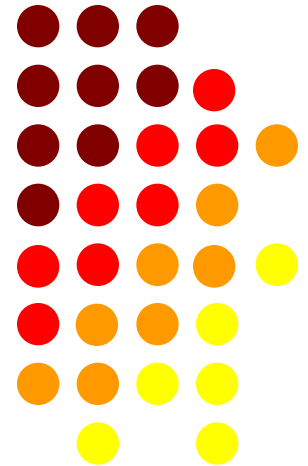


# Lecture 1

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.

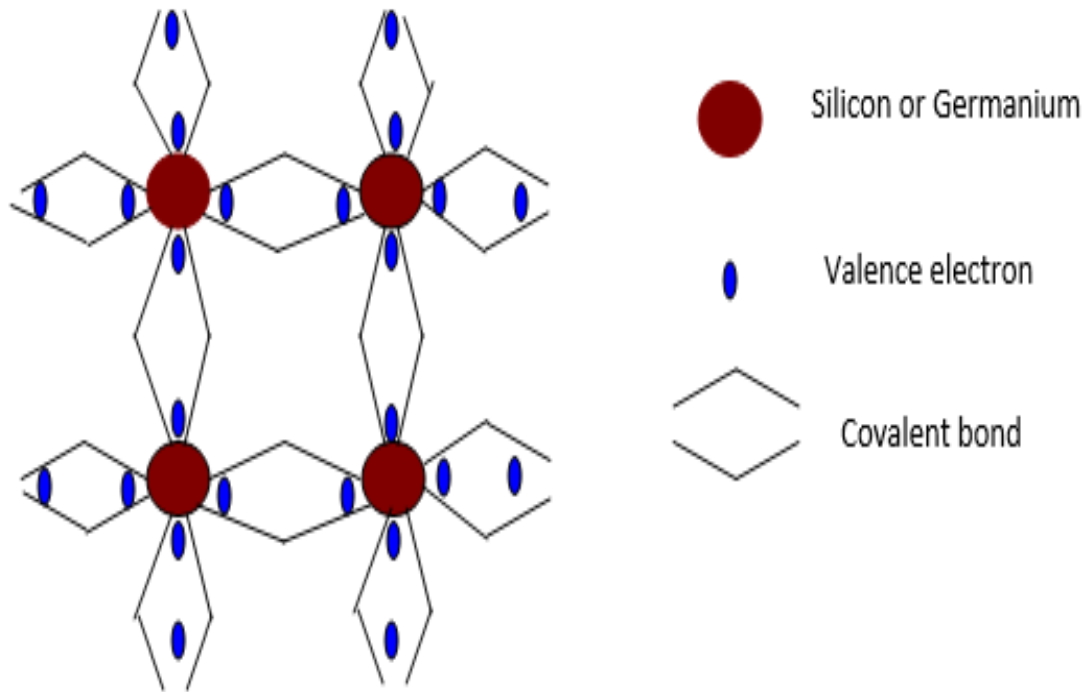
Example: Silicon  
Germanium



- 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 (**0-K**)

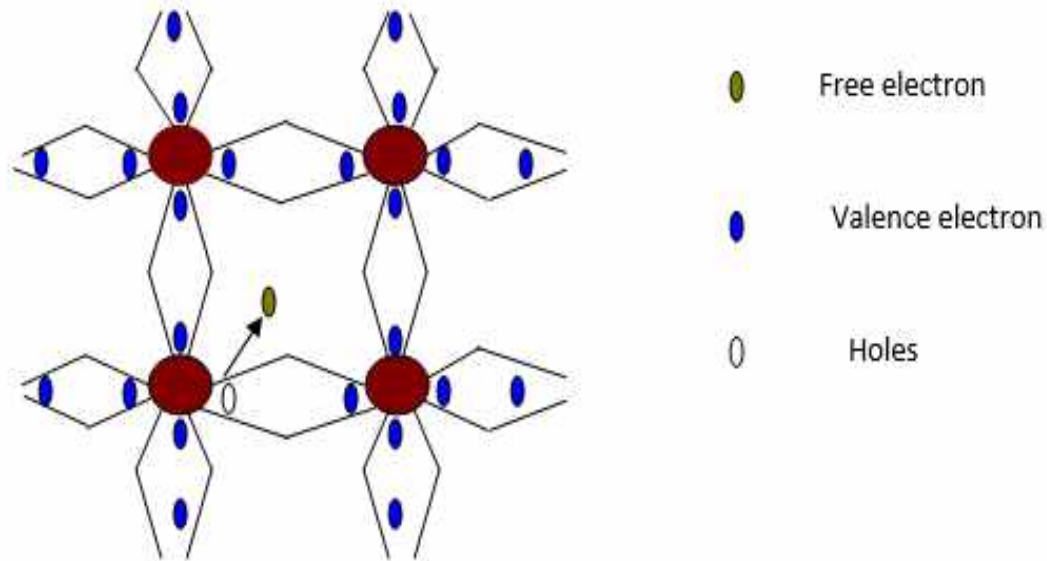


# Crystalline structure of Intrinsic Semiconductor at Room Temperature:

- 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

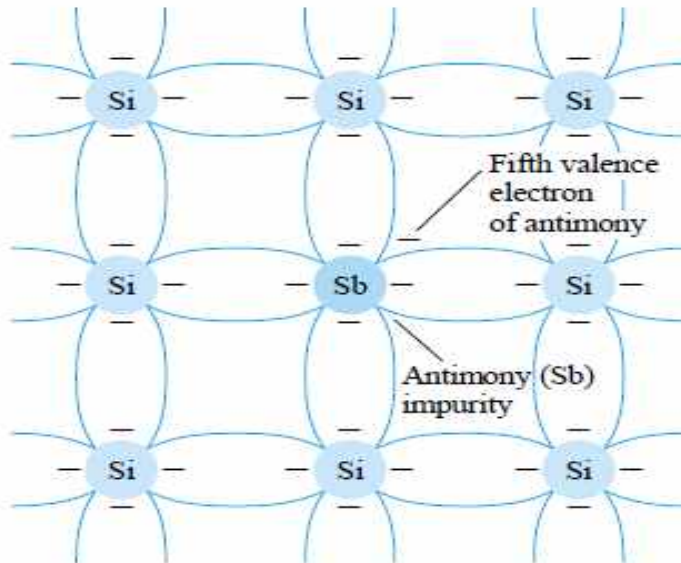


Figure 1.5 : n-type semiconductor

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



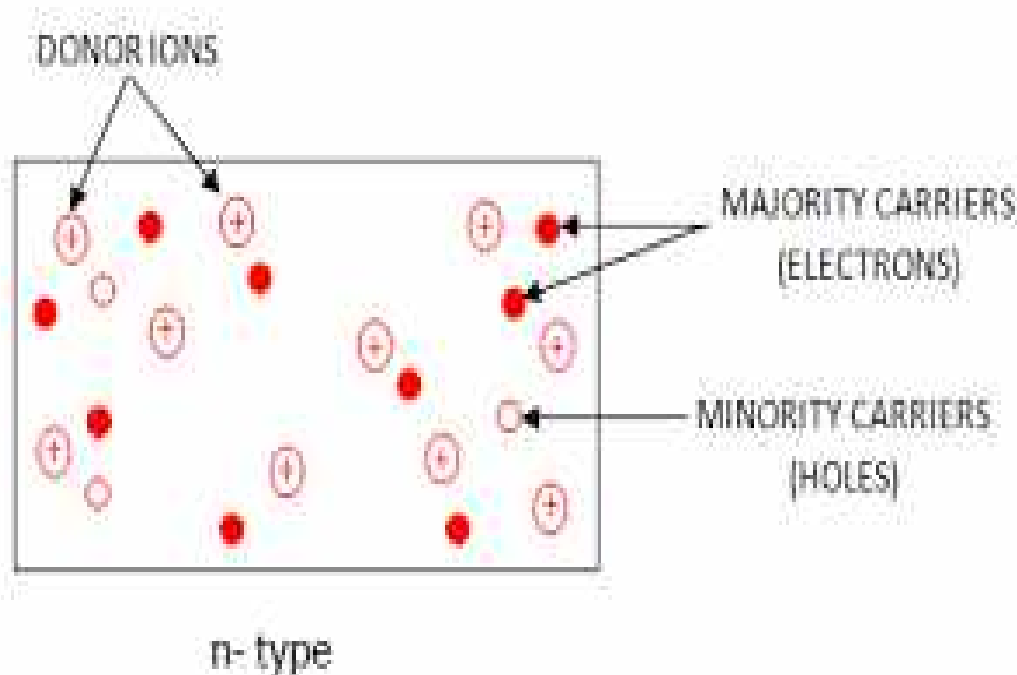
- For each Antimony atom added, one free electron will be available in the silicon crystal.
- Though each Antimony atom provides one free electrons yet an extremely small amount of Phosphorus impurity provides enough atoms to supply millions of free electrons.
- Due to thermal energy, still hole electrons 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



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

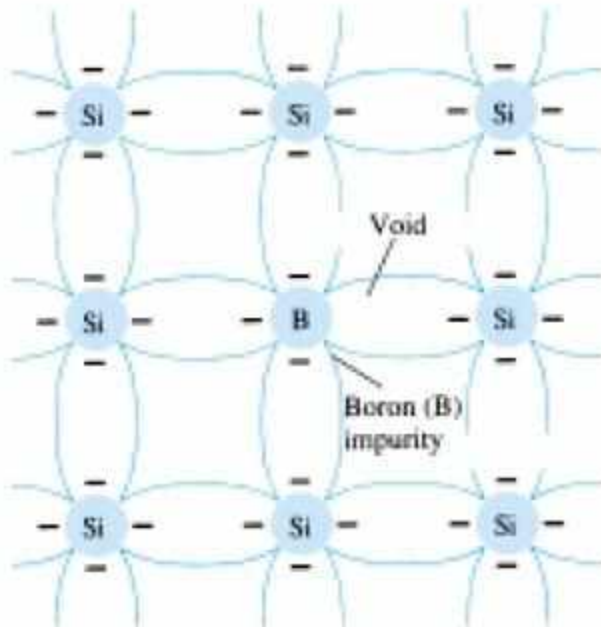


- Such impurities which produce p-type semiconductors are known as acceptor impurities
- Because the holes created can accept the electrons in the semi conductor crystal.



- 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 4<sup>th</sup> valence electrons of silicon left out because of short of one electron as shown in Fig 1.7





*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.*

**Figure 1.7 p-type semiconductors**



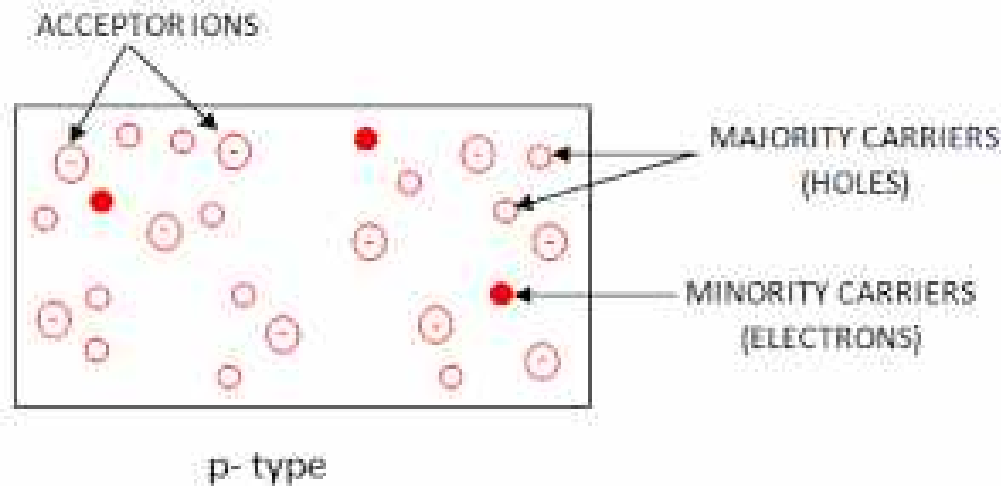
Thus in an p type semiconductor there are three types of charged particles:

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



# 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 one part of a semiconductor has a higher concentration than another part, then there is movement of charge carriers from the higher concentration side to the lower concentration side. This process is called diffusion.
- **Diffusion Current** is the current when movement of charge carriers is due to a 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.



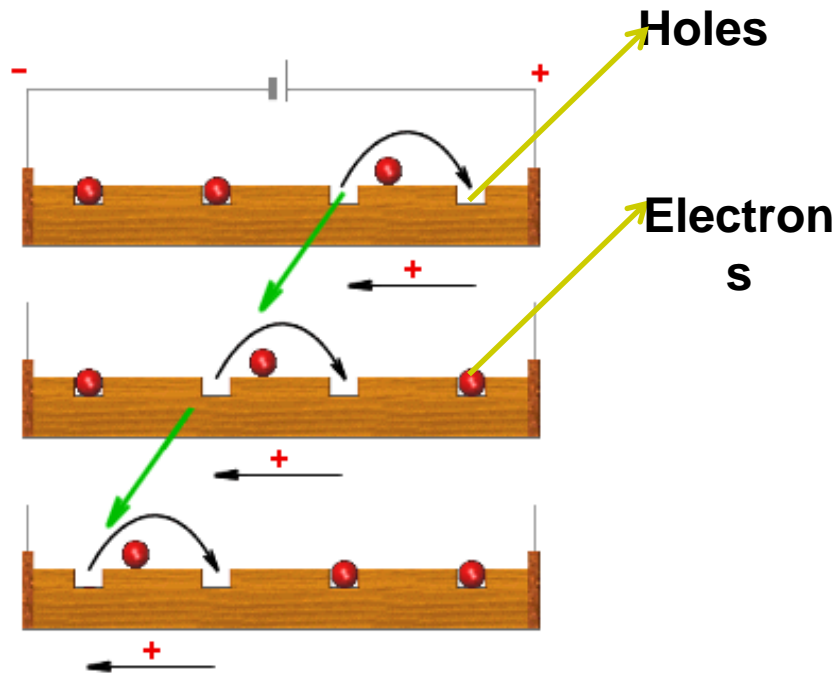
# Electron Motion:

- 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.



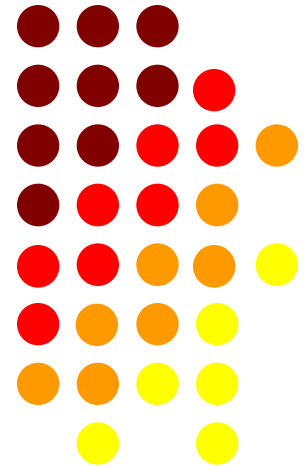
- The unit of electric current is Ampere (A)
- Since the flow of electric current is constituted by the movement of
  - Electrons in conduction band
  - Holes in valence band

Electrons and holes are referred as charge carriers.



# Lecture 2

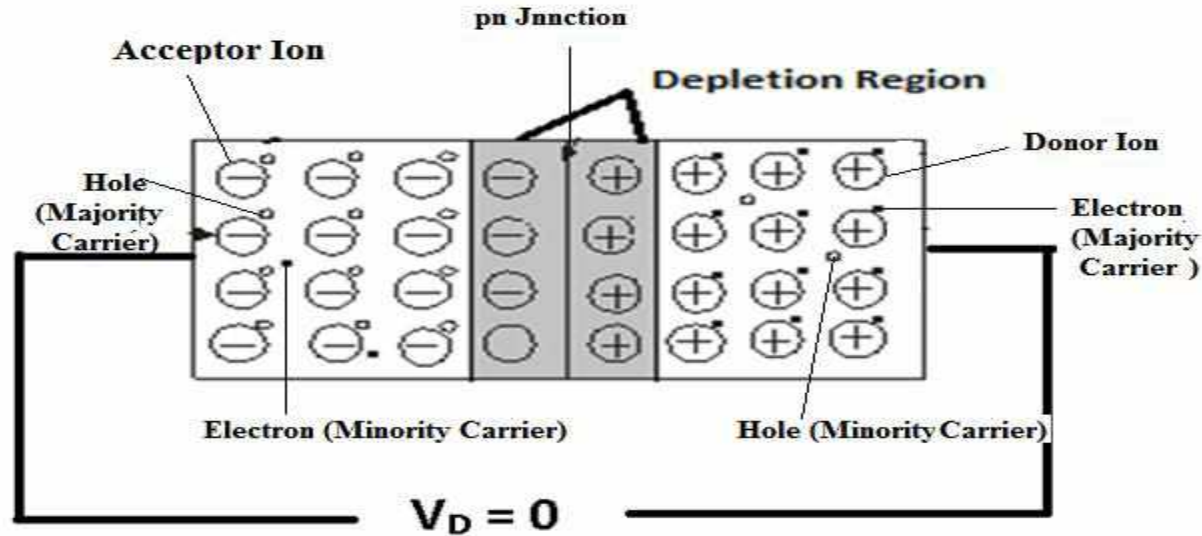
Working of semiconductor diode  
in no bias, forward bias  
conditions & reverse bias  
condition



# 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.

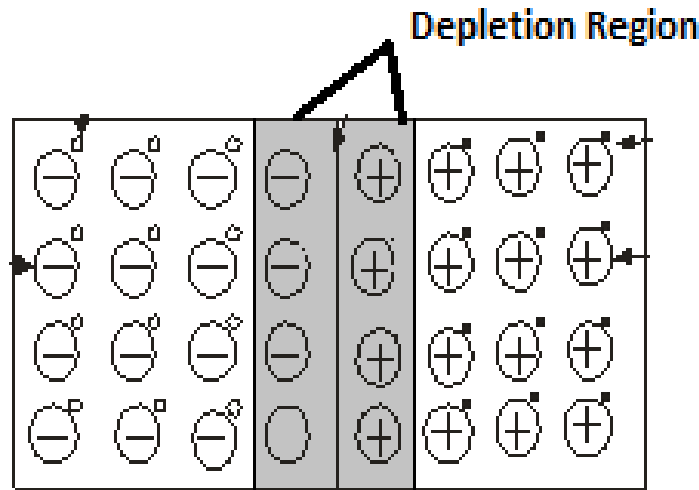




Initially there is diffusion of charge Carriers (electrons and holes) from both sides of the junction. These free charge Carriers recombine near the junction due to which region is formed which is known as depletion region



- Due to recombination between electron and holes a region near the junction is formed which contains only immobile ions and there is no free 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

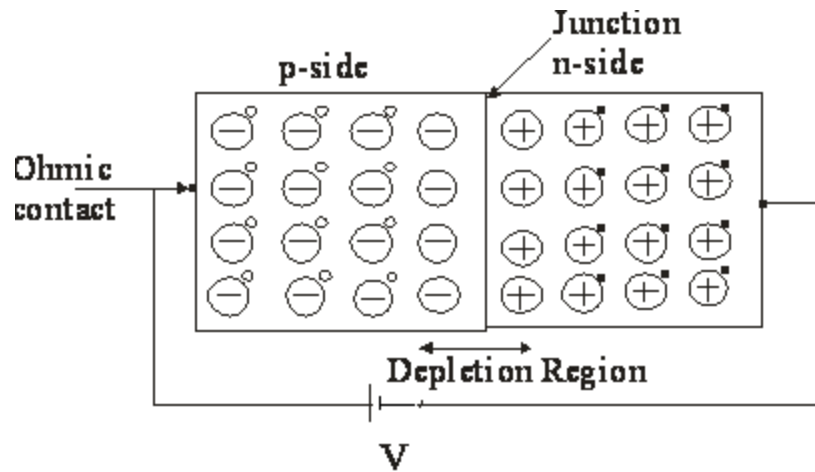
Connecting a p-n junction to an external d.c. voltage source is called biasing.

- 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:

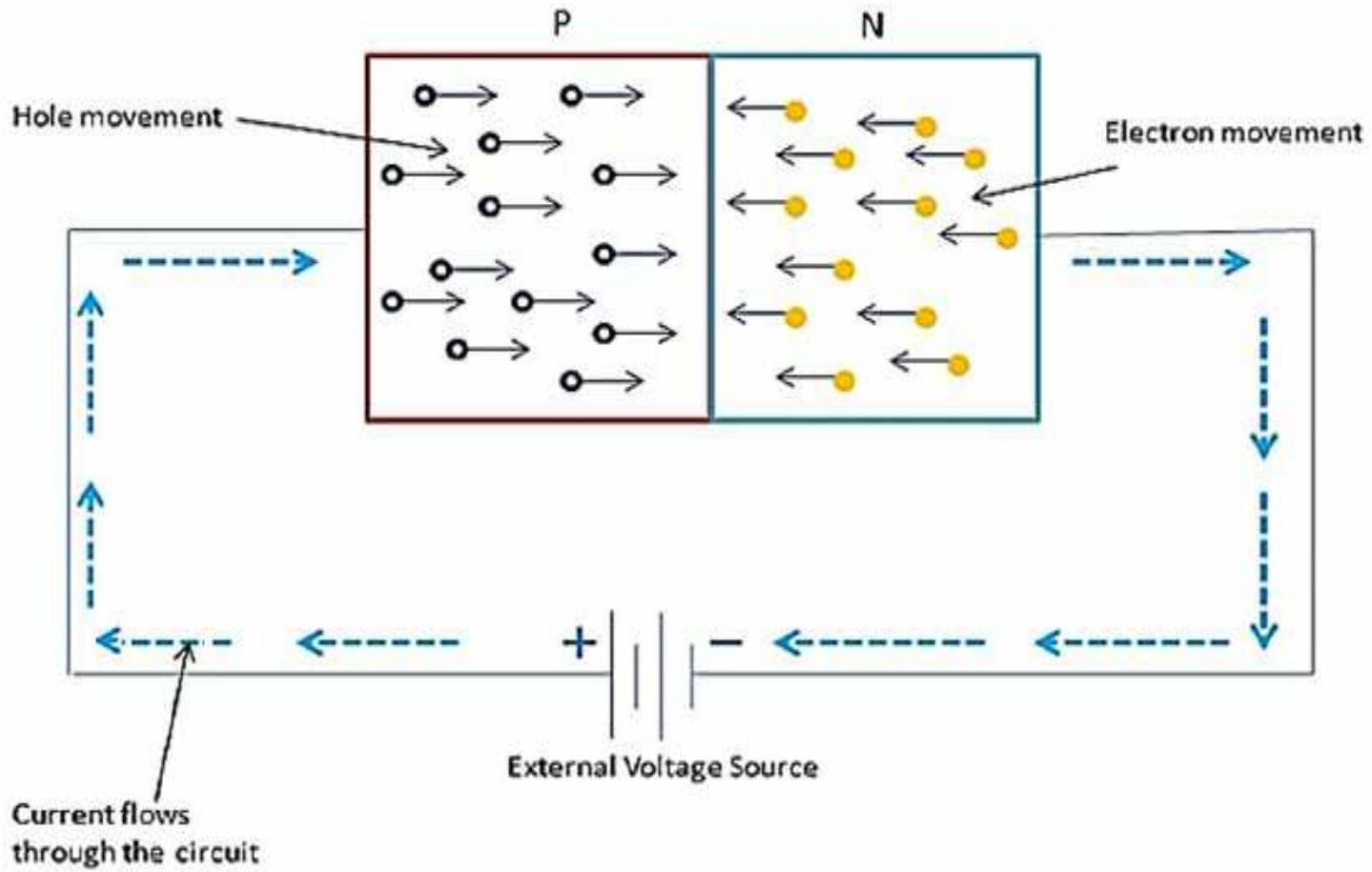




Majority carriers on both sides of the junction will move towards the junction

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



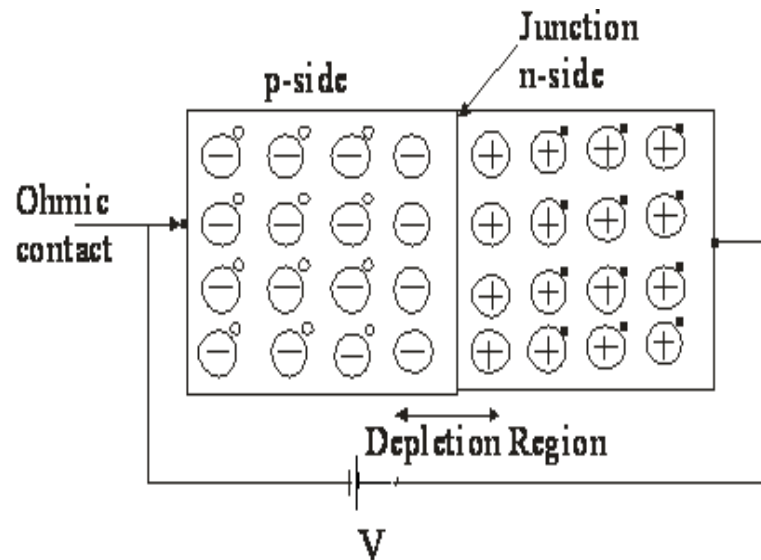


- As the majority carriers move towards the junction, width of depletion region will decrease.
- Net current across the junction is only due to majority charge carriers and its directions from p to n.
- A minimum positive voltage is required to start conduction in this condition. This minimum positive voltage is known as knee voltage or cut in voltage

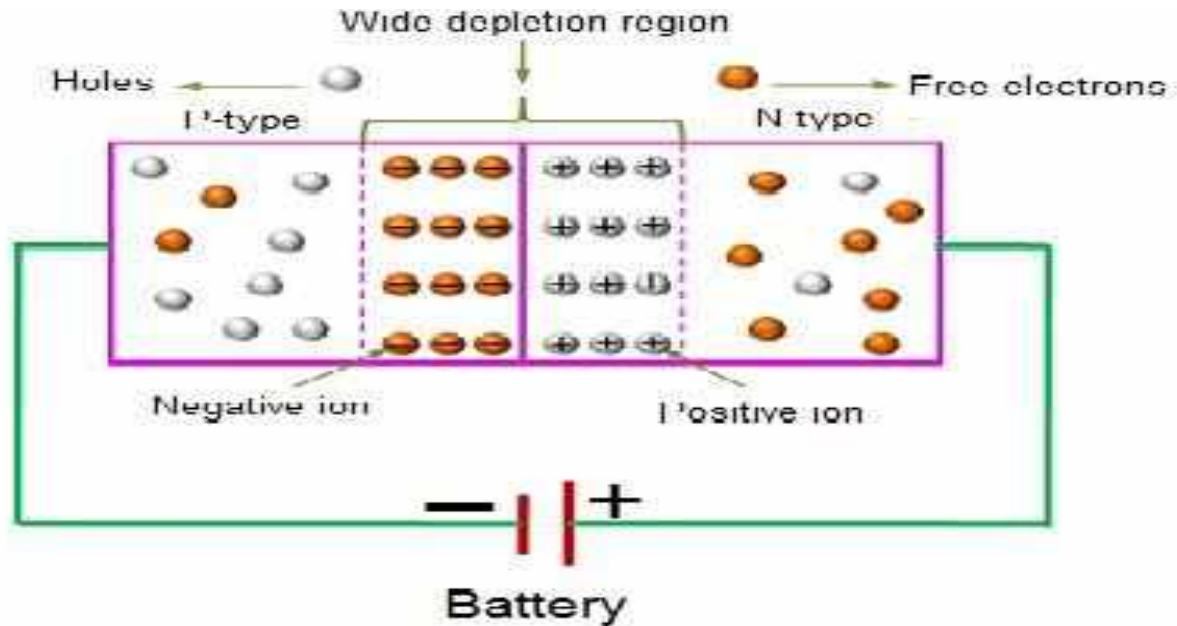


# Reverse Biasing

- 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.

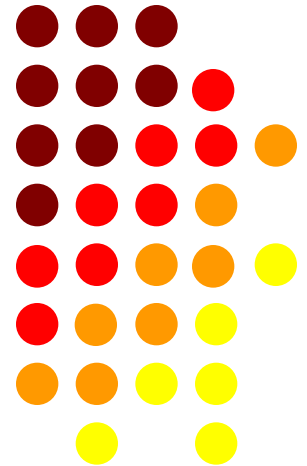


- As the majority of the carriers move away from the junction, width of depletion will increase
- Net current across the junction is only due to minority charge carriers and its directions from n to p.
- In Reverse bias condition the current across the junction is very small and become constant at very 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

$I_0$  = Reverse Saturation Current or Leakage Current

$V_D$  = Diode Voltage

$\eta$  (Ideality Factor) = 1 for Ge and 2 for Si

$V_T$  = Volt Equivalent of Temperature

$$= \frac{k}{11,600} \text{ Volts ( T should be in } ^\circ \text{K)}$$

At Room Temperature  $V_T = 26 \text{ mV}$



# Graphical Understanding of Diode Equation

Diode current equation is given by

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

## 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

$$V_D = +ve$$

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

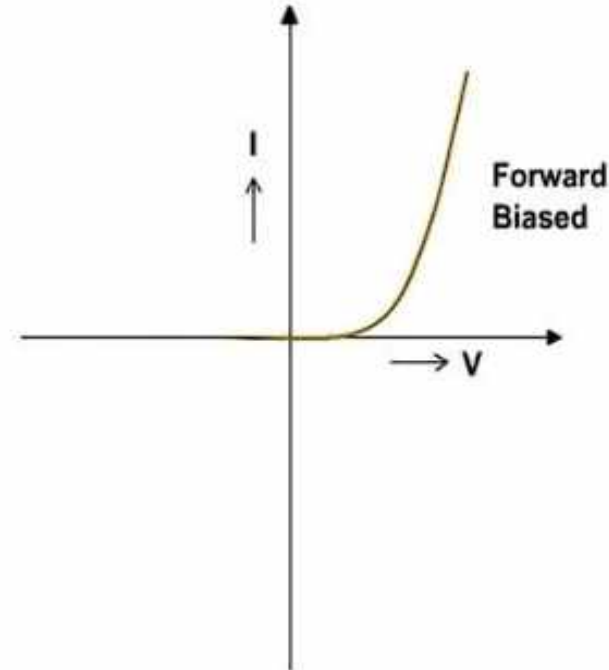
$$\text{But } e^{V_D/\eta V_T} \gg 1$$

So we can neglect the 1

therefore equation 1 becomes

$$I_D \cong I_0 e^{V_D/\eta V_T}$$

Hence Forward characteristics is of exponential nature.



# Reverse Bias Condition

$$V_D = -ve$$

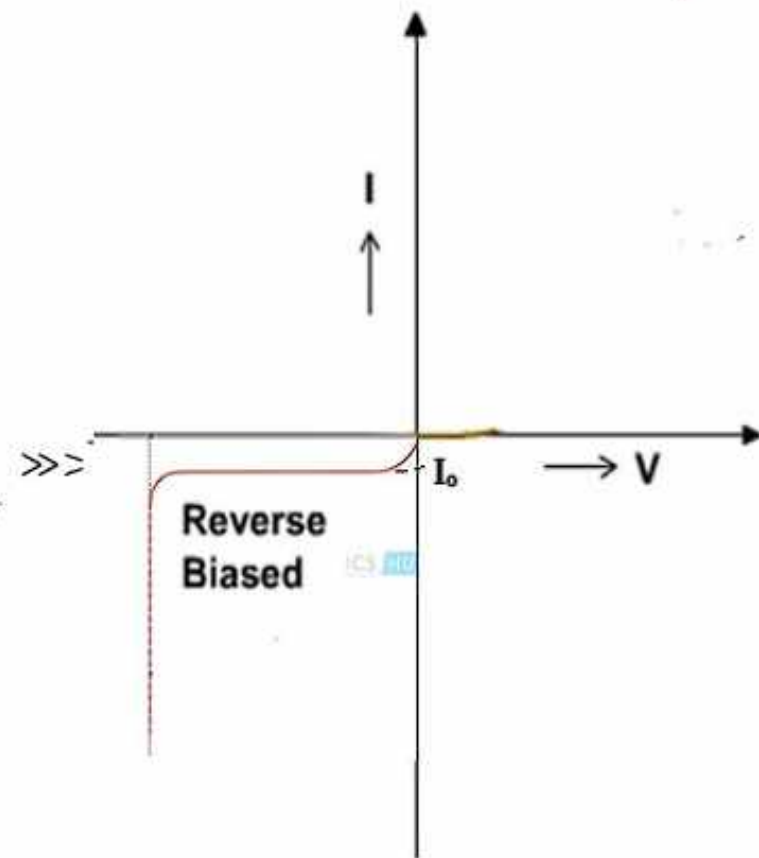
$$I_D = I_0 \left( e^{-V_D/\eta V_T} - 1 \right)$$

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

Therefore equation 1 becomes

$$I_D = I_0 (-1)$$

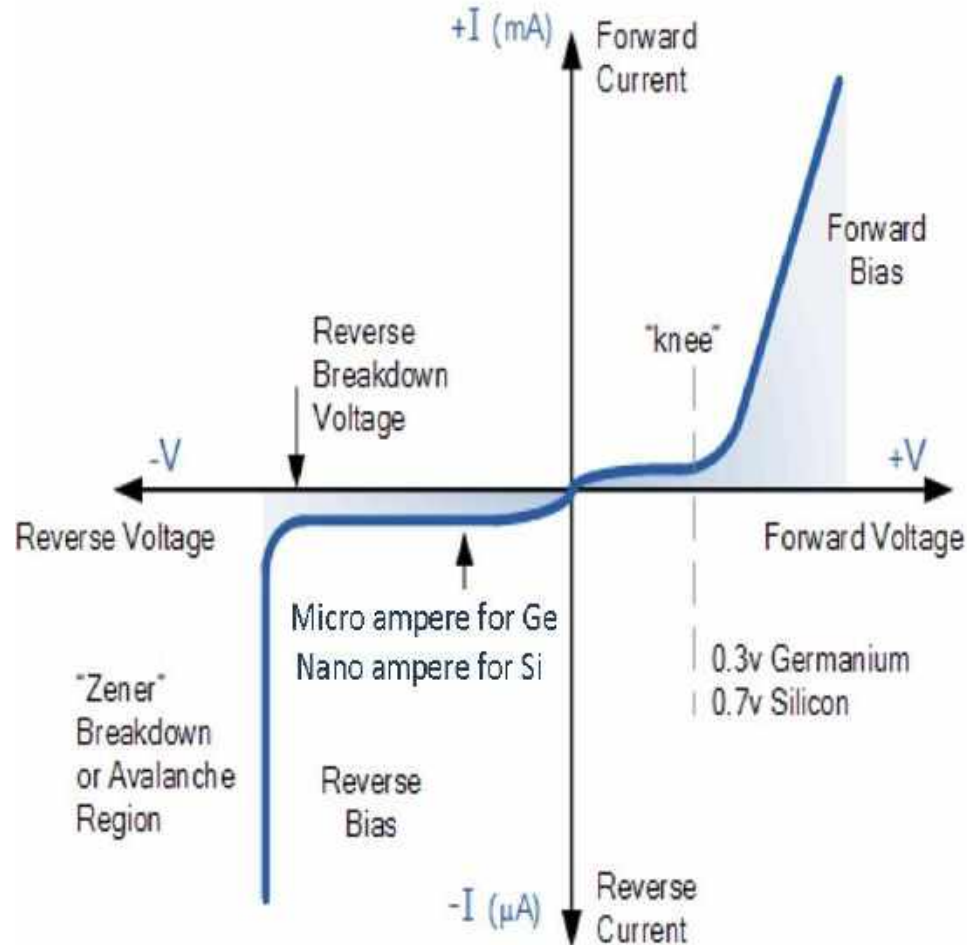
$$I_D = -I_0$$



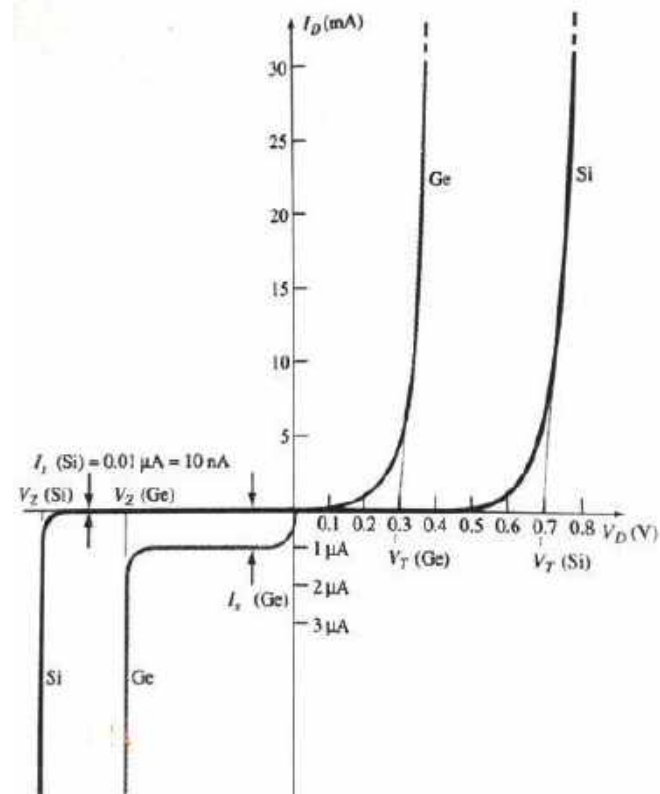
So reverse characteristic can be represented by straight line. (3<sup>rd</sup> quadrant)



# V-I characteristics of p-n junction diode



In equation 1 the value of current  $I$  also depends on  $\eta$ , 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  $\mu\text{A}$ )



# 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,  $V_r = 0.3\text{v}$

For Si,  $V_r = 0.7\text{v}$



# Temperature Dependence of V-I Characteristic

The diode current

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

Two parameters  $I_S$  and  $V_T$  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.

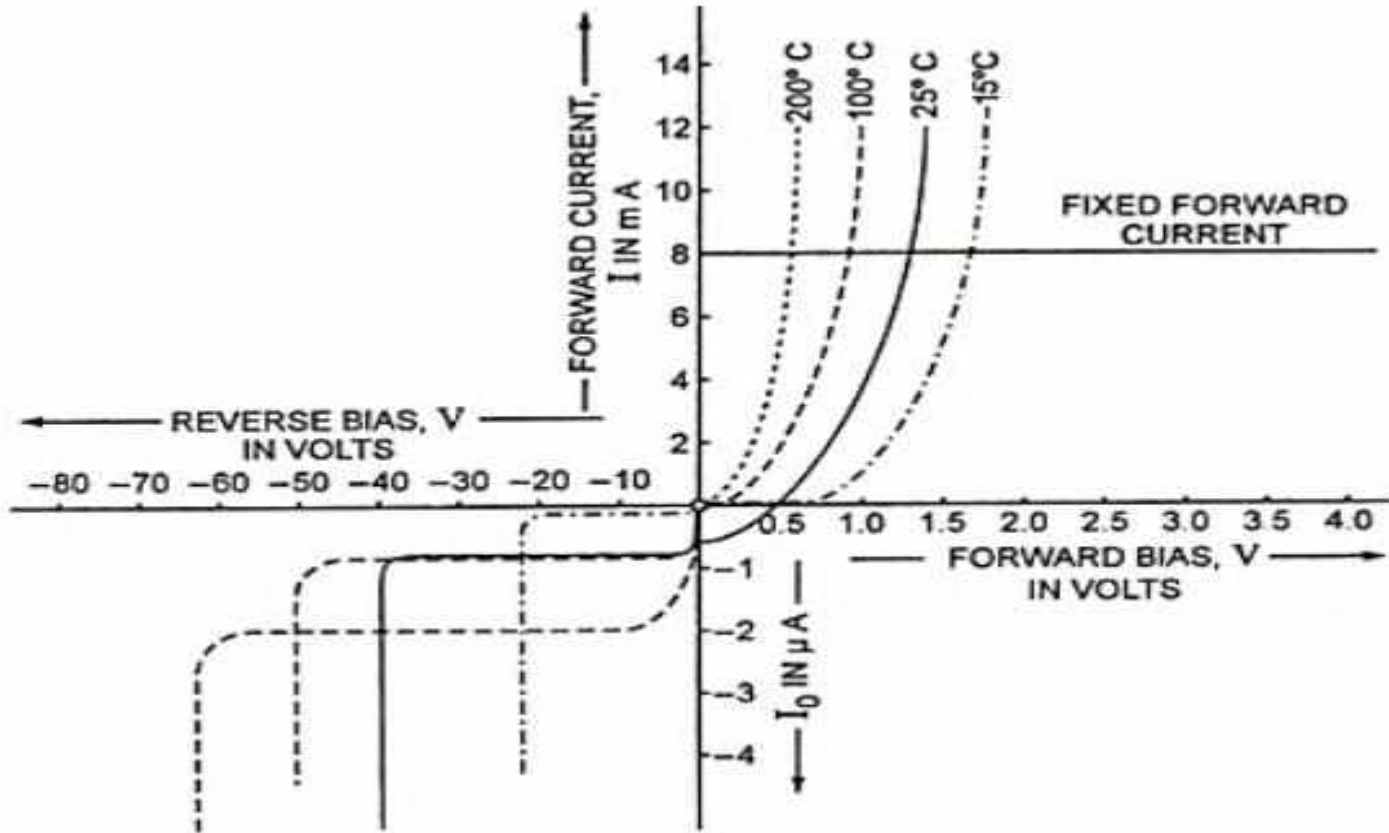
2. Reverse Bias :

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

$$I_{02} = I_{01} \left( 2^{T_2 - T_1 / 10} \right) = I_{01} \left( 2^{\Delta T / 10} \right)$$

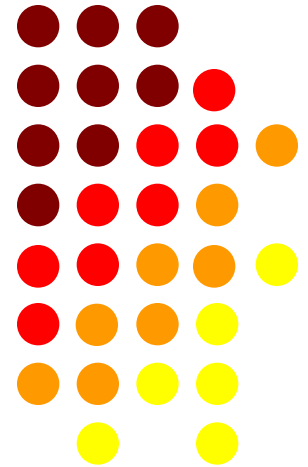
Breakdown voltage: Voltage increases with increase in temperature and vice versa.





# 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 :**

**$I = 1 \text{ mA}$  ,  $T = \text{Room temperature}$ , so  $V_T = 26 \text{ mV}$ ,  
 $V = 0.15 \text{ V}$**

**For Ge,  $\eta = 1$**

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

$$1 \times 10^{-3} = I_0 \left( e^{0.15/26 \times 10^{-3}} - 1 \right)$$

**$I_0 = 3.1319 \text{ micro ampere}$**



**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  $1.17 \times 10^{-9} \text{A}$  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

$\eta$  = ideality factor

$V_T$  = thermal voltage

$V$  = applied voltage



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

$$I_0 = 1.17 \times 10^{-9} \text{A}, V_T = 0.0252 \text{V}, \eta = 2, V = 0.4 \text{V}$$

$$\text{Therefore, } I = 1.17 \times 10^{-9} \times (e^{0.4/2 \times 0.025} - 1) =$$

- $$= 1.17 \times 10^{-9} \times (2980.9 - 1) = 3.486 \text{mA}.$$



**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  $25^{\circ}\text{C}$  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

$\eta$  = ideality factor

$V_T$  = thermal voltage

$V$  = applied voltage



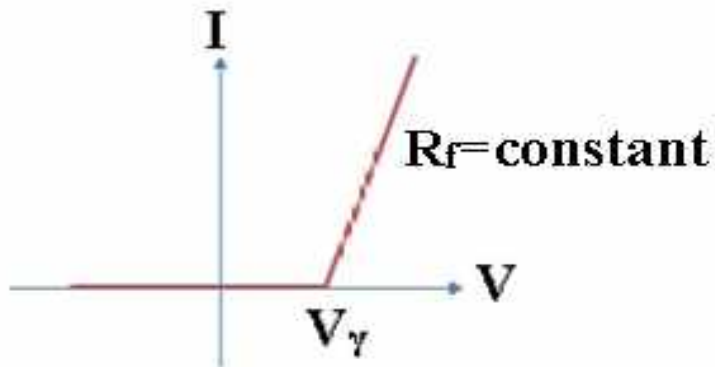
- $V_T$  at  $T = 25+273=298$  is  $298/11600 = 0.0256V$ ,  $\eta = 1.5$ ,  $I = 1mA$ ,  $I_0 = 10^{-10}A$

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



## 1. Piecewise linear equivalent circuits:

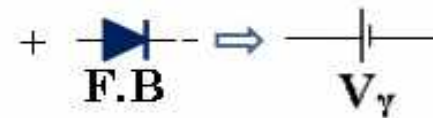
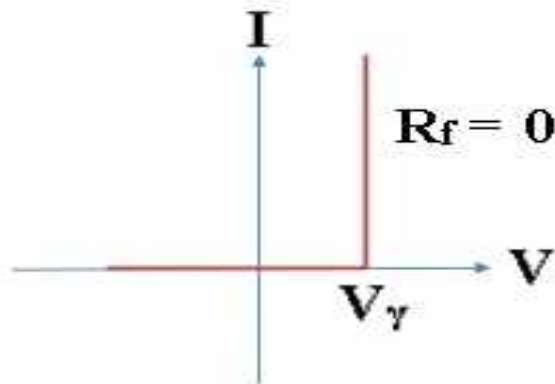
In this circuit diode non-linear characteristics is replaced by a straight line. So, resistance of diode is constant i.e.  $R_f$  is constant. Diode is replaced by battery with resistance in series.



# Diode Equivalent Circuit

## 2. Simplified equivalent circuits:

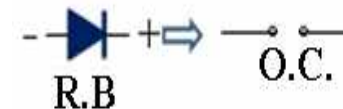
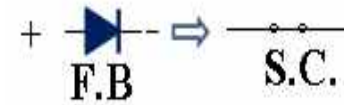
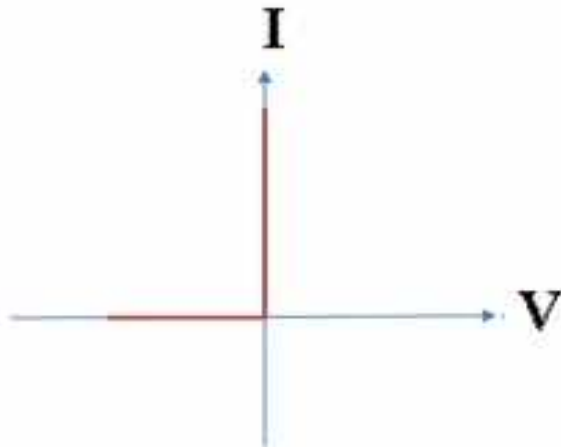
Since diode forward resistance is low so it can be neglected i.e.  $R_f = 0$ . Diode is replaced by battery.



# Diode Equivalent Circuit

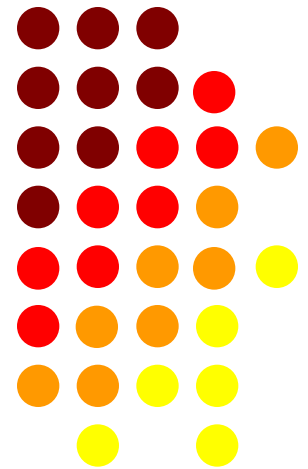
## 3. Ideal equivalent circuits:

In ideal diode  $R_f = 0$ ,  $V_y = 0$  and  $I_o = 0$ . An ideal diode can be used as a perfect switch.

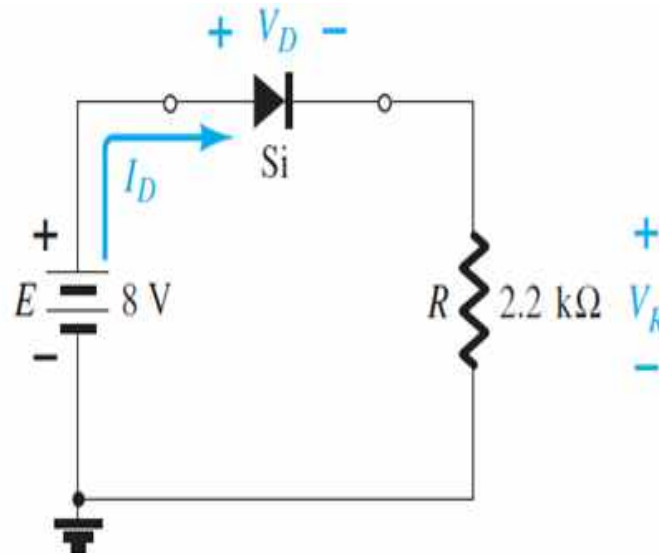


# Lecture 5

Problems based on  
series & parallel  
circuits of diodes

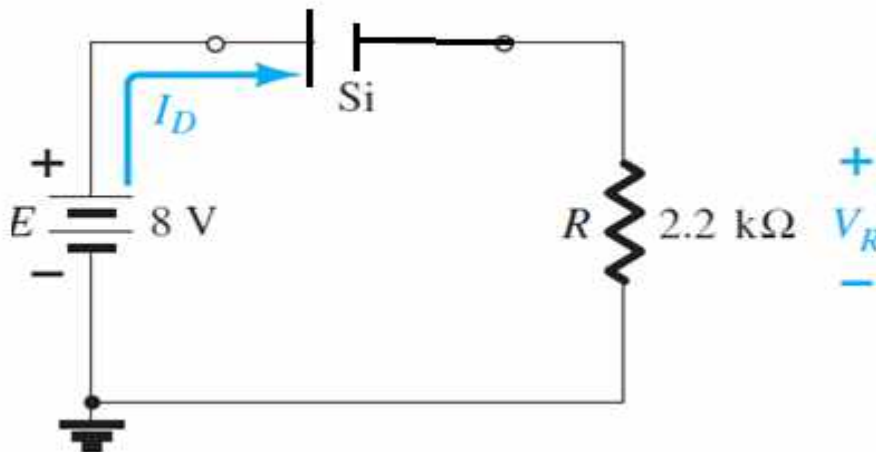


**Example: 1** For the series diode configuration shown in fig. determine  $V_D$ ,  $V_R$  and  $I_D$ .



**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,

0.7 V



**Applying KVL**

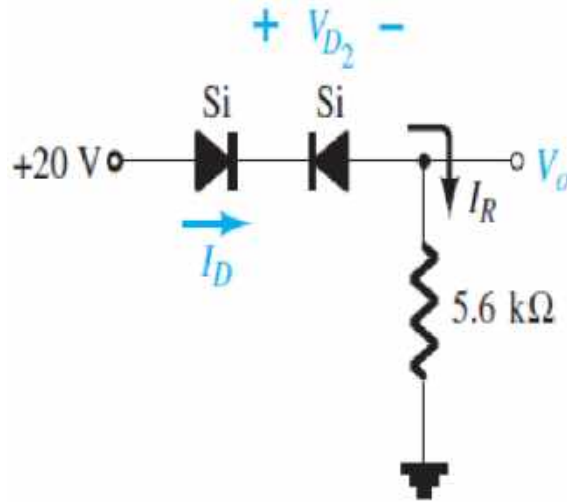
$$- 0.7 - 2.2 \text{ K } I_D + 8 = 0$$

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

$$V_R = I_D R = 3.32 \text{ mA} \times 2.2 \text{ k}\Omega = 7.3 \text{ V}$$



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



$$I_D = 0$$

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

Applying Kirchhoff's voltage law in a clockwise direction gives

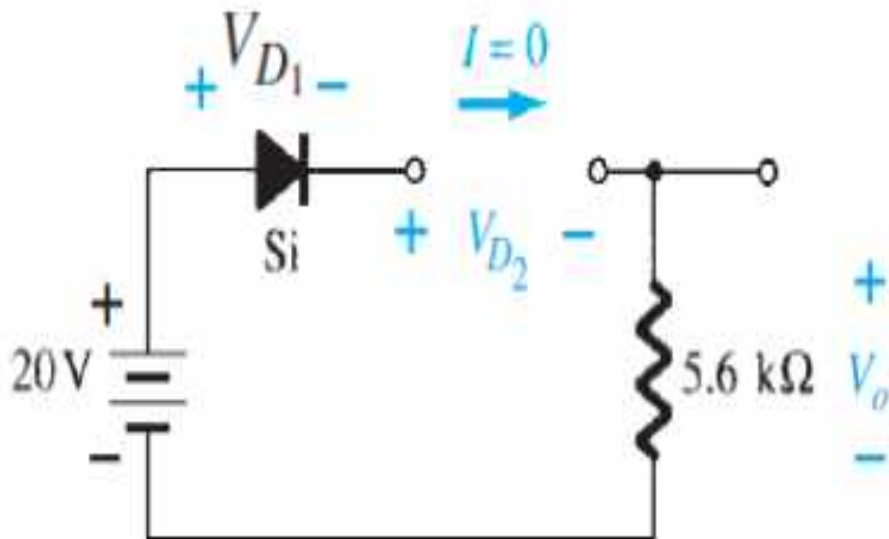
$$20 - 0.7 - V_{D2} - V_o = 0$$

$$V_{D2} = 20 - 0.7 - 0 = 19.3 \text{ V}$$

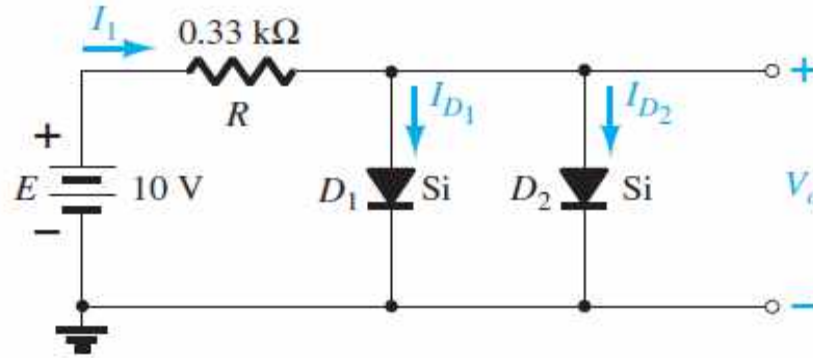


Solution:

Equivalent circuit



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

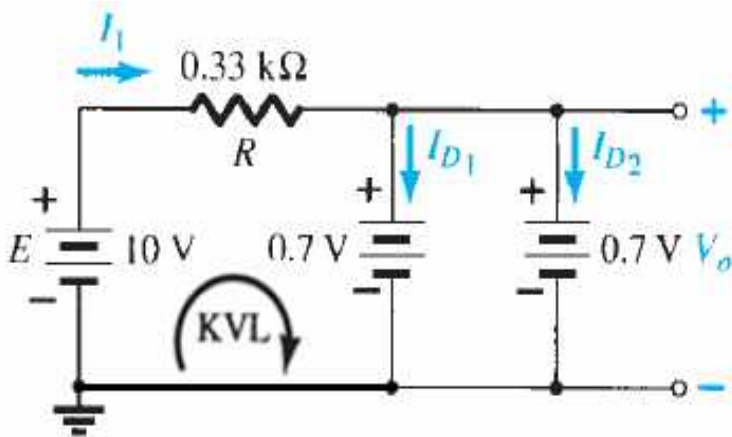


**Solution :**

**Applying KVL**

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

$$I_1 = 28.8 \text{ mA}$$



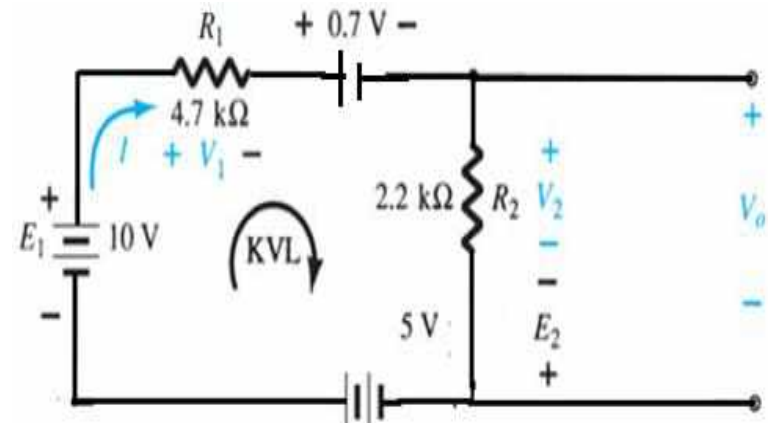
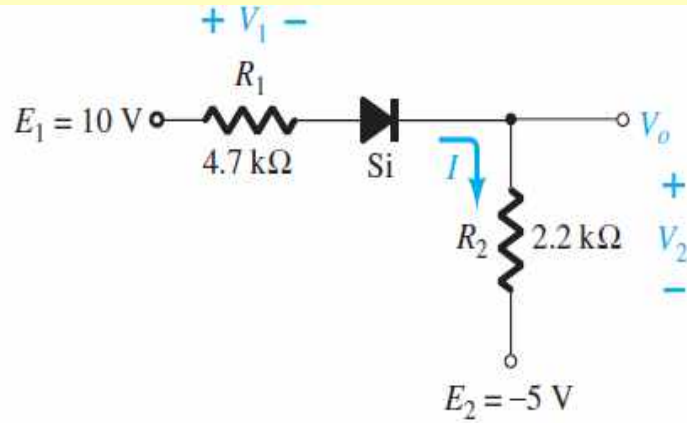
Assuming diodes of similar characteristics, we have

$$I_{D1} = I_{D2} = \frac{I_1}{2} = \frac{28.18 \text{ mA}}{2} = 14.09 \text{ mA}$$

**KVL :  $V_o - 0.7 = 0$  ,  $V_o = 0.7 \text{ V}$**



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



Applying KVL

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

$$I_1 = 28.8 \text{ mA}$$

$$- 4.7 \text{ K}\Omega I - 0.7 \text{ V} - 2.2 \text{ K}\Omega I + 5 - 10 = 0$$

$$I = 2.07 \text{ mA}$$

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

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

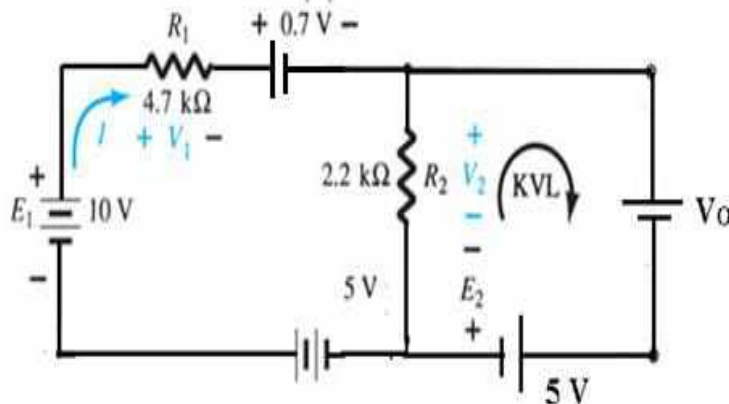
Applying KVL

$$-V_O - 5\text{V} + 4.55\text{V} = 0$$

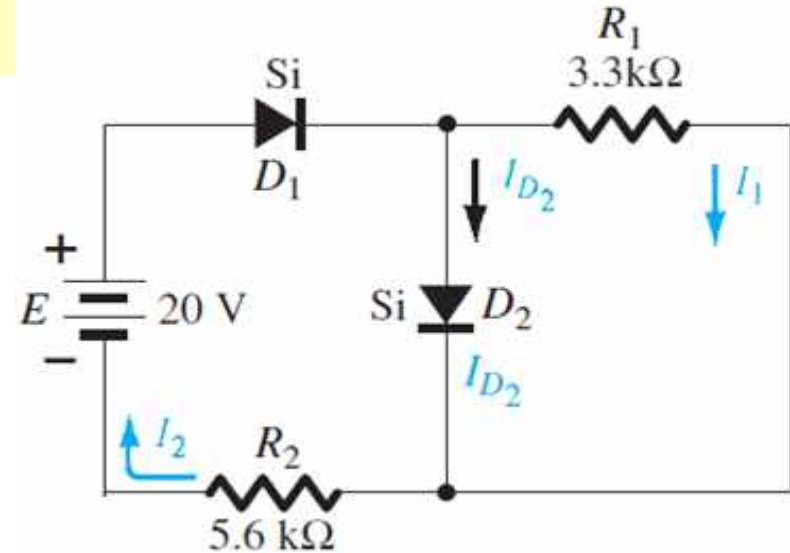
$$V_O = -0.45 \text{ V}$$



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



Applying KVL

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

$$I_2 = 3.32 \text{ mA}$$

Applying KVL

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

$$I_1 = 0.212 \text{ mA}$$

Now from KCL

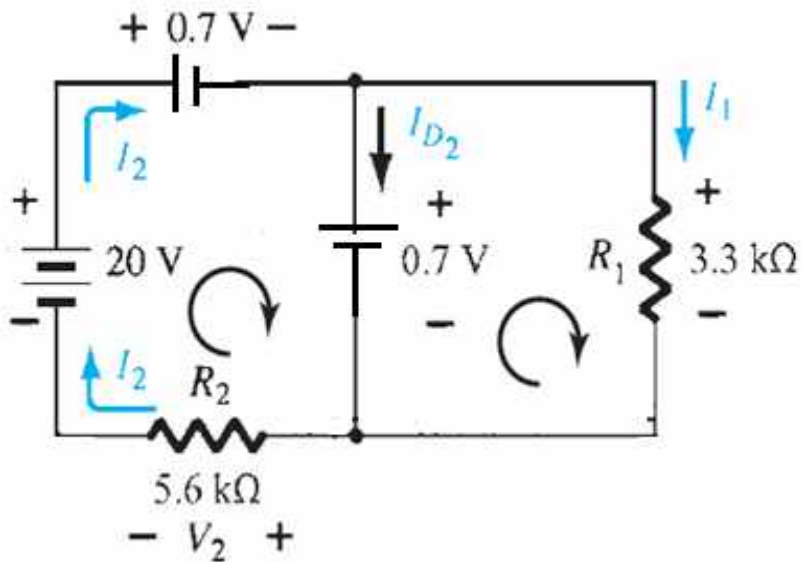
$$I_1 + I_{D1} = I_2$$

$$I_{D1} = I_2 - I_1$$

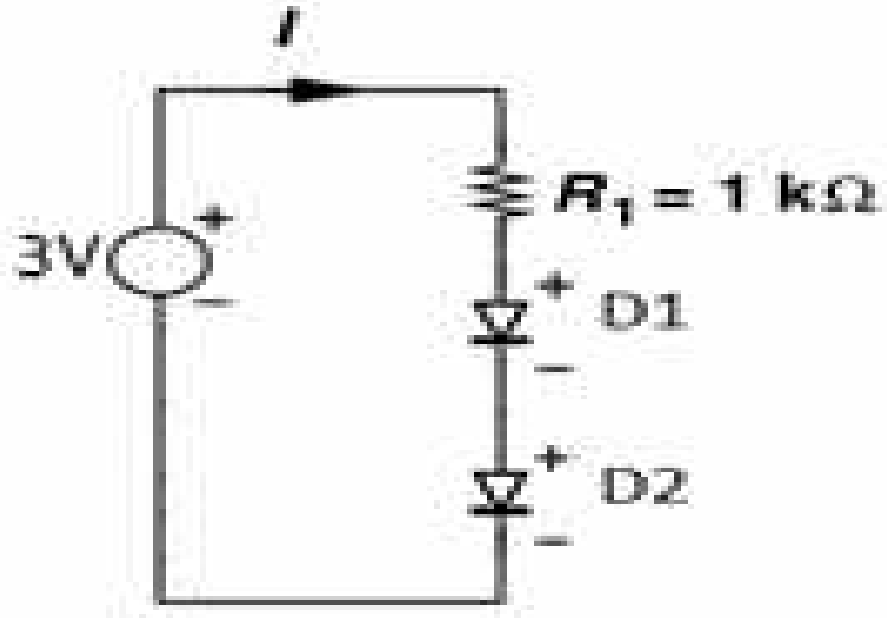
$$I_{D1} = 3.32 \text{ mA} - 0.212 \text{ mA}$$

$$= 3.102 \text{ mA}$$

Solution:  
Equivalent circuit



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



✦ Explanation: Let  $V_D$  be the voltage of diode, then by Kirchoff's loop rule

✦ 
$$3V = 2V_D + IR_1$$

✦ This method of assumption contains small error but it is the simplest method.

✦ Let  $V_D$  be 0.6V.

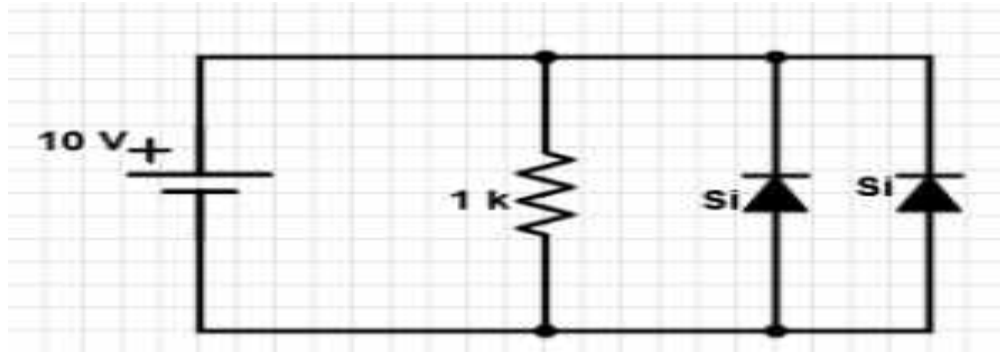
✦ Now the current  $I = (3-1.2)/1k = 1.8mA$ .

The  $V_D = V_T \ln((I/I_0)+1) = 0.58V$

Hence current is  $(3-(2 \times 0.58))/1k = 1.84mA$ .



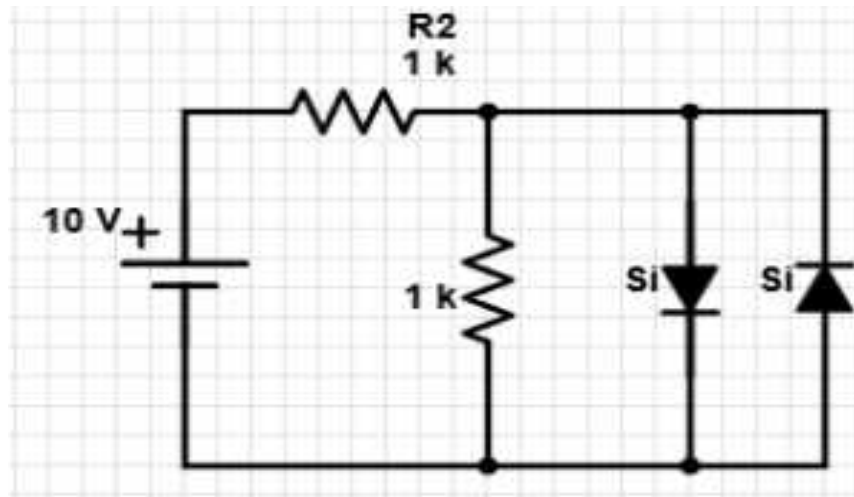
**Example: 6.** From the given circuit, what is the value of current flowing through the 1 k resistor parallel to the diodes?



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



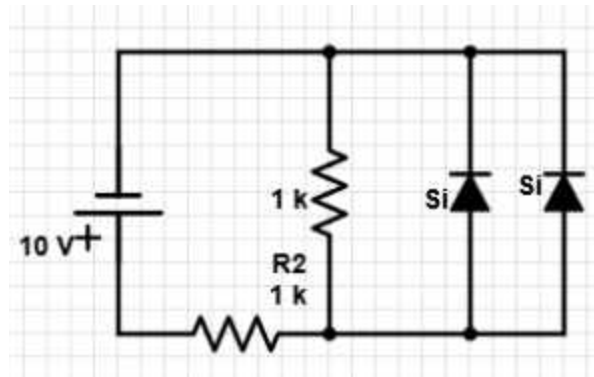
**Example 7.** From the given circuit, what is the value of current flowing through the 1 k resistor?



- ✦ 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  $\Rightarrow$  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  $\Omega$ . If the forward resistance of diode is 10  $\Omega$ , find :**

- (i) peak current through diode**
- (ii) peak output voltage**

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



★ **Solution :**

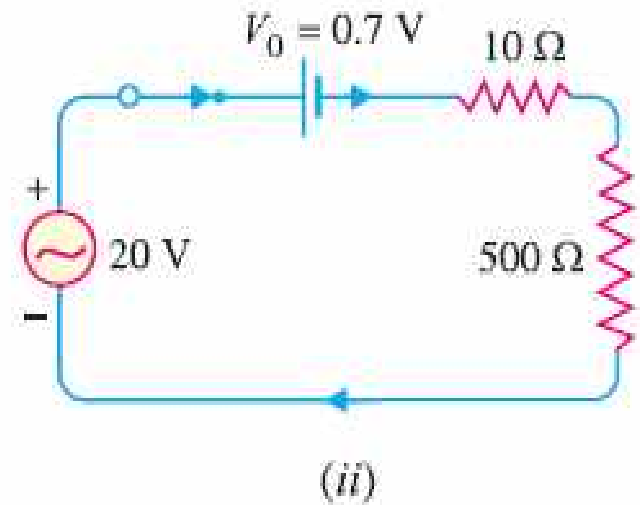
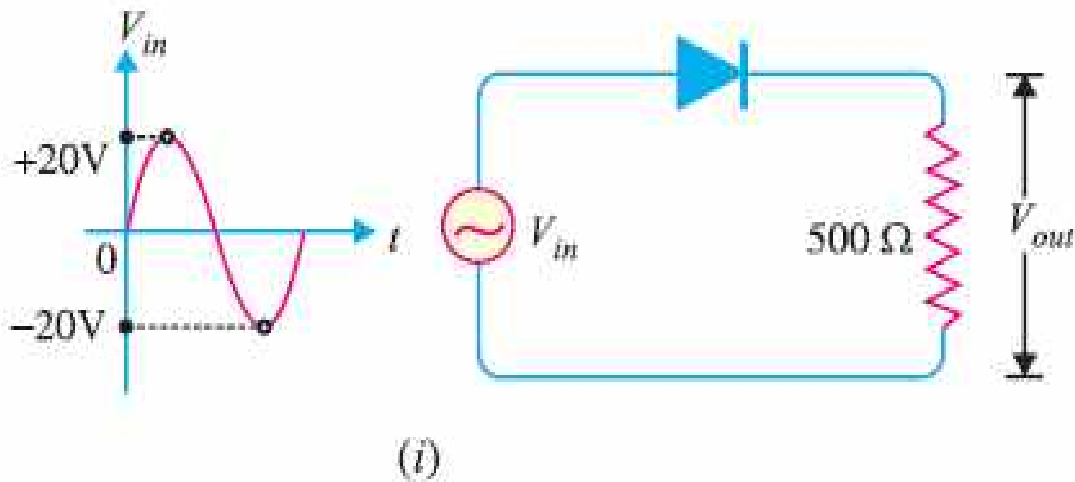
★ Peak input voltage = 20 V

Forward resistance,  $r_f = 10 \Omega$

Load resistance,  $R_L = 500 \Omega$

Potential barrier voltage,  $V_0 = 0.7 \text{ V}$

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.  $V_{in} = V_F = 20 \text{ V}$

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

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

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



# 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

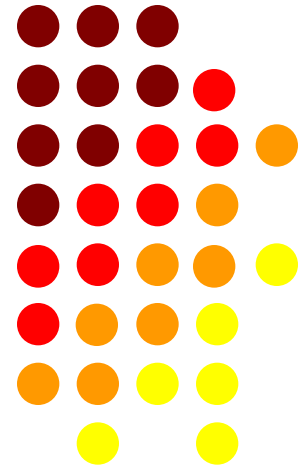
$$(I_f)_{peak} = \frac{V_F}{R_L} = \frac{20 \text{ V}}{500 \Omega} = 40 \text{ mA}$$

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



# Lecture 6

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



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)**



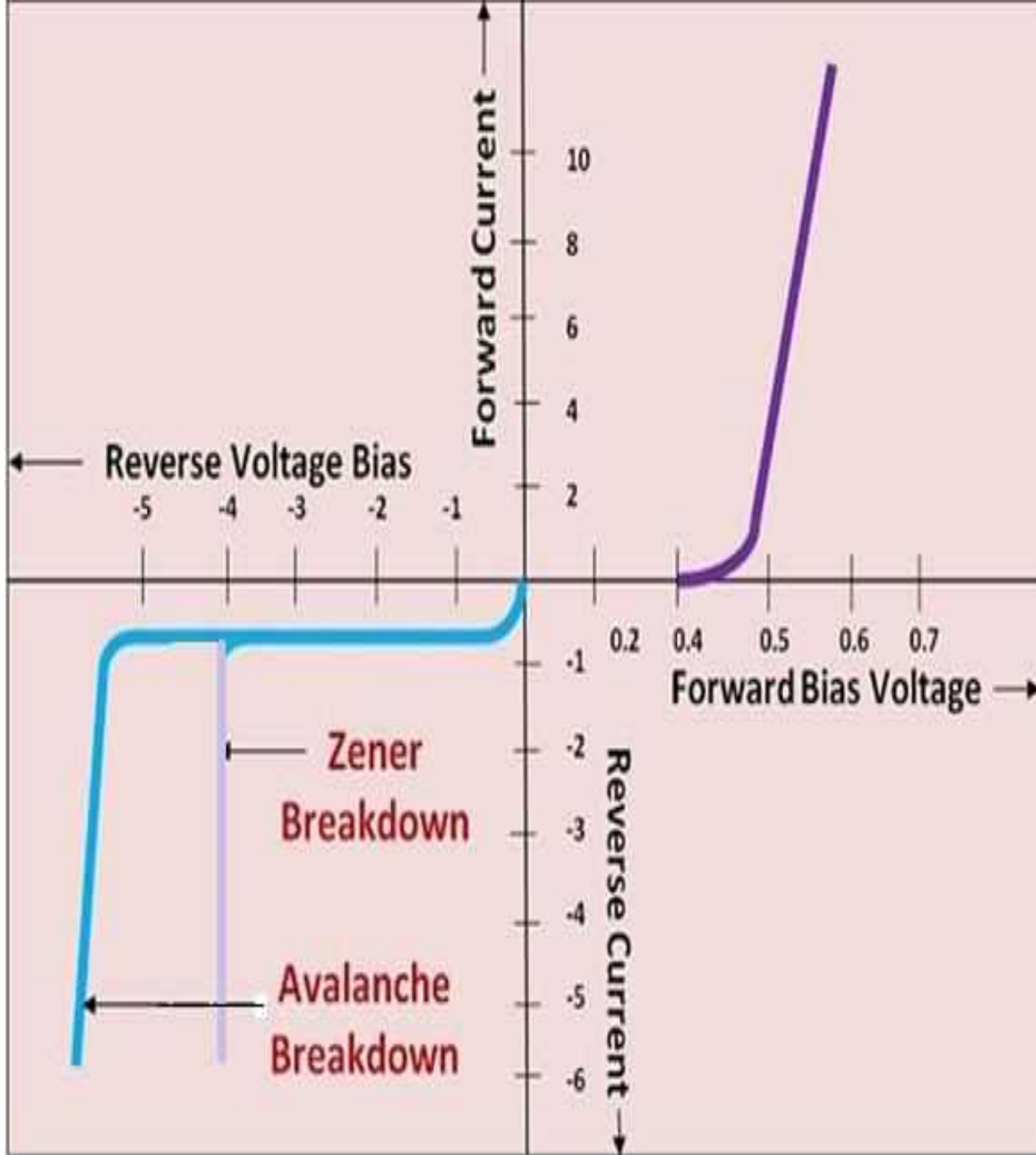
# Avalanche Breakdown

- 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.



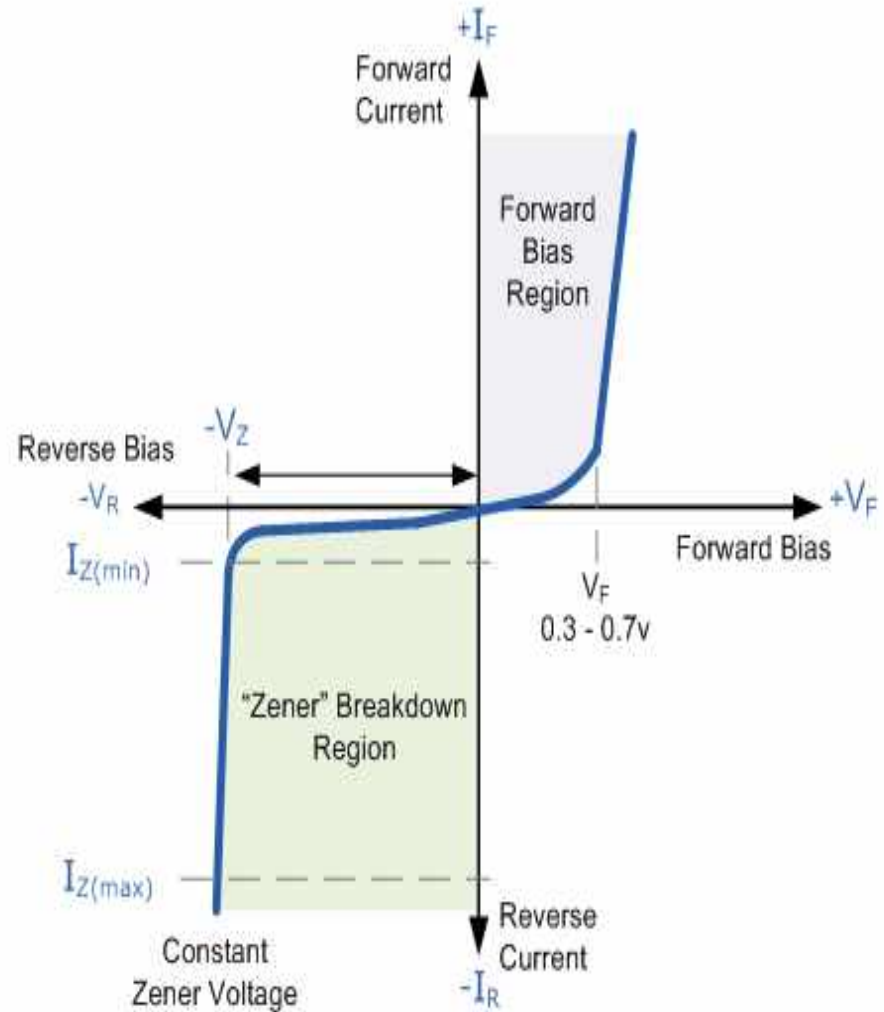
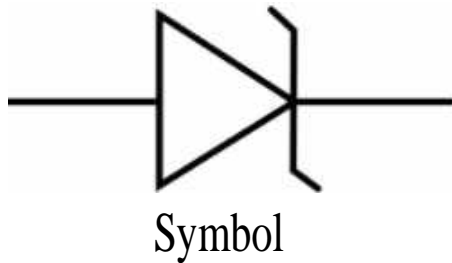
- While travelling, these accelerated minority carriers will collide with the stationary atoms and impart some of the kinetic energy to the valence electrons present. These valence electrons will break their covalent bonds and jump into the conduction band to become free for conduction.
- Now these newly 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)**



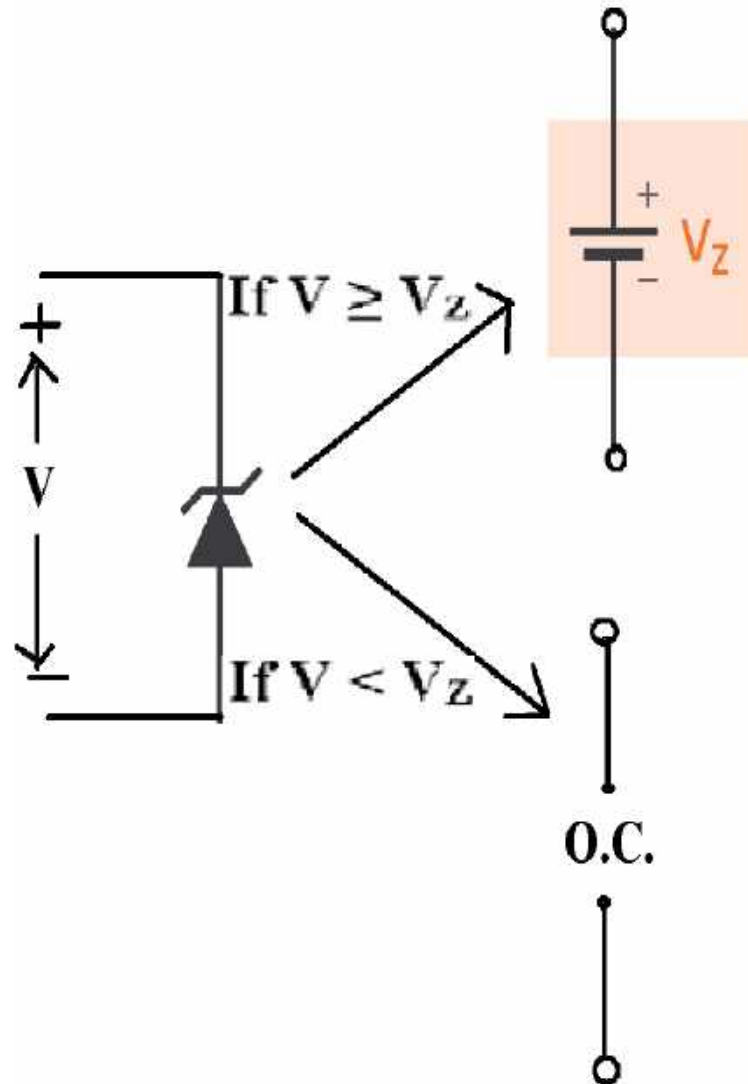


# Zener Diode

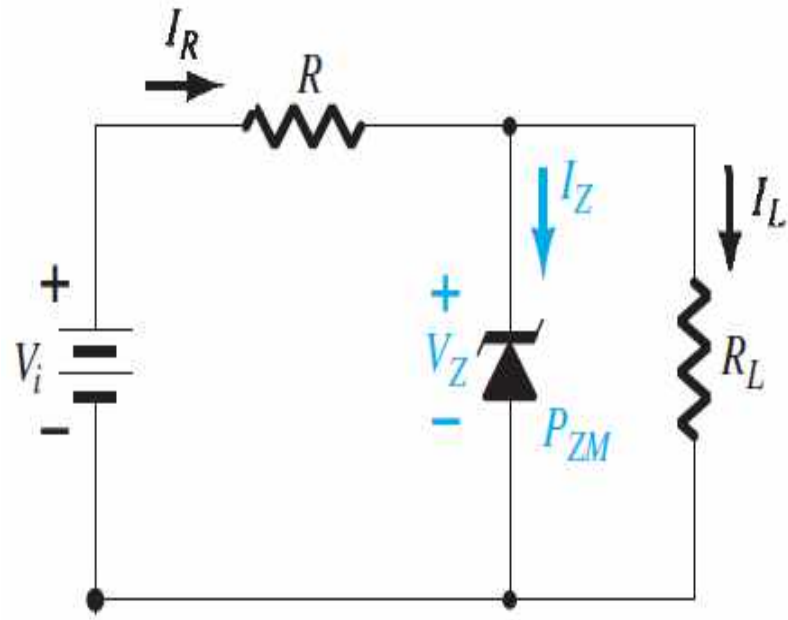
- Zener diode is a special diode, which works in breakdown
- It is used for voltage regulation



# 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.

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

$$\uparrow I_R = \uparrow I_Z + I_L \dots \dots \dots 2$$

← 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

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

$$\downarrow I_R = \downarrow I_Z + I_L \dots\dots\dots 2 \quad \text{Constant}$$

**(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.

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

$$I_R = \uparrow I_Z + I_L \dots\dots 2$$

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.

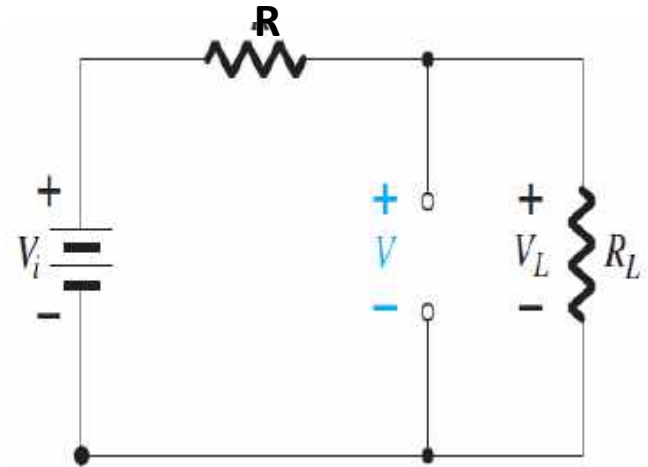
→  $I_L \uparrow = \frac{V_L}{R_L} = \frac{V_Z}{R_L \downarrow} \dots\dots 1$   
 Constant  $I_R = \downarrow I_Z + I_L \uparrow \dots\dots 2$



# Steps for Solving Zener Diode Numerical

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

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



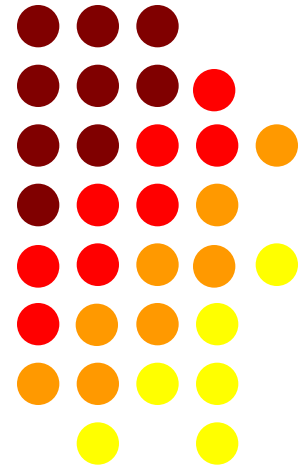
If  $V \geq V_Z$ , the Zener diode is on, and the appropriate equivalent model can be substituted.  
If  $V < V_Z$ , the diode is off, and the open-circuit equivalence is substituted.

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

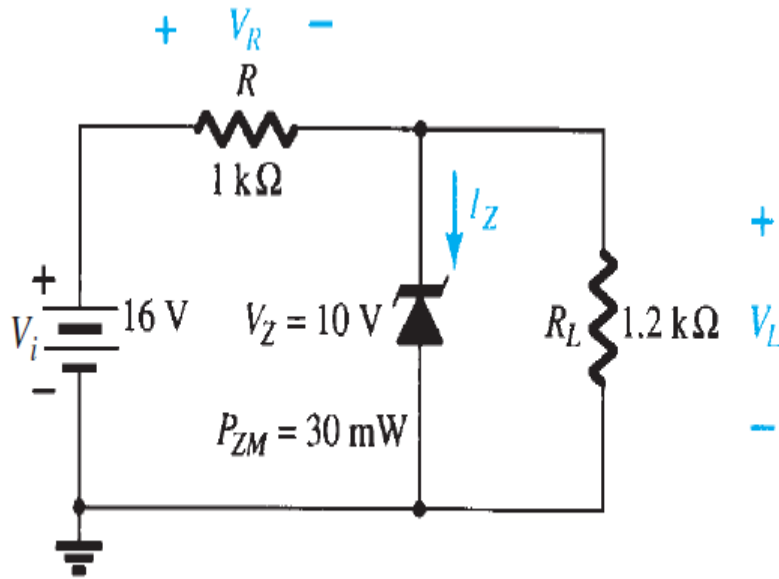


# Lecture 7

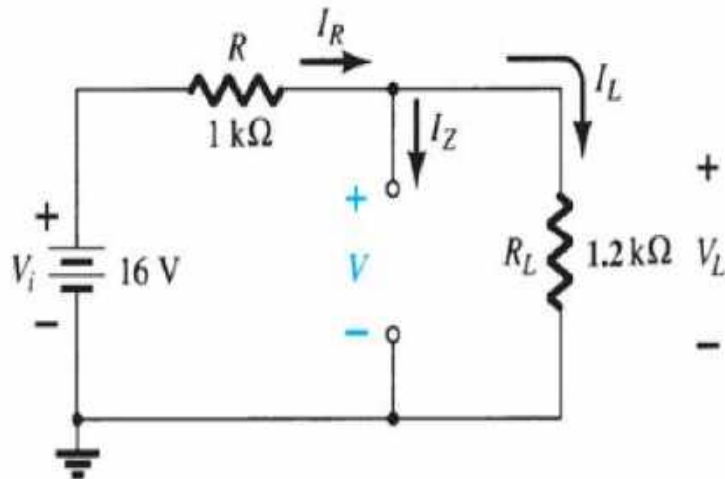
## Problems based on voltage regulator



**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:**

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

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

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

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

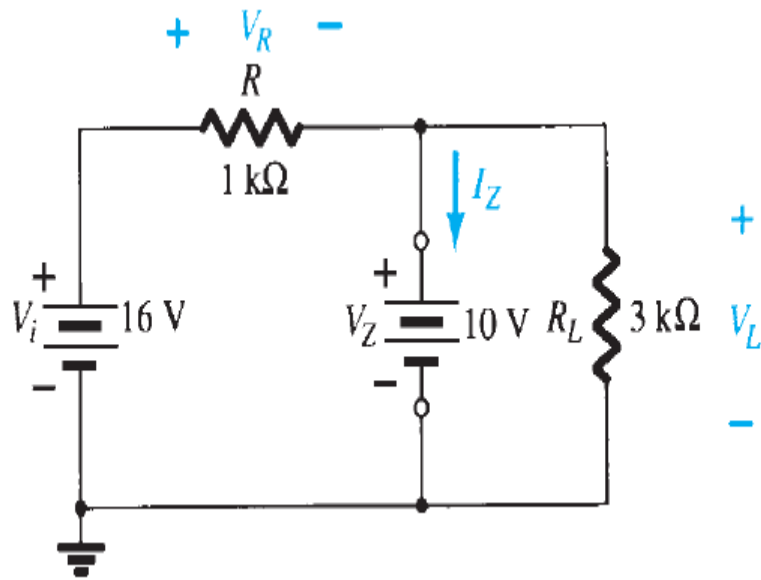
$$P_Z = V_Z I_Z = V_Z(0\text{ A}) = 0\text{ W}$$

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

Since  $V = 12\text{ V}$  is greater than  $V_Z = 10\text{ V}$ ,

the diode is in the “on” state





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

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

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

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

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

The power dissipated is

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

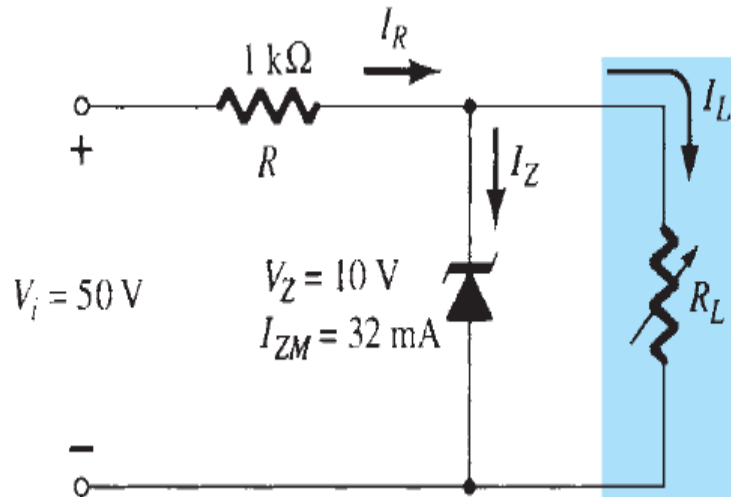
which is less than the specified  $P_{ZM} = 30 \text{ mW}$ .



## 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.



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

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

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

$$10 / 250 = 0.04 \text{ A}$$

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

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

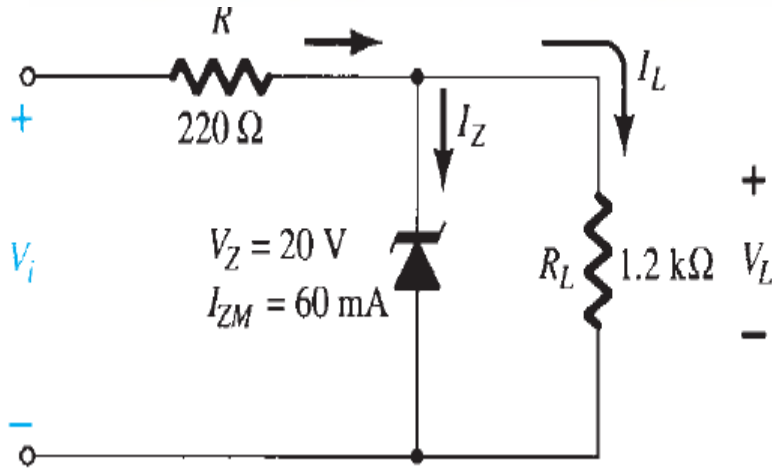
$$I_{L_{\min}} = I_R - I_{ZM} = 40 \text{ mA} - 32 \text{ mA} = 8 \text{ mA}$$

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



### 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

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

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

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

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

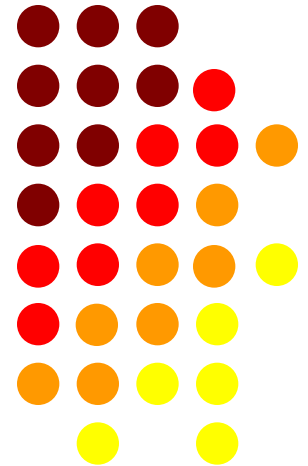
$$\begin{aligned} I_{R_{\max}} &= I_{ZM} + I_L \\ &= 60 \text{ mA} + 16.67 \text{ mA} \\ &= 76.67 \text{ mA} \end{aligned}$$

$$\begin{aligned} V_{i_{\max}} &= I_{R_{\max}} R + V_Z \\ &= (76.67 \text{ mA})(0.22 \text{ k}\Omega) + 20 \text{ V} \\ &= 16.87 \text{ V} + 20 \text{ V} \\ &= 36.87 \text{ V} \end{aligned}$$



# Lecture 8

## Working of Half wave and Full wave rectifiers

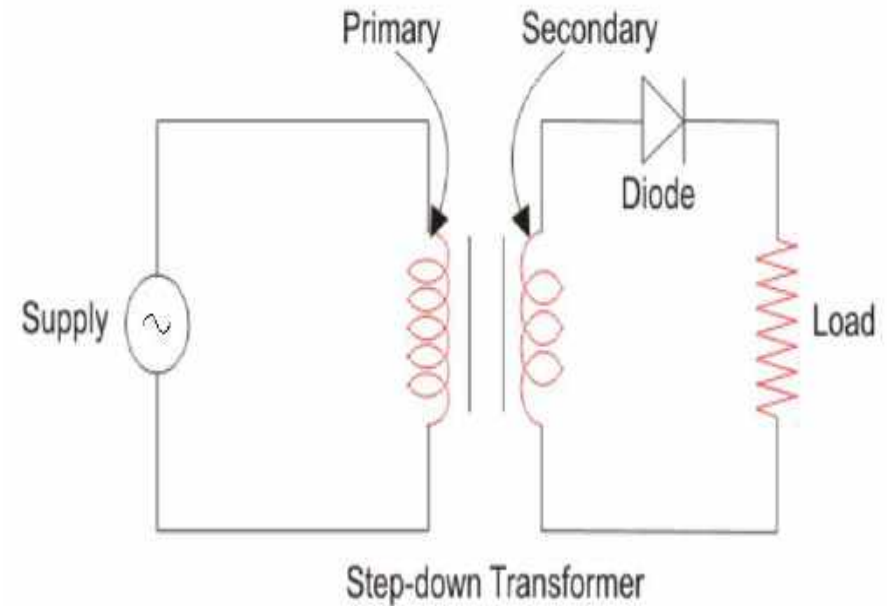


- Rectifiers are circuits which convert ac into pulsating dc or bipolar signal into unipolar signals.
- Rectifiers are grouped into two categories depending on the period of conduction.
  - 1. Half-wave rectifier.
  - 2. Full-wave rectifier.
- Centre tapped full-wave rectifier
- Bridge rectifier



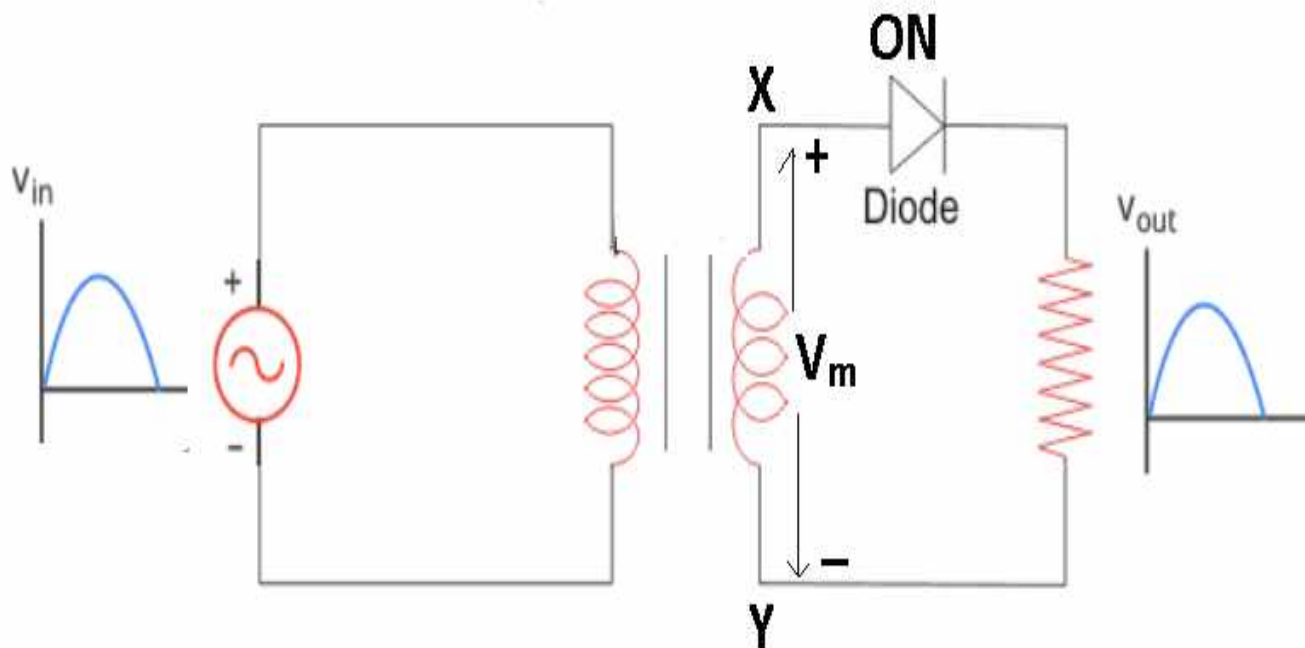
# Half-Wave Rectifier

- 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  $R_L$ .



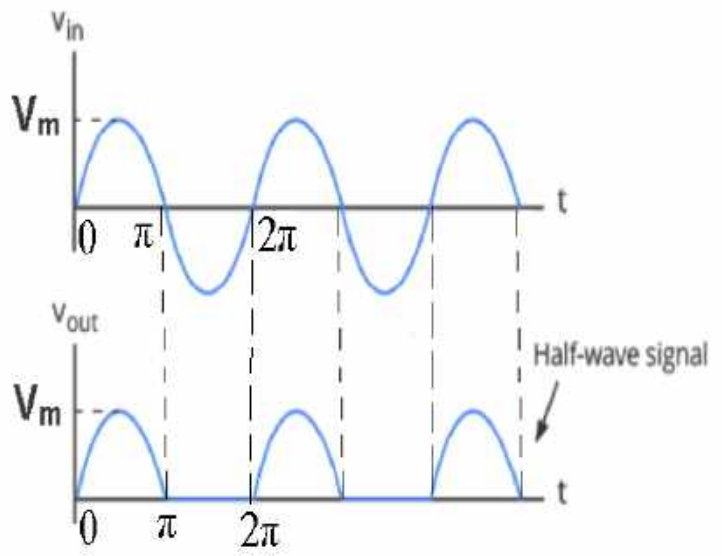
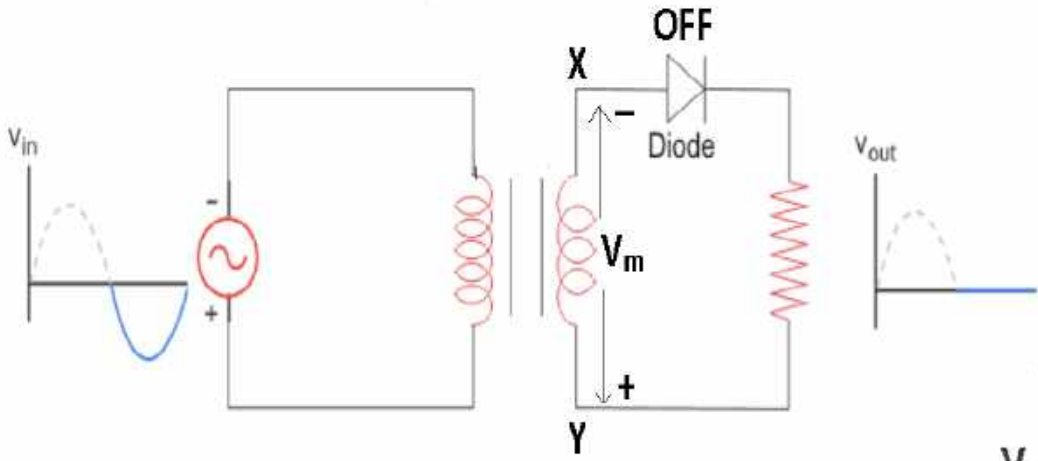
# Working

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  $R_L$  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



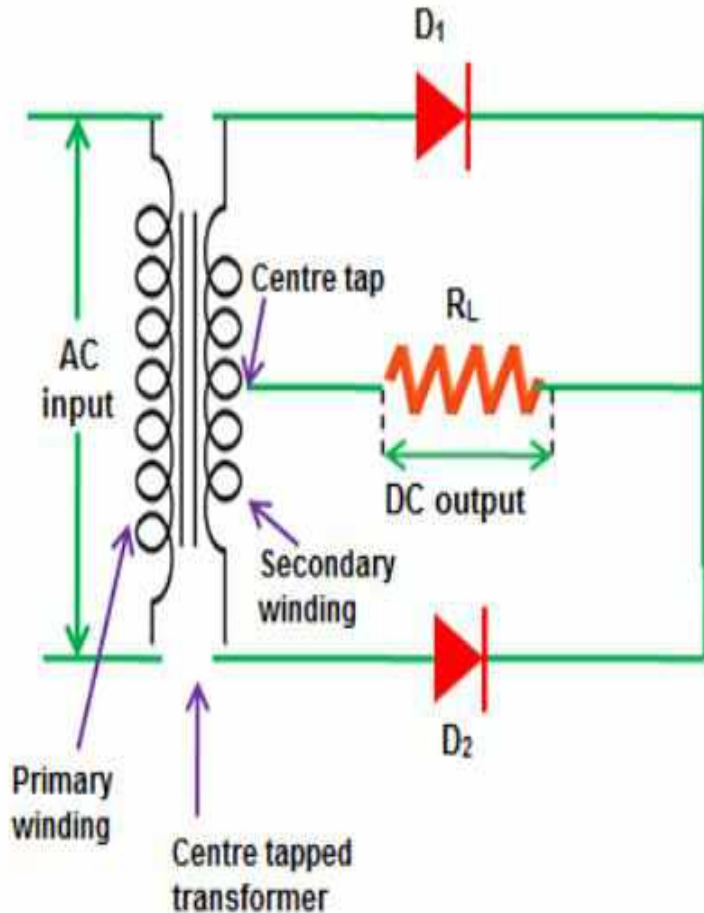
# FULL-WAVE RECTIFIER

Full-wave rectifiers are of two types

- Centre tapped full-wave rectifier
- Bridge rectifier



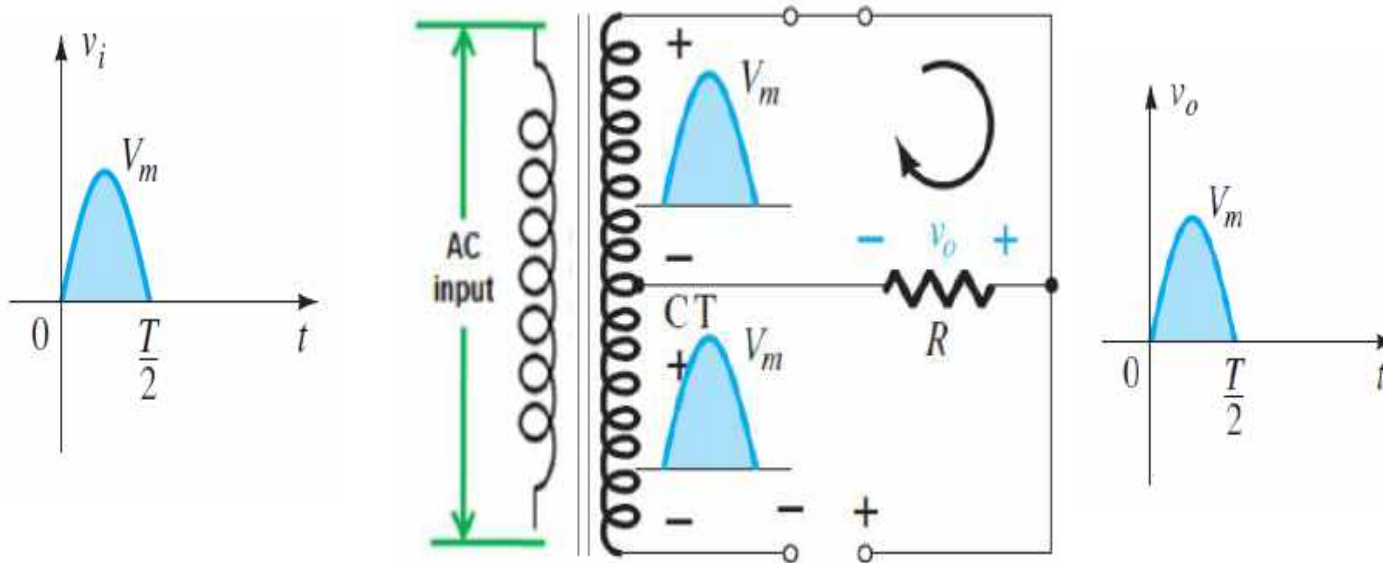
# Centre Tapped Full –Wave Rectifier



- 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.

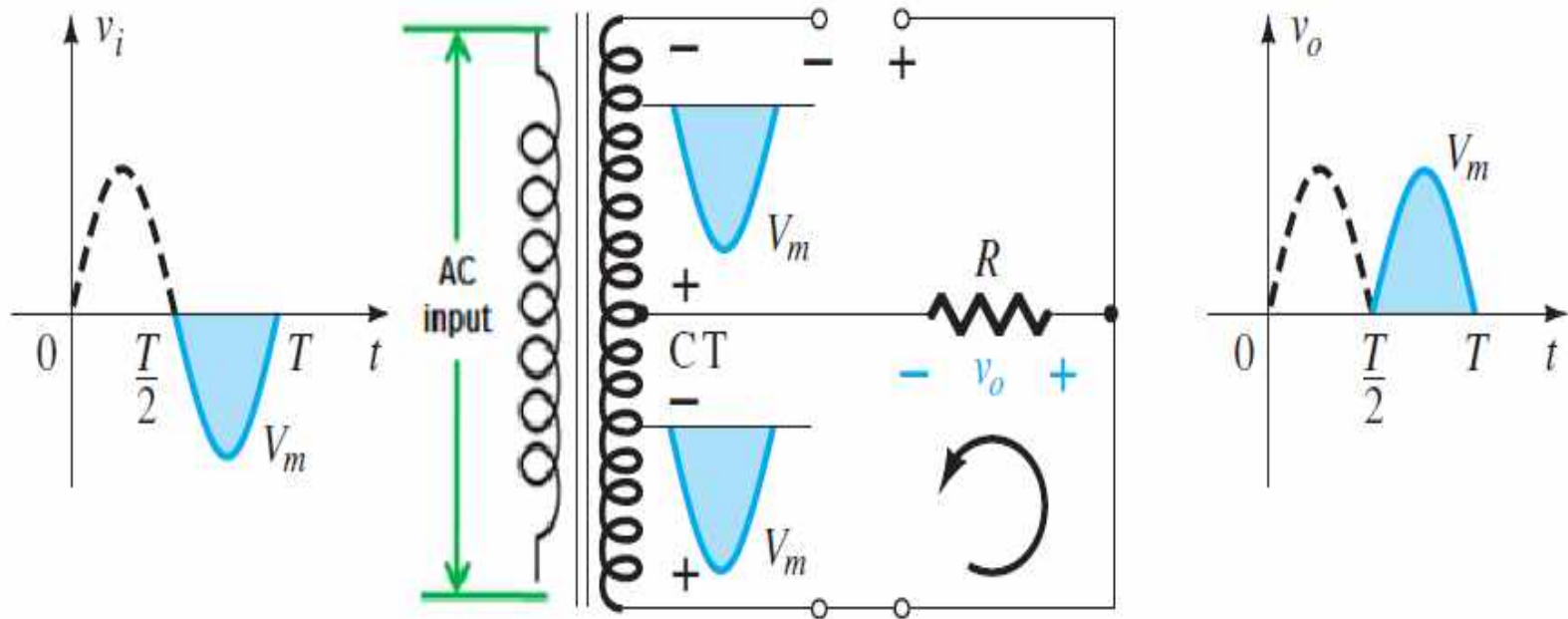


- **Positive Half Cycle:**
- Diode D1 is short circuited and D2 is open circuited. Current flows through the upper half of the secondary winding.

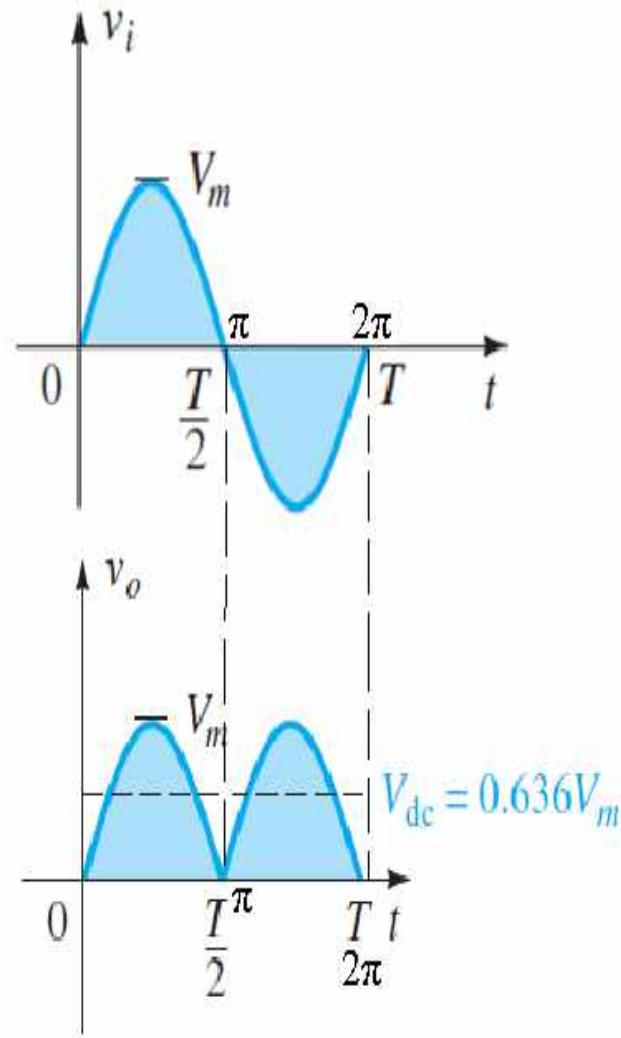


- **Negative Half Cycle:**

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

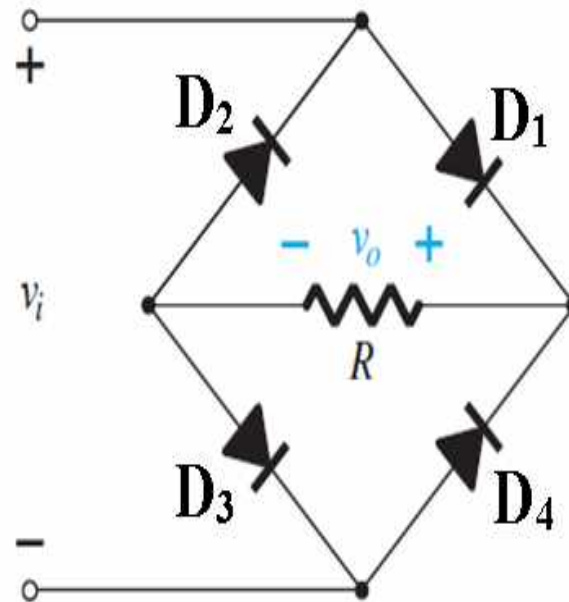
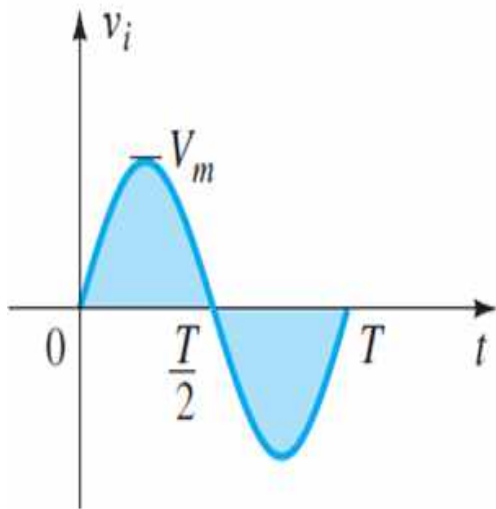


Complete input and output waveform can be shown as



# Bridge Rectifier

The bridge rectifier uses four diodes connected in bridge pattern.



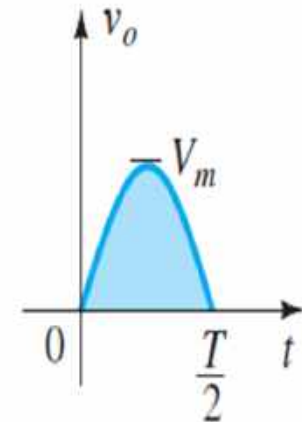
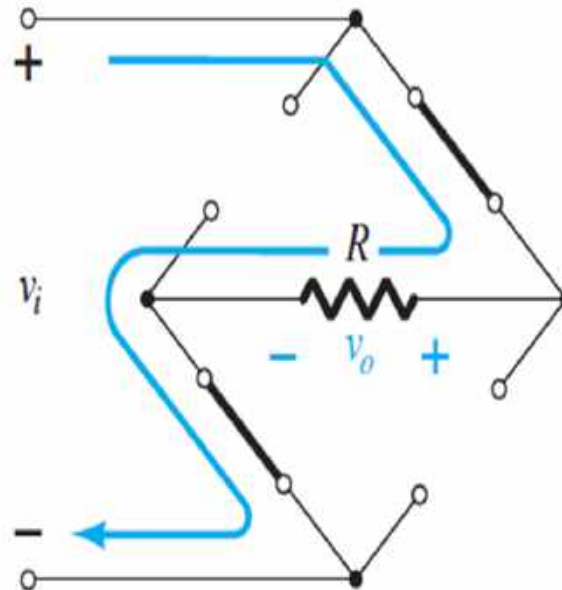
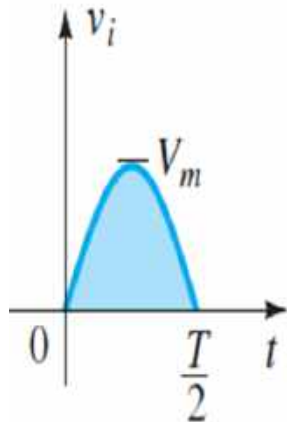
*Full-wave bridge rectifier.*



# Operation of Bridge Rectifier

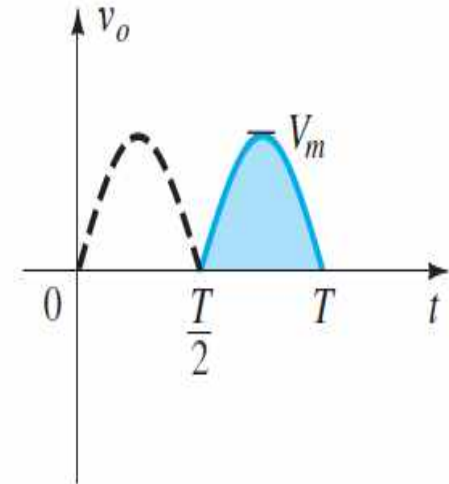
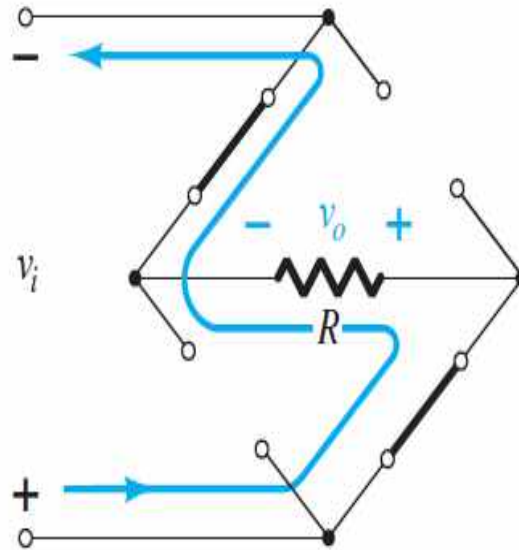
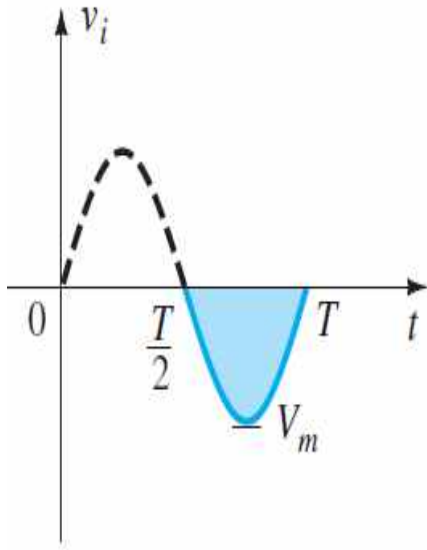
- **Positive Half Cycle:**

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.



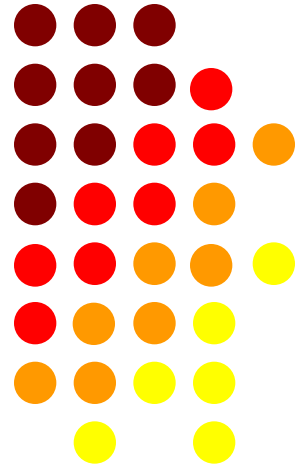
- **Negative Half Cycle:**

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





### iii) rms output (Load) current $I_{rms}$

$$\begin{aligned}
 I_{dc} &= \sqrt{\frac{1}{T} \int_0^T (I_m \sin\theta)^2 d\theta} \\
 &= \sqrt{\frac{1}{2\pi} \int_0^{2\pi} (I_m \sin\theta)^2 d\theta} \\
 &= \sqrt{\frac{I_m^2}{2\pi} \int_0^\pi \left(\frac{1 - \cos 2\theta}{2}\right) d\theta} \\
 &= \sqrt{\frac{I_m^2}{4\pi} \left[\theta - \frac{\sin 2\theta}{2}\right]_0^\pi} \\
 &= \sqrt{\frac{I_m^2}{4\pi} \left[(\pi - 0) - \left(\frac{\sin 2\pi}{2} - \frac{\sin 2 \times 0}{2}\right)\right]} \\
 &\boxed{I_{rms} = \frac{I_m}{2}}
 \end{aligned}$$

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

$$\begin{aligned}
 V_{rms} &= I_{rms} \times R_L \\
 &= \frac{I_m}{2} \times R_L \\
 &= \frac{V_m}{2(R_L + r_f)} \times R_L
 \end{aligned}$$

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( $\eta$ ):

$$\begin{aligned}\eta &= \frac{\text{dc output power}}{\text{ac input power}} = \frac{P_o(\text{dc})}{P_i(\text{ac})} \\ &= \frac{I_{dc}^2 \times R_L}{I_{rms}^2 \times (R_L + r_f)} \\ &= \frac{\left(\frac{I_m}{\pi}\right)^2 \times R_L}{\left(\frac{I_m}{2}\right)^2 \times (R_L + r_f)} \\ &= \frac{4 \times R_L}{\pi^2 \times (R_L + r_f)}\end{aligned}$$

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

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

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

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

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

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

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

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

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

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

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

If  $r_f = 0$

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

If diode is not ideal

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



### iii) rms output (Load) current $I_{rms}$

$$\begin{aligned}
 I_{rms} &= \sqrt{\frac{1}{\pi} \int_0^{\pi} (I_m \sin\theta)^2 d\theta} \\
 &= \sqrt{\frac{I_m^2}{\pi} \int_0^{\pi} \left(\frac{1 - \cos 2\theta}{2}\right) d\theta} \\
 &= \sqrt{\frac{I_m^2}{2\pi} \int_0^{\pi} \left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}} \\
 &= \sqrt{\frac{I_m^2}{2\pi} \left[ (\pi - 0) - \left(\frac{\sin 2\pi}{2} - \frac{\sin 2 \times 0}{2}\right) \right]}
 \end{aligned}$$

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

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

$$\begin{aligned}
 V_{rms} &= I_{rms} \times R_L \\
 &= \frac{I_m}{\sqrt{2}} \times R_L \\
 &= \frac{V_m}{\sqrt{2}(R_L + r_f)} \times R_L
 \end{aligned}$$

If  $r_f = 0$

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



## 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

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

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

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

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

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

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

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



## vii) Peak Inverse Voltage (PIV):

**For Centre tap:**

$$\text{PIV} = 2V_m$$

**For Bridge :**

$$\text{PIV} = V_m$$

## viii) Ripple frequency or output frequency ( $f_r$ ):

For full wave rectifier

$$f_r = 2f_i$$

## 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.



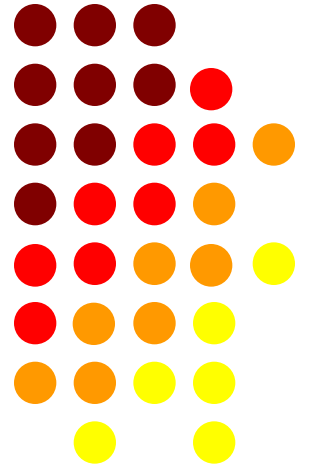
# Comparison between HWR & FWR

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	$V_m/\pi$ .	$2V_m/\pi$ .	$2V_m/\pi$ .
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	$V_m$	$2V_m$	$V_m$

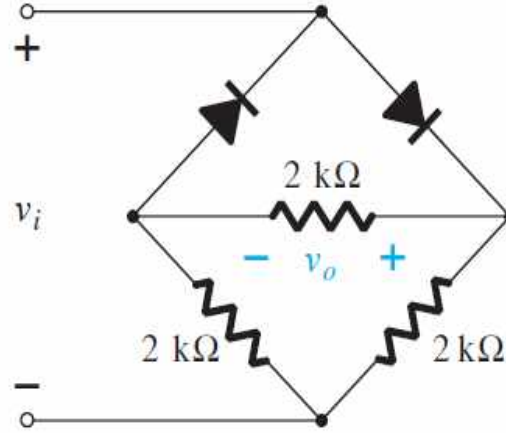
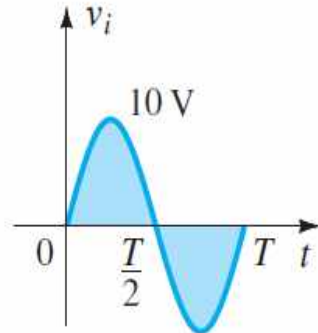


# Lecture 10

## Numerical based on rectifiers

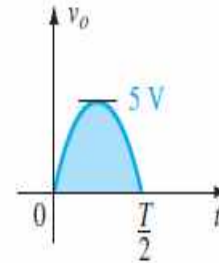
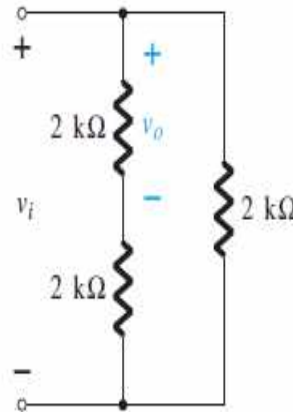
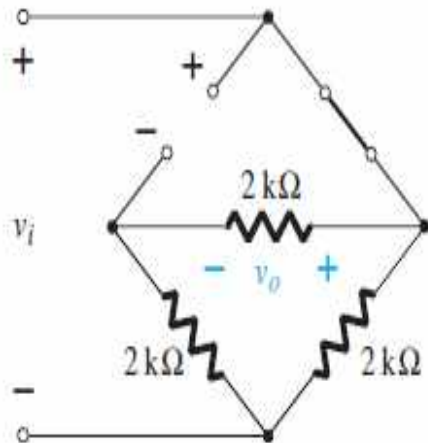
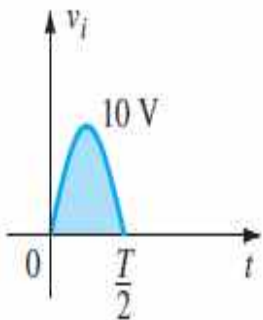


**Example:1** Determine the output waveform for the following figure and calculate the output dc level and required PIV of each diode.



**Solution :**

• **Positive Half Cycle:**



$$V_o = \frac{1}{2} \times 10$$

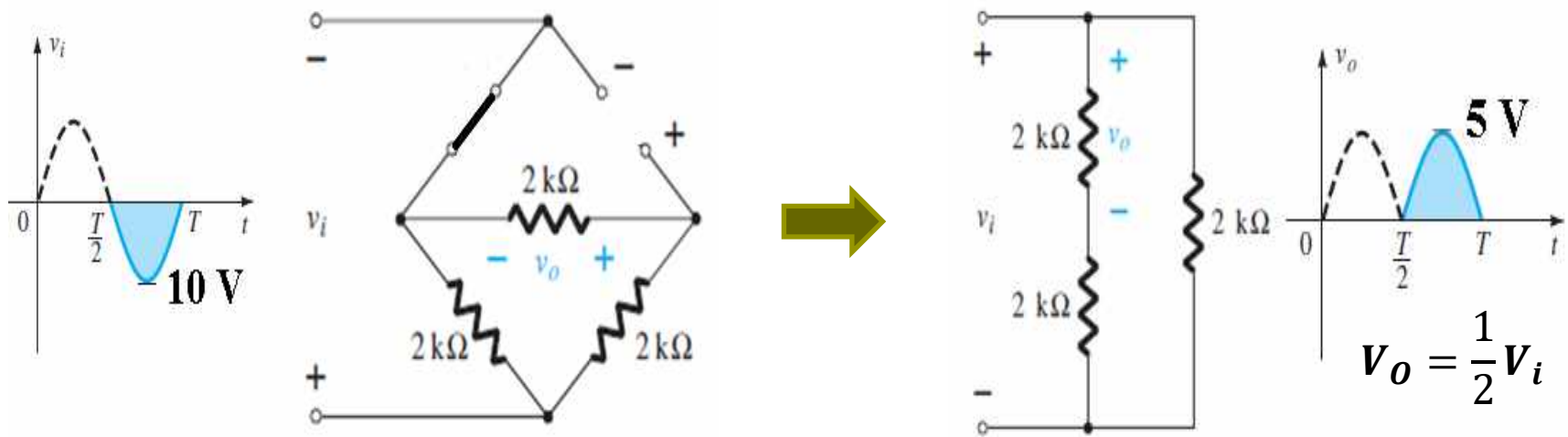
$$V_o = \frac{1}{2} V_i$$

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

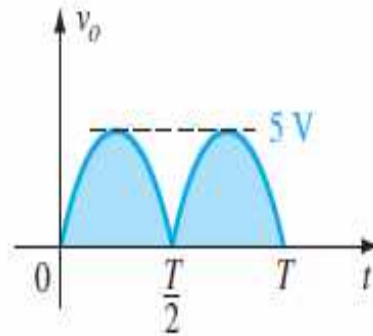
$$V_o = 5 \text{ V}$$



• Negative Half Cycle:



So out waveform will be:



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

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

$$V_o = \frac{1}{2} \times 10$$

$$V_o = 5 \text{ V}$$

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

$$= 0.636 \times$$

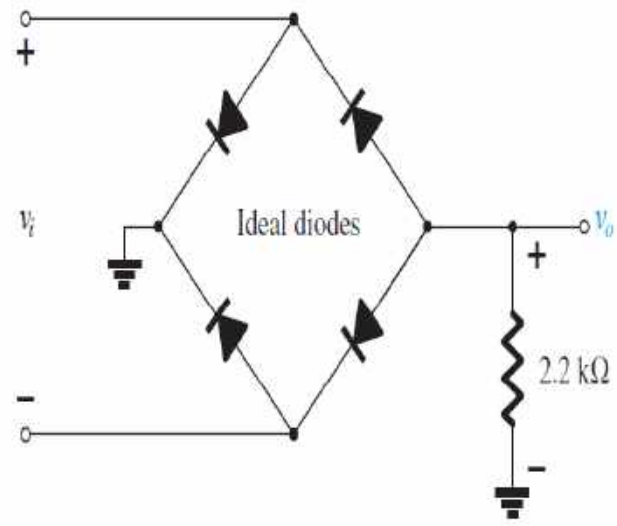
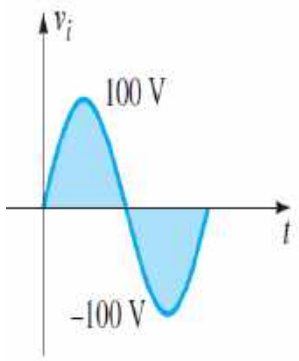
$$(5 \text{ V})$$

$$= 3.18 \text{ V}$$

$$\text{PIV} = 5\text{V}$$



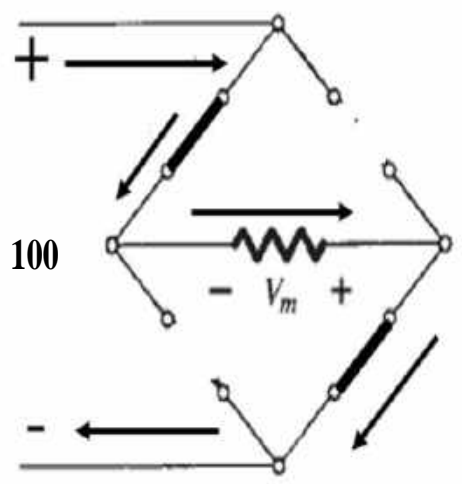
# Example:2 Determine $V_O$ and required PIV rating of each diode.



**Solution :**

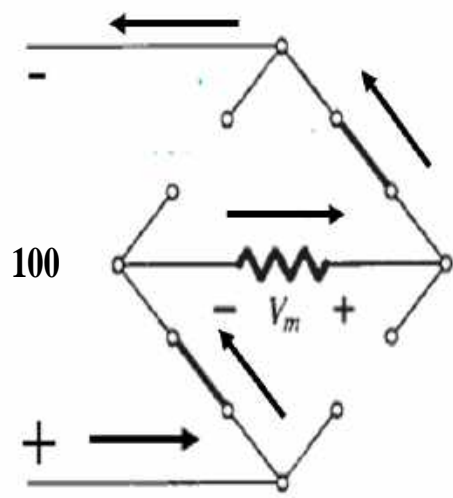
$V_O = 100$   
Output waveform:

• Positive Half Cycle:



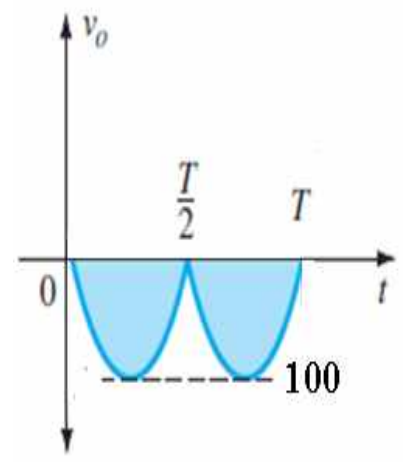
$V_O = -100$

• Negative Half Cycle:



$V_O = -100$

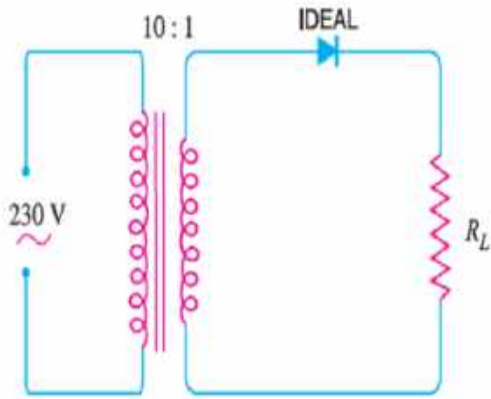
• Output waveform:



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 :**



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)

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

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

**Primary to secondary turns is**

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

R.M.S. primary voltage  
= 230 V

∴ Max. primary voltage is

$$\begin{aligned} V_{pm} &= (\sqrt{2}) \times \text{r.m.s. primary voltage} \\ &= (\sqrt{2}) \times 230 = 325.3 \text{ V} \end{aligned}$$

**(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  $20 \Omega$ . The transformer r.m.s. secondary voltage from centre tap to each end of secondary is  $50 \text{ V}$  and load resistance is  $980 \Omega$ . Find : (i) the mean load current (ii) the r.m.s. value of load current

**Solution :**

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

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

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

**i)**

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

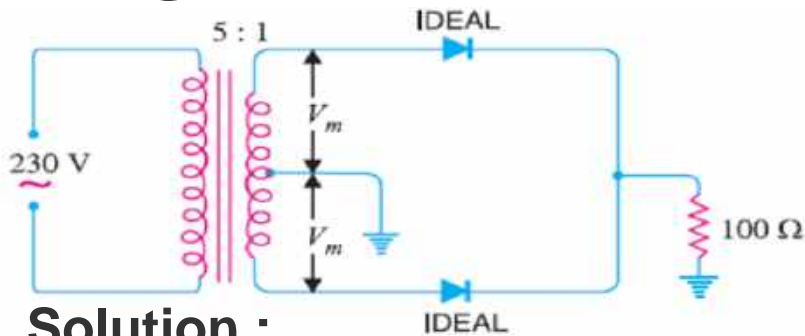
**ii)**

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,  $N_1 / N_2 = 5$

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,  $I_{dc} =$

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

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

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

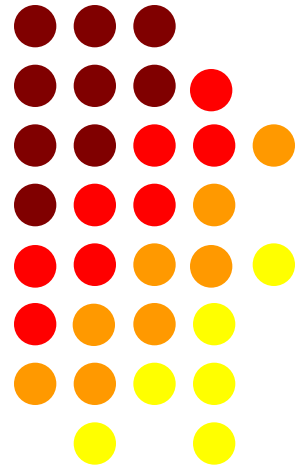
Since  $r_f = 0$

Rectification efficiency = **81.2 %**



# Lecture 11

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

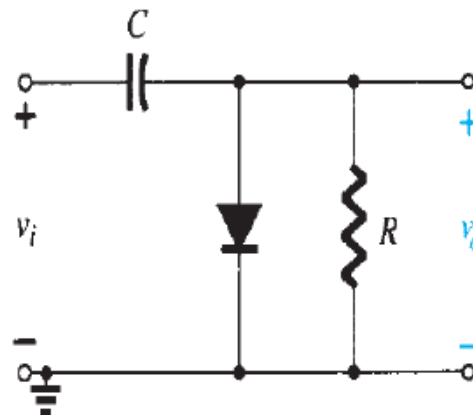
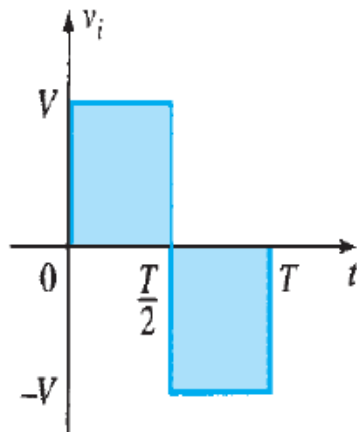


# Clamper Circuits:

- 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



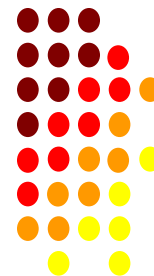
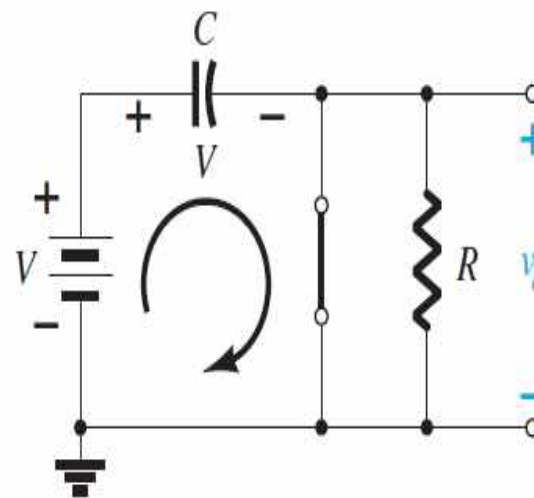
## In Positive Cycle:

- 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

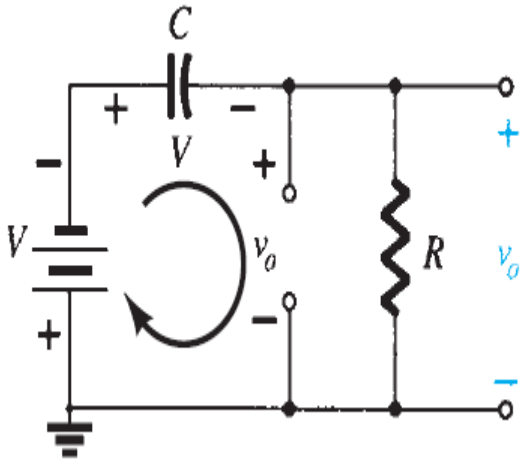
$$-V + V - V_o = 0$$

$$\text{So } V_o = 0$$



## In Negative Cycle:

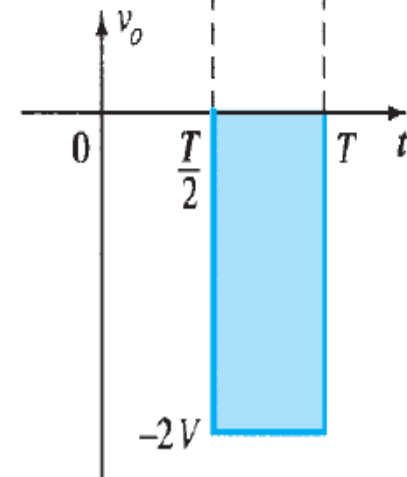
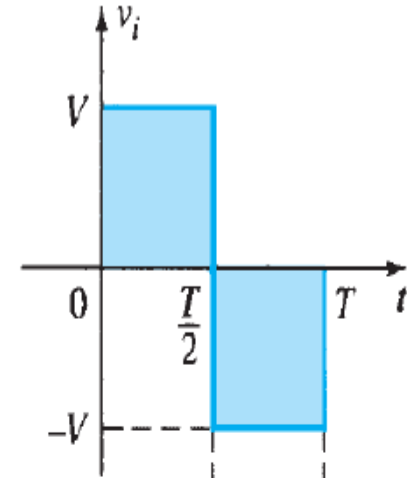
- In negative cycle Diode is reverse biased and acts as open circuit.
- Since Time constant (RC) is high. So, capacitor maintains its voltage during



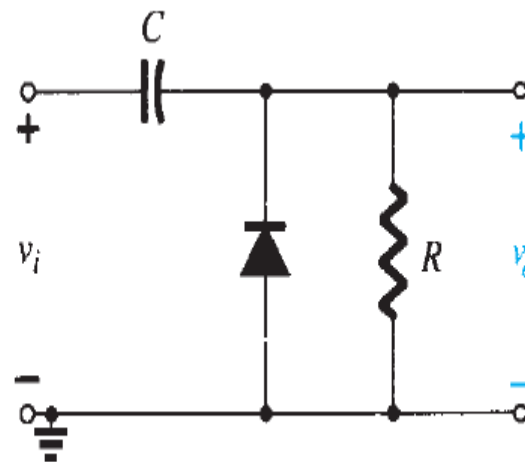
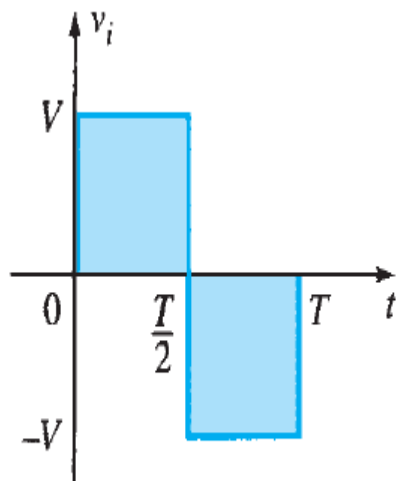
Applying KVL

$$-V - V - V_0 = 0$$

$$\text{So } V_0 = -2V$$



# Positive Clamper Circuit



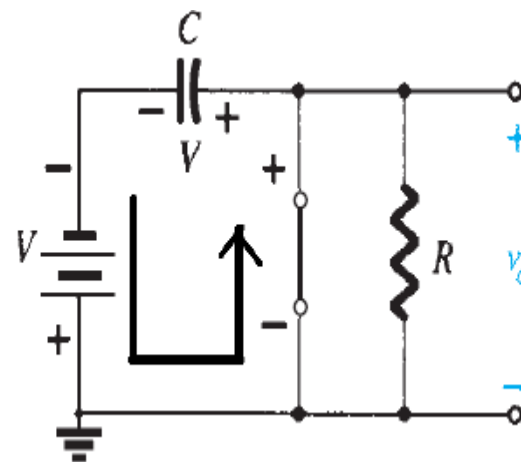
## In Negative Cycle:

- 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

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

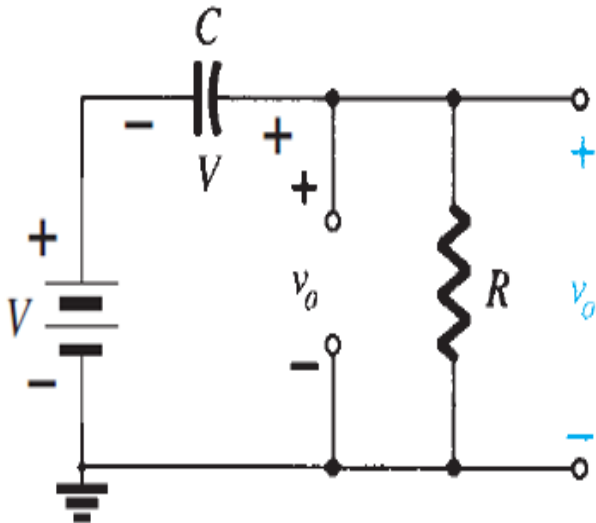
$$\text{So } V_o = 0$$



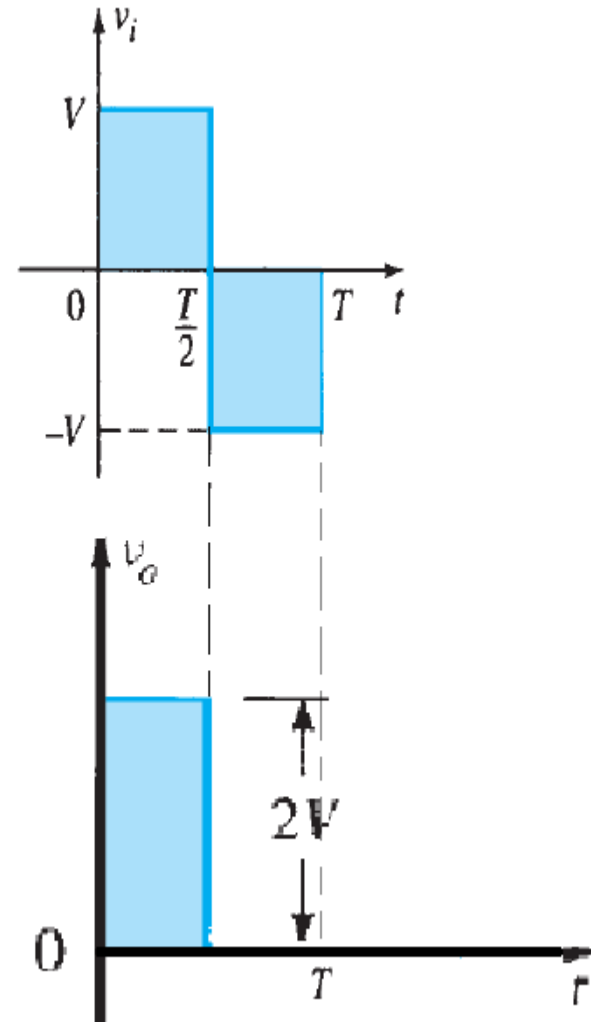
## In Positive Cycle:

- 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.

$$\begin{aligned} \text{KVL} \\ +V + V - V_0 &= 0 \\ V_0 &= 2V \end{aligned}$$

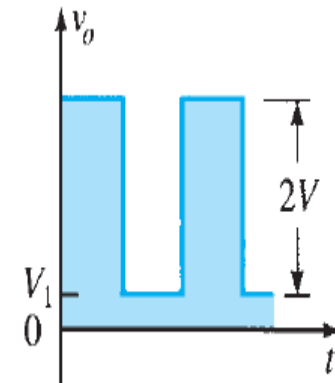
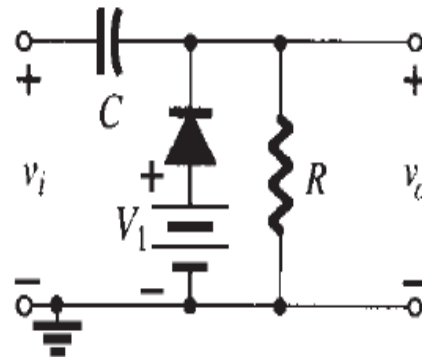
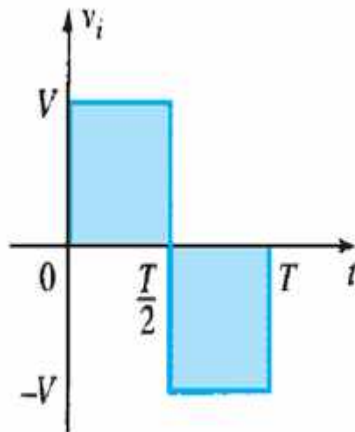
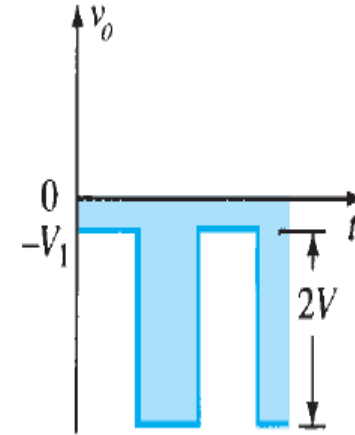
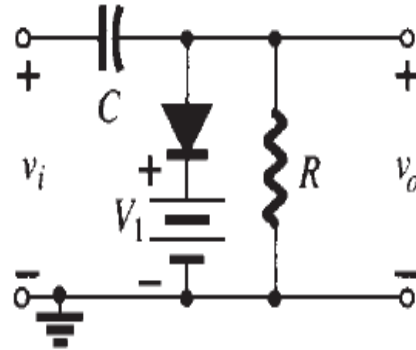
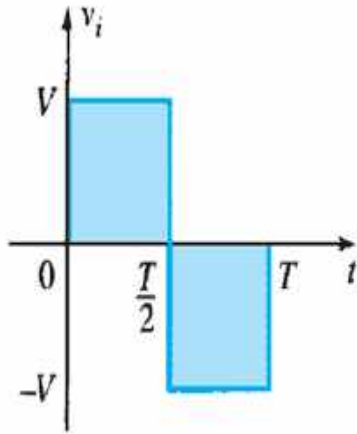


## Input-Output Waveform

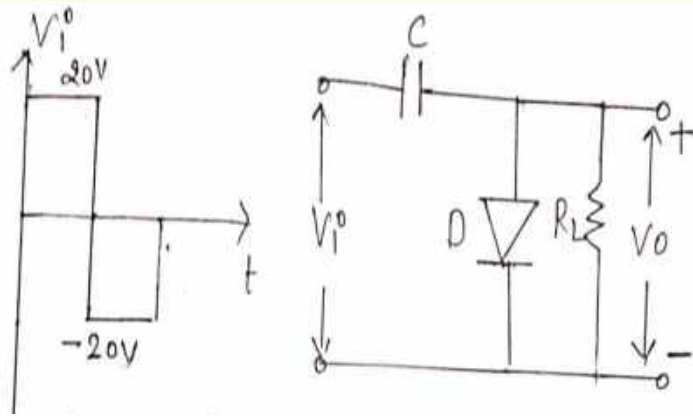


# Biased Clamper Circuits

- 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



Input-output waveform  $\frac{v_o}{v_i}$

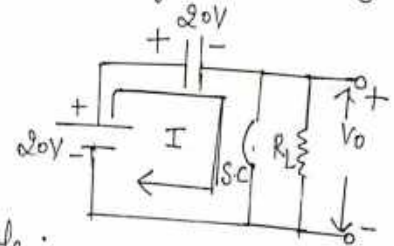
Ans: It is negative clamper.

i) for positive cycle:  
Diode is forward biased and acts as a short circuit. So capacitor is charged up to voltage 20V.

Applying KVL

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

So  $V_o = 0$

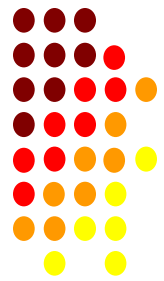
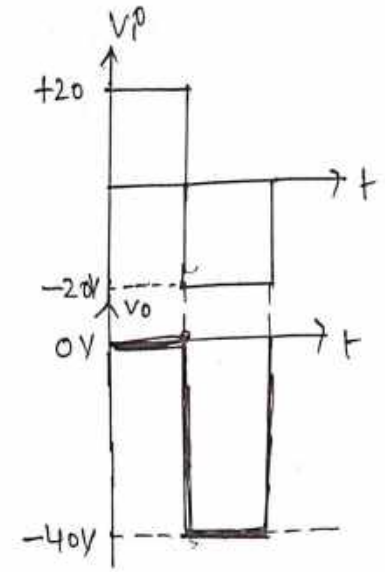
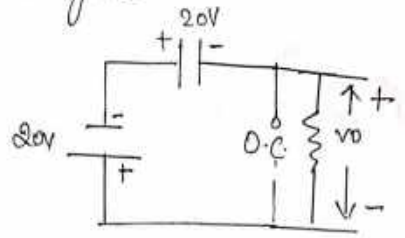


ii) for negative cycle:  
Diode is reverse biased and acts as open circuit. Capacitor maintains its voltage during negative cycle.

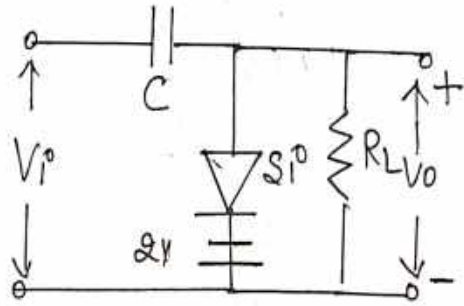
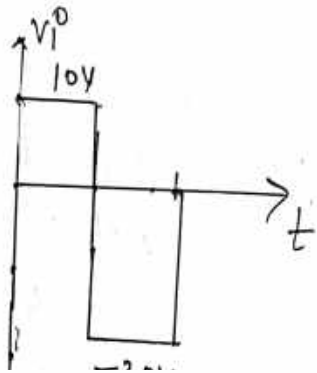
Applying KVL

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

$\Rightarrow V_o = -40V$



# Example:2 Sketch the output for the following circuit



Ans: It is negative clamper.

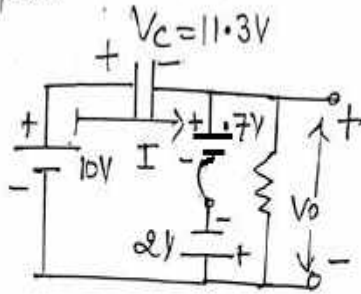
(i) for positive cycle:-

Diode is forward biased and capacitor charges up to voltage  $V_c$ .

Applying KVL

$$-V_c - 0.7V + 2 + 10 = 0$$

$$\boxed{V_c = 11.3V}$$



Applying KVL

$$-11.3V - V_o + 10 = 0$$

$$\boxed{V_o = -1.3V}$$

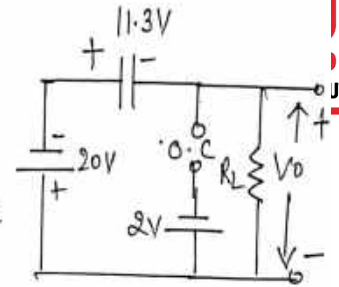
(ii) for negative cycle:-

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

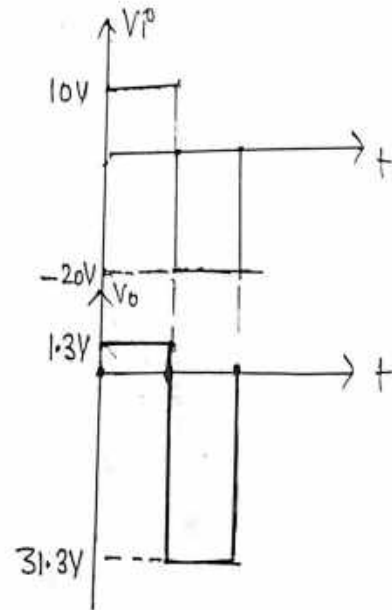
Applying KVL

$$-11.3 - V_o - 10 = 0$$

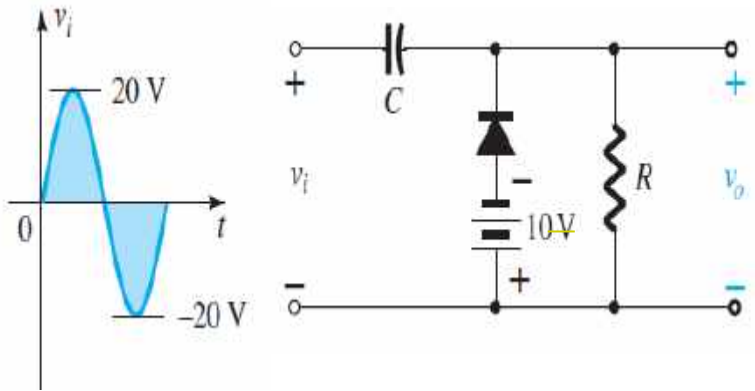
$$\boxed{V_o = -21.3V}$$



Input - Output waveform :-



# Example:3 Sketch the output for the following circuit

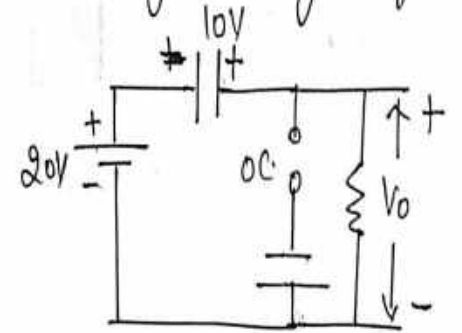


Diode is reverse biased and acts as open circuit.  
Capacitor maintain its voltage during negative cycle.

Applying KVL

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

$$\boxed{V_o = 30V}$$



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

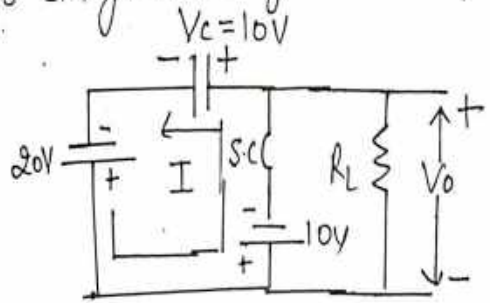
$$+V_c + 10 - 20 = 0$$

$$V_c = 10V$$

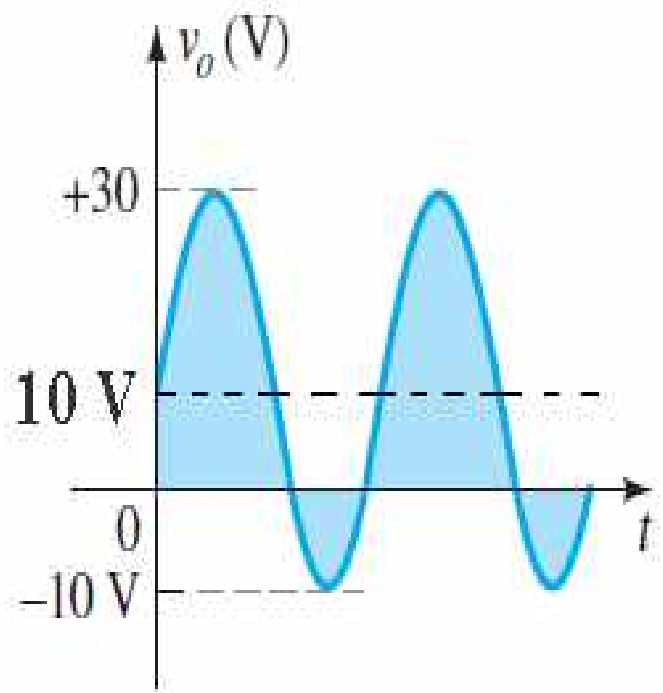
Applying KVL

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

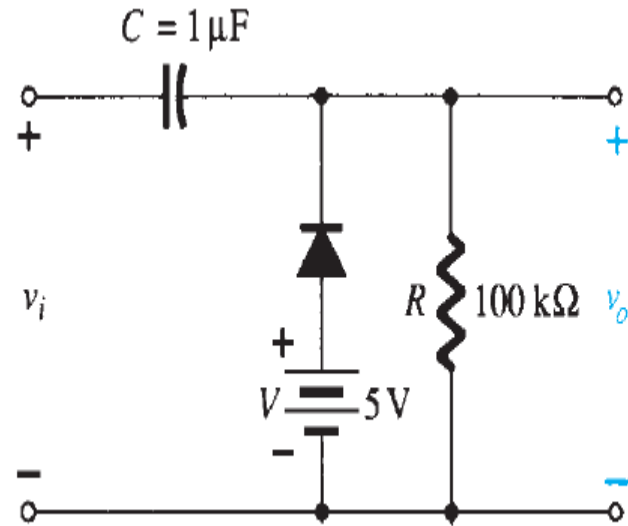
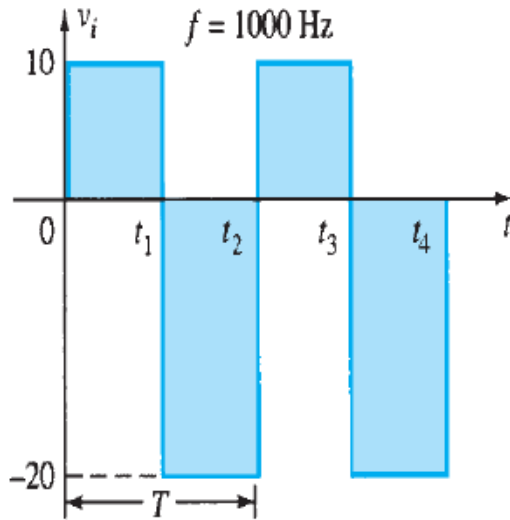
$$\boxed{V_o = -10}$$



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



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



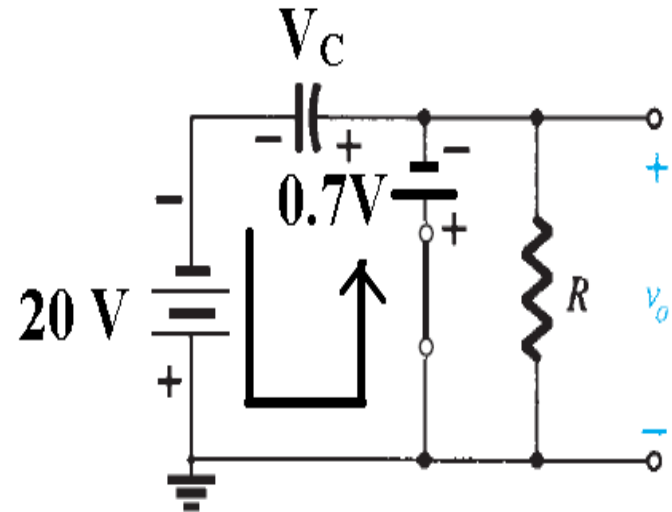
**Solution:** Clamper is positive so we start the analysis from negative cycle.

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

Applying KVL

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

$$\text{So } V_C = 24.3V$$

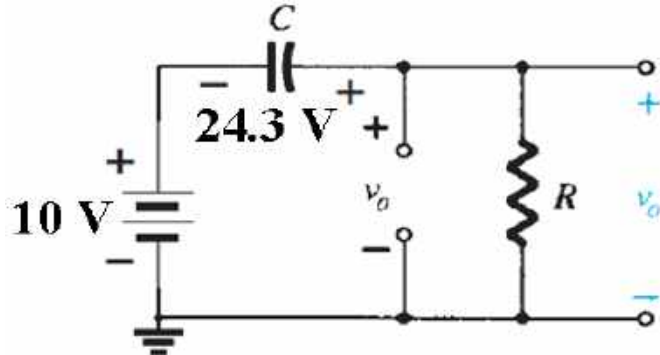


## Applying KVL

$$+24.3 \text{ V} - V_O - 20 \text{ V} = 0$$

$$\text{So } V_O = 4.3 \text{ V}$$

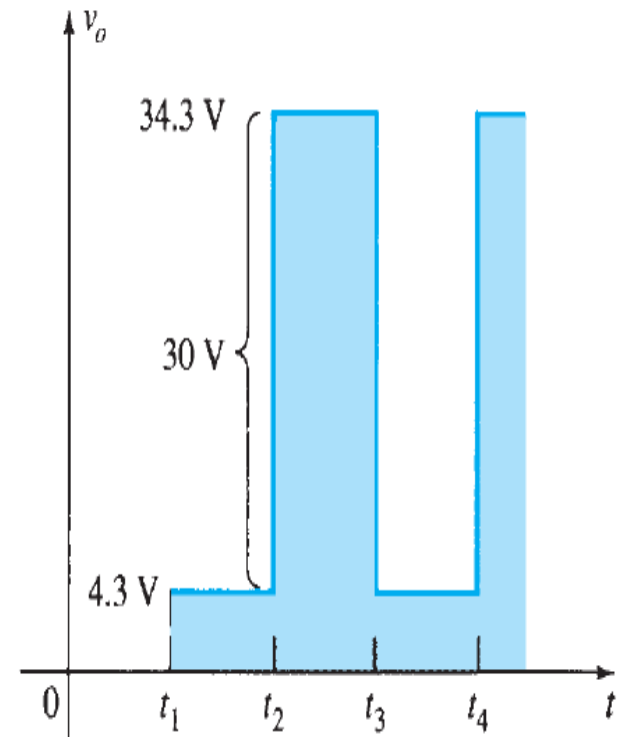
In Positive cycle Diode is reverse biased and acts as open circuit. Since Time constant (RC) is high. So, capacitor maintains its voltage during negative cycle.



## Applying KVL

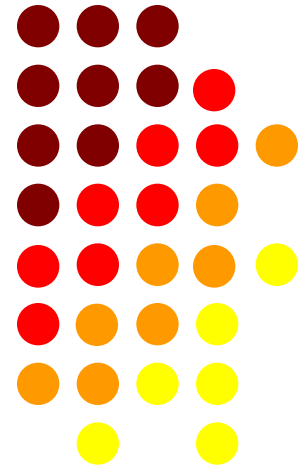
$$24.3 \text{ V} - V_O + 10 \text{ V} = 0$$

$$\text{So } V_O = 34.3 \text{ V}$$



# 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

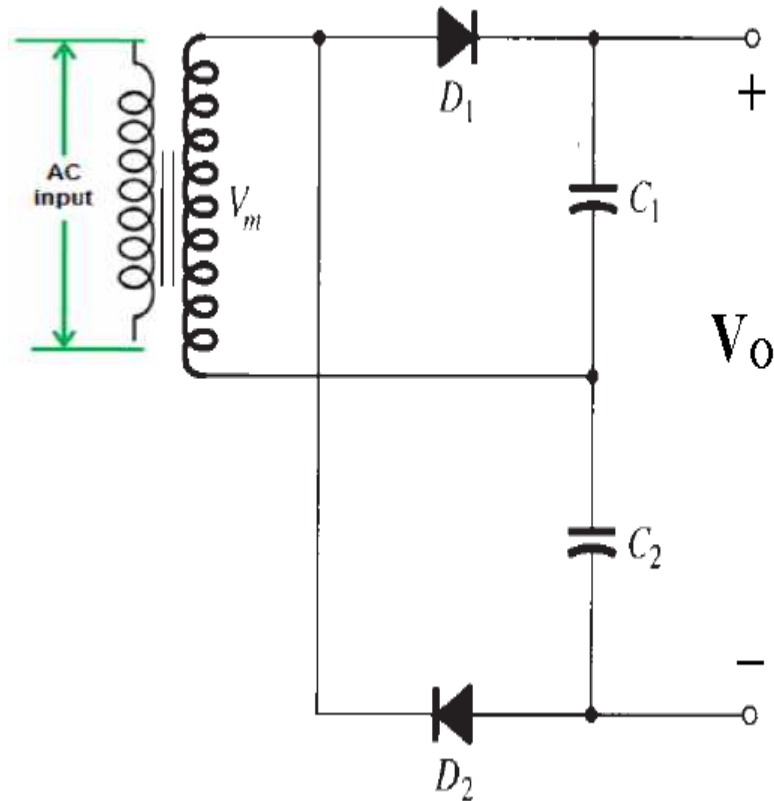


- **Voltage doubler is again classified as:**
  1. Half Wave Voltage Doubler
  2. Full Wave Voltage Doubler



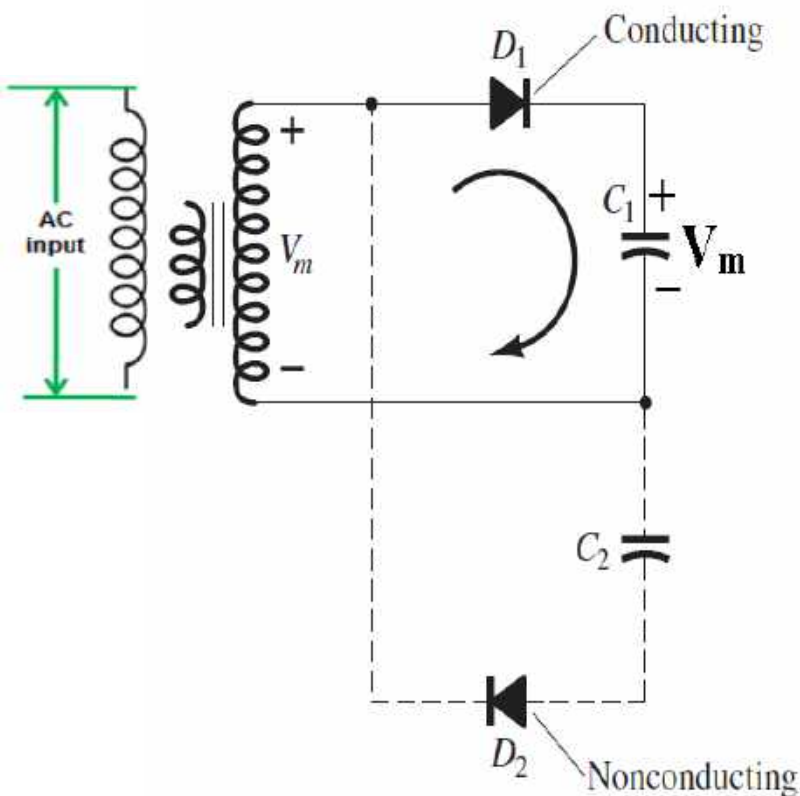
# Full wave Voltage Doubler Circuit

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

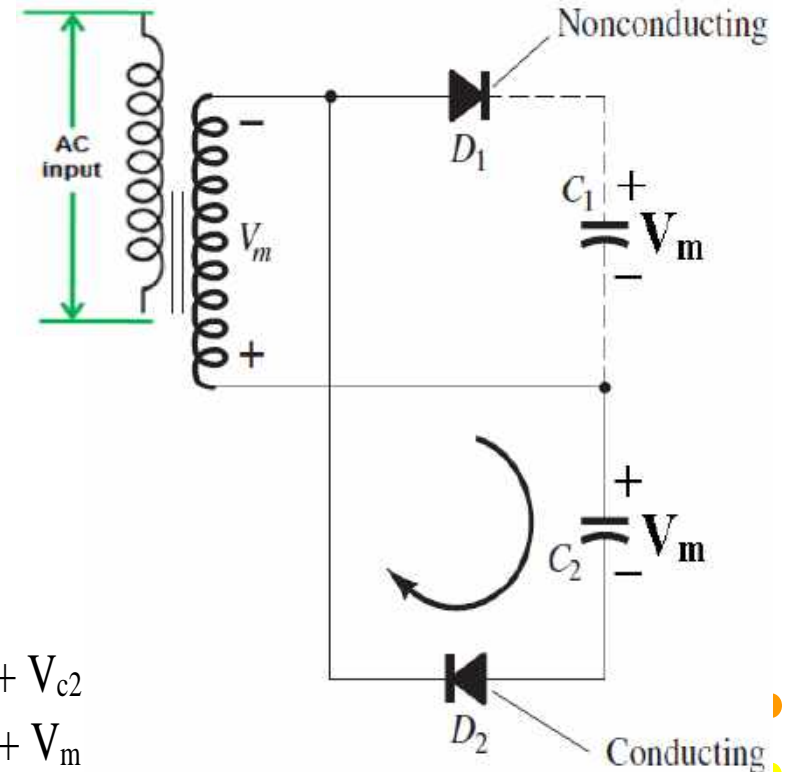


# Working

- 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  $V_m$ .



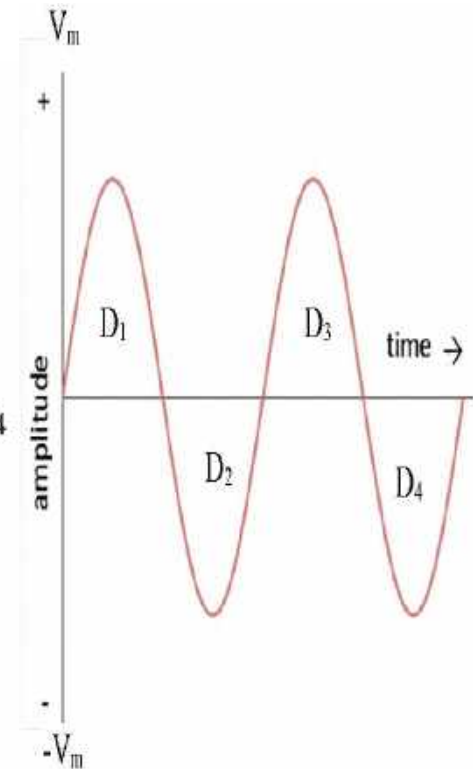
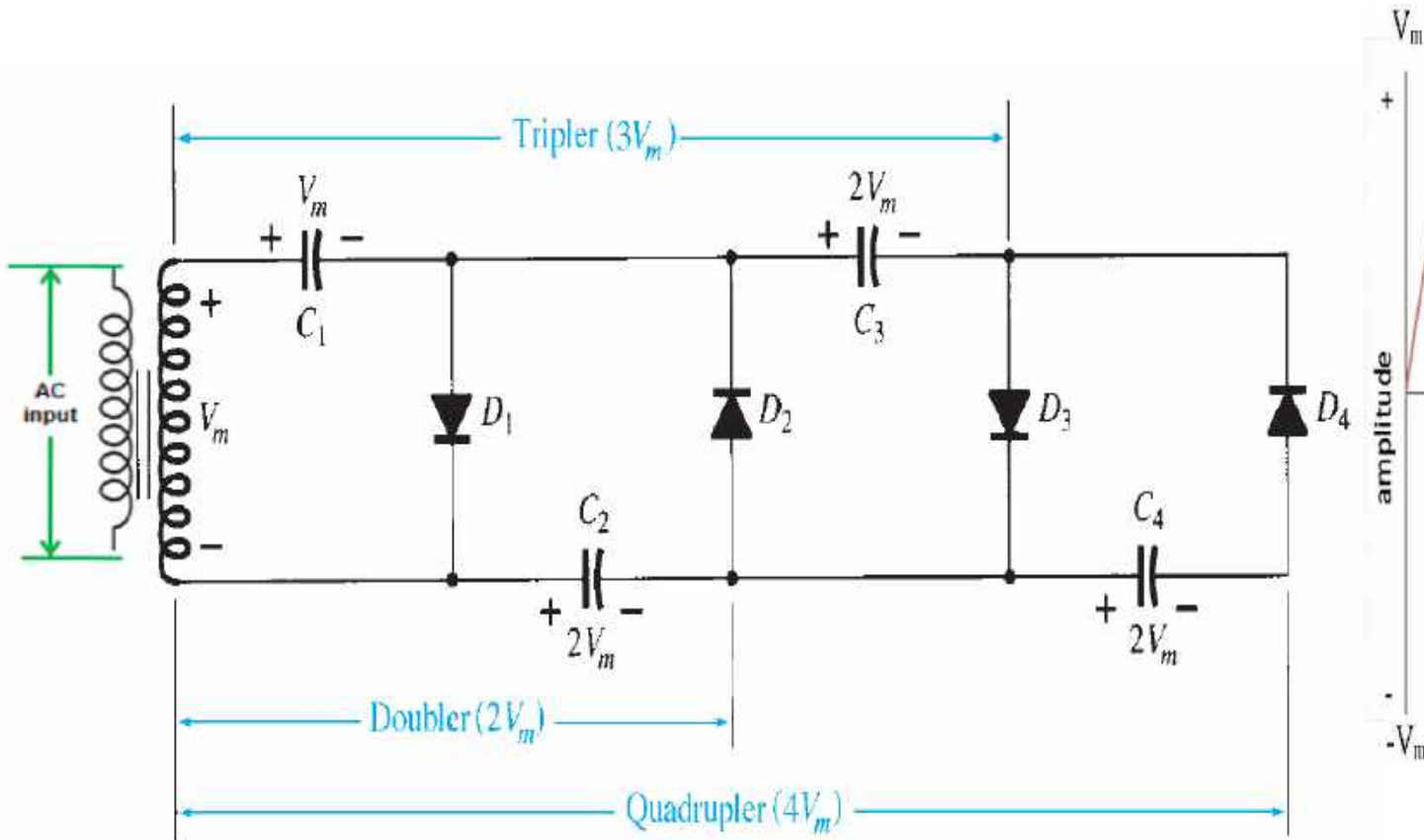
- Negative Cycle:**  
 $D_2$  is forward biased so it is on but  $D_1$  is reverse biased so it is off. So, capacitor  $C_2$  charges up to voltage  $V_m$ .



$$\begin{aligned}
 V_0 &= V_{c1} + V_{c2} \\
 &= V_m + V_m \\
 &= 2V_m
 \end{aligned}$$



# 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**

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

$$\text{So } V_{C2} = 2V_m$$

- Second Positive Cycle:

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

**Applying KVL**

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

$$\text{So } V_{C3} = 2V_m$$

- Second Negative Cycle:

**Applying KVL**

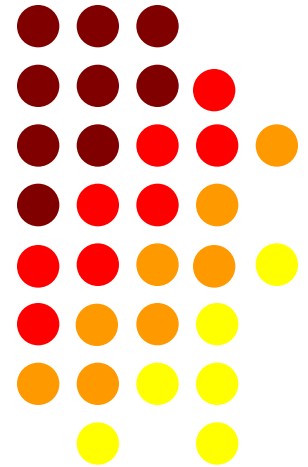
$$-V_m - 2V_m + V_{C4} + 2V_m - V_m = 0$$

$$\text{So } V_{C4} = 2V_m$$



# 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 positive clipper:**

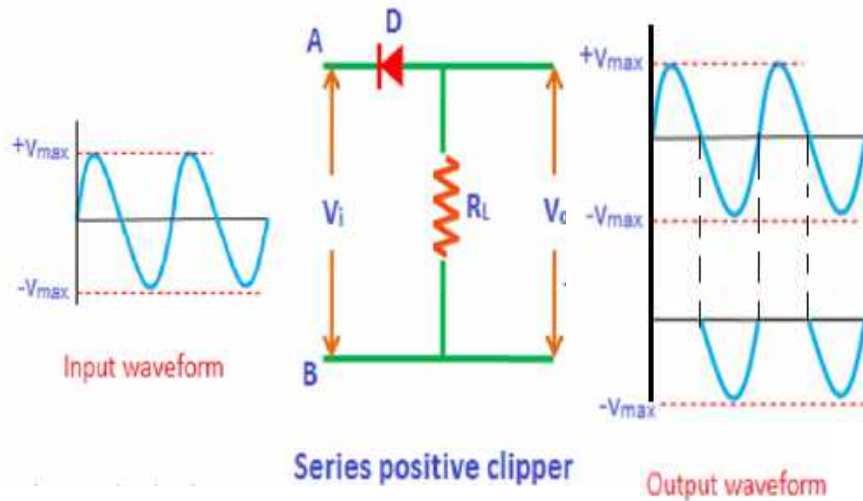


## a) Series Positive clipper:

### 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

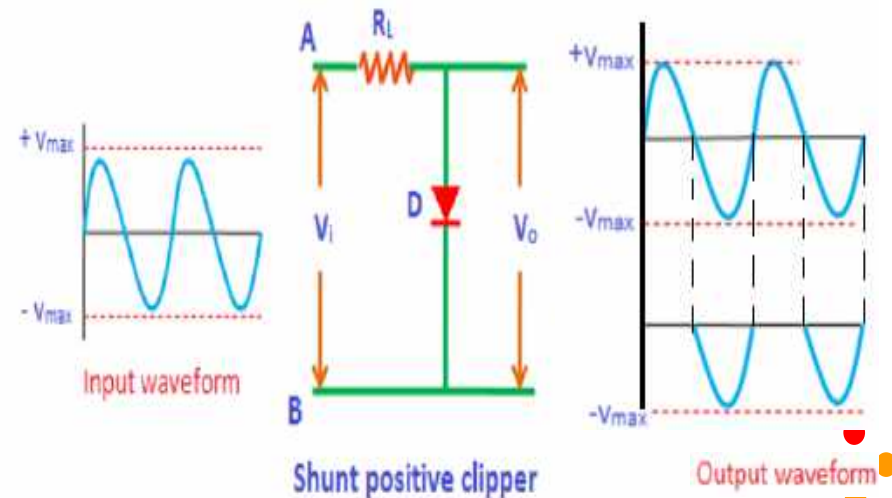


## a) Shunt positive clipper:

### 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

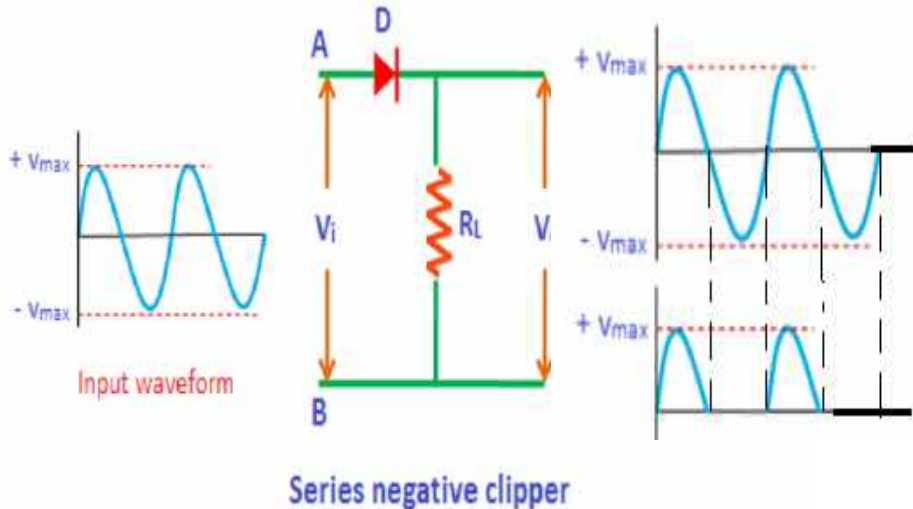


**ii) Negative clipper:** A positive clipper removes the negative half cycle of the input voltage. Negative clipper is of two type:

**a) Series Negative clipper:**  
**Operation:**

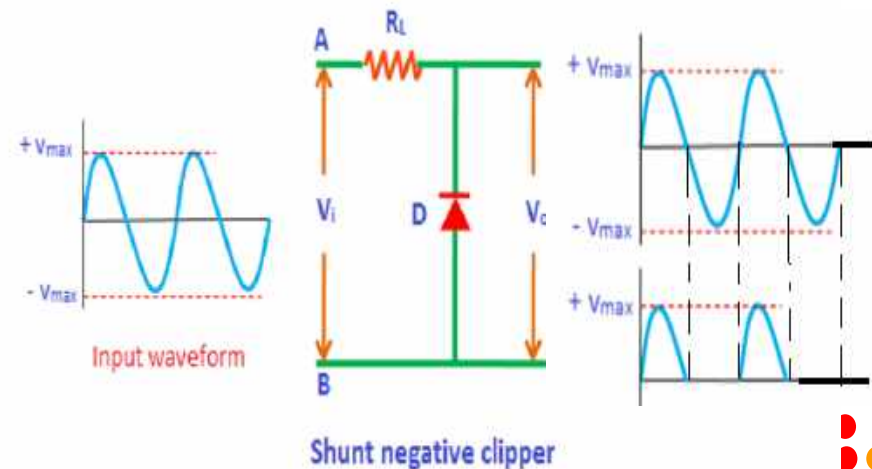
In positive cycle diode is forward biased. So diode is on and output will be equal to input voltage.

In negative cycle diode is



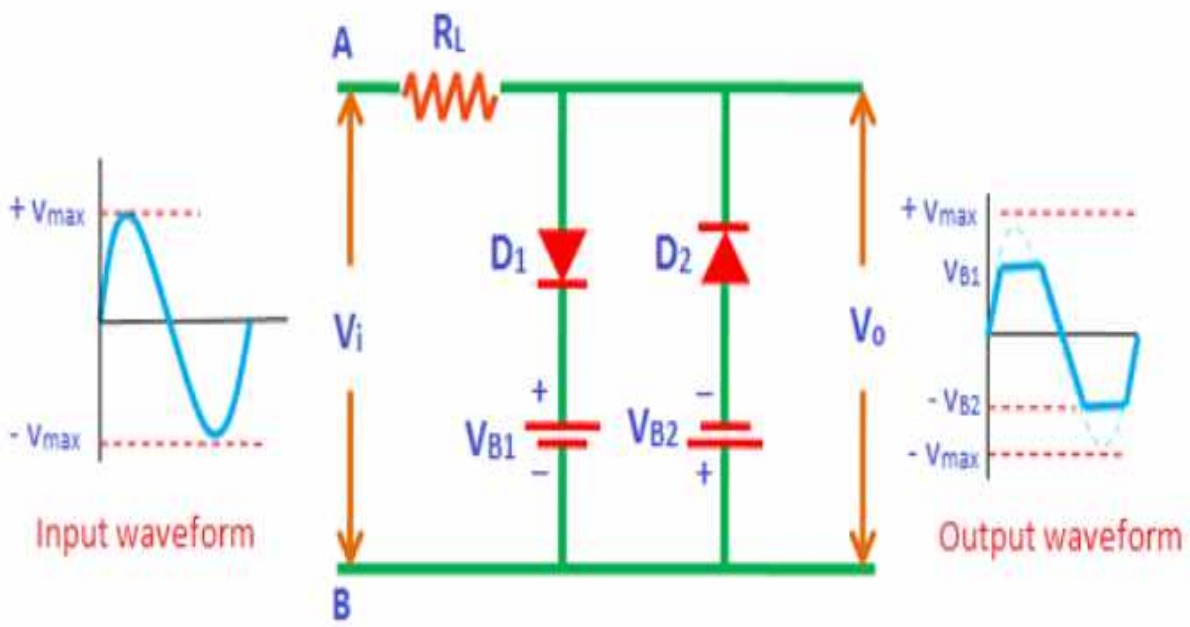
**b) Shunt negative clipper:**  
**Operation:**

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



### 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:

$$V_{Y1} - V_{B1} = 0$$

$$V_{Y1} = V_{B1}$$

$$V_{Y2} + V_{B2} = 0$$

$$V_{Y2} = -V_{B2}$$

i)  $V_i < -V_{B2}$

$D_1$  OFF,  $D_2$  ON

So  $V_o = -V_{B2}$

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

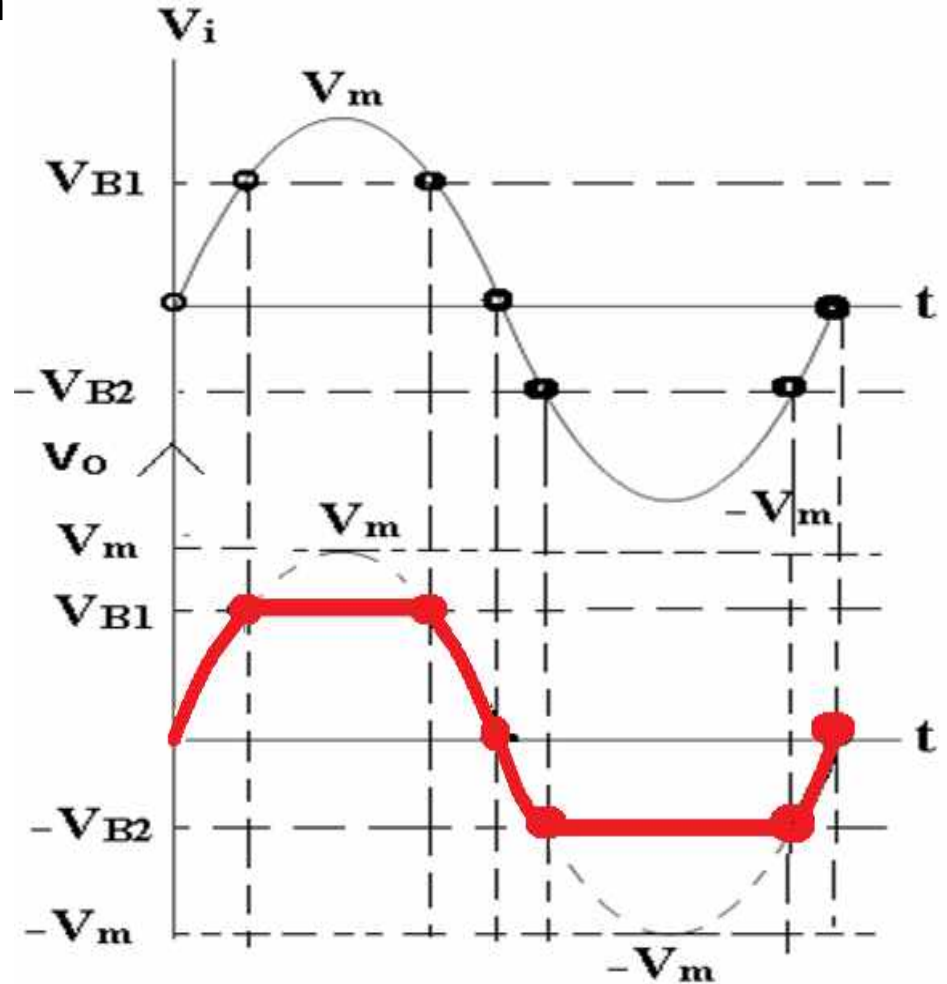
$D_1$  OFF,  $D_2$  OFF

So  $V_o = V_i$

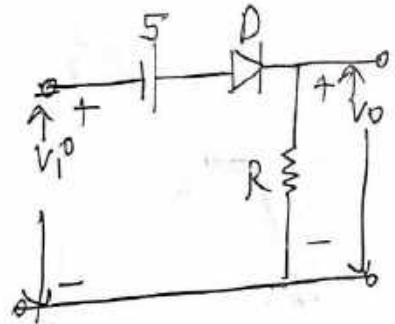
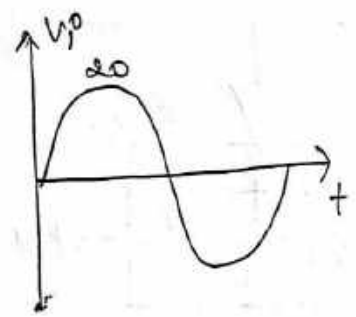
iii)  $V_i > V_{B1}$

$D_1$  ON,  $D_2$  OFF

So  $V_o = V_{B1}$



# Example: 1 Find the output for the following circuit.

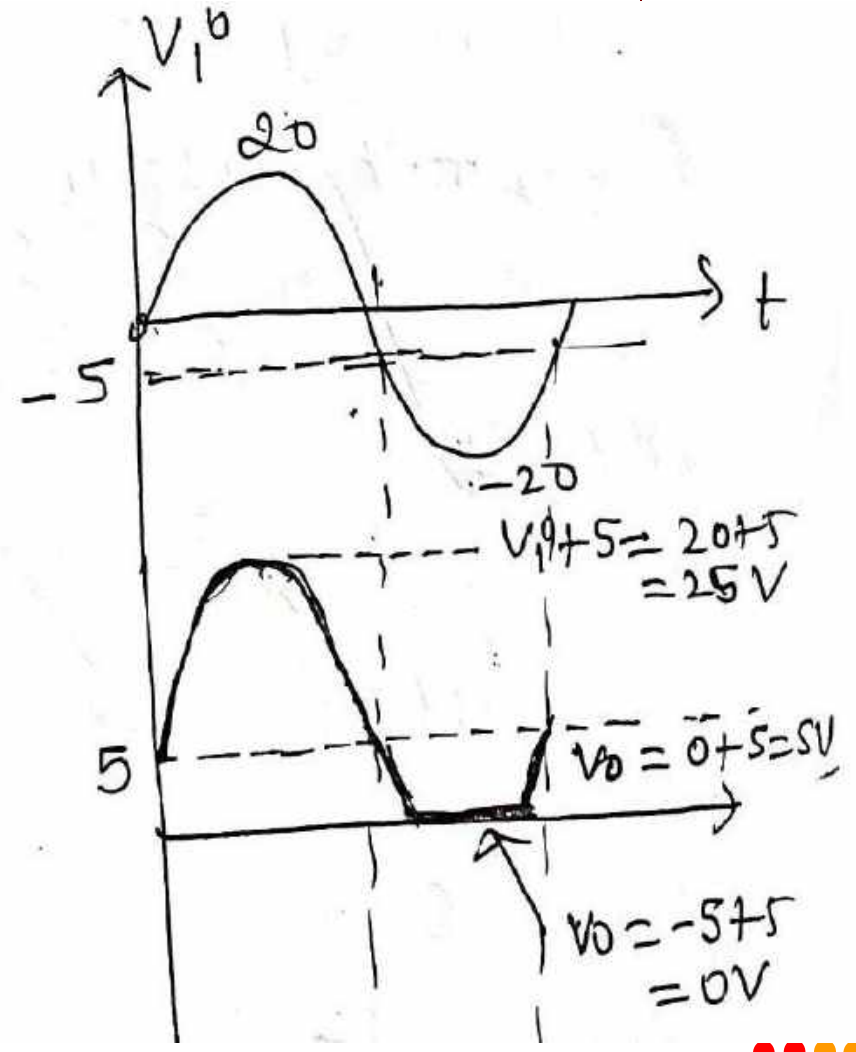
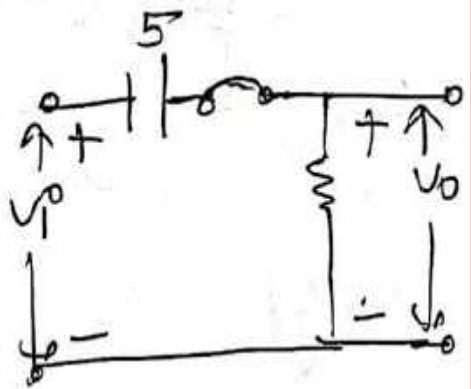


Soln Transition voltage  $V_v + 5 = 0$   
 $V_v = -5$

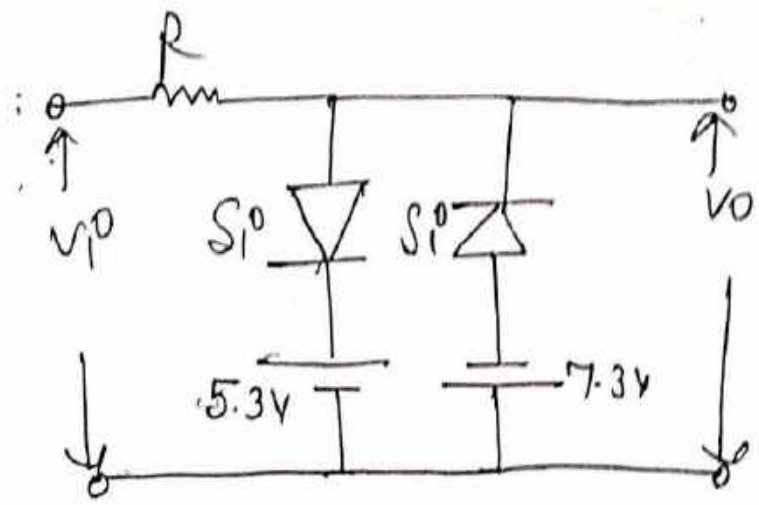
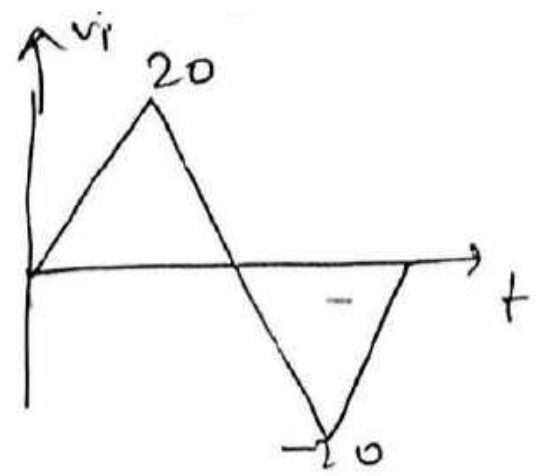
(i)  $V_1^o < -5$   
 $D \rightarrow \text{off}$   
 $V_o = 0$

(ii)  $V_1^o > -5$

$$\frac{V_1^o + 5 - V_o}{V_o = V_1^o + 5}$$



# Example:2 Sketch the output for the following circuit.



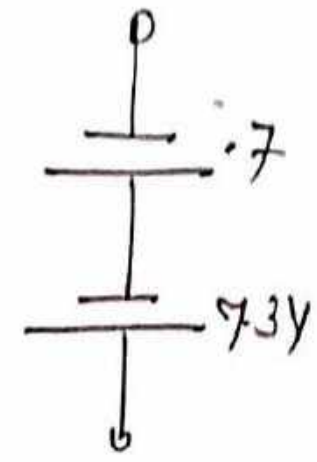
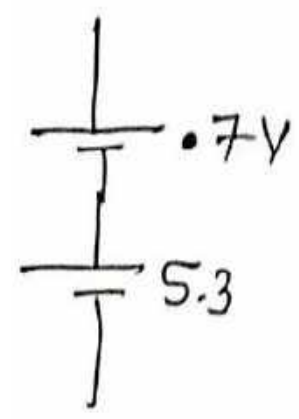
Soln. Transition Voltage

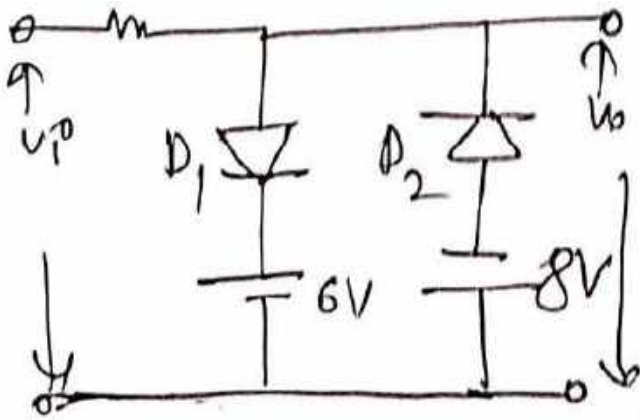
$$V_{i1} - 0.7 - 5.3 = 0$$

$$V_{i1} = 6V$$

$$V_{i2} + 0.7 + 7.3 = 0$$

$$V_{i2} = -8V$$

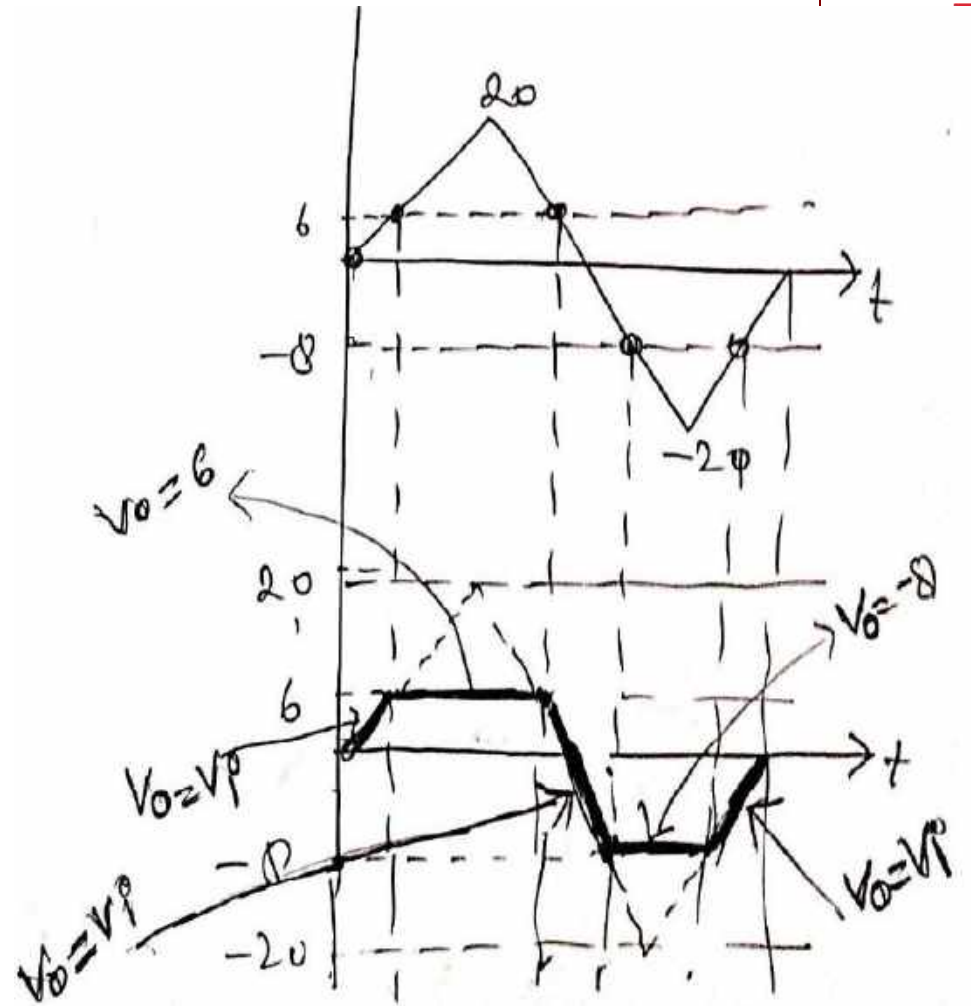




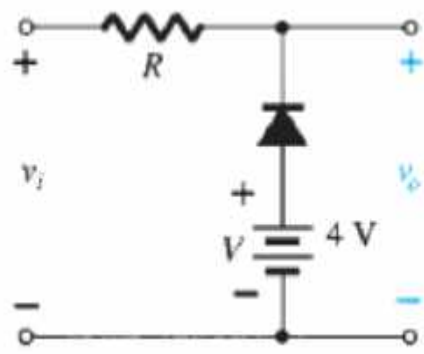
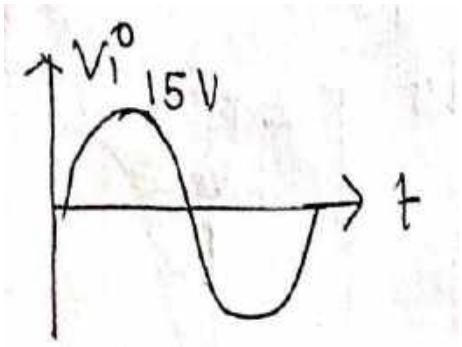
i)  $v_i^p < 0$   
 $D_1$  off,  $D_2$  ON  
 $v_o = -8V$

(ii)  $8 < v_i^p < 6$   
 $D_1$  off,  $D_2$  off  
 $v_o = v_i^p$

(iii)  $v_i^p > 8$   
 $D_1$  ON,  $D_2$  off  
 $v_o = +6$



# Example:3 Sketch the output for the following circuit.

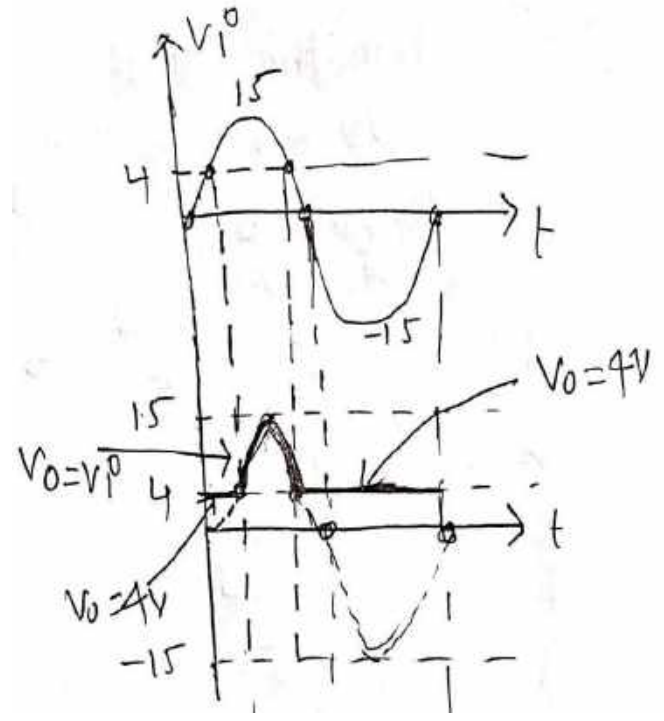


Solution

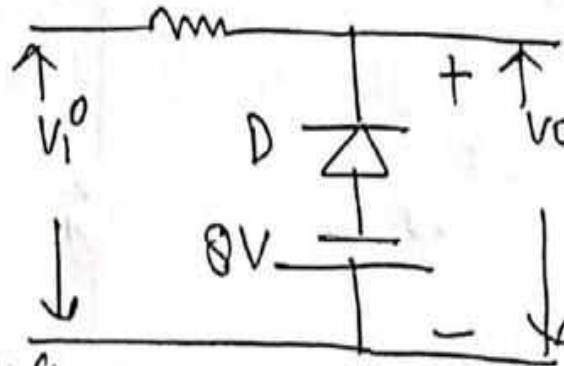
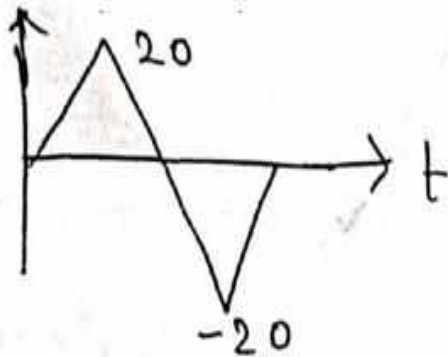
Transition Voltage ( $V_T$ )  
 $V_T - 4 = 0$   
 $V_T = 4$

(i)  $V_1^o > 4$   
 $D \rightarrow ON$   
 $V_0 = 4V$

(ii)  $V_1^o < 4$   
 $D \rightarrow OFF$   
 $V_0 = V_1^o$



# Example:4 Sketch the output for the following circuit.



Sol<sup>n</sup>: Transition voltage ( $V_T$ )

$$V_T + 8 = 0$$

$$V_T = -8V$$

(i)  $v_i^o < -8$

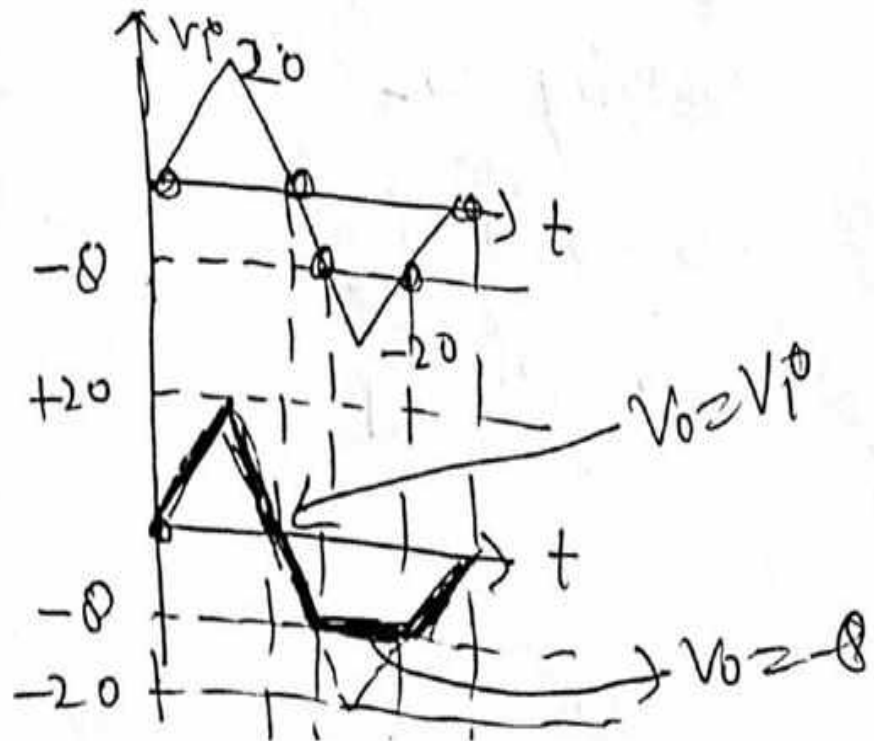
$D \rightarrow \text{off}$

$$V_o = v_i^o$$

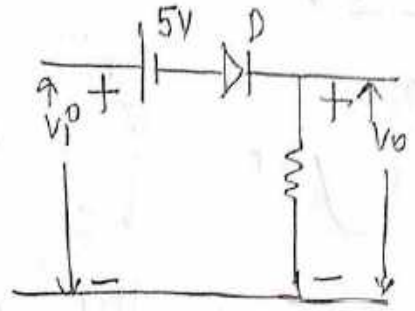
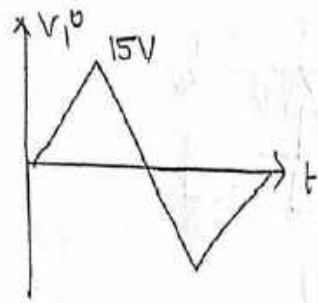
(ii)  $v_i^o > -8$

$D \rightarrow \text{ON}$

$$V_o = -8V$$



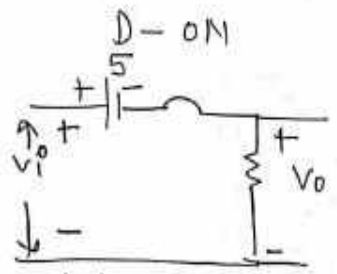
# Example: 5 Sketch the output for the following circuit.



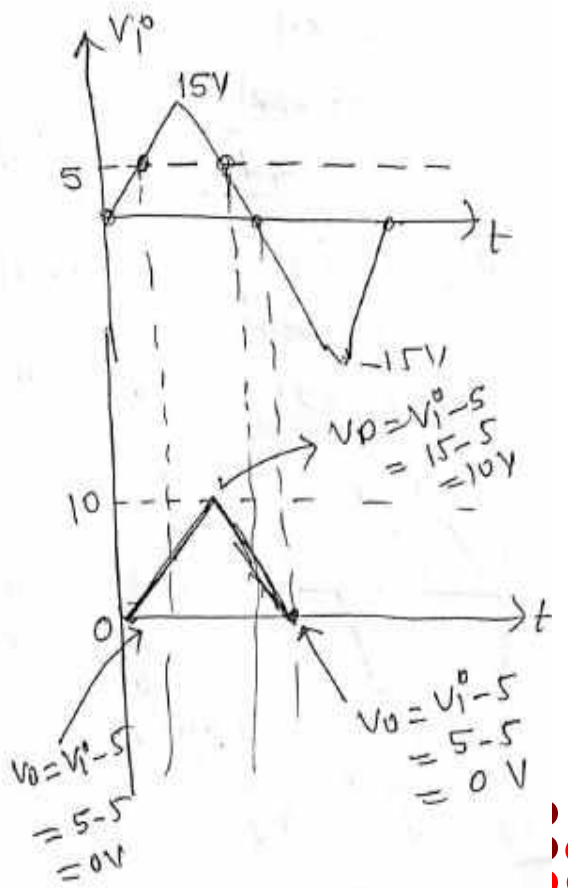
Sol<sup>n</sup>: Transition Voltage  
 $V_D - 5 = 0$   
 $V_D = 5$

(i)  $V_i^o < 5$   
 $D \rightarrow \text{off}$   
 $V_o = 0$

(ii)  $V_i^o > 5$

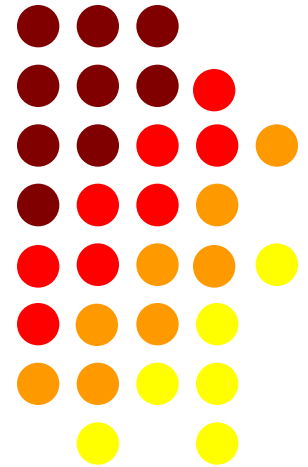


Applying KVL  
 $-5 - V_o + V_i^o = 0$   
 $V_o = V_i^o - 5$



## Lecture 14

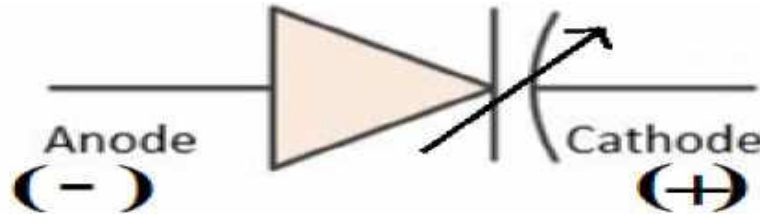
# Special Purpose diodes



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



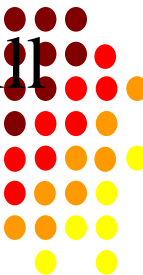
## Symbol:



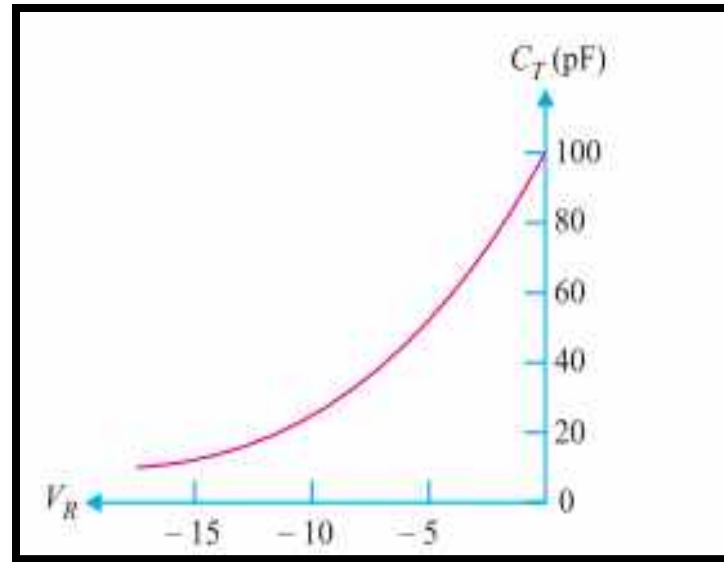
- Varactor diode is used in reverse bias condition. In reverse bias condition, the diode capacitance is given by

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

- 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



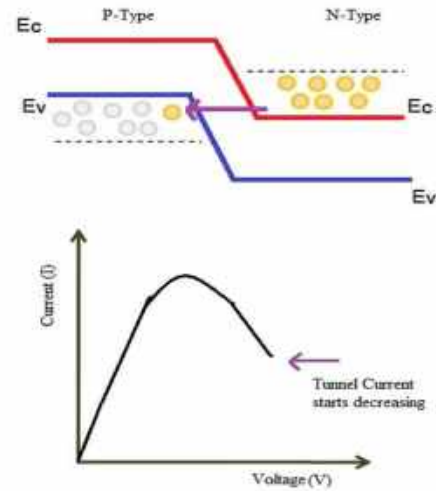
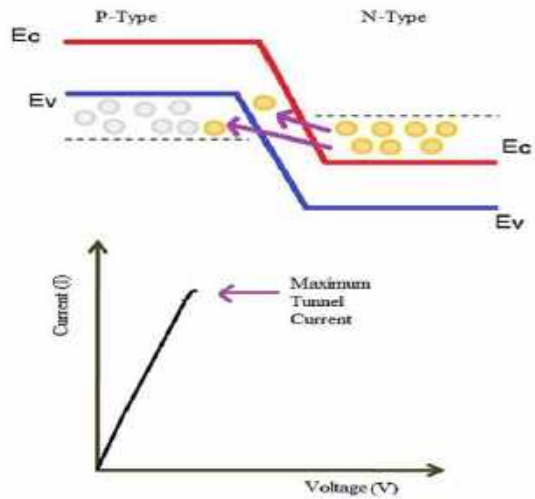
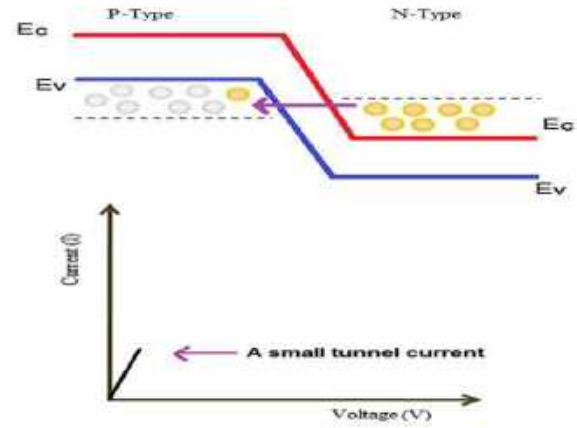
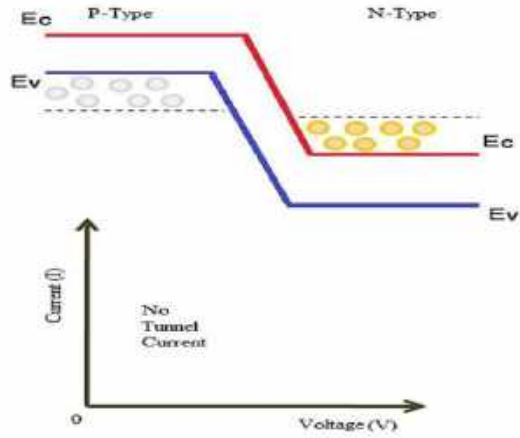


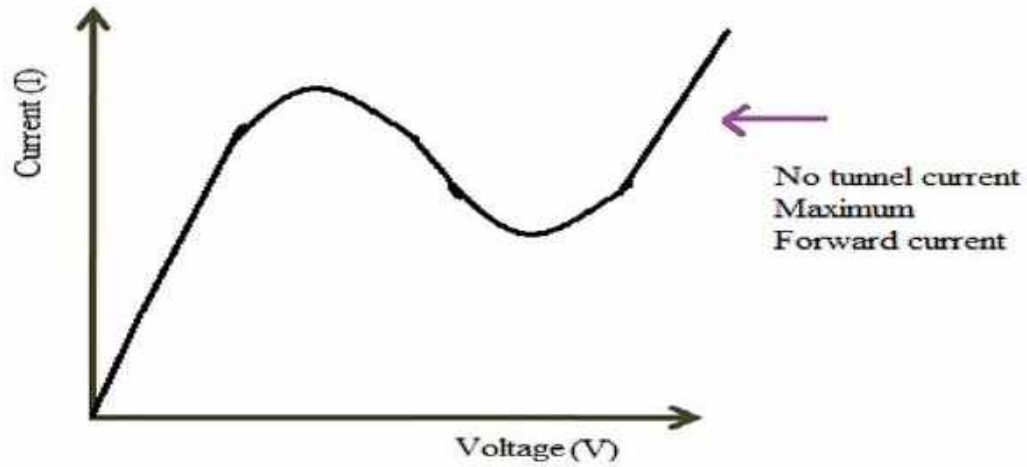
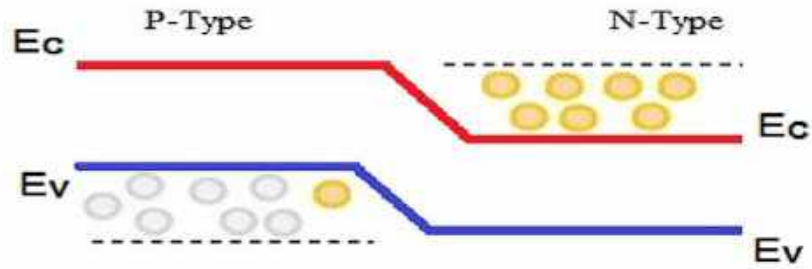
- Tunnel diode is very highly doped diode.
- The doping of Tunnel diode is 1000 times greater than simple diode.
- So, depletion layer is very narrow and is of the order of 10 nm.

## 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.





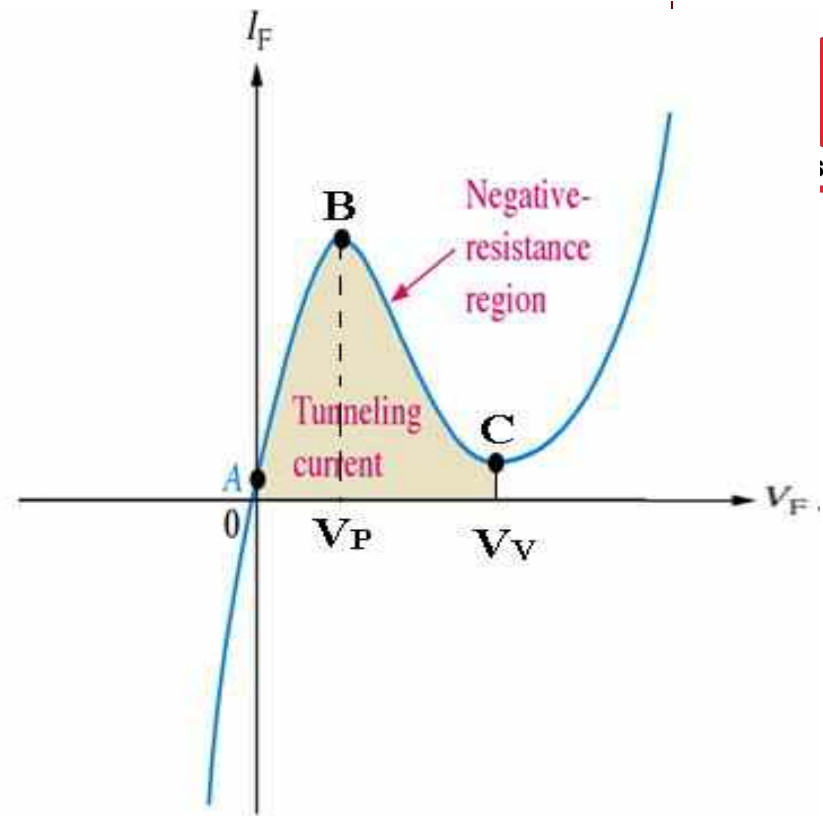


# V-I characteristics of Tunnel diode

**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 works as normal diode.



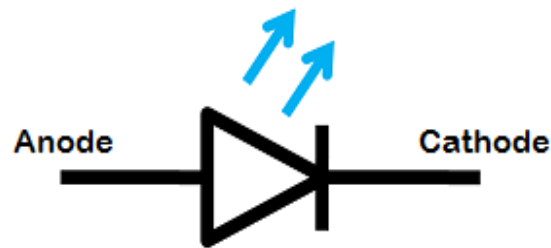
## Application:

- 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.

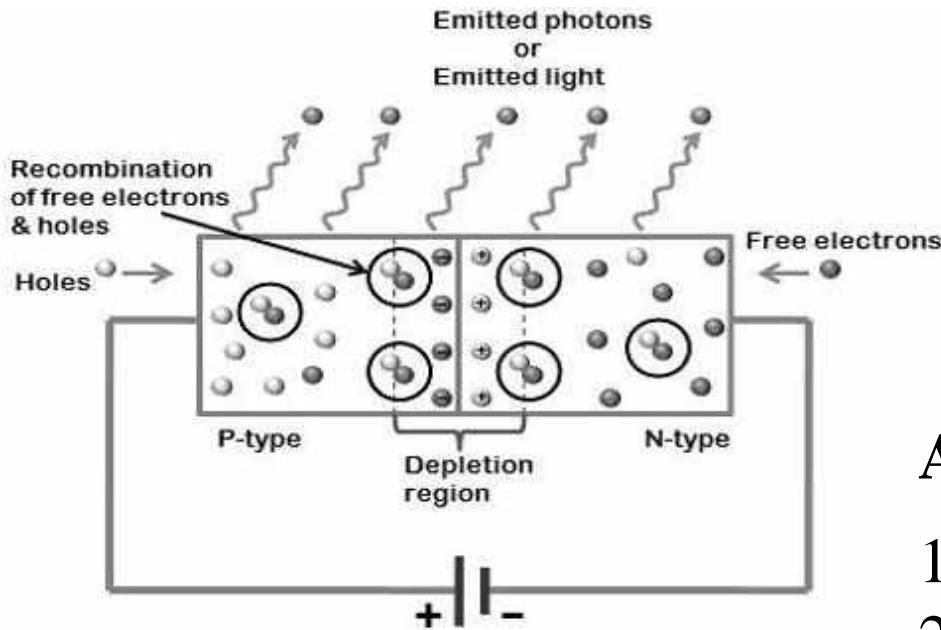


S.N.	Material	Colour
1	GaN	Blue (at 5 V)
2	GaN	White (at 4 V)
3	GaAsP	Red (at 1.8 V)
4	GaAsP	Orange (at 2 V)
5	GaP	Green

## 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.

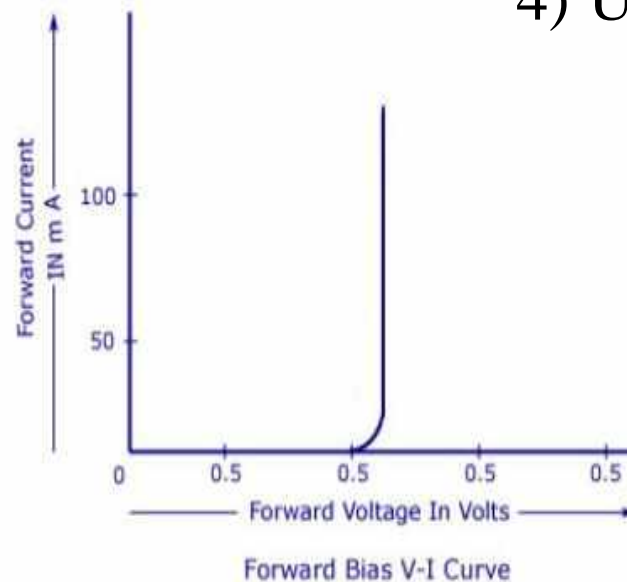


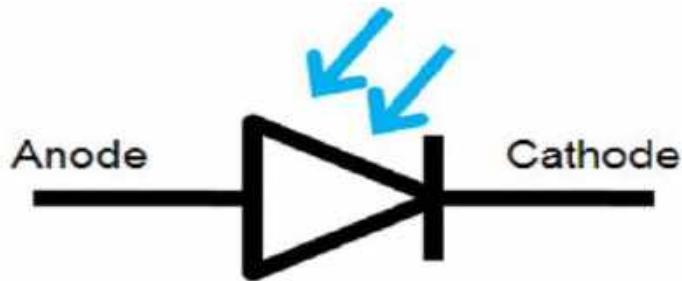


## Application:

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

## V-I characteristics:

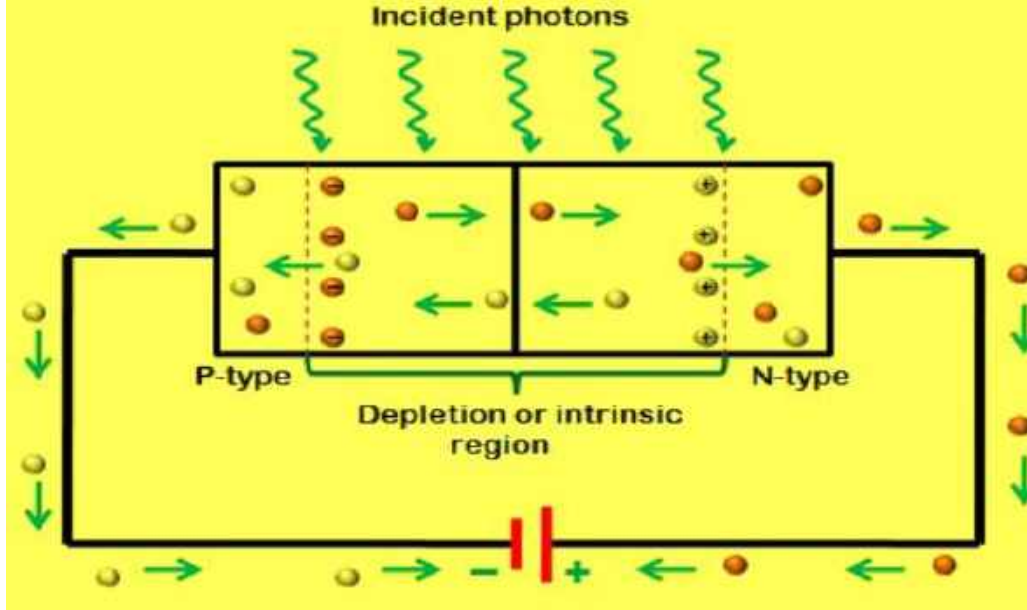




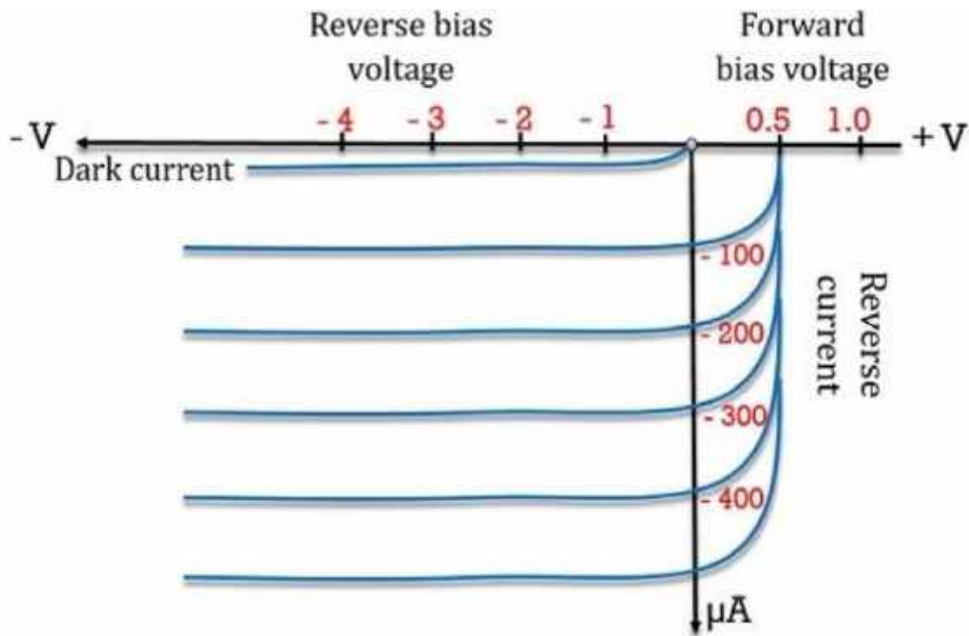
## Working principle:

- 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

