IRE 105 ELECTRONICS DEVICES AND APPLICATIONS

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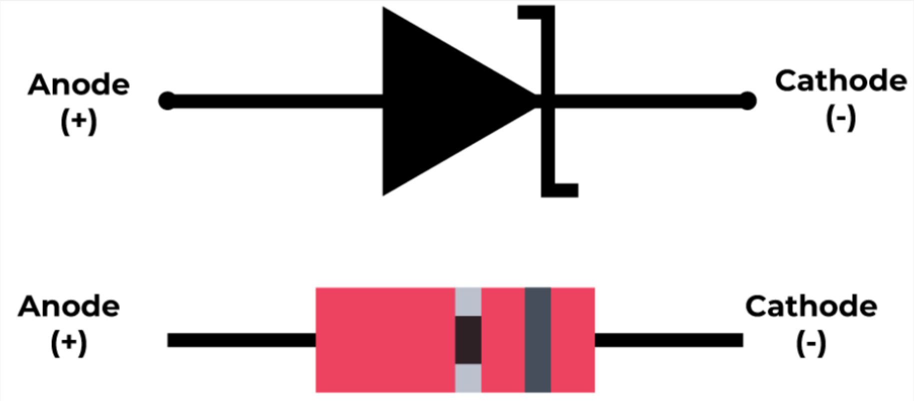
ZENER DIODE

- A heavily doped p-n junction diode that works in reverse bias conditions is called a **Zener Diode**.
- Zener diode that is also known as a breakdown diode is a heavily doped semiconductor device that has been specially designed to operate in the reverse direction. When the potential reaches the Zener voltage which is also known as Knee voltage and the voltage across the terminal of the Zener diode is reversed, at that point time, the junction breaks down and the current starts flowing in the reverse direction. This effect is known as the **Zener effect**

ZENER DIODE CIRCUIT DIAGRAM

- The figure given below is the circuit diagram of the Zener diode. The Zener diode has applications in various electronic devices and it works in reverse biasing conditions. In reverse biasing, the P-type material of the diode is connected with the negative terminal of the power supply, and the n-type material is connected with the positive terminal of the power supply. The diode consists of a very thin depletion region as it is made up of heavily doped semiconductor material.



ZENER DIODE CIRCUIT DIAGRAM

- A Zener diode can be packed in many ways. Some Zener diodes are used where high levels of power dissipation are required. The Zener diode which is the most commonly used is contained within a small glass encapsulation having a band around one end marking the cathode side of the diode.
- There are two tags at the end of the bar in the circuit symbol of the Zener diode, one in the upward direction and the other in the lower direction, as shown in the figure given below. In this way, we can easily distinguish between the Zener diode and other diodes.

ZENER DIODE WORKING

- High-level impurities are added to a Zener diode to make it more conductive and thus the Zener diodes can easily conduct electricity compared to other p-n junction diodes. These impurities reduce the depletion layer of the Zener diode and make it very thin. Thus, this diode also works even if the voltage applied is very small.
- In no biassing condition of the Zener diode, all the electrons accumulate in the valence band of the p-type semiconductor material and thus no current flow occurs through the diode.
- In reverse bias conditions, if the Zener voltage is equal to the supplied voltage, the diode conducts electricity in the direction of reverse bias. When the Zener voltage equals the supplied voltage the depletion layer vanishes completely.

ZENER DIODE WORKING IN REVERSE BIASED

- In forward-biased conditions, the Zener Diode works like any normal diode but in the reverse-bias condition, a small leak current flows through the diode. As we keep increasing the reverse voltage it reaches a point where the reverse voltage equals the breakdown voltage. The breakdown voltage is represented as V_z and in this condition the current start flowing in the diode. After the breakdown voltage the current increase drastically unit it reaches a stable value.
- In reverse bias condition, two kinds of breakdowns occur for Zener Diode which are,
- Avalanche Breakdown
- Zener Breakdown

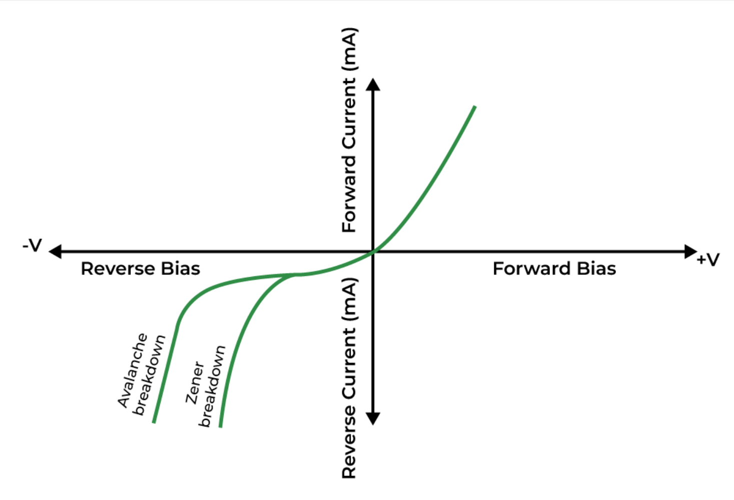
AVALANCHE BREAKDOWN

- The phenomenon of Avalanche breakdown occurs both in the ordinary diode and Zener Diode at high reverse voltage. For a high value of reverse voltage, the free electron in the PN junction diode gains energy and acquires high velocity and these high-velocity electrons collide with other atoms and knock electrons from that atoms. This collision continues and new electrons are available for conducting current thus the current increase rapidly in the diode.
- This phenomenon of a sudden increase in the current is called the Avalanche breakdown. This phenomenon damages the diode permanently whereas the Zener diode is a specific diode that is made to operate in this reverse voltage area.
- If the reverse voltage is greater than 6V the avalanche breakdown happens in the Zener diode.

ZENER BREAKDOWN

- Zener breakdown happens in heavily doped PN junction diodes. In these diodes, if the reverse bias voltages reach closer to Zener Voltage, the electric field gets stronger and is sufficient enough to pull electrons from the valance band. These electrons then gain energy from the electric field and break free from the atom.
- Thus, for these diodes in the Zener breakdown region, a slight increase in the voltage causes a sudden increase in the current.

VI CHARACTERISTICS OF ZENER DIODE



V-I characteristics of a Zener Diode can be studied under the following two headings,

Forward Characteristics of Zener Diode

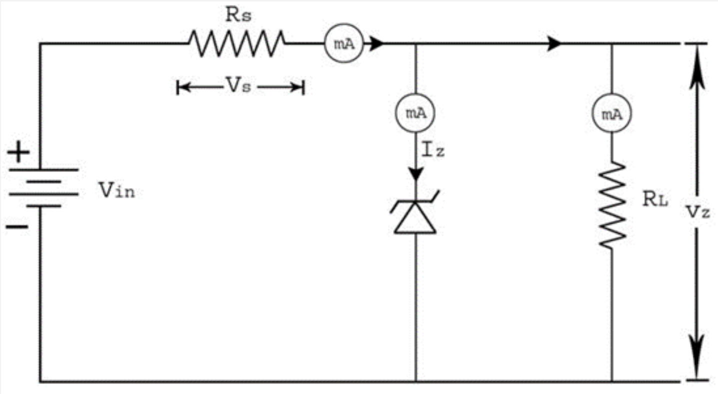
Forward characteristics of the Zener Diode are similar to the forward characteristics of any normal diode. It is clearly evident from the above diagram in the first quadrant that the VI forward characteristics are similar to other P-N junction diodes.

Reverse Characteristics of Zener Diode

In reverse voltage conditions a small amount of current flows through the Zener diode. This current is because of the electrons which are thermally generated in the Zener diode. As we keep increasing the reverse voltage at any particular value of reverse voltage the reverse current increases suddenly at the breakdown point this voltage is called Zener Voltage and is represented as V_z.

ZENER DIODE AS VOLTAGE REGULATORS

- The function of a regulator is to provide a constant output voltage to a load connected in parallel with it in spite of the ripples in the supply voltage or the variation in the load current and the zener diode will continue to regulate the voltage until the diodes current falls below the minimum $I_{Z(min)}$ value in the reverse breakdown region. It permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value - the breakdown voltage known as the Zener voltage. The Zener diode specially made to have a reverse voltage breakdown at a specific voltage. Its characteristics are otherwise very similar to common diodes. In breakdown the voltage across the Zener diode is close to constant over a wide range of currents thus making it useful as a shunt voltage regulator.



ZENER DIODE AS VOLTAGE REGULATORS

- The purpose of a voltage regulator is to maintain a constant voltage across a load regardless of variations in the applied input voltage and variations in the load current. A typical Zener diode shunt regulator is shown in Figure 3. The resistor is selected so that when the input voltage is at $V_{IN(min)}$ and the load current is at $I_{L(max)}$ that the current through the Zener diode is at least $I_{z(min)}$. Then for all other combinations of input voltage and load current the Zener diode conducts the excess current thus maintaining a constant voltage across the load. The Zener conducts the least current when the load current is the highest and it conducts the most current when the load current is the lowest.

- If there is no load resistance, shunt regulators can be used to dissipate total power through the series resistance and the Zener diode. Shunt regulators have an inherent current limiting advantage under load fault conditions because the series resistor limits excess current.

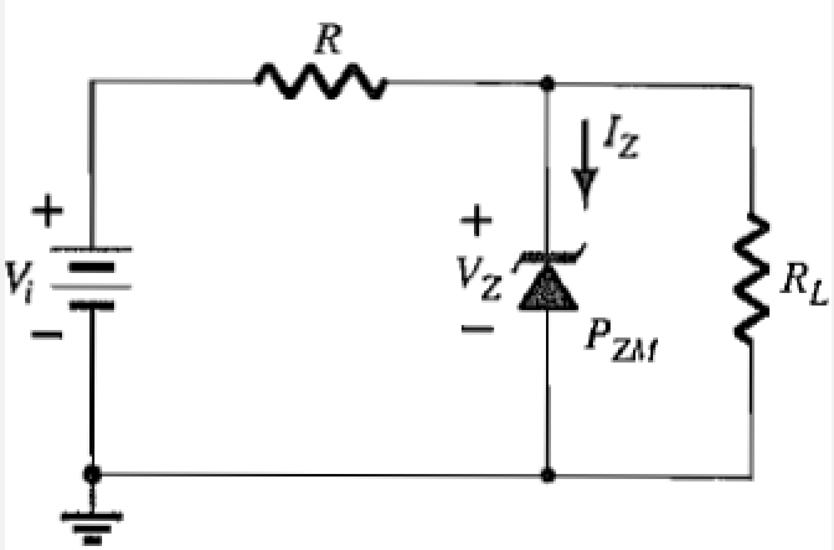
- A zener diode of break down voltage V_z is reverse connected to an input voltage source V_i across a load resistance R_L and a series resistor R_S. The voltage across the zener will remain steady at its break down voltage V_Z for all the values of zener current I_Z as long as the current remains in the break down region. Hence a regulated DC output voltage $V_0 = V_Z$ is obtained across RL, whenever the input voltage remains within a minimum and maximum voltage.

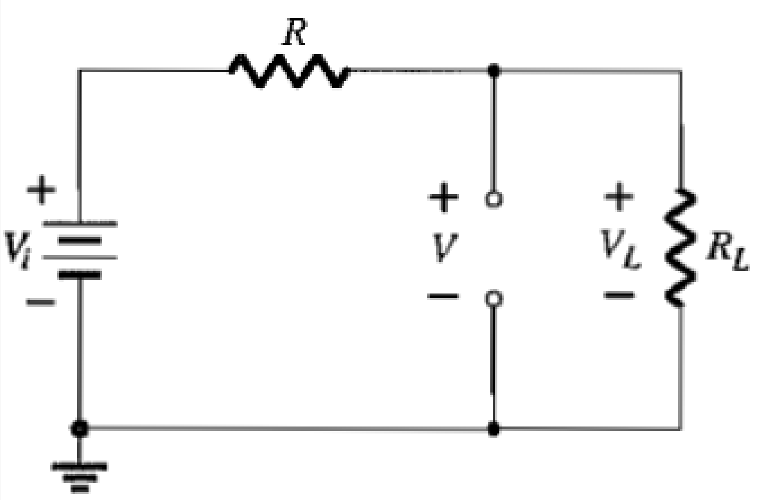
always first of all make out if the zenner diode is ON or OFF

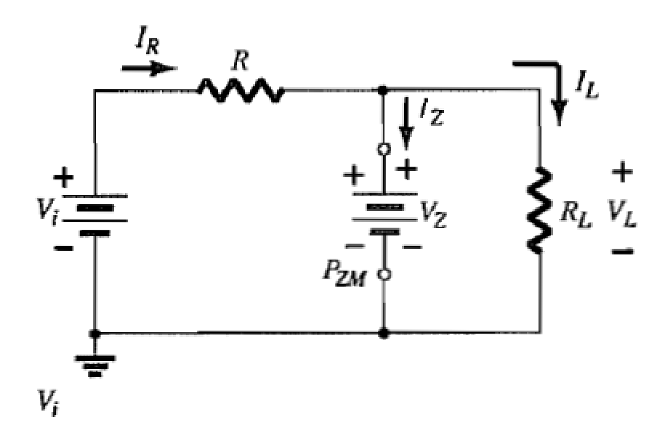
if VL calculated from the circuit and VZ is not given,
then if VL > VZ ; zenner diode ON
if VL < VZ ; zenner diode OFF

if VZ s given,
VL = VZ

V_I AND R FIXED







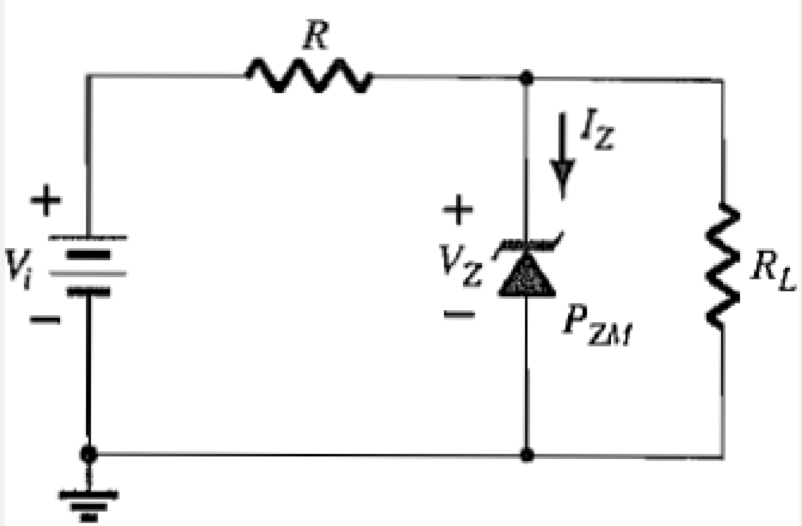
FIXED R_L VARIABLE V_i

For fixed values of R_L in Fig. 2.106, the voltage V_i must be sufficiently large to turn the Zener diode on. The minimum turn-on voltage $V_i = V_{i_{min}}$ is determined by

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

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

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



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

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

FIXED Vi VARIABLE RL

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

Solving for R_L, we have

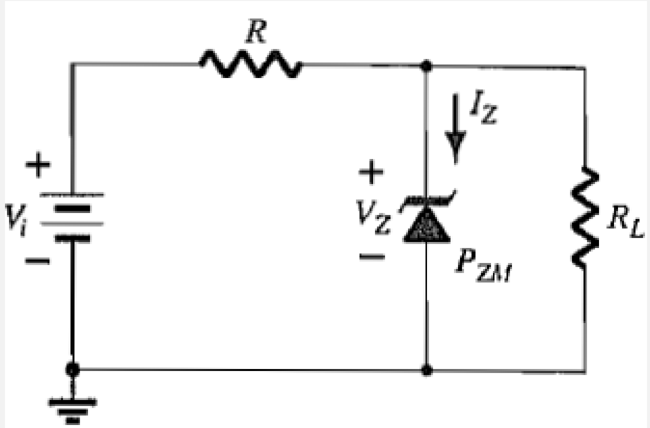
$$\boxed{R_{L_{min}} = \frac{R V_Z}{V_i - V_Z}}$$

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

$$\boxed{V_R = V_i - V_Z}$$

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

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



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

and the maximum load resistance as

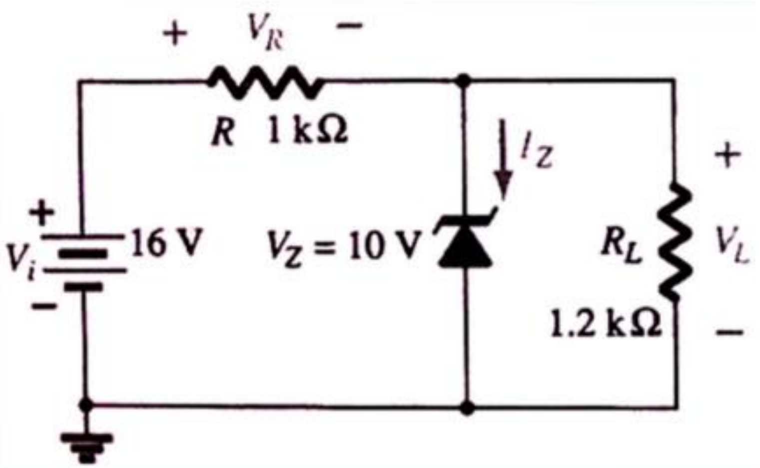
$$\boxed{R_{L_{max}} = \frac{V_Z}{I_{L_{min}}}}$$

PROBLEM 1

Example

For the Zener diode regulator,

1. Determine V_L , V_R , I_Z and P_Z.
2. If the load is changed to $R_L = 3\ k\Omega$, repeat the above problem.



Solution:

1. Determine the voltage across the Zener diode to determine its state:

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

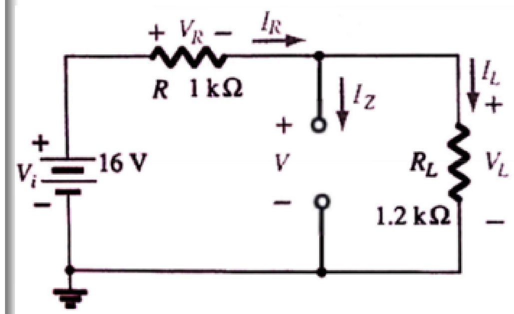
Since the voltage across the Zener is smaller than V_Z and the diode is reverse, then the Zener is OFF.

$$V_L = V_{zener} = 8.73\ V$$

$$V_R = V_i - V_L = 16 - 8.73 = 7.27\ V$$

$$I_Z = 0$$

$$P_Z = 0 \text{ Watts}$$



Example

PROBLEM 1

Solution:

2. If $R_L = 3\ k\Omega$:

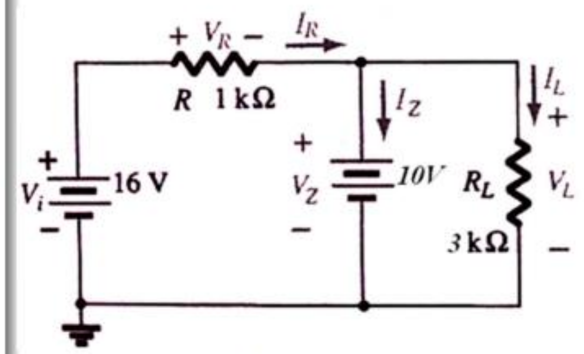
$$V_{zener} = V_i \frac{R_L}{R + R_L} = \frac{16 \times 3}{1 + 3} = 12\ V$$

Since the voltage across the zener is greater than V_Z then the zener is operating in the zener region and can be approximated as battery with V_Z:

$$V_L = V_Z = 10V$$

$$V_R = V_i - V_L = 16 - 10 = 6V$$

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



Example

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

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

The power dissipated by the Zener diode is:

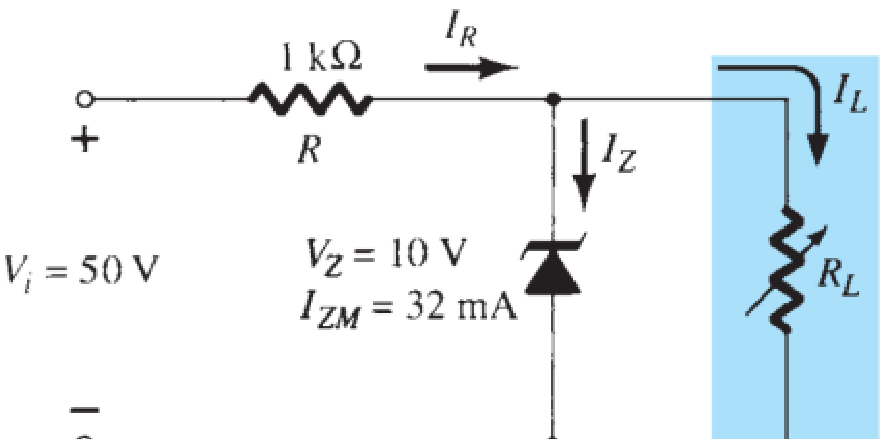
$$P_Z = I_Z \times V_Z = 26.7\ mW$$

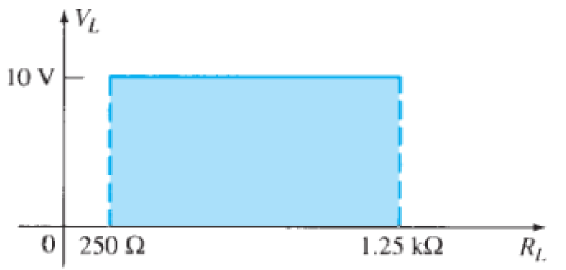
PROBLEM 2

$-v_i + R I_R + V_z = 0$

Example: $\rightarrow$

1. For the shown network, determine the range of R_L and I_L that will result in V_L being maintained at 10 V.
2. Determine the maximum wattage rating of the diode.





$$R_{Lmin} = \frac{R\ V_Z}{V_i - V_Z} = \frac{1\ k\Omega\ 10V}{50V - 10V}$$

$$R_{Lmin} = 250\ \Omega$$

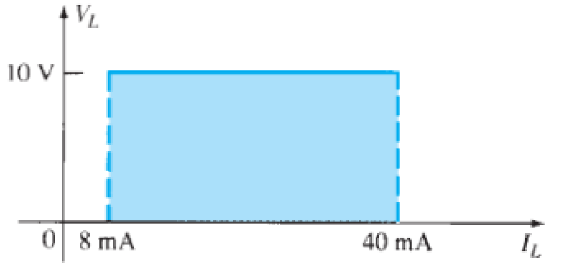
$$I_{Lmax} = \frac{V_L}{R_L} = \frac{V_Z}{R_{Lmin}} = \frac{10}{250} = 40mA$$

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

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

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

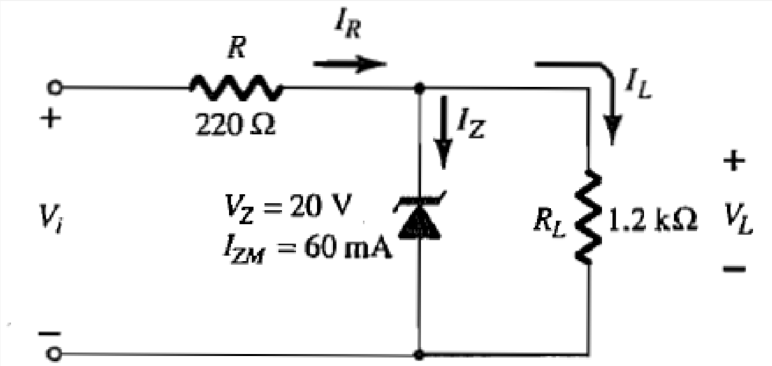
$$R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{10\ \ V}{8\ \ mA}$$



$$P_{Zmax} = V_Z\ I_{ZM} = (10\ \ V)(32\ \ mA) = 320mW$$

PROBLEM 3

- Determine the range of values of Vi that will maintain the Zener diode of the figure below in the "ON" state.



$$V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

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

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

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