Lecture 1

Introduction of Semiconductors:

Intrinsic & Extrinsic Semiconductors, Types of currents, Movement of electrons & holes etc.

Classification of Semiconductors

Semiconductors are classified into two types.

- Intrinsic semiconductors.
- Extrinsic semiconductors.

Intrinsic Semiconductors:

- A semiconductor in an extremely pure form is known as Intrinsic semiconductor.

Example: Silicon

Germanium

- Silicon and Germanium are tetravalent (having 4 valence electrons).

- Each atom forms a covalent bond or electron pair bond with the electrons of neighboring atom.

Crystalline structure of Intrinsic Semiconductor at Low Temperature:

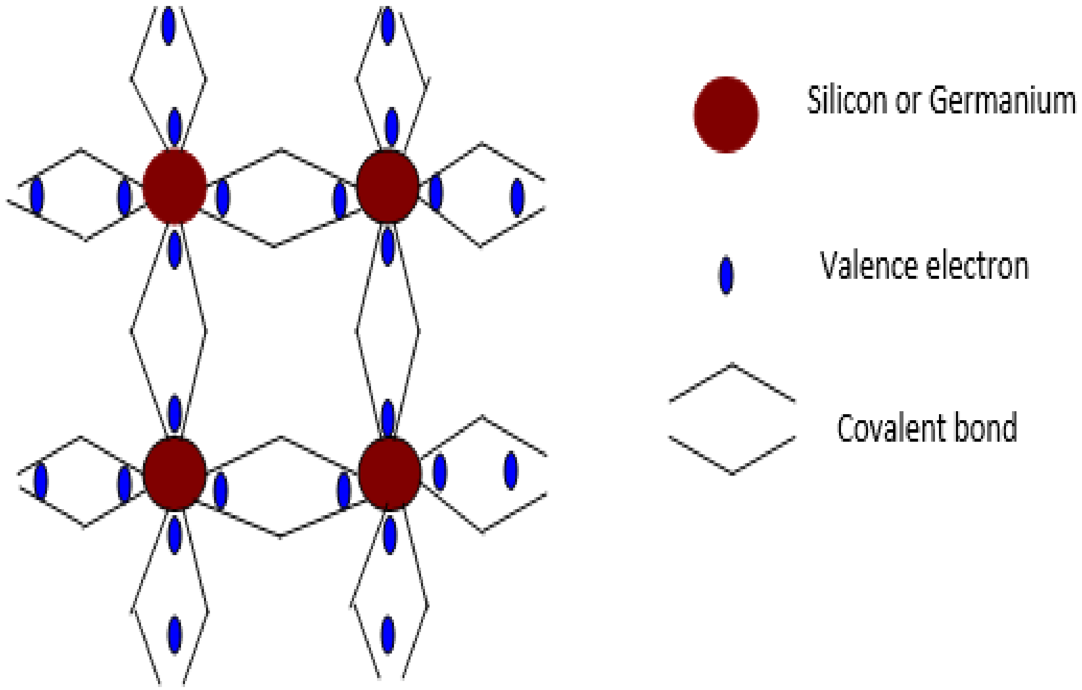


Figure1.3. Crystalline structure of Silicon (or Germanium) at Low Temperature

- Atoms hence has no free electrons available for conduction (All the valence electrons are tightly bounded)

- The semiconductor therefore behaves as an Insulator at absolute zero temperature (O-K)

Crystalline structure of Intrinsic Semiconductor at Room Temperature:

- In previous case, the atom had no free electrons available for conduction (i.e. All the valence electrons were tightly bounded)
- But, At room temperature, some of the valence electrons gain enough thermal energy to break up the covalent bonds.
- This breaking up of covalent bonds sets the electrons free and is available for conduction.

- When an electron escapes from a covalent bond and becomes free electrons a vacancy is created in a covalent bond as shown in figure below:

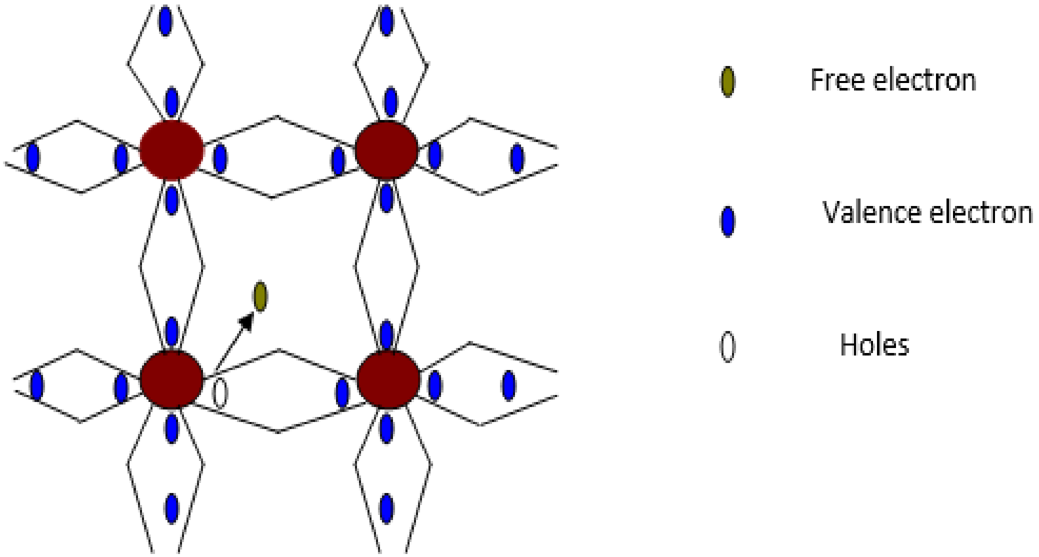


Figure1.4. Crystalline structure of Silicon (or Germanium) at Room Temperature

- Such a vacancy is called Hole & carries a positive charge

- It moves under the influence of an electric field in the direction of the electric field applied.

- The semiconductor crystal is electrically neutral as,

- Numbers of holes = Number of electrons (Since,Hole is nothing but an absence of electrons)

Extrinsic Semiconductors

- When an impurity is added to an intrinsic semiconductor its conductivity changes.
- This process of adding impurity to a semiconductor is called Doping and the impure semiconductor is called extrinsic semiconductor.
- Depending on the type of impurity added, extrinsic semiconductors are further classified as:

  n-type semiconductor

  p-type semiconductor

N-Type Semiconductor

- When a small quantity of Pentavalent impurity is added to a pure semiconductor it is called as n-type semiconductor.

- Addition of Pentavalent impurity provides a large number of free electrons in a semiconductor crystal.

-

- Examples for Pentavalent impurities:

  - Arsenic

  - Antimony

  - Phosphorus

- Such impurities which produce n-type semiconductors are known as Donor impurities

- because they donate or provide free electrons to the semiconductor crystal.

- To understand the formation of n-type semiconductor, consider a pure silicon crystal with an impurity say Antimony added to it as shown in figure 1.5

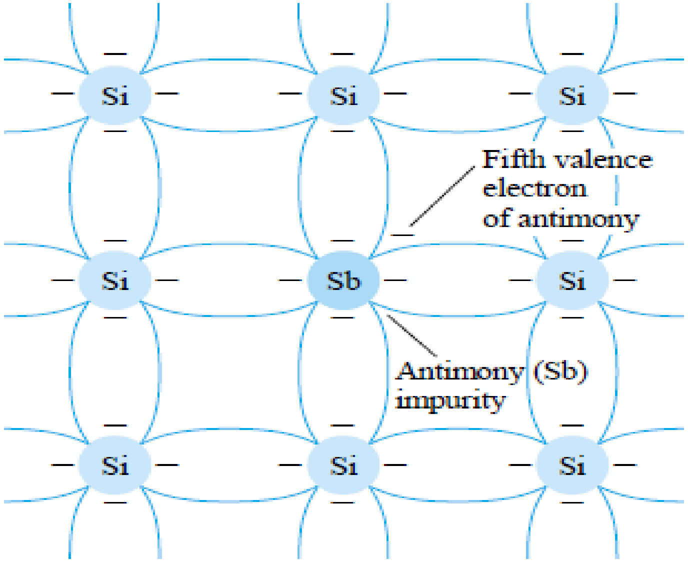


Figure 1.5 : n-type semiconductor

The 5th Valence electron of the pentavalent impurity finds no place in the covalent bond thus, it becomes nearly free and travels to the conduction band

- For each Antimony atom added, one free electron will be available in the silicon crystal.

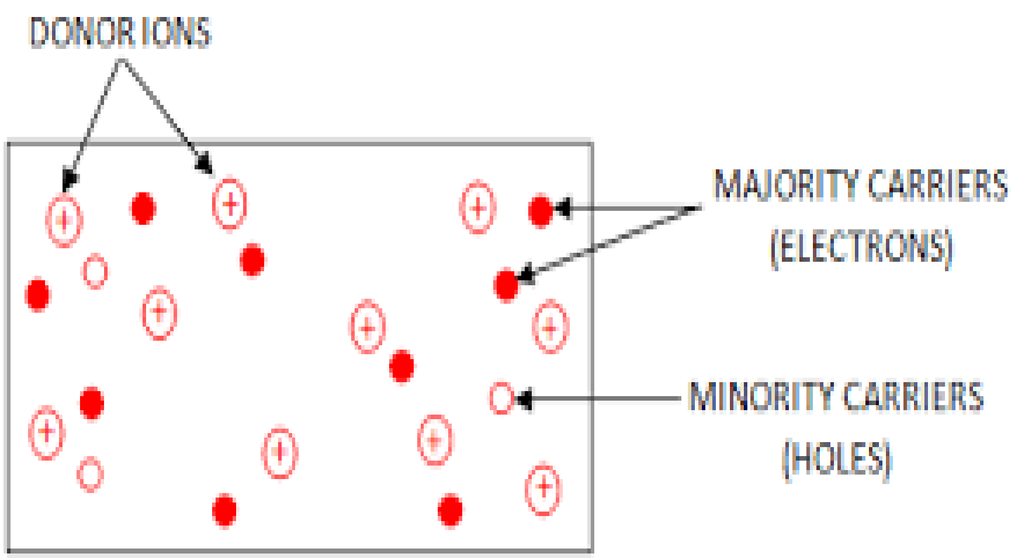
- Though each Antimony atom provides one free electrons yet an extremely small amount of Phosphorus impurity provides enough atoms to supply millions of free electrons.

- Due to thermal energy, still hole electrons pairs are generated but the number of free electrons are very large in number when compared to holes.

- Thus in an n type semiconductor there are three types of charged particles:

1. Donor Ion (Positively Charged)
2. Majority carriers (here electrons which are negatively charged)
3. Minority carriers (here holes which are positively charged

- The resulting n type semiconductor is still electrically neutral
- Here it must be remembered that ions are not free to move, and only carriers are mobile



n- type

P- Type Semiconductor

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 large number of holes in the semiconductor crystals.

- Example:

  Gallium

  Indium

  Boron

- Such impurities which produce p-type semiconductors are known as acceptor impurities

- Because the holes created can accept the electrons in the semi conductor crystal.

- Silicon atom has 4 valence electrons and Gallium or BORON has 3 electrons.

- When Boron is added as impurity to silicon 3 valence electrons of Gallium or BORON make 3 covalent bonds with 3 valence electrons of silicon.

- The 4th valence electrons of silicon left out because of short of one electron as shown in Fig 1.7

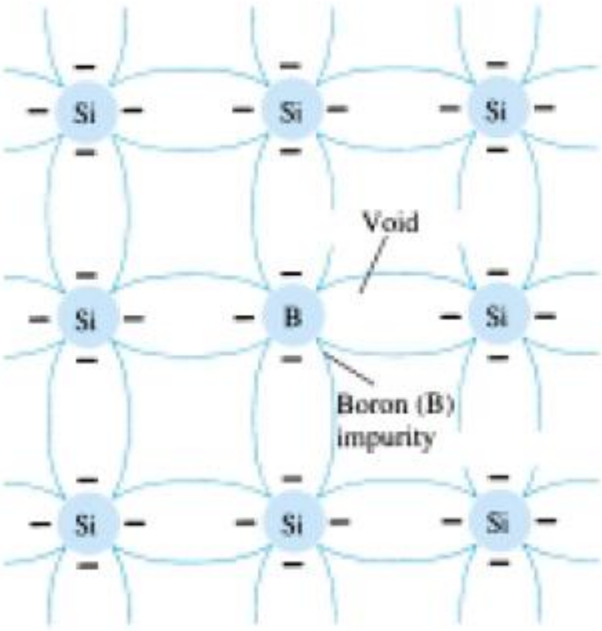


Figure 1.7 p-type semiconductors

This absence of electron is called a hole. Therefore for each Boron atom added one hole is created, a small amount of Boron provides millions of holes.

Thus in an p type semiconductor there are three types of charged particles:

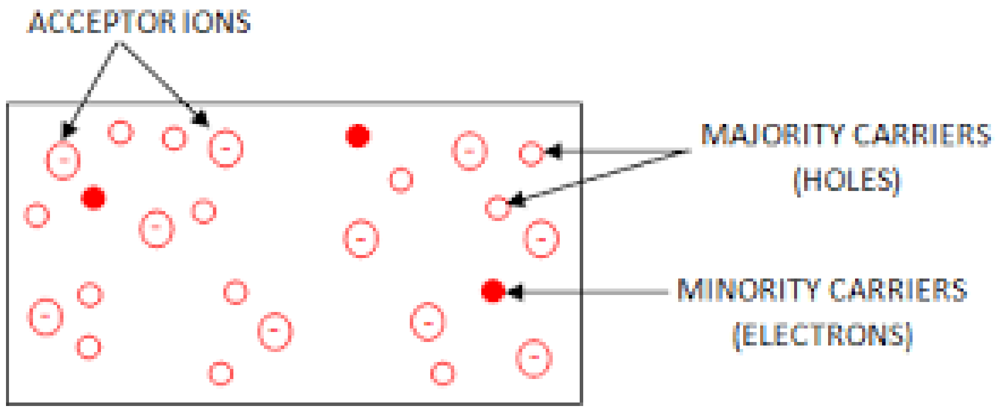
1. Acceptor Ion (Negatively Charged)

2. Majority carriers (here holes which are positively charged)

3. Minority carriers (here electrons which are negatively charged)

The resulting p type semiconductor is still electrically neutral

Here it must be remembered that ions are not free to move, and only carriers are mobile



p- type

Types of Current in Semiconductors

There are two types of currents in semiconductors:

1. Drift Current &
2. Diffusion Current

- **Drift Current** is the current due to flow of charge carriers under the
  influence of external electric field.

- If on part of semiconductor has higher concentration than other part, then there is movement of charge carriers from higher concentration side to lower concentration side. This process is called diffusion.

- **Diffusion Current** is the current when movement of charge carriers is due to concentration gradient.

Conduction in Solids:

- Conduction in any given material occurs when a voltage of suitable magnitude is applied to it, which causes the charge carriers within the material to move in a desired direction.

- Conduction is due to electrons motion or Holes* transfer or both.

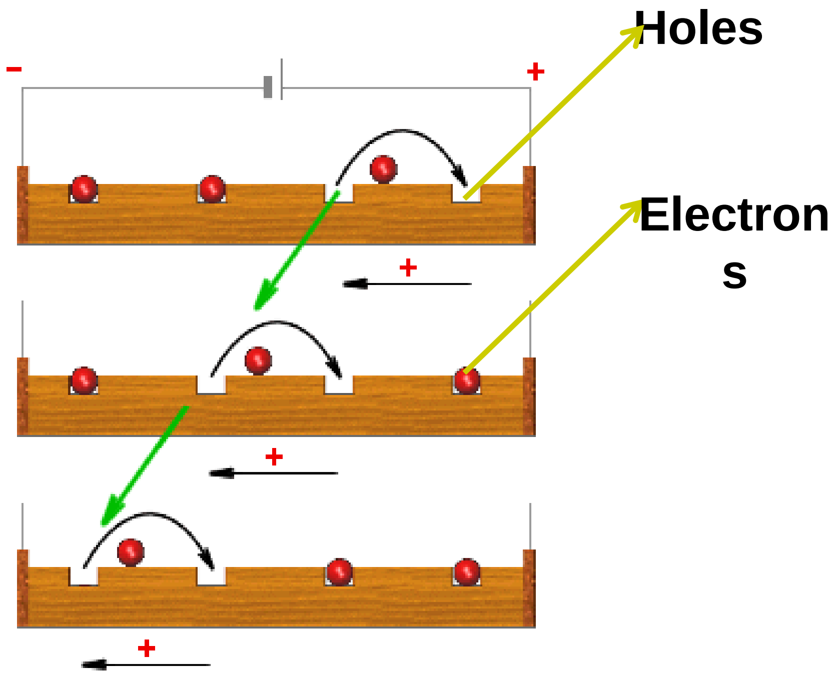
Electron Motion:

- Free electrons in the conduction band are moved under the influence of the applied electric field.

- Since electrons have negative charge they are repelled by the negative terminal of the applied voltage and attracted towards the positive terminal.

Hole Transfer:

- Hole transfer involves the movement of holes.
- Holes may be thought of positive charged particles and as such they move through an electric field in a direction opposite to that of electrons.



- The unit of electric current is Ampere (A)
- Since the flow of electric current is constituted by the movement of
  - Electrons in conduction band
  - Holes in valence band

Electrons and holes are referred as charge carriers.

Lecture 2

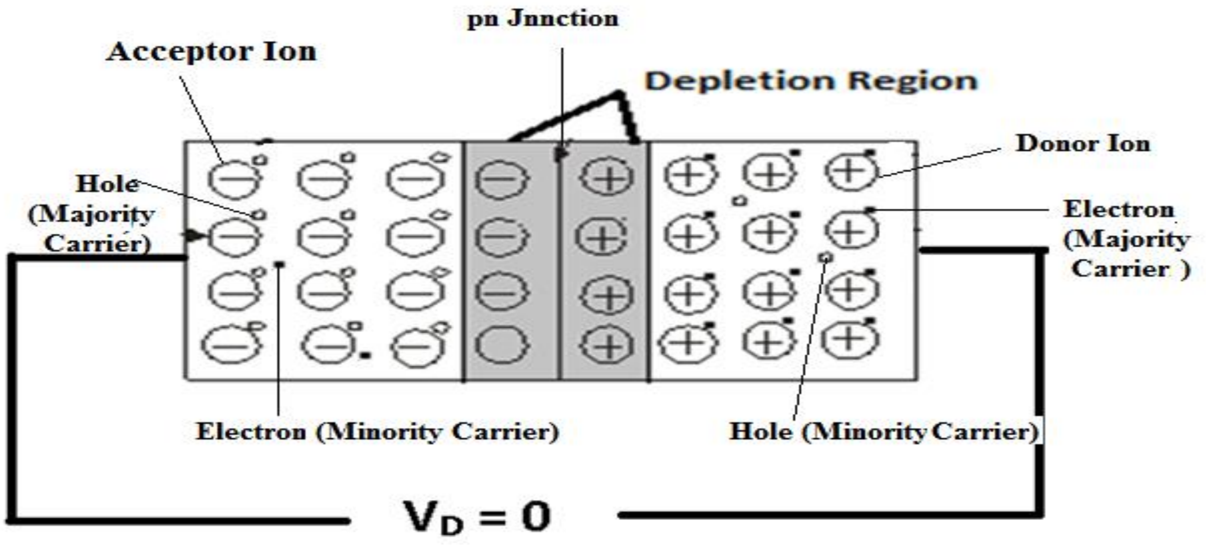
Working of semiconductor diode in no bias, forward bias conditions & reverse bias condition

p-n junction diode (Unbiased Condition)

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

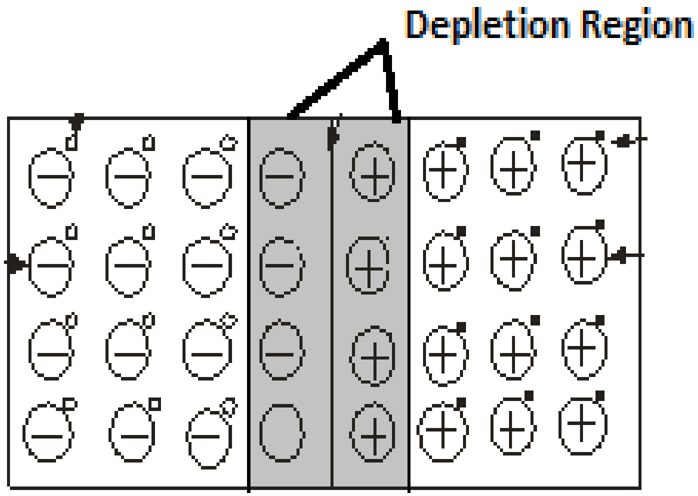
- The p-n junction is also called as semiconductor diode.

- The left side material is a p-type semiconductor having –ve acceptor ions and +vely charged holes. The right side material is n-type semiconductor having +ve donor ions and free electrons.



Initially there is diffusion of charge Carriers (electrons and holes) from both sides of the junction. These free charge Carriers recombine near the junction due to which reason is formed which is known as depletion region

- Due to recombination between electron and holes a region near the junction is formed which contains only immobile ions and there is no fee charge carrier in this region. After formation of this region diffusion across the junction stops.



- A barrier is developed at the junction which is called barrier potential or cut-off voltage or knee voltage. Value of barrier potential for Ge is 0.2 - 0.3 V and for Si is 0.6 - 0.7 V

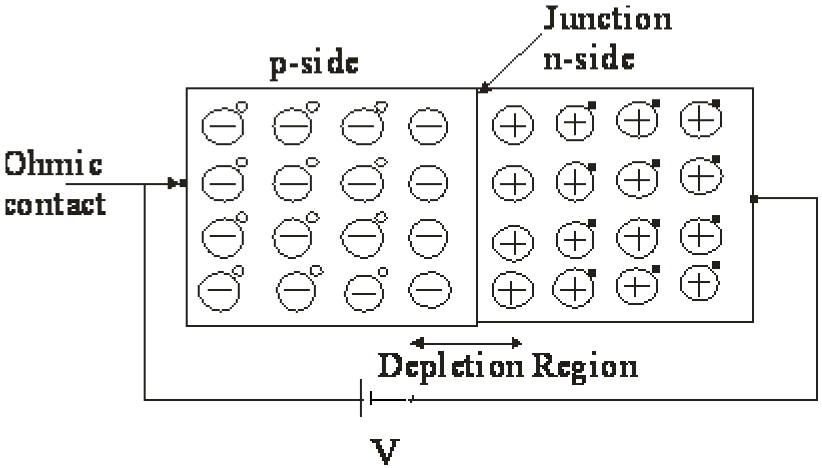
Biasing of p-n Junction

Connecting a p-n junction to an external d.c. voltage source is called biasing.

- Forward biasing
- Reverse biasing

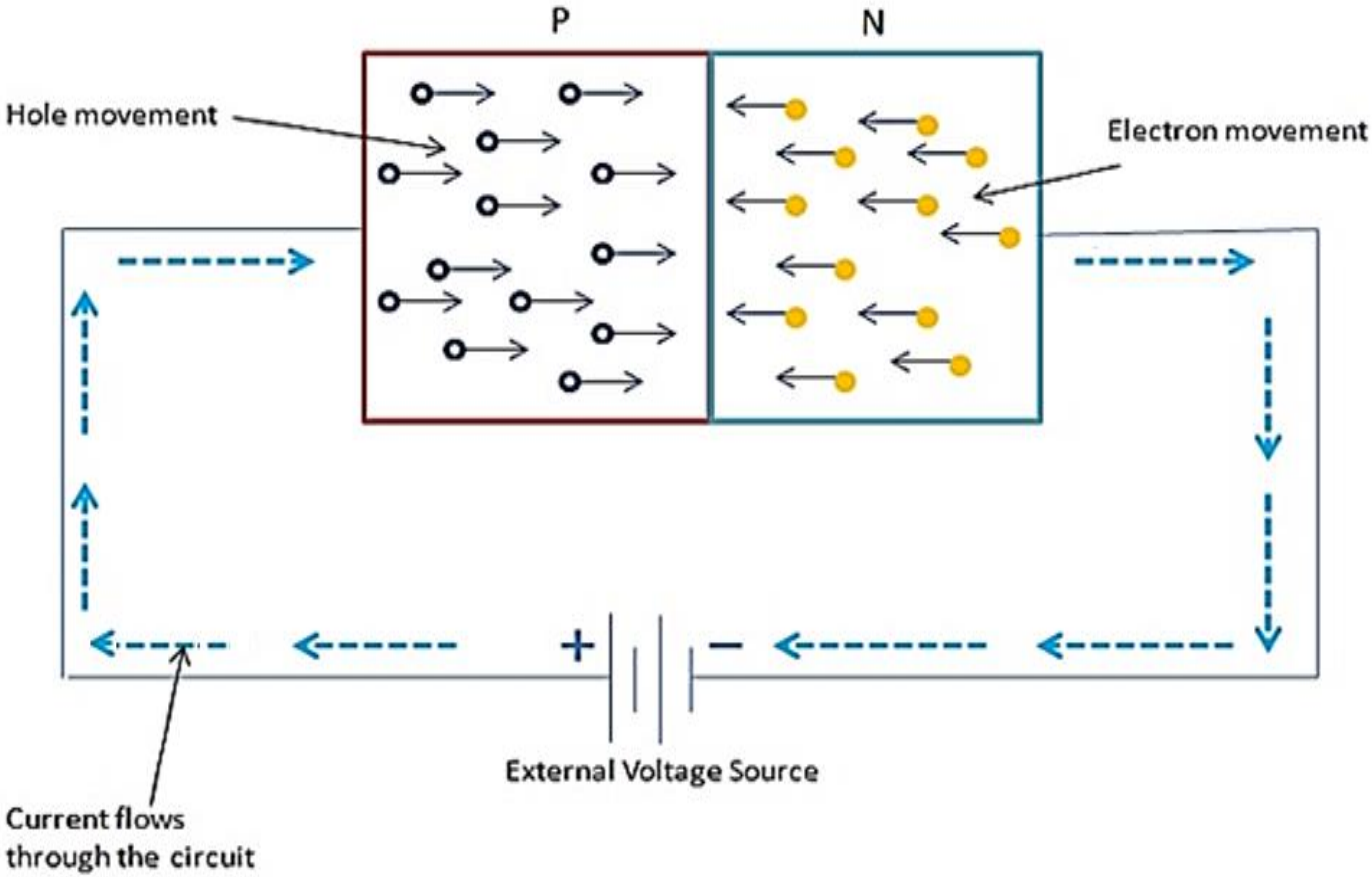
Forward Bias Condition

In this condition p-type semiconductor is connected to positive and n-type semiconductor is connected to negative terminal of the battery. Due to this biasing we can observe following effects:



Majority carriers on both sides of the junction will move towards the junction

Minority Carriers on both sides of the junction will move away from the junction


P
N
Hole movement
Electron movement
+
−
External Voltage Source
Current flows
through the circuit

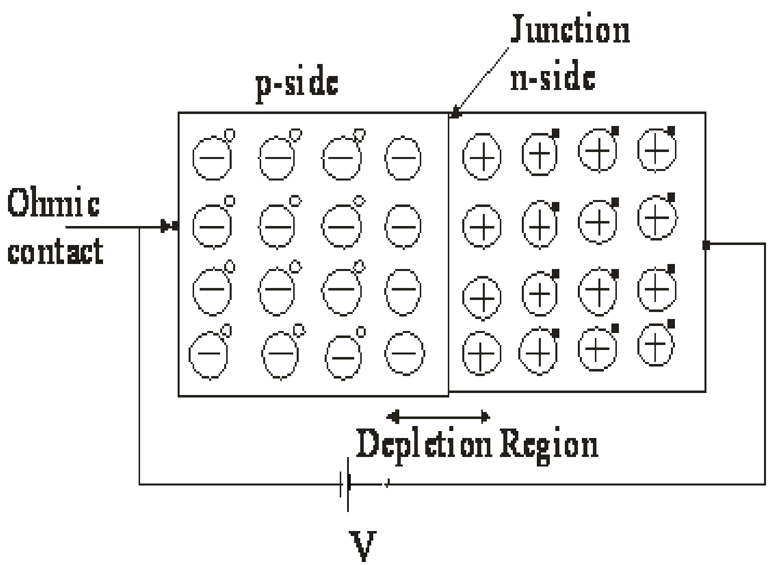
- As the majority carriers move towards the junction, width of depletion region will decrease.

- Net current across the junction is only due to majority charge carriers and its directions from p to n.

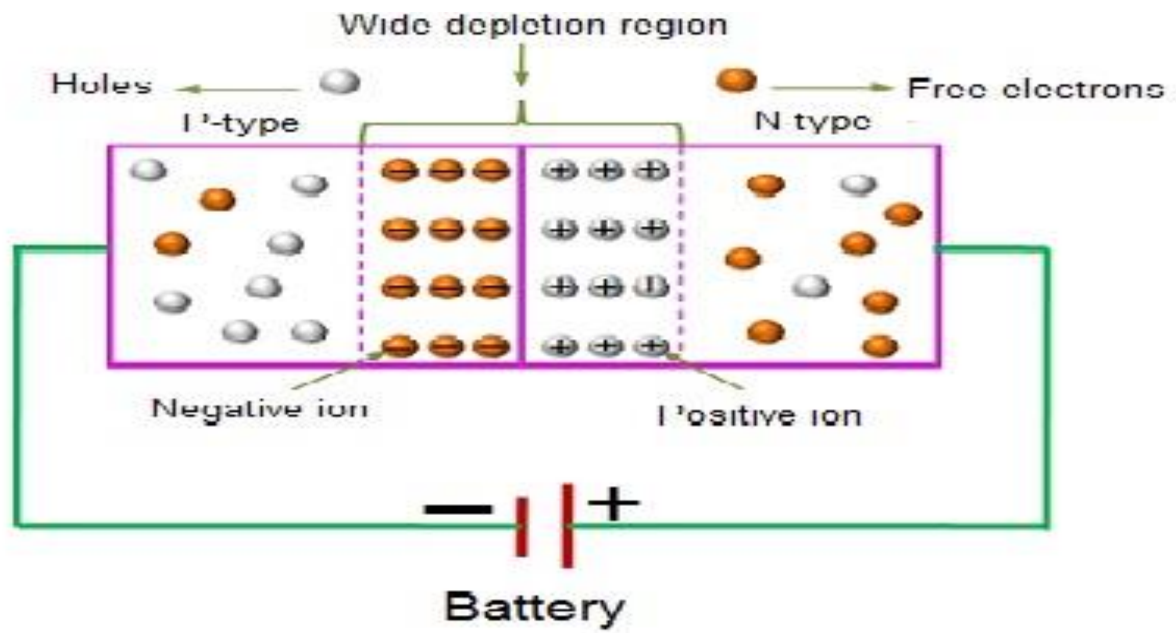
- A minimum positive voltage is required to start conduction in this condition. This minimum positive voltage is known as **knee** voltage or **cut in** voltage

Reverse Biasing

- In this condition n-type semiconductor is connected to positive and p-type is connected to negative terminal of the battery. Due to this biasing, following effects can occur:



- Majority carriers on both sides of junction will move away from the junction
- Minority Carriers on both sides of junction will move towards Junction.



- As the majority of the carriers move away from the junction, width of depletion will increase

- Net current across the junction is only due to minority charge carriers and its directions from n to p.

- In Reverse bias condition the current across the junction is very small and become constant at very low reverse bias Voltage. This constant current is known as **reverse saturation current** or **leakage current**.

Lecture 3

Explanation of diode equation, V/I characteristics of pn junction diode, Analysis of effect of temperature on different parameters of diode

V-I Characteristics of P-n diode

- Irrespective of whether the diode is forward bias or reverse bias, the current I_D flowing through the diode is related to the applied voltage V_D by the equation

$$I_D = I_0 \left(e^{V_D / \eta V_T} - 1 \right)$$

Where

I_D = Diode Current

I_O = Reverse Saturation Current or Leakage Current

V_D = Diode Voltage

η (Ideality Factor) = 1 for Ge and 2 for Si

V_T= Volt Equivalent of Temperature

$= \frac{[illegible]}{11,600}$ Volts (T should be in ^{O} K)

At Room Temperature V_T = 26 mV

Graphical Understanding of Diode Equation

Diode current equation is given by

$$I_D = I_0\left(e^{V_D/\eta V_T} - 1\right) \ldots\ldots 1$$

Unbiased Condition

$$V_D = 0$$

So, equation 1 becomes

$$I_D = I_0\,(e^{0/\eta V_T} - 1) = 0$$

So, curve passes through $V_D = 0$ and $I_D = 0$ i.e. origin.

Graphical Understanding of Diode Equation

Forward Bias Condition

$V_D = +ve$

$$I_D = I_O\left(e^{+V_D/\eta V_T} - 1\right)$$

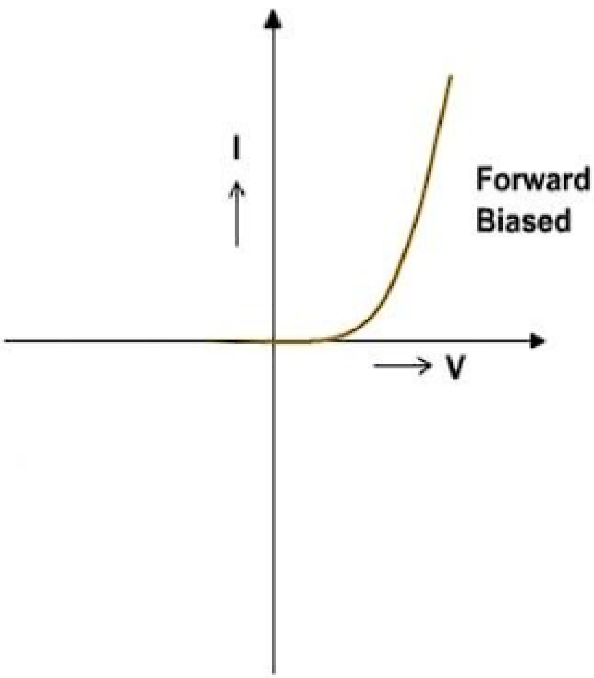
But $e^{V_D/\eta V_T} \gg 1$

So we can neglect the 1

therefore equation 1 becomes

$$I_D \cong I_O e^{V_D/\eta V_T}$$

Hence Forward characteristics is of exponential nature.

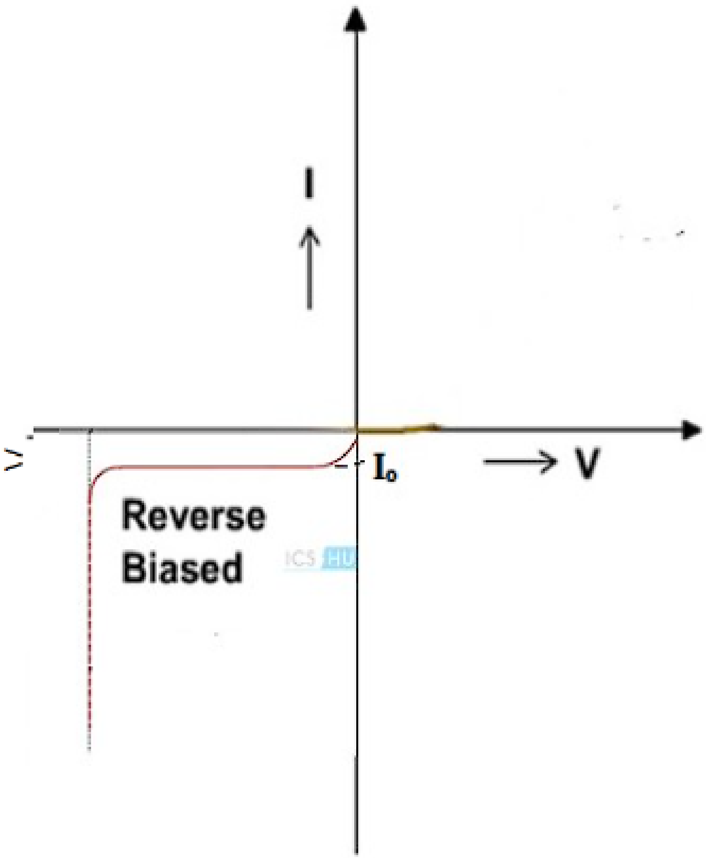


Reverse Bias Condition

$V_D = -ve$

$$I_D = I_O\left(e^{-V_D/\eta V_T} - 1\right)$$

Since $e^{-V_D/\eta V_T} = 1/e^{V_D/\eta V_T}$ **and** $1/e^{V_D/\eta V_T}$ >>



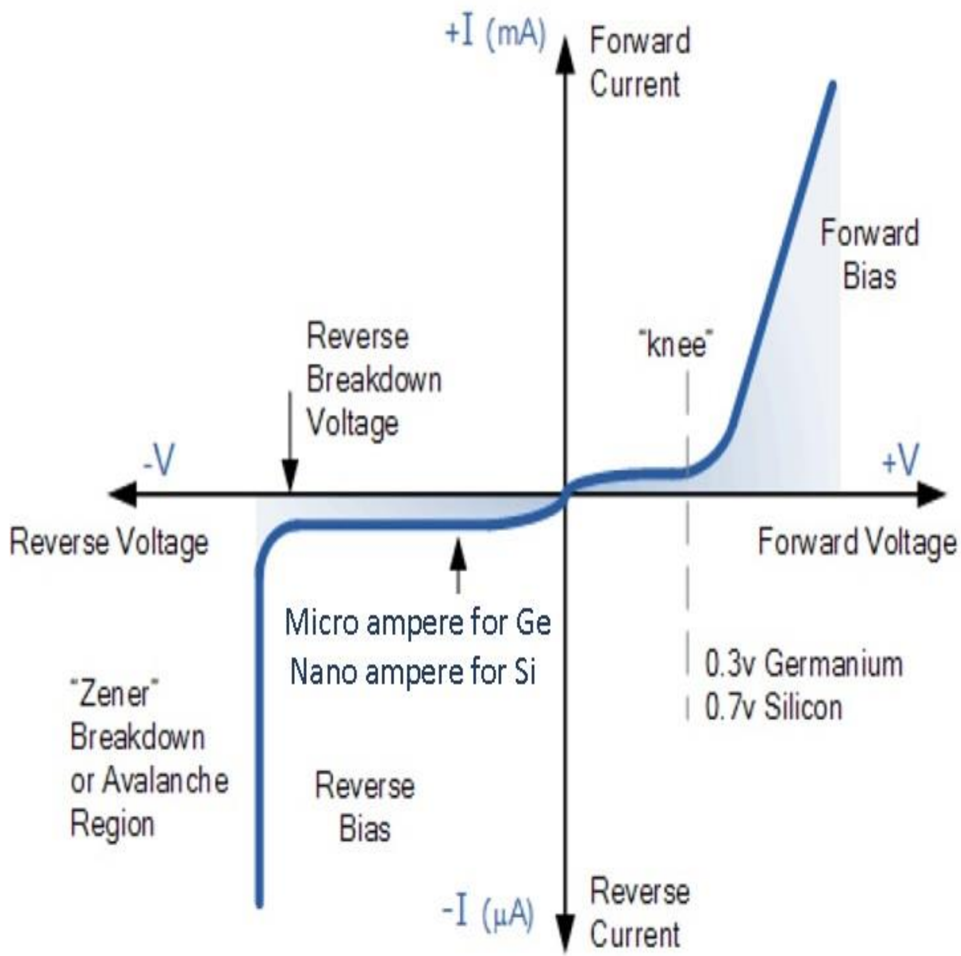
Therefore equation 1 becomes

$$I_D = I_O\ (-1\ )$$

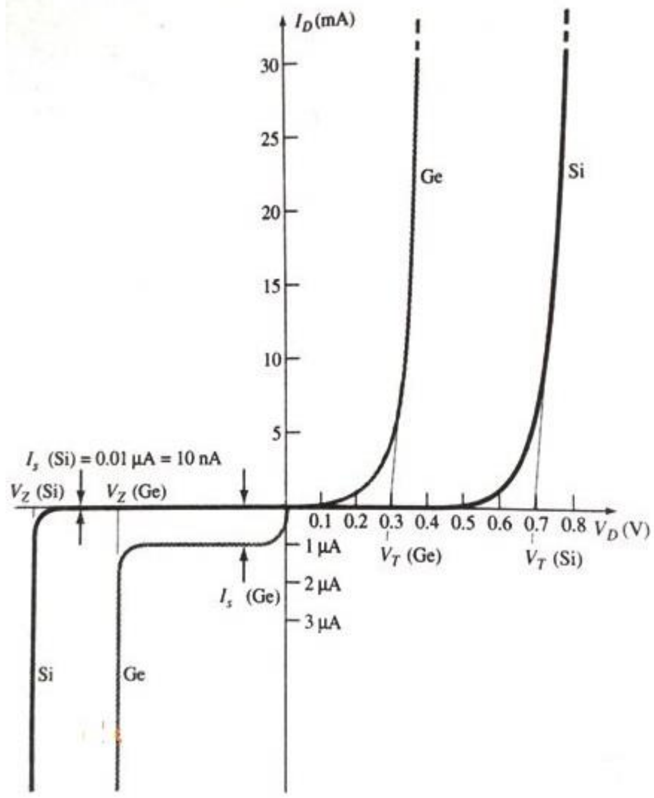
$$I_D = -I_O$$

So reverse characteristic can be represented by straight line. (3rd quadrant)

V-I characteristics of p-n junction diode



In equation 1 the value of current *I* also depends on η , which is =1 for Ge and =2 for Si hence we obtain two curves, one for Ge and another for Si shown in figure below



- From these curves it can be seen that the reverse saturation current of Ge diodes is more.
- This current is also known as leakage current.
- We note that the leakage current is quite small and have hence has been plotted in enlarged scale (in µA)

Cut in voltage or Knee Voltage or Cut-in Voltage

- Cut in voltage V_r is defined as the voltage at which 1% of the rated current flows.
- In practical terms, this is the voltage at which the diode may be considered to start the conduction

For Ge, V_r = 0.3v

For Si, V_r = 0.7v

Temperature Dependence of V-I Characteristic

The diode current $$I_D = I_0 \left(e^{V_D/\eta V_T} - 1\right)$$

Two parameters Is and VT in the expression for diode current are temperature dependent.

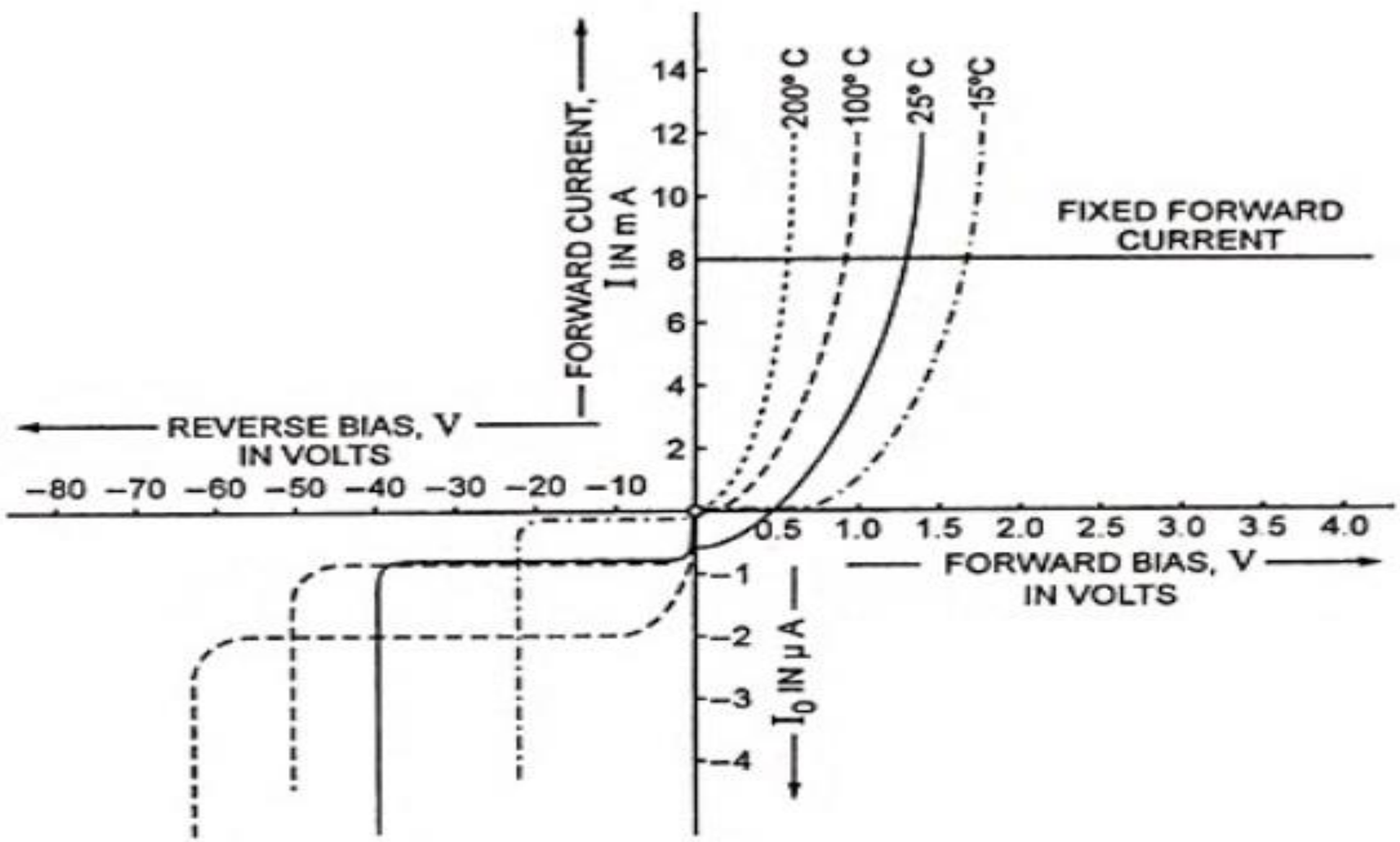
Effect of temperature:

1. Forward Bias : The characteristics of Si diode shift to left at the rate of 2.5 mV/ deg C rise in temperature and vice versa.
2. Reverse Bias :

   Saturation current: Reverse saturation Current doubles for 10 deg C rise in temperature.

   $$I_{02} = I_{01}\left(2^{T2-T1/10}\right) = I_{01}\left(2^{\Delta T/10}\right)$$

   Breakdown voltage: Voltage increases with increase in temperature and vice versa.



FORWARD CURRENT, I IN mA
14
12
10
8
6
4
2
200° C
100° C
25° C
-15°C
FIXED FORWARD CURRENT
REVERSE BIAS, V IN VOLTS
-80 -70 -60 -50 -40 -30 -20 -10
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
FORWARD BIAS, V IN VOLTS
-1
-2
-3
-4
I_0 IN μA

Lecture 4

Problems based on diode equation and temperature effect, Illustration of ideal and simplified circuit representation of diode based on approximations

Example 1: A Ge diode carries a current of 1 mA at room temperature when a forward bias of 0.15 V is applied. Estimate the reverse saturation current at room temperature.

Solution :

I= 1 mA , T=Room temperature, so V_T = 26mV, V=0.15 V

For Ge, η=1

$$I = I_O\left(e^{V/\eta V_T} - 1\right)$$

$$1X10^{-3} = I_O\left(e^{0.15/26X10^{-3}} - 1\right)$$

I_O = 3.1319 micro ampere

Example 2. Calculate the forward bias current of a Si diode when forward bias voltage of 0.4V is applied, the reverse saturation current is 1.17×10^{-9}A and the thermal voltage is 25.2mV.

- Explanation: Equation for diode current

  $I=I_0(e^{(V/\eta V_T)}-1)$

- where I_0 = reverse saturation current

  η = ideality factor

  V_T = thermal voltage

  V = applied voltage

- Since in this question ideality factor is not mentioned it can be taken as one.

  I_0 = 1.17 x 10^{-9}A, V_T = 0.0252V, η = 2, V = 0.4V

  Therefore, I = 1.17×10^{-9}x($e^{0.4/2*0.025}$ -1)=

- = 1.17 x 10^{-9} x (2980.9-1)= 3.486mA.

Example 3. Find the applied voltage on a forward biased diode if the current is 1mA and reverse saturation current is 10^{-10}. Temperature is 25°C and takes ideality factor as 1.5.

- Explanation: Equation for diode current

  $I=I_0(e^{(V/\eta V_T)}-1)$ where I_0 = reverse saturation current

  η = ideality factor

  V_T = thermal voltage

  V = applied voltage

- V_T at T = 25+273=298 is 298/11600 = 0.0256V, η = 1.5, I = 1mA, $I_0 = 10^{-10}$A

$$V = \eta V_T \ln\left(\left(\frac{I}{I_0}\right) + 1\right) = 1.5 \times 0.0256 \times \ln\left(\frac{10^{-3}}{10^{-10}} + 1\right) = 0.618V$$

Diode Equivalent Circuit

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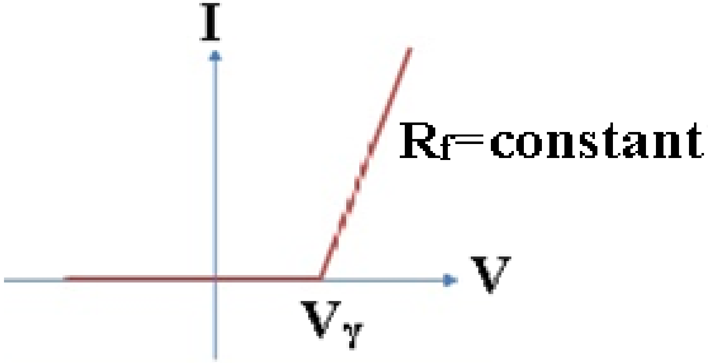
1.Piecewise linear equivalent circuits:

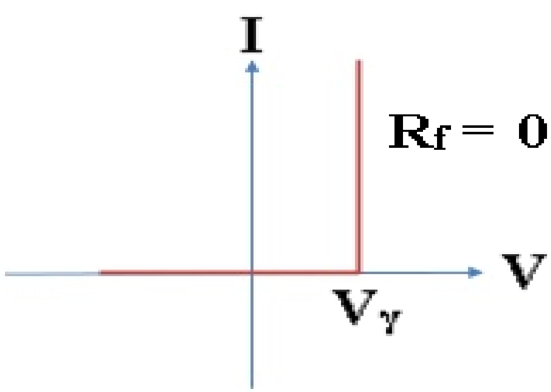
In this circuit diode non-linear characteristics is replaced by a straight line. So, resistance of diode is constant i.e. R_f is constant. Diode is replaced by battery with resistance in series.

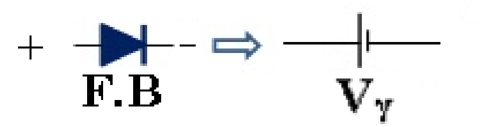


Diode Equivalent Circuit

2. Simplified equivalent circuits:

Since diode forward resistance is low so it can be neglected i.e. $R_f = 0$. Diode is replaced by battery.

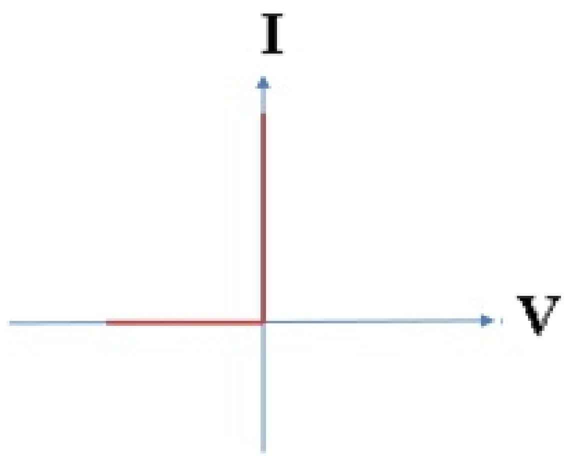


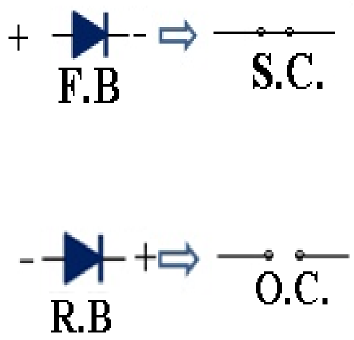


Diode Equivalent Circuit

3. Ideal equivalent circuits:

In ideal diode $R_f = 0$, $V_\gamma = 0$ and $I_O = 0$. An ideal diode can be used as a perfect switch.

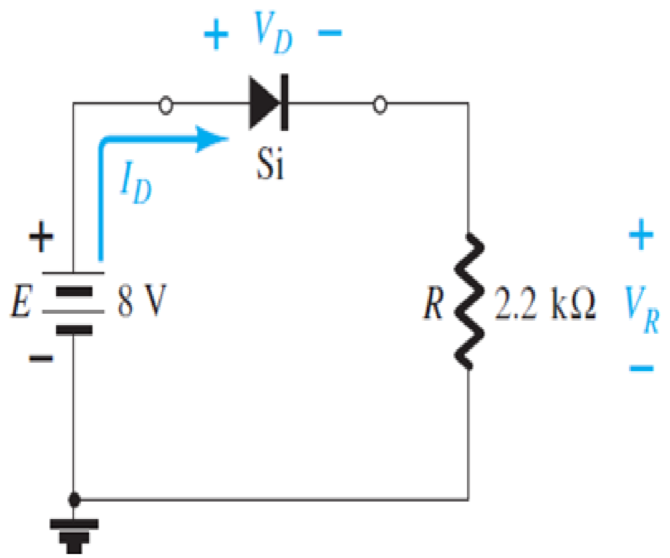




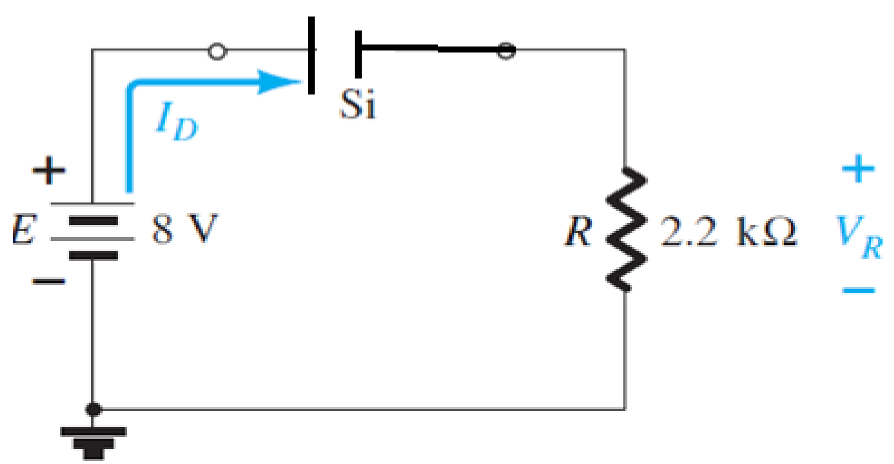
Lecture 5

Problems based on series & parallel circuits of diodes

Example: 1 For the series diode configuration shown in fig. determine V_D, V_R and I_D.



Solution: Since the applied voltage establishes a current in the clockwise direction to match the arrow of the symbol and the diode is in the "on" state,



Applying KVL

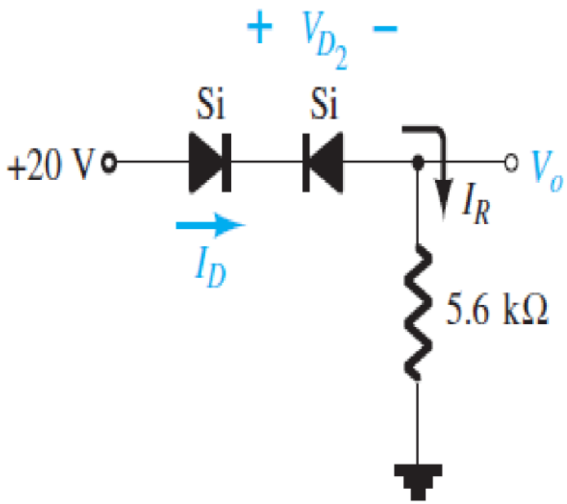
$$-0.7 - 2.2\,K\,I_D + 8 = 0$$

$$I_D = 3.32\text{ mA}$$

$$V_R = I_D R = 3.32\text{ mA} \times 2.2\text{ K}\Omega$$

$$= 7.3\text{ V}$$

Example:2 Determine I_D, V_{D2} and V_O for the following figure.



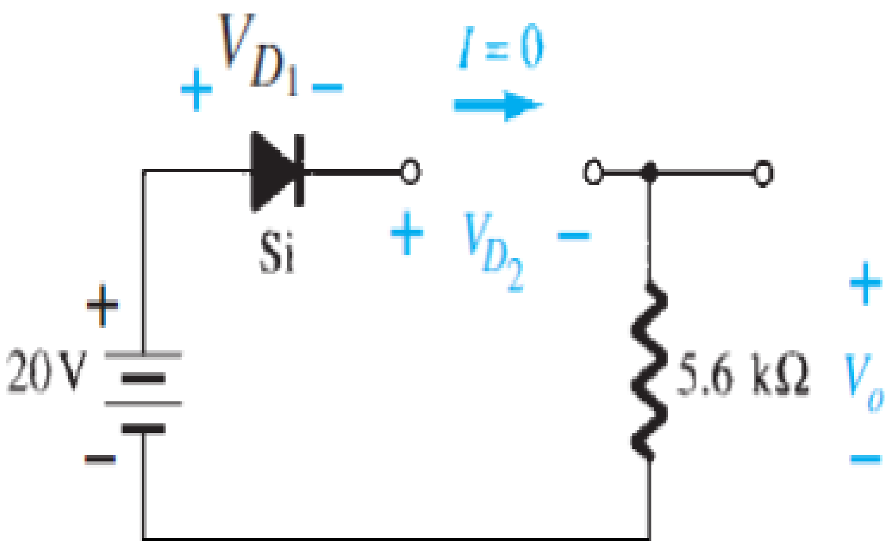
Solution:

$$I_D = 0$$

$$V_o = I_R R = I_D R = (0\text{ A})R = \mathbf{0\ V}$$

Equivalent circuit

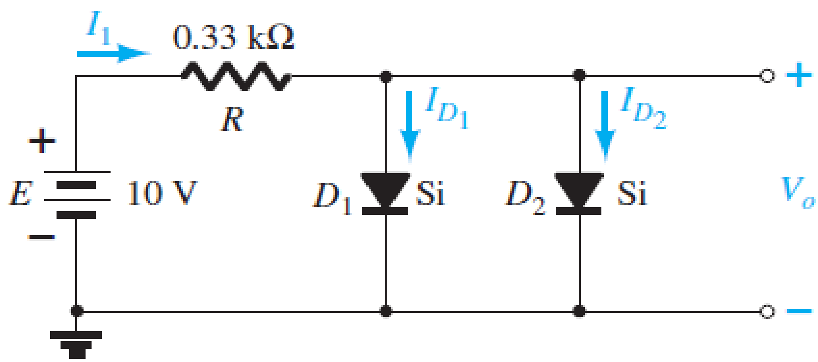
Applying Kirchhoff's voltage law in a clockwise direction gives



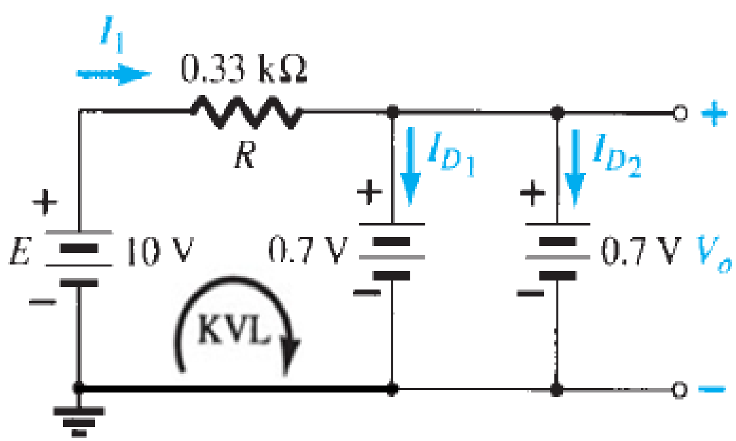
20-07-VD2-VO = 0

VD2 = 20-0.7-0 = 19.3 V

Example: 3 Determine V_o, I_1, I_{D1} and I_{D2} for the parallel diode configuration shown in fig.



Solution :



Applying KVL

$$-0.33I_1\ K\Omega - 0.7V + 10 = 0$$

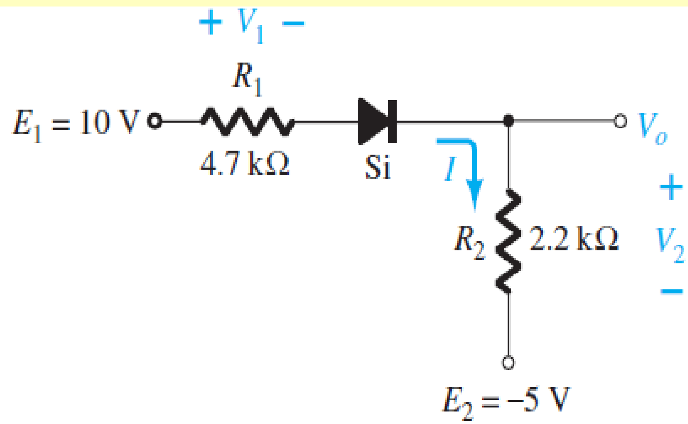
$$I_1 = 28.8\ mA$$

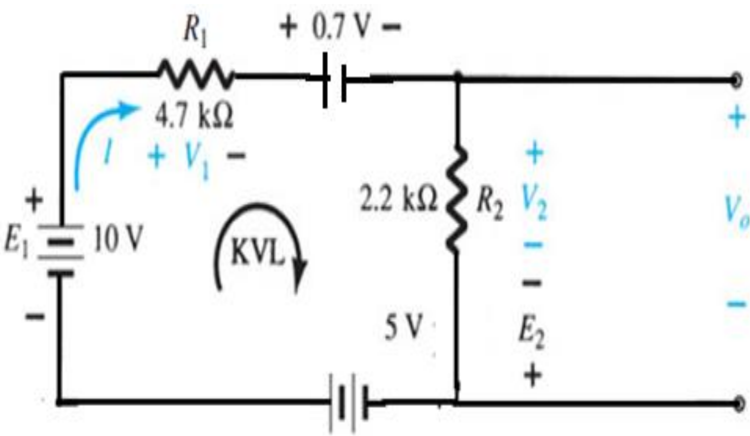
Assuming diodes of similar characteristics, we have

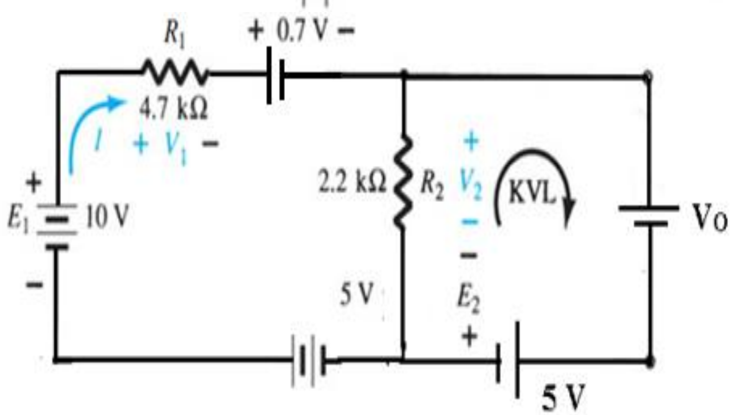
$$I_{D_1} = I_{D_2} = \frac{I_1}{2} = \frac{28.18\ \text{mA}}{2} = \mathbf{14.09\ mA}$$

KVL : VO-0.7 =0 ,   VO=0.7 V

Example:5 Determine I, V_1, V_2 and V_O for the following figure.







Applying KVL

$-0.33I_1$ KΩ -0.7V + 10 = 0

I_1 = 28.8 mA

- 4.7 KΩ I- 0.7 V – 2.2 KΩ I +5 - 10 =0

I= 2.07 mA

$$V_1 = IR_1 = (2.07\text{ mA})(4.7\text{ k}\Omega) = \mathbf{9.73\text{ V}}$$

$$V_2 = IR_2 = (2.07\text{ mA})(2.2\text{ k}\Omega) = \mathbf{4.55\text{ V}}$$

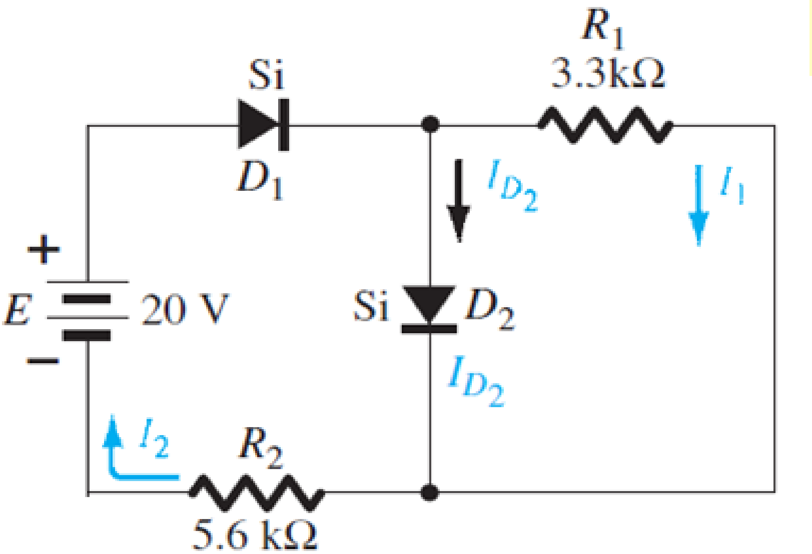
Applying KVL

$-V_O$ – 5V + 4.55V = 0

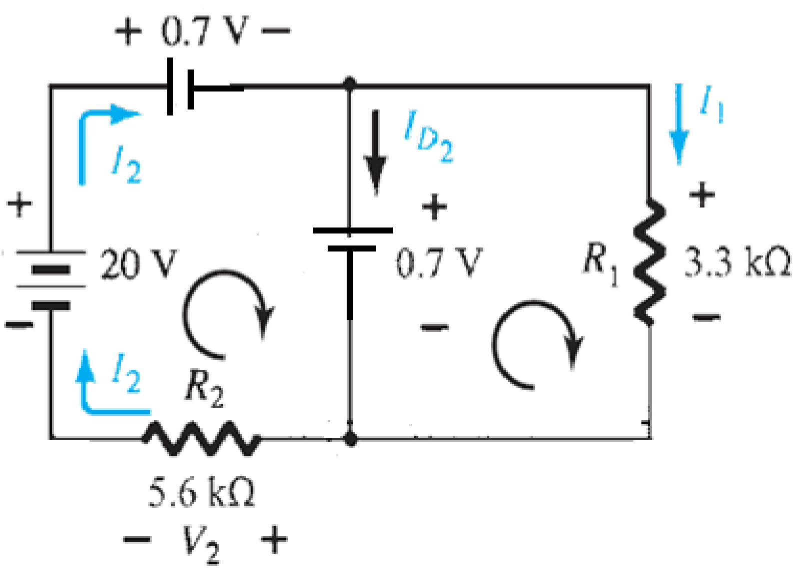
V_O = -0.45 V

The minus sign indicates that V_o has a polarity opposite to that appearing in Fig.

Example: 4 Determine I_1, I_2, and I_{D2} for the



Solution:
Equivalent circuit



Applying KVL

$- 0.7V - 0.7V - 5.6K\Omega\ I_2 + 20 = 0$

$I_2 = 3.32\ mA$

Applying KVL

$- 0.33K\Omega\ I_1 + 0.7V = 0$

$I_1 = 0.212\ mA$

Now from KCL

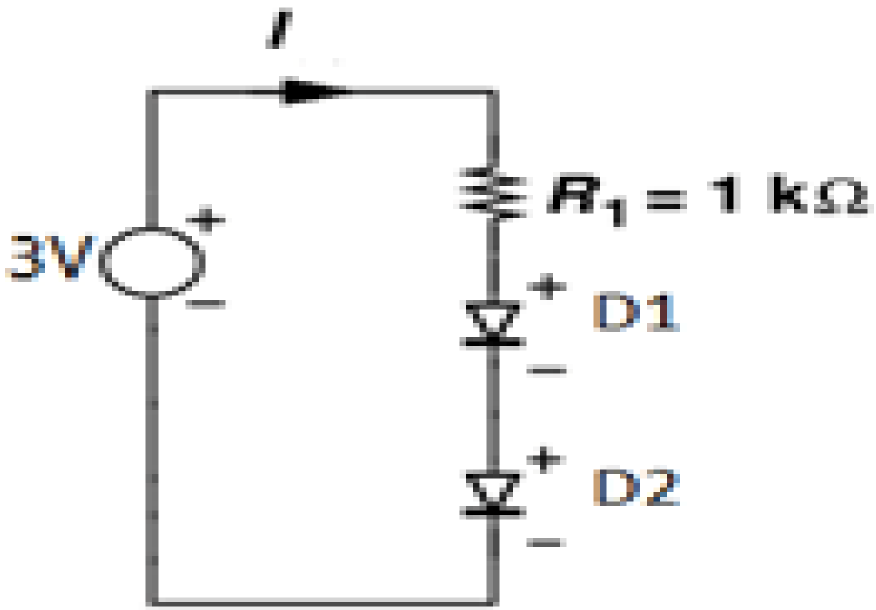
$I_1 + I_{D1} = I_2$

$I_{D1} = I_2 - I_1$

$I_{D1} = 3.32\ mA – 0.212\ mA$

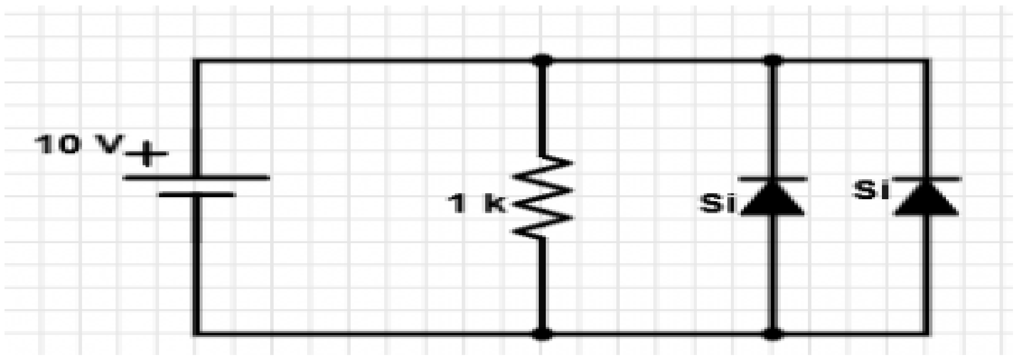
$= 3 .102\ mA$

Example: 5 Find current I through the circuit using characteristic equation of diode. The terminal voltage of each diode is 0.6V. Reverse saturation current is 10^{-12}A.



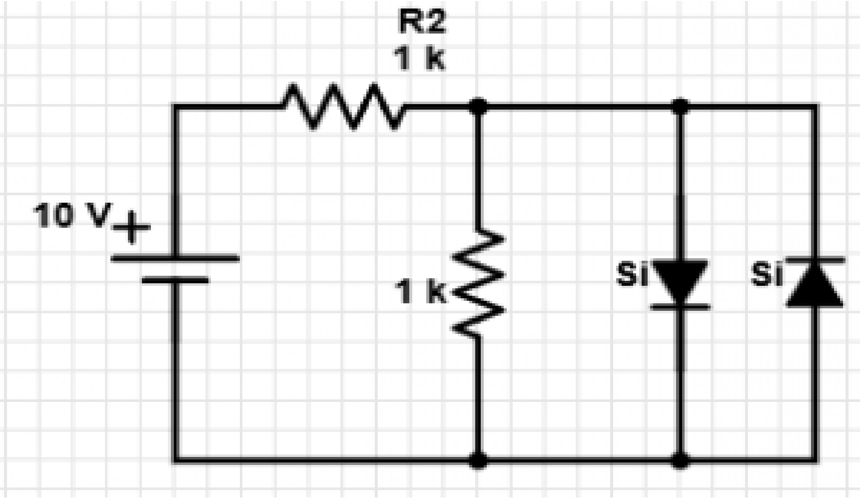
- Explanation: Let V_D be the voltage of diode, then by Kirchoff's loop rule
- $3V = 2V_D + IR1$
- This method of assumption contains small error but it is the simplest method.
- Let V_D be 0.6V.
- Now the current I = (3-1.2)/1k = 1.8mA.
  The $V_D = V_T \ln((I/I_O)+1) = 0.58V$
  Hence current is (3-(2×0.58))/1k = 1.84mA.

Example: 6. From the given circuit, what is the value of current flowing through the 1 k resistor parallel to the diodes?



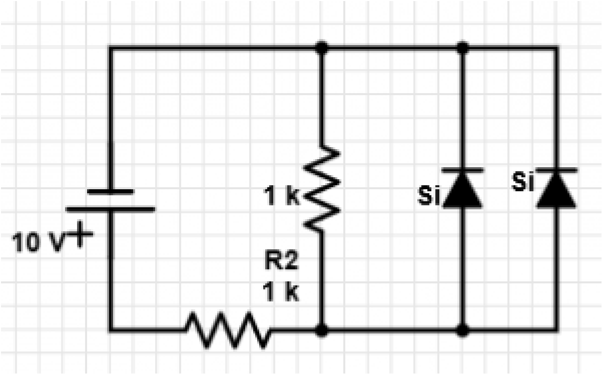
- Explanation: As both the diodes are reverse biased. Voltage drop across the resistor = 10 V. Hence, current = 10 V/1 k = 10 mA.

Example 7. From the given circuit, what is the value of current flowing through the 1 k resistor?



- Explanation: As one of the diodes is forward biased, voltage drop across it = 0.7 V. Now, as this diode is in parallel with the given resistor, voltage across resistor = 0.7 V => current = 0.7 mA.

Example 8. In the given circuit, what is the value of the current through the series resistor R_2?



- Explanation: The voltage across the diodes is 0.7 V as they are forward biased. Hence, the current through the series resistor = (10-0.7)/1k = 9.3 mA.

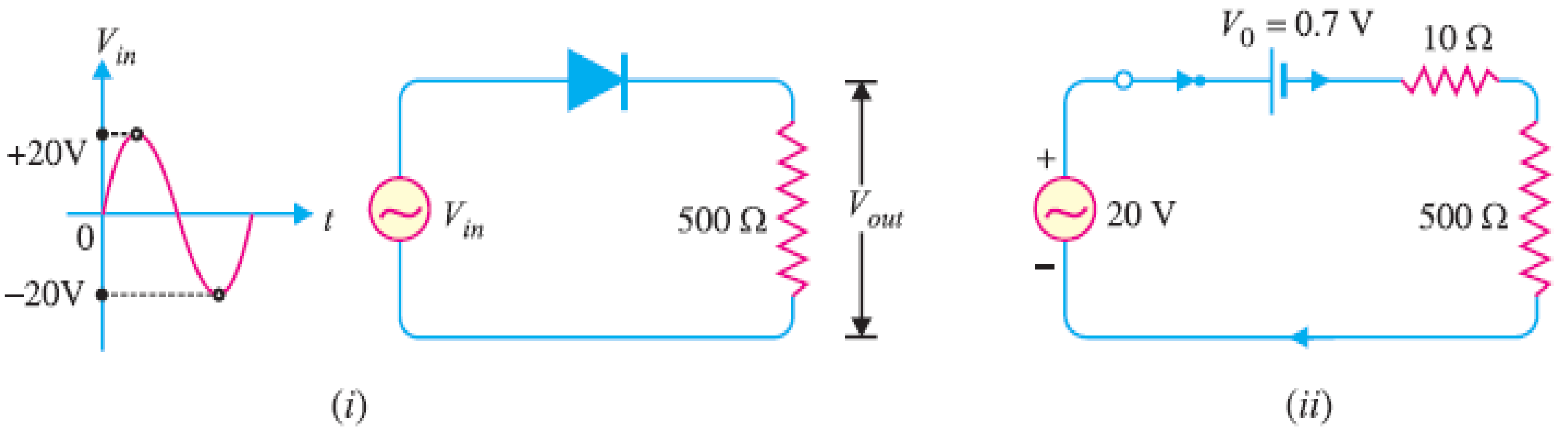
Example 9. An a.c. voltage of peak value 20 V is connected in series with a silicon diode and load resistance of 500 Ω. If the forward resistance of diode is 10 Ω, find :

(i) peak current through diode

(ii) peak output voltage

What will be these values if the diode is assumed to be ideal ?

- **Solution :**
- Peak input voltage = 20 V
  Forward resistance, r_f = 10 Ω
  Load resistance, R_L = 500 Ω
  Potential barrier voltage, V_0 = 0.7 V
  The diode will conduct during the positive half-cycles of a.c. input voltage only.



(i) The peak current through the diode will occur at the instant when the input voltage reaches positive peak i.e. Vin = VF = 20 V

$$\therefore \quad V_F = V_0 + (I_f)_{peak}[r_f + R_L] \quad ...(i)$$

or

$$(I_f)_{peak} = \frac{V_F - V_0}{r_f + R_L} = \frac{20 - 0.7}{10 + 500} = \frac{19.3}{510} \text{ A} = \mathbf{37.8 \text{ mA}}$$

$$\text{Peak output voltage} = (I_f)_{peak} \times R_L = 37.8 \text{ mA} \times 500\ \Omega = \mathbf{18.9 \text{ V}}$$

Ideal Diode Case:

For an ideal diode, put $V_0 = 0$ and $r_f = 0$ in equation (i).

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

or

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

$$\text{Peak output voltage} = (I_f)_{peak} \times R_L = 40\text{ mA} \times 500\ \Omega = \mathbf{20\text{ V}}$$

Lecture 6

Explanation of two breakdown conditions under reverse bias conditions, Zener diode As Shunt voltage regulator

Breakdown Mechanism in Reversed Biased Diode

If the reverse-bias applied to a P-N junction is increased; a point will reach when the junction breaks down and reverse current rises sharply. This specific value of the reverse bias voltage is called breakdown voltage (V_Z). The following two processes cause junction breakdown due to the increase in reverse bias voltage.

(1) Zener Breakdown

(2) Avalanche Breakdown

Zener Breakdown:

- It occurs in highly doped diode. In highly doped diode width of depletion region is narrow.
- So electric field is very high **in the depletion region**. So, force is very high.
- This high force pulled the valence electrons into conduction band by breaking covalent bonds.
- These electrons become free electrons which are available for conduction.
- A large no. of such free electrons will constitute a large reverse current and called the Zener effect.
- Zener breakdown occurs less than 6 V.
- Temperature coefficient is negative. **(raising the temperature will cause smaller breakdown voltage)**

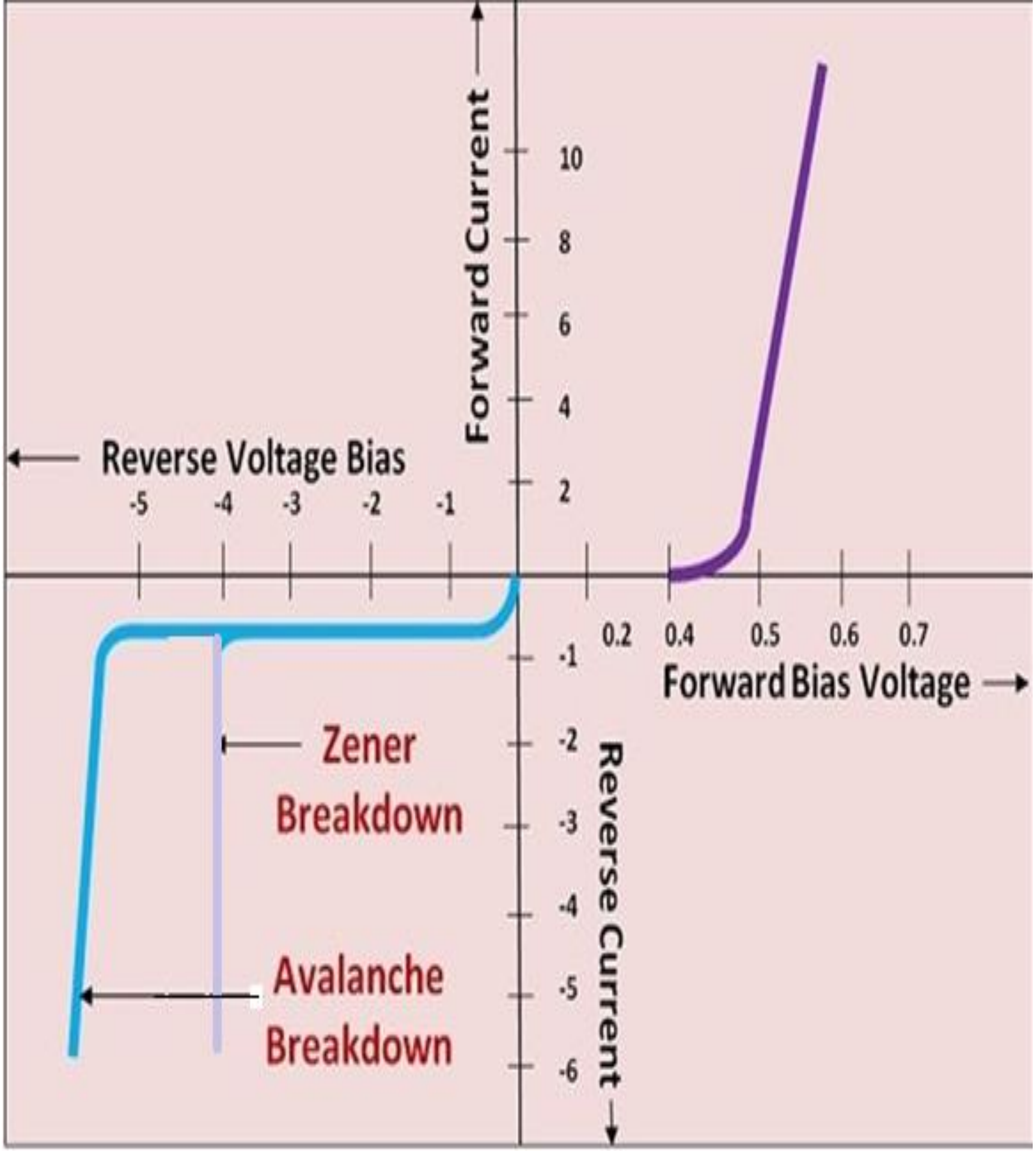
Avalanche Breakdown

- It occurs in lightly doped diode. In lightly doped diode width of depletion region is wide.

- So electric field is low. So, force is low. This low force cannot break the covalent bonds.

- . As we increase the reverse voltage applied to the diode, the kinetic energy of minority carriers increases.

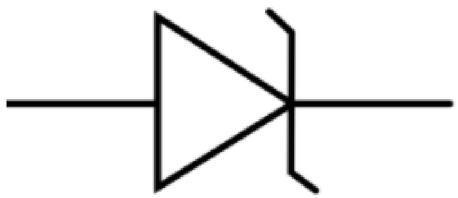
- While travelling, these accelerated minority carriers will collide with the stationary atoms and impart some of the kinetic energy to the valence electrons present. These valence electrons will break their covalent bonds and jump into the conduction bond to become free for conduction.
- Now these newly generated free electrons get accelerated. They will knock out some more valence electrons by means of collision. This phenomenon is called as carrier multiplication or Avalanche effect.
- Avalanche breakdown occurs greater than 6 V.
- Temperature coefficient is positive. **(raising the temperature will cause larger breakdown voltage)**



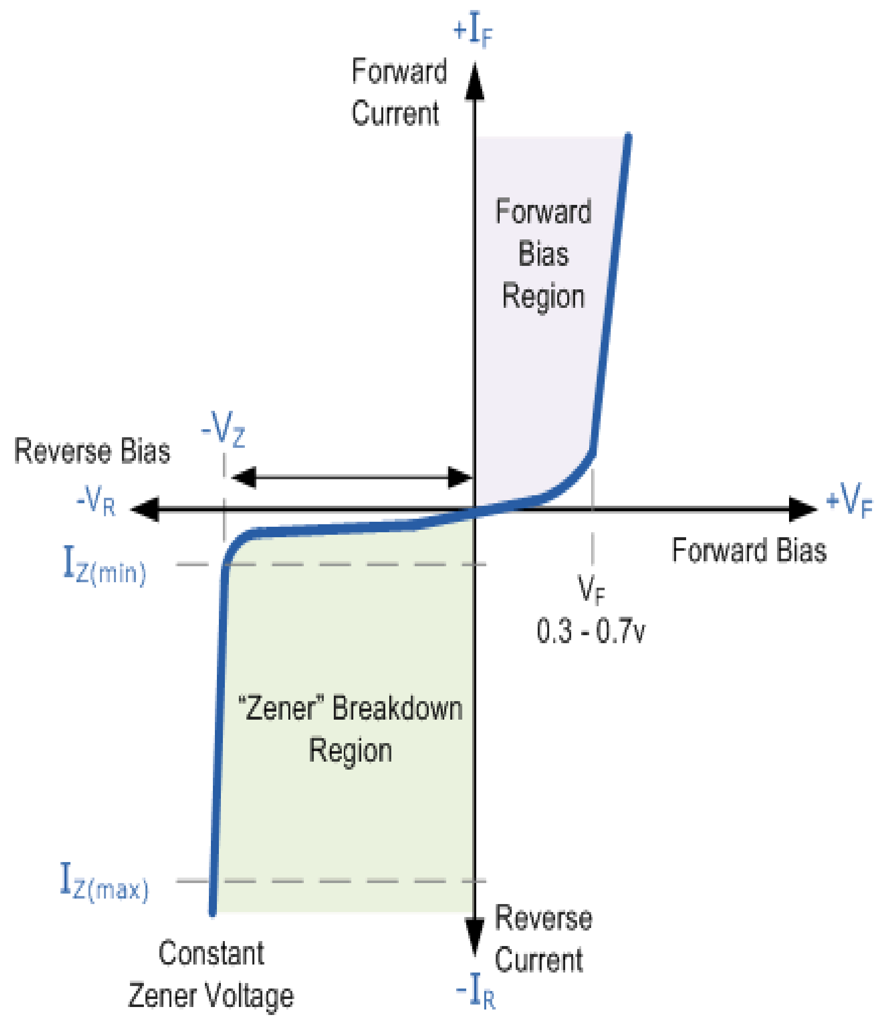
GROUP OF INSTITUTIONS

Zener Diode

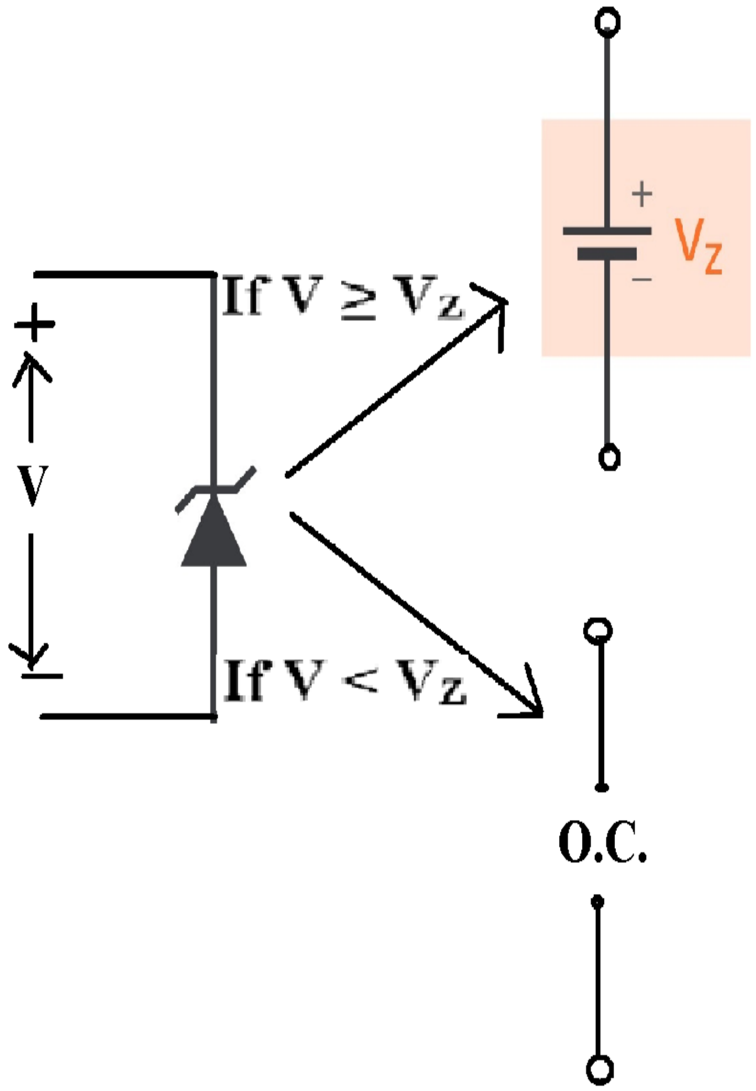
- Zener diode is a special diode, which works in breakdov
- It is used for voltage regu



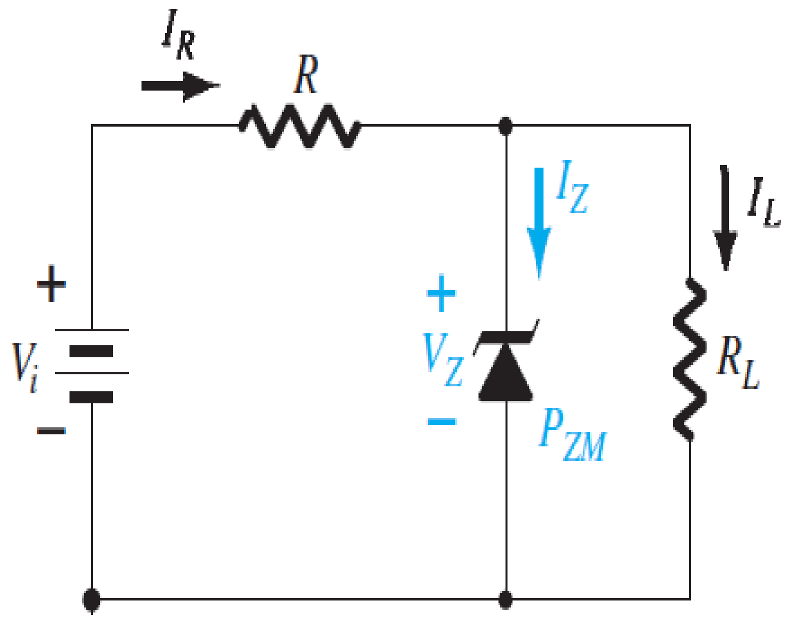
Symbol



Equivalent Circuit:



Zener Diode as Shunt Regulator



(i) Variable V_i and fixed R_L

a) If V_i is increased then I_R also increase. Since I_L is constant so increment in I_R will increase I_Z. But I_Z should be less than $I_{Z(max)}$. So, output voltage remains constant.

$$\uparrow I_R = \frac{\uparrow V_i - V_Z}{R} \ldots\ldots..1$$

$$\uparrow I_R = \uparrow I_Z + I_L \ldots\ldots\ldots.2$$

Constant

b) If V_i is decreased then I_R also decrease. Since I_L is constant so decrement in I_R will decrease I_Z. But I_Z should be greater than $I_{Z(min)}$. So, output voltage remains constant

$$\downarrow I_R = \frac{\downarrow V_i - V_Z}{R} \ldots \ldots . . 1$$

$$\downarrow I_R = \downarrow I_Z + I_L \ldots \ldots \ldots . 2$$

Constant

(ii) Fixed V_i and variable R_L

a) If R_L is increased then I_L will decrease. Since I_R is constant so decrement in I_L will increase I_Z. But I_Z should be less than $I_{Z(max)}$. So, output voltage remains constant.

$$I_L \downarrow = \frac{V_L}{R_L} = \frac{V_Z}{R_L \uparrow} \; . . 1$$

$$I_R = \uparrow I_Z + I_L \; \ldots . 2$$

Constant

b) If R_L is decreased then I_L will increase. Since I_R is constant so increment in I_L will decrease I_Z. But I_Z should be greater than $I_{Z(min)}$. So, output voltage remains constant.

$$I_L \uparrow = \frac{V_L}{R_L} = \frac{V_Z}{R_L \downarrow} \quad \ldots\ldots 1$$

Constant

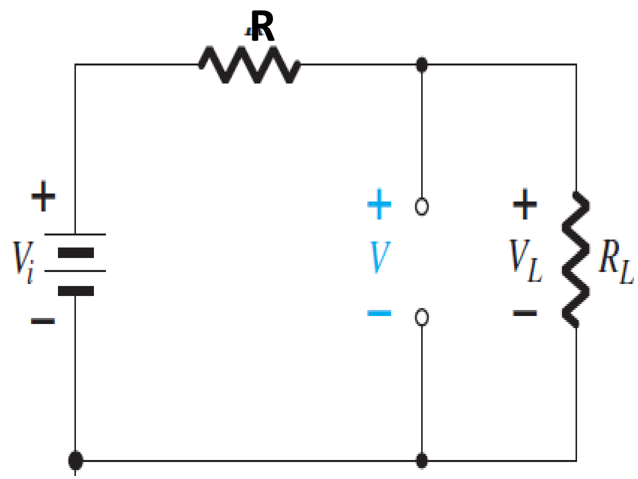
$$I_R = \downarrow I_Z + I_L \uparrow \quad \ldots\ldots 2$$

Steps for Solving Zener Diode Numerical

GROUP OF INSTITUTIONS

1. *Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.*

$$V = V_L = \frac{R_L V_i}{R + R_L}$$



If $V \geq V_Z$, the Zener diode is on, and the appropriate equivalent model can be substituted.
If $V < V_Z$, the diode is off, and the open-circuit equivalence is substituted.

2. *Substitute the appropriate equivalent circuit and solve for the desired unknowns.*

Lecture 7

Problems based on voltage regulator

Example:1 For the Zener diode network of Fig. 2.115, determine V_L, V_R, I_Z, and P_Z.

b. Repeat part (a) with $R_L = 3\ \text{k}\Omega$.

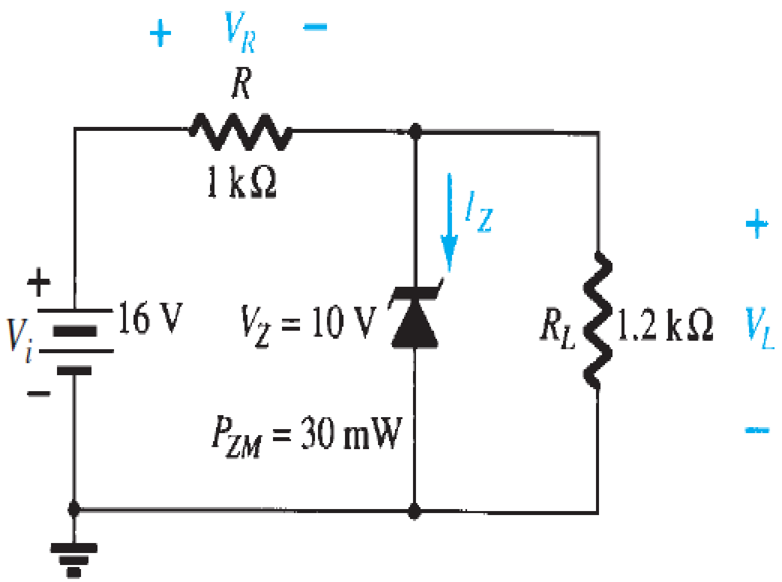
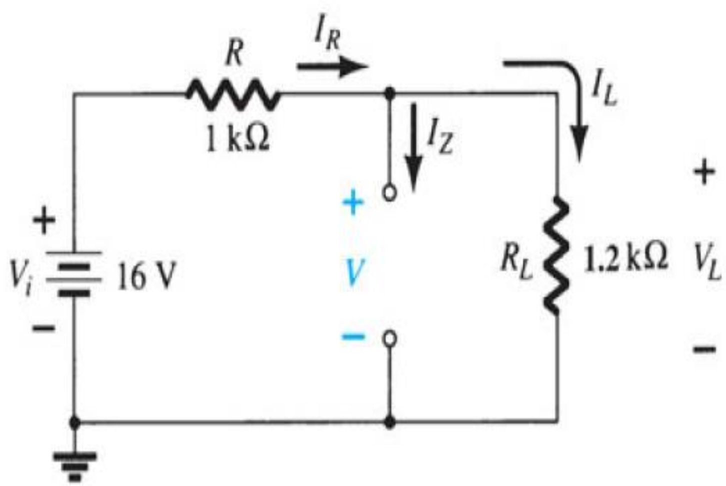


FIG. 2.115



Solution:

a. $$V = \frac{R_L V_i}{R + R_L} = \frac{1.2\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 1.2\ \text{k}\Omega} = 8.73\ \text{V}$$

$$V_L = V = \mathbf{8.73\ V}$$

$$V_R = V_i - V_L = 16\ \text{V} - 8.73\ \text{V} = \mathbf{7.27\ V}$$

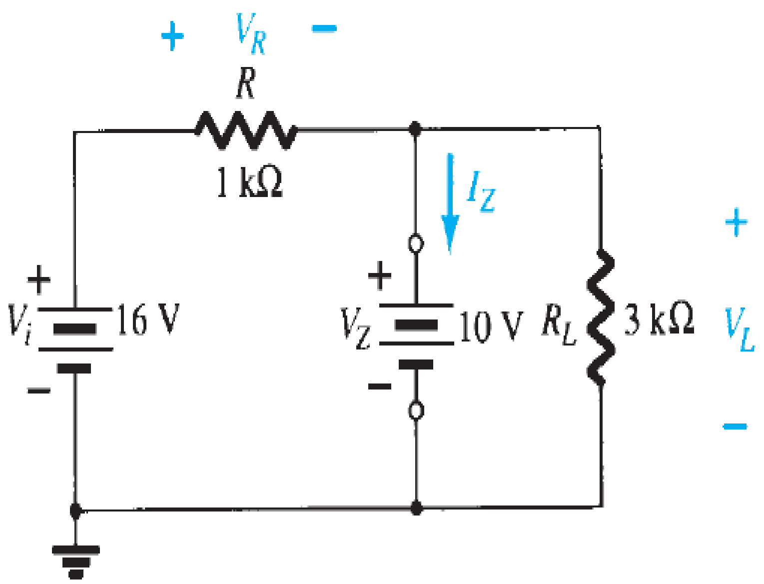
$$I_Z = \mathbf{0\ A}$$

$$P_Z = V_Z I_Z = V_Z(0\ \text{A}) = \mathbf{0\ W}$$

b. $$V = \frac{R_L V_i}{R + R_L} = \frac{3\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 3\ \text{k}\Omega} = 12\ \text{V}$$

Since $V = 12$ V is greater than $V_Z = 10$ V,

the diode is in the "on" state



$$V_L = V_Z = \mathbf{10\ V}$$

$$V_R = V_i - V_L = 16\ \text{V} - 10\ \text{V} = \mathbf{6\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{10\ \text{V}}{3\ \text{k}\Omega} = 3.33\ \text{mA}$$

$$I_R = \frac{V_R}{R} = \frac{6\ \text{V}}{1\ \text{k}\Omega} = 6\ \text{mA}$$

$$\begin{aligned} I_Z &= I_R - I_L \\ &= 6\ \text{mA} - 3.33\ \text{mA} \\ &= \mathbf{2.67\ mA} \end{aligned}$$

The power dissipated is

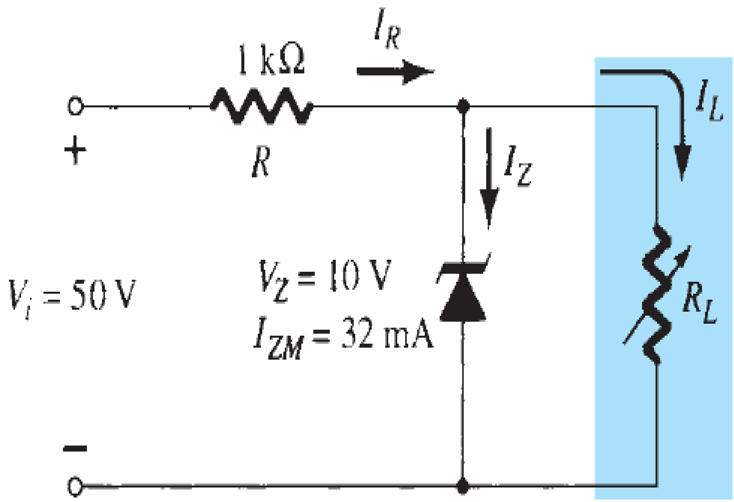
$$P_Z = V_Z I_Z = (10\ \text{V})(2.67\ \text{mA}) = \mathbf{26.7\ mW}$$

which is less than the specified $P_{ZM} = 30$ mW.

Example:2

10/250 = 40

For the network of Fig. 2.119, determine the range of R_L and I_L that will result in V_{RL} being maintained at 10 V.



$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$R_{L_{\min}} = \frac{R V_Z}{V_i - V_Z} = \frac{(1\ \text{k}\Omega)(10\ \text{V})}{50\ \text{V} - 10\ \text{V}} = \frac{10\ \text{k}\Omega}{40} = \mathbf{250\ \Omega}$$

$$I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}$$

10 / 250=0.04 A

$$V_R = V_i - V_Z = 50\ \text{V} - 10\ \text{V} = \mathbf{40\ V}$$

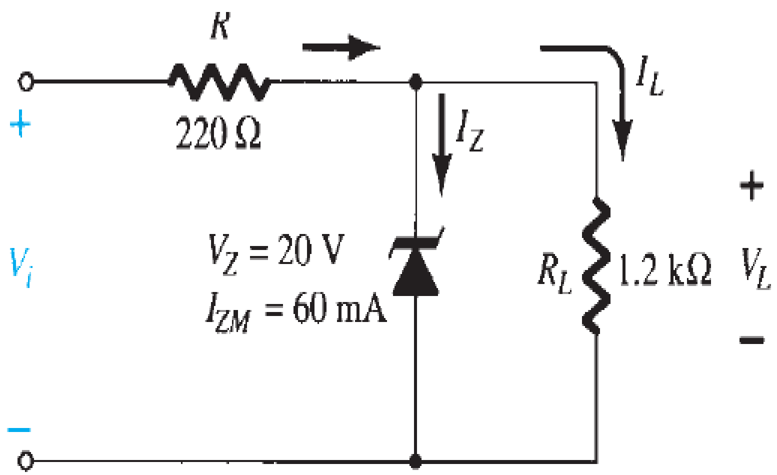
$$I_R = \frac{V_R}{R} = \frac{40\ \text{V}}{1\ \text{k}\Omega} = \mathbf{40\ mA}$$

$$I_{L_{\min}} = I_R - I_{ZM} = 40\ \text{mA} - 32\ \text{mA} = \mathbf{8\ mA}$$

$$R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}} = \frac{10\ \text{V}}{8\ \text{mA}} = \mathbf{1.25\ k\Omega}$$

Example:3

Determine the range of values of V_i that will maintain the Zener diode in the "on" state.



Solution:

The minimum turn-on voltage $V_i = V_{i_{min}}$ is determined by

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L}$$

$$= \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20\ \text{V}}{1.2\ \text{k}\Omega} = 16.67\ \text{mA}$$

$$I_{R_{max}} = I_{ZM} + I_L$$

$$= 60\ \text{mA} + 16.67\ \text{mA}$$

$$= 76.67\ \text{mA}$$

$$V_{i_{max}} = I_{R_{max}} R + V_Z$$

$$= (76.67\ \text{mA})(0.22\ \text{k}\Omega) + 20\ \text{V}$$

$$= 16.87\ \text{V} + 20\ \text{V}$$

$$= \mathbf{36.87\ V}$$

Lecture 8

Working of Half wave and Full wave rectifiers

RECTIFIERS

- Rectifiers are circuits which converts ac into pulsating dc or bipolar signal into unipolar signals.

- Rectifiers are grouped into two categories depending on the period of conductions.

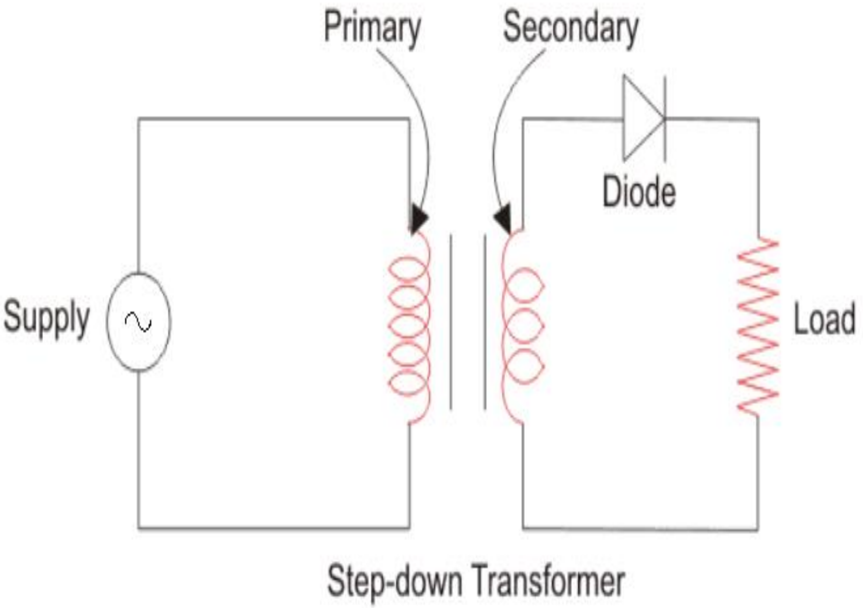
- 1. Half-wave rectifier.
- 2. Full- wave rectifier.

- Centre tapped full-wave rectifier
- Bridge rectifier

Half-Wave Rectifier

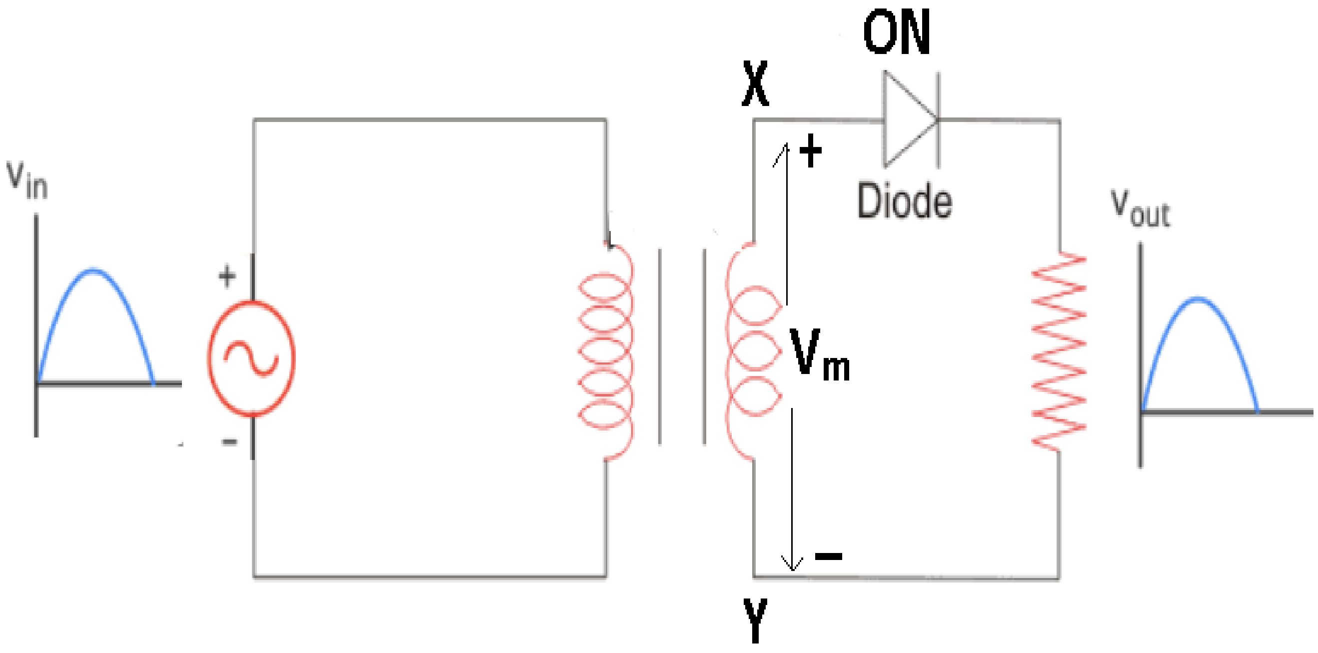
- The transformer is employed in order to step-down the supply voltage and also to prevent from shocks

- The diode is used to rectify the a.c. signal while , the pulsating d.c. is taken across the load resistor $R_{L.}$



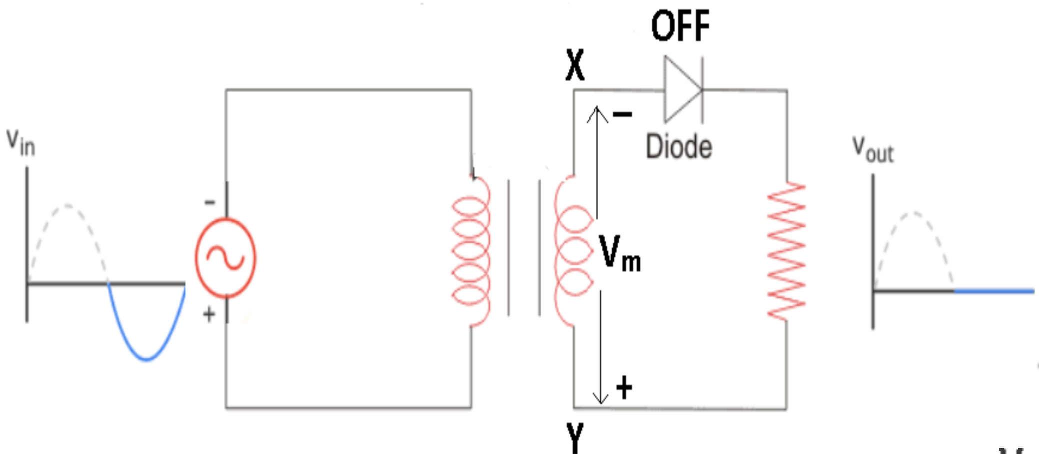
Working

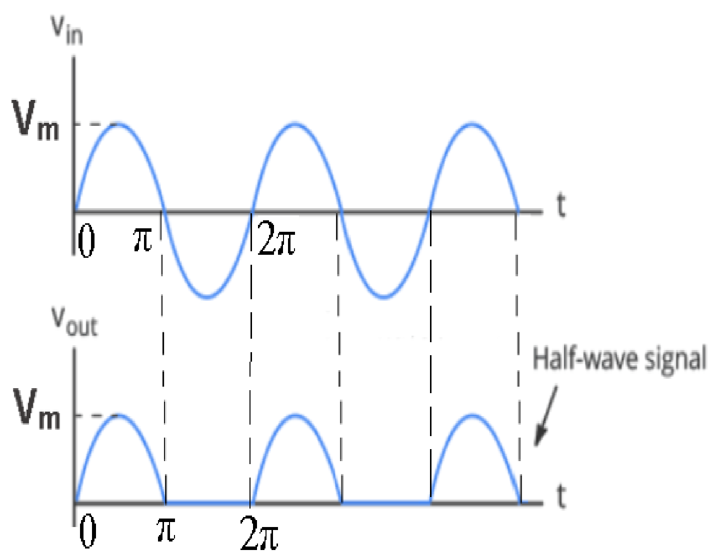
During the +ve half cycle, the end X of the secondary is +ve and end Y is -ve . Thus, forward biasing the diode. As the diode is forward biased, the current flows through the load RL and a voltage is developed across it.



During the –ve half-cycle the end Y is +ve and end X is –ve thus, reverse biasing the diode. As the diode is reverse biased there is no flow of current through RL thereby the output voltage is zero.

Half Wave Rectifier Waveforms



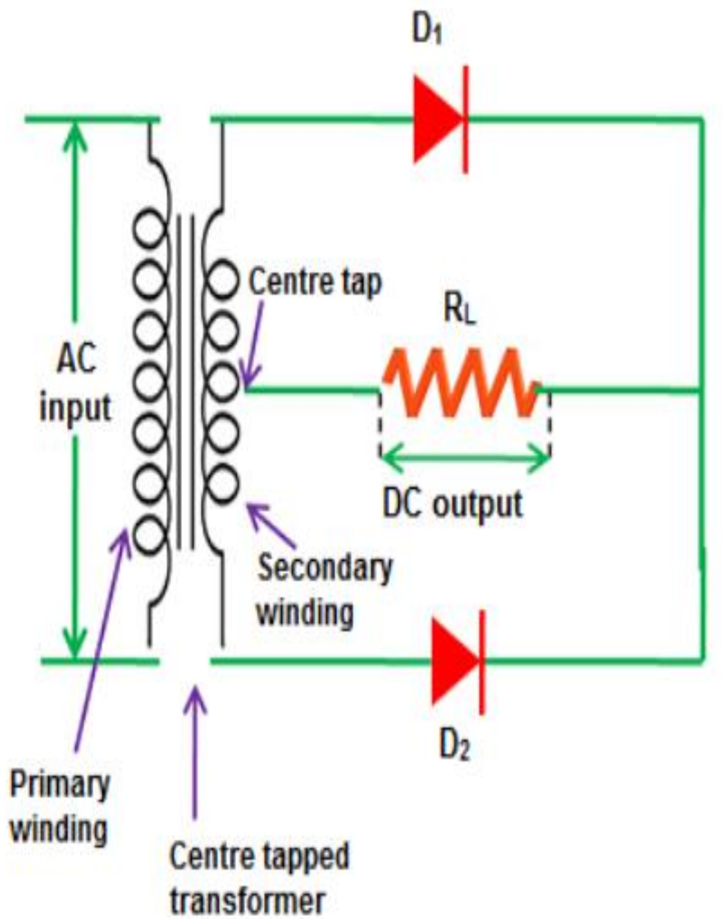


FULL-WAVE RECTIFIER

Full-wave rectifiers are of two types

- Centre tapped full-wave rectifier
- Bridge rectifier

Centre Tapped Full –Wave Rectifier



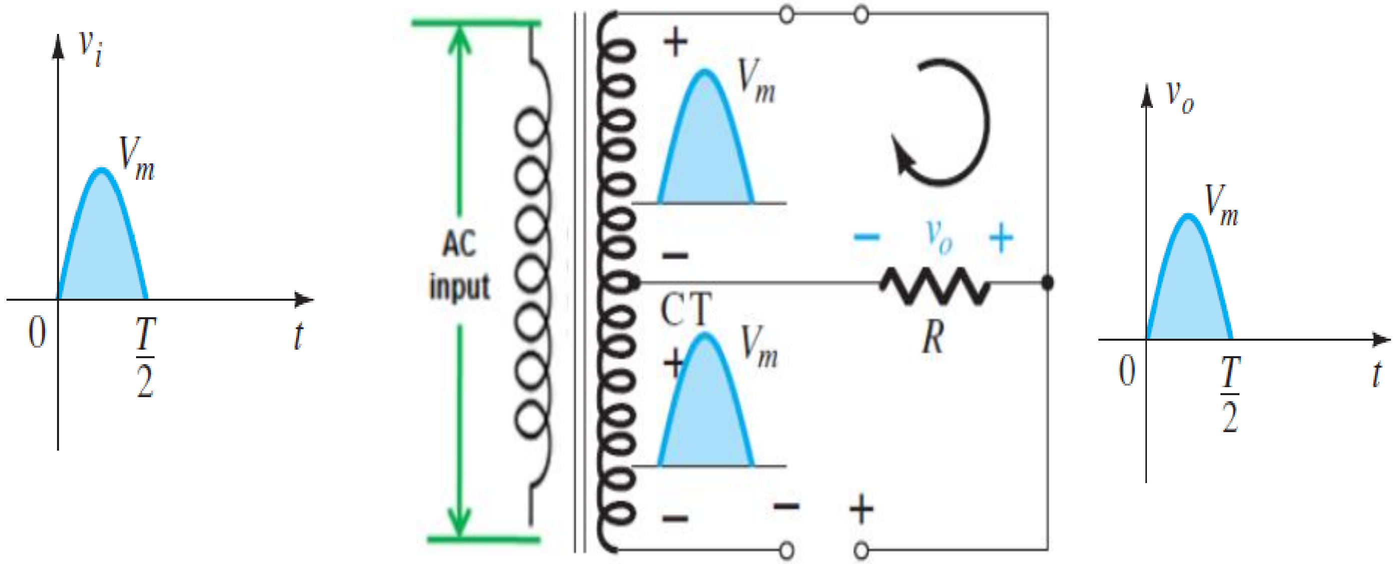
- Current flows through the load resistance in the same direction during the full cycle of the input signal.

- Centre tap transformer is used where secondary winding is divided in two equal **halves** at the middle point of the winding.

Working

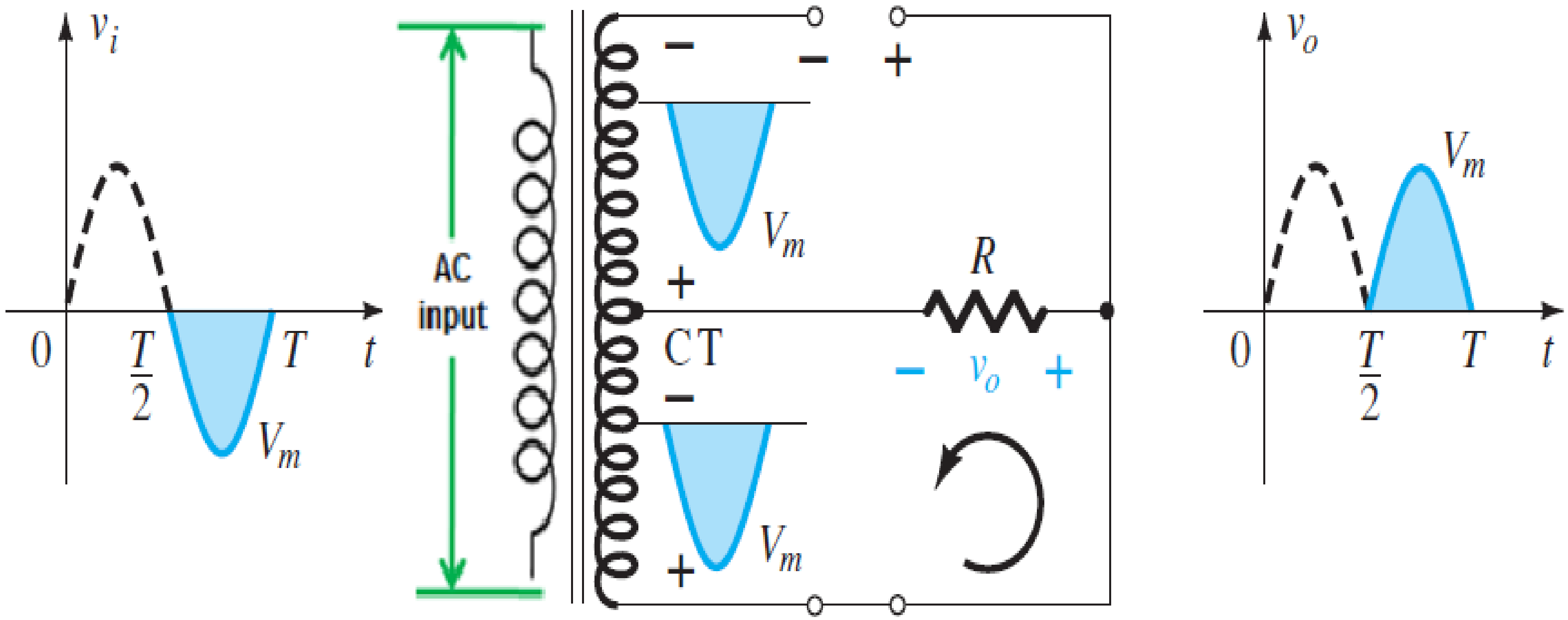
- **Positive Half Cycle:**

- Diode D1 is short circuited and D2 is open circuited. Current flows through the upper half of the secondary winding.

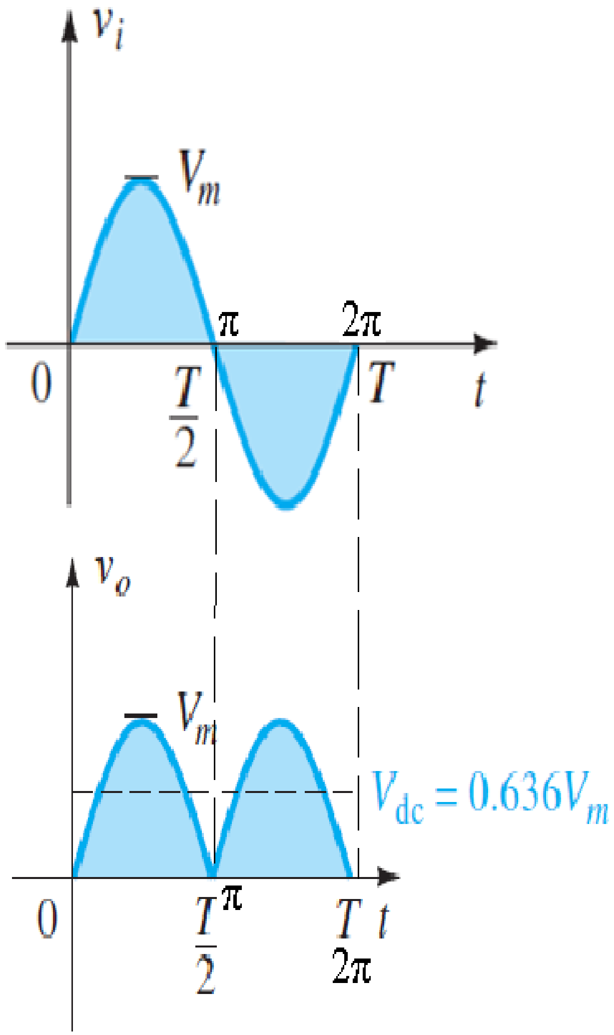


- **Negative Half Cycle:**

- Diode D2 is short circuited and D1 is open circuited. Current flows through the lower half of the secondary winding.

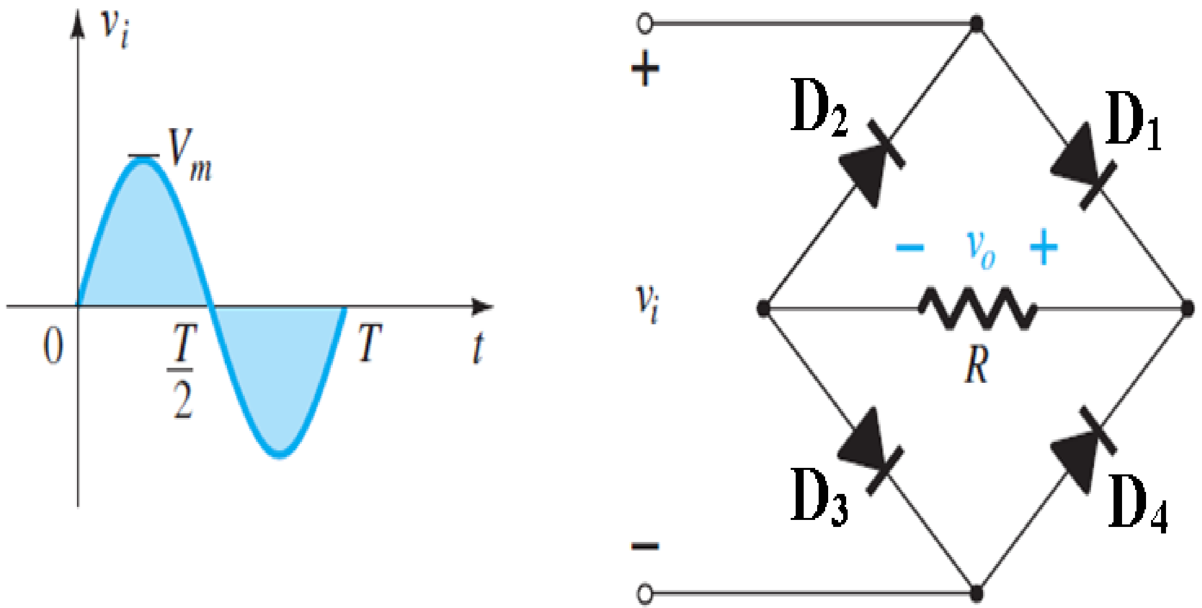


Complete input and output waveform can be shown as:



Bridge Rectifier

The bridge rectifier uses four diodes connected in bridge pattern.

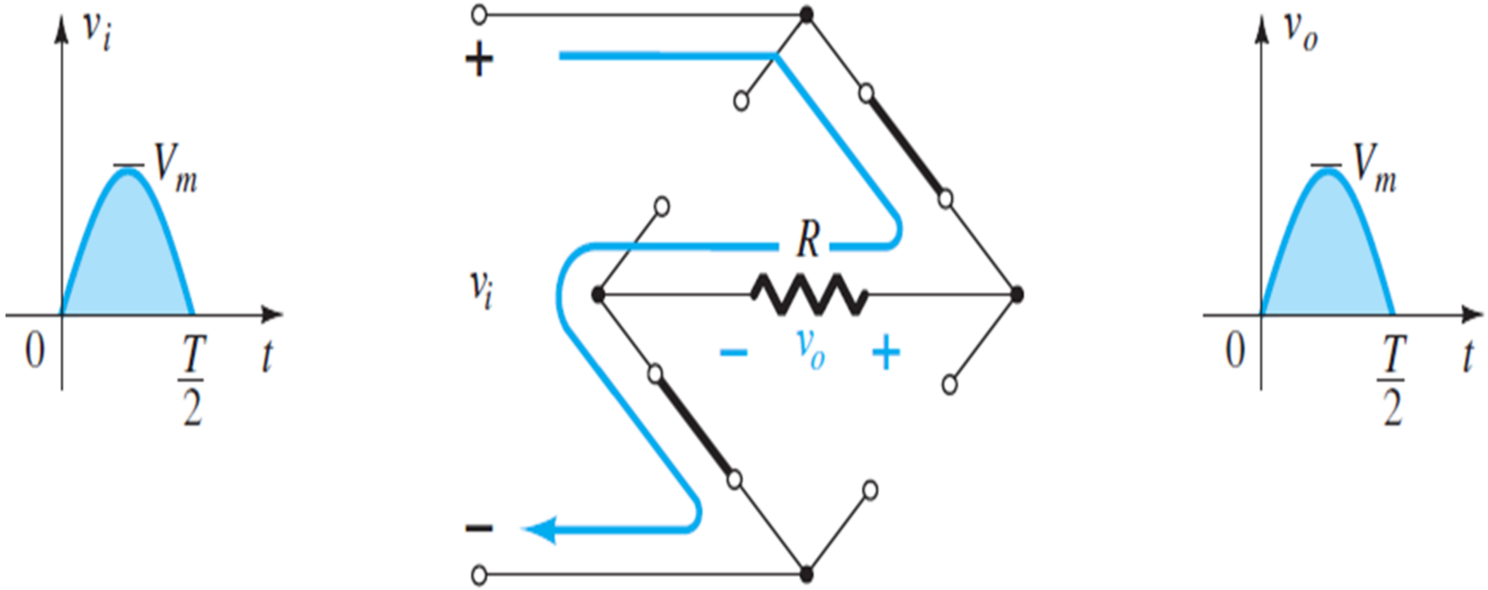


Full-wave bridge rectifier.

Operation of Bridge Rectifier

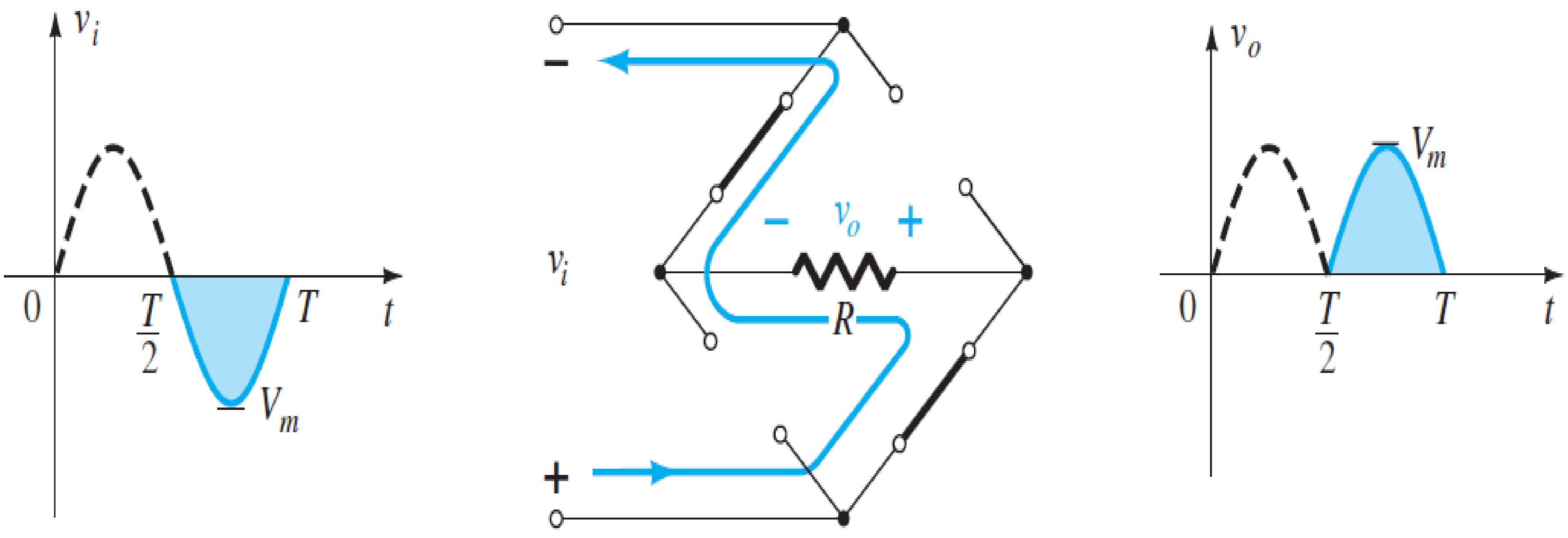
- **Positive Half Cycle:**

Diode D1 and D3 are short circuited and D2 and D4 are open circuited. Current flows through D1 and D3 to give the output voltage across the resistor.



- **Negative Half Cycle:**

Diode D1 and D3 are open circuited and D2 and D4 are short circuited. Current flows through D2 and D4 to give the output voltage across the resistor.



Lecture 9

Different parameters of rectifiers and comparison between rectifiers on basis of these parameters

Different parameters of Half Wave Rectifier

Let $v = V_m \sin\theta$ be the voltage across the secondary winding.

Hence the circuit current = (VmSin/(RL +rf)=ImSinθ

Where $I_m = \frac{V_m}{R_L + r_f}$

R_L = load resistance

r_f = diode resistance

i) DC or Average Output (Load) current I_{dc}:

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\theta \; d\theta$$

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

$$= \frac{I_m}{2\pi}[-cos\pi + cos0]$$

$$= \frac{I_m}{2\pi}[-(-1)+1] = \frac{I_m}{2\pi} X\, 2$$

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

ii) DC or Average Output (Load) Voltage V_{dc}

$$V_{dc} = I_{dc}\, X\, R_L$$

$$= \frac{I_m}{\pi} X\, R_L$$

$$= \frac{V_m}{\pi(R_L + r_f)} X\, R_L$$

If $r_f = 0$

$$\boxed{V_{dc} = \frac{V_m}{\pi} = 0.318V_m}$$

If diode is not ideal

$$\boxed{V_{dc} = \frac{V_m - V_\gamma}{\pi} = 0.318(V_m - V_\gamma)}$$

iii) rms output (Load) current Irms

$$I_{dc} = \sqrt{\frac{1}{T}\int_0^T (I_m \sin\theta)^2 \, d\theta}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (I_m \sin\theta)^2 \, d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \left(\frac{1-cos2\theta}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\theta - \frac{sin2\theta}{2}\right]_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[(\pi - 0) - \left(\frac{sin2\pi}{2} - \frac{sin2X0}{2}\right)\right]}$$

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

iv) rms output (Load) voltage V_{rms} :

$$V_{rms} = I_{rms} \; X \; R_L$$

$$= \frac{I_m}{2} X \; R_L$$

$$= \frac{V_m}{2(R_L + r_f)} X \; R_L$$

If $r_f = 0$

$$\boxed{V_{rms} = \frac{V_m}{2}}$$

v) Ripple factor(r):

- The output of rectifier has ac component (also known as ripple) and dc component both.
- Ripple factor measure, how much amount of ac component is present in the output.
- So, the effectiveness of a rectifier depends on the magnitude of ripple in the output.
- Smaller the ripple more effective is the rectifier.

" The ratio of rms value of a.c. component to the d.c. component in the rectifier output is known as ripple factor"

$$r = \frac{I_{ac}}{I_{dc}}$$

- By definition the effective (ie rms) value of total load current is given by

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

Where I_{dc}= value of dc component

I_{ac} = rms value of ac component

- Divide both R.H.S and L.H.S. by I_{dc} we get

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$

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

$$= \sqrt{\left(\frac{I_m/_2}{I_m/_\pi}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

$$\boxed{r = 1.21}$$

So, ripple factor of half wave rectifier is very high

vi) Rectification efficiency or Power conversion efficiency(η):

$$\eta = \frac{dc\ output\ power}{ac\ input\ power} = \frac{P_0(dc)}{P_i(ac)}$$

$$= \frac{I_{dc}^2\ X\ R_L}{I_{rms}^2\ X\ (R_L + r_f)}$$

$$= \frac{\left(I_m/_\pi\right)^2\ X\ R_L}{\left(I_m/_2\right)^2\ X\ (R_L + r_f)}$$

$$= \frac{4\ X\ R_L}{\pi^2\ X\ (R_L + r_f)}$$

If $r_f = 0$

$$\eta_{max} = \frac{4}{\pi^2}$$

$$\boxed{\eta_{max} = 40.6\ \%}$$

So, efficiency of half wave rectifier is low.

vii) Peak Inverse Voltage (PIV):

- It is the maximum reverse voltage that can be applied across a diode without damaging it.
- For half wave rectifier PIV = V_m (Voltage across secondary winding.)

viii) Ripple frequency or output frequency (f_r):

It is the frequency of output wave in rectifier.

For half wave rectifier

$$\boxed{f_r = f_i}$$

Different parameters of **Centre Tapped Full –Wave Rectifier and Bridge Rectifier.**

Let $v = V_m \sin\theta$ be the voltage across the secondary winding.

Let $i = I_m \sin\theta$ be the current across the secondary winding.

Where $I_m = \frac{V_m}{R_L + r_f}$ R_L = load resistance

r_f = diode resistance

i) DC or Average Output (Load) current I_{dc}:

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

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

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

$$= \frac{I_m}{\pi}[-(-1) + 1] = \frac{I_m}{\pi} X\ 2$$

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

ii) DC or Average Output (Load) Voltage V_{dc}

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

$$= \frac{2I_m}{\pi} X\ R_L$$

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

If $r_f = 0$

$$\boxed{V_{dc} = \frac{2V_m}{\pi} = 0.636V_m}$$

If diode is not ideal

$$\boxed{V_{dc} = \frac{2(V_m - V_\gamma)}{\pi} = 0.636(V_m - V_\gamma)}$$

iii) rms output (Load) current Irms

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} (I_m \sin\theta)^2 \; d\theta}$$

$$= \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi} \left(\frac{1 - cos2\theta}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \left[\theta - \frac{sin2\theta}{2}\right]_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[(\pi - 0) - \left(\frac{sin2\pi}{2} - \frac{sin2X0}{2}\right)\right]}$$

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

iv) rms output (Load) voltage V_{rms} :

$$V_{rms} = I_{rms}\, X\, R_L$$

$$= \frac{I_m}{\sqrt{2}} X\, R_L$$

$$= \frac{V_m}{\sqrt{2}(R_L + r_f)} X\, R_L$$

If $r_f = 0$

$$\boldsymbol{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

v) Ripple factor(r):

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

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

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1}$$

$$\boxed{r = .48}$$

VI) Rectification efficiency

$$\eta = \frac{dc\ output\ power}{ac\ input\ power} = \frac{P_O(dc)}{P_i(ac)}$$

$$= \frac{I_{dc}^2\ X\ R_L}{I_{rms}^2\ X\ (R_L + r_f)}$$

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

$$= \frac{8\ X\ R_L}{\pi^2\ X\ (R_L + r_f)}$$

$$\eta = \frac{.812}{1 + \frac{r_f}{R_L}}$$

If $r_f = 0$ $\quad \eta_{max} = .812$

$$\boxed{\eta_{max} = 81.2\ \%}$$

vii) Peak Inverse Voltage (PIV):

For Centre tap:
PIV = 2Vm

For Bridge :
PIV= Vm

viii) Ripple frequency or output frequency (f_r):

For full wave rectifier

$$\boxed{f_r = 2f_i}$$

Disadvantages of Centre tapped full –wave rectifier

- Since, each diode uses only one-half of the transformer secondary voltage the d.c. output is comparatively small.
- It is difficult to locate the center-tap on secondary winding of the transformer.
- The diodes used must have high Peak-inverse voltage.

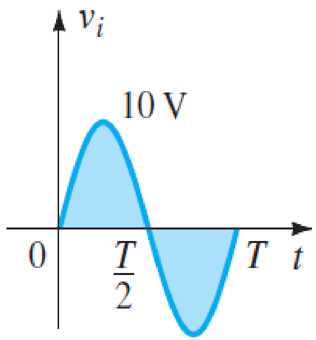
Comparison between HWR & FWR

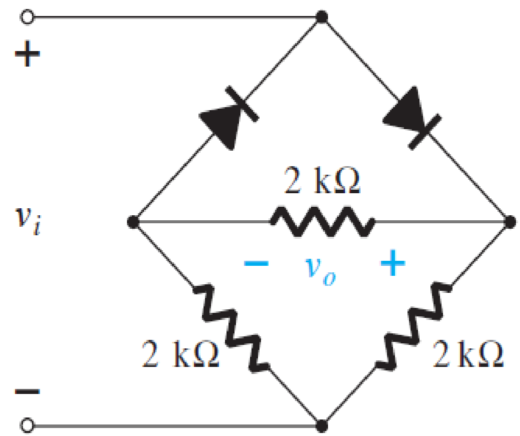
S.No.	Parameters	Half Wave Rectifier	Full Wave	
			Center-Tapped Rectifier	Bridge Rectifier
1	Operation	Conducts during positive half cycles.	Conducts during both the half cycles	Conducts during both the half cycles
2	Number of diodes	1	2	4
3	The average (dc) load voltage	V_m / π.	$2V_m / \pi$.	$2V_m / \pi$.
4	RMS load current	$I_m/2$.	$I_m/\sqrt{2}$.	$I_m/\sqrt{2}$.
5	Ripple Factor	1.21	0.48	0.48
6	Efficiency	41%.	81.2%.	81.2%.
7	PIV	V_m	$2V_m$	V_m

Lecture 10

Numerical based on rectifiers

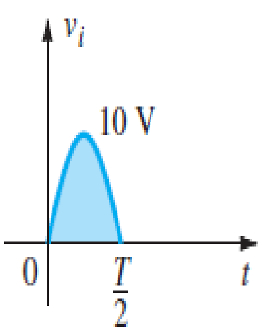
Example:1 Determine the output waveform for the following figure and calculate the output dc level and required PIV of each diode.

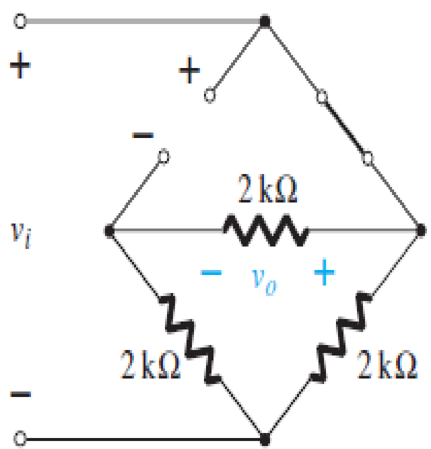


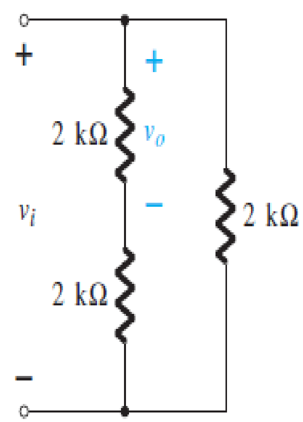


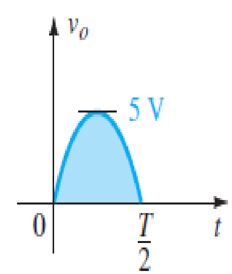
Solution :

- **Positive Half Cycle:**









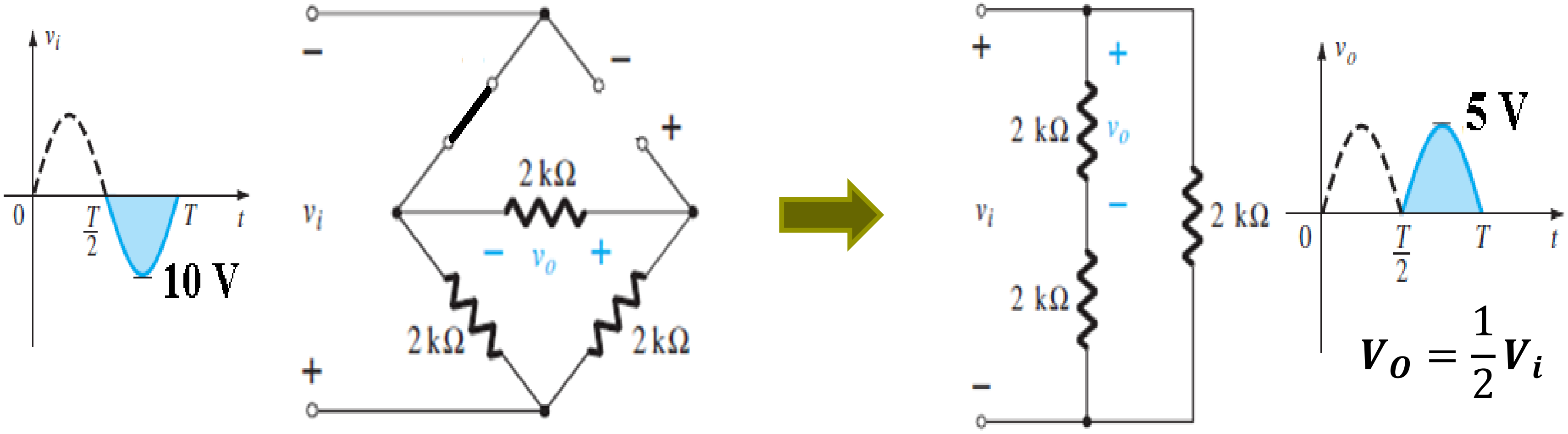
$$V_O = \frac{1}{2} V_i$$

$$V_O = \frac{1}{2} V_{imax}$$

$$V_O = \frac{1}{2} X\ 10$$

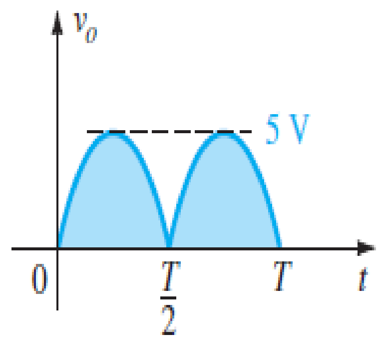
V_O =5 V

- **Negative Half Cycle:**



$$V_O = \frac{1}{2} V_i$$

So out waveform will be:



$$V_O = \frac{1}{2} V_{imax}$$

$$V_O = \frac{1}{2}\ X\ 10$$

V_O =5 V

$$V_{dc} = \frac{2V_m}{\pi} = 0.636V_m$$

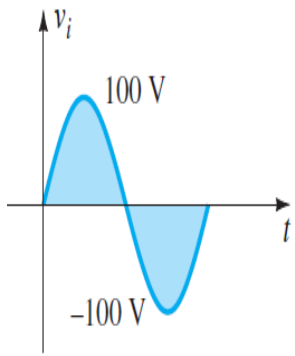
= 0.636 X

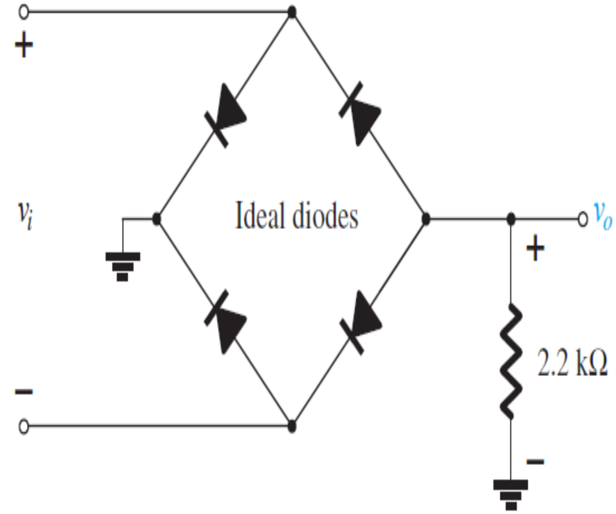
(5 V)

= 3.18 V

PIV = 5V

Example:2 Determine V_O and required PIV rating of each diode.

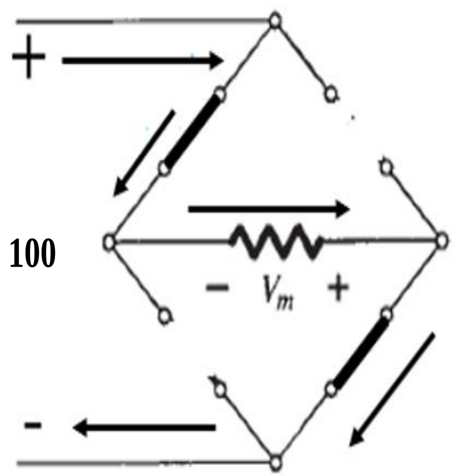




Solution :

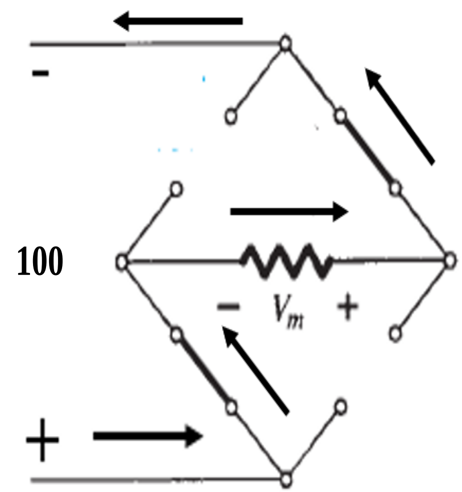
$V_O = 100$
Output waveform:

- **Positive Half Cycle:**



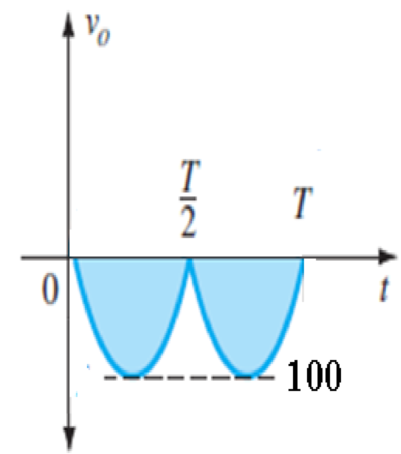
$V_O = -100$

- **Negative Half Cycle:**



$V_O = -100$

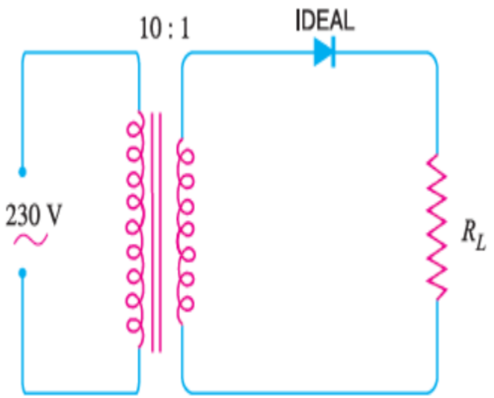
- **Output waveform:**



Required PIV = 100 V

Example:3 An a.c. supply of 230 V is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal

Solution :



Primary to secondary turns is

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

R.M.S. primary voltage

$$= 230 \text{ V}$$

∴ 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)

$$I_{d.c.} = \frac{I_m}{\pi}$$

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

(ii) The peak inverse voltage is equal to the maximum secondary voltage, i.e

∴ Peak inverse voltage = 32.53 V

Example:4 A full-wave rectifier uses two diodes, the internal resistance of each diode may be assumed constant at 20 Ω. The transformer r.m.s. secondary voltage from centre tap to each end of secondary is 50 V and load resistance is 980 Ω. Find : (i) the mean load current (ii) the r.m.s. value of load current

Solution :

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

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

Max. load current, $I_m = \dfrac{V_m}{r_f + R_L} = \dfrac{70.7\text{ V}}{(20+980)\,\Omega} = 70.7\text{ mA}$

i)

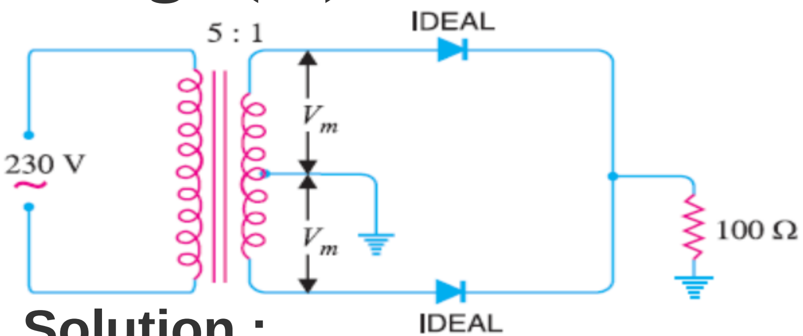
Mean load current, $I_{dc} = \dfrac{2I_m}{\pi} = \dfrac{2 \times 70.7}{\pi} = 45\text{ mA}$

ii)

R.M.S. value of load current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = 50\text{ mA}$$

Example:5 **In the centre-tap circuit shown in Fig, the diodes are assumed to be ideal i.e. having zero internal resistance. Find :(i) d.c. output voltage(ii) peak inverse voltage (iii) rectification efficiency**



Solution :

Primary to secondary turns, N1 / N2 = 5

R.M.S. primary voltage = 230 V

∴ R.M.S. secondary voltage

$= 230 \times (1/5) = 46\text{ V}$

Maximum voltage across secondary

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

Maximum voltage across half secondary winding is

$V_m = 65/2 = 32.5\text{ V}$

(i) Average current, Idc =

$$\frac{2V_m}{\pi R_L} = \frac{2 \times 32.5}{\pi \times 100} = 0.207\text{ A}$$

(ii) The peak inverse voltage is equal to the maximum secondary voltage, $PIV = 65\text{ V}$

(iii) Rectification efficiency $= \dfrac{0.812}{1 + \dfrac{r_f}{R_L}}$

Since $r_f = 0$

Rectification efficiency = 81.2 %

Lecture 11

Different types of clampers and steps to draw their waveforms, Problems based on clampers

Clamper Circuits:

- A clamper is an electronic circuit that changes the DC level of a signal to the desired level without changing the shape of the applied signal.

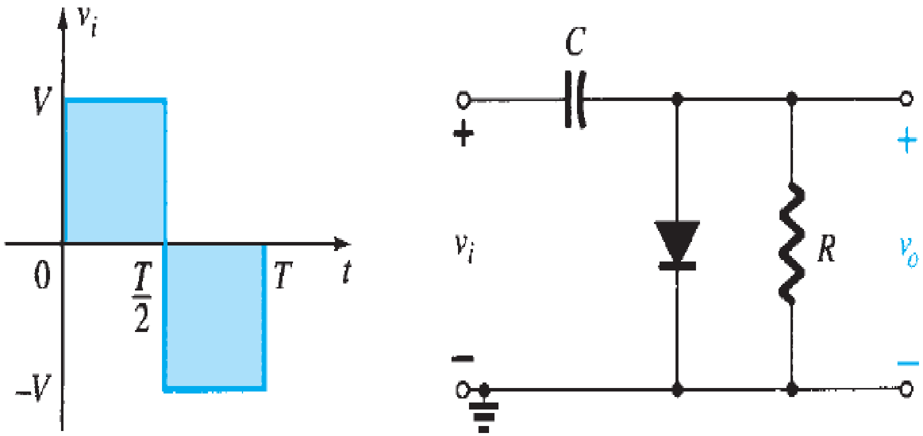
- In other words, the clamper circuit moves the whole signal up or down to set either the positive peak or negative peak of the signal at the desired level

- A clamper is made up of a capacitor, diode and resistor.

- **Clamper circuits are of three types:**

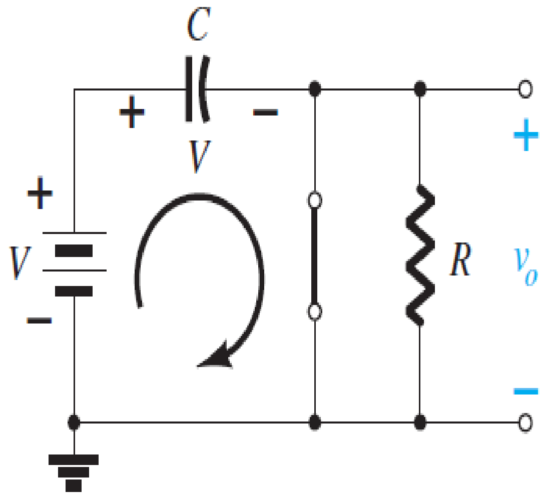
i) Negative clampers
ii) Positive clampers
iii) Biased clampers

Negative Clamper Circuit



In Positive Cycle:

- **In positive cycle diode is forward biased and acts as a short circuit.**
- **So capacitor is quickly charged to voltage V because time constant(RC) is low**



Applying KVL

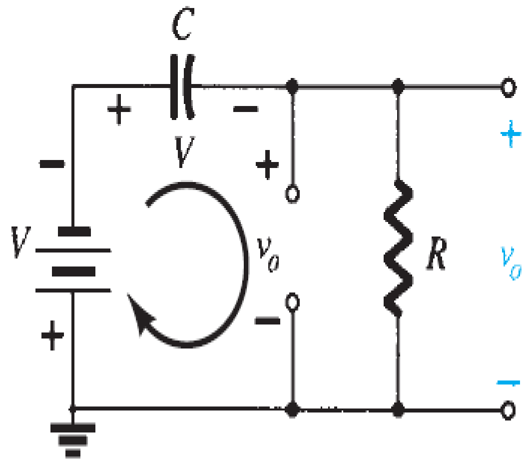
$-V + V - V_O = 0$

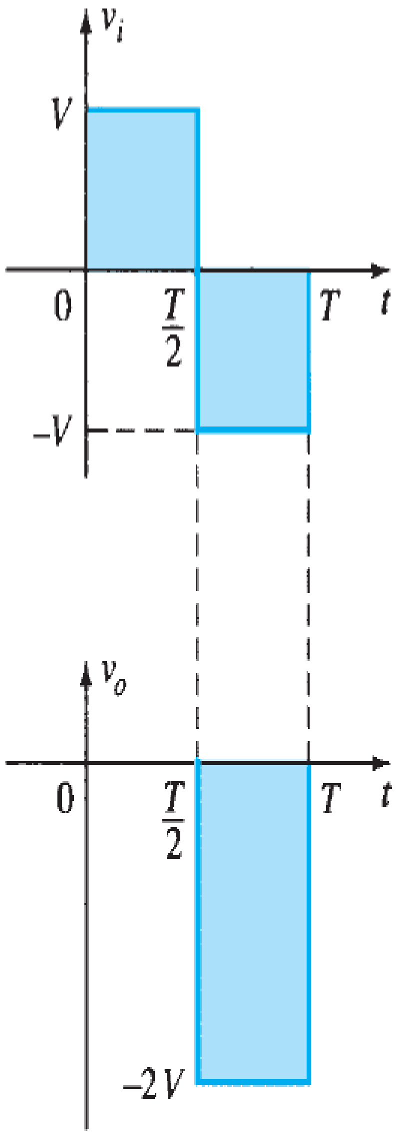
So $V_O = 0$

In Negative Cycle:

Input-Output Waveform

- **In negative cycle Diode is reverse biased and `acts as open circuit.**
- **Since Time constant (RC) is high. So, capacitor maintains its voltage during**



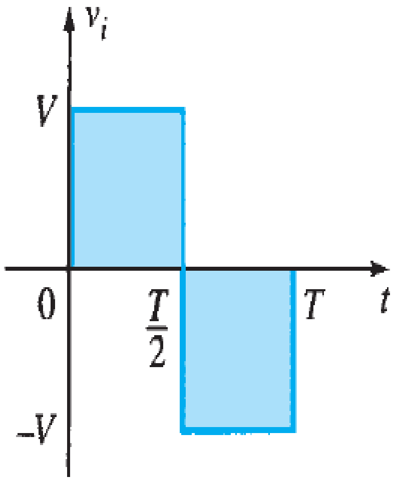


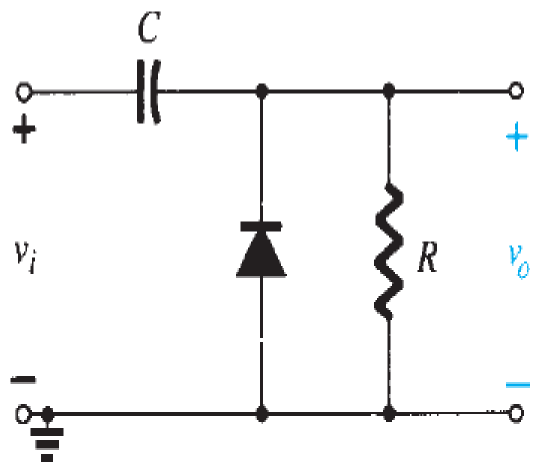
Applying KVL

$-V - V - V_O = 0$

So $V_O = -2V$

Positive Clamper Circuit





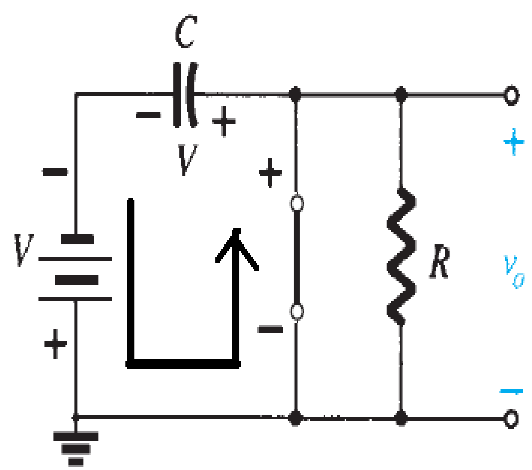
In Negative Cycle:

- In negative cycle diode is forward biased and acts as a short circuit.
- So capacitor is quickly charged to voltage V because time constant (RC) is low

Applying KVL

$-V + V - V_O = 0$

So $V_O = 0$



In Positive Cycle:

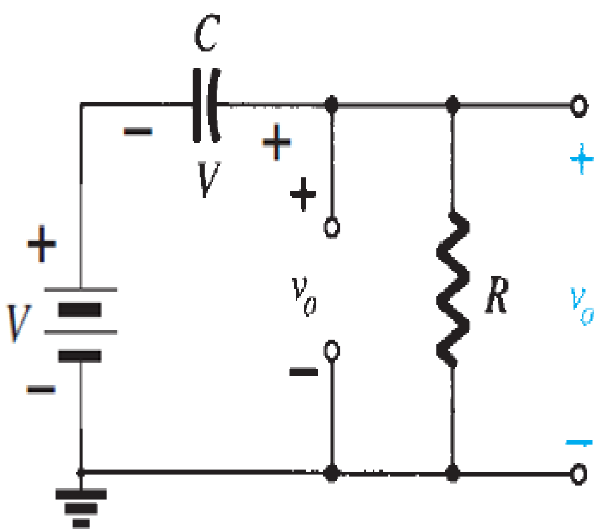
- In Positive cycle Diode is reverse biased and `acts as open circuit.

- Since Time constant (RC) is high. So, capacitor maintains its voltage during negative cycle.

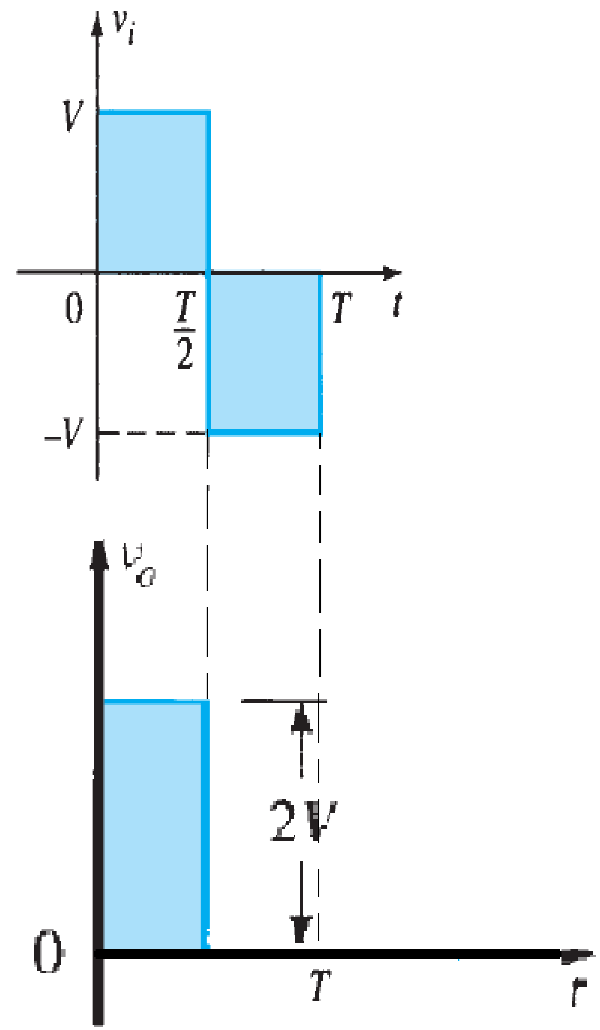
KVL

+V+V-V0=0

VO= 2V

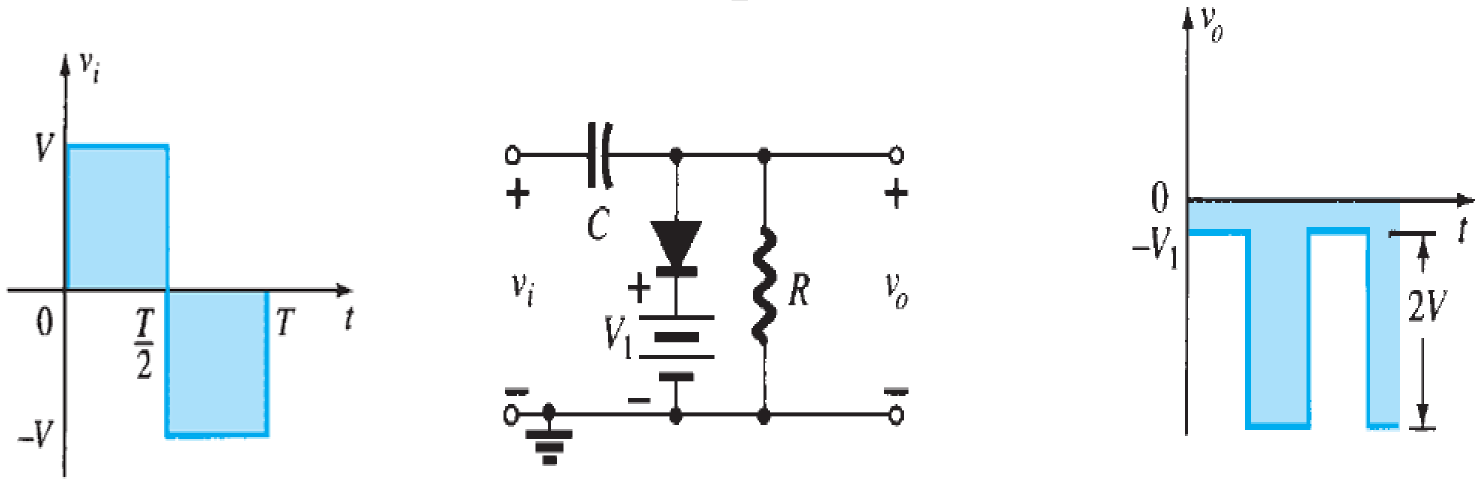


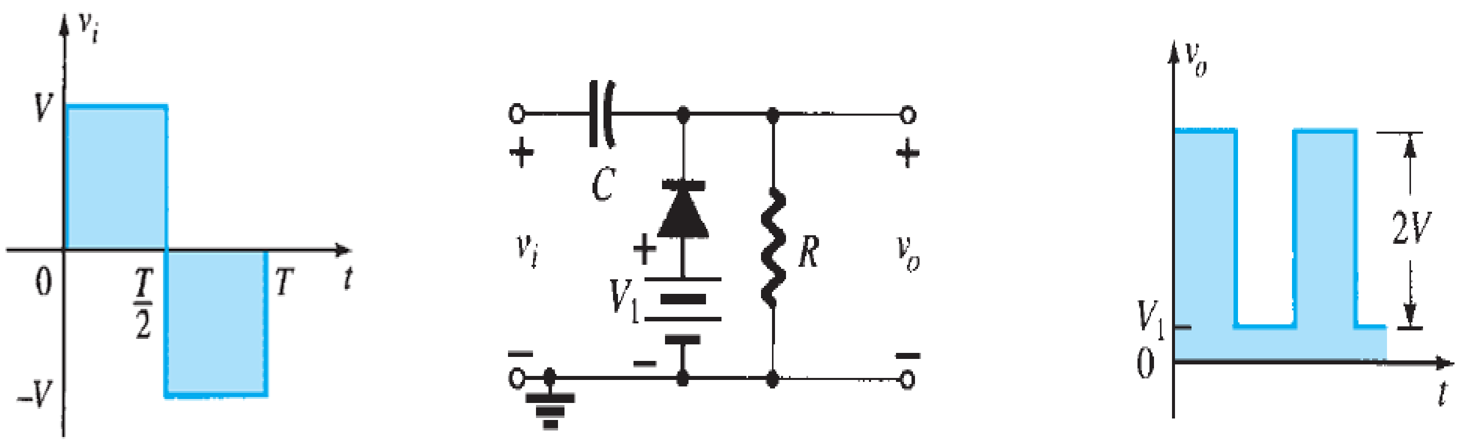
Input-Output Waveform



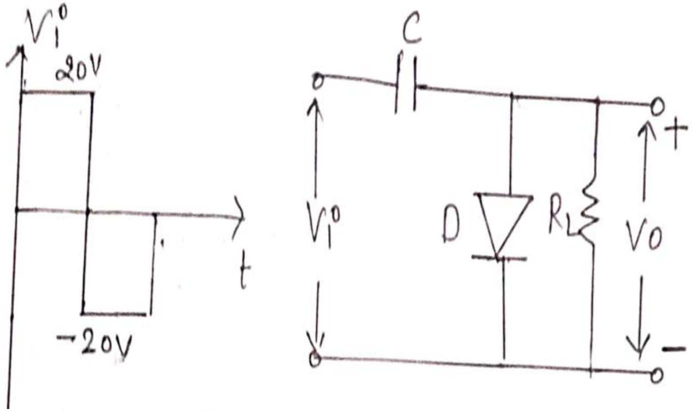
Biased Clamper Circuits

- When a dc supply is used in the clamper circuits then they are known as biased clamper circuit.





Example:1 Sketch the output for the following circuit

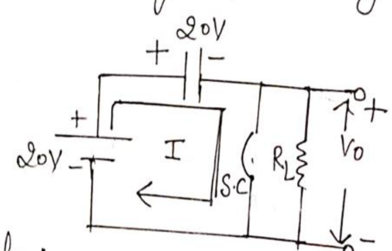


Ans:- It is negative clamper.

i) for positive cycle:-

Diode is forward biased and acts as a short circuit. So capacitor is charges up to voltage 20V.

Applying KVL



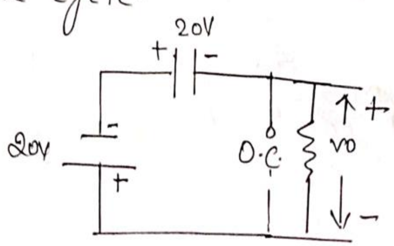
$-20V - V_o + 20V = 0$

So $\boxed{V_o = 0}$

ii) for negative cycle:-

Diode is reverse biased and acts as open circuit. capacitor maintains it's voltage during negative cycle.

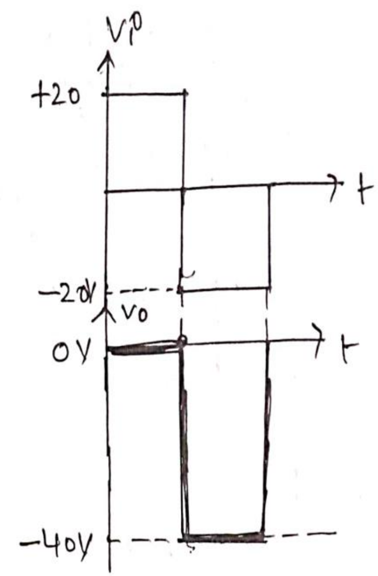
Applying KVL



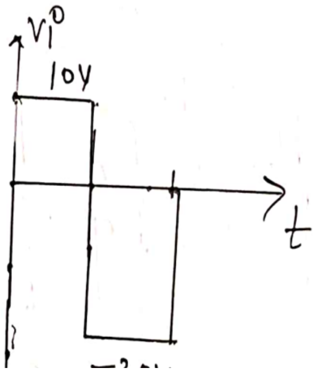
$-20V - V_o - 20V = 0$

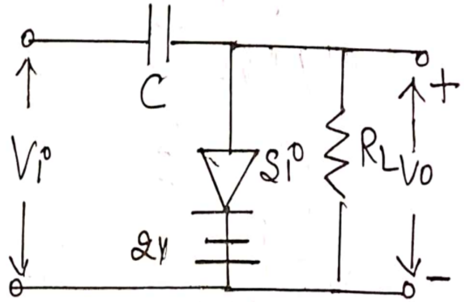
$\Rightarrow \boxed{V_o = -40V}$

Input - output waveform:-



Example:2 Sketch the output for the following circuit

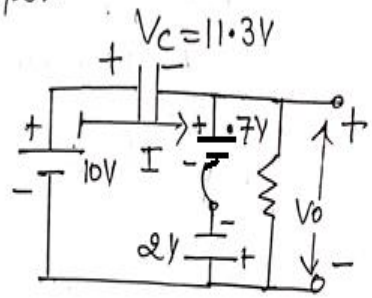




Ans: It is negative clamper.

(i) for positive cycle:

Diode is forward biased and capacitor charges up to voltage. Vc.



Applying KVL

$-V_c - .7V + 2 + 10 = 0$

$V_c = 11.3V$

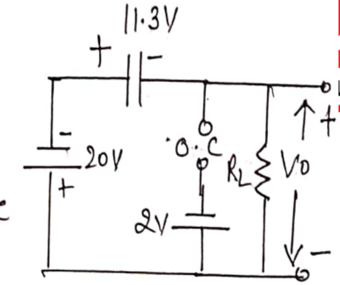
Applying KVL

$-11.3V - V_o + 10 = 0$

V0=-1.3 V

(ii) for negative cycle:

Diode is reverse biased. so diode acts as open circuit. Capacitor maintains it's voltage during negative cycle

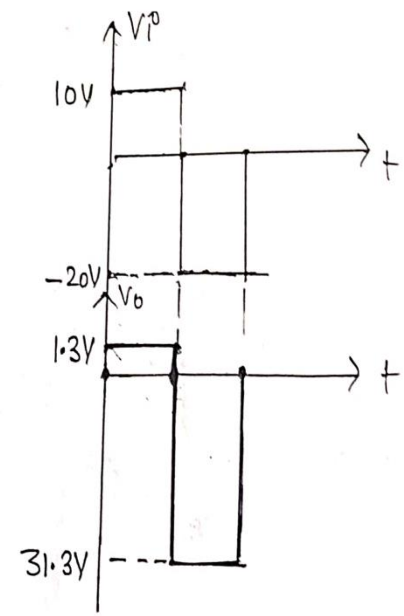


Applying KVL

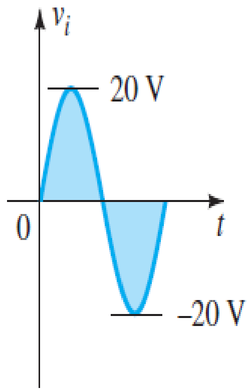
-11.3 –VO-10=0

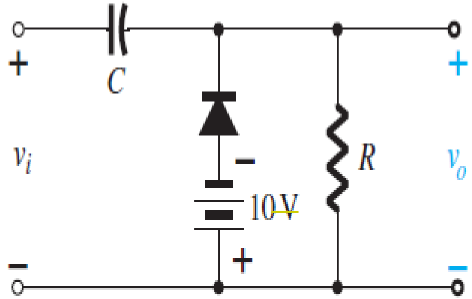
V0= -21.3 V

Input - Output waveform:



Example:3 Sketch the output for the following circuit





Ans:- It is positive clamper.

(i) for negative cycle.

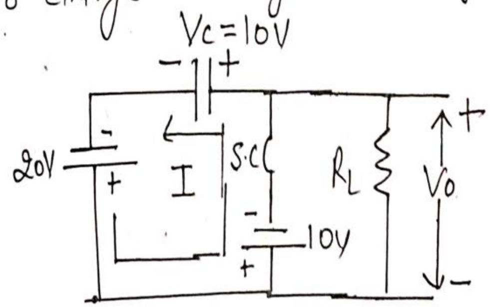
Diode is forward biased and acts as a short circuit

So. capacitor starts to charge and charges up to voltage V_c.

Applying KVL

$+V_c + 10 - 20 = 0$

$V_c = 10V$



Applying KVL

$+10V - V_o - 20V = 0$

$\boxed{V_o = -10}$

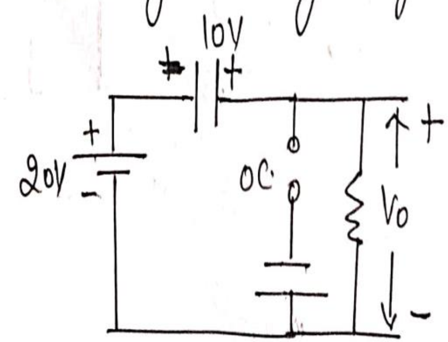
[Note:- o/p sine wave starts from $\frac{-10+30}{2} = 10V$ and goes up to 30V in +ve cycle and upto –10V in –ve cycle]

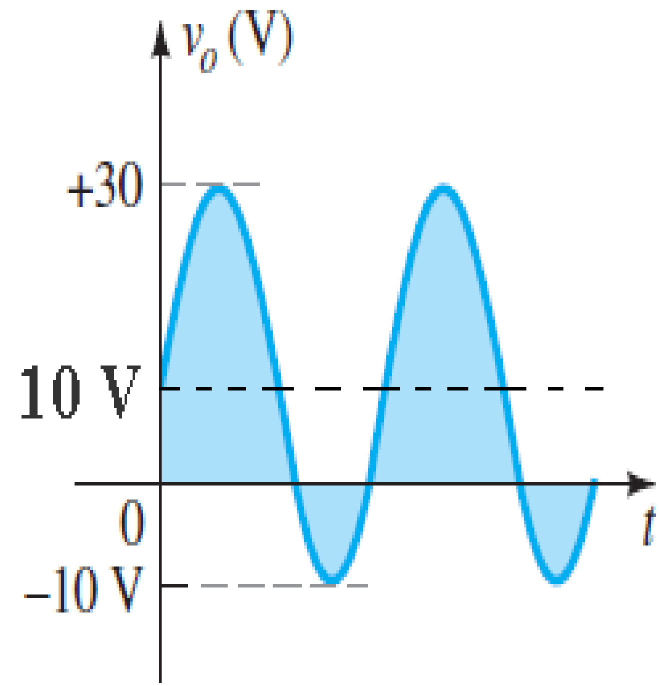
Diode is reverse biased and acts as open circuit. Capacitor maintain it's voltage during negative cycle.

Applying KVL

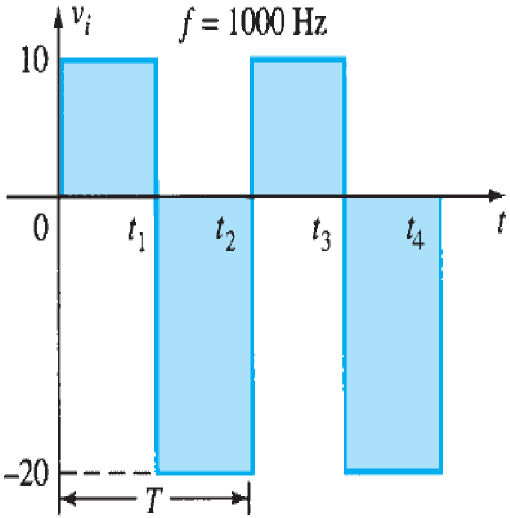
$+10V - V_o + 20V = 0$

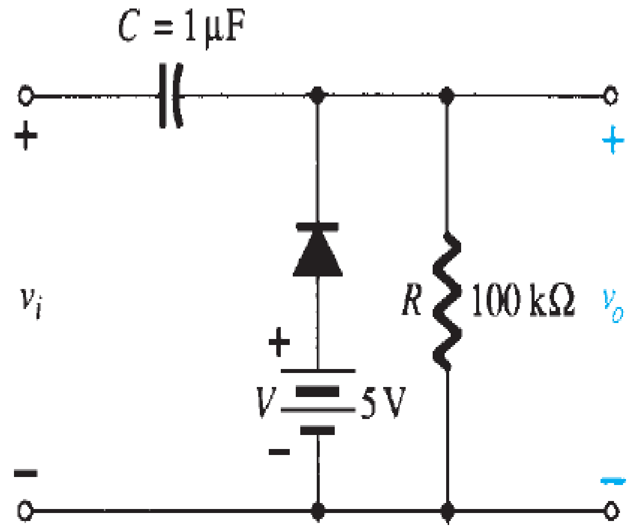
$\boxed{V_o = 30V}$





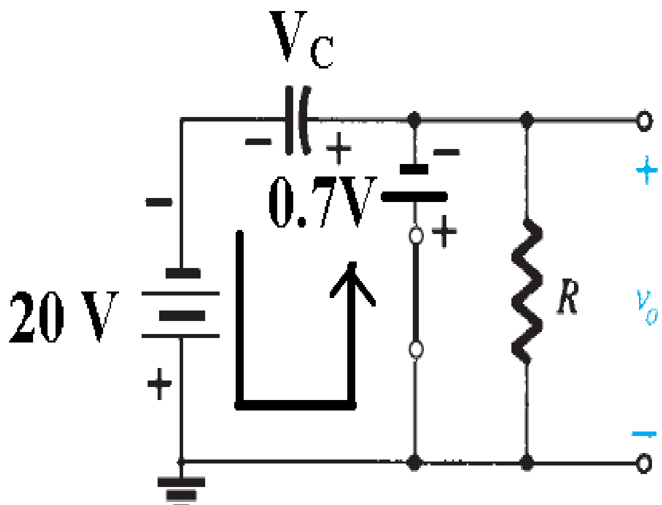
Example:4 Find the output for the following circuit. Diode is of Si.





Solution: **Clamper is positive so we starts the analysis from negative cycle.**

In negative cycle Diode is forward biased and `acts as short circuit. So capacitor charges up to voltage 24.3 V



Applying KVL

V_C **+0.7V-20 V - 5 V-** $V_O = 0$

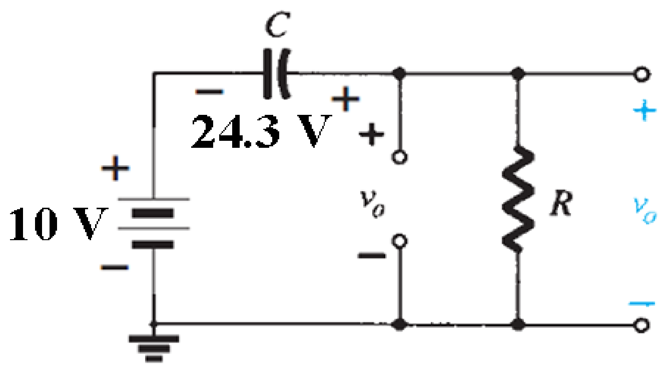
So $V_C = 24.3$ **V**

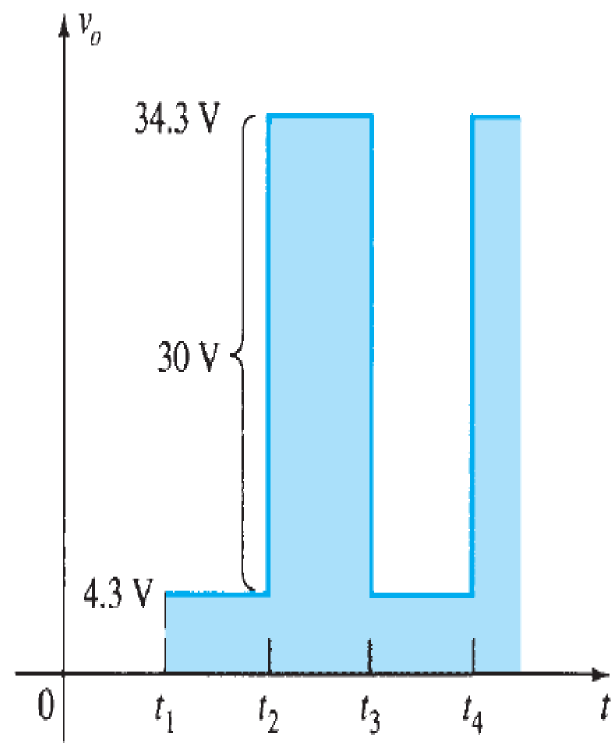
Applying KVL

$+24.3\ V - V_O - 20\ V = 0$

So $V_O = 4.3\ V$

In Positive cycle Diode is reverse biased and `acts as open circuit. Since Time constant (RC) is high. So, capacitor maintains its voltage during negative cycle.





Applying KVL

$24.3\ V - V_O + 10\ V = 0$

So $V_O = 34.3\ V$

Lecture 12

Voltage multiplier

Voltage Multiplier Circuit.

- Voltage-multiplier circuits produce a dc output voltage that is some multiple of the peak ac input voltage to this circuit.
- On the basis of multiplying factor, voltage multiplier circuit can be classified as:

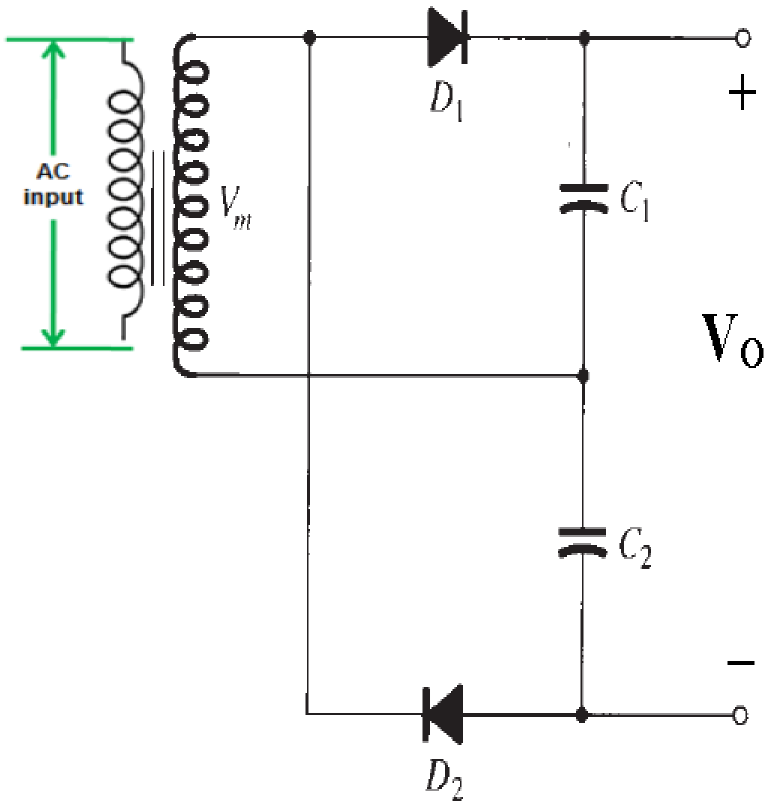
1. Voltage Doubler
2. Voltage Tripler
3. Voltage Quadrupler

- **Voltage doubler is again classified as:**

- **1.** Half Wave Voltage Doubler
- **2.** Full Wave Voltage Doubler

Full wave Voltage Doubler Circuit

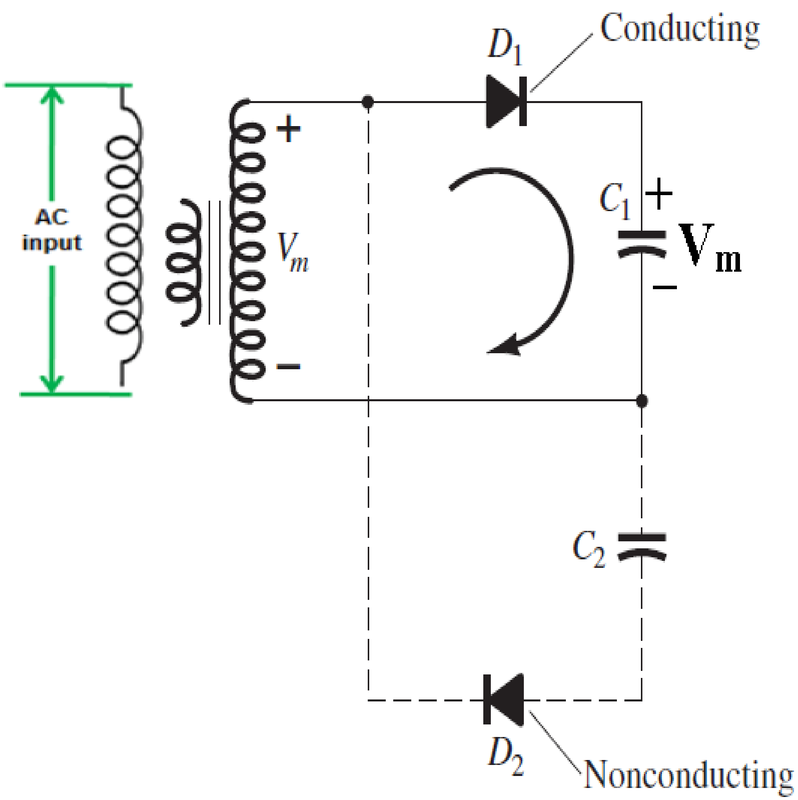
- In full wave doubler a full wave rectifier is used.
- Clamper circuit is not used.



Working

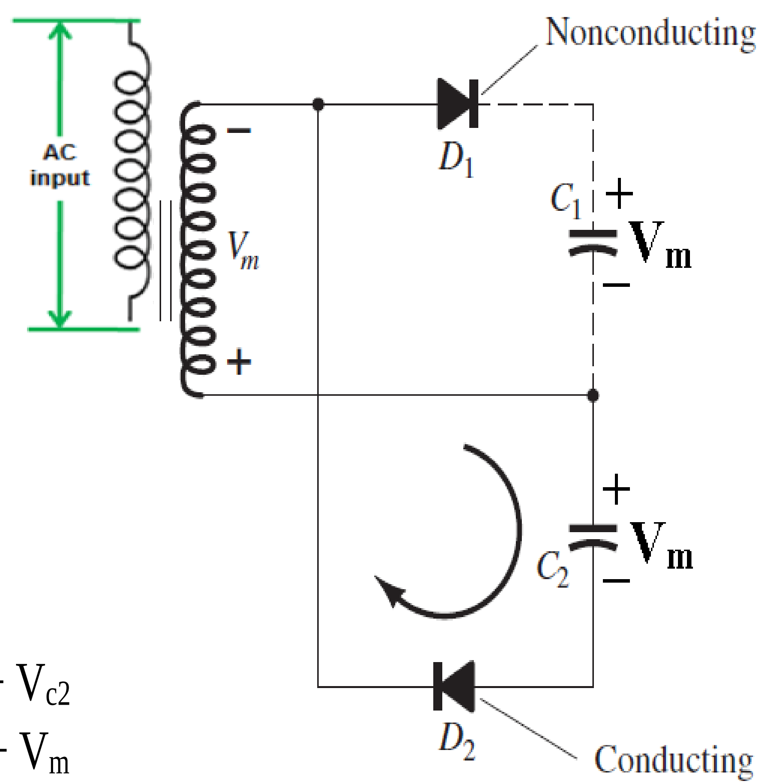
- **Positive Cycle:**

  D_1 is forward biased so it is on but D_2 is reverse biased so it is off. So, capacitor C_1 charges up to voltage V_m.



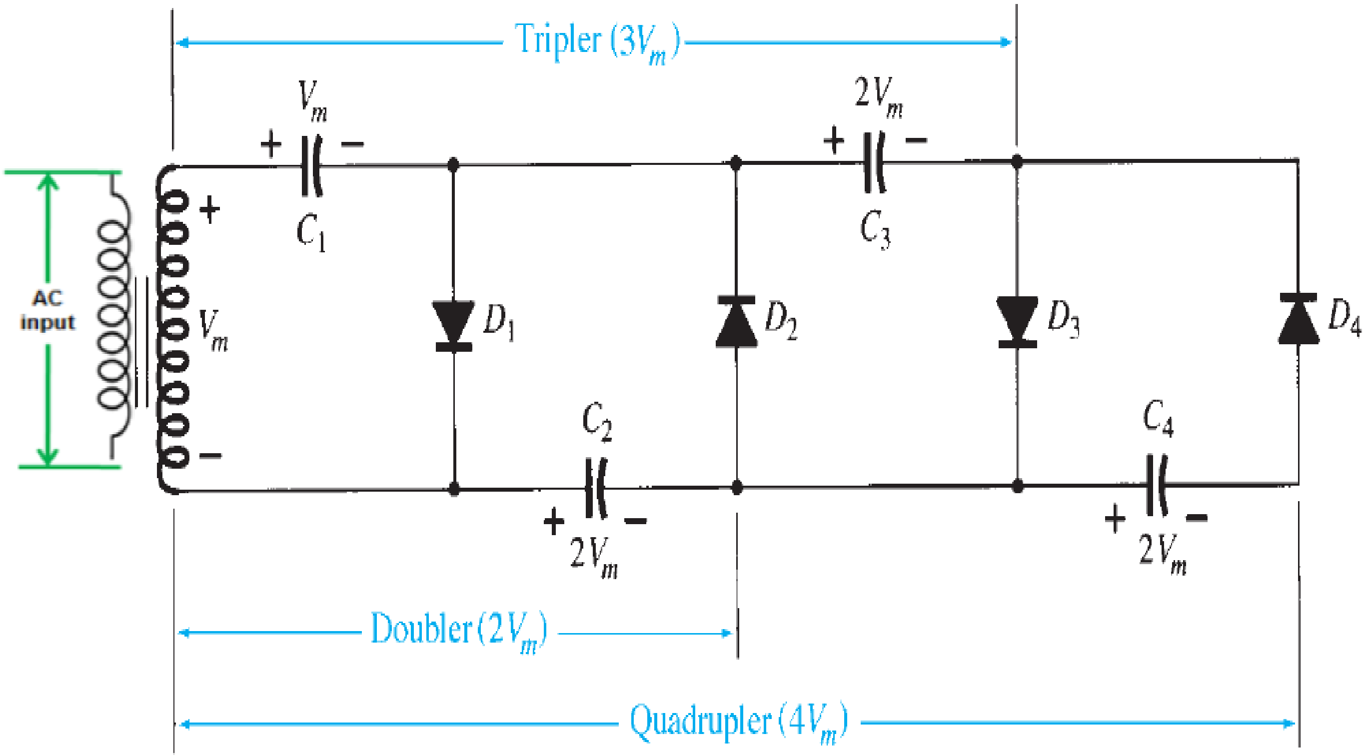
- **Negative Cycle:**

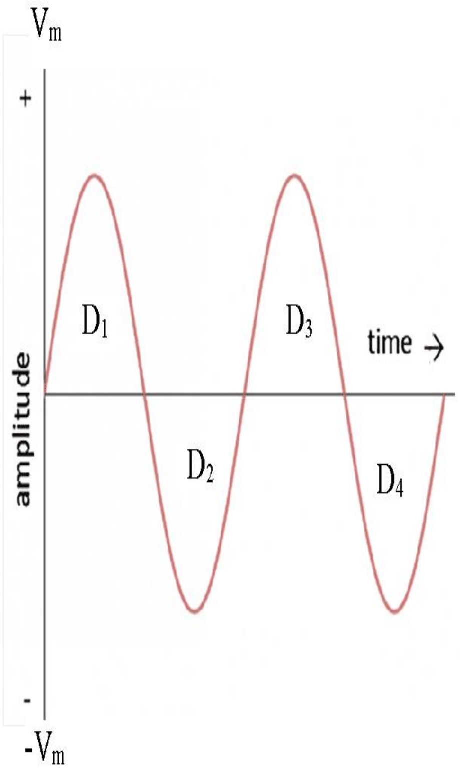
  D_2 is forward biased so it is on but D_1 is reverse biased so it is off. So, capacitor C_2 charges up to voltage V_m.



$$V_O = V_{c1} + V_{c2}$$
$$= V_m + V_m$$
$$= 2V_m$$

Half Wave Doubler, Tripler, Quadrupler Circuit





Working

- First Positive Cycle:

D_1 is on. So, capacitor C_1 charges up to voltage V_m

- First Negative Cycle:

D_2 is on. So, capacitor C_2 charges up to voltage $2V_m$.

Applying KVL

$$-V_m + V_{C2} - V_m = 0$$

So $V_{C2} = 2V_m$

- Second Positive Cycle:

D_3 is on. So, capacitor C_3 charges up to voltage $2V_m$.

Applying KVL

$$-V_m - V_{C3} + 2V_m + V_m = 0$$

So $V_{C3} = 2V_m$

- Second Negative Cycle:

Applying KVL

$$-V_m - 2V_m + V_{C4} + 2V_m - V_m = 0$$

So $V_{C4} = 2V_m$

Lecture 13

Clippers: Introduction, types and problems

Clipper Circuits:

Clipper: Clipper is a circuit which is used to clip-off or remove some portion of input waveform. Clippers are of following type.

i) Positive clipper

ii) Negative clipper

iii)Biased clipper

i) **Positive clipper:** A positive clipper removes the positive half cycle of the input voltage. Positive clipper is of two type:

a) **Series Positive clipper:**

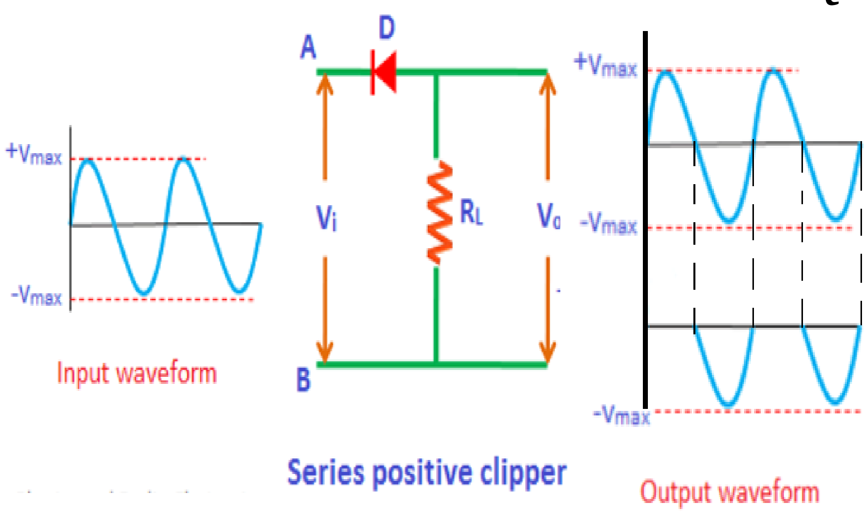
b) **Shunt plosive clipper:**

a) Series Positive clipper:

Operation:

In positive cycle diode is reverse biased. So, diode is off and output will be zero.

In negative cycle diode is forward biased. So, diode is On and output will be negative input

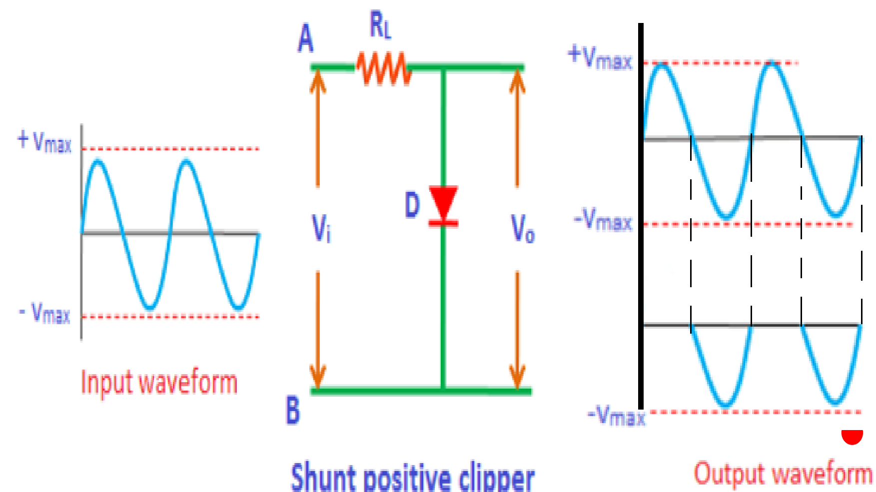


a) Shunt plosive clipper:

Operation:

In positive cycle diode is forward biased. So diode is on and output will be zero.

In negative cycle diode is reverse biased. So diode is off and output will be negative input



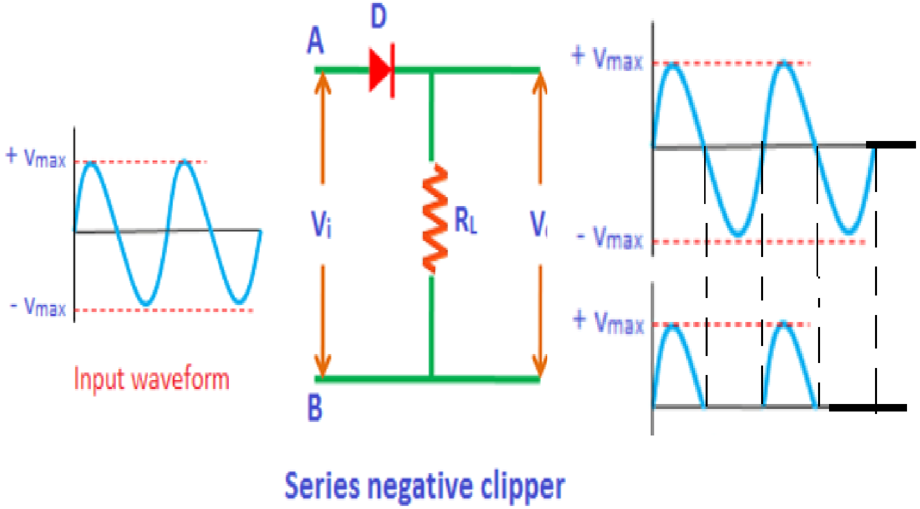
ii) Negative clipper: A positive clipper removes the negative half cycle of the input voltage. Negative clipper is of two type:

a) Series Negative clipper:

Operation:

In positive cycle diode is forward biased. So diode is on and output will be equal to input voltage.

In negative cycle diode is

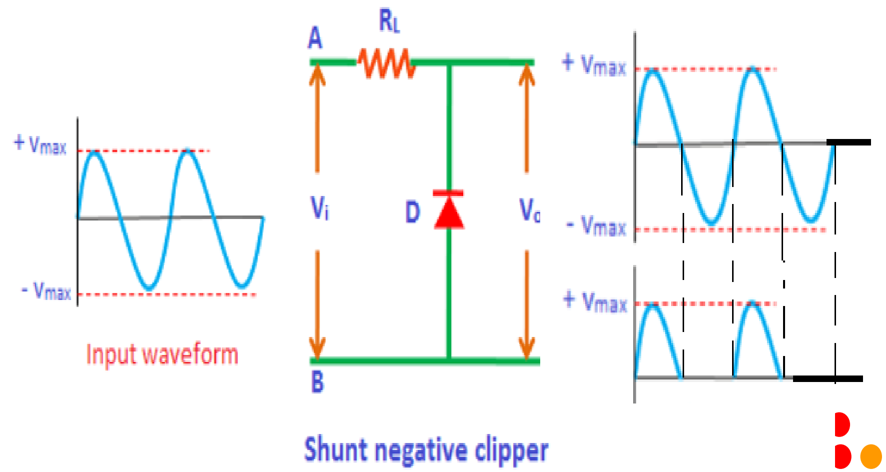


Series negative clipper

b) Shunt negative clipper:

Operation:

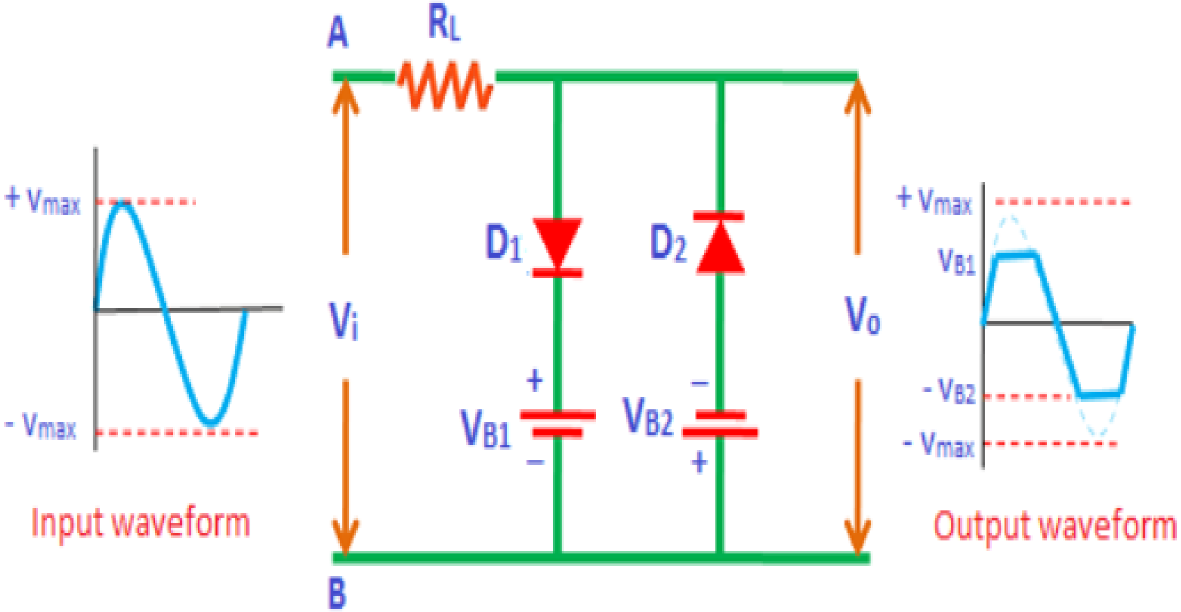
In positive cycle diode is forward biased. So, diode is on and output will be equal to input voltage.



Shunt negative clipper

iii) Two Way clipper:

Biased clipper is used to clip-off or remove a small portion of positive cycle or negative cycle or both. This is achieved by adding a battery in series with diode.



Dual (Combination) clipper

Operation:

First, we find the transition voltage:

$V_{\gamma 1} - V_{B1} = 0$

$V_{\gamma 1} = V_{B1}$

$V_{\gamma 2} + V_{B2} = 0$

$V_{\gamma 2} = -V_{B2}$

i) $V_i < -V_{B2}$

D_1 OFF, D_2 ON

So $V_O = -V_{B2}$

ii) $-V_{B2} \leq V_i \leq V_{B1}$

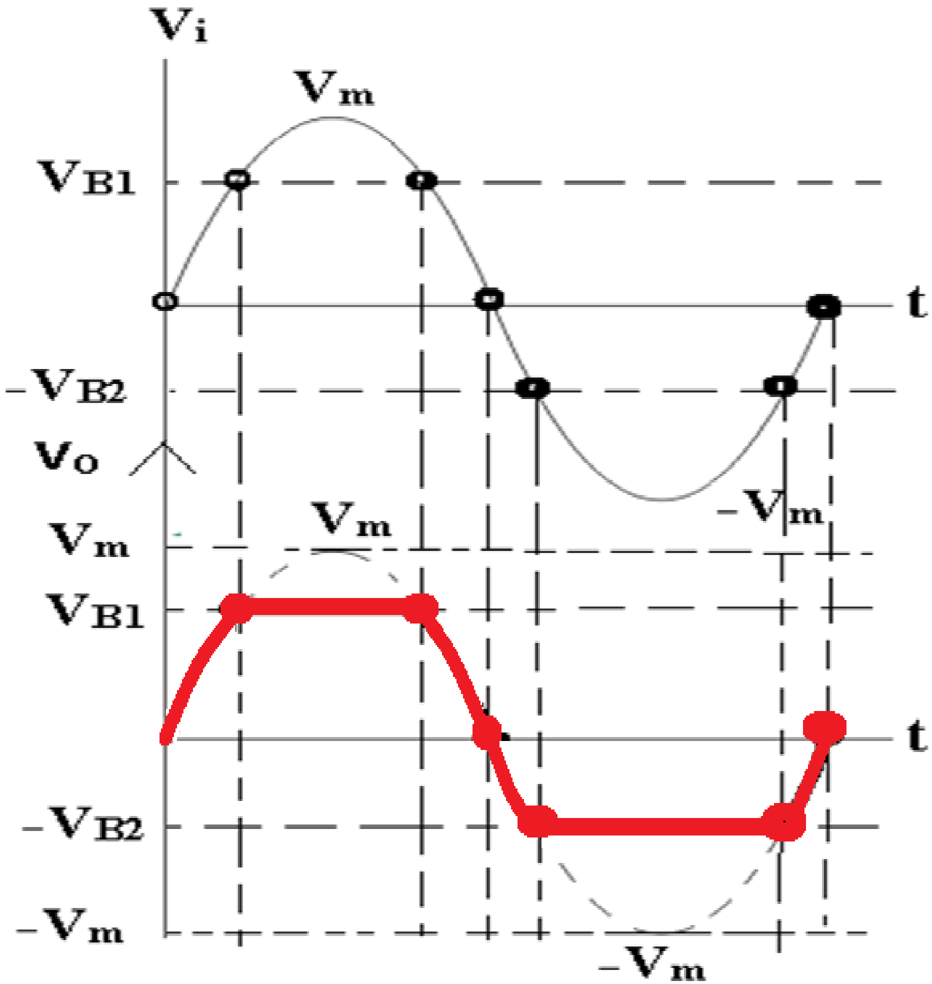
D_i OFF, D_2 OFF

So $V_O = V_i$

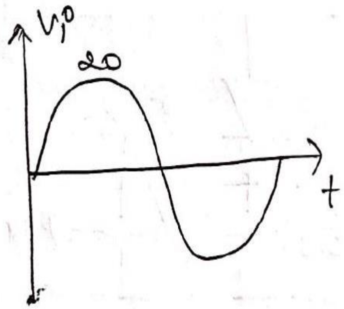
iii) $V_i > V_{B1}$

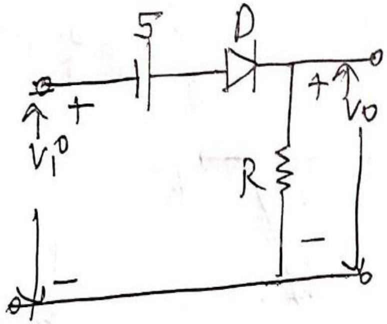
D_i ON, D_2 OFF

So $V_O = V_{B1}$



Example:1 Find the output for the following circuit.





Sol^n Transition voltage $V_v + 5 = 0$

$V_v = -5$

i) $V_i < -5$

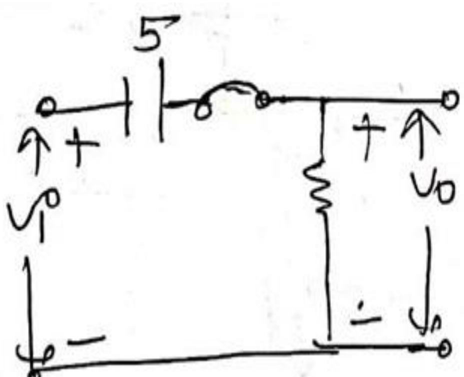
D → off

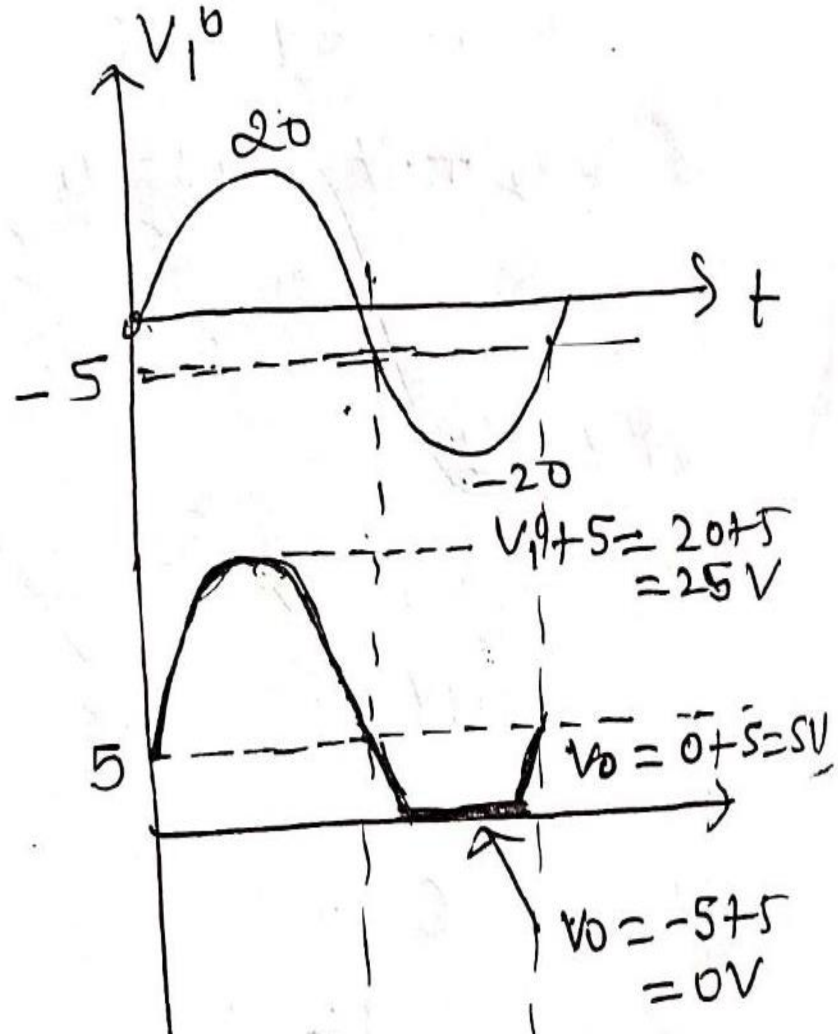
$V_o = 0$

(ii) $V_i > -5$

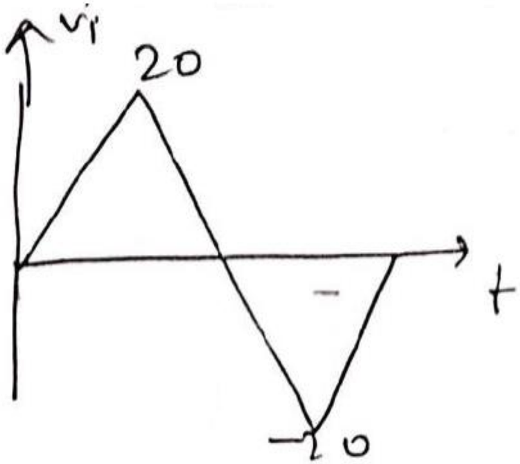
$V_i + 5 - V_o$

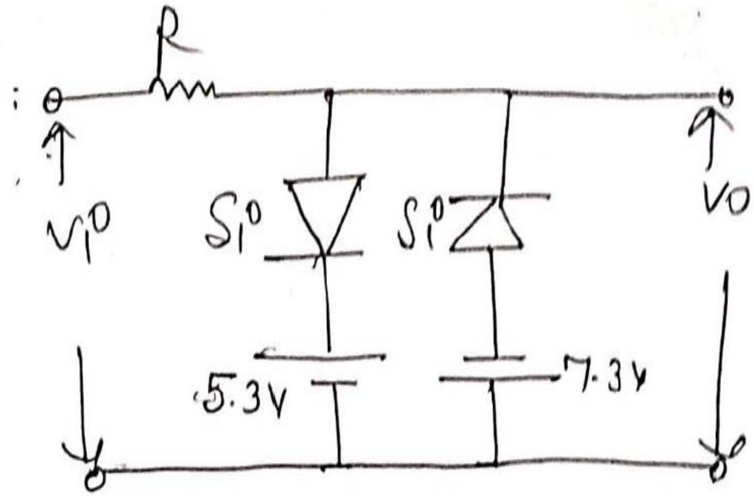
$V_o = V_i + 5$





Example:2 Sketch the output for the following circuit.





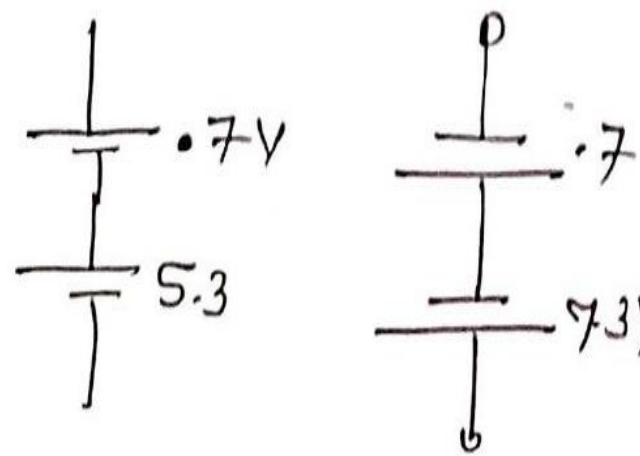
Soln. Transition voltage

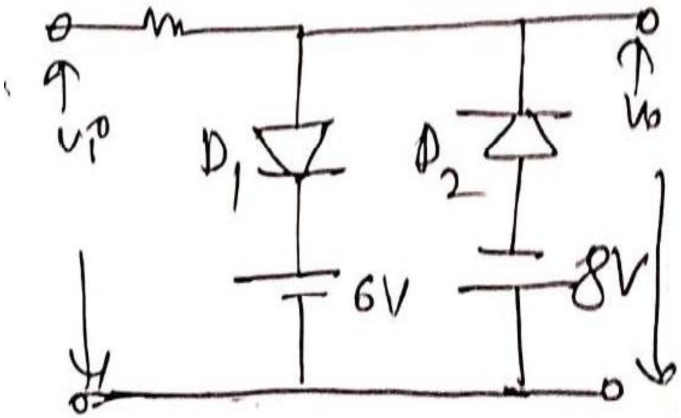
$V_{V_1} - .7 - 5.3 = 0$

$V_{V_1} = 6V$

$V_{V_2} + .7 + 7.3 = 0$

$V_{V_2} = -8V$





(i) $V_i < -8$

D_1 off, D_2 - ON

$V_o = -8V$

(ii) $-8 < V_i < 6$

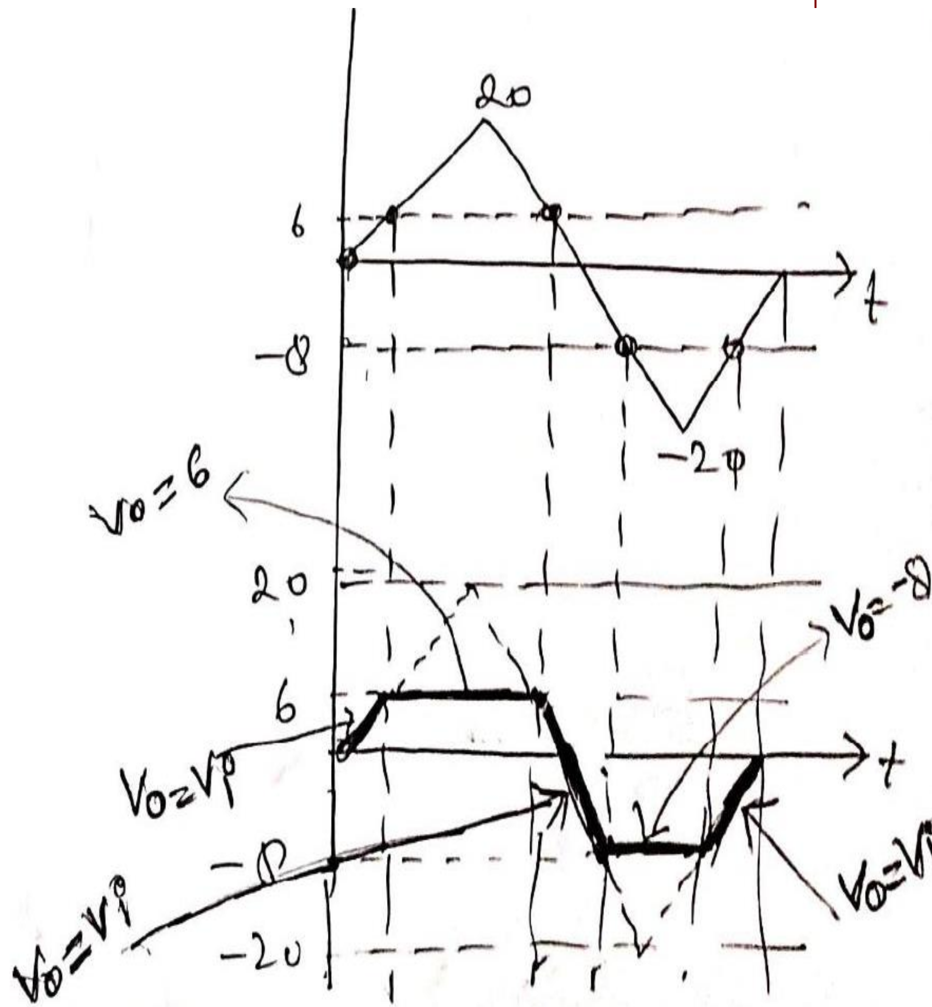
D_1 off D_2 off

$V_o = V_i$

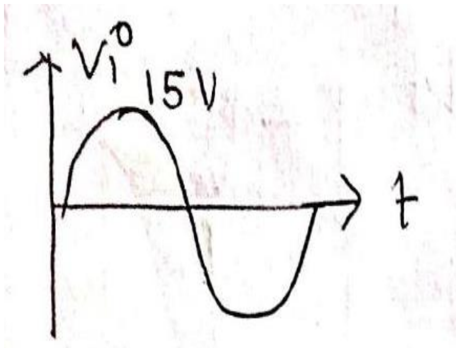
(iii) $V_i > 8$

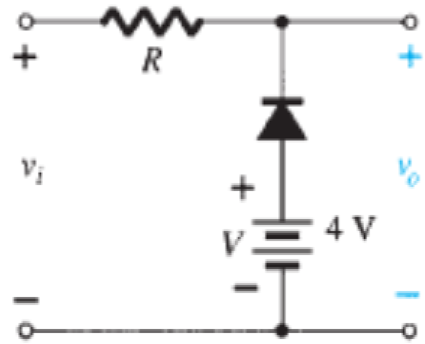
D_1 ON, D_2 off

$V_o = +6$



Example:3 Sketch the output for the following circuit.





Solution:

Transition Voltage (V_r)

$V_r - 4 = 0$

$V_r = 4$

(i) $V_i > 4$

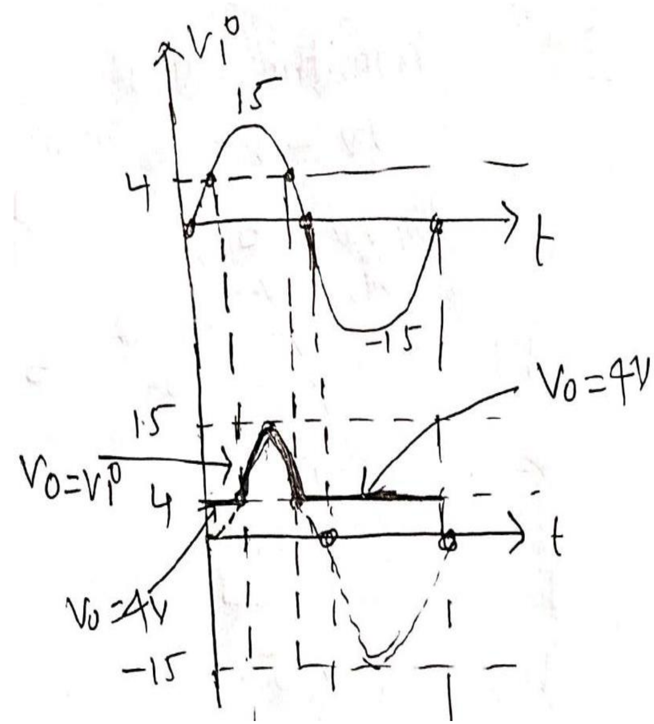
D → ON

$V_o = 4V$

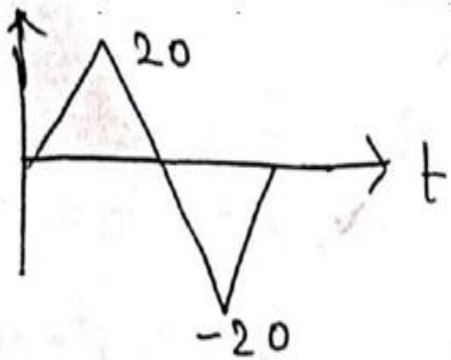
(ii) $V_i < 4$

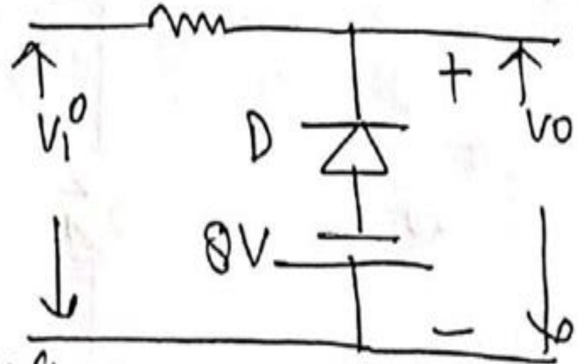
D → off

$V_o = V_i$



Example:4 Sketch the output for the following circuit.





Soln: Transition Voltage (V_r)

$V_r + 8 = 0$

$V_r = -8V$

(i) $V_i < -8$

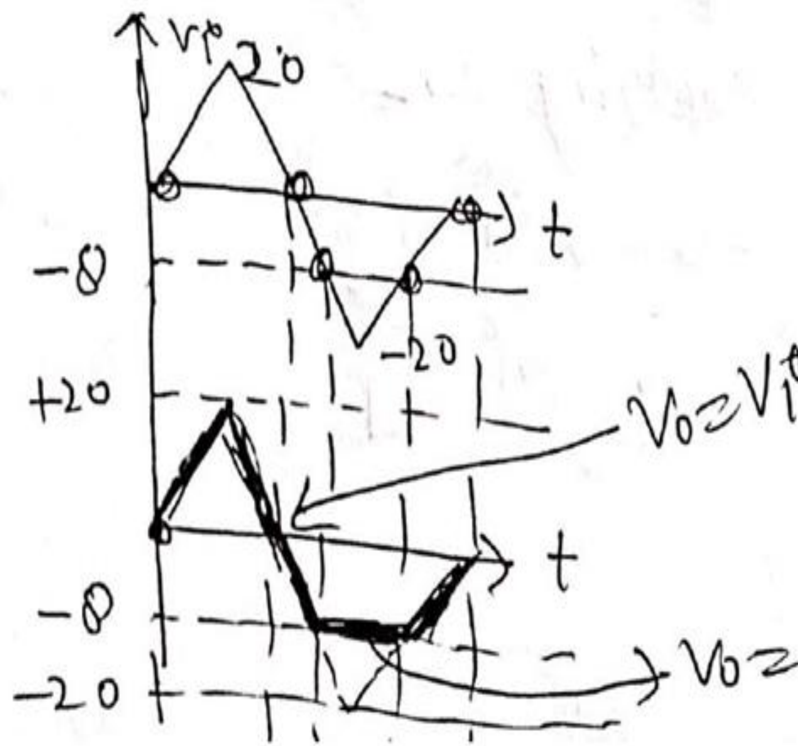
D → off

$V_o = V_i$

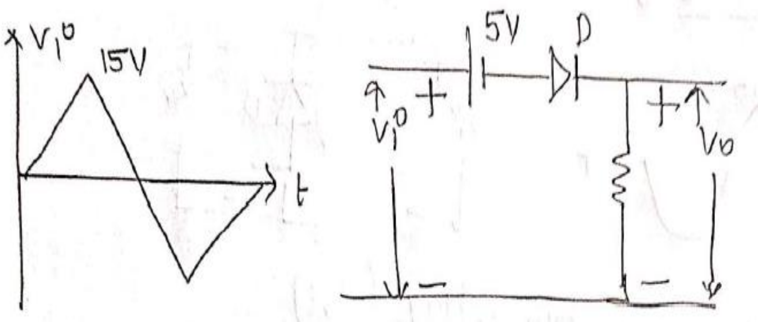
(ii) $V_i > -8$

D → ON

$V_o = -8V$



Example:5 Sketch the output for the following circuit.



Soln.: Transition Voltage

$V_D - 5 = 0$

$V_V = 5$

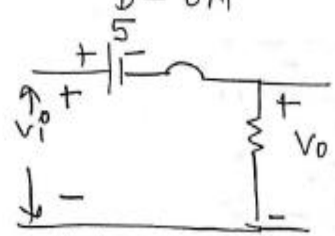
(i) $V_i^o < 5$

D → off

$V_o = 0$

(ii) $V_i^o > 5$

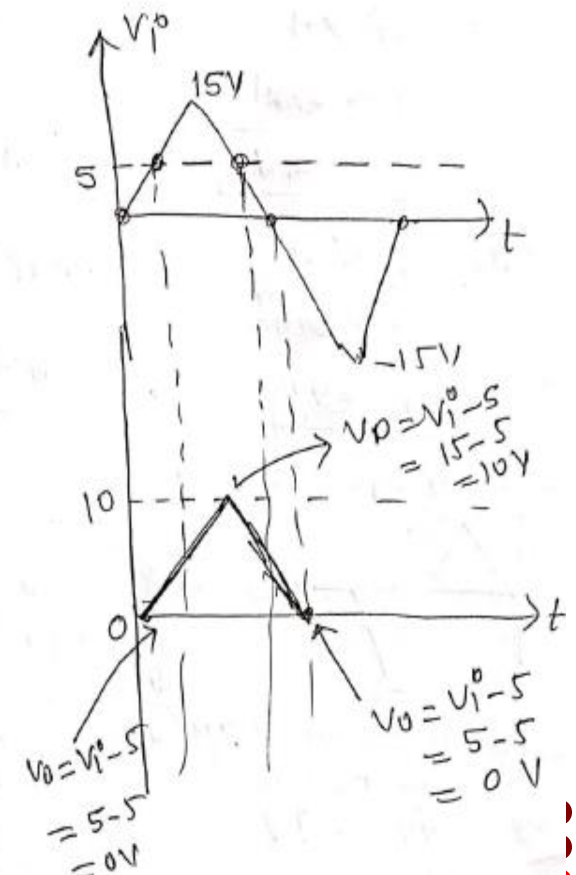
D − ON



Applying KVL

$-5 - V_o + V_i^o = 0$

$V_o = V_i^o - 5$



Lecture 14

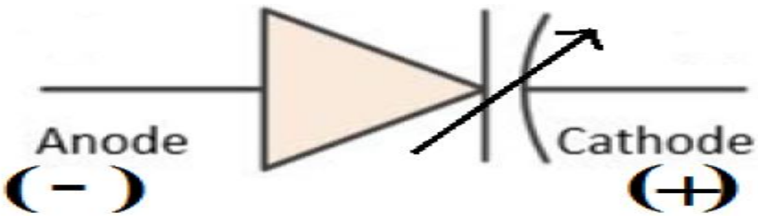
Special Purpose diodes

Special Purpose two terminal Devices

- **Varactor Diodes**
- **Tunnel Diodes**
- **Light-Emitting Diodes**
- **Photo Diodes**
- **Liquid-Crystal Displays**

Varactor Diodes (Vari Cap)

Symbol:

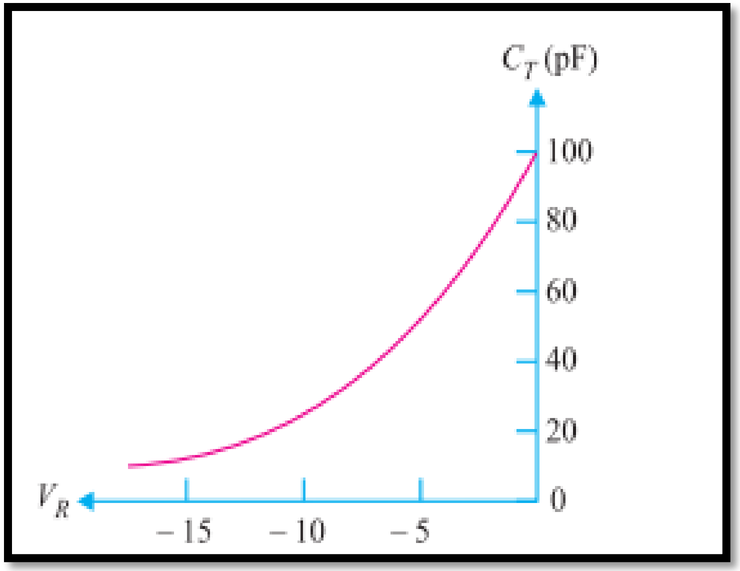


- Varactor diode is used in reverse bias condition. In reverse diode capacitance is given by

$$C = \varepsilon \frac{A}{W}$$

- If reverse voltage is increased then width of depletion layer will increase. So, C will decrease. If reverse voltage is decreased then width of depletion layer will decrease. So, C will increase.

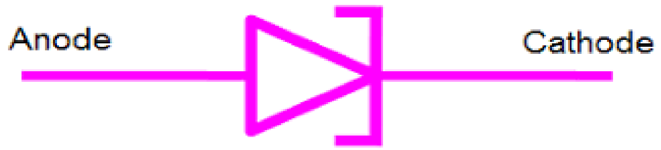
Characteristics:



Application:

1) FM modulator
2) Tuning circuit
3) In TV receiver
4) In Radio receiver

Tunnel Diode

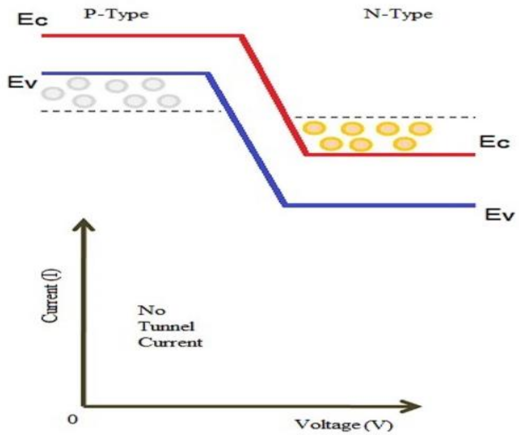


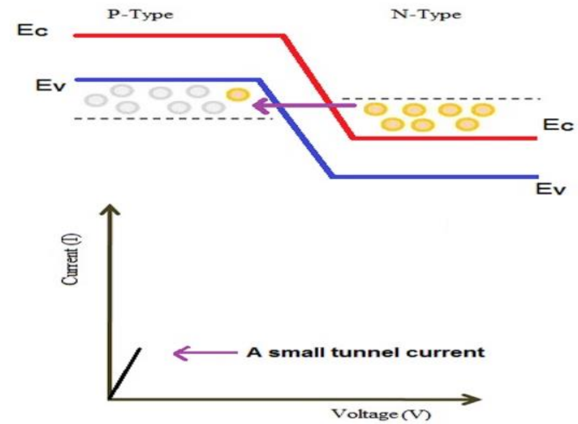
Tunnel diode symbol

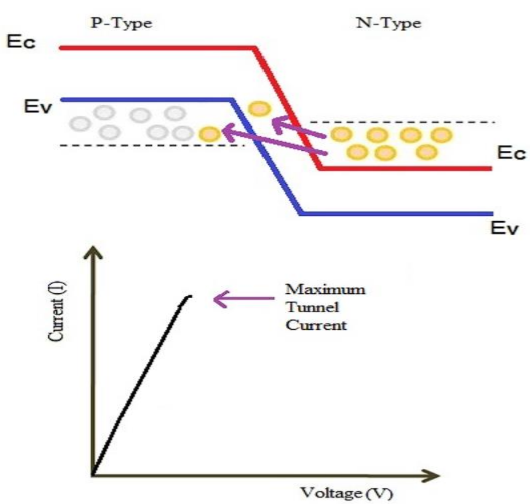
- Tunnel diode is very highly doped diode.
- The doping of Tunnel diode is 1000 times greater than simple diode.
- So, depletion layer is very narrow and is of the order of 10 nm.

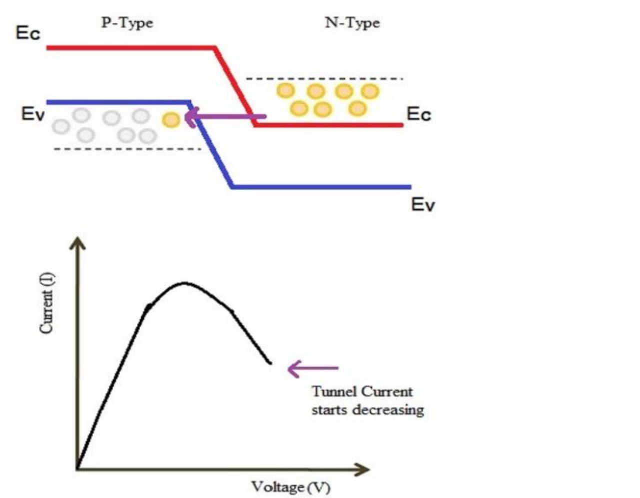
Working principle:

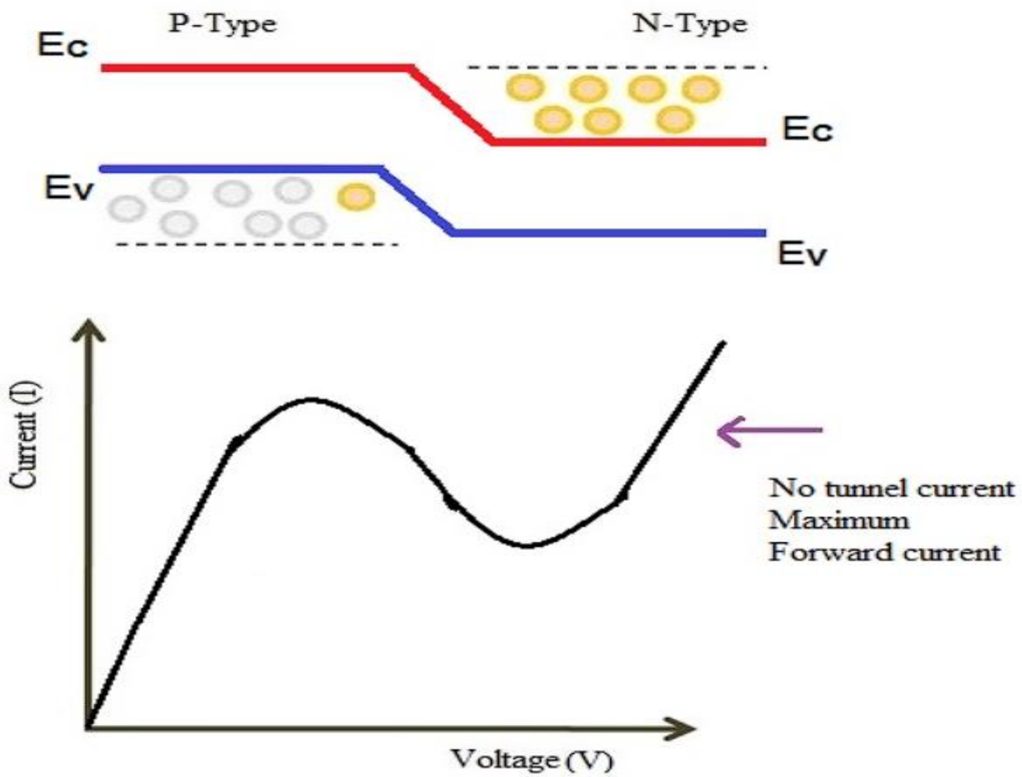
- In p-n junction a potential barrier exists. According to classical mechanics an electron can pass the barrier if it has an energy equal or greater than energy of potential barrier.
- If doping is very high then according to quantum mechanics a electron with energy less than barrier energy can penetrate the barrier or cross the barrier, This effect is called tunneling effect and such diode are called Tunnel diode.


Ec
P-Type
N-Type
Ev
Ec
Ev
Current (I)
No
Tunnel
Current
0
Voltage (V)


P-Type
N-Type
Ec
Ev
Ec
Ev
Current (I)
A small tunnel current
Voltage (V)


P-Type
N-Type
Ec
Ev
Ec
Ev
Current (I)
Maximum
Tunnel
Current
Voltage (V)


P-Type
N-Type
Ec
Ev
Ec
Ev
Current (I)
Tunnel Current
starts decreasing
Voltage (V)

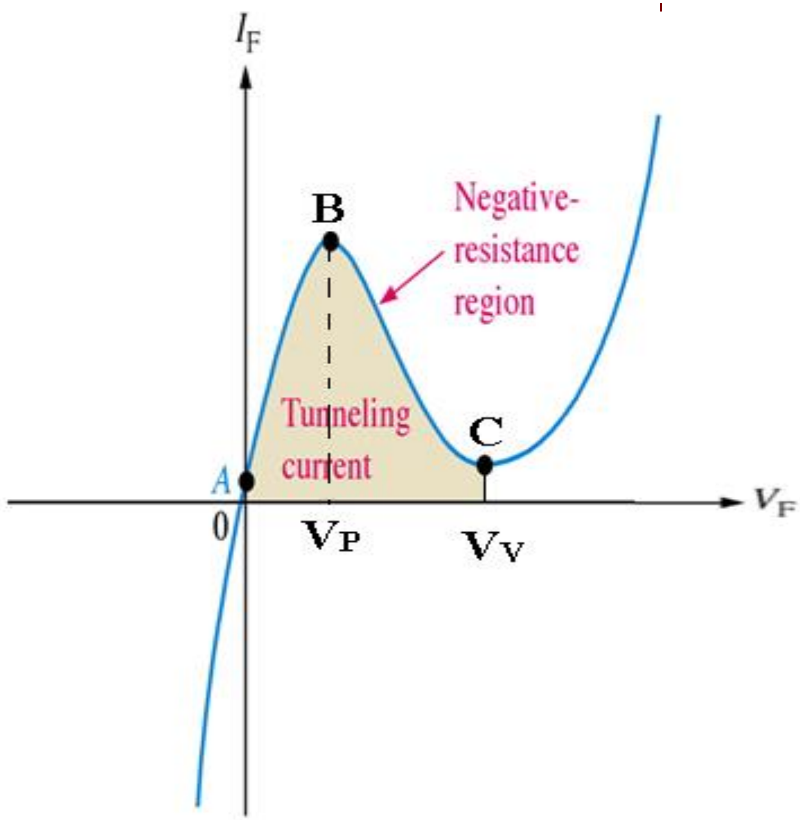

P-Type
N-Type
Ec
Ec
Ev
Ev
Current (I)
Voltage (V)
No tunnel current
Maximum
Forward current

V-I characteristics of Tunne

Point A to B: Current increases till point B at very low voltage due to tunnelling effect.

Point B to C: Current decreases till point C. At point C current is minimum and diode shows negative resistance.

After point C: Tunnel diode woks as normal diode.

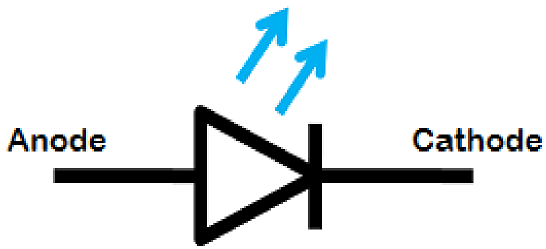


Application:

1) Microwave application
2) Microwave oscillation
3) Binary memory.

Light Emitting Diode (LED)

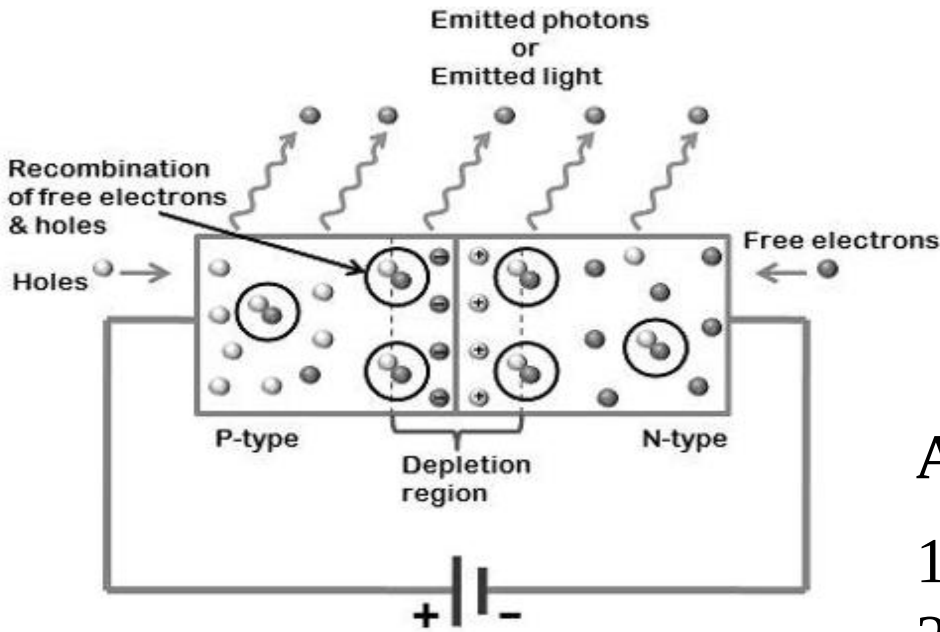
- Light emitting diode (LED) is a special diode which give light, when forward biased. Materials like gallium, phosphorus and arsenic are used for the manufacturing of LED.



S.N.	Material	Colour
1	GaN	Blue (at 5 V)
2	GaN	White (at 4 V)
3	GaAsP	Red (at 1.8 V)
4	GaAsP	Orange (at 2 V)
5	GaP	Green

Working principle:

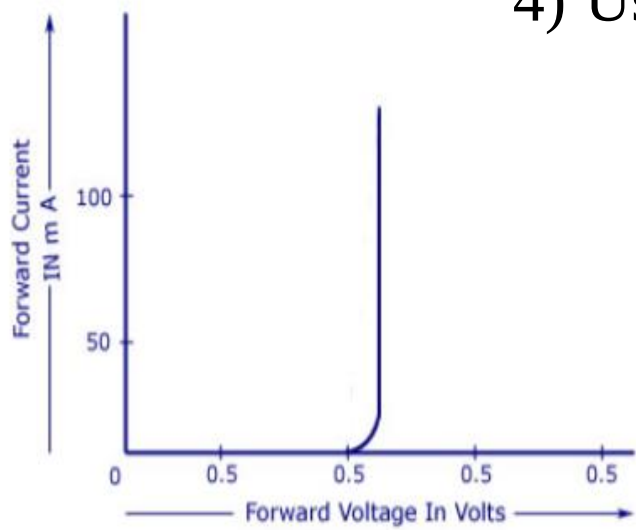
- When LED is forward biased then hole in p-type and electron in n-type start to cross the junction and recombine with each other.
- Simple diode (Si or Ge) produce heat in recombination process. But LED produce light in recombination.



Application:

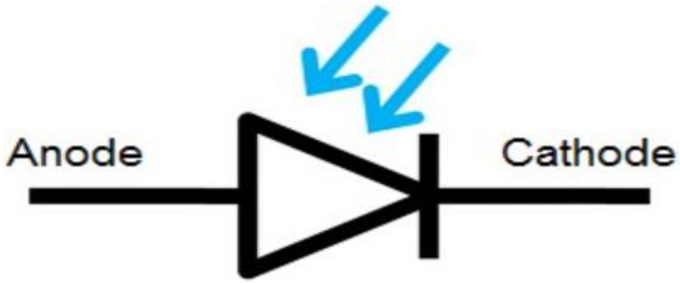
1) Used in digital clocks.
2) Used in calculators.
3) Used in mobile, TV display.
4) Used in seven segment display.

V-I characteristics:



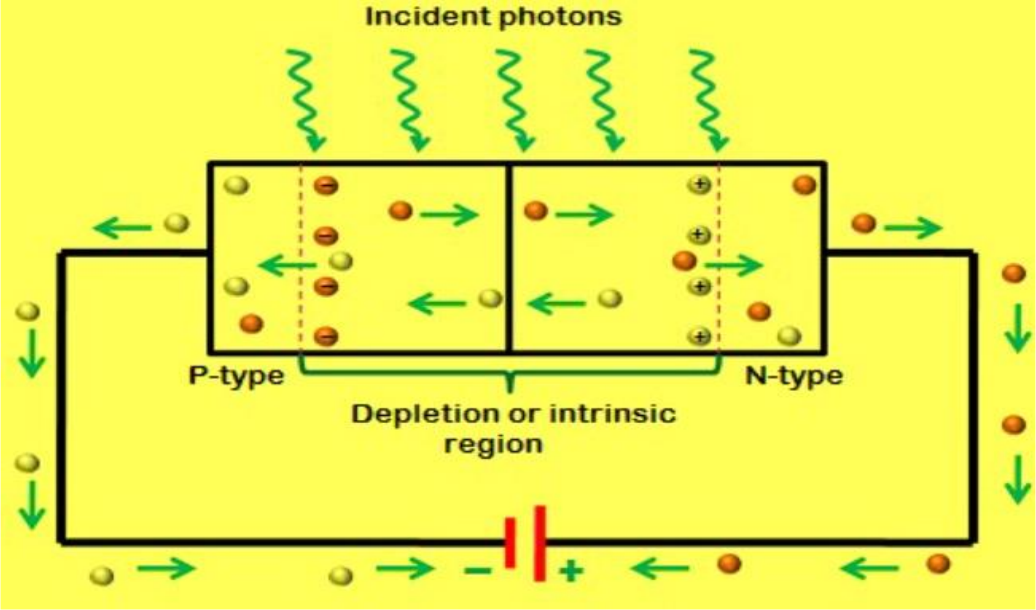
Forward Bias V-I Curve

Photodiode

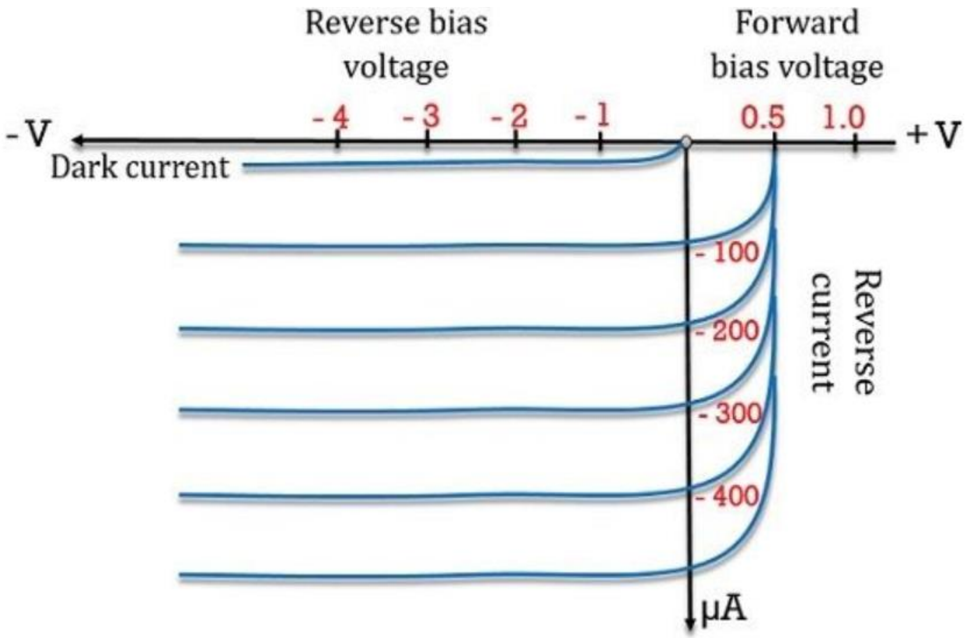


Working principle:

- When a light or photon is used to illuminate p-n junction then photon hits the immobile ions present in the depletion layer.
- If energy of photon is greater than 1.1 eV than covalent bond will break. So, electron hole pair are generated.
- Due to electric field, electron-hole pairs move away from the junction. Hence, holes move to anode and electrons move to the cathode to produce photocurrent. This entire process is known as **photoelectric effect.**



V-I characteristics of photodiode:



Application:

1) Optical communication system.

2) Medical devices

3) Solar cell panels.

4) Smoke detectors

5) Camera light meters, and street lights