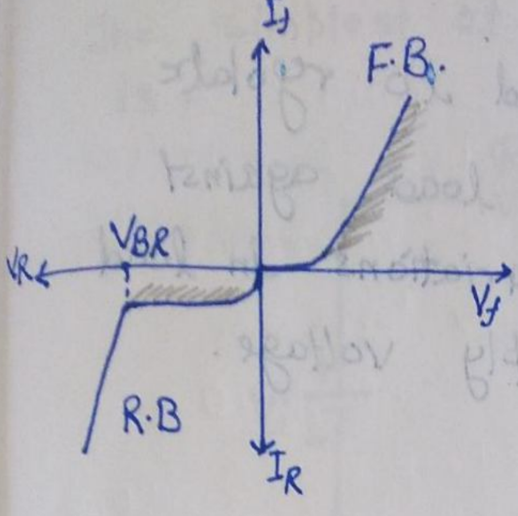
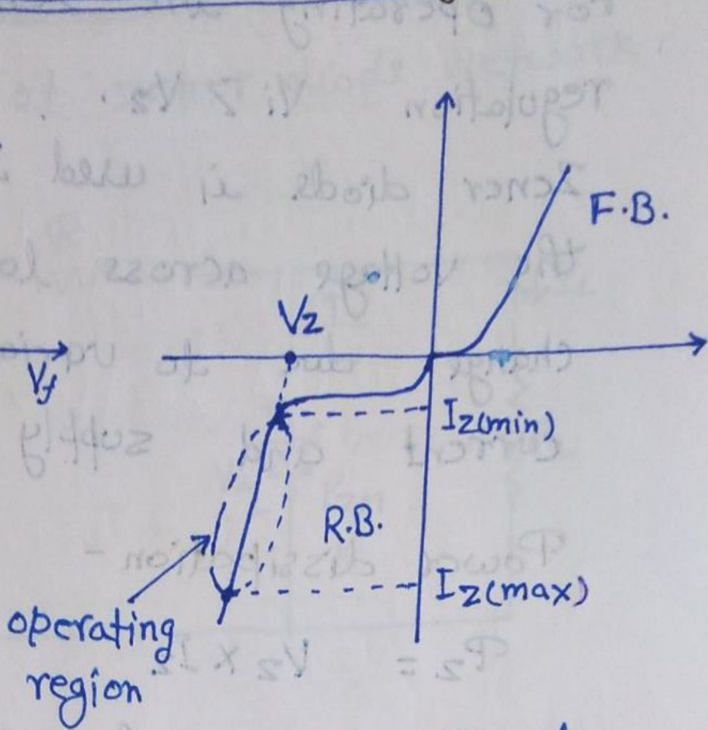
Zener Diode as a Shunt Regulator →



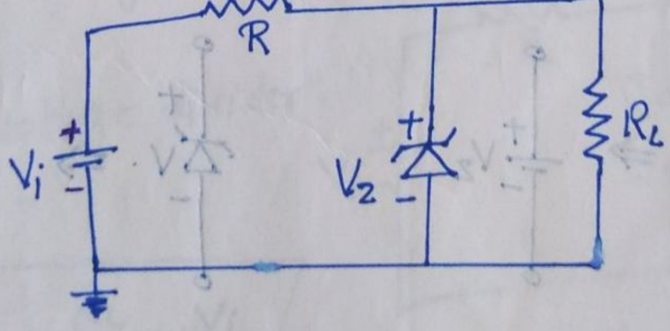
Normal Diode



Zener Diode

Zener diode works only in reverse biased region and does not work in forward biased. Basic zener regulator ckt -

Symbol



Basic zener regulator
(Shunt Regulator)

For operating the zener diode as regulation $V_i > V_Z$.
Zener diode is used to regulate the voltage across load against change due to variations in load current and supply voltage.

Power dissipation -

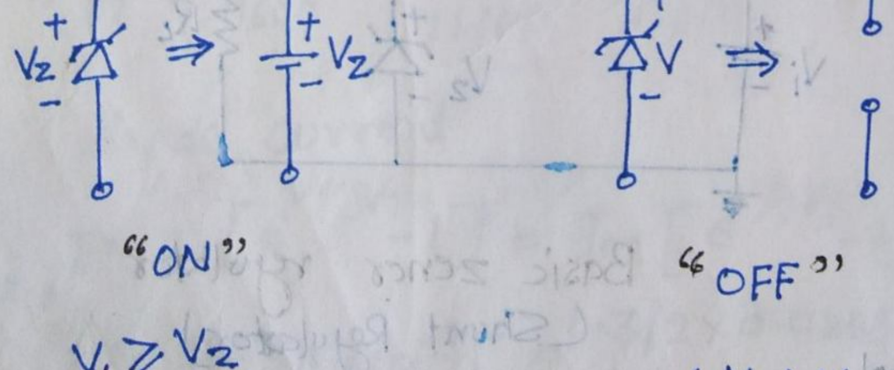
$$P_Z = V_Z \times I_Z$$

The maximum value of power dissipation is -

$$\boxed{P_{ZM} = V_Z \times I_{ZM}}$$

Where, I_{ZM} = maximum zener current

Thus

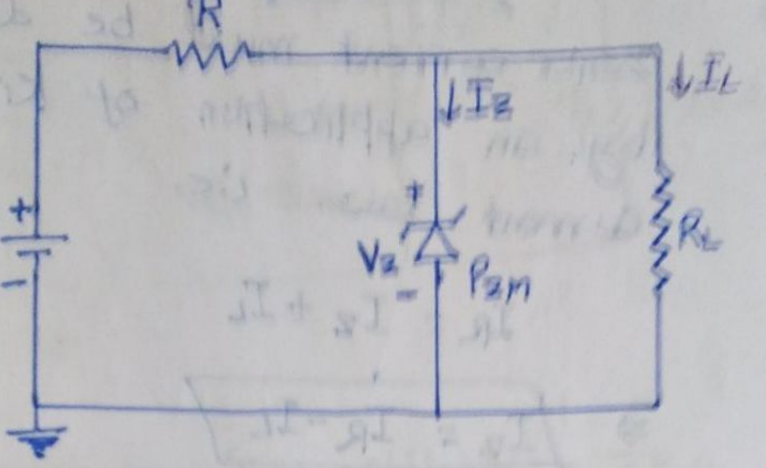


$V_L \geq V_Z$

$0 < V_L < V_Z$

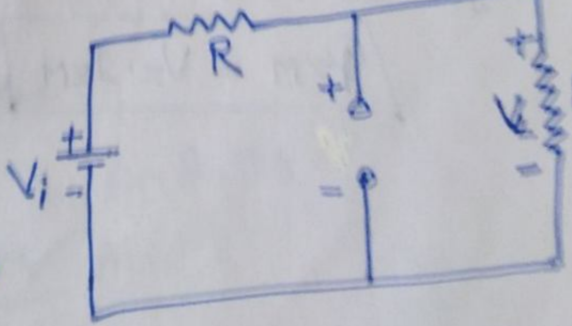
1. V_i and R_L fixed :-

The simplest of zener diode network is -



The analysis can fundamentally be broken down into two steps -

stepI - Determine the state of zener diode by removing it from the network and calculating the voltage across the load.



By voltage divider rule -

$$\boxed{V_L = \frac{R_L}{R+R_L} \cdot V_i}$$

Case1 - If $V_L < V_Z$, then zener diode is 'off'

Case2 - If $V_L \geq V_Z$, then zener diode is 'ON'

Step II - If zener diode is ON then we take

$$\boxed{V_L = V_Z}$$

Zener current must be determined by an application of Kirchhoff's current law. i.e.

$$I_R = I_Z + I_L$$

$$\Rightarrow \boxed{I_Z = I_R - I_L}$$

Where,

$$I_L = \frac{V_L}{R_L} \quad \text{and} \quad I_R = \frac{V_R}{R} = \frac{V_i - V_Z}{R}$$

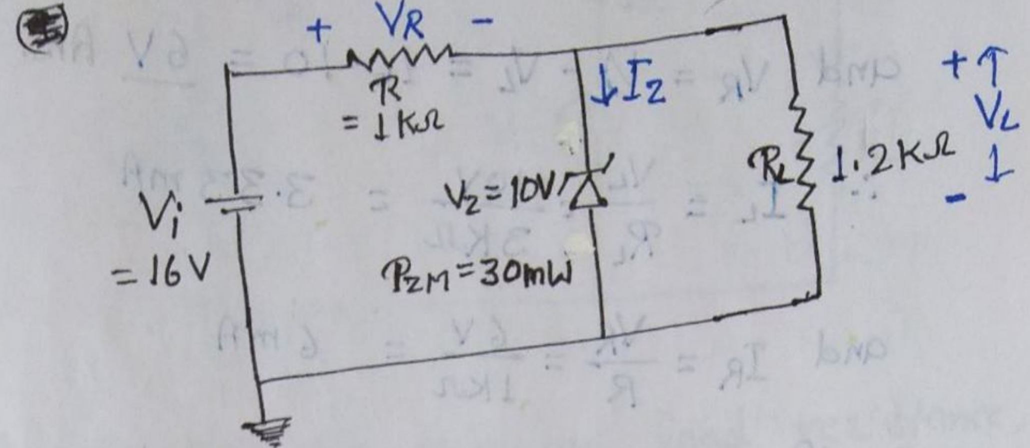
Power dissipated by the zener diode is -

$$\boxed{P_Z = V_Z \times I_Z}$$

Which must be less than the P_{ZM} specified for the device

$$\boxed{P_{ZM} = V_Z \cdot I_{ZM}}$$

Q. For the zener diode network of following fig (a) determine V_L, V_R, I_Z and P_Z



(b) Repeat part (a) with $R_L = 3K\Omega$.

Sol^n - The voltage across load R_L i.e. V_L

$$V_L = \frac{R_L}{R+R_L} \cdot V_i = \frac{1.2}{1+1.2} \times 16 = 8.73V$$

Since V_L (8.73 V) < V_Z (10V), the zener diode is in "off" state

$\therefore I_Z = \underline{0\,A}$ Ans.

$V_L = \underline{8.73\,V}$ Ans.

$\therefore V_R = V_i - V_L = 16 - 8.73$

$= \underline{7.27V}$ Ans.

and $P_Z = V_Z \cdot I_Z = V_Z \times 0 = \underline{0\,W}$ Ans.

(b) when $R_L = 3K\Omega$ then

$$V_L = \frac{R_L}{R_L+R} \cdot V_i = \frac{3}{4} \times 16 = 12\,V$$

Since, $V_L > V_Z$, the diode is in "on" state:

$$\therefore V_L = V_Z = \underline{10V} \ \underline{Ans.}$$

and $V_R = V_i - V_L = 16 - 10 = \underline{6V}$ Ans.

$$\therefore I_L = \frac{V_L}{R_L} = \frac{10V}{3K\Omega} = 3.33\,mA$$

and $I_R = \frac{V_R}{R} = \frac{6V}{1K\Omega} = 6\,mA$

so that,

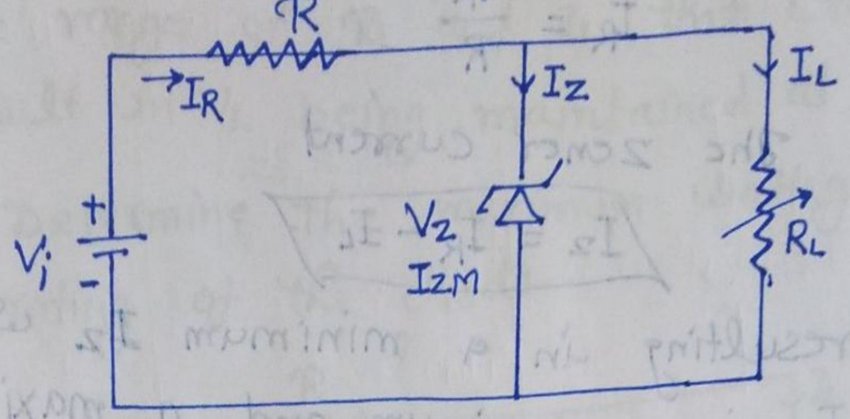
$$I_Z = I_R - I_L$$
$$= 6mA - 3.33mA$$
$$= \underline{2.67\,mA} \text{ Ans.}$$

The power dissipated,

$$P_Z = V_Z \cdot I_Z$$
$$= (10V) \cdot (2.67\,mA)$$
$$= 26.7\,mW$$

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

2- Fixed V_i and Variable R_L :→



To determine the minimum load resistance, ($R_{L(min)}$) that will turn the zener diode on, simply calculate the value of R_L that will result in a load voltage

$V_L = V_Z$ i.e.

$$V_L = V_Z = \frac{R_{L(min)}}{R_{L(min)} + R} \cdot V_i$$

$$\Rightarrow R_{L(min)} \cdot V_Z + R V_Z = R_{L(min)} \cdot V_i$$

$$\Rightarrow R_{L(min)} [V_i - V_Z] = R V_Z$$

$$\Rightarrow \boxed{R_{L(min)} = \frac{R \cdot V_Z}{V_i - V_Z}}$$

$$\therefore \boxed{I_{L(max)} = \frac{V_L}{R_{L(min)}} = \frac{V_Z}{R_{L(min)}}}$$

Once the diode is in the on state, the voltage across R remains fixed at

$$V_R = V_i - V_Z$$

and I_R remains fixed at

$$I_R = \frac{V_R}{R}$$

The zener current

$$\boxed{I_Z = I_R - I_L}$$

resulting in a minimum I_Z when I_L is a maximum and a maximum I_Z when I_L is a minimum value.

Since I_R is constant

Since I_Z is limited to I_{ZM},

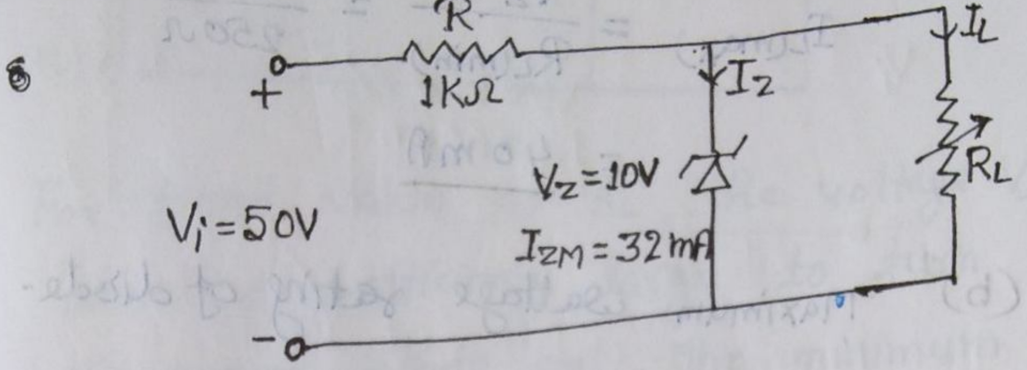
$$\therefore \boxed{I_{L(min)} = I_R - I_{ZM}}$$

and the maximum load resistance is-

$$R_{L(max)} = \frac{V_Z}{I_{L(min)}}$$

Q: For the n/w of following fig., determine the range of R_L and I_L that will result in V_L being maintained at 10V.

(b) Determine the maximum wattage rating of the diode.



Soln- To determine the value of R_L that will turn the zener diode "ON"

$$R_L(min) = \frac{RV_Z}{V_i - V_Z} = \frac{(1K\Omega)(10V)}{50V - 10V}$$

$$= \frac{10K\Omega}{40} = \underline{250\,\Omega}$$

The voltage across the resistor R is the

$$V_R = V_i - V_Z = 50V - 10V = 40V$$

$$\therefore I_R = \frac{V_R}{R} = \frac{40V}{1K\Omega} = 40mA$$

$\therefore$ The minimum level of I_L is -

$$I_L(min) = I_R - I_{ZM} = 40 - 32$$

$$= \underline{8mA}$$

Now, the max value of R_L

$$R_{L(max)} = \frac{V_Z}{I_{L(min)}} = \frac{10V}{8mA}$$

$$= \underline{1.25 K\Omega}$$

and max. value of I_L –

$$I_{L(max)} = \frac{V_Z}{R_{L(min)}} = \frac{10V}{250\Omega}$$

$$= \underline{40 mA}$$

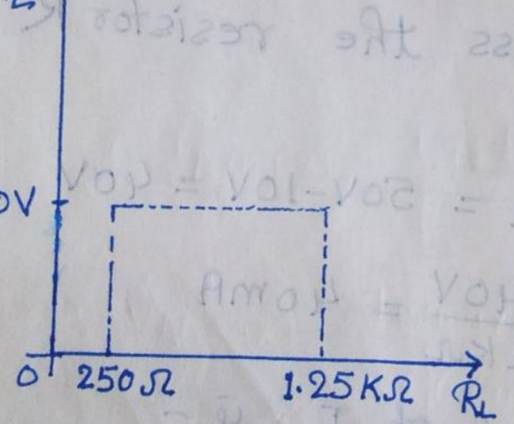
(b) Maximum wattage rating of diode-

$$P_{max} = V_Z \cdot I_{ZM}$$

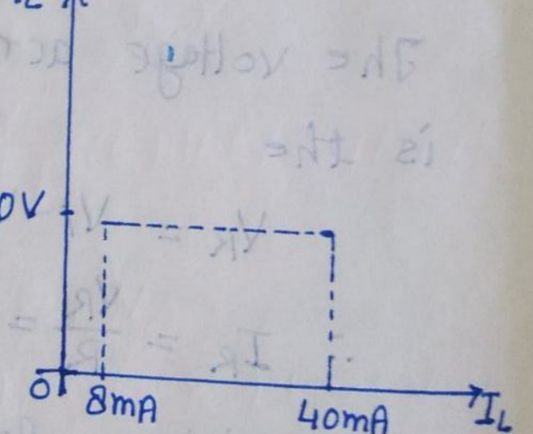
$$= (10V)(32mA)$$

$$= 320 mW$$

A plot of V_L versus R_L and for V_L Vs I_L is shown below-

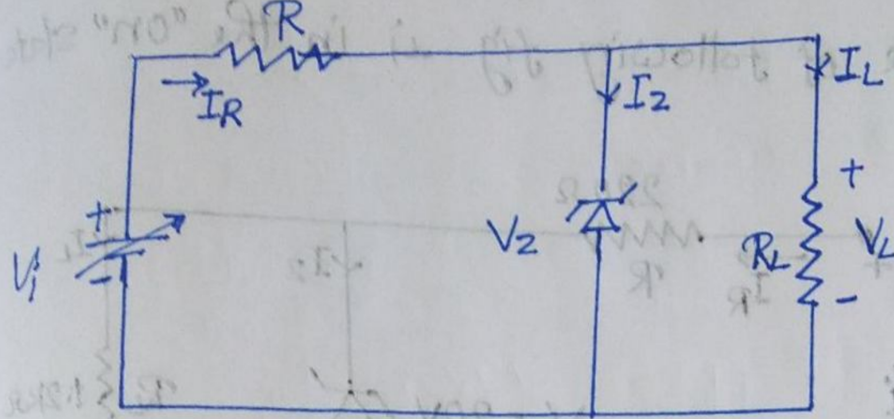


fig(a)



fig(b)

3- Variable V_i and fixed R_L :→



For fixed value of R_L, the voltage V_i must be sufficienty large to turn the zener diode on. The minimum turn-on voltage $V_i = V_{i(min)}$ is determined by

$$V_L = V_Z = \frac{R_L}{R+R_L} \cdot V_{i(min)}$$

$$\therefore \boxed{V_{i(min)} = \frac{(R+R_L)V_Z}{R_L}}$$

Since $I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$ = fixed

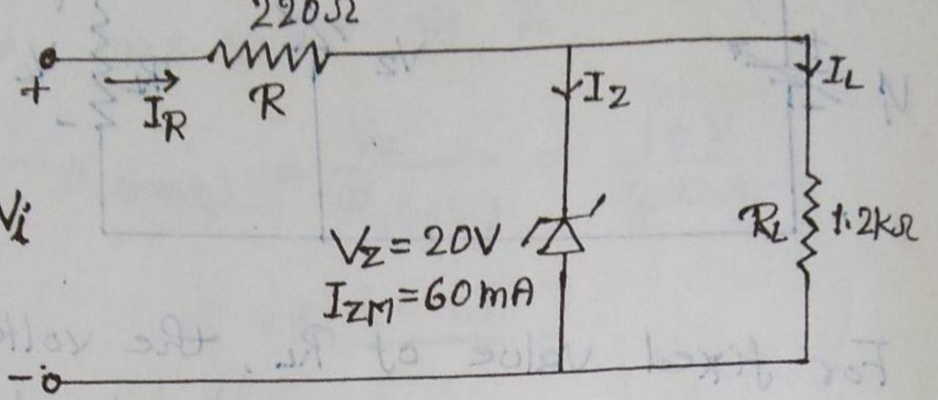
Then max. value of I_R will be

$$I_{R(max)} = I_{ZM} + I_L$$

$$\therefore \; V_{i(max)} = V_{R(max)} + V_Z$$

$$\Rightarrow \boxed{V_{i(max)} = I_{R(max)} \cdot R + V_Z}$$

Q. Determine the range of values of V_i that will maintain the zener diode of following fig is in the "on" state



Soln – Minimum value of V_i is

$$V_L = V_Z = \frac{R_L}{R_L+R} \cdot V_{i(min)}$$

$$\Rightarrow V_{i(min)} = \frac{R_L+R}{R_L} \cdot V_Z = \frac{1.2+0.220}{1.2} \times 20$$

$$\simeq 23.67\,V$$

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

$$\therefore I_{R(max)} = I_{ZM} + I_L = 60 + 16.67 = 76.67\,mA$$

$$\therefore V_{i(max)} = I_{R(max)} \cdot R + V_Z$$
$$= (76.67\,mA) \times (0.220\,k\Omega) + 20V$$
$$= 16.87\,V + 20\,V$$
$$\boxed{= 36.87\,V}$$