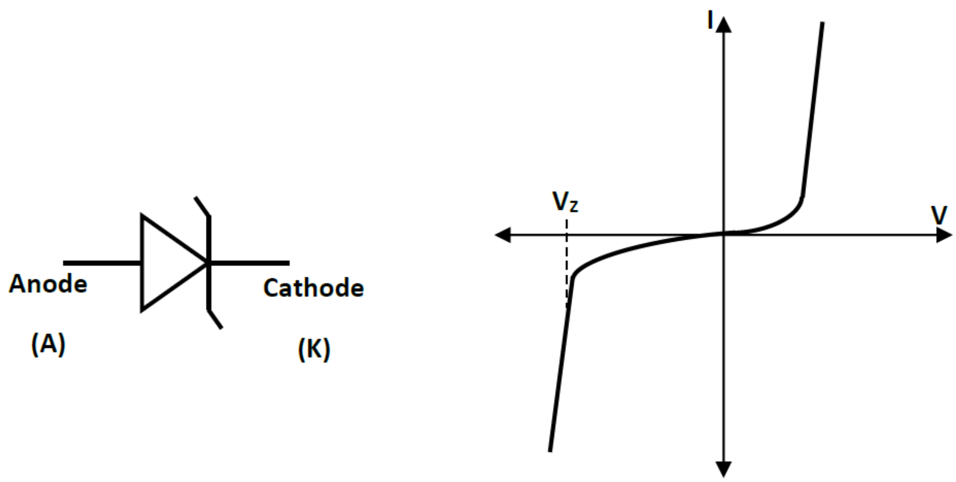
Zener diode

A Zener diode is a silicon p-n junction device that is designed for operation in the reverse breakdown region. The breakdown voltage of a zener diode is set by carefully controlling the doping level during manufacture.

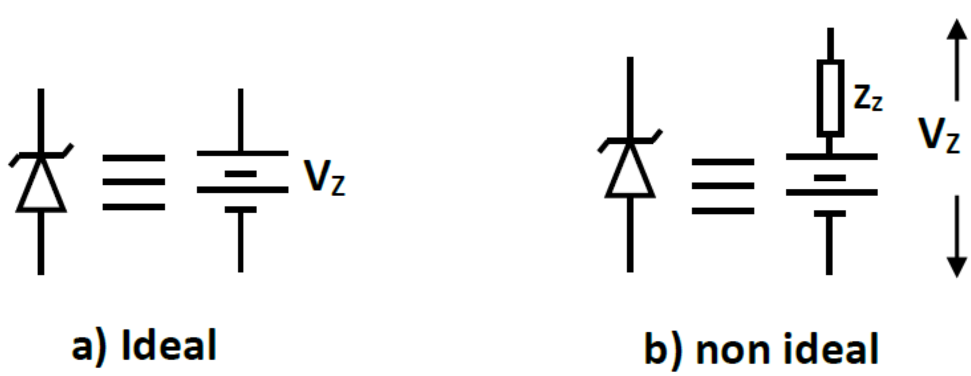
The ability to keep the reverse voltage across its terminal essentially constant is the key feature of the zener diode. A zener diode operating in breakdown acts as a voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse current values.



- if a zener diode is forward bias, it operates the same as a rectifier diode.

Zener equivalent circuit:

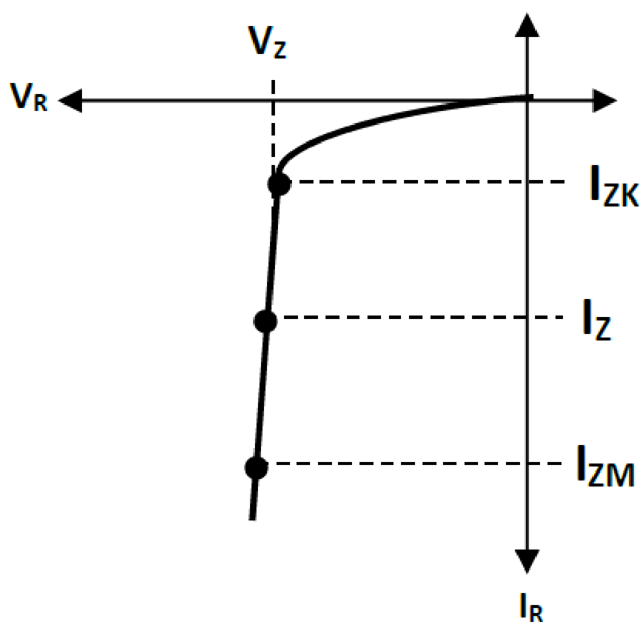
Figure below shows the model of a zener diode in the reverse breakdown;



It has a constant voltage drop equal to nominal zener voltage. This constant voltage drop is represented by a dc voltage source even though the zener diode dose not actually produces an emf voltage. The dc source simply indicates that the effect of reverse breakdown is a constant voltage across the zener terminal.

Breakdown characteristics

Figure below shows the reverse position of a zener diodes characteristic curve.



Where, I_{ZK} (Zener knee (minimum) current).

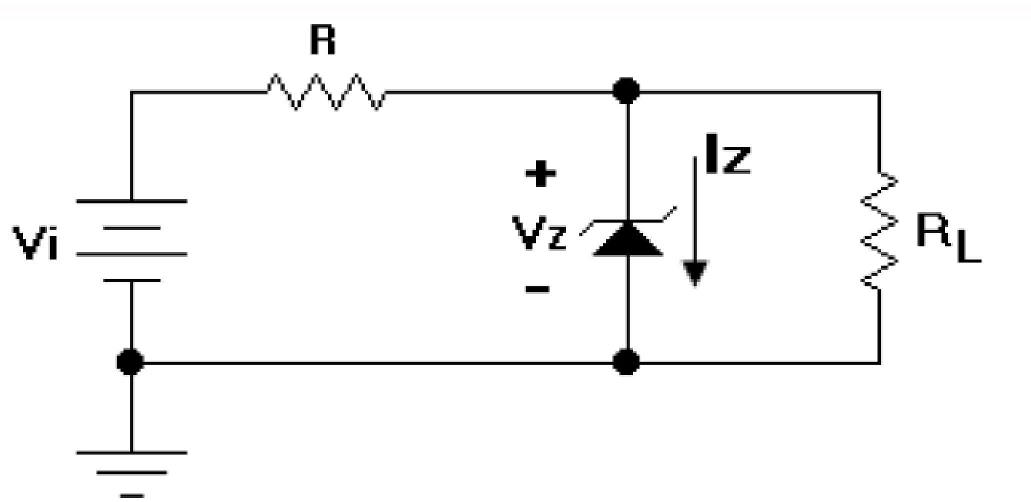
I_Z (Zener current).

I_{ZM} (Zener maximum current).

V_Z (zener voltage at IZ).

Minimum value of reverse current, I_{ZK} must be maintained in order to keep the diode in breakdown for voltage regulation. You can see from the curve Above, that when the reverse current is reduced below the knee of the curve, the voltage decreases drastically and regulation lost. Also there is a maximum current I_{ZM} above which the diode may be damaged due to excessive power dissipation. So basically, the zener diode maintains a nearly constant voltage across its terminal for values of reverse current ranging from I_{ZK} to I_{ZM}.

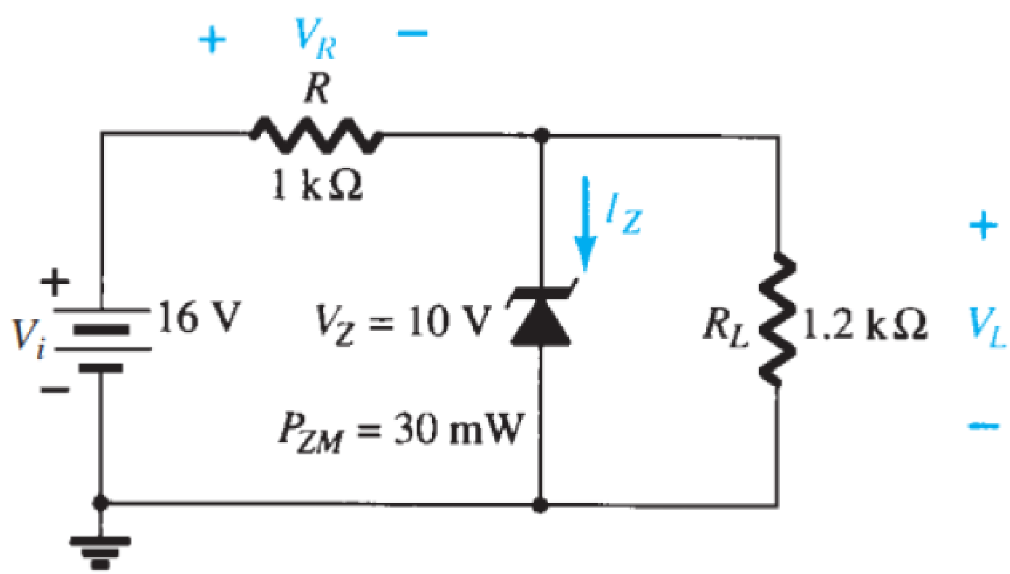
The zener diode as a voltage regulator:



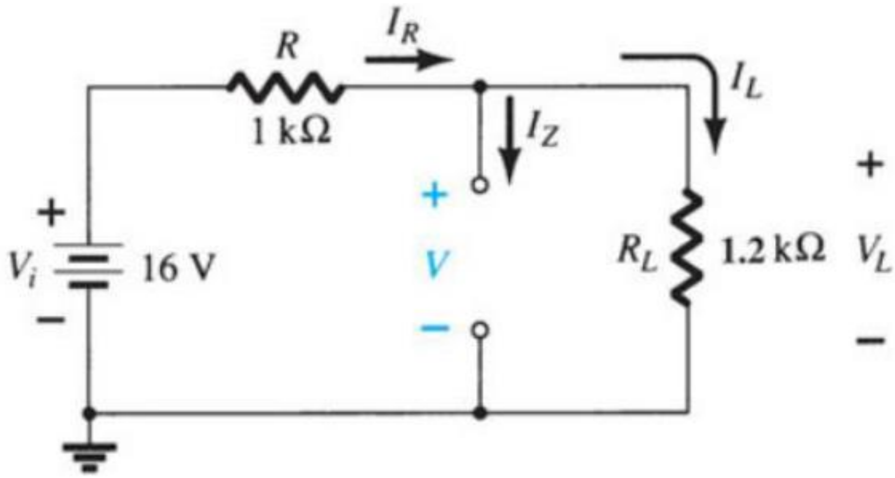
The basic zener regulator is shown in figure above. There are three states for the circuit above;

a) Vi and RL Fixed

Example 4.1: for the circuit of figure below determine V_L, V_R, I_Z, and P_Z.



Solution: First we must find the voltage across the load;



$V = V_L = V_i \times \frac{R_L}{R+R_L} = 16V \times \frac{1.2K\Omega}{1K\Omega + 1.2K\Omega} = 8.7272\ V$

$\because V_Z = 10\ V$

$\therefore V < V_Z \Longrightarrow$ The zener diode is in the off state.

$V_R = V_i - V_L = 16 - 8.7272 = 7.2728\ V$

$I_Z = 0\ A$

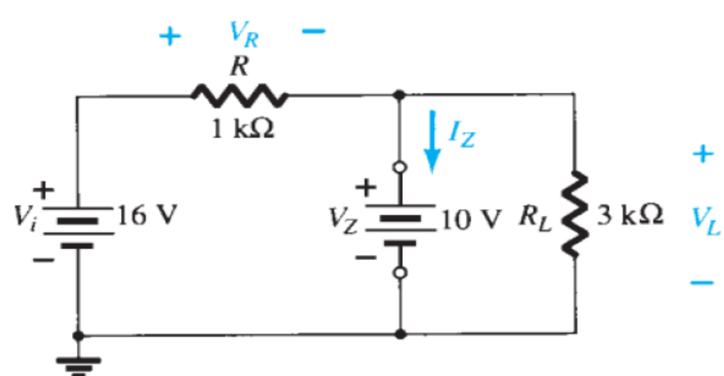
$P_Z = V_Z \times I_Z = 0\ W$

Example 4.2: Repeat Example 4.1 with $R_L = 3\ K\Omega$

Solution:

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

$\because V > V_Z$



$\because V_L = V_Z = 10\ V$

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

$I_L = V_L / R_L = 10\ V / 3K\Omega = 3.3333\ mA$

$I_R = V_R / R = 6\ V / 1K\Omega = 6\ mA$

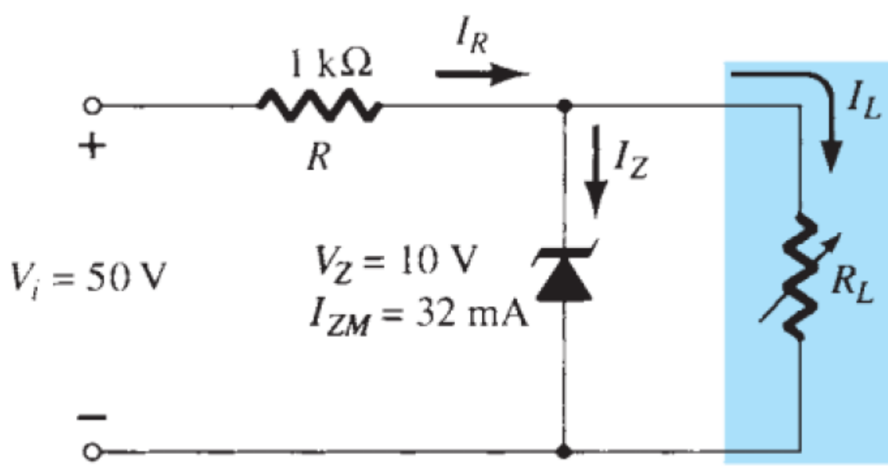
$I_Z = I_R - I_L = 6mA - 3.33mA = 2.6667\ mA$

$P_Z = V_Z \times I_Z = 10V \times 2.67mA = 26.667\ mW$

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

b) Fixed Vi and variable RL

Example 4.3: For the network of figure below determine the range of R_L, I_L that will result in V_{RL} being maintained at 10 V.



Solution: To determine the value of RL that will turn the zener diode ON

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

$\boldsymbol{R_{Lmin}} = \frac{R\ V_Z}{V_i - V_Z} = \frac{1K\Omega \times 10V}{50V - 10V} = \frac{10K\Omega}{40\ V} = 250\ \Omega$

The voltage across the resistor R is then

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

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

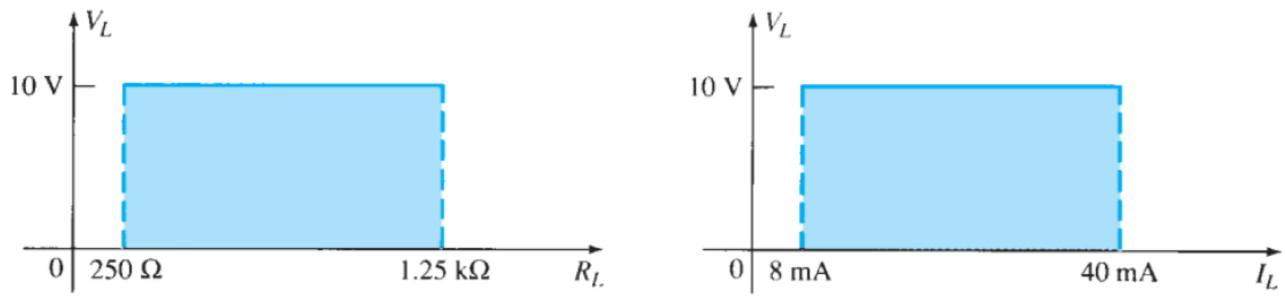
The minimum level of I_L is then:

$\boldsymbol{I_{Lmin}} = I_R - I_{ZM} = 40\text{m}A - 32\text{m}A = 8\ \text{m}A$

Determine the maximum value of R_L:

$\boldsymbol{R_{Lmax}} = \frac{V_Z}{I_{Lmin}} = 10V/8\text{m}A = 1.25\ K\Omega$

A plot of V_L versus R_L and for V_L versus I_L appears in Figure below.



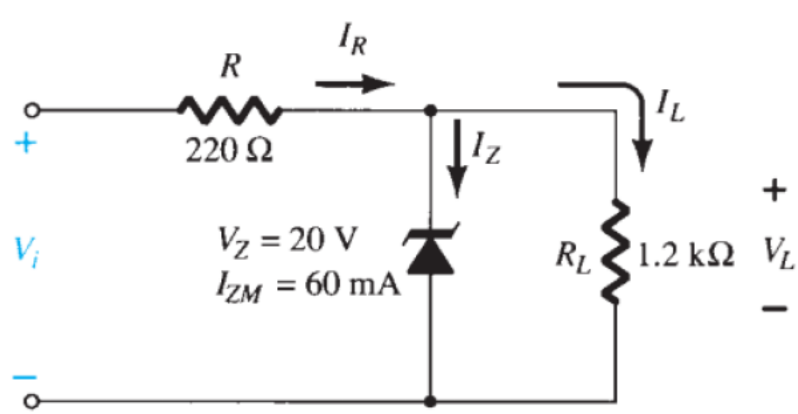
Q/ Calculate the maximum wattage rating of the diode in the previous example?

Answer:

$P_{Zmax} = V_Z\ I_{ZM} = 10V \times 32\text{m}A = 320\ \text{m}W$

c) Fixed R_L and variable V_i

Example 4.4: Determine the rang of Vi that will maintain the zener diode of figure below in the **on** state.



Solution:

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

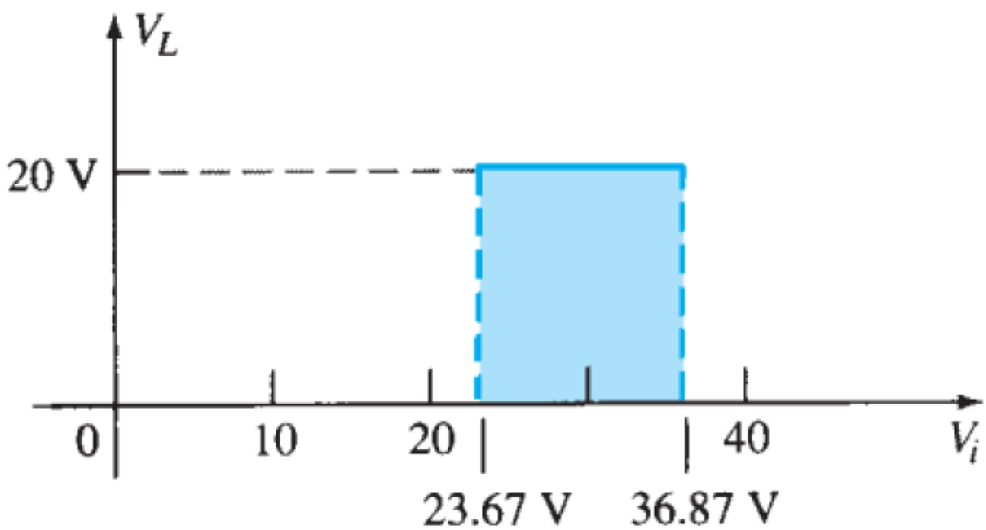
$\boldsymbol{V_{imin}} = \frac{(R_L + R)\, V_Z}{R_L} = \frac{(1200\Omega + 220\Omega)(20V)}{1200\Omega} = 23.67\ V$

$I_L = V_L / R_L = V_Z / R_L = 20V / 1.2K\Omega = 16.67\ mA$

$I_{Rmax} = I_{ZM} + I_L = 60mA + 16.67mA = 76.67\ mA$

$\boldsymbol{V_{iMax}} = I_{Rmax}\, R + V_Z = (76.67\ mA)(0.22K\Omega) + 20V = 36.87V$

A plot of V_L versus V_i is provided in Figure below



Zener diode as limiter