CHAPTER 14
SEMI CONDUCTOR ELECTRONICS: MATERIALS, DEVICES AND SIMPLE CIRCUITS

INTRODUCTION

- **1897** - Invention of vacuum diode by J.A. Fleming
- **1906** - Invention of vacuum triode by Lee De Forest. Subsequently introduced vacuum tetrode and pentode tubes.
- Vacuum tube devices are bulky, consume high power, operate generally at high voltages (~100 V) and have limited life and low reliability.
- **1939** - Invention of semiconductor diode by Russel Ohl
- **1943** - The world's first computer 'ENIAC'. It occupied an area of around 1800 square feet. It had 18,000 vacuum tubes and it weighed around 50 tons.
- **1948** - Invention of semiconductor transistor by Bardeen, Brattain and Shockley (1956 Nobel prize)
- **1958** – Invention of Integrated Circuit (IC)

CLASSIFICATION OF MATERIALS ON THE BASIS OF CONDUCTIVITY

(i) Conductors:

They possess very low resistivity (or high conductivity).

$$\rho \sim 10^{-2} - 10^{-8}\,\Omega m\left(\sigma \sim 10^{2} - 10^{8}\,Sm^{-1}\right)$$

(ii) Semiconductors:

They have resistivity or conductivity intermediate to metals and insulators.

$$\rho \sim 10^{-5} - 10^{6}\,\Omega m\left(\sigma \sim 10^{5} - 10^{-6}\,Sm^{-1}\right)$$

(iii)Insulators:

They have high resistivity (or low conductivity).

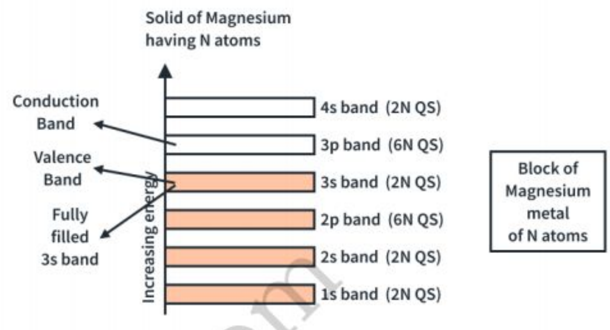
$$\rho \sim 10^{11} - 10^{19}\,\Omega m\left(\sigma \sim 10^{-11} - 10^{-19}\,Sm^{-1}\right)$$

ENERGY BANDS IN SOLIDS

In a single isolated atom, the electronic energy levels are widely separated and the energy of the electron is decided by the orbit in which it revolves around the nucleus. But in solids, the atoms are closely spaced and hence the electrons in the outermost energy levels of nearby atoms influence each other. This changes the nature of the electron motion in a solid from that of an isolated atom.

In reality, a solid is made up of millions of atoms. When millions of atoms are brought close to each other, the valence orbitals and the unoccupied orbitals are split according to the number of atoms. In this case, the energy levels will be closely spaced and will
be difficult to differentiate the orbitals of one atom from the other and they look like a band as shown in Figure.

The range of energy possessed by the electrons in a solid is called the energy band.



VALANCE BAND

It is the highest occupied energy band at absolute zero temperature. In insulators and semi conductors it is completely filled. In metals it is partially filled or overlaps with the conduction band allowing electron movement.

CONDUCTION BAND

It is the next higher band above the valance band. In insulators and semi conductors , it is empty at absolute zero and it is separated by a band gap with valance band. In metals either the conduction band overlaps with valance band or the valance band itself is partially filled and acts as the conduction band

ENERGY BAND GAP ,E_g

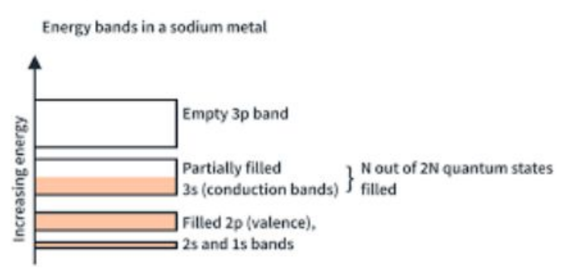
The gap between the top of the valence band and bottom of the conduction band is called the energy band gap (Energy gap ,E_g). It may be large, small, or zero, depending upon the material.

ENERGY BANDS IN METALS, INSULATORS AND IN SEMI CONDUCTORS

METALS

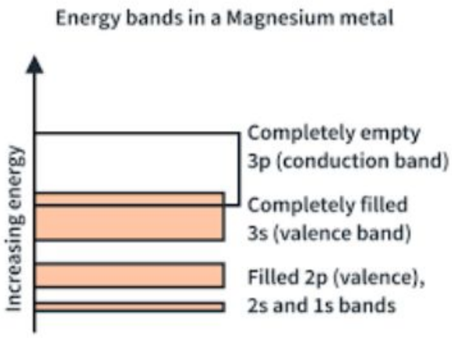
There are two main types of band structures in metals:

1. **Partially Filled Bands**

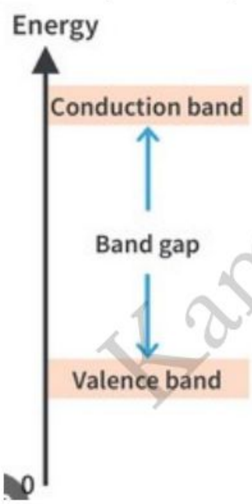


The highest occupied energy band (valance band) is not completely filled and acts as the conduction band. So the electrons are free to move within the band.
Eg: Sodium, copper

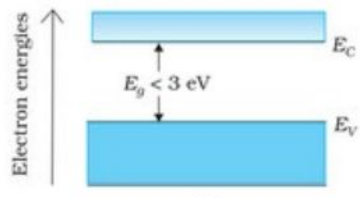
2. Overlapping Bands
The valance band and the conduction band overlap, eliminating any band gap.
Eg: Magnesium



INSULATORS
The valance band is completely filled (at absolute zero) and conduction band is completely empty (at absolute zero) and separated by large band gap (E_g>3V)



SEMICONDUCTORS
Semiconductors have an energy band structure similar to insulators but with a smaller band gap. At absolute zero it has completely filled valence band and completely empty conduction band. Ie, At absolute zero it behaves like an insulator.
Because of the small band gap, at room temperature some electrons from valence band can acquire enough energy to cross the energy gap and enter the
conduction band. These electrons (though small in numbers) can move in the conduction band. Hence, the resistance of semiconductors is lower than that of insulators.

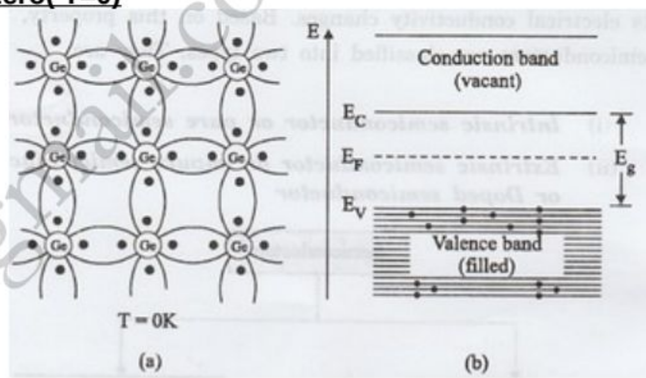


(c)

CLASSIFICATION OF SEMI CONDUCTORS

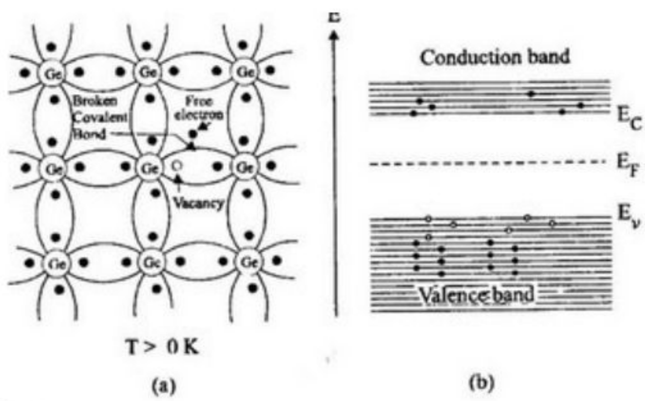
1. INTRINSIC SEMICONDUCTOR
A semi conductor in its purest form is called an intrinsic semi conductor. It conducts electricity due to thermally excited electrons and holes.

Schematic representation of an intrinsic Ge Crystal and its Band Diagram at absolute zero(T=0)



An intrinsic semiconductor will behave like an insulator at T = 0 K .

Schematic representation of an intrinsic Ge Crystal and its Band Diagram at T>0



NOTE

- As the temperature increases, these electrons get more thermal energy , break–away the covalent bonds and become free electrons contributing to conduction. These free electrons (with charge –e) leaves a vacancy with an effective charge (+e). This vacancy with the effective positive electronic charge is called a hole.

- In intrinsic semiconductors, the number of free electrons, n_e is equal to the number of holes,n_h.

$$n_e = n_h = n_i$$

- The total current, I is thus the sum of the electron current I_e and the hole current I_h :

$$I = I_e + I_h$$

Example 14.1 NCERT

C, Si and Ge have same lattice structure. Why is C insulator while Si and Ge intrinsic semiconductors?

Solution

The 4 bonding electrons of C, Si or Ge lie, respectively, in the second, third and fourth orbit. Hence, energy required to take out an electron from these atoms (i.e., ionisation energy Eg) will be least for Ge, followed by Si and highest for C. Hence, number of free electrons for conduction in Ge and Si are significant but negligibly small for C

Doping

It is the process of adding impurities to increase the conductivity of a semiconductor. The impurity atoms are called dopants.

2. EXTRINSIC SEMICONDUCTORS

Extrinsic semiconductors are the doped semi-conductors

Depending on the type of impurities added, there are two types of semiconductors

(i) N Type Semiconductor (Pentavalent doping)

(ii) P Type Semiconductor (Truivalent doping)

(i) N Type Semiconductor

It is obtained by doping an intrinsic semi conductor(Ge or Si) with pentavalent atoms like As, Sb, P etc.

Schematic representation of an N Type Si Crystal and its Band Diagram

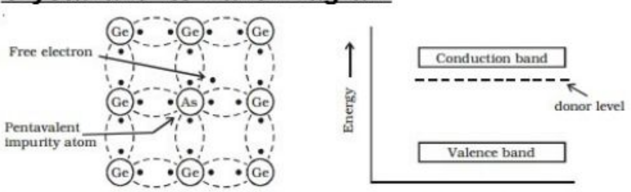


Fig a N-type semiconductor Fig b Energy band diagram of N-type semiconductor

NOTE

- The pentavalent dopant is donating one extra electron for conduction and hence is known as donor impurity.
- The donor impurity becomes +ve ion
- In an N Type semiconductor the total number of conduction electrons n_e is due to the electrons contributed by donors and those generated intrinsically, while the total number of holes n_h is only due to the holes intrinsically.
- Therefore the electrons are the majority carriers in an N Type semiconductor

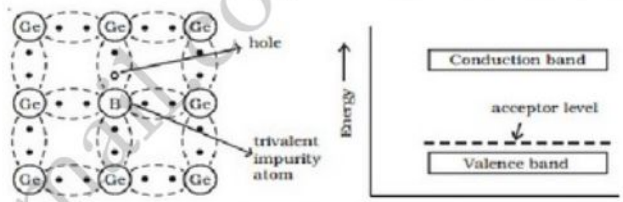
$$n_e >> n_h$$

- Though the net charge of an N type semiconductor is neutral since the total no of positive charges(holes and +ve donor ion) and total no of negative charges(electrons) are same.

(ii) P Type Semiconductor

It is obtained by doping an intrinsic semi conductor(Ge or Si) with trivalent atoms like B, Al, In etc.

Schematic representation of a P Type Si Crystal and its Band Diagram



a P-type semiconductor Fig b Energy band diagram of a P-type semiconductor

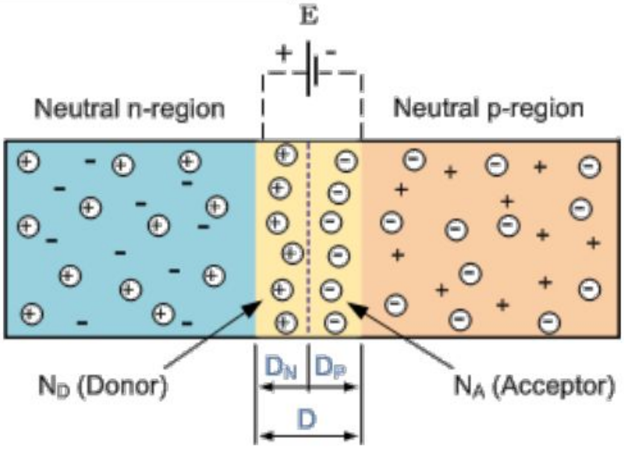
NOTE

- Here the vacancy of electron creates a hole. As the trivalent impurities creates holes the trivalent impurities becomes effectively negatively charged.
- The trivalent dopant is accepting one electron for conduction and hence is known as donor impurity.
- The acceptor impurity becomes -ve ion
- In a P Type semiconductor the total number of holes n_h is due to the holes contributed by acceptors and those generated intrinsically, while the total number of electrons is only due to the electrons intrinsically
- Therefore the holes are the majority carriers in a P Type semiconductor

$$n_h >> n_e$$

- Though the net charge of a P Type semiconductor is neutral since the total no of positive charges(holes) and total no of negative charges (electrons and -ve acceptor ions) are same.

PN JUNCTION DIODE



A p-n junction can be formed by adding a small quantity of pentavalent impurity to a p-type semiconductor or by adding a small quantity of trivalent impurity to an n-type semiconductor.

Two important processes occur during the formation of a p-n junction: diffusion and drift.

1. Diffusion

The holes diffuse from p-side to n-side (p → n) and electrons diffuse from n-side to p-side (n → p). This motion of charge carriers give rise to Diffusion current across the junction. Due to diffusion, a layer of positive charge (or positive space-charge region) is developed on n-side of the junction and a layer of negative charge (or negative space-charge region) is developed on the p-side of the junction .

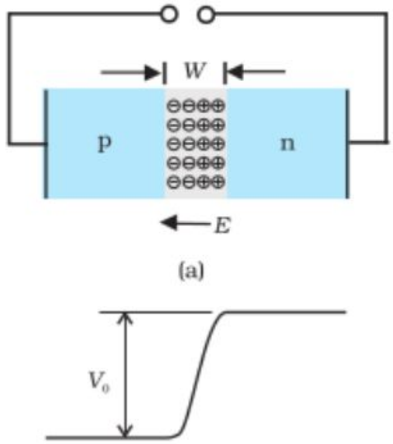
Depletion region (Depletion layer)

The space-charge on either side of the junction together is known as depletion region. The depletion layer consist of immobile ion-cores and no free electrons or holes. This is responsible for a junction potential barrier.

2.Drift

The positive charge on n-side of the junction and negative charge on p- side of the junction develops an electric field. Due to this field, an electron(minority carrier) on p-side of the junction moves to n-side and a hole(minority carrier) on n- side of the junction moves to p-side. The motion of charge carriers due to the electric field is called drift. Initially, diffusion current is large and drift current is small. As the diffusion process continues, the electric field strength increases and hence drift current also increases. This process continues until the diffusion current equals the drift current.. Thus in a p-n junction under equilibrium there is no net current.

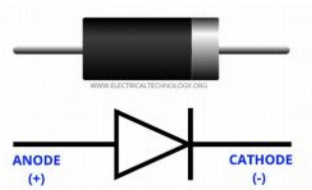
Barrier Potential



The loss of electrons from the n-region and the gain of electron by the p- region causes a difference of potential across the junction of the two regions. Since this potential tends to prevent the movement of electron from the n region into the p region, it is often called a barrier potential. The barrier potential of a Ge diode is 0.2Vand that of a Si diode is 0.7V.

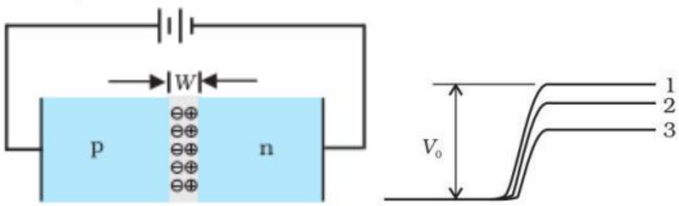
SEMICONDUCTOR DIODE (PN JUNCTION DIODE)

Symbol for p-n junction diodE



PN Junction Diode under Forward Bias

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



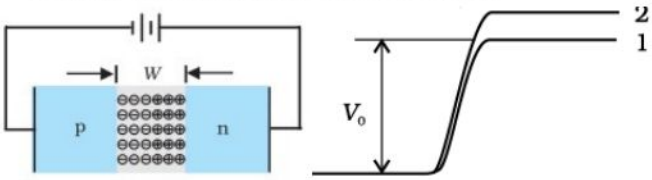
- The direction of the applied voltage (V) is opposite to barrier potential V_0 . As a result, the depletion layer width decreases and the barrier height is reduced.
- The effective barrier height under forward bias is (V_0 – V).
- At high applied voltage, electrons from n-

side cross the depletion region and reach p-side . Similarly, holes from p-side cross the junction and reach the n-side.

- This motion of majority carriers on either side gives rise to diffusion current.
- The magnitude of this current is usually in mA.

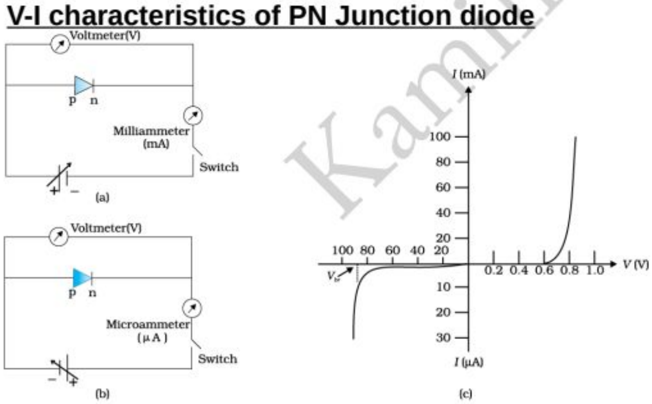
PN Junction Diode nder Reverse Bias

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



- The direction of the applied voltage (V) is same as barrier potential V_0 . As a result, the depletion layer width increases and the barrier height is increased.
- The effective barrier height under reverse bias is (V_0 + V).
- The flow of electrons from n → p and holes from p → n is suppressed. Thus, diffusion current, decreases enormously compared to the diode under forward bias.
- The electric field of the junction is such that the minority carriers are drifted to majority zone which gives rise to drift current.
- The drift current is of the order of a few μA.

V-I characteristics of PN Junction diode



- In forward bias, the current first increases very slowly, till the voltage across the diode crosses a certain value. . This voltage is called the **threshold voltage or cut-in voltage** (0.2V for germanium diode and 0.7 V for silicon diode).
- After threshold voltage, the diode current increases significantly , even for a very small increase in the diode bias voltage.
- For the diode in reverse bias, the current is very small (~μA) and almost remains constant with change in bias. It is called reverse saturation current. However, at very high reverse bias called break down voltage V br , the current suddenly increases. The general purpose diode are not used beyond the reverse saturation current region.

Threshold Voltage

The forward voltage beyond which the diode current increases significantly is called threshold voltage or cut-in voltage.

Break down Voltage

The reverse voltage at which the reverse current increases suddenly is called break down voltage.

APPLICATIONS OF PN JUNCTION DIODE

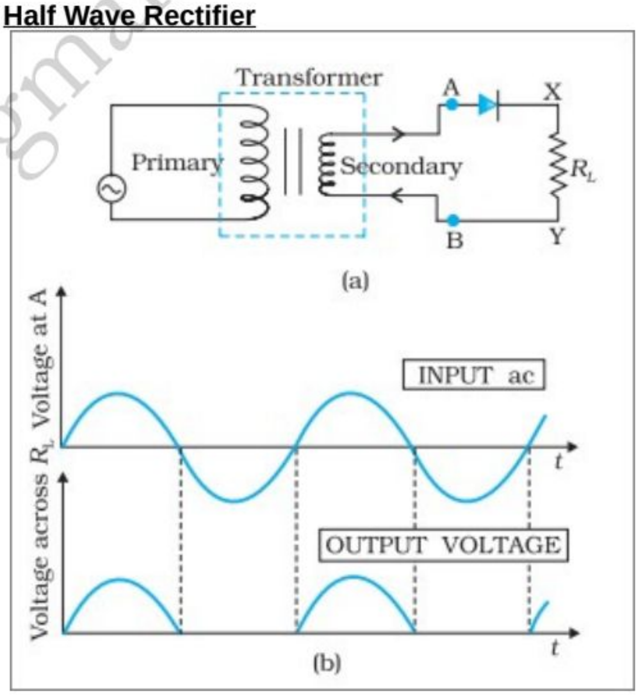
Rectification

The process of converting alternating current to direct current is called Rectification

Rectifier

The circuit used for rectification is called rectifier.

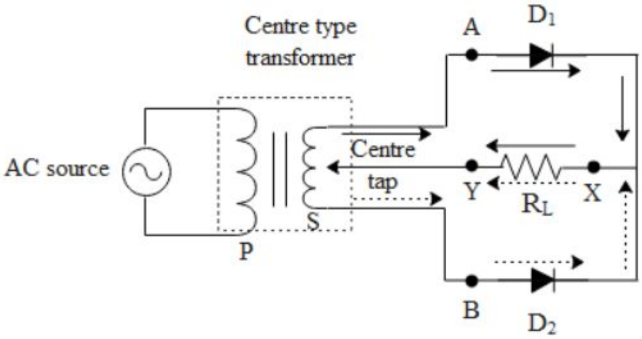
Half Wave Rectifier



- During +ve cycle of input AC end A of the transformer become +ve and B becomes -ve. So the diode is in forward bias and conducts
- During negative cycle of input AC end A becomes -ve and B becomes +ve. So the diode is in reverse bias and does not conduct.
- Since the rectified output of this circuit is only for half of the input ac wave it is called

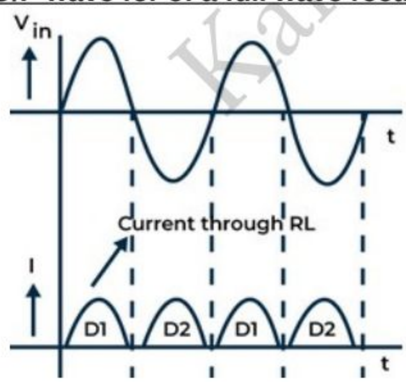
as half-wave rectifier.

Full wave rectifier

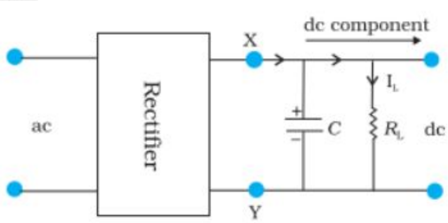


- For a full-wave rectifier the secondary of the transformer is provided with a centre tapping and so it is called centre-tap transformer.
- During this positive half cycle, diode D 1 gets forward biased and conducts ,while D2 being reverse biased is not conducting. Hence we get an output current and a output voltage across the load resistor R_L .
- During negative half cycle, diode D1 would not conduct but diode D2 conducts, giving an output current and output voltage across R_L in the same direction as in positive half. Thus, we get output voltage during both the positive as well as the negative half of the cycle.
- This is a more efficient circuit for getting rectified voltage or current than the half wave rectifier.

I/P and O/P wave for of a full wave rectifier



FILTERS



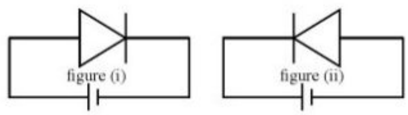
A-capacitor is connected in parallel with the load resistance as shown in the fig. Reactance of capacitor is given by: $X_c = \frac{1}{c\,\omega}$

Hence capacitor offers some opposition to the flow of current through it. But for d.c $\omega = 0$, hence $X_c = \text{infinity}$.

(b)

i.e capacitor behaves as open circuit for d.c. Therefore a.c. component in the output of rectifier passes through capacitor and very small amount of a.c. passes through the load. Whereas there is no effect on the amount of dc that passes through load resistance. Since a.c.component through load resistance decreases, hence ripple factor decrease

PREVIOUS QUESTIONS

1.a)	In which figure the diode is under forward biased condition ? 	1
b)	Draw the circuit diagram of a full wave rectifier and explain its working.	3
2.a)	Give the classification of materials based on energy band diagram.	3
b)	Differentiate between intrinsic and extrinsic semiconductors.	1
3.	A rectifier is used to change AC voltage into DC Voltage :	
a)	With a diagram explain the working of a full wave rectifier, having two diodes.	3
b)	What is the output frequency of full wave rectifier if the input frequency is 50 Hz ?	
4.	What is a rectifier ? Draw the circuit diagram and input, output wave forms of a full wave rectifier	3

	With the help of a circuit diagram, explain the working of a half wave rectifier. Draw the input and output waveforms.	