Experiment No.6

Zener Diode Application

Object

The purposes of this experiment are to demonstrate Zener diode as a simple voltage regulator.

Required Parts and Equipment's

1. Variable DC Power Supply.
2. Digital Multimeters.
3. Zener Diode, ZPD (3.6V, 0.5W).
4. Carbon Resistors 330Ω (2W), 1kΩ (2W).
5. Variable Box Resistor
6. Leads and Wires.

Theory

A Zener diode operating in breakdown acts as a voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse current values.

The minimum value of reverse current required to maintain the Zener diode in breakdown for voltage regulation is known as the knee current I_{ZK} as illustrated in Fig.1. When the reverse current is reduced below I_{ZK}, the voltage decreases drastically and regulation is lost.

On the other hand, the maximum current that the diode can withstand is abbreviated as I_{ZM}, and is defined as the Zener current above which the diode may be damaged due to excessive power dissipation. This current can be determined from:

$$I_{ZM} = \frac{P_{ZM}}{V_Z}$$

Where PZM represents the maximum DC power dissipation of the zener diode, which is usually specified in the datasheet.

So, the practical operating range of the zener diode current should be maintained between I_{ZK} and I_{ZM} for proper voltage regulation.

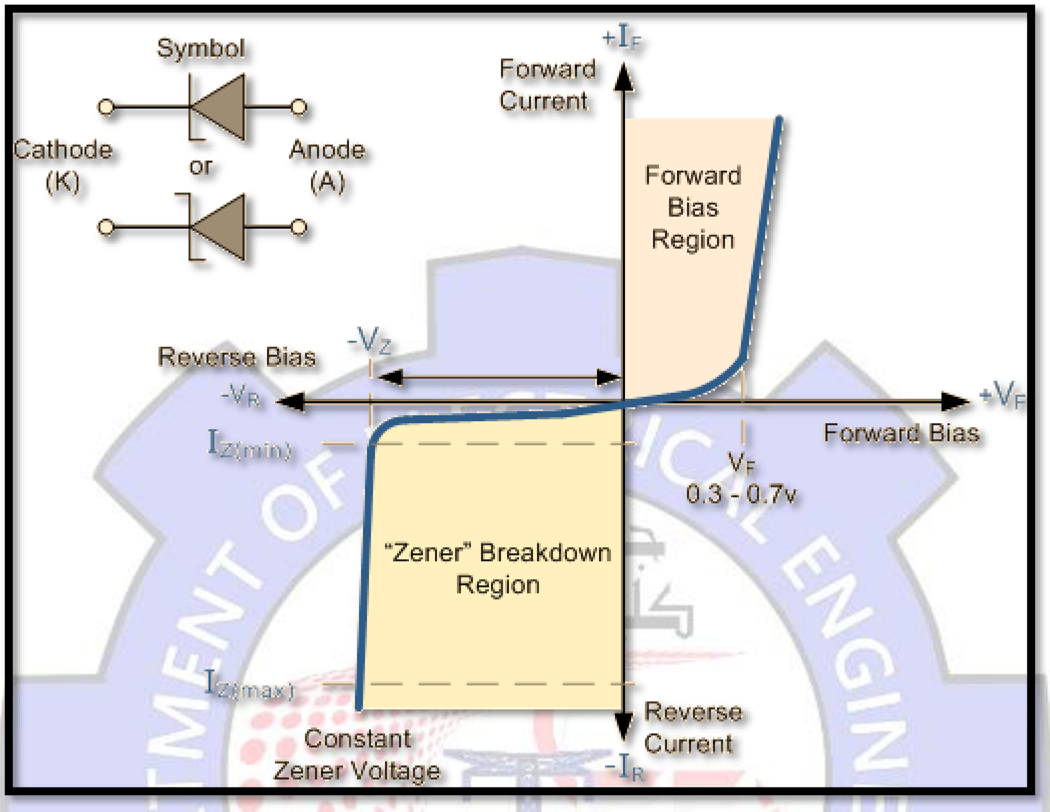

Figure 1: Zener Diode Symbol and IV Characteristic

Fig.2 shows the ideal and practical models of the zener diode in the reverse breakdown region.

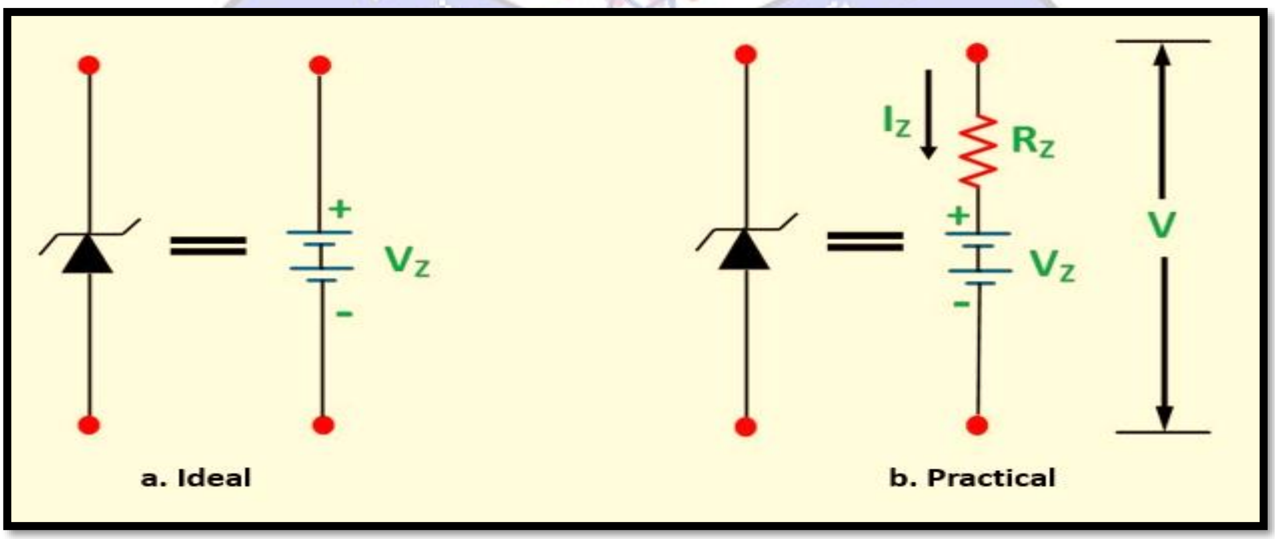

Figure 2: Zener Diode Equivalent Circuit Models

The ideal model of the zener diode shown in Fig.2a has a constant voltage drop equal to the nominal zener voltage. This constant voltage drop is represented by a DC voltage source which indicates that the effect of reverse breakdown is simply a constant voltage across the zener terminals.

Fig.2b represents the practical model of the zener diode, in which the internal zener resistance R_Z is included. Since the actual voltage curve is not ideally vertical, a change in zener current ΔI_Z produces a small change in zener voltage ΔV_Z as illustrated in Fig.3. By Ohm's law, the ratio of ΔV_Z to ΔI_Z is the zener diode internal resistance as expressed in the following equation:

$$R_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

In most cases, we can assume that R_Z is constant over the full linear range of the zener diode current values.

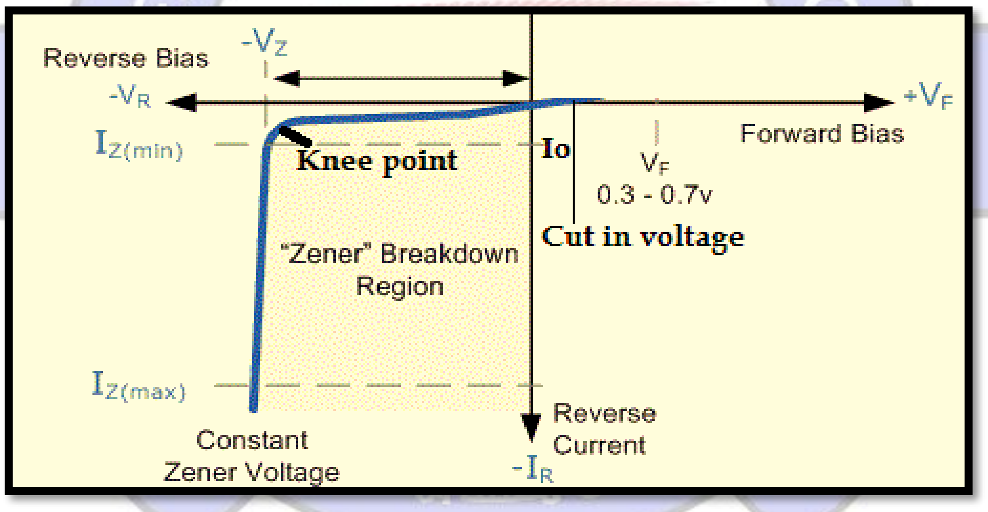

Figure 3: Reverse Characteristic of a Zener Diode Showing the Determination of the Internal Resistance R_Z

- **The Zener Diode as a Voltage Regulator**

The zener diode is often used as a voltage regulator in DC power supplies. Fig.4 presents a simple voltage regulator circuit. In this circuit, the zener diode should maintain a constant output voltage against variations in input voltage Vin, or load resistance RL. Resistor RS is used as a series current limiting resistor.

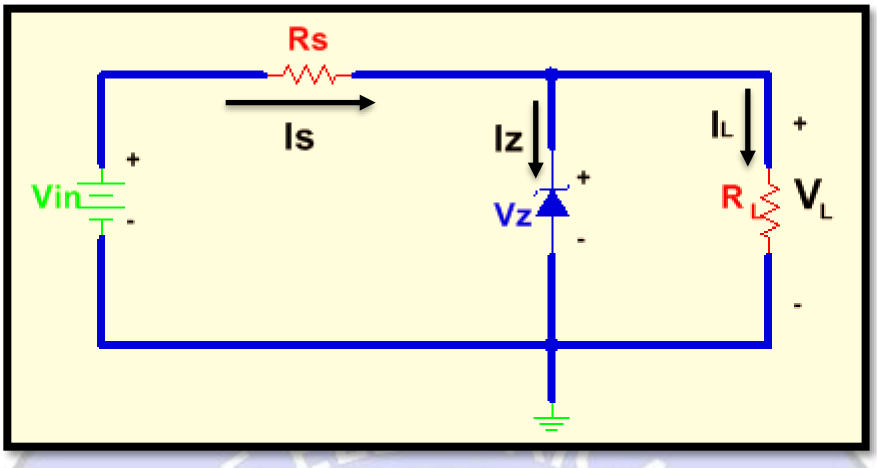

Figure 4: Simple Zener Diode Voltage Regulator

The analysis of the circuit depends on the state of the zener diode if it enters the zener breakdown region or not. To determine the state of the zener diode, we can remove it from the circuit temporarily and calculate the voltage across the open circuit. The load voltage in this case can be obtained from the voltage divider rule:

$$V_L = \frac{R_L . V_{in}}{R_S + R_L}$$

If $V_L \geq V_Z$, then the zener diode is ON, and the appropriate equivalent model can be substituted. On the other hand, if $V_L < V_Z$, the zener diode is OFF, and it is substituted with an open circuit.

When the zener diode operates in its zener breakdown region, it can be substituted simply with a constant voltage source V_Z. In this case:

$$V_L = V_Z$$

The source current $I_S$can be found from the equation:

$$I_S = \frac{V_{in} - V_Z}{R_S}$$

The load current is calculated as the ratio of load voltage to load resistance:

$$I_L = \frac{V_L}{R_L}$$

The zener current is obtained by applying Kirchhoff's current law:

$$I_Z = I_S - I_L$$

The power dissipated by the zener diode is determined from:

$$P_Z = V_Z . I_Z$$

This value of P_Z must be less than the maximum power rating of the diode P_{ZM} in order to avoid damaging the zener diode.

- **Zener Voltage Regulator with a Variable Load Resistance**

Fig.5 shows a zener voltage regulator with a variable load resistor across the output terminals. The zener diode maintains a nearly constant voltage across RL as long as the zener current is greater than I_{ZK} and less than I_{ZM}. This is called load regulation.

When the output terminals of the zener regulator are open ($R_L = \infty$), the load current is zero and the entire source current IS passes through the zener diode. When a load resistor R_L is connected, part of the source current passes through the zener diode, and part through R_L. As

R_L is decreased, the load current I_L increases and I_Z decreases. The source current passing through R_S remains essentially constant.

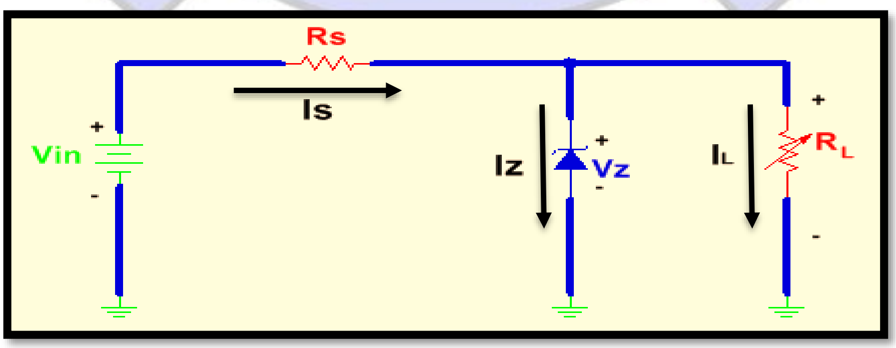

Figure 5: Zener Regulator with Variable Load Resistance and Fixed Input Voltage

To determine the minimum load resistance that will turn on the zener diode, we simply calculate the value of R_L that will result in a load voltage $V_L = V_Z$. Assuming I_{ZK}=0, we have from voltage divider rule:

$$V_L = V_Z = \frac{R_L.V_{in}}{R_S + R_L}$$

Solving for R_L yields:

$$R_{L(\min)} = \frac{R_S.V_z}{V_{in} - V_Z}$$

- **Zener Voltage Regulator with a Variable Input Voltage**

Fig.6 illustrates how a zener diode can be used to regulate a varying input DC voltage. This is called input or line regulation.

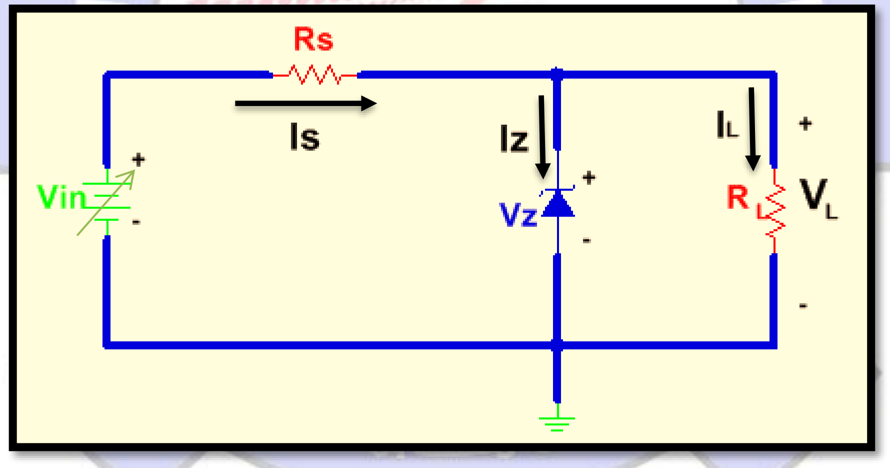

Figure 6: Zener Regulator with Variable Input Voltage and Fixed Load Resistance

For fixed values of R_L , the input voltage must be sufficiently large to turn on the zener diode. Neglecting I_{ZK} , the minimum turn-on voltage is determined by:

$$V_L = V_Z = \frac{R_L.V_{in}}{R_S + R_L}$$

Solving for V_{in}, we have:

$$V_{in(\min)} = \frac{(R_S + R_L).V_Z}{R_L}$$

The maximum value of V_{in} is limited by the maximum zener current I_{ZM}. We have:

$$I_{s(\max)} = I_{ZM} + I_L$$

I_L is given by:

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

Therefore, the maximum input voltage is given by:

$$V_{in(\max)} = I_{s(\max)}.R_S + V_Z$$

Or,

$$V_{in(\max)} = \left(I_{ZM} + \frac{V_Z}{R_L}\right).R_S + V_Z$$

Procedure

1. Connect the zener diode test circuit shown in Fig.7. Increase the input voltage gradually in several steps from 0 to 15V, and record V_Z and I_Z according to Table 1.

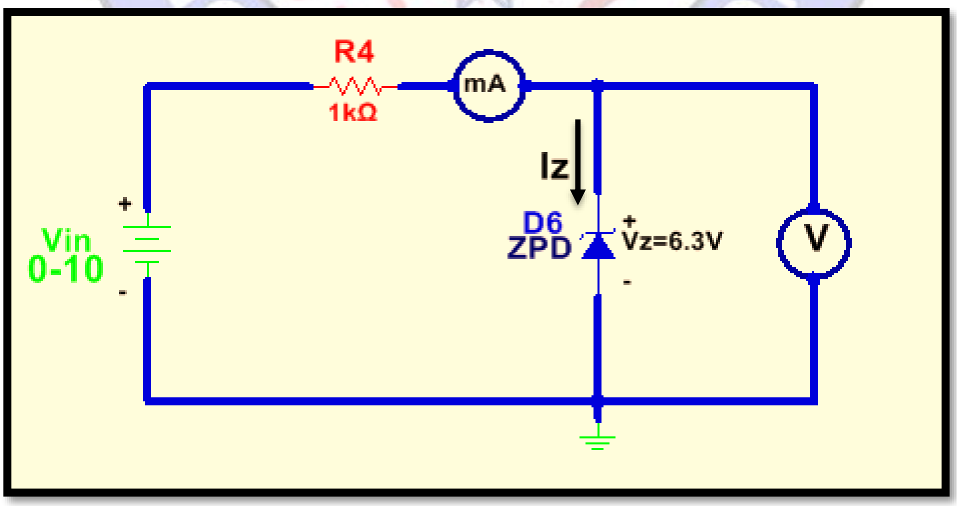

Figure 7: Practical Circuit Used to Obtain the Characteristics of the Zener Diode

$V_{in}(V)$	$V_Z(V)$	$I_Z(mA)$
0		
1		
2		
3		
4		
4.5		
5		
5.5		
6		
7		
8		
10		
12		
14		
15		

Table 1: Recorded Data for the Circuit of Figure 7

2. Connect the voltage regulator circuit shown in Fig.8, and vary the load resistor $R_L$in several steps as shown in Table 2. Record V_L, I_s, I_Z, and I_L where I_L = I_s-I_Z.
3. Connect the voltage regulator circuit shown in Fig.9, and vary the input voltage in several steps from 0 to 15V as shown in Table 3. Record V_L, I_s, I_Z, and I_L where I_L = I_s-I_Z.

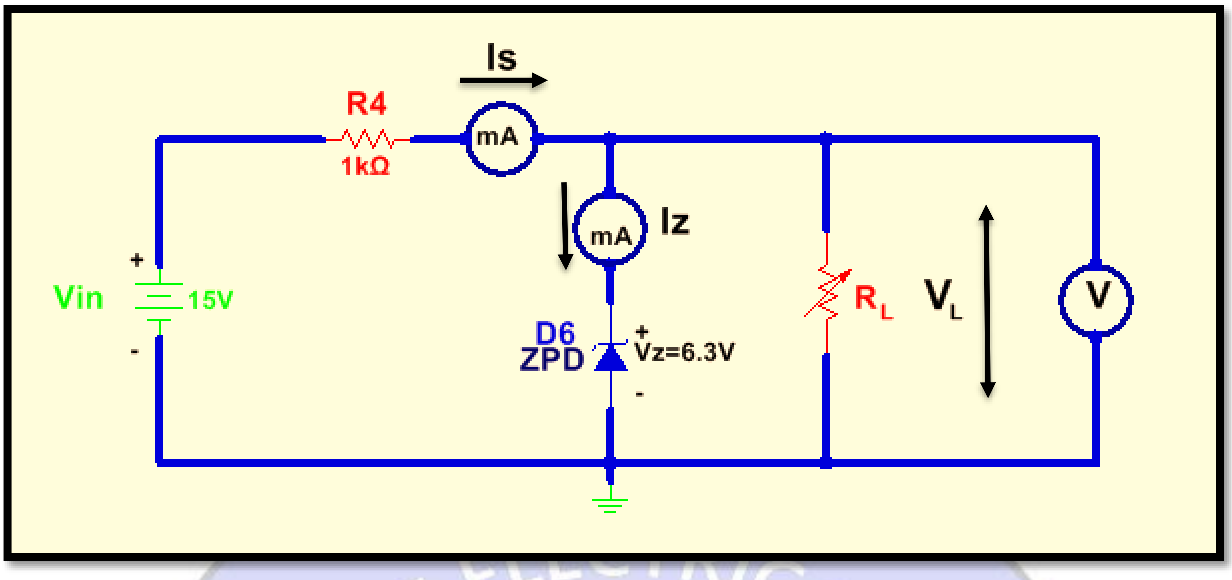

Figure 8: Practical Circuit for Zener Diode Voltage Regulator with Variable Load Resistor

$R_L(\Omega)$	$V_L(V)$	$I_S(mA)$	$I_Z(mA)$	$I_L(mA)$
50				
100				
150				
200				
300				
500				
800				
1.0K				
1.5K				
2.0K				
4.0K				
100K				

Table 2: Recorded Data for the Voltage Regulator Circuit of Figure 8

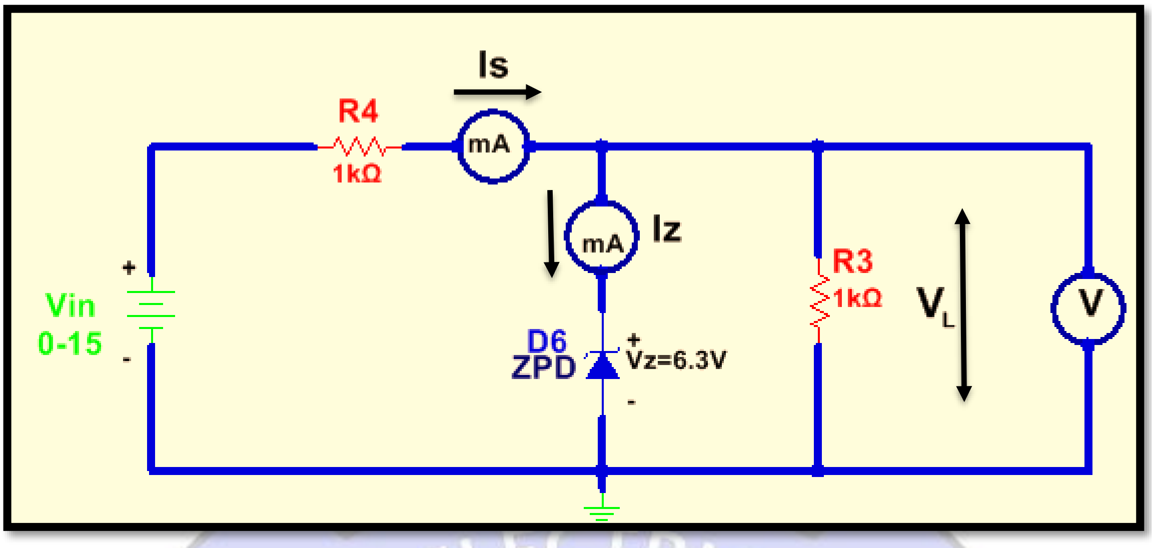

Figure 9: Practical Circuit for Zener Diode Voltage Regulator with Variable Input Voltage

$R_L(\Omega)$	$V_L(V)$	$I_S(mA)$	$I_Z(mA)$	$I_L(mA)$
0				
1				
2				
4				
5				
6				
6.5				
7				
10				
12				
14				
15				

Table 3: Recorded Data for the Voltage Regulator Circuit of Figure 9

Discussion

1. Plot the characteristic curve of the zener diode in the reverse-breakdown region from the results obtained in step 1 of the procedure.
2. Determine the internal resistance R_Z of the zener diode from your data. Do this calculation only on the straight-line breakdown region of the characteristic curve plotted in step 1 above.
3. Determine the power dissipation in the zener diode for the maximum zener current flowing through it from the obtained data of step1 in the procedure, and compare it with P_{ZM}.
4. For the zener diode voltage regulator circuit of Fig.8, sketch the relation between V_L and I_L (V_L versus I_L). Plot the relation between I_s and R_L. Sketch also the relation between I_Z and I_L. Comment on the resulting curves.
5. Calculate the theoretical minimum value of R_L required for putting the zener diode in the zener breakdown region for the regulator circuit of Fig.8. What value of load resistance results in the maximum zener current? Determine the maximum Zener current $I_{Z(\max)}$ in this case and compare it with I_{ZM}.
6. Plot the relation between V_L and V_{in} for the voltage regulator circuit in Fig.9, and comment on the resulting sketch. From this sketch, determine the minimum value of input voltage required to turn-on the zener diode.
7. Calculate the theoretical minimum value of V_{in} required to turn-on the zener diode in the voltage regulator circuit of Fig.9. Determine also the maximum permissible value of V_{in} knowing that the maximum DC power dissipation of the PZD zener diode is 0.5W.
8. Explain the difference between line regulation and load regulation.