Chapter - 14 : Semiconductors

A. Classification on the basis of conductivity and resistivity :

1) **Metals :**

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

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

2) **Semi conductors :**

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

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

3) **Insulators :**

$\rho = 10^{11} - 10^{18}$

$\sigma = 10^{-11} - 10^{-18}$

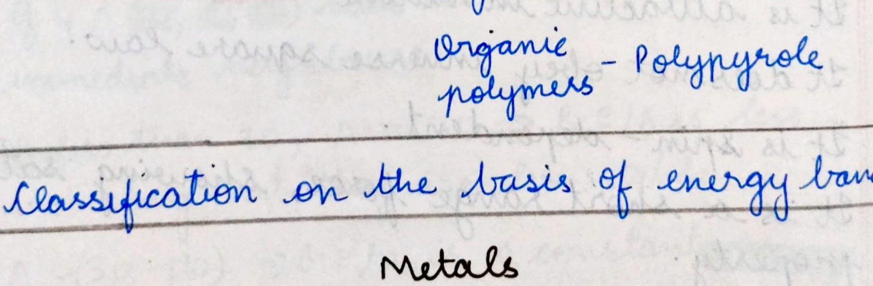
B. Classification on the basis of type of matter

Semiconductors

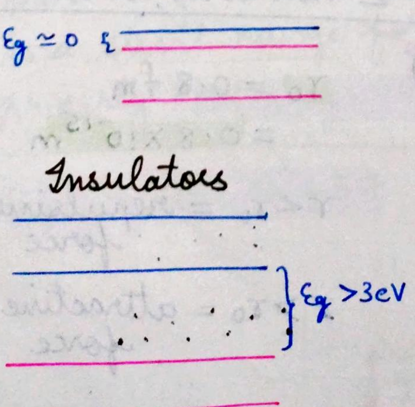
- Elemental
  - Si, Ge
- Compound
  - Inorganic - GaAs, CdS
  - Organic - anthracene
  - Organic polymers - Polypyrole

C. Classification on the basis of energy bands

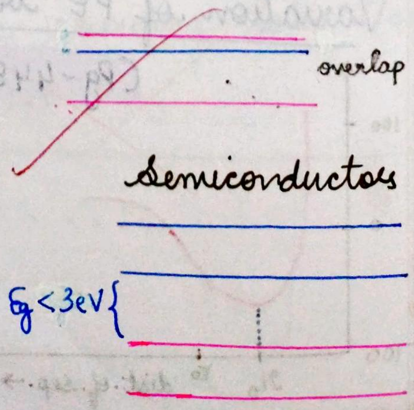
Metals



Insulators



Semiconductors



Metals: In metals, either a conduction band is partially filled and the valence band is partially empty, or the conduction and valence bands overlap. When there is overlap, e^- from valence band can easily move into conduction band. due to this, large number of electrons are available for conduction. Thus resistance of metals is low and conduction is high.

Semiconductors: Here finite but small band gap exists ($E_g < 3\,eV$). Due to this, at room temp. some e^- from valence band can acquire enough energy to cross the energy gap and enter the conduction band. Hence resistance of semiconductor is not high as that of insulators.

Insulators: A large band gap ($E_g > 3\,eV$) exist. There are no e^- in the conduction band, so no conduction is possible. The energy gap is so large that e^- cannot be ~~exil~~ excited from the valence band to the conduction band by thermal excitation. So it is a bad conductor.

Intrinsic semi conductors:

- They have 4 valence e^- and each of these 4 valence electrons are shared by the silicon atom with its 4 nearest neighbours. These electrons form covalent bond and are strongly held at low temperatures.

- As temperature rises, more thermal energy becomes available to the electrons and they break away, becoming free electrons.

- The free electron with charge $-q$ leaves a vacant space with an effective charge $+q$. This vacant space is called a hole.

- As many electrons break away, so many holes are created.

- Therefore, no. of free electrons = no. of holes.

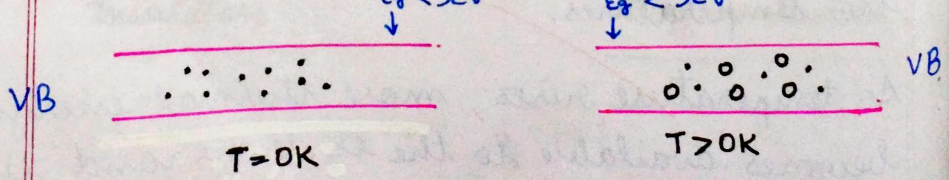
$n_e = n_h = n_i$, n_i = no. of intrinsic charge carriers.

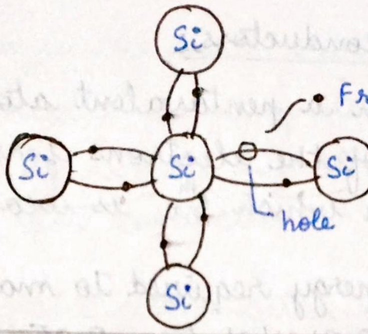
- Apart from electrons, holes also move as shown in the diagram. An electron from covalent bond at region 2 may jump to vacant space at region 1. Thus the hole has moved from region 1 to region 2.

- The free electron moves independently and gives rise to electron current I_e. The holes move towards the negative potential of the battery and gives rise to hole current.

The total current is sum of electron current and hole current.

$$I_e + I_h = I$$





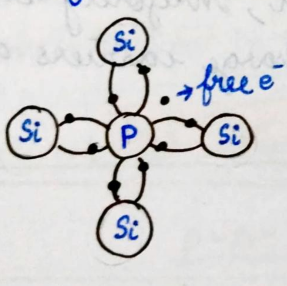
Extrinsic semi-conductors:

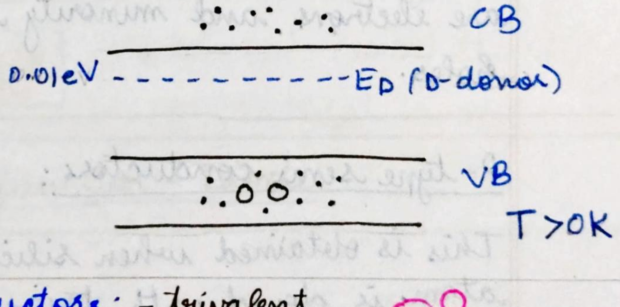
When a small amount (a few parts per million) of a suitable impurity is added to a semi-conductor, its conductivity is increased to a greater extent.

Such materials are called as extrinsic semi-conductors.

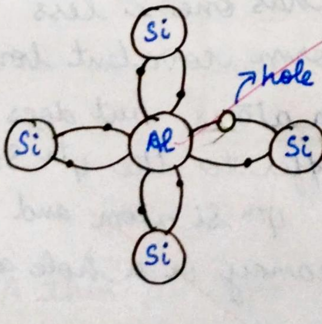
This addition of impurity is called doping and the impurities are called dopents.

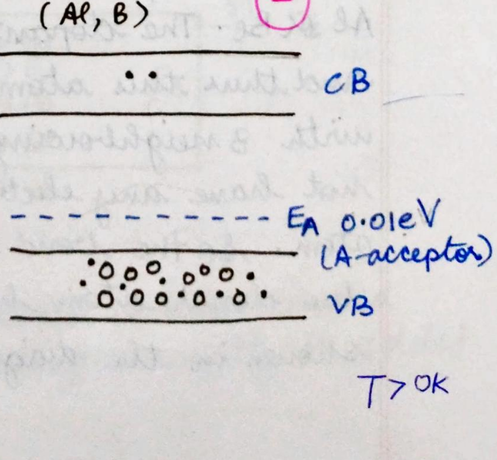
A. n-type semi conductors: – penta valent (P, As)





B. p-type semi conductors: – trivalent (Al, B)





n-type semi conductors:

If we dope with a pentavalent atom like Phosphorous, 4 of the electrons form covalent 4 Si atoms which 5^{th} e^- is weakly bound.

The ionisation energy required to make this electron free is small: 0.01 eV of Ge, 0.05 eV of Si. So even at room temperature it is free to move. Thus the ~~p~~ dopent atom is providing one free electron for conduction and hence is known as donor impurity.

Hence the total no of conduction electrons is due to the electrons contributed by the donor atoms and that generated due to increase in temperature. But the no of holes is only due to increase in temperature.

$\therefore n_e >> n_h$.

So in n-type semiconductor, majority charges are electrons and minority charge carriers are holes.

P-type semi conductors:

This is obtained when silicon or Germanium atom is doped with trivalent impurity like Al or Be. The dopant atom has one e^- less and thus this atom can form covalent bond with 3 neighbouring silicon atoms, but does not have any electron to offer to the 4^{th} Si atom. So the bond between 4^{th} Si atom and the donor atom has a vacancy or a hole as shown in the diagram.

An electron in the outer orbit of an atom in the neighbourhood may jump to fill this vacancy, thus leaving behind a hole. This hole is now available for conduction.

Every dopant atom gives one hole in addition to the intrinsically generated (due to inc. in temp) holes while the source of conduction electrons is only intrinsic generation.

Thus the no. of holes is very much greater than no. of electrons : $n_n >>> n_e$.

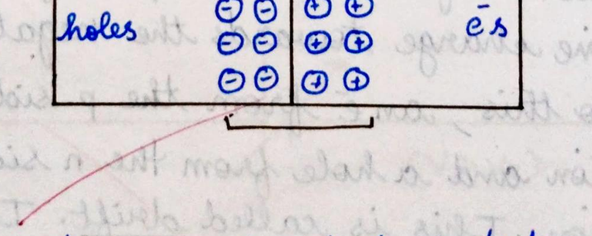
So holes are majority charges and electrons are minority charges.

As the dopant atom accepts an electron, it is called as acceptor impurity.

In thermal equilibrium, the electron and hole concentration in the semi-conductor is given as:

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

p-n-junction - Diode



A thin p-type semiconductor is taken and a small amount of pentavalent impurity is added to it.

Now it contains a p region and an n region and a junction between the 2.

As soon as a p-n junction is formed, 2 processes take place.

1) Diffusion
2) Drift

Diffusion: The majority charge carriers start to diffuse from a region of high conc. to the region of low conc. This phenomenon is called diffusion. This gives rise to diffusion durrent from p to n.

When an e^- diffuses from n to p, it leaves behind an ionised donor atom on the n side, so a layer of positive charge is developed on the n side.
Similarly when a hole diffuses from p to n it leaves behind an ionised acceptor atom so a layer of negative charge is developed on the p side of the junction. This space charge region on the either side of the junction is called depletion region.

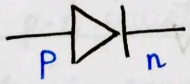
An electric field is developed from the positive charge towards the negative charge. Due to this, an e^- from the p side of the junction and a hole from the n side of the junction. This is called drift. The current due to this motion is called drift current.

Initially diffusion current is large and drift current is small. As the process continues, diffusion current decreases and drift current increases. At equilibrium, net current across the junction is zero.

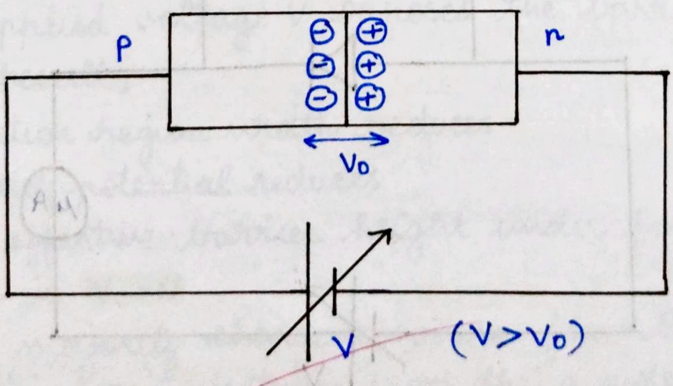
The loss of $\bar{e}$ from n region and the gain of $\bar{e}$ from p region causes a difference of potential across the junction. This difference of potential is called barrier potential. The potential depends upon:

Nature of semiconductor,
Temperature,
Amount of doping.

Biasing of a p-n junction

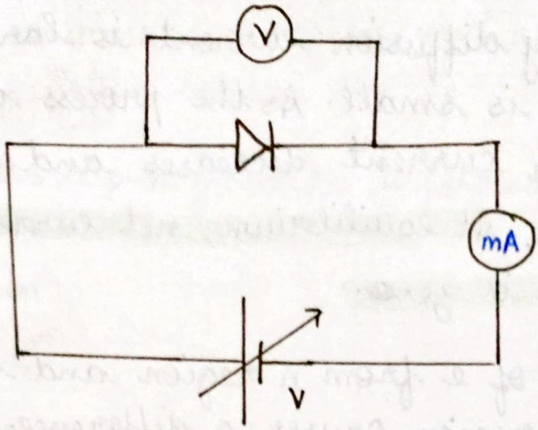
Diode: 

FORWARD BIASING

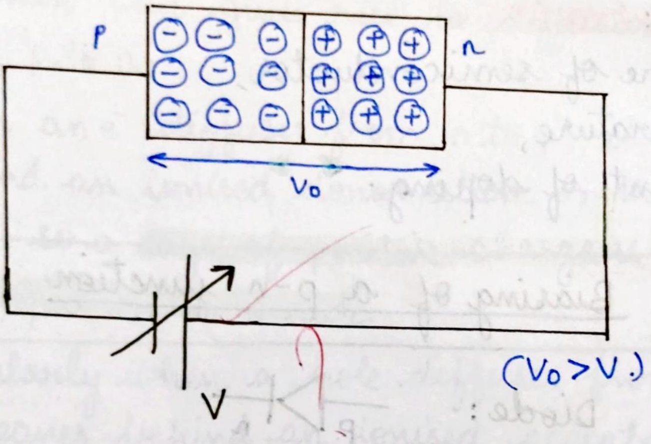


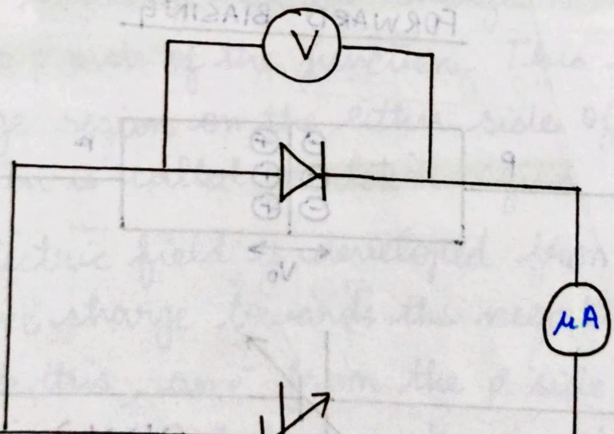
- Depletion region width reduces
- Barrier potential reduces $(V_0 - V)$

Minority charge carrier injection



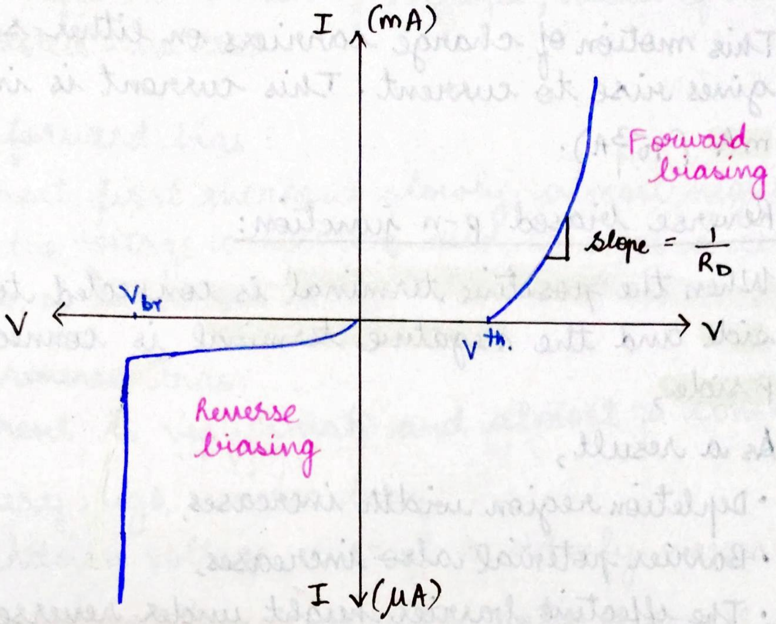
REVERSE BIASING





- Depletion region width increases
- Barrier potential increases ($V_0 + V$)

V-I characteristics of a diode:



V^{th} - Threshold voltage

V_{br} - Breakdown / cutoff voltage

$R_D = \Delta V / \Delta I$ (Dynamic resistance).

Forward biasing of p-n junction diode:

- p type semi conductor is connected to the positive terminal of the battery and the n-type semiconductor is connected to the negative terminal of the battery.

The applied voltage V opposes the barrier potential as a result,

- Depletion region width reduces
- Barrier potential reduces
- The effective barrier height under forward bias is $V_0 - V$
- The majority charge carriers flow towards the junction. The electrons from the n side move to the p side, and the holes from the p side move to the n side. This is known as minority charge carrier injection.

The effective resistance across the p-n junction decreases.

- This motion of charge carriers on either side gives rise to current. This current is in mA (10^{-3}A).

Reverse biased p-n junction:

When the positive terminal is connected to n side and the negative terminal is connected to p side,

As a result,

- Depletion region width increases,
- Barrier potenial also increases,
- The effective barrier height under reverse bias is $V_0 + V$.

This suppressed the flowe of e^- from n to p and holes from p to n, thus decreasing the diffusion current.

The resistance of the p-n junction becomes very large.

The e^- from p side and the holes from the n side come close to the junction and are swept to their majority zone. This gives rise to drift current of the order of few μA. ($\times 10^{-6}$A). This current is called reverse saturation current.

The current in reverse bias is independent of voltage upto a critical voltage known as breakdown voltage.

When $V = V_{br}$, the reverse current increases sharply. This results in over-heating of the diode and the diode gets destroyed.

VI characteristics of a diode:

For different values of voltages, values of current is noted and the

For forward bias:
Current first increases slowly, almost negligibly, till the voltage across the diode crosses a certain value of "threshold voltage". ($Si = 0.7V$, $Ge = 0.2V$)

For reverse bias:
Current is very small and almost a constant.

At very high reverse bias:
At Breakdown voltage, current suddenly increases.

Dynamic resistance: It is the ratio of small change in voltage to small change in current. (R_D)

Rectifier:
It is a device used to convert AC to DC.

Principle: An ideal diode conducts only when it is forward biased and does not conduct when it is reverse biased.

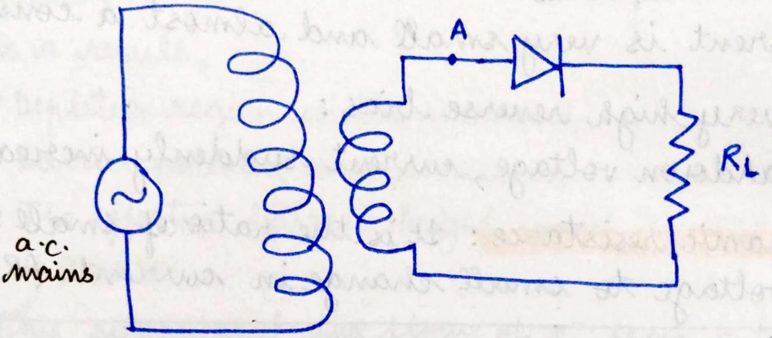
Working:

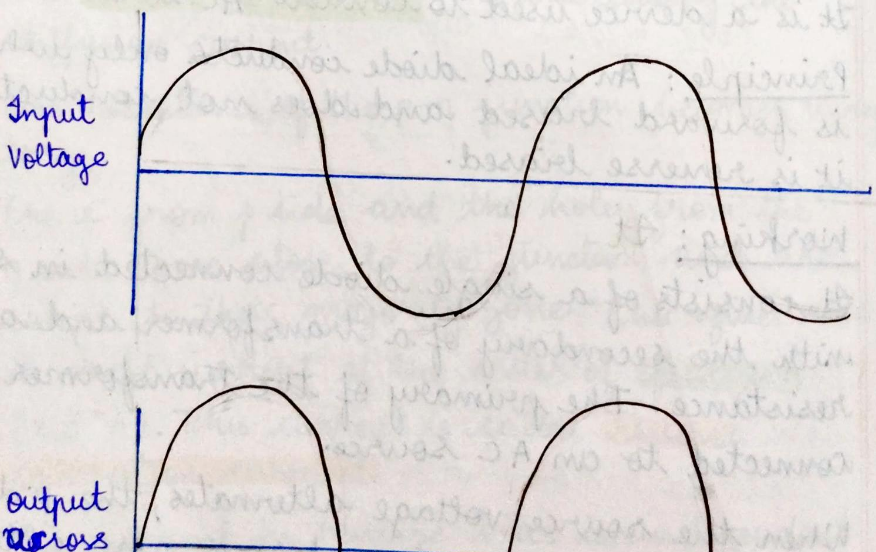
- It consists of a single diode connected in series with the secondary of a transformer and a load resistance. The primary of the transformer is connected to an AC source.
- When the source voltage alternates, the p.d. across the secondary of the transformer also alternates.
- When end A becomes +ve, the diode is forward biased and it conducts, producing a p.d. across R_L.
- When end A is negative, the diode is reverse biased and no current flows through R_L.

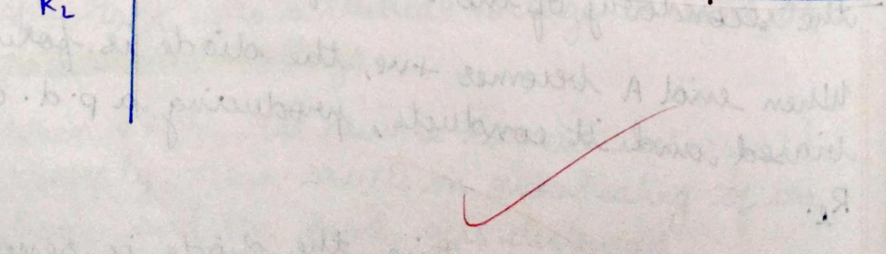
- Thus in positive half-cycle of A.C, there is current to the load resistor and we get an output voltage, but there is no current in the negative half-cycle.

Therefore only half of the wave is rectified and output is passed through a filter circuit.

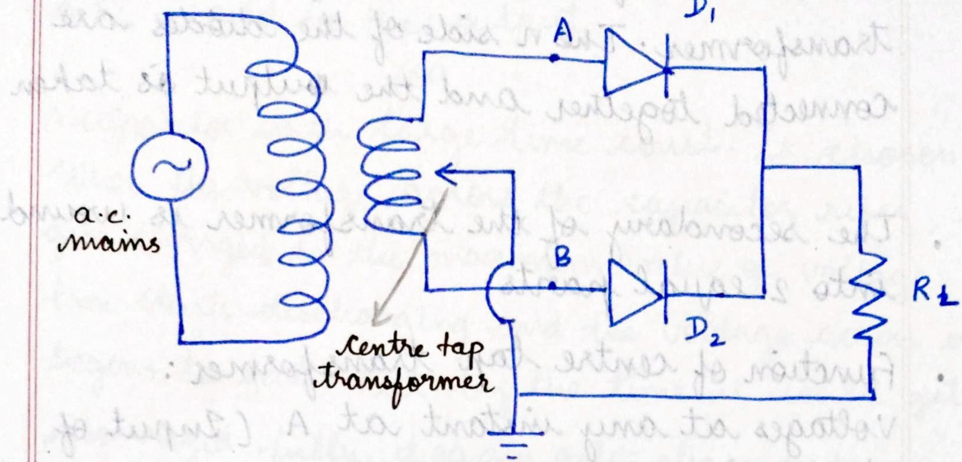
(3 marks) **Half wave rectifier**

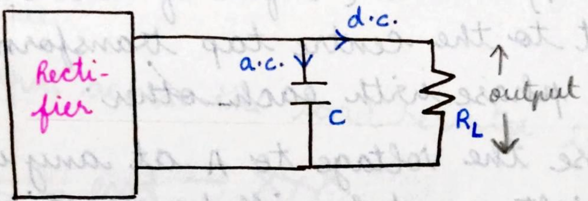




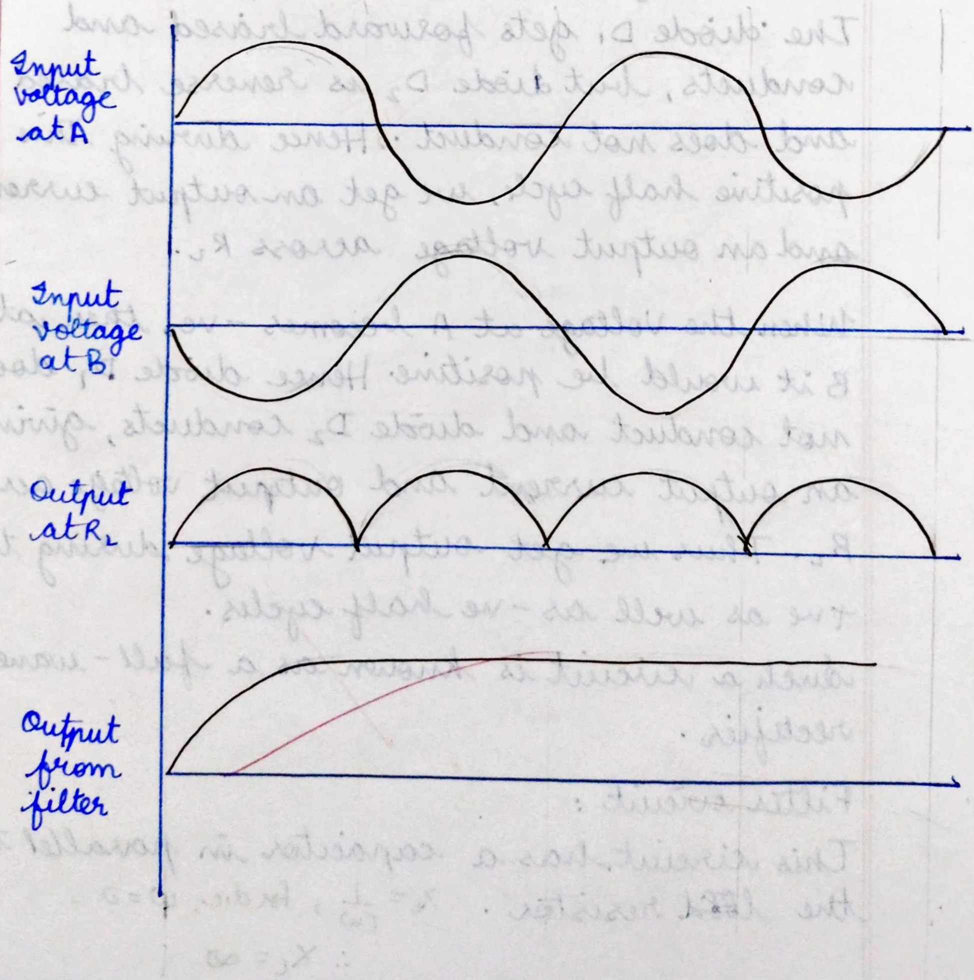


(3 marks) Full wave rectifier





Filter Circuit.



- The p side of the 2 diodes are connected to the ends of the secondary of the transformer. The n side of the diodes are connected together and the output is taken

- The secondary of the transformer is wound into 2 equal parts.

- Function of centre tap transformer:

Voltages at any instant at A (Input of diode D_1) and B (Input of diode D_2) with respect to the centre tap transformer are out of phase with each other.

Suppose the voltage to A at any instant is +ve, Voltage at B will be negative.

The diode D_1 gets forward biased and conducts, but diode D_2 is reverse biased and does not conduct. Hence during this positive half cycle, we get an output current and an output voltage across R_L.

When the Voltage at A becomes -ve, then at B it would be positive. Hence diode D_1 does not conduct and diode D_2 conducts, giving an output current and output voltage across R_L. Thus we get output voltage during the +ve as well as -ve half cycles.

Such a circuit is known as a full-wave rectifier.

Filter circuit:

This circuit has a capacitor in parallel to the ~~load~~ resistor. $X_C = \frac{1}{C\omega}$, for d.c, $\omega = 0$.

$\therefore X_C = \infty$

The capacitor blocks d.c., so all the a.c. components will be filtered away and only d.c., would be the output.

(Or)

A capacitor with large time const. is chosen. When the voltage across the capacitor rises, it gets charged to the maximum value of voltage. It then starts discharging and the voltage across it begins to fall. But by the time it could get discharged fully, it again gets charged to the peak value.

So output across the load resistor becomes const.

485 - end - XXX

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