ZENER DIODE AS VOLTAGE REGULATOR

- After the ripples have been smoothed or filtered from the rectifier o/p, we get a sufficiently steady d.c o/p.
- The problem with this d.c o/p voltage is that it varies with the i/p a.c voltage or load.
  i.e If the input voltage increases, the D.C o/p voltage also increases & if load current increases, the o/p d.c voltage falls.
- In many applications we need a fixed o/p voltage regardless of the changes in the i/p voltage or load.
- Thus to improve the constancy of the d.c o/p voltage, a voltage regulator circuit is used.
- Zener diode can be used as voltage regulator to provide a const. voltage. The simplest ckt is as shown below:

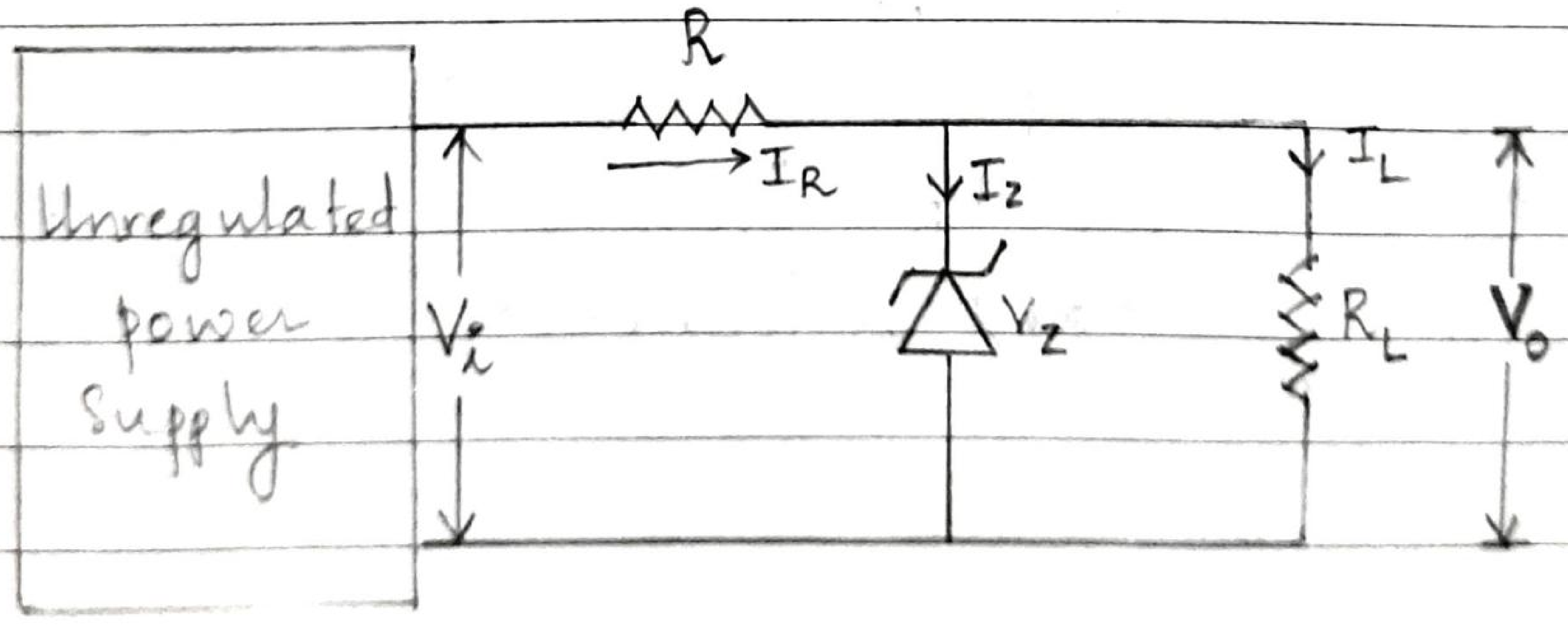

Fig: Zener-Diode Voltage Regulator circuit.

- The regulator ckt consists of a resistor R connected in series with input voltage & a zener diode connected in parallel with the load. The zener diode is selected in such a way that its breakdown voltage is equal to the desired regulating output.
- Zener diode will <u>maintain constant voltage</u> $V_Z = V_0$ across the load as long as i/p voltage is above V_Z.
- The current from the power supply splits at the j^n

$$\therefore \boxed{I_R = I_Z + I_L}$$

R_L FIXED, V_i VARIES:

- <u>Suppose i/p voltage V_i increases</u>, the excess voltage is dropped across R & the current I_R increases. This increases the current through zener I_Z (I_L cannot change since R_L is fixed). Thus total current is balanced & load current remains constant. $\therefore V_0$ remains constant.
- <u>Suppose i/p voltage V_i decreases</u>, voltage drop across R is reduced, I_R decreases and I_Z also falls. Because of the self adjusting voltage drop across R, the o/p V_0 fluctuates to a much lesser extent.

V_i FIXED, R_L VARIES:

- <u>Suppose R_L increases</u>, load current I_L decreases, the zener diode passes extra current so that I_R is kept constant (Since V_i is constant) The output voltage of the circuit is thus stabilized.
- <u>Suppose R_L decreases</u>, I_L increases, the current I_Z falls by the same percentage inorder to maintain constant current I_R So that voltage drop across R remains constant & hence V_0 remains constant

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Thus 3 conditions can be considered:
1. Fixed Supply & Load
2. Fixed Supply & Variable Load
3. Fixed Load & Variable Supply.

(1) V_i & R_L FIXED

A Simple Zener diode regulator is shown:- (fig(a))
The applied d.c voltage is fixed & so is the load resistor.
The analysis can be broken down into 2 steps:

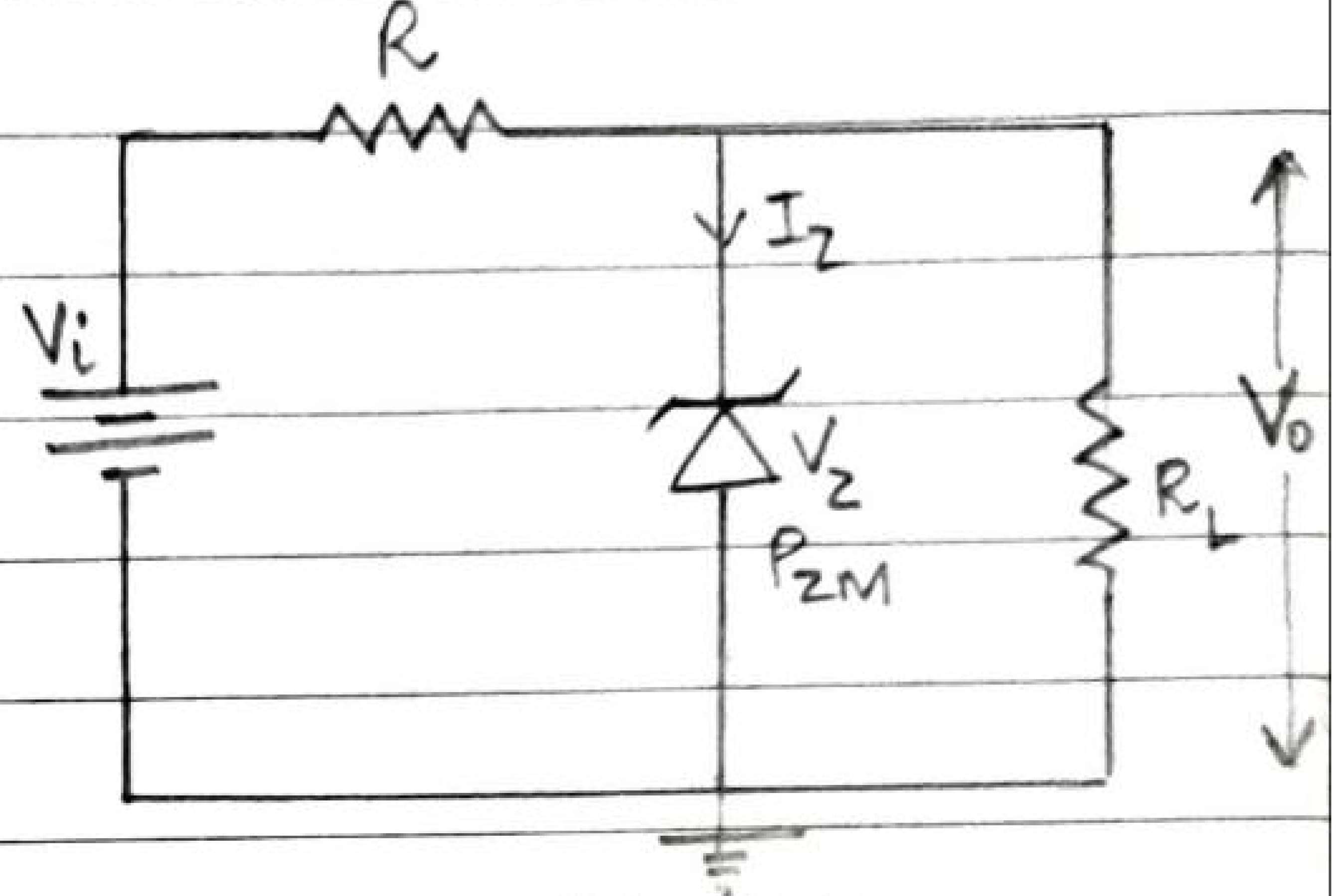
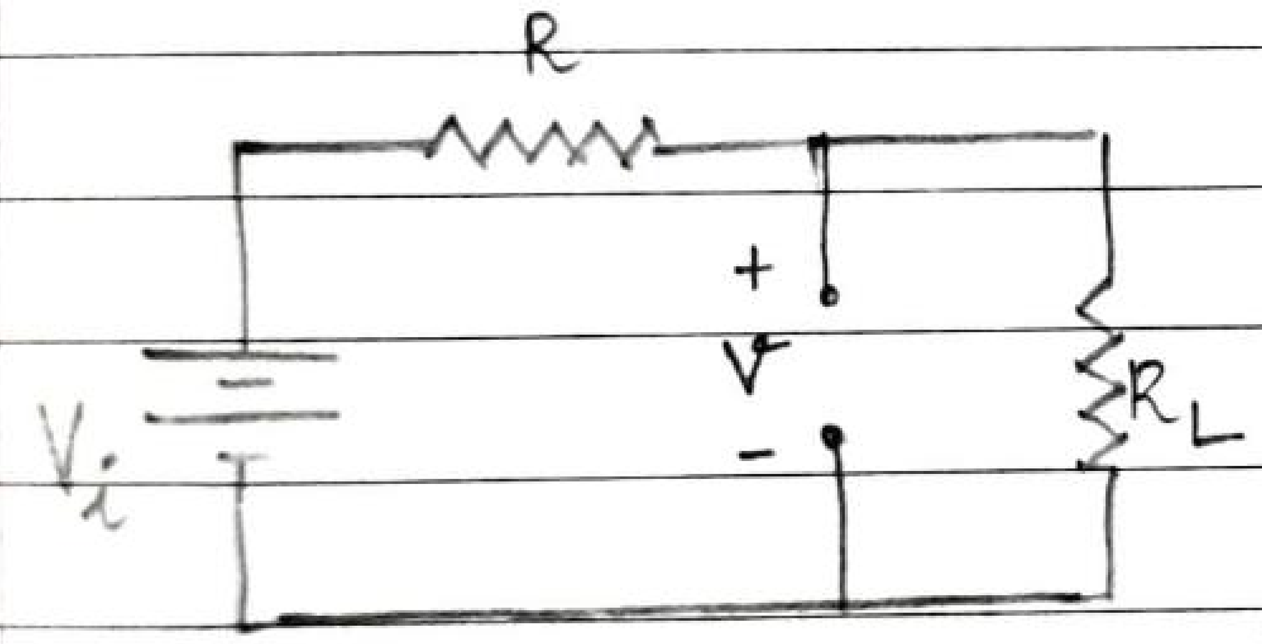


fig (a)

Step 1: Determine the state of the Zener diode by calculating the voltage across it. i.e Apply Voltage Divider Rule.



fig(b)

i.e find v (fig(b))

$$v = \frac{V_i \times R_L}{R + R_L} \quad (= V_L)$$

If $v \geq V_Z$, Zener diode is ON
If $v < V_Z$, diode is off ∴ Open ckt

Step 2: Substitute the appropriate equivalent ckt & solve for the desired unknowns.

If $v \geq V_Z$, ckt can be drawn as in fig(c).

Here $\boxed{V_L = V_Z}$

& $I_R = I_Z + I_L$

where $I_L = \frac{V_L}{R_L}$ & $I_R = \frac{V_R}{R} = \frac{V_i - V_Z}{R}$

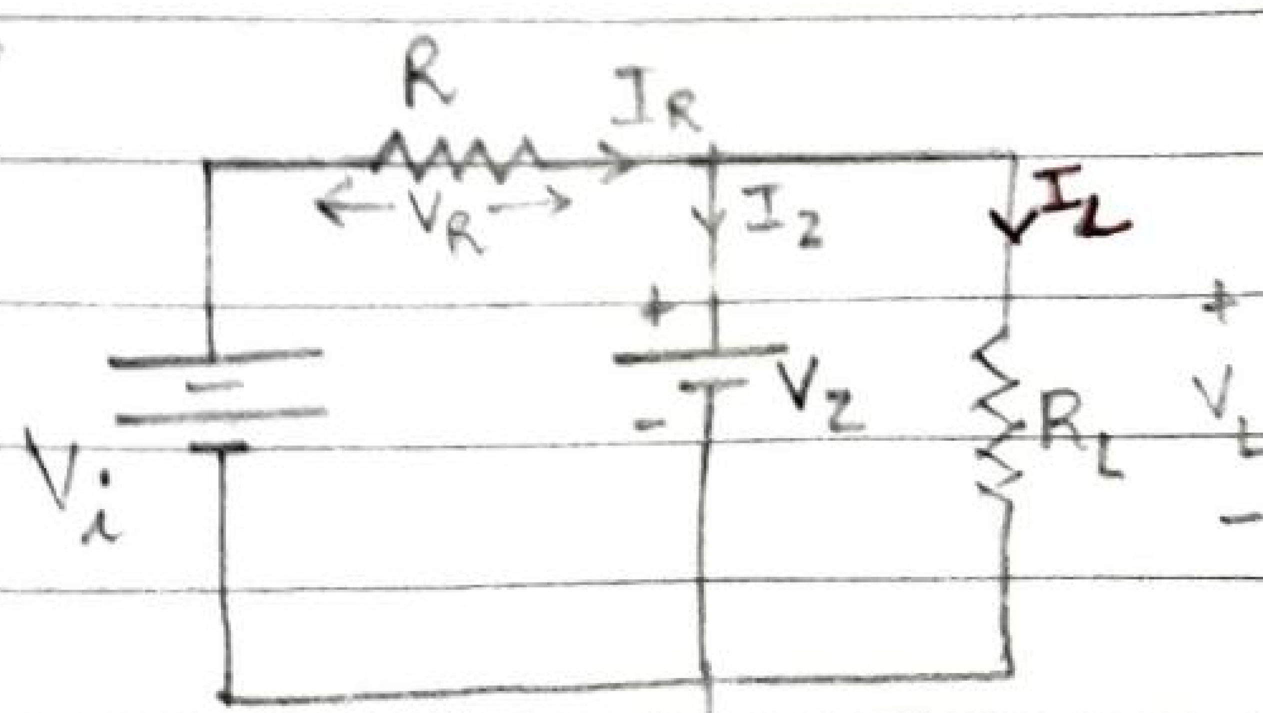
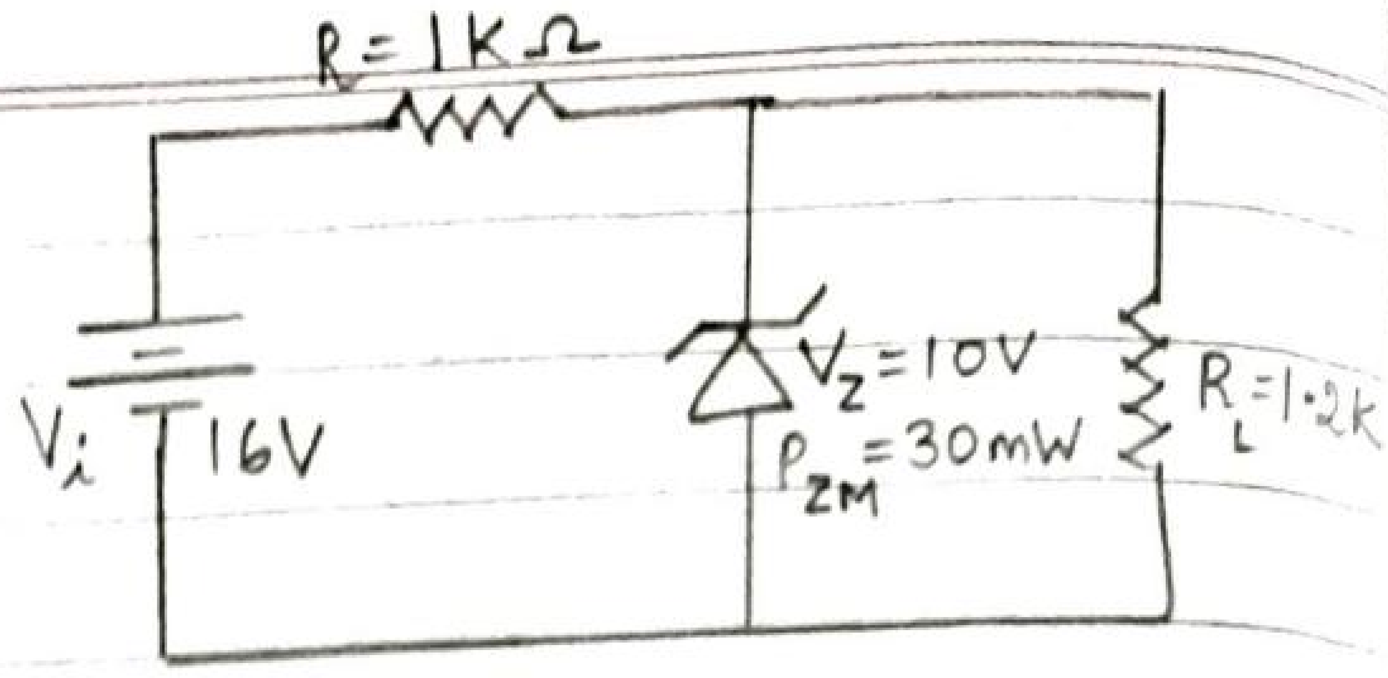


fig (c)

The power dissipated by Zener is given by $\boxed{P_Z = V_Z I_Z}$

This must be less than P_{ZM}

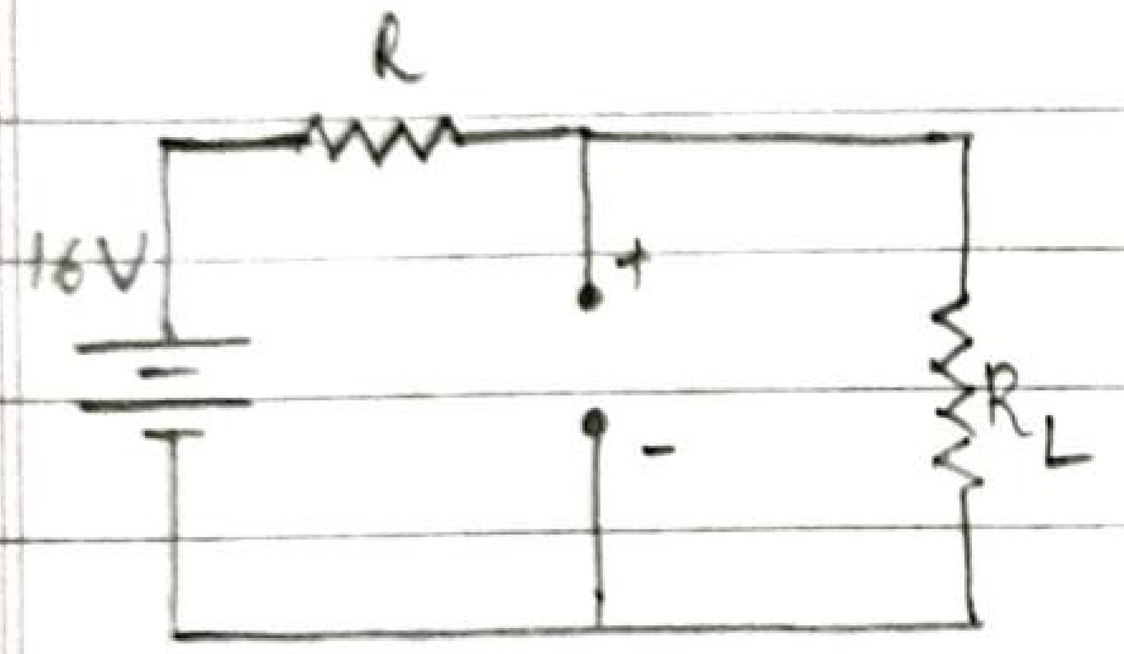
Q. For zener diode of the given network, determine:
(a) V_L, V_R, I_Z & P_Z
(b) Repeat with $R_L = 3k\Omega$.



Sol^n :— Determine the state of zener:

$$V = \frac{V_i \times R_L}{R_L + R} = \frac{16 \times 1.2k\Omega}{1.2k\Omega + 1k\Omega} = 8.73\,V$$

This value is less than V_Z ($\because V_Z = 10V$) $\therefore$ Zener is off. openckt.



$V_L = V = 8.73\,V$

$V_R = V_i - V_Z = 16 - 8.73$
$= 7.27\,V$

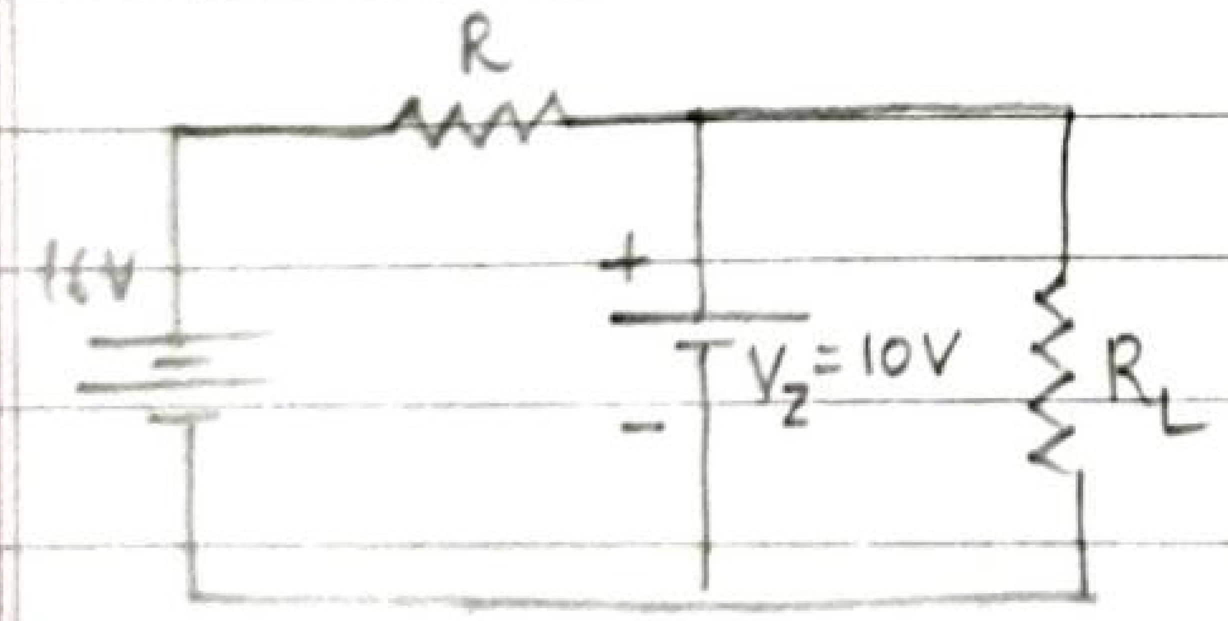
$I_Z = 0$ Amp.

$P_Z = V_Z \times I_Z = 0$ Watts.

(b) With $R_L = 3k\Omega$.

$$V = \frac{V_i \times R_L}{R_L + R} = \frac{16 \times 3k\Omega}{3k\Omega + 1k\Omega} = 12\,V$$

$12V > 10V$ $\therefore$ Zener is ON.



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

$\therefore V_L = V_Z = 10\,V$

$V_R = \frac{V_i - V_Z}{R} = \frac{16 - 10}{1k\Omega} = 6mA.$

$I_Z = I_R - I_L = 6mA - 3.33mA$
$= 2.67\,mA$

$P_Z = V_Z I_Z = 10 \times 2.67mA = 26.7\,mW$
$(< 30mW)$

Q. A Zener diode is specified as having a breakdown voltage of 9.1 V, with a max power dissipation of 364 mW. What is the max current the diode can handle?

Sol^n:- $P_{ZM} = I_{ZM} \times V_Z$

$$\therefore I_{ZM} = \frac{P_{ZM}}{V_Z} = \frac{364\,mW}{9.1\,V} = \frac{364 \times 10^{-3}}{9.1} = 40\,mA.$$

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② FIXED V_i, VARIABLE R_L

- Due to the limited region (breakdown region) that the zener diode can operate, there is a specific range of resistor values that ensures that zener is in 'ON' state.
- Too small a load resistance $(V_L < V_Z)$, I_L will be large, I_Z will fall by a large percentage & the zener will be in 'OFF' state.
- Too large a load resistance, I_L will be negligible, max current will flow through zener which might exceed I_{Zmax}

To determine the minimum load resistance that will turn the zener diode ON, we calculate the value of R_L that results in load voltage $V_L = V_Z$. That is,

$$V_L = V_Z = \frac{V_i \times R_{L_{min}}}{R_{L_{min}} + R}$$

$$\therefore V_Z(R_{L_{min}} + R) = V_i \times R_{L_{min}}$$

$$\therefore \boxed{R_{L_{min}} = \frac{V_Z \times R}{V_i - V_Z}}$$

Any load resistance > $R_{L_{min}}$ will ensure that zener is in 'ON' state.

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

fixed.

Once the diode is ON, $\boxed{V_R = V_i - V_Z}$ & $\boxed{I_R = \frac{V_R}{R}}$

Zener current : $I_Z = I_R - I_L$

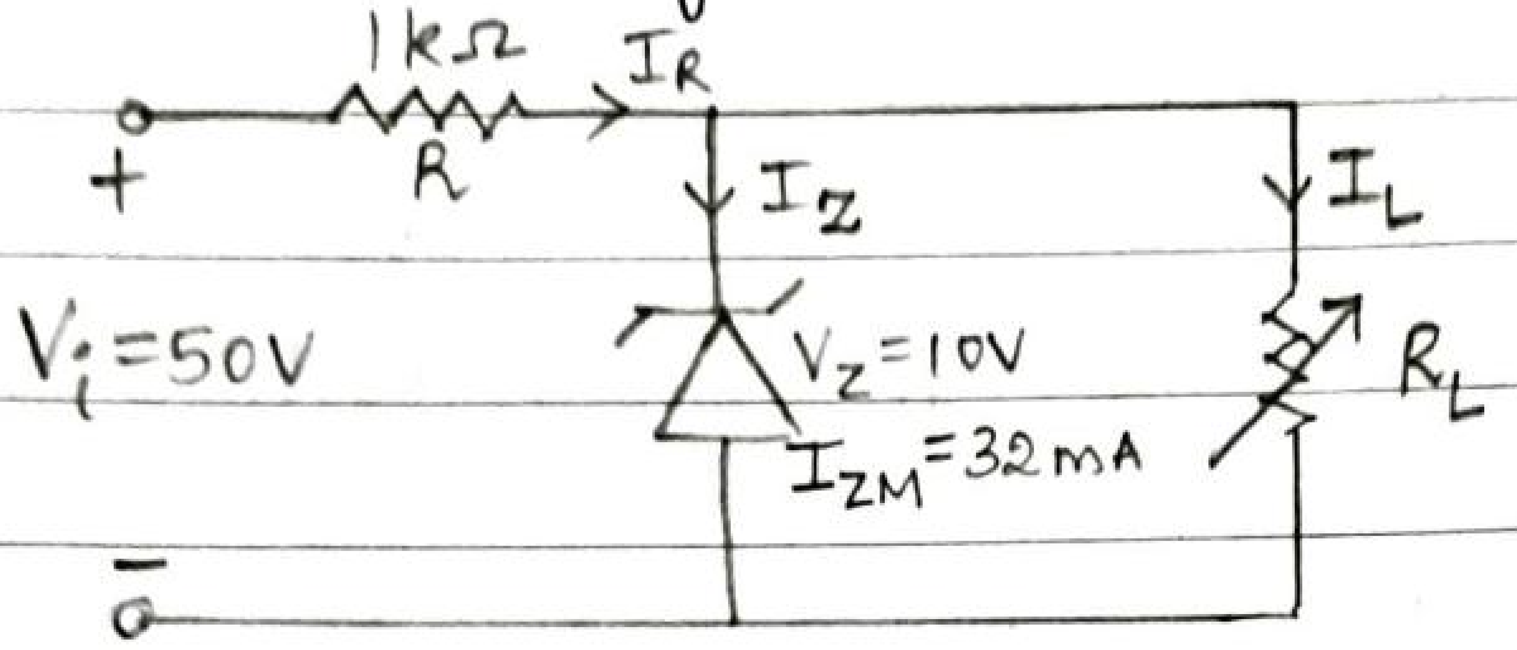
When I_L is min, max I_Z flows & when I_L is max, min I_Z flows thr' zener (∵ I_R is constant).

$$\therefore \boxed{I_{L_{min}} = I_R - I_{ZM}}$$

*I_{Zmax} is written as I_{ZM}.

$$\therefore \boxed{R_{L_{max}} = \frac{V_Z}{I_{L_{min}}}}$$

Q. For the given network (a) determine the range of R_L & I_L that will result in V_L being maintained at 10V.
(b) Determine the maximum wattage rating of the diode.
(c) If zener max wattage is increased to 380 mW, what is the new value of I_{Lmin}?



Sol^n :— (a) $R_{Lmin} = \dfrac{R V_z}{V_i - V_z}$

$= \dfrac{1k \times 10}{50 - 10} = 250\,\Omega$.

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

$I_R = \dfrac{V_R}{R} = \dfrac{40}{1k\Omega} = 40\,mA$.

$I_{Lmin} = I_R - I_{ZM} = 40mA - 32mA = 8\,mA$.

$I_{Lmax} = \dfrac{V_z}{R_{Lmin}} = \dfrac{10}{250} = 40\,mA$.

$R_{Lmax} = \dfrac{V_z}{I_{Lmin}} = \dfrac{10}{8mA} = 1.25\,k\Omega$.

$\therefore\ 250\,\Omega < R_L < 1.25\,k\Omega$

$8\,mA < I_L < 40\,mA$.

(b) $P_{zmax} = I_{ZM} \times V_z = 32mA \times 10V = 320\,mW$

(c) If $P_{zmax(new)} = 380\,mW$

$I_{ZM(new)} = \dfrac{P_{zmax(new)}}{V_z} = \dfrac{380\,mW}{10} = 38\,mA$

$\therefore$ New value of $I_{Lmin} = I_R - I_{ZM(new)} = 40\,mA - 38\,mA$

$= 2\,mA$

(3) **FIXED R_L, VARIABLE V_i**

For fixed values of R_L, V_i must be sufficiently large to turn the zener diode ON.

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

$$V_L = V_Z = \frac{V_{i_{min}} \times R_L}{R + R_L}$$

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

I_L is fixed at $I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$

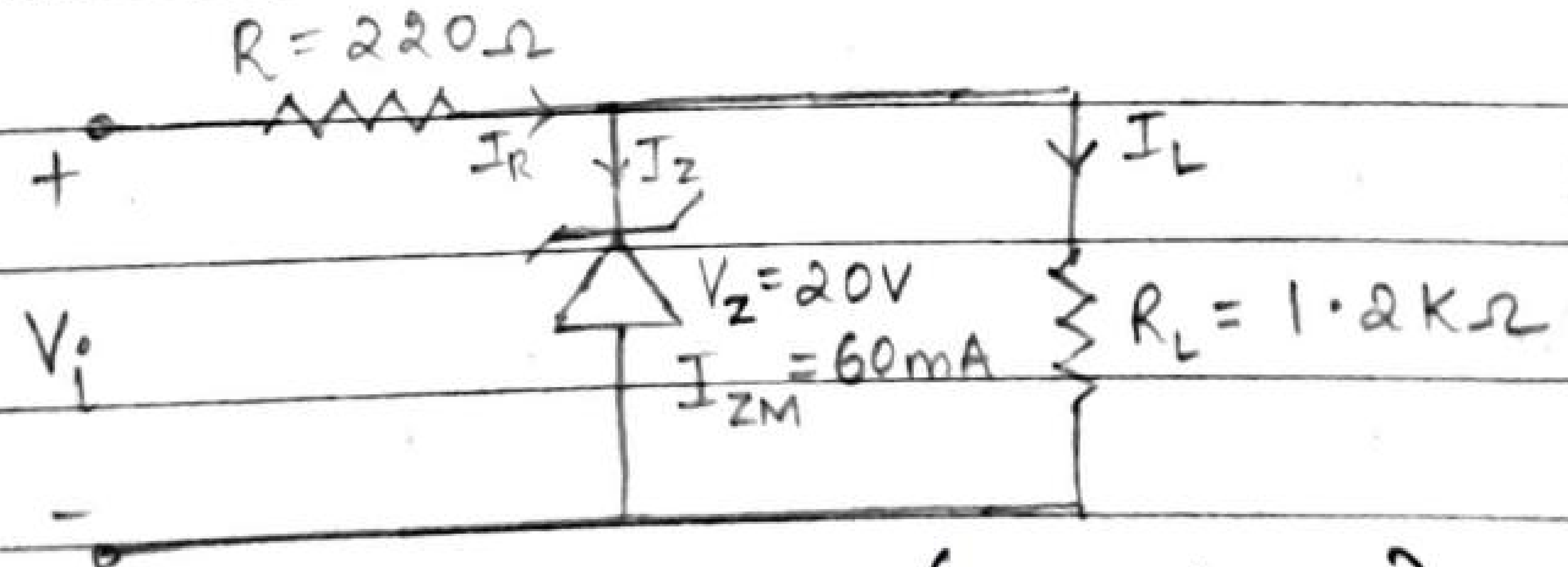
When I_R is max, maximum current flows thr' zener

$$\therefore \boxed{I_{R_{max}} = I_{ZM} + I_L}$$

Since $I_{R_{max}} = \frac{V_{i_{max}} - V_Z}{R} \Rightarrow \boxed{V_{i_{max}} = (I_{R_{max}} \times R) + V_Z}$

OR $\boxed{V_{i_{max}} = V_{R_{max}} + V_Z}$

Q. Determine the range of values of V_i that will maintain the zener diode in 'ON' state.



Soln :- $V_{i_{min}} = \frac{V_Z(R_L + R)}{R_L} = \frac{20(1.2K + 220)}{1.2K} = 23.67\ V$

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

$I_{R_{max}} = I_{ZM} + I_L = 60mA + 16.67\ mA = 76.67\ mA$.

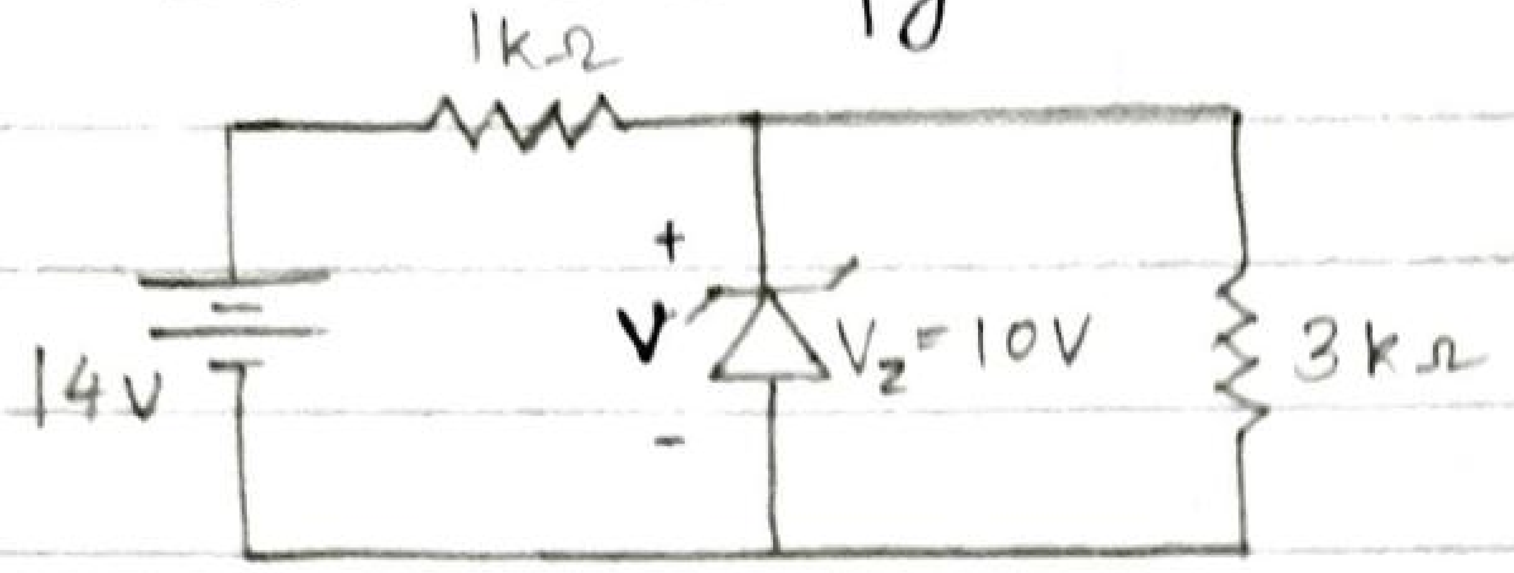
$V_{i_{max}} = I_{R_{max}} R + V_Z$

$= (76.67\ mA \times 220) + 20 = 36.87\ V$

$\therefore 23.67V < V_i < 36.87\ V$

Problems :

Q1) In the ckt shown, is the zener diode in 'ON' state or 'OFF' state. Justify.

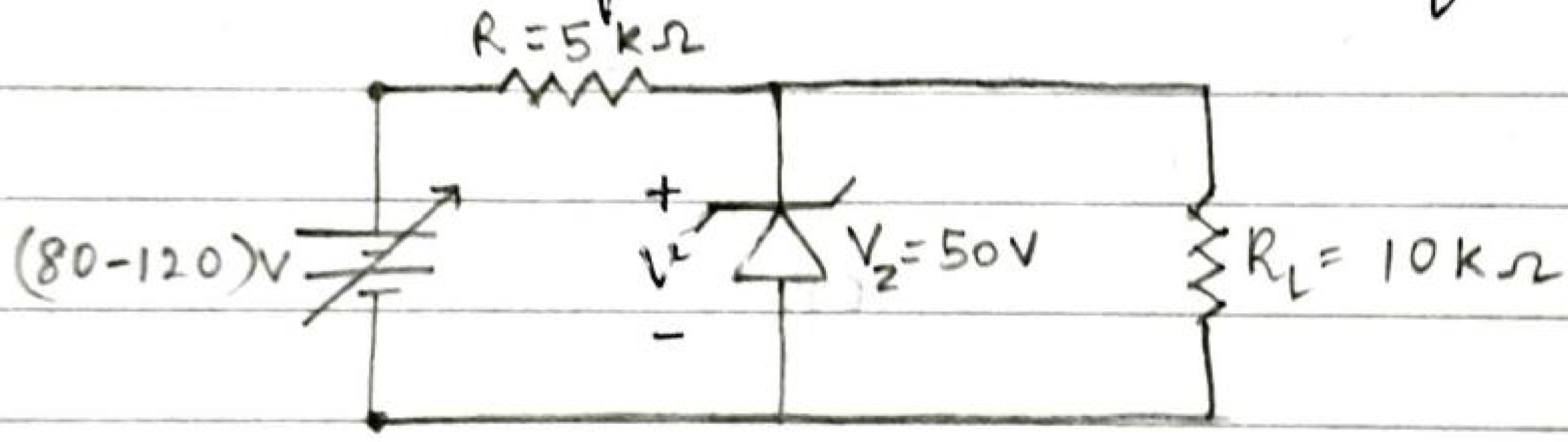


Sol^n : $V = \dfrac{V_i \times R_L}{R_L + R}$

$= \dfrac{14 \times 3k\Omega}{3k\Omega + 1k\Omega} = 10.5\ V$

$\therefore V > V_z \quad \therefore$ Zener is in ON state.

** Q2) Determine maximum & minimum values of zener diode current for the ckt below if $V_z = 50V$.



Sol^n :- V_i varies from 80V to 120V.

To ensure zener is in ON state for this entire range, atleast V_{imin} (i.e 80V) should be enough to turn it ON

$V = \dfrac{V_i \times R_L}{R_L + R} = \dfrac{80 \times 10k\Omega}{10k\Omega + 5k\Omega} = 53.33V$

$\therefore V > V_Z \quad \therefore$ Zener is always in ON state.

(i) Consider $V_{imin} = 80V$

$I_{R_{min}} = \dfrac{V_R}{R} = \dfrac{V_{imin} - V_z}{R} = \dfrac{80 - 50}{5k\Omega} = 6mA$.

$I_L = \dfrac{V_z}{R_L} = \dfrac{50}{10k\Omega} = 5mA$

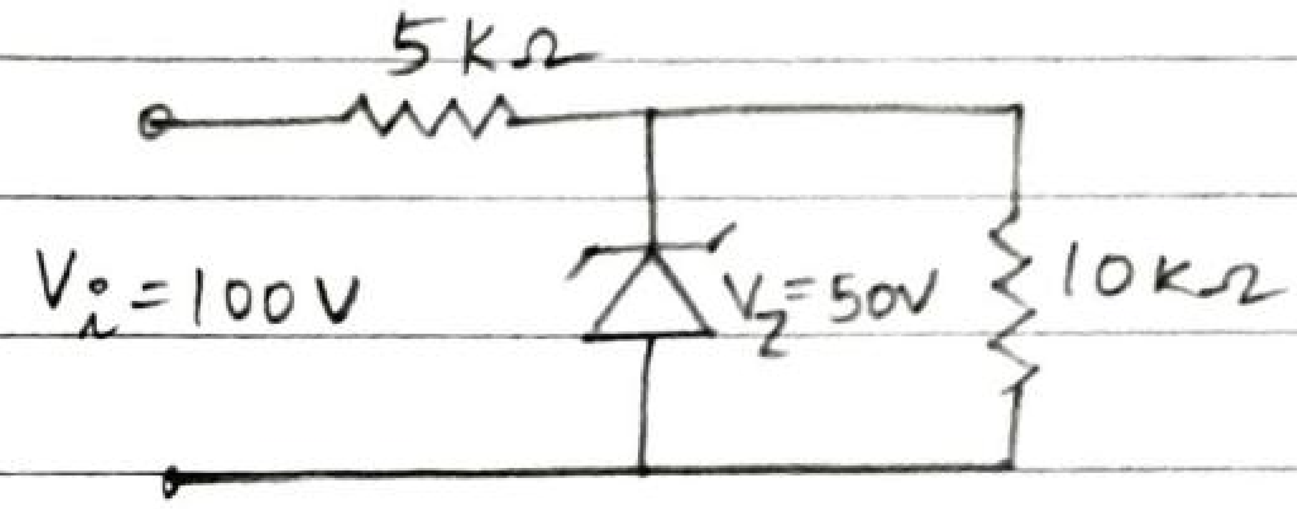
$\therefore \underline{I_{zmin}} = I_{Rmin} - I_L = 6mA - 5mA = \underline{1mA}$

(ii) Consider $V_{imax} = 120V$

$I_{R_{max}} = \dfrac{V_{imax} - V_z}{R} = \dfrac{120 - 50}{5k\Omega} = 14\ mA$.

$\therefore I_{Z_{max}} = I_{R_{max}} - I_L = 14\,mA - 5\,mA = \underline{\underline{9\,mA}}$.

Q3) For the circuit shown, find the voltage drop across 5kΩ resistance.



Soln: Step1 : Make sure zener is in 'ON' state

$$V = \frac{V_i \times R_L}{R_L + R} = \frac{100 \times 10k\Omega}{15k\Omega}$$

$$= 66.67\,V$$

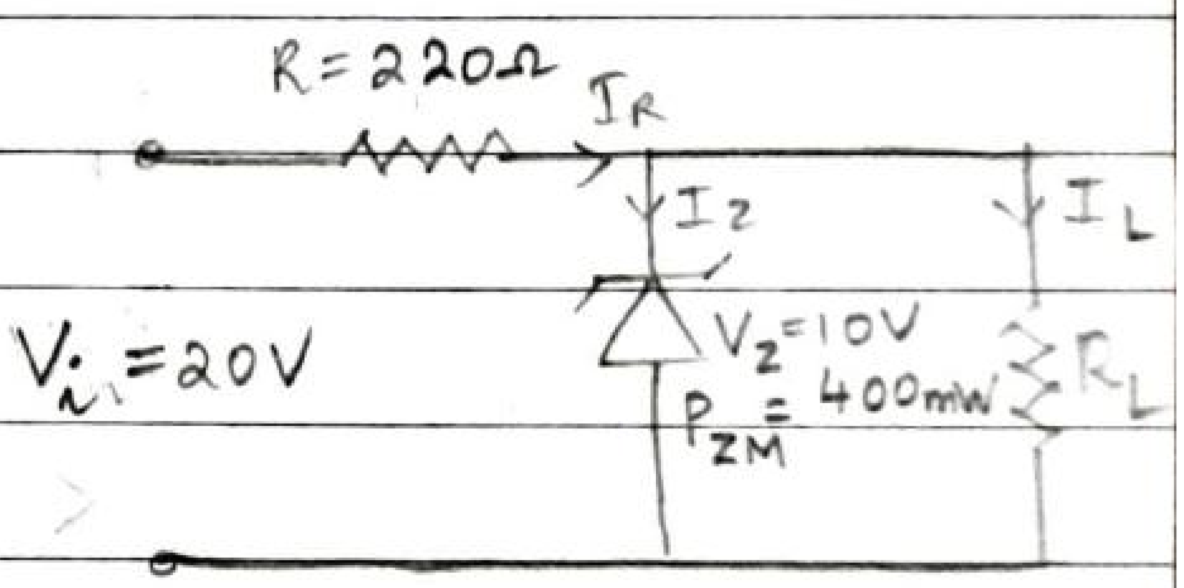
$\because V > V_Z \therefore$ Zener diode is in ON state. $\therefore V_L = V_Z = 50V$.

$\therefore V_R = V_i - V_z = 100 - 50 = \underline{\underline{50V}}$

★ Q4) For the ckt shown, determine :-

(a) V_L, I_L, I_Z & I_R with $R_L = 200\Omega$

(b) Repeat with $R_L = 50\Omega$.



Soln :- (a) For $R_L = 200\Omega$.

*check first for zener state

$$V = \frac{V_i R_L}{R_L + R} = \frac{20 \times 200}{200 + 220} = 9.524\,V$$

$V < V_Z$ $\therefore$ zener is in OFF state (open circuit)

$\therefore V_L = 9.524V$, $I_Z = 0$ Amp.

$$I_L = I_R = \frac{V_i}{R + R_L} = \frac{20}{220 + 200} = 47.62\,mA.$$

(b) For $R_L = 50\Omega$

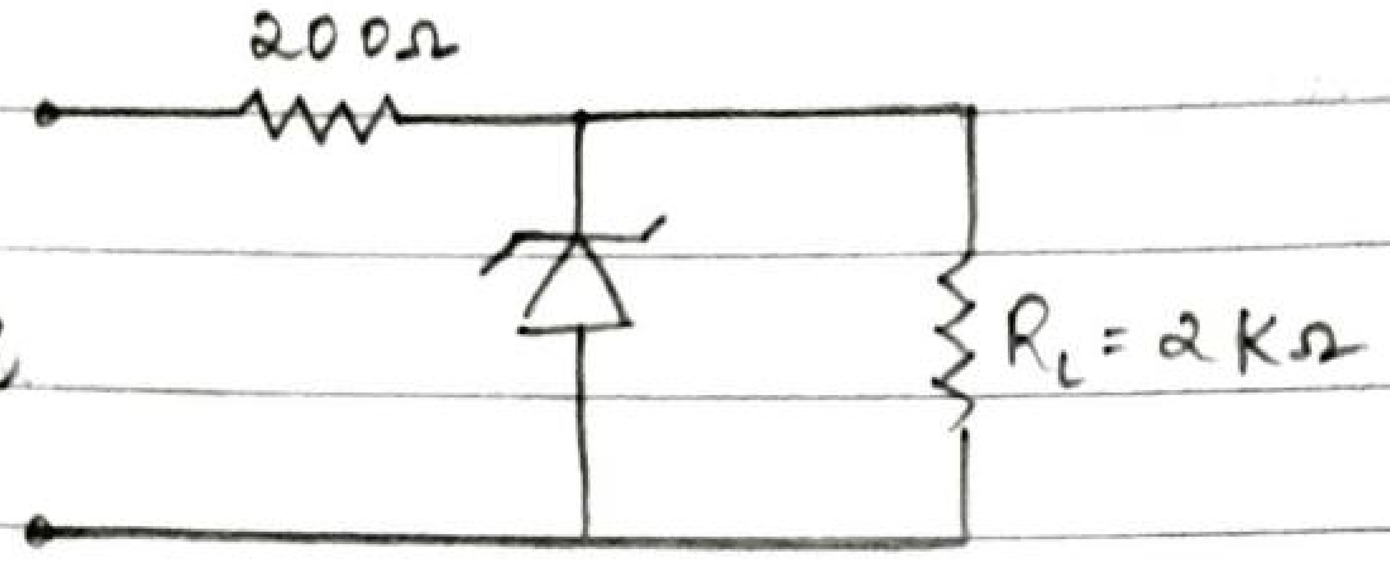
* Check for zener state

$$V = \frac{V_i \times R_L}{R + R_L} = \frac{20 \times 50}{50 + 220} = 3.7V$$ $\therefore$ Zener is OFF (o.c)

$V_L = 3.7V$, $I_Z = 0$ Amp.

$$I_L = I_R = \frac{V_i}{R_L + R} = \frac{20}{220 + 50} = 74.07\,mA.$$

Q5) Over what range of i/p voltage will the zener ckt shown maintain 30V across the 2kΩ load assuming that series resistance R = 200Ω & Zener current rating = 25mA.



Soln :- Given $V_Z = 30V$ & $I_{ZM} = 25mA$.

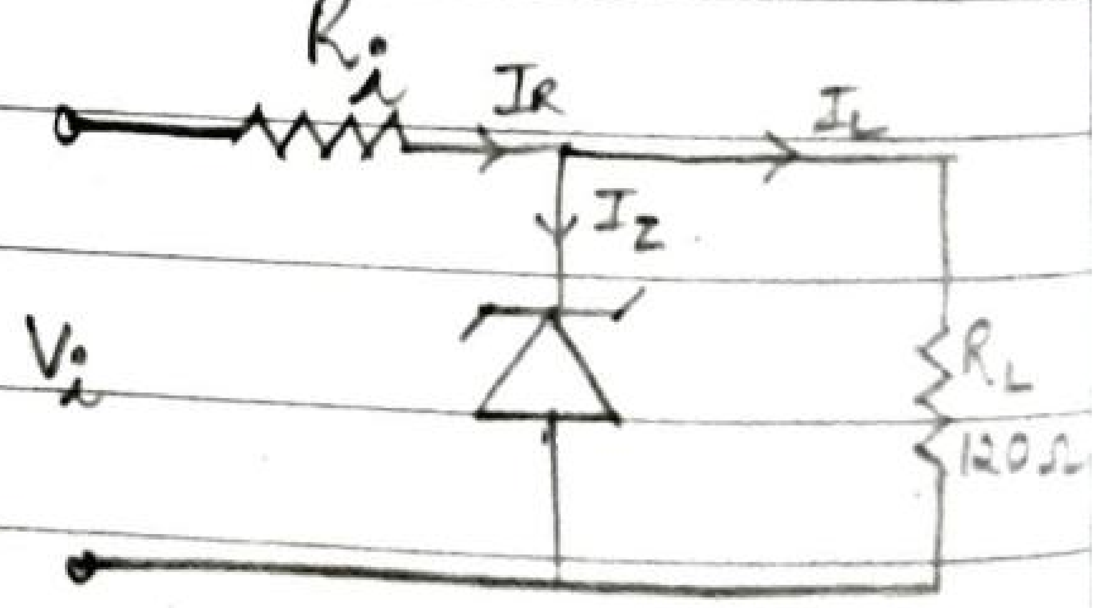
$$V_{i_{min}} = \frac{V_Z(R_L+R)}{R_L} = \frac{30(2k+200)}{2k} = 33V$$

$$I_{R_{max}} = I_{ZM} + I_L$$
$$= 25mA + 15mA \qquad \left(\because I_L = \frac{V_L}{R_L} = \frac{30}{2k\Omega} = 15mA\right).$$
$$= 40mA.$$

$$V_{i_{max}} = (I_{R_{max}} \times R) + V_Z$$
$$= (40mA \times 200) + 30 = 38V$$

$$\therefore \quad 33V < V_i < 38V.$$

Q6) The zener diode regulator ckt, has a fixed voltage drop of 12V across it as long as I_Z is maintained between 20mA to 200mA. Find R_i so that V_L remains at 12V while V_i varies from 15V to 19.5V.



Soln :- I_L is fixed, Since R_L is fixed

$$\therefore I_L = \frac{V_L}{R_L} = \frac{12}{120} = 100mA.$$

For $V_{i_{min}} = 15V$

$$V_{R(min)} = V_{i_{min}} - V_Z = 15 - 12 = 3V$$

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For $V_{i_{max}} = 19.5\,V$

$V_{R(max)} = V_{i_{max}} - V_Z = 19.5 - 12 = 7.5V.$

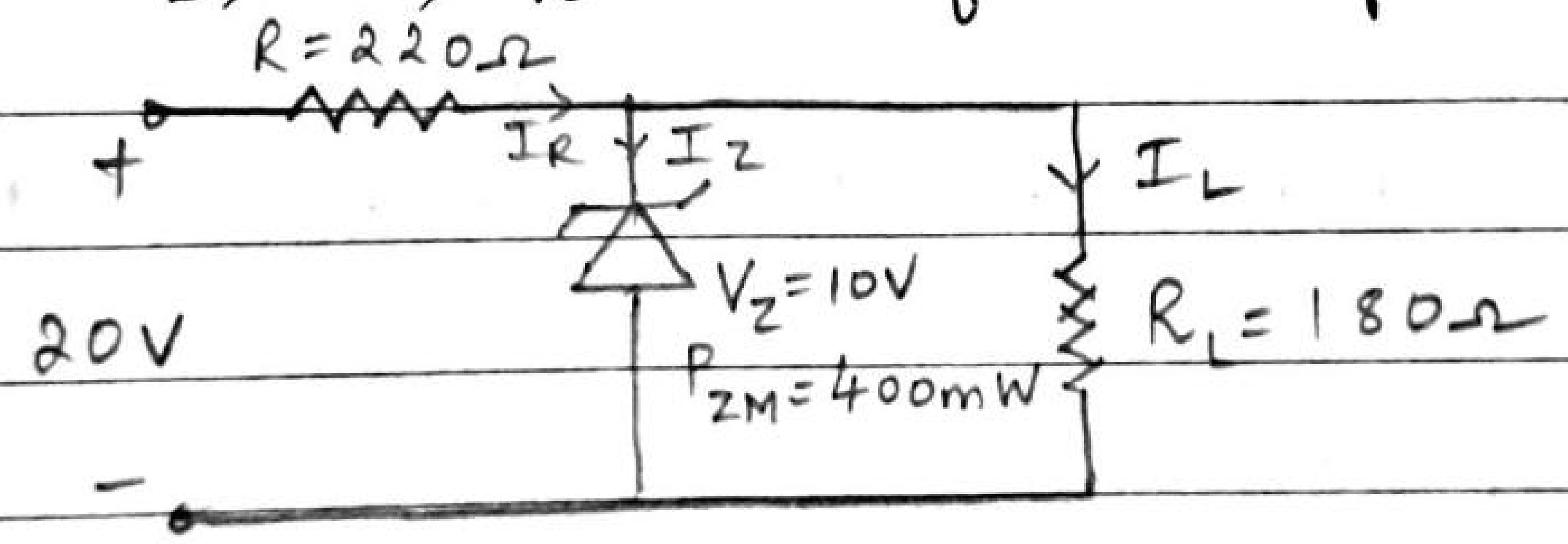
Now, $I_{R_{min}} = I_{Z_{min}} + I_L = 20mA + 100mA = 120mA$

& $I_{R_{max}} = I_{Z_{max}} + I_L = 200mA + 100mA = 300mA$.

$\therefore R_i = \dfrac{V_{R_{min}}}{I_{R_{min}}} = \dfrac{3\,V}{120mA} = 25\,\Omega$ **OR** $R_i = \dfrac{V_{R_{max}}}{I_{R_{max}}} = \dfrac{7.5V}{300mA} = 25\,\Omega$

$\therefore R_i = 25\,\Omega$

Q7) Determine V_L, I_L, I_R & I_Z for the foll n/w if $R_L = 180\Omega$.



Soln: Check state of zener:

$V = \dfrac{V_i \times R_L}{R_L + R} = \dfrac{20 \times 180}{180 + 220} = 9V < V_Z$

$\therefore$ Zener is **OFF**

$V_L = V = 9V$

$I_L = \dfrac{V_L}{R_L} = \dfrac{9}{180} = 50mA$

$I_Z = 0$ Amp

$I_R = I_L = 50mA$

$\left[I_R = \dfrac{V_R}{R} = \dfrac{20-9}{220} = 50mA \right.$

More Problems: Sedha Pg 470

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