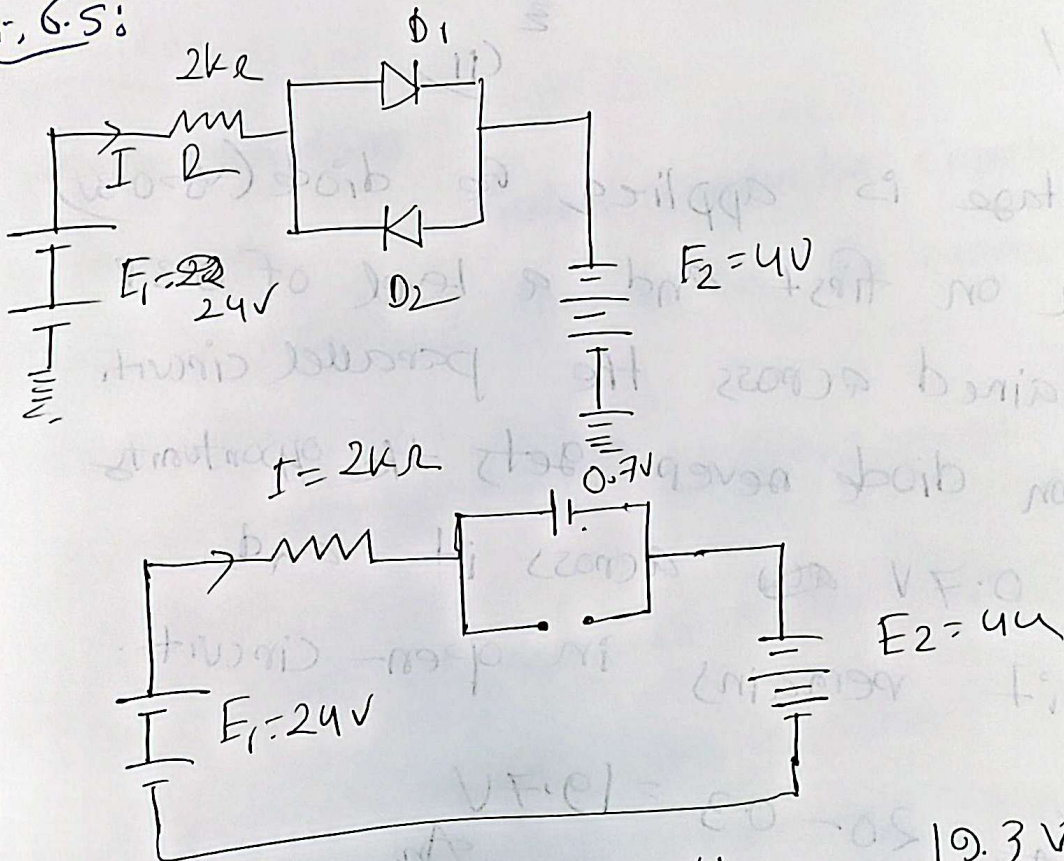
$$\text{net circuit voltage} = 10 - 0.7 - 0.7 = 8.6 \text{ V}$$

$$\text{total resistance} = 1 + 48 + 1 = 50 \Omega$$

$$\text{circuit current} = \frac{8.6}{50} = 0.172 \text{ A} = 172 \text{ mA}$$

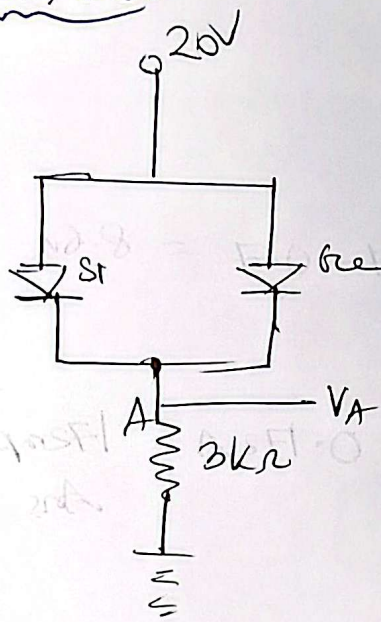
Ans

Exm. 6.5:

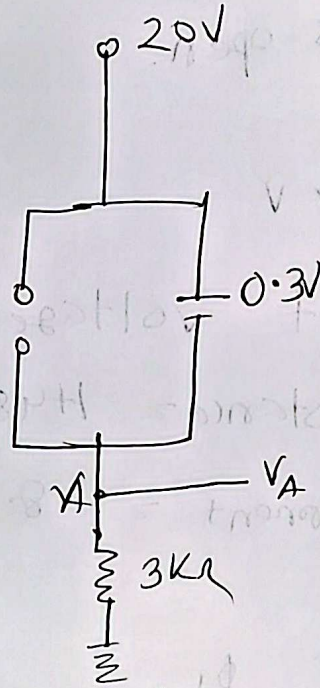


$$\therefore I = \frac{24 - 0.7 - 4}{2} = \frac{19.3 \text{ V}}{2 \text{ k}\Omega} = 9.65 \text{ mA}$$

Exm. 6.6:



(i)



(ii)

when voltage is applied, Ge diode ($V_b = 0.3V$) will turn on first and a level of 0.3V is maintained across the parallel circuit. The silicon diode never gets the opportunity to have 0.7V across it and therefore it remains in open-circuit.

$$V_A = 20 - 0.3 = 19.7V$$

① Identify Forward current, Peak inverse voltage, reverse current or leakage current and why they are important in diode operation.

⇒ 1. Forward current: It is the maximum forward current that a diode can conduct without damage. If exceeded, the diode will be destroyed due to overheating.

Importance:

1. ~~Power handling~~

1. Determines the diode's conduction capability.

2. Helps in selecting the diode for current-handling applications.

3. Protects the diode from overcurrent damage.

2. Peak Inverse voltage: It is the maximum reverse voltage that a diode can withstand without destroying the function. If the reverse voltage across PIV, the diode will be destroyed due to overheating.

(2)

Importance:

1. It is very important when diode is used as a rectifier.
2. Ensures that the diode does not fail in rectifier circuits.
3. Protects circuits from high voltage spikes.
4. Helps in selecting a diode with sufficient voltage rating to prevent damage.

3. Leakage Current or reverse currents

A small current flows when the diode is reverse biased. This current is due to the minority carriers. It increases with temperature.

Importance:

1. Affects efficiency in rectifier circuits.
2. Can lead to power loss if too high.
3. Important in low-power & precision circuits.

Half-wave rectifiers

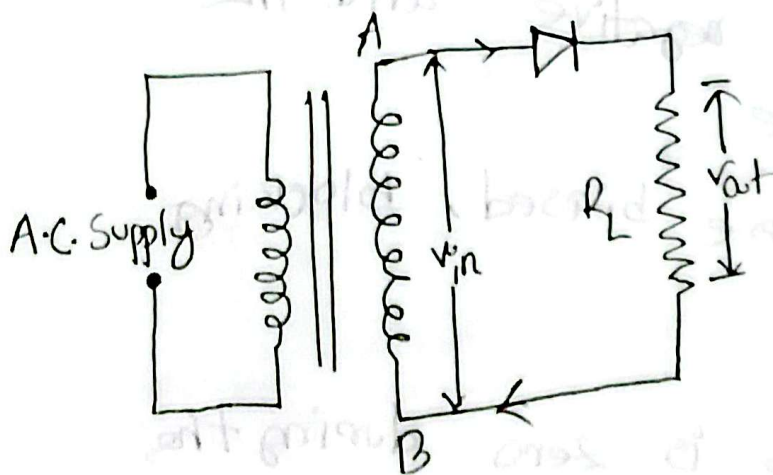
(3)

A half-wave rectifier is a circuit that converts AC into DC by allowing only one half-cycle of the AC signal to pass while blocking the other half.

Circuit Components:

1. AC input source
2. Diode
3. Load resistor

Diagram



I/O voltage diagram:

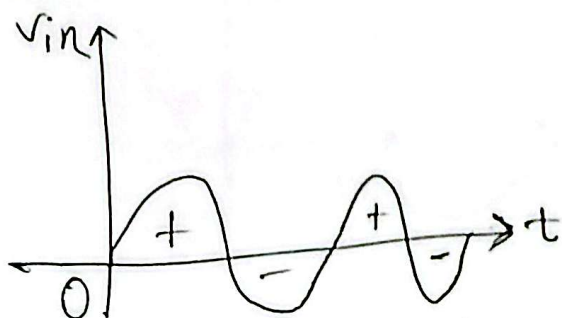


Fig: Input voltage.

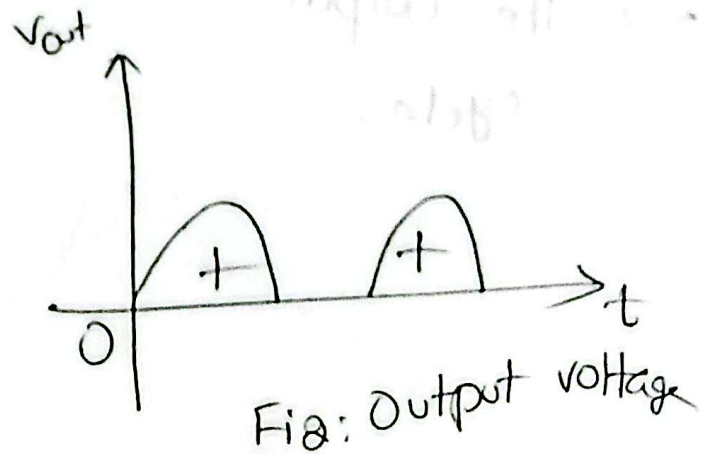


Fig: Output voltage

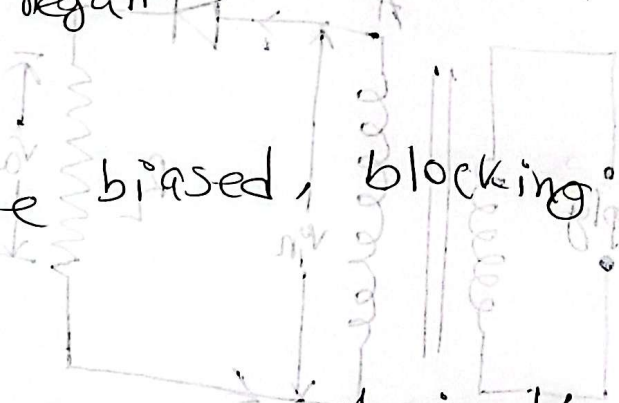
Working Principles

During the Positive Half-cycle:

- The anode of the diode becomes positive and the cathode is negative.
- The diode is forward biased and current flows through the load resistor (R_L).
- The output voltage follows the positive half of the input AC waveform.

During the negative Half-cycle:

- The anode becomes negative and the cathode is positive.
- The diode is reverse biased, blocking current flow.
- The output voltage is zero during the cycle.



Advantages:

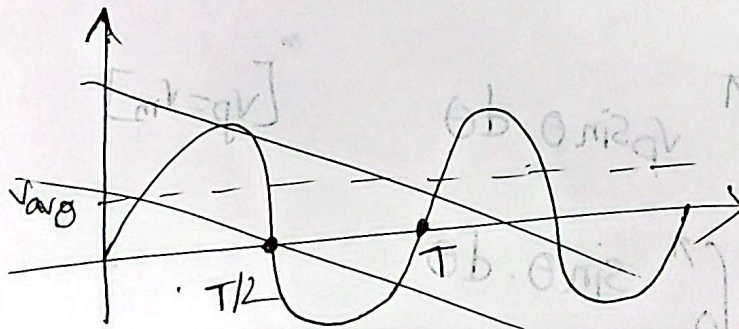
1. Simple circuit design
2. Low cost
3. Smaller size
4. Easy to use

Disadvantages:

1. Low efficiency
2. Pulsating DC output
3. High Ripple Factor
4. Lower Output voltage & Current

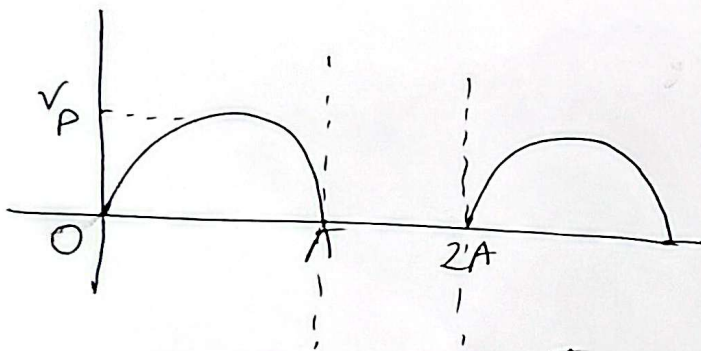
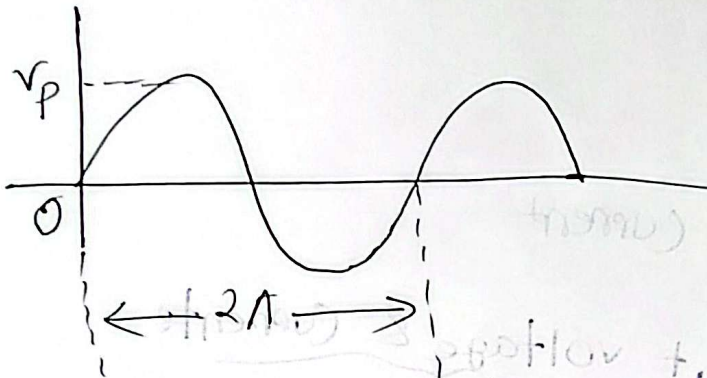
Average values of Output voltage & Current

1. Average output voltage:



(6)

$$\begin{aligned}
 V_{dc} = V_{avg} &= \frac{1}{T} \int_0^T v(t) \cdot dt \\
 &= \frac{1}{T} \left[\int_0^{T/2} V_m \sin \omega t \cdot dt + 0 \right] \\
 &= \frac{1}{T} \int_0^{T/2} V_m \sin \omega t \cdot dt \\
 &= \frac{1}{T} V_m \int_0^{T/2} \sin \omega t \cdot dt \\
 &= \frac{1}{T} \cdot V_m \left[-\frac{\cos \omega t}{\omega} \right]_0^{T/2}
 \end{aligned}$$



$$\begin{aligned}
 V_{dc} = V_{Avg} &= \frac{1}{2\pi} \int_0^{\pi} v_p \sin \theta \cdot d\theta \\
 &= \frac{v_p}{2\pi} \int_0^{\pi} \sin \theta \cdot d\theta
 \end{aligned}$$

$$[v_p = v_m]$$

$$= \frac{V_p}{2\pi} [-\cos 0]_0^{\pi}$$

$$= \frac{V_p}{2\pi} [-\cos \pi - (-\cos 0)]$$

$$= \frac{V_p}{2\pi} [-1 - (-1)]$$

$$= -\frac{V_p}{2\pi}$$

$$= \frac{V_p}{2\pi} [-\cos \pi - (-\cos 0)]$$

$$= \frac{V_p}{2\pi} (-\cos \pi + \cos 0)$$

$$= -\frac{V_p}{2\pi} (\cos \pi - \cos 0)$$

$$= -\frac{V_p}{2\pi} [-1 - 1]$$

$$= -\frac{V_p}{2\pi} (-2)$$

$$= \frac{V_p}{\pi} = \frac{V_m}{\pi}$$

$$V_{dc} = 0.318 V_p = 0.318 V_m$$

2. Average currents

$$\begin{aligned} I_{dc} &= \frac{V_{dc}}{R_L} = \frac{V_m}{\pi} \times \frac{1}{R_L} \\ &= 0.318 \frac{V_m}{R_L} \\ &= 0.318 I_m \end{aligned}$$

$$= \frac{I_m}{\pi}$$

$$\text{Or, } I_{dc} = \frac{1}{2\pi} \int_0^\pi I_m \sin \theta \cdot d\theta$$

$$= \frac{I_m}{2\pi} \int_0^\pi \sin \theta \cdot d\theta$$

$$= \frac{I_m}{2\pi} [-\cos \theta]_0^\pi$$

$$= \frac{I_m}{2\pi} [-\cos \pi + \cos 0]$$

$$= -\frac{I_m}{2\pi} [\cos \pi - \cos 0]$$

$$= -\frac{I_m}{2\pi} [-1 - 1]$$

$$= \frac{I_m}{2\pi} (-2)$$

$$I_{dc} = \frac{I_m}{\pi}$$

$$\begin{aligned} I_{dc} &= \frac{1}{2\pi} \int_0^\pi i \cdot d\theta \\ &= \frac{1}{2\pi} \int_0^\pi \frac{V_m \sin \theta}{r_f + R_L} \cdot d\theta \\ &= \frac{V_m}{2\pi(r_f + R_L)} \int_0^\pi \sin \theta \cdot d\theta \end{aligned}$$

$$= \frac{V_m}{2\pi(r_f + R_L)} [-\cos \theta]_0^\pi$$

$$= \frac{V_m}{2\pi(r_f + R_L)} \times 2$$

$$= \frac{I_m}{\pi}$$

$$\left[I_m = \frac{V_m}{r_f + R_L} \right]$$

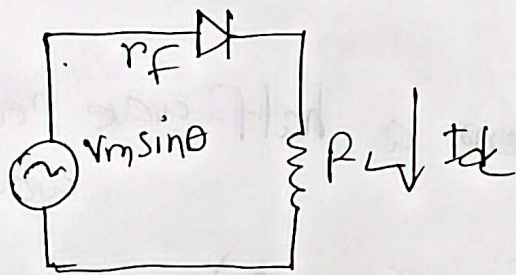
Efficiency of half-wave rectifiers

The ratio of d.c. power output to the applied input a.c. power is known as rectifier efficiency.

$$\eta = \frac{\text{d.c. power output}}{\text{input a.c. power}}$$

$$\text{Input A.C. power, } P_{ac} = I_{rms}^2 (r_f + R_L)$$

$$\text{Output D.C. power, } P_{dc} = I_{dc}^2 \times R_L$$



d.c. powers The output current is pulsating direct current. Therefore, in order to find d.c power - average current has to be found out.

$$\begin{aligned} I_{av} = I_{dc} &= \frac{1}{2\pi} \int_0^{\pi} i \, d\theta \\ &= \frac{1}{2\pi} \int_0^{\pi} \frac{v_m \sin \theta}{r_f + R_L} \, d\theta \\ &= \frac{v_m}{2\pi (r_f + R_L)} \int_0^{\pi} \sin \theta \, d\theta \end{aligned}$$

$$\begin{aligned}
 &= \frac{V_m}{2\pi(r_f + R_L)} [-\cos \theta]_0^\pi \\
 &= \frac{V_m}{2\pi(r_f + R_L)} \times 2 = \frac{V_m}{r_f + R_L} \times \frac{1}{\pi} \\
 &= \frac{I_m}{\pi} \left[-I_m \times \frac{V_m}{r_f + R_L} \right] = \pi
 \end{aligned}$$

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{I_m}{\pi} \right)^2 \times R_L$$

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

$$I_{rms} = I_m / 2 \quad (\text{For a half-wave rectified wave})$$

$$P_{ac} = \left(\frac{I_m}{2} \right)^2 \times (r_f + R_L)$$

$$\therefore \eta = \frac{\left(\frac{I_m}{\pi} \right)^2 \times R_L}{\left(\frac{I_m}{2} \right)^2 \times (r_f + R_L)}$$

$$= \frac{0.406 R_L}{r_f + R_L} = \frac{0.406}{1 + \frac{r_f}{R_L}}$$

(11)
The efficiency will be maximum if P_{dc} is maximum

max rectifier efficiency 96.6%

ex: (12) If the applied input ac power to a half wave rectifier is 100 watts, the d.c. output power obtained is 96 watts.

D) What is the rectification efficiency?

(i) what happens to remaining 40 watts?

(i)

$$\text{rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{96}{100} = 96\%$$

(ii)

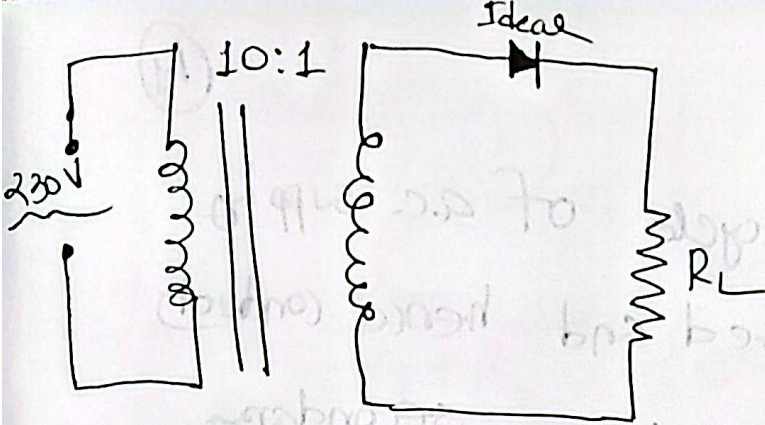
96% of efficiency of rectification does not mean that 4% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The loss a.c. power is obtained as follows:

positive half-cycles and 50 w in negative half-cycle. (K)
The 50-w in the negative half-cycles are not supplied at all. Only 50 w in the positive half-cycles are converted into 40 w.

$$\therefore \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

Although 100 w of a.c. power was supplied the half-wave rectifier accepted only 50 w and converted it into 40 w d.c. power. Therefore, it is appropriate to say that efficiency of rectification is 40% and not 80% which is power efficiency.

Example 6.13: An a.c. supply of 230V is applied to a half wave rectifier circuit through a transformer of turn ratio 10:1. Find (i) the output d.c. voltage & (ii) the peak inverse voltage. Assume the diode to be ideal.



⇒ Primary to secondary turns is

$$\frac{N_1}{N_2} = \frac{10}{1}$$

R.M.S. primary voltage = 230V.

∴ MAX. primary voltage is

$$V_{pm} = (\sqrt{2}) \times \text{r.m.s. primary voltage}$$

$$= (\sqrt{2}) \times 230 = 325.3 \text{ V}$$

Max. secondary voltage is

$$V_{sm} = V_{pm} \times \frac{N_2}{N_1} = 325.3 \times \frac{1}{10} = 32.53 \text{ V}$$

$$I_{dc} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = 10.36 \text{ V}$$

(ii)

(14)

During the negative half-cycle of a.c. supply the diode is reverse biased and hence conducts no current. Therefore the maximum secondary voltage appears across the diode.

$$\therefore \text{Peak inverse voltage} = 32.53 \text{ V (Ans.)}$$

Example 6.14: A crystal diode having internal resistance $r_f = 20 \Omega$ is used for half wave rectification. If the applied voltage $v = 50 \sin \omega t$ and load resistance

$$R_L = 800 \Omega \text{ find:}$$

- i) I_m, I_{dc}, I_{rms}
- ii) a.c. power input & d.c. power output.
- iii) d.c. output voltage
- iv) efficiency of rectification.

$$\Rightarrow v = 50 \sin \omega t$$

$$\therefore \text{Maximum voltage} = 50 \text{ V.}$$

$$V_m = \uparrow$$

(i)

$$I_m = \frac{V_m}{r_f + R_L} = \frac{50}{(50 + 120)} = 0.041 \text{ A}$$

$$I_{dc} = \frac{V_m}{\pi} \times \frac{I_m}{I} = \frac{61}{\pi} = 19.4 \text{ A}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{61}{\sqrt{2}} = 30.5 \text{ mA}$$

(ii)

ac power input = $(I_{rms})^2 \times (r_f + R_L)$
 $= \left(\frac{30.5}{1000}\right)^2 \times (900 + 800)$
 $= 0.74 \text{ W}$

dc power input = $(I_{dc})^2 \times R_L$
 $= \left(\frac{19.4}{1000}\right)^2 \times (800)$
 $= 0.301 \text{ W}$

(iii)

d.c. output voltage, $V_{dc} = \frac{V_m}{\pi} I_{dc} \times R_L$

$$= \frac{50}{\pi} \times \frac{19.4 \times 800}{1000}$$

$$= \frac{10}{\pi} = 15.82 \text{ V (Ans.)}$$

(iv)

$$\text{efficiency} = \frac{0.301}{0.763} \times 100 = 39.5\%$$

Example: 6.15 A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω . The diode has a resistance of 25 Ω . Calculate a.c. voltage.

$\Rightarrow$ d.c. output voltage, $V_{dc} = 50 \text{ V}$

Load, $R_L = 800 \Omega$

Diode, $r_f = 25 \Omega$

$$V_{dc} = I_{dc} \times R_L$$

$$I_{dc} = \frac{50}{800} =$$

Let, V_m be the maximum value of a.c voltage required.

$$V_{dc} = I_{dc} \times R_L$$

$$\Rightarrow I_{dc} = \frac{I_m}{\pi} \quad \left[I_m = \frac{V_m}{r_f + R_L} \right]$$
$$\Rightarrow V_{dc} = \frac{V_m}{\pi (r_f + R_L)} \times R_L$$

$$\Rightarrow 50 = \frac{V_m}{\pi (25 + 80)} \times 800$$

$$\Rightarrow V_m = \frac{50 \times \pi \times 800}{800}$$
$$= 162 \text{ V (Ans.)}$$

A center-tapped full-wave rectifier circuit that converts the entire input AC signal into DC using two diodes and a center-tapped transformer.

Circuit (components):
1. Center-tapped transformer
2. Two diodes
3. Load Resistor
4. A.C input source

6.11: Full-wave Rectifier

A full wave rectifier is an electronic circuit that converts AC ~~current~~ to DC using both the positive & negative ~~signal~~ halves of an AC signal. The current flows in the same direction.

Common full-wave rectifiers are:

- (i) Centre-tap full-wave rectifier
- (ii) Full-wave bridge rectifier.

6.12: Centre-tap full-wave Rectifier

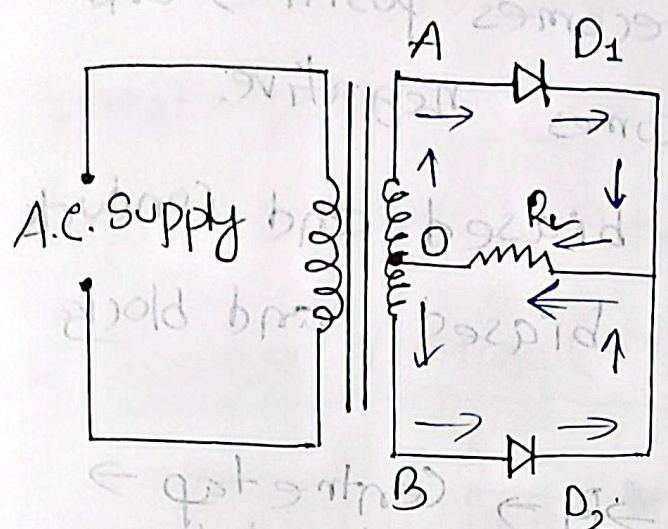
A centre tap full wave rectifier is an electronic circuit that converts the entire input AC signal into DC using two diodes and a centre-tapped transformer.

Circuit Components:

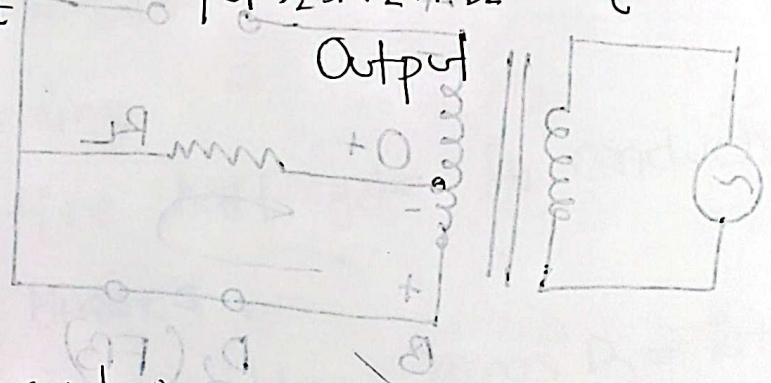
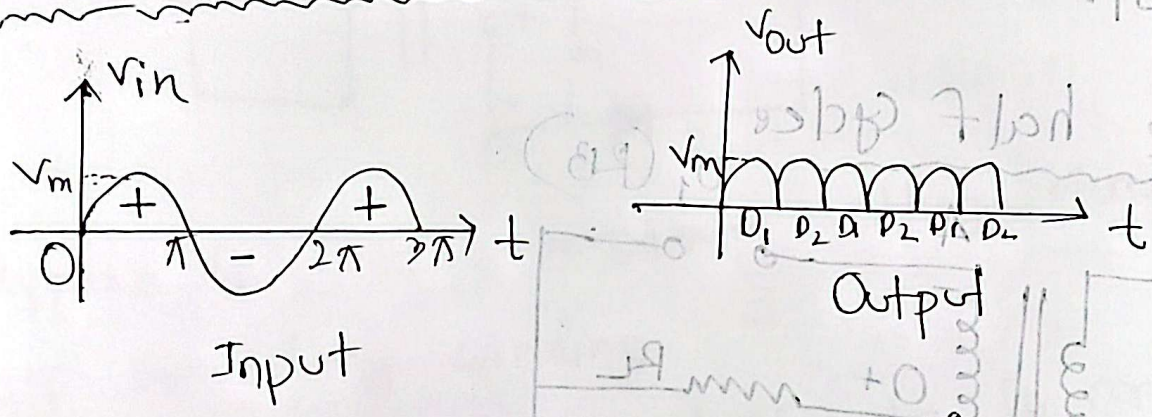
- 1. Center-tapped transformer
- 2. Two diodes
- 3. Load Resistor
- 4. A.C input source.

Diagram

19

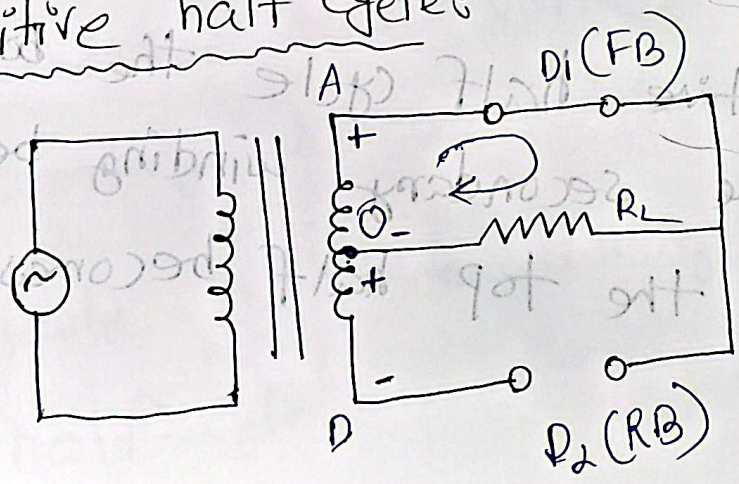


Input/Output voltage diagram

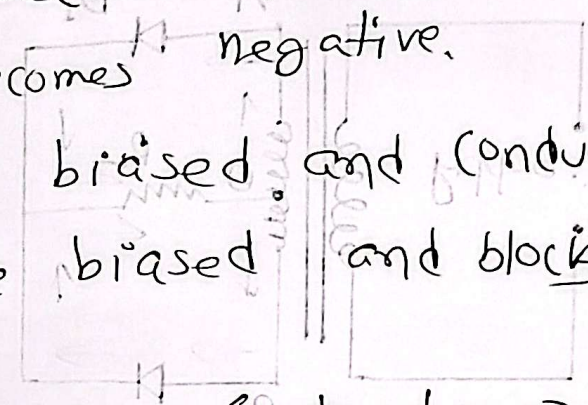


Working Principle:

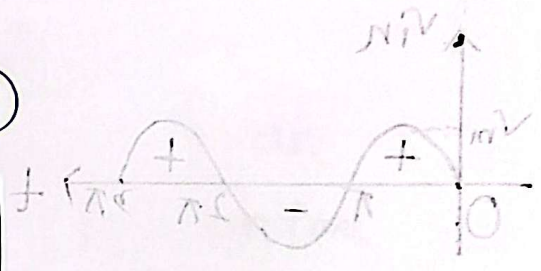
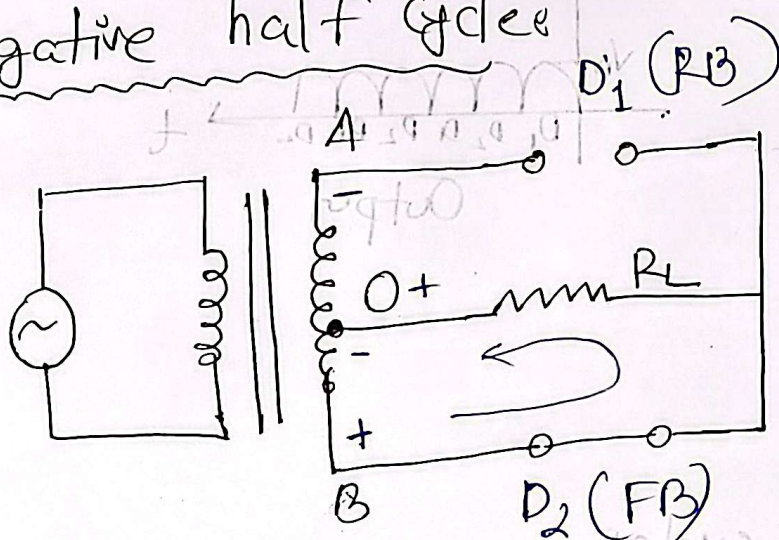
① Positive half cycle



- During Positive half cycle the top half of the secondary winding becomes positive, and the bottom half becomes negative.
- Diode D_1 is forward biased and conducts
- Diode D_2 is reverse biased and blocks current.
- Current path: $D_1 \rightarrow R_L \rightarrow \text{Centre tap} \rightarrow \text{back to the source}$
- Output: Positive voltage across R_L



② Negative half cycle

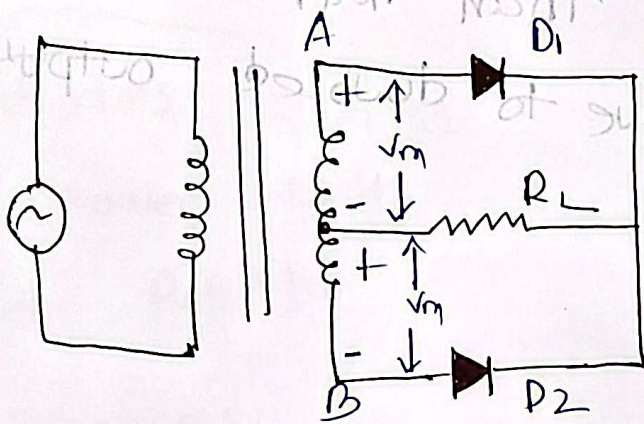


- During Negative half cycle the bottom half of the secondary winding becomes positive, and the top half becomes negative.

(2)

- Diode D_2 is forward biased and conducts
- Diode D_1 is reverse biased and blocks current
- Current path : $D_2 \rightarrow R_L \rightarrow$ Centre tap. - back to the source.
- Output: Positive voltage across R_L

Peak Inverse Voltage (PIV):



Suppose V_m is the maximum voltage across the half secondary winding.

- During the positive half-cycle D_1 conducts and D_2 is reverse biased.

→ The reverse across voltage across $D_2 =$ Total secondary voltage $(2V_m)$.

- Similarly $D_1 = 2V_m$ during the negative half-cycle.

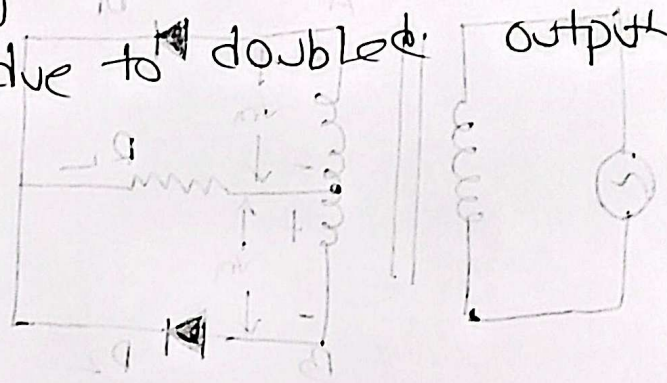
(23)

So, the peak inverse voltage is twice the maximum voltage across the half secondary winding.

$$PIV = 2V_m$$

Advantages:

- higher efficiency than half-wave rectifiers
- Lower ripple due to doubled frequency ($2f$)
- Simple Design.



Disadvantages:

- It is difficult to locate the centre tap on the secondary winding.
- The diodes must have high peak inverse voltage.
- The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

5.13: Full-wave Bridge Rectifier:

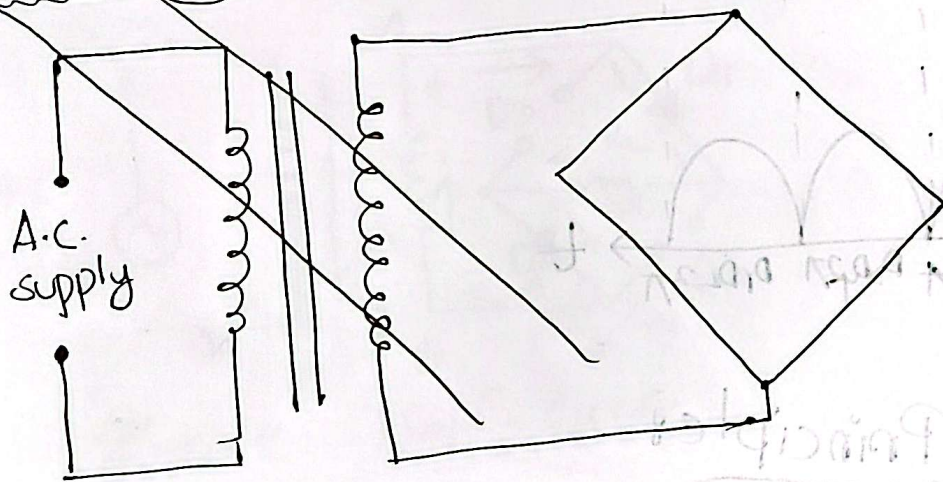
(23)

A full-wave bridge rectifier is an electronic circuit that converts an alternating current (A.C.) into a Direct current (D.C.) using four diodes arranged in a bridge configuration.

Circuit Components:

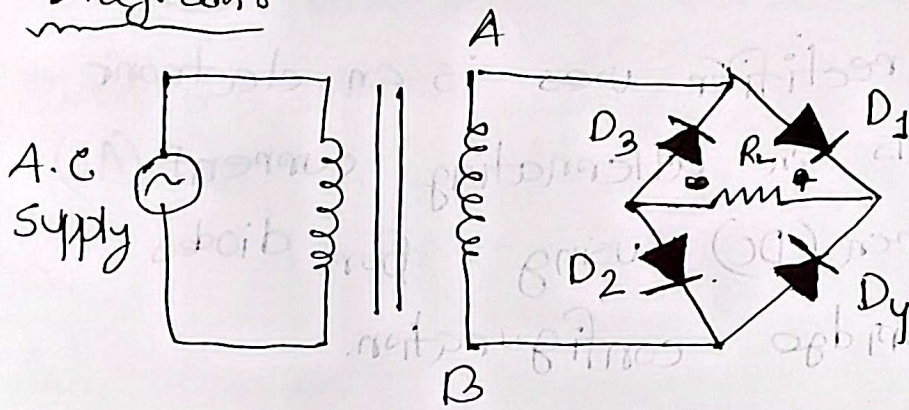
1. Four diodes.
2. A.C. Power supply
3. Load Resistor

Circuit Diagram:

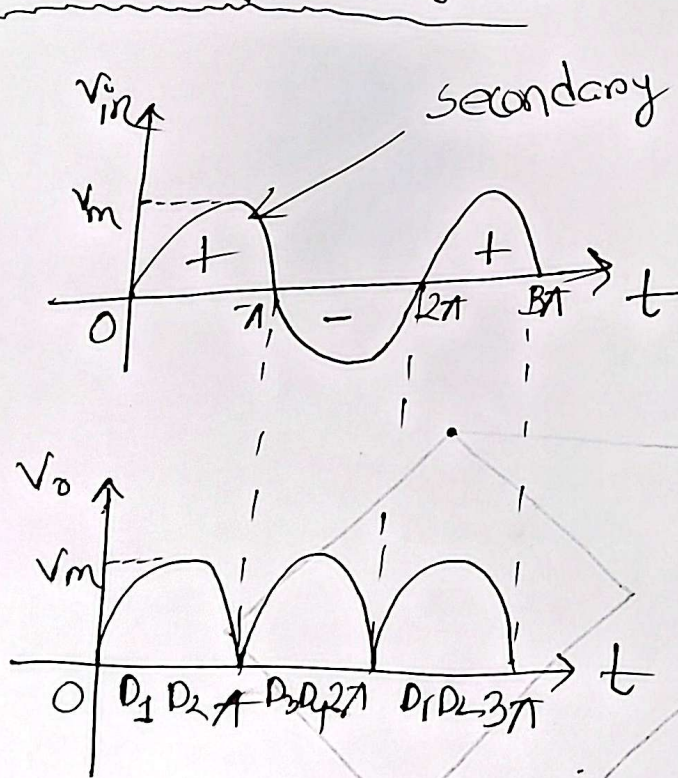


① Positive half cycle
Point A is positive and B is negative.

Diagram:



I/O Voltage Diagrams

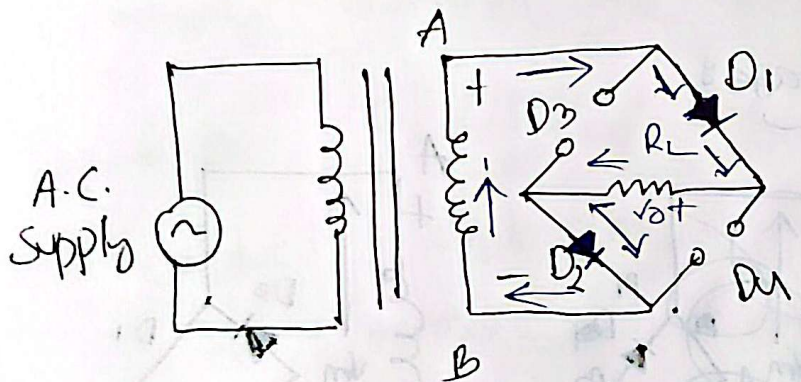
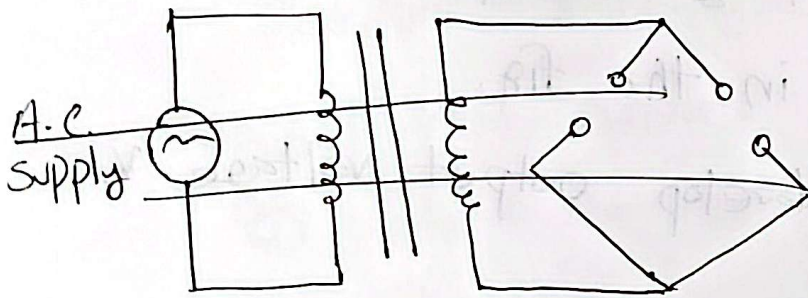


Working Principles

① Positive half-cycle:

→ Point A is positive and B is negative.

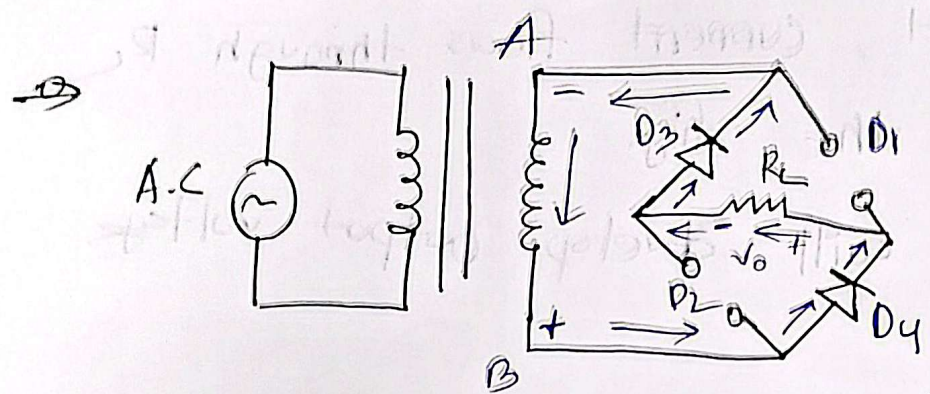
- Diodes D_1 & D_2 are forward biased. (~~conducting~~)
- Diodes D_3 & D_4 are reverse biased (~~blocking~~)
- D_1 & D_2 Conduct, current flows through R_L as shown in the fig.
- This current will develop output voltage across R_L .



② Negative Half-cycle:

- Point A is negative & B is positive.

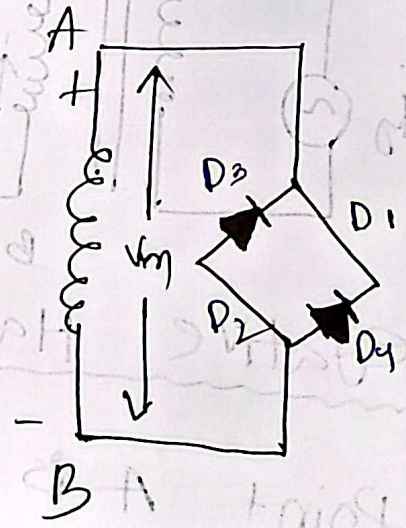
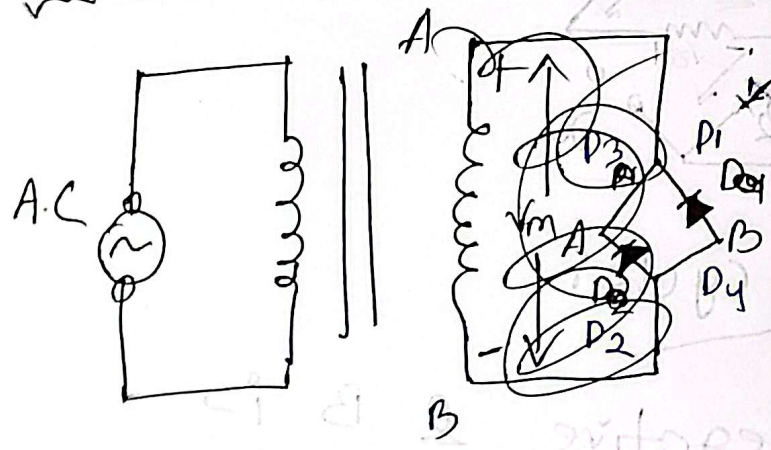
- Diodes D_3 & D_4 are forward biased.
- Diodes D_1 & D_2 are reverse biased.



- D_3 & D_4 conduct & current flows through R_L as shown in the fig.

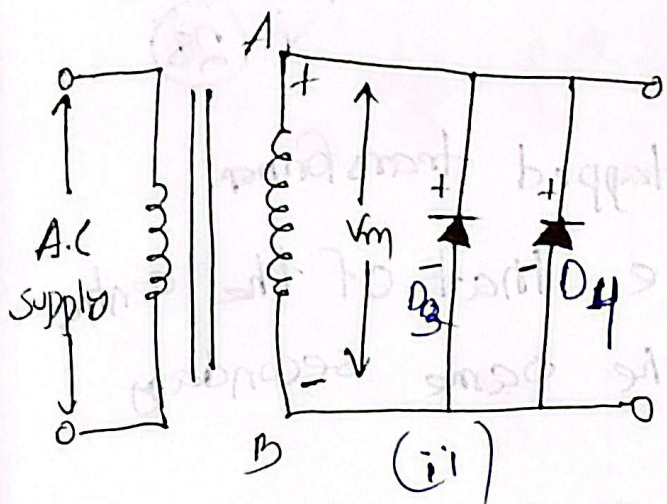
- The current develop output voltage across R_L .

Peak Inverse Voltage



(i)

(27)



- PIV is the maximum reverse voltage a diode experiences when it is not conducting.
- During Positive half-cycle, D_1 & D_2 are forward biased and conduct and the voltage across D_3 & D_4 is V_m (reverse biased).
- Similarly, during the negative half-cycle, D_3 & D_4 are forward biased and conduct, and the voltage across D_1 & D_2 is V_m (reverse biased).
- It is clear that in the fig(ii) two reverse biased diodes D_3 & D_4 and the secondary transformer are in parallel.
- Hence, $PIV = V_m$

(28)

Advantages:

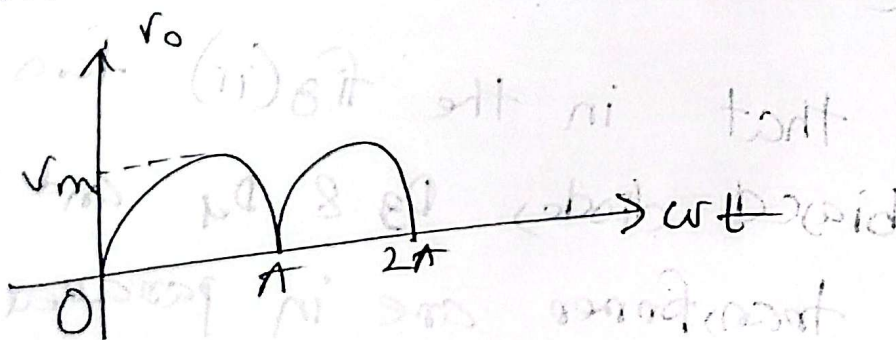
- No need for a centre-tapped transformer
- The output is twice that of the centre tap circuit for the same secondary voltage.
- The PIV is one-half that of the centre tap circuit (for same d.c. output).

Disadvantages:

- It requires four diodes.
- Higher voltage drop.

□ Average value of output voltage & currents

Average dc voltage:



$$V_o = V_m \sin \omega t$$

$$V_{av} = V_{dc} = \frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t \cdot d(\omega t) \quad (29)$$

$$= \frac{V_m}{\pi} \int_0^{\pi} [-\cos \omega t]_0^{\pi}$$

$$= \frac{V_m}{\pi} [-\cos \pi - (-\cos 0)]$$

$$= \frac{V_m}{\pi} (1+1)$$

$$\boxed{V_{av} = \frac{2V_m}{\pi}}$$

Average DC Currents

$$I_{av} = \frac{V_{av}}{R}$$

$$= \frac{2V_m}{\pi R}$$

$$\therefore I_{av} = \frac{2I_m}{\pi}$$

$$I_{dc} = \frac{2I_m}{\pi}$$

$$\left[I_m = \frac{V_m}{R} \right]$$

or,

$$I_{av} = I_{dc} = \frac{1}{\pi} \int_0^{\pi} I_m \sin \omega t \cdot d(\omega t)$$

$$= \frac{I_m}{\pi} [-\cos \omega t]_0^{\pi}$$

$$= \frac{I_m}{\pi} [-\cos \pi - (-\cos 0)]$$

$$= \frac{I_m}{\pi} (1+1)$$

$$\boxed{\therefore I_{av} = \frac{2I_m}{\pi}}$$

Efficiency of Full-wave Rectifier

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{ac} = (I_{rms})^2 \times (R_L + r_f)$$

$$I_{dc} = \frac{2I_m}{\pi}$$

$$P_{dc} = I_{dc}^2 \times R_L$$

$$= \left(\frac{2I_m}{\pi} \right)^2 \times R_L$$

For a full-wave rectified wave, we have

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$P_{ac} = \left(\frac{I_m}{\sqrt{2}} \right)^2 \times (r_f + R_L)$$

$$\therefore \eta = \frac{(2I_m/\pi)^2 \times R_L}{\left(\frac{I_m}{\sqrt{2}} \right)^2 \times (r_f + R_L)}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{r_f + R_L}$$

$$= 0.812 \frac{R_L}{r_f + R_L}$$

$$= \frac{0.812 R_L}{r_f + R_L}$$

$$= \frac{0.812}{1 + \frac{r_f}{R_L}}$$

(3)

The efficiency will be maximum if r_f is negligible as compared to R_L .

$$\therefore \text{Maximum efficiency} = 81.2\%$$

→ Full wave rectifier is more effective than half wave rectifier.

Exm: 6.16

$$r_f = 20 \Omega, R_L = 980 \Omega$$

$$V = 50 \text{ V}$$

$$\text{max a.c. voltage, } V_m = 50 \times \sqrt{2} = 70.7 \text{ V}$$

$$\text{max load current, } I_m = \frac{V_m}{r_f + R_L}$$

$$= \frac{70.7}{20 + 980}$$

$$= 70.7 \text{ mA}$$

$$\text{i) Mean load current, } I_{av} = \frac{2 I_m}{\pi}$$

$$= \frac{2 \times 70.7}{\pi}$$

$$= 45 \text{ mA}$$

$$\text{ii) R.M.S value of load current, } I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = 50 \text{ mA}$$

Exm: 6.17.

(32)

Primary to secondary turns, $N_1/N_2 = 5/1$

R.M.S Primary voltage = 230 V

R.M.S. Secondary voltage = $230 \times \frac{1}{5} = 46V$

~~R.M.S~~ Maximum voltage across

$$\text{secondary} = 46 \times \sqrt{2} = 65V$$

$\therefore$ Maximum voltage across half secondary winding is, $V_m = 65/2 = 32.5V$

$$i) \quad I_{dc} = \frac{2V_m}{\pi R_L} = \frac{2 \times 32.5}{\pi \times 100} = 0.207A$$

$$\therefore \text{d.c. output voltage, } V_{dc} = I_{dc} \times R_L \\ = 0.207 \times 100 \\ = 20.7V$$

$$ii) \quad PIV = 2 \times 32.5 = 65V_{\text{Ave.}}$$

$$iii) \quad \eta = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

Since $r_f \rightarrow 0$

$$\therefore \eta = 81.2\% \text{ (Ave.)}$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$V_2 = 230 \times \frac{N_2}{N_1}$$

$$= 230 \times \frac{1}{2}$$

$\therefore$ P.M.S Secondary voltage =

Maximum voltage across

i) $V_{dc} = \frac{2V_m}{\pi}$
 $= 51.75 \text{ V (dc)}$

ii) PIV = $2 \times 81.3 \text{ V (dc)}$

iii) $f_{out} = 2 \times f_{in} = 2 \times 50 = 100 \text{ Hz}$

Expt. 6.21:

(34)

The a.c. voltage across transformer secondary

is 12 V r.m.s.

$$\therefore \text{Peak secondary voltage } V_s(\text{pk}) = 12 \times \sqrt{2} \\ \approx 16.97\text{ V}$$

i) Peak output voltage

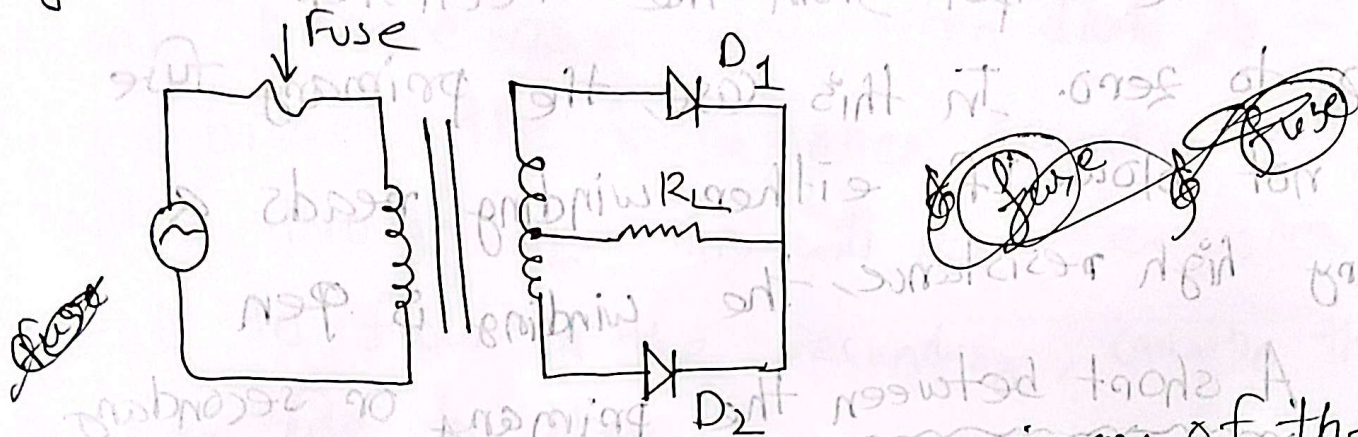
$$V_{\text{out}}(\text{pk}) \approx 16.97 - (2 \times 0.7) \\ \approx 15.57\text{ V}$$

$$\therefore V_{\text{dc}} = \frac{2 V_{\text{out}}(\text{pk})}{\pi} \approx \frac{2 \times 15.57}{\pi} \\ \approx 9.91\text{ V}_A$$

$$\text{ii) } I_{\text{dc}} = \frac{V_{\text{dc}}}{R_L} = \frac{9.91}{12\text{ k}\Omega} \\ \approx 825.8\text{ }\mu\text{A}$$

Faults in Centre-tap Full wave Rectifiers (3s)

The faults in a centre-tap full wave rectifier may occur in the transformer or rectifier diodes.



A fuse is connected to in the primary of the transformer for protection purposes.

we can divide the rectifier faults into two classes:

1. Faults in Transformer
2. Faults in rectifier diodes

1. Faults in Transformer The transformer in a rectifier circuit can develop the following faults:

- i) A shorted primary or secondary winding: In most cases, a shorted primary or shorted secondary will cause the fuse in the primary to blow. If the fuse does not blow, the d.c. output from the rectifier will be extremely low and the transformer itself will be very hot.

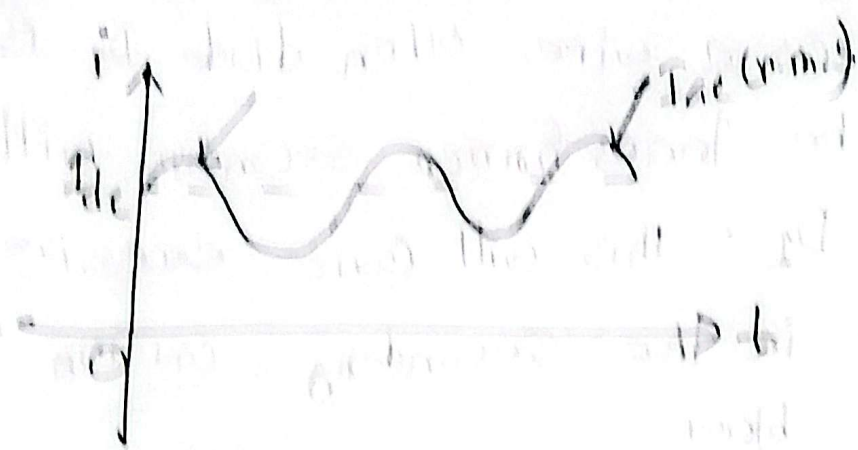
ii) An open primary or secondary winding: when the primary or secondary winding of the transformer opens, the output from the rectifier will drop to zero. In this case, the primary fuse will not blow. If either winding reads a very high resistance, the winding is open.

iii) A short between the primary or secondary winding and the transformer frame: If either

winding shorts to the transformer casing, the primary fuse will blow. This fault can be checked by measuring the resistances from the winding leads to the transformer casing. A low resistance measurement indicates that a winding-to-case short exists.

2. Faults in Rectifier Diodes: If a fault occurs in a rectifier diode, the circuit conditions will indicate the type of fault:

The smaller the ripple factor the more lesser the effective of a.c. component, hence more effective the rectifier.



$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2} \quad \left[\text{dividing throughout by } I_{dc} \right]$$

$$\text{Ripple factor} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$= \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

i) for half-wave rectification:

$$I_{rms} = \frac{I_m}{2}, \quad I_d = \frac{I_m}{\pi}$$

$$\therefore \text{Ripple factor} = \sqrt{\frac{(I_m/2)^2}{(I_m/\pi)^2} - 1}$$

$$= 1.21$$

The results in greater pulsations in the output.
Therefore, half-wave rectifier is ineffective for
conversion of a.c into d.c.

ii) for full-wave rectification:

$$I_{rms} = \frac{I_m}{\sqrt{2}}, \quad I_d = \frac{2I_m}{\pi}$$

$$\therefore \text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1}$$

$$= 0.48$$

The pulsations in the output will be less
than in half-wave rectifier. For this reason
full wave rectifier is more effective for
conversion of a.c into d.c.

(34)

i) If one diode in the centre-tap full wave rectifier is ~~open~~ shorted, the primary fuse will blow. Suppose in the fig D_2 is shorted. Then diode D_2 will behave as a wire. When diode D_1 is forward biased, the transformer secondary will be shorted through D_1 . This will cause excessive current to flow in the secondary, causing the primary fuse to blow.

ii) If one diode in the centre-tap full wave rectifier is open, the output from the rectifier will resemble the output from a half wave rectifier. The remedy is to replace the diode.

Ripple factor The ratio of r.m.s value of a.c. component to the d.c. component in the rectifier output is known as ripple factor.

$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c. component}}{\text{value of d.c. component}} \\ = \frac{I_{ac} \text{ (r.m.s.)}}{I_{dc}}$$

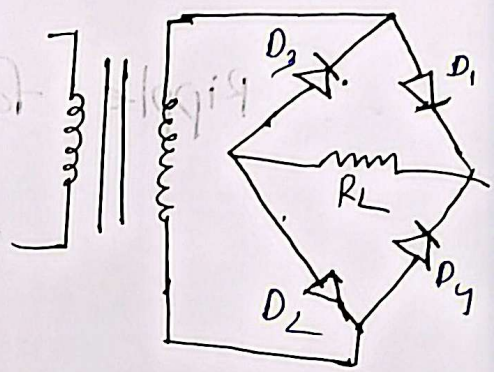
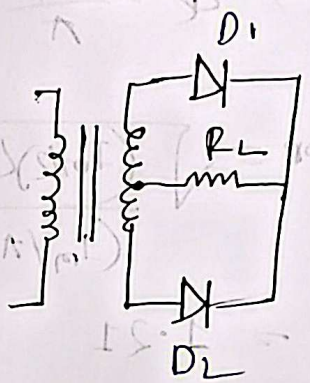
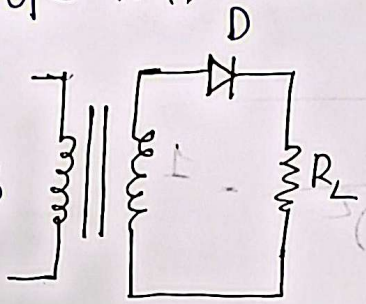
Comparison of Rectifiers

Rectifier type: Half wave

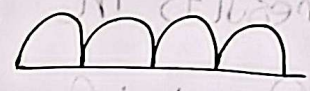
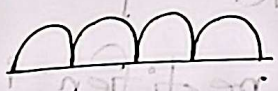
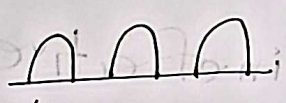
Full-wave Centre-tap

Full-wave Bridge Rectifier

Schematic diagram :



Typical output waveform :

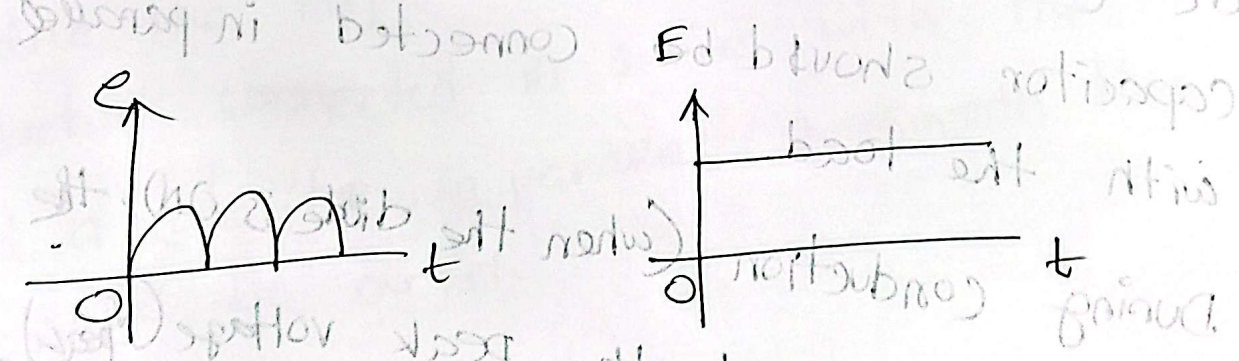
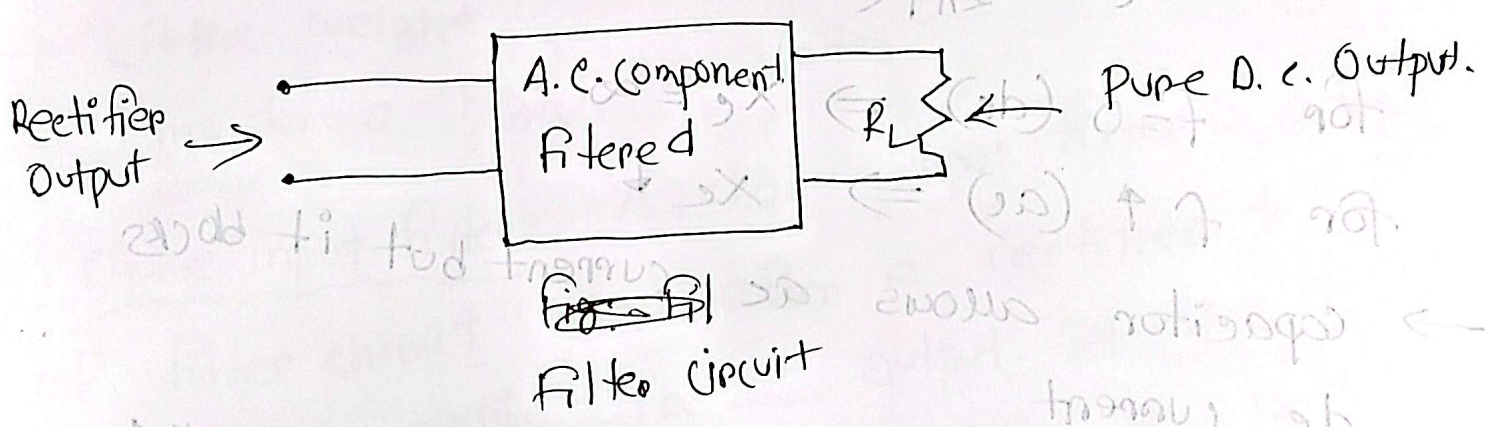


SL. NO.	Particulars	Half-wave	Centre-tap	Bridge type
1	NO. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2f_{in}$	$2f_{in}$
6	Peak Inverse voltage	V_m	$2V_m$	V_m

Filter Circuits A filter circuit is a device which removes the a.c. component of rectifier output but allows the d.c. component to reach the load.

A filter circuit should be installed between the rectifier and the load as show in the following fig.

A filter circuit is generally a combination of inductors and capacitors.



Types of Filter circuits

i) Capacitor filters A capacitor filter is the simplest and most common filter used in power supplies to reduce ripple voltage in the rectifier output.

It consists of a capacitor connected in parallel with the load resistor.

Working Principles

$$X_c = \frac{1}{2\pi fC}$$

for $f = 0$ (dc) $\Rightarrow X_c = \infty$

for $f \uparrow$ (ac) $\Rightarrow X_c \downarrow$

→ capacitor allows ac current but it blocks dc current

→ capacitor should be connected in parallel with the load.

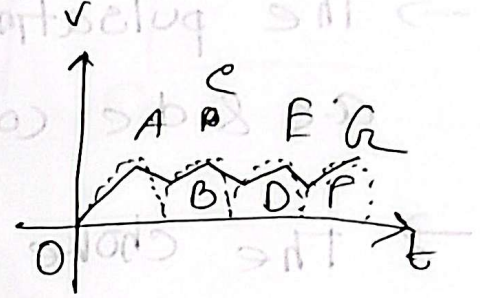
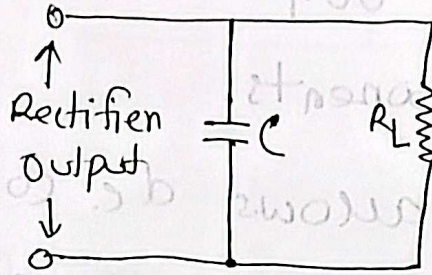
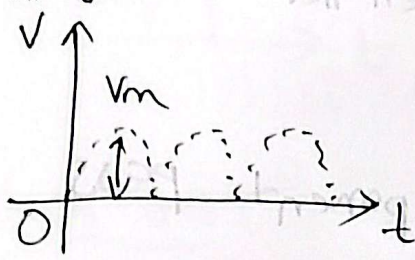
→ During conduction (when the diode is ON), the capacitor charges to the peak voltage (V_{peak}).

→ During non-conduction (when the diode is OFF), the capacitor discharges through the load,

maintaining a small smoother DC output.

(43)

Advantages:



Advantages:

- Simple & Low-cost
- Small size
- Little weight
- Provides a high Peak Voltage.

ii) Choke input filter A choke input filter is a type of filter circuit used after a rectifier to reduce the ripple in DC output. It uses an inductor connected in series with the load and a capacitor in parallel to smooth the rectified DC output.

Working Principle:

(44)

→ The pulsating output of rectifier contains a.c. & d.c. components.

→ The choke allows d.c. component pass but not allow to pass a.c. component.

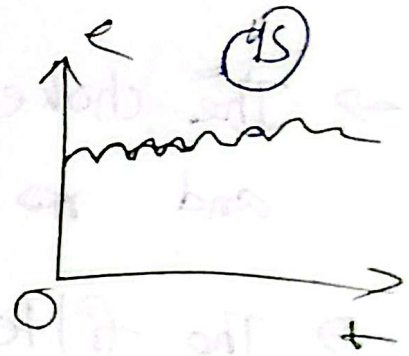
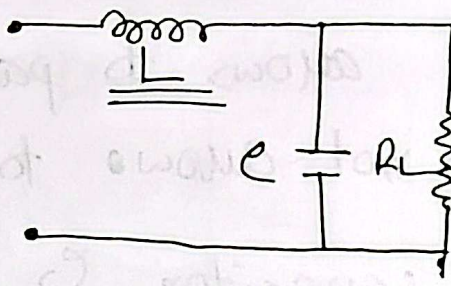
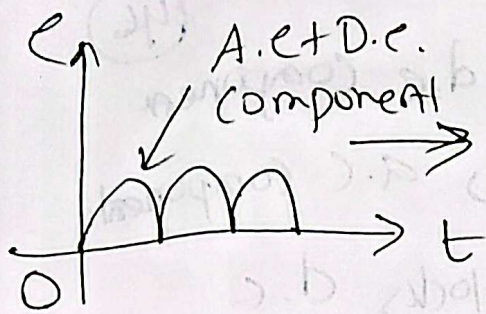
→ ~~The capacitor~~ Now the rectifier output contains d.c. component & the remaining part of a.c. component which was a.c. component.

⇒ Now the ~~low~~ capacitor allows to pass but do not allow to pass d.c. component because

$$\text{for } d.c. \omega = f = 0$$

$$X_C = \frac{1}{2\pi f C} = \infty$$

→ Therefore only d.c. component reaches the load. In this way, the filter circuit has filtered out the a.c. component from the rectifier output.



Advantages:

- Low Ripple voltage
- Efficient for high current

iii) Capacitor input filter or π -filter:

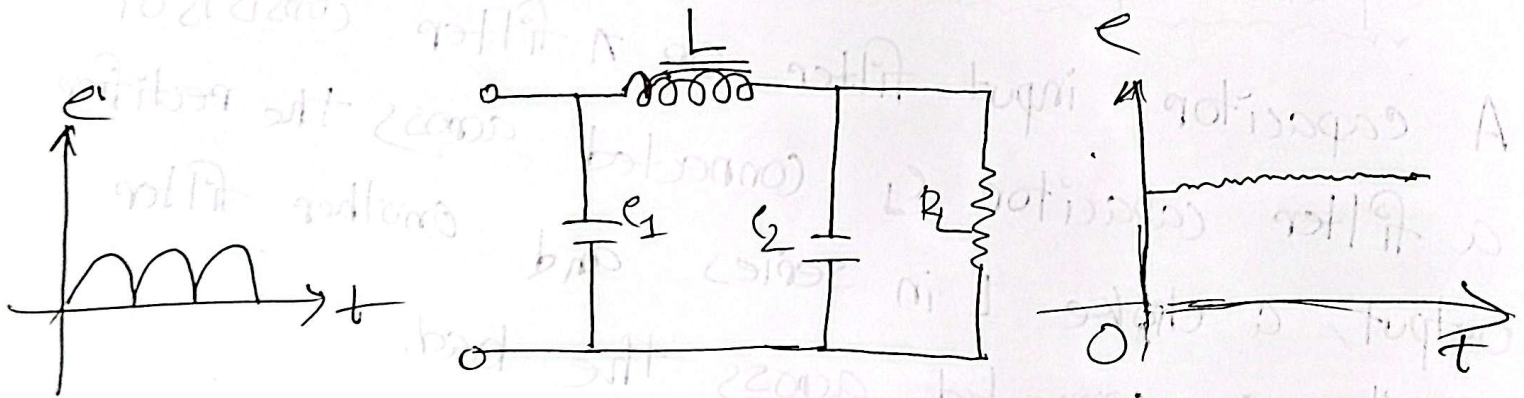
A capacitor input filter or π filter consists of a filter capacitor C_1 connected across the rectifier output, a choke L in series and another filter capacitor C_2 connected across the load.

Working Principles:

- The pulsating output from the rectifier contains a.c & d.c. components
- The filter capacitor C_1 allows a.c. component to pass through it but block d.c. component and d.c. ~~pass through~~ continues journey the L .

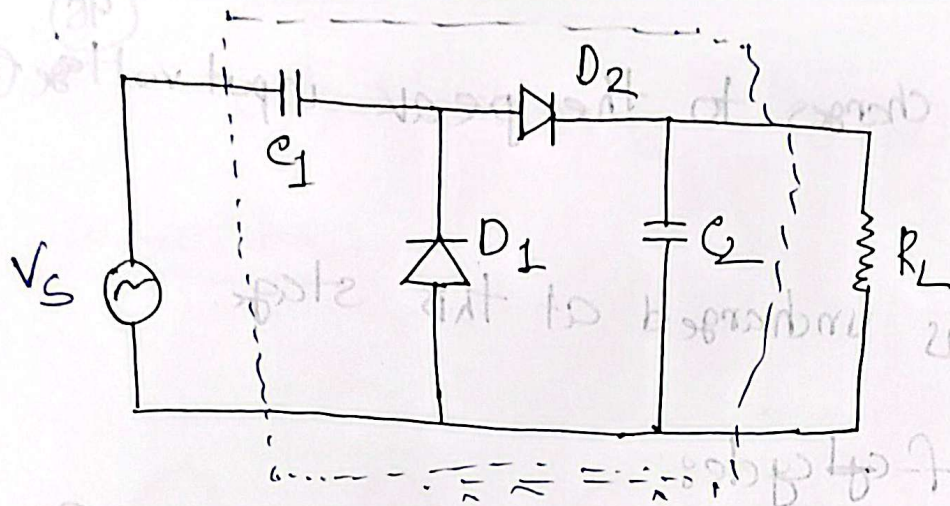
→ The choke L allows to pass d.c. component and ~~no~~ do not allow to pass a.c. component.

→ The filter capacitor C_2 blocks d.c. component but allows a.c. component to pass through in it. Thus, d.c. only component appears across the load.



Half-wave Voltage Divider & Doubler

A half-wave voltage doubler is a type of voltage multiplier circuit that doubles the input AC voltage using two diodes & two capacitors.



(47)

Half-wave voltage Doubler

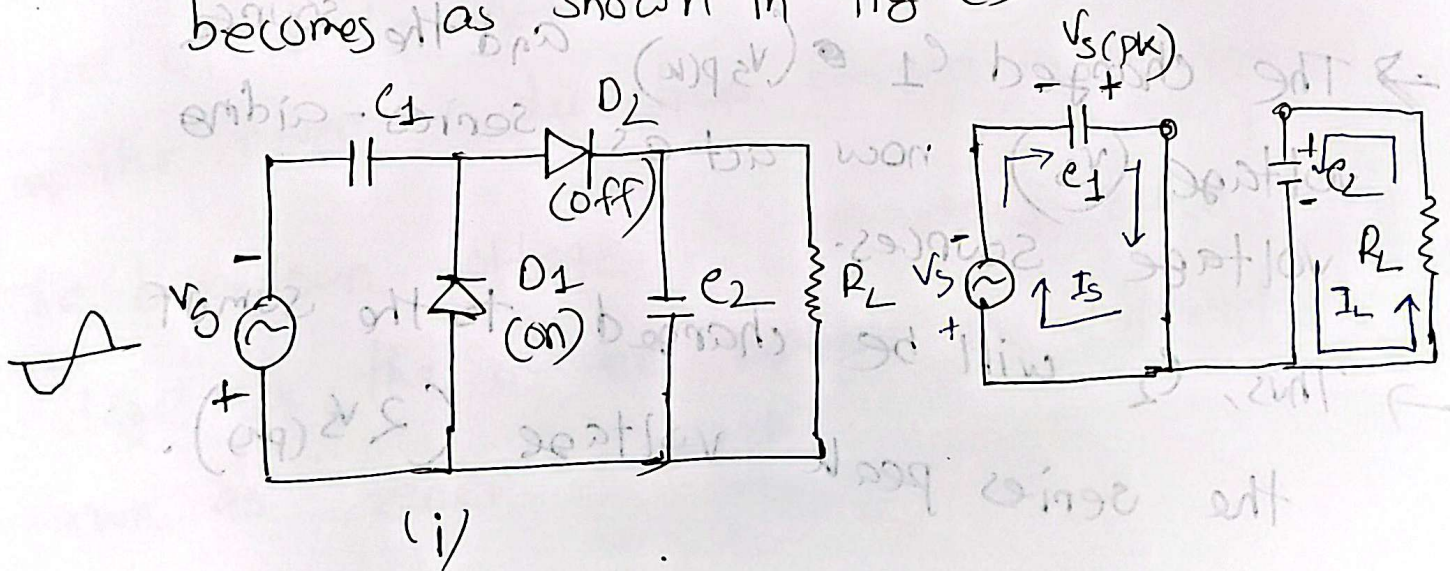
Working Principle:

1. Positive half-cycle: Negative half-cycle:

→ D_1 is forward biased & D_2 is reverse biased

→ D_1 can be represented by a short & D_2 as an open. The equivalent circuit then

becomes as shown in fig (ii)



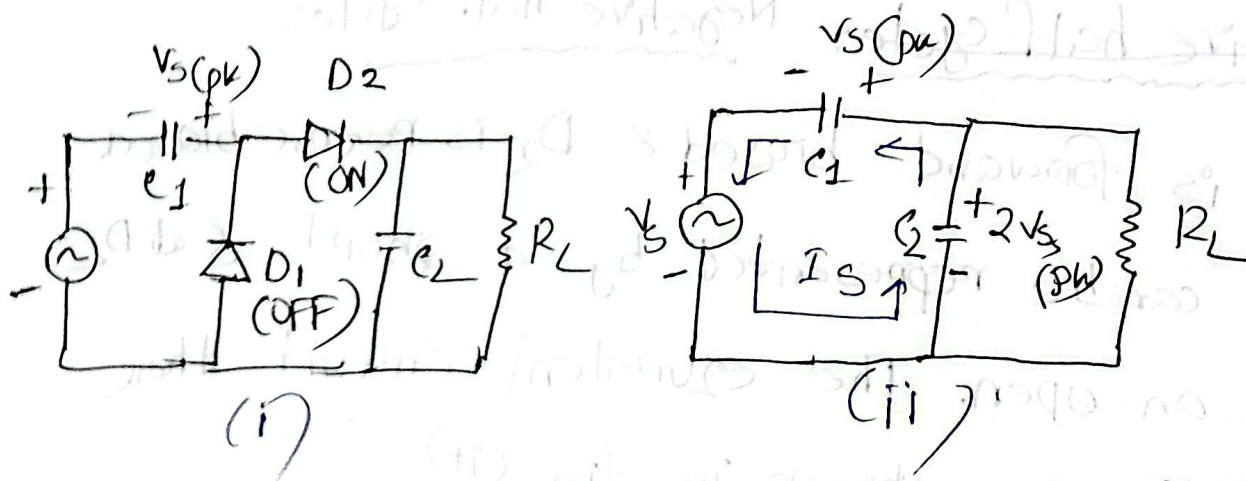
(48)

→ Capacitor C_1 charges to the peak input voltage $V_s(pk)$.

→ C_2 remains uncharged at this stage.

2. Positive half-cycle:

→ D_1 is reverse biased and D_2 is forward biased and the equivalent circuit shows in figure



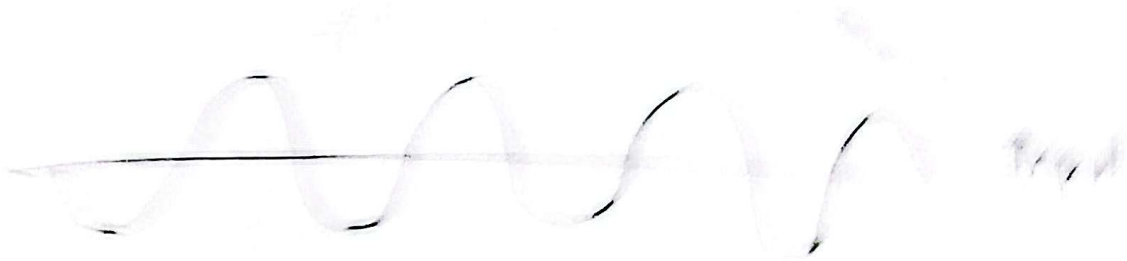
→ The charged C_1 ($V_s(pk)$) and the source voltage (V_s) now act as series-aiding voltage sources.

→ Thus, C_2 will be charged to the sum of the series peak voltage ($2V_s(pk)$).

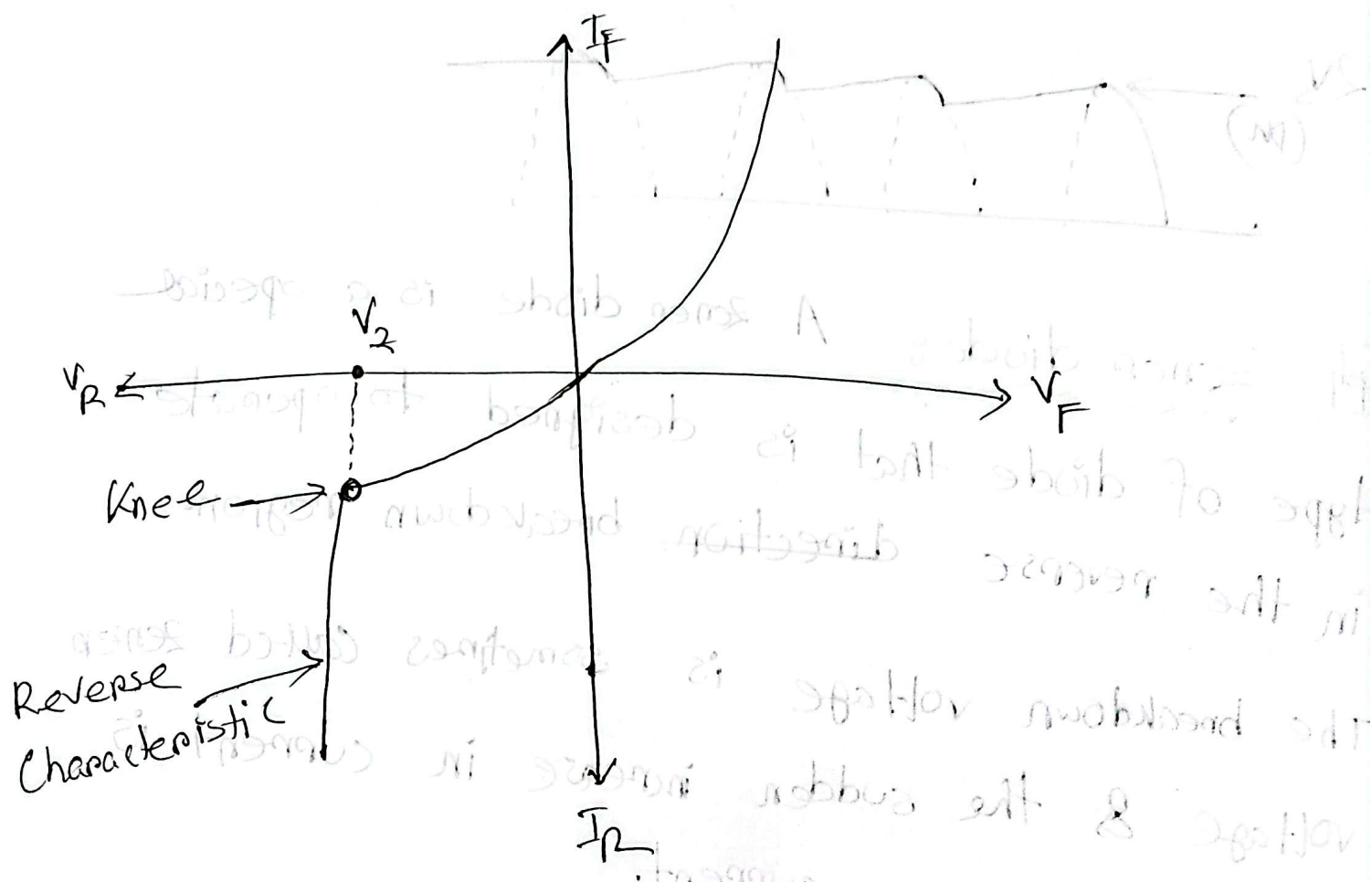
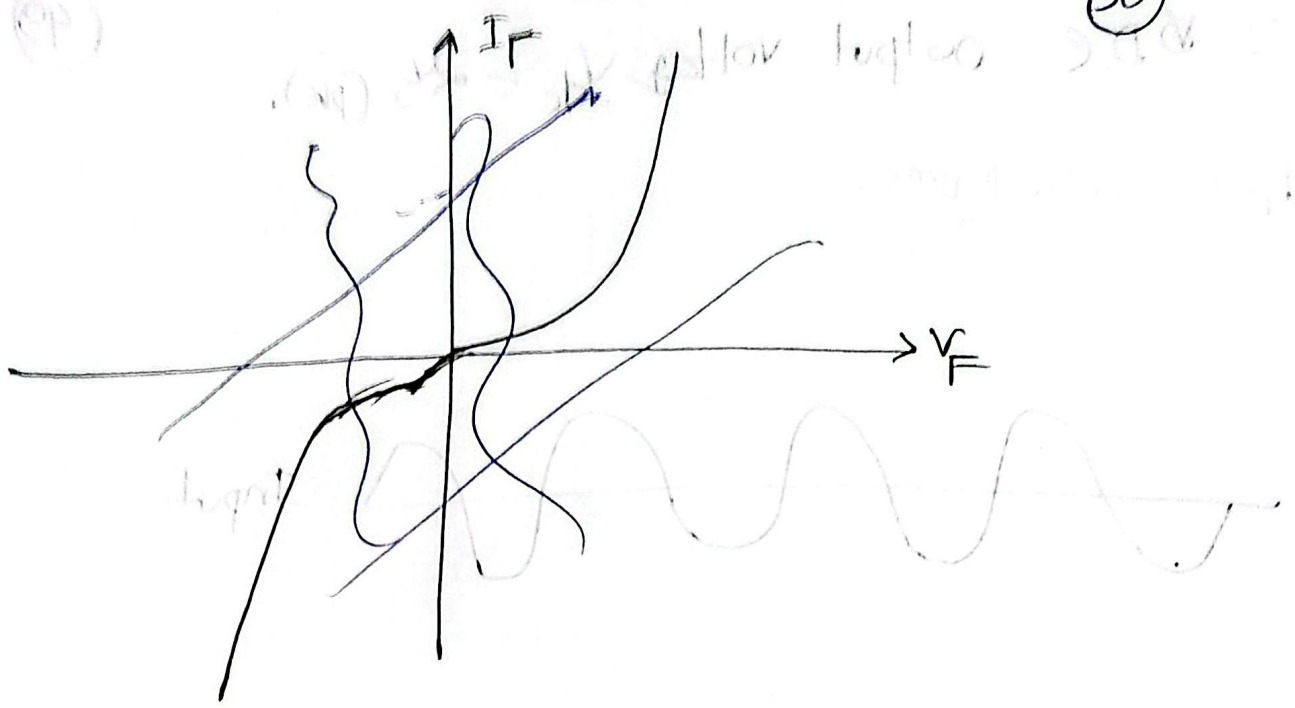
OSC output voltage $V_o \approx 2V_i$ (p.p.)

(11)

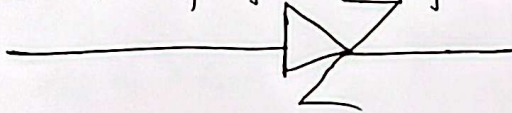
AC wave form:



A sine wave is a periodic waveform that oscillates sinusoidally. It is the simplest form of an AC signal. The amplitude of the wave represents the maximum value it reaches, and the frequency represents the number of cycles per second. In this case, the output voltage is approximately twice the input voltage (p.p.).

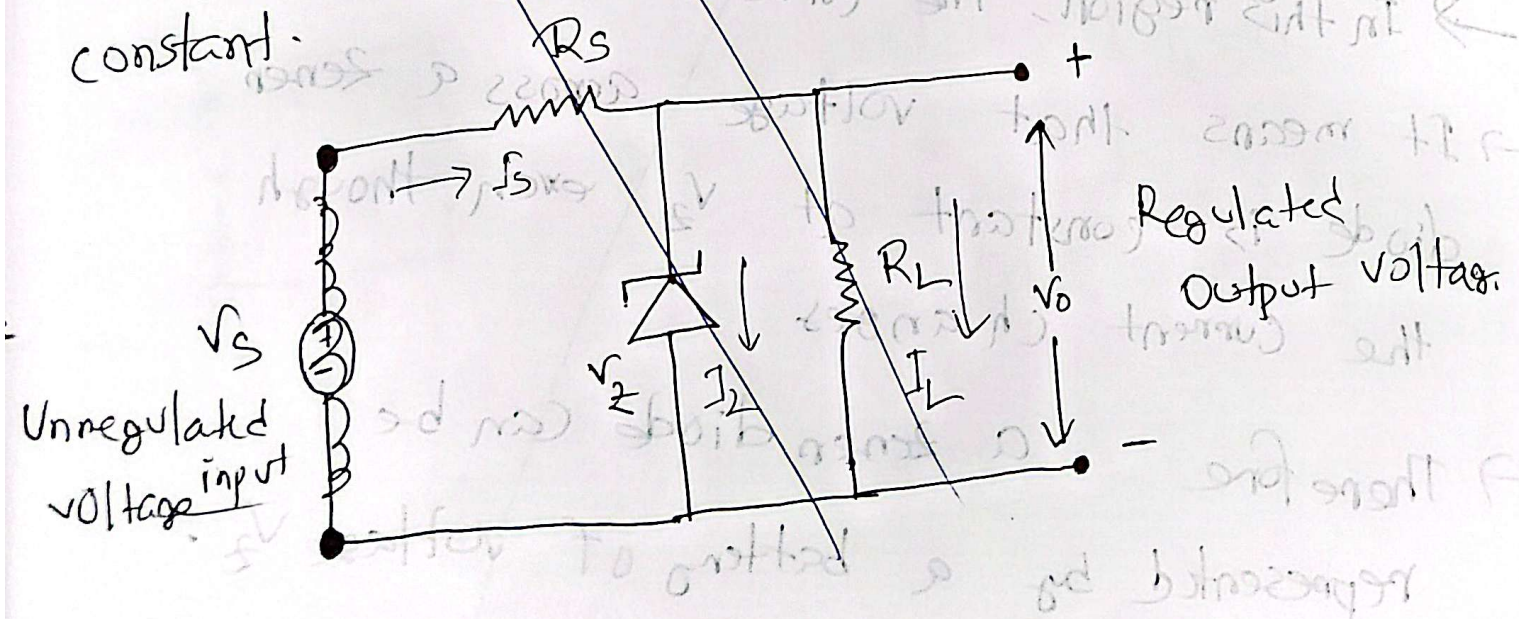


- It has high doping
- It does not follow ohm's law.

- A zener diode is always reverse connected. (9)
- It is always reverse biased.
- A zener diode has sharp breakdown voltage, called zener voltage V_Z .
- When forward biased, its characteristics are just those of ordinary diode.
- A zener diode is like an ordinary diode except that it is properly doped.
- 

Zener diode as a voltage regulator:

Voltage Regulator is designed to ensure that output voltage of a power supply remains constant.



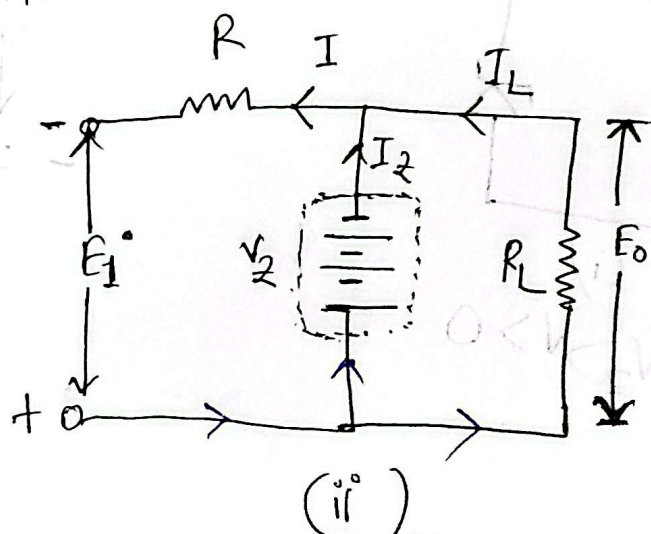
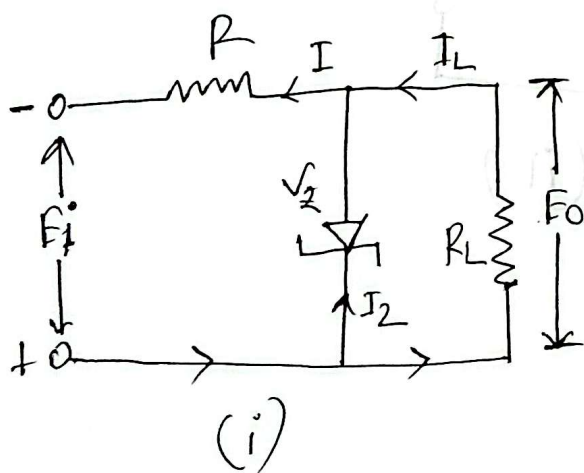
Zener diode as voltage stabiliser/regulator

A voltage stabilizer or regulator is designed to ensure that output voltage of a power supply remains constant. A Zener diode can be used as a voltage regulator to provide a constant voltage from source.

→ Zener diode works as a voltage regulator in reverse bias.

→ R absorbs the output voltage to maintain constant voltage.

→ Zener will maintain a constant voltage $V_z (= E_0)$ across the load.



$$\text{Voltage Regulation (\%)} = \frac{V_{\text{no load}} - V_{\text{full load}}}{V_{\text{full load}}} \times 100$$

Working Principle:

(55)

Case-1: Input voltage < Zener voltage ($E_i < V_z$)

Case-1: The input voltage increases:

- Since the Zener is in the breakdown region, the Zener diode is equivalent to a battery V_z .
- It is clear that output voltage remains constant at $V_z (= E_o)$.
- Excess input voltage is dropped across R .
- The Zener will conduct the increase of current in I while the load current remains constant.
- Hence, ^{total} output voltage E_o remains constant.

Case-2: Input voltage is constant but the load resistance R_L decreases:

- This will cause an increase in load current.
- Zener diode does not conduct.
- The additional load current will come

from a decrease in Zener current I_Z .

→ The output voltage stays at constant value.

Voltage drop across $R \approx E_i - E_o$

Current through R , $I = I_Z + I_L$

$$R = \frac{E_i - E_o}{I_Z + I_L}$$

⊞ Vacuum diode: A vacuum diode is the simplest form of vacuum tube that consists of two electrodes - a cathode & an anode. It allows current to flow in one direction only, similar to a semiconductor diode.

Construction:

→ Cathode: Heated to emit electrons

→ Anode: A metal plate to collect electrons

→ Envelope: High-vacuum glass or metal

tube to prevent ~~electron~~ electron collisions. with ~~or~~

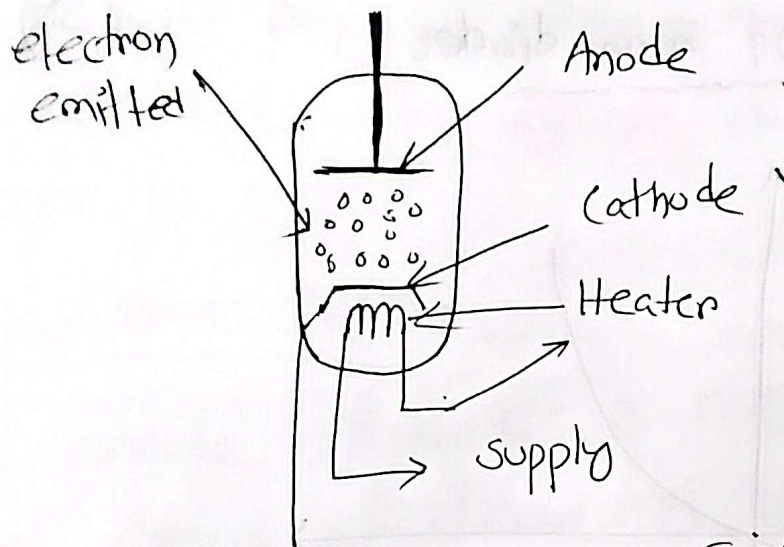


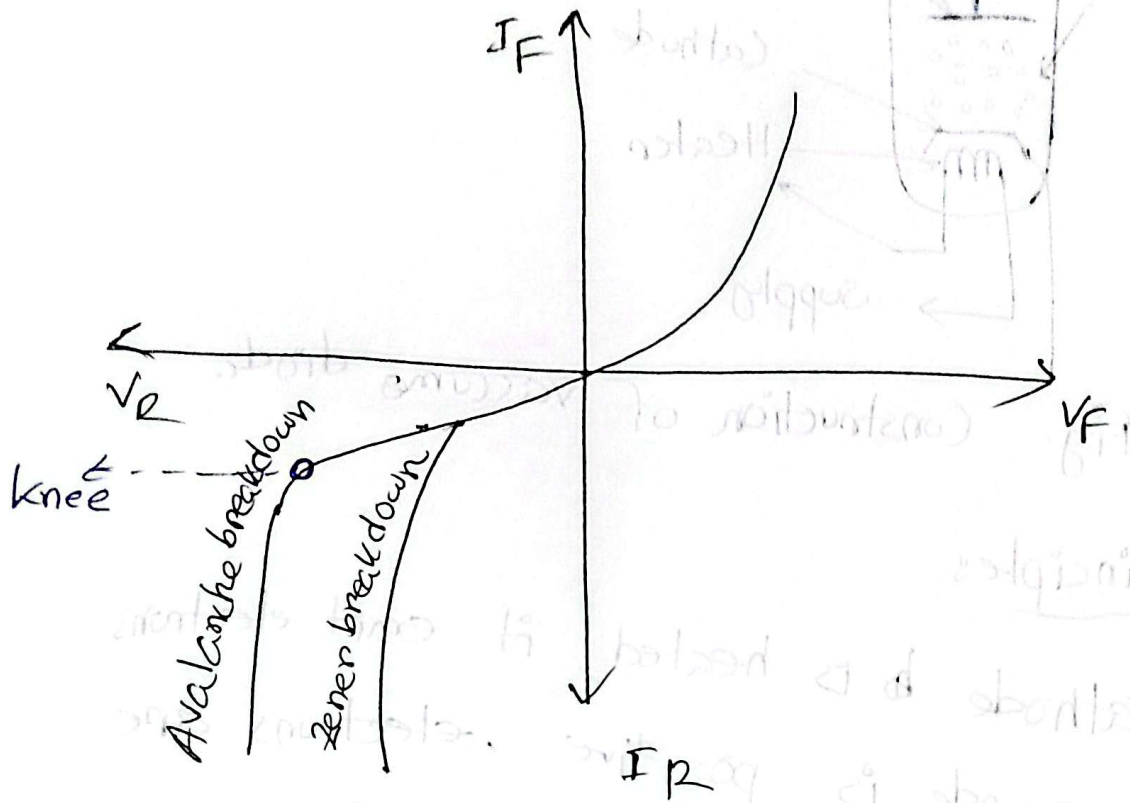
Fig: Construction of vacuum diode.

Working Principle:

- when cathode is heated, it emits electrons
- If the anode is positive, electrons are attracted to it and current flows.
- If the anode is negative, electrons are repelled, no current flows.
- Hence, vacuum diode allows current in only one direction, acting as a rectifier.

V-I characteristics of Zener diodes

(58)



The graph has two main regions:

1. Forward Bias Region
2. Reverse Bias Region

1. Forward Bias Region (Normal diode similar)

→ The anode of the diode becomes positive and the cathode of the diode becomes negative.

→ It acts like a PN-junction diode.

- very small forward voltage drop.
- A small increase in voltage causes an exponential increase in current.

2. Reverse Bias Region:

- The anode of diode is negative, and the cathode of diode is positive.
- At a certain reverse voltage, the diode enters the breakdown region.
- There are two types of ~~breakdown~~ region. They are:

* Before Zener Breakdown:

- Only tiny leakage current flows.
- Acts as an insulator.

* After Zener Breakdown:

- Suddenly, large reverse current flows.
- voltage across diode remains almost constant, even if current increases.
- That is why it is used as a voltage regulator.

(50)

Voltage Multiplier: A voltage multiplier is an electric circuit consisting of capacitors and diodes and is used to multiply the voltage level of an AC signal. The voltage multiplier receives an AC voltage of lower value, converts it into a DC voltage and increases its voltage level.

Types: 1. Voltage Doubler

2. " Tripler

3. " Quadripler

If peak A.C input is V_m the DC output voltage can be $2V_m$, $3V_m$, $4V_m$ etc.

E.g. $V_o = 2V_m \rightarrow$ Doubler

$V_o = 3V_m \rightarrow$ Tripler

$V_o = 4V_m \rightarrow$ Quadripler



Application:

→ CRT TV

→ X-ray machine

→ Laser device

→ Taser guns

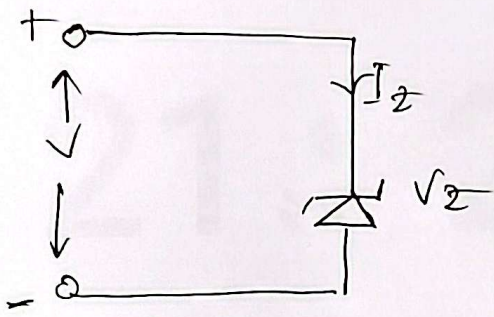
→ Sensors

Q1 Equivalent circuit of Zener diode The analysis of circuits (6)

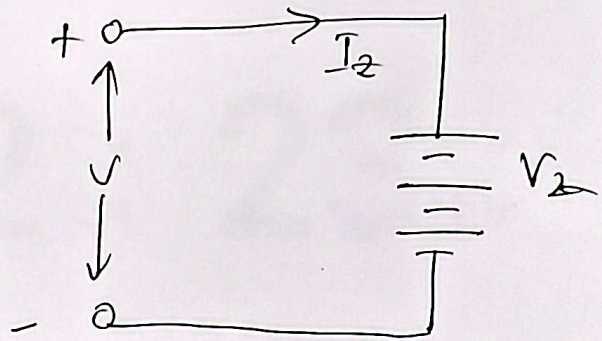
Using Zener diodes can be made quite easily by replacing the Zener diode by its equivalent circuit.

(i) "ON" state:

- when $V_s \geq V_z$ the current increases sharply
- In this region, the curve is almost vertical,
- It means that voltage across a Zener diode is constant at V_z even though the current changes
- Therefore, a Zener diode can be represented by a battery of voltage V_z shown in Fig (ii)
- This condition is said to be "ON"



(i)
 $V_s \geq V_z$



(ii)
equivalent circuit
of Zener in "ON" state.

(62)

a) "OFF" state:

→ when $V < V_Z$ but greater than 0, the Zener diode is in "OFF" state.

→ Under this condition, the Zener diode can be represented by an open circuit shown in Fig (ii).

