University of Calcutta

Semester 4

PHYSICS

Paper: PHS-A-CC-4-10-TH (OLD SYLLABUS)

ZENER DIODE, ZENER DIODE AS VOLTAGE REGULATOR

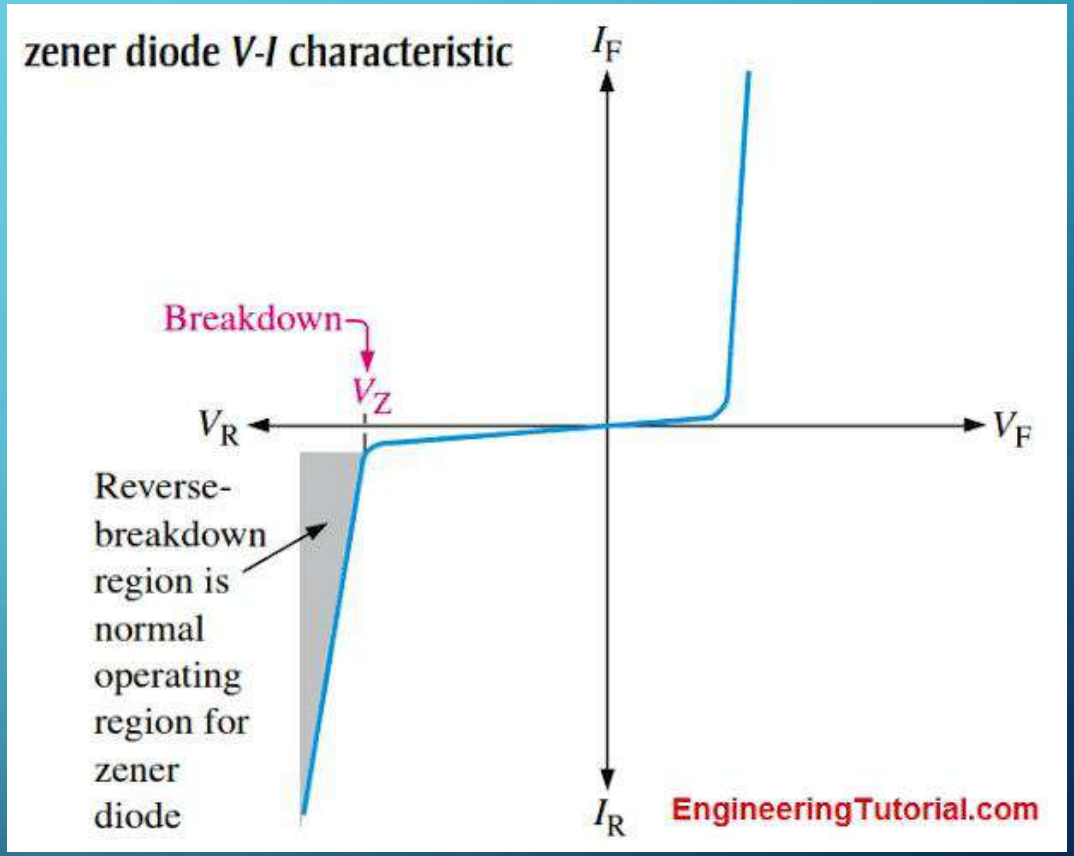
Dr. Koel Adhikary,

Department of Physics

Government Girls' General Degree College

SPECIAL CHARACTERISTICS OF ZENER DIODE

Zener diode is basically like an ordinary PN junction diode but normally operated in reverse biased condition. But ordinary PN junction diode connected in reverse biased condition is not used as Zener diode practically. A Zener diode is a specially designed, highly doped PN junction diode.

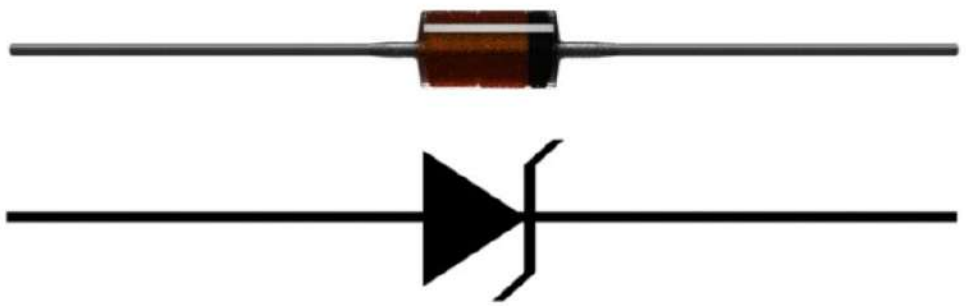


WHY ZENER DIODE IS HEAVILY DOPED ?

Zener diode is heavily doped than the normal p-n junction diode. Hence, it has very thin depletion region. Therefore, zener diodes allow more electric current than the normal p-n junction diodes.

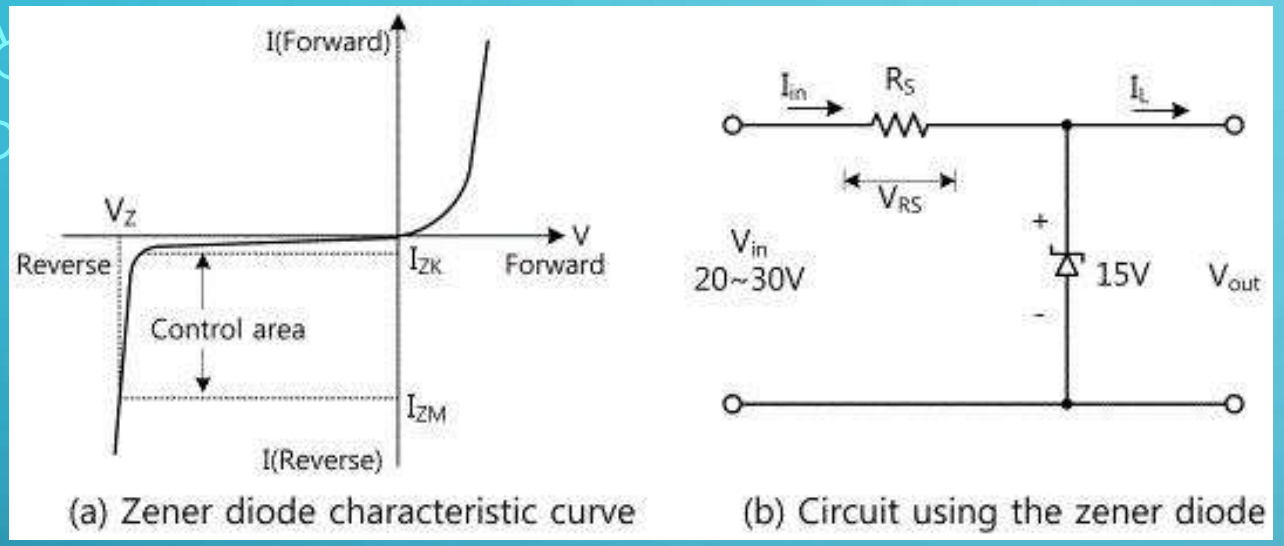
KEY WORDS OF ZENER DIODE

Here is the Zener diode symbol

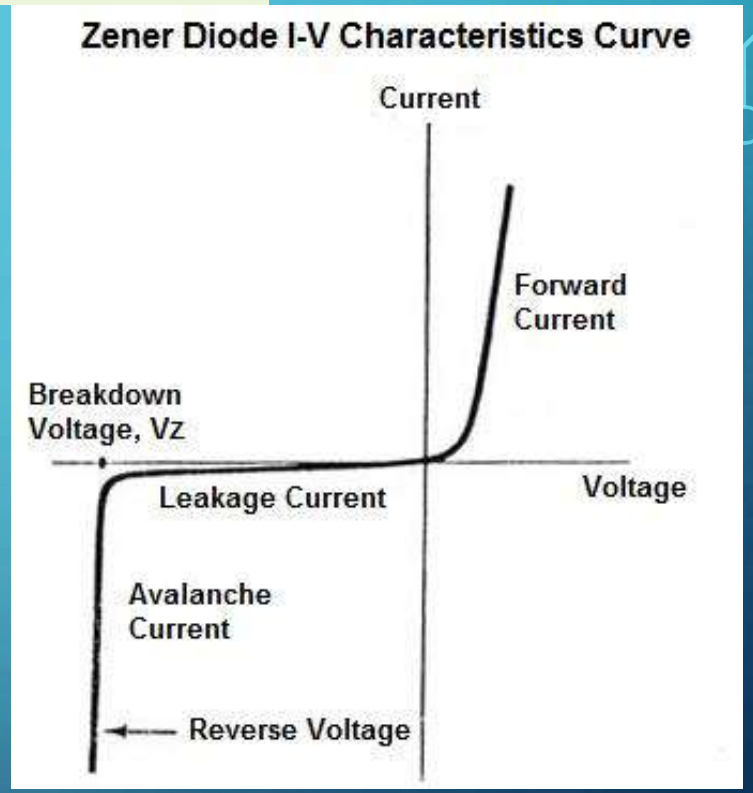


exciting and unique kind of diode. Zener diodes are heavily doped than ordinary diodes. They have extra thin depletion region. When we apply a voltage more than the Zener breakdown voltage (can range from 1.2 volts to 200 volts), the depletion region vanishes, and large current starts to flow through the junction. There is a crucial difference between an ordinary diode and a Zener diode. The depletion region regains its original position after removal of the reverse voltage in Zener diode whereas in regular diodes, they don't, and hence they get destroyed.

CHARACTERISTICS CURVE OF ZENER DIODE



(a) Zener diode characteristic curve (b) Circuit using the zener diode



https://youtu.be/JdL3DnnFHXw

WORKING PRINCIPLE OF ZENER DIODE

Usually, the condition of the diode with basic p–n as its junction during reverse bias is that there is no chance of conduction because the depletion region width is comparatively high.

- As the applied reverse voltage tends to increase that result in the increment of the width of the depletion region. Even there exist some minority carriers which gain some energy because of increment of reverse voltage.
- Due to the gain in kinetic energy of the minority carriers, these free electrons in movement collide with the stationary ions. This results in the formation of more free electrons.
- Further, these again collide with remaining stationary ions and this process continues it is referred to as **carrier multiplication**.
- Because of carrier multiplication, a huge multiple of free electrons are created and the complete region of the diode becomes conductive resulting in the breakdown known as avalanche breakdown.
- Generally, this is not the case in the Zener diode. In Zener diode, the junction is doped with the highest concentration. Because of this reason when the reverse voltage has applied the width of the depletion region tends to minimize.
- As there exist the maximum concentration of the impure atoms in it. It creates the maximum number of ions in it.
- As soon as the diode exceeds the threshold value the electrons that are in the covalent bonds tend to come out in the depletion region so that it can make depletion region conductive.
- Hence this type of breakdown is referred to as Zener breakdown**.** The occurrence of this breakdown will be at certain voltage termed as **Zener voltage**.
- Just as cut in voltage in normal diode here it is Zener voltage. Once the applied voltage exceeds the value of voltage it tends to conduct.
- This value of the Zener voltage is properly adjusted at the time of manufacturing by the proper concentration in doping.
- In case of occurring of break down further, there is no possibility of occurrence of avalanche breakdown.

FOLLOW THE LINKS

https://youtu.be/Kj6Vpm6m9lU

https://youtu.be/TLgALezzVFI

TYPES OF BREAKDOWN

DIFFERENCE BETWEEN ZENER AND AVALANCHE BREAKDOWN

Zener Breakdown	Avalanche breakdown
1.This occurs at junctions which being heavily doped have narrow depletion layers	1. This occurs at junctions which being lightly doped have wide depletion layers.
2. This breakdown voltage sets a very strong electric field across this narrow layer.	2. Here electric field is not strong enough to produce Zener breakdown.
3. Here electric field is very strong to rupture the covalent bonds thereby generating electron-hole pairs. So even a small increase in reverse voltage is capable of producing Large number of current carriers.	3. Her minority carriers collide with semi conductor atoms in the depletion region, which breaks the covalent bonds and electron-hole pairs are generated. Newly generated charge carriers are accelerated by the electric field which results in more collision and generates avalanche of charge carriers. This results in avalanche breakdown.
4. Zener diode exhibits negative temp: coefficient. Ie. breakdown voltage decreases as temperature increases.	4. Avalanche diodes exhibits positive temp: coefficient. i.e breakdown voltage increases with increase in temperature.

TYPES OF BREAKDOWN-continued

Zener Breakdown	Avalanche breakdown
1.This occurs at junctions which being heavily doped have narrow depletion layers .	1.This occurs at junctions which being lightly doped have wide depletion layers.
2.This breakdown voltage sets a very strong electric field across this narrow layer.	2.Here electric field is not strong enough to produce Zener breakdown.
3.Here electric field is very strong to rupture the covalent bonds thereby generating electron-hole pairs. So even a small increase in reverse voltage is capable of producing large number of current carriers. i.e. why the junction has a very low resistance. This leads to Zener breakdown.	3.Her minority carriers collide with semi conductor atoms in the depletion region, which breaks the covalent bonds and electron-hole pairs are generated. Newly generated charge carriers are accelerated by the electric field which results in more collision and generates avalanche of charge Carriers. This results in avalanche breakdown.

TYPES OF BREAKDOWN-continued

Breakdown Diodes

- Differences between Zener breakdown and Avalanche breakdown:

Zener breakdown	Avalanche breakdown
1. The Zener breakdown occurs in HIGH doping diodes.	1. The avalanche breakdown occurs in LOW doping diodes.
2. The breakdown occurs within the depletion region.	2. The breakdown occurs outside the depletion region.
3. The breakdown voltage is lesser than zener that of avalanche breakdown.	3. The breakdown voltage is more than breakdown voltage.

- As Zener breakdown voltage is less than that of avalanche breakdown voltage, hence Zener breakdown is said to occur before the avalanche breakdown.

Doping	↑	Breakdown voltage (V_B)	↓
Doping	↓	Breakdown voltage (V_B)	↑

- Hence we can say if we increase the doping of a diode, the chances of zener breakdown increases and hence breakdown voltage decreases.

TYPES OF BREAKDOWN-continued

AVELENCHE BREAKDOWN

https://youtu.be/fSW-I9-8L-M

https://youtu.be/uZETSfwdCVI

ZENER BREAKDOWN

https://youtu.be/5iD4-nsp14Y

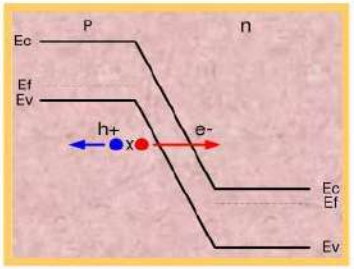
SUMMARY OF ZENER AND AVELENCH BREAKDOWN

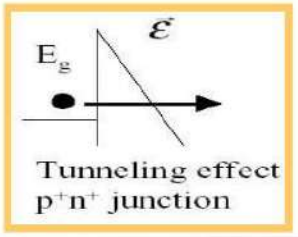
Zener Breakdown Mechanism:

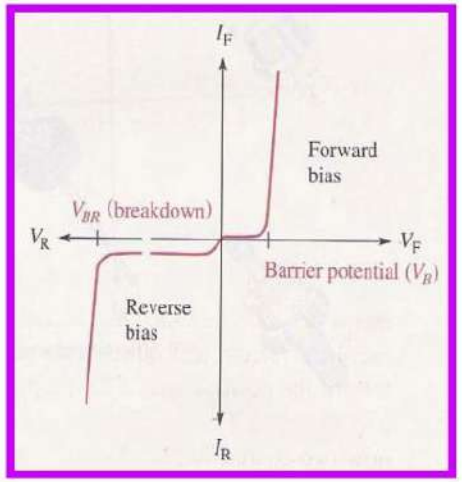
- ❖Highly Doped Junction (narrow W)
- ❖Mechanism is termed Tunneling or Zener Breakdown

◆Zener effect

Doping level > $10^{18}/Cm^3$



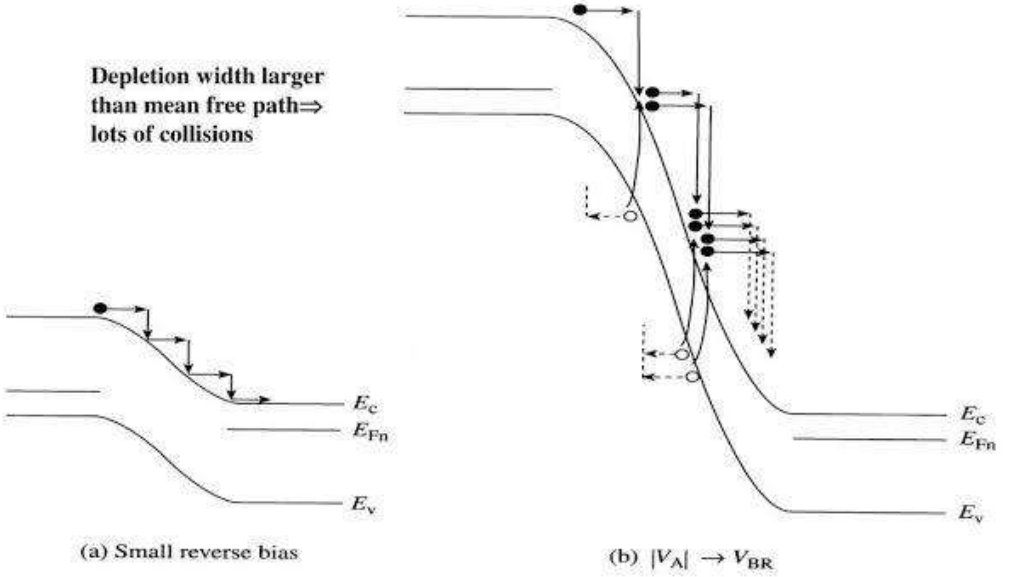




Semiconductor Devices

Energy Band diagram; Avalanche Breakdown:

Depletion width larger than mean free path⇒ lots of collisions



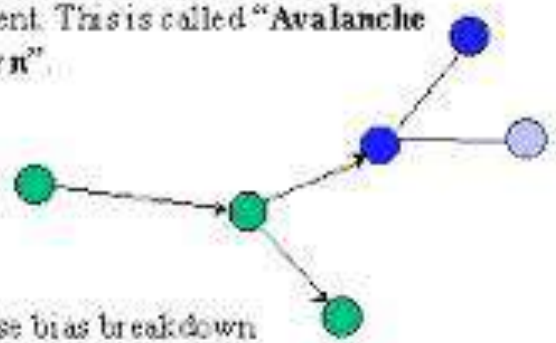
(a) Small reverse bias

(b) $|V_A| \rightarrow V_{BR}$

https://youtu.be/rnRIxPzhX9k

Reverse bias breakdown

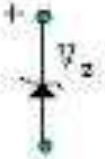
As the magnitude of the reverse bias voltage is increased, the current remains at I_s but eventually, the reverse bias field is so strong that thermally generated electrons (or holes) acquire enough kinetic energy to ionise atoms within the crystal structure. These in turn ionise other atoms leading to a very swift multiplication effect and a large current. This is called "**Avalanche breakdown**".

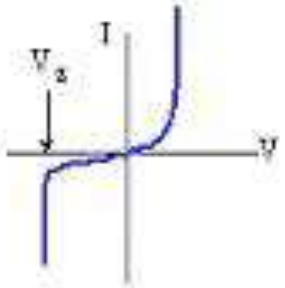


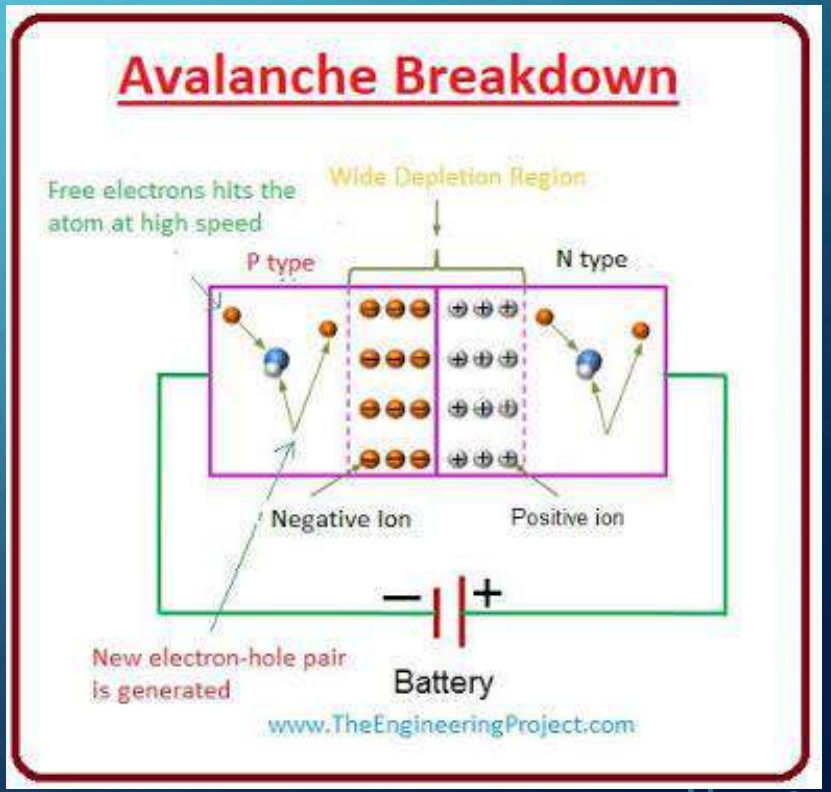
The reverse bias breakdown voltage is about 500V for Germanium and about 1kV for Silicon

If the impurity doping density is high enough, then the depletion region is narrow enough (even in reverse bias) to allow the electric field across the region to be very high. The high accelerating field and narrow depletion region allows electrons to tunnel through. This is called "**Zener breakdown**" Zener diodes are designed to breakdown in reverse bias. They can withstand a relatively large reverse current without damage. The reverse bias voltage leading to zener breakdown is adjustable during manufacture of the device.

Typical zener diodes have breakdown voltages anywhere between 2 to 200V depending on the application.





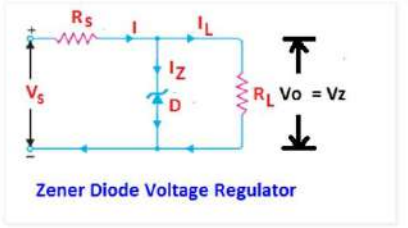


ZENER DIODE AS A VOLTAGE REGULATOR

https://youtu.be/6dmfI_H5k7U

https://youtu.be/6xGCOrPBL4s

The circuit diagram of the voltage regulator is as shown below.



Zener Diode Voltage Regulator

The followings two conditions must be meet to function the zener diode as a voltage regulator.

1. The Zener diode must be connected in the reverse bias.
2. The supply voltage Vs must be more than the zener breakdown voltage

In the circuit above, the Zener diode D is connected in the reverse bias. The resistance Rs is connected in the series of the diode to limit the current flowing through the diode.The zener diode maintains the constant output voltage Vo regardless of the variation in the input voltage or variation in the load current. Let us understand how the zener diode in the above circuit maintains the constant output volttage with variation in the supply voltage and/or the variation in the load current.

SOME CASES

Case1- When the output is not connected to the load

When output is not connected to the load the the supply current I is equal to the Zener current. The resistance is connected in the series of the diode to limit the zener current in the safe operation region. The correct selection of the series resistance is must for operation of Zener diode as a voltage regulator.

If the resistance value is selected too high the current through the Zener diode will be too low to pass the current through the Zener diode and , in this condition the output voltage V0 will be equal to the supply voltage Vs. The output voltage will be equal to the Zener Voltage only if the Zener starts conducting. The Zener current(Iz) should not exceed above the maximum current rating of the diode.

Rs(Min) = (Vs-Vz)/ Iz(max)

Case2- When the input supply varies in the specified range

When input voltage is maximum in the specified voltage range, the increased voltage leads to increase in the Zener Current(Iz). In the reverse VI characteristics of the Zener diode, if the reverse voltage is increased above the Zener breakdown voltage, the current through the Zener diode increase and the voltage across the diode remains constant.

$I = I_Z + I_L$

The increased supply voltage cause increase in the Zener current. Thus the input supply current I gets increased in the same proportion to the increased Zener current and, the load current and voltage across the load (I_L x Rs = Vz) remains fairly constant.

When the input supply voltage is minimum in the specified voltage range, the Zener current decrease and consequently the input supply current I decrease. The decreased Zener current should not be less than specified minimum Zener Current(Iz-Min.) else the zener conduction will stop. The output voltage and load current remains constant if the current flowing through the diode is equal to or more than the rated minimum Zener current(Iz-min).

Case3- When the load current increase

With an increase in the load current(I_L),the Zener current(Iz) gets decreased and thus the total current(I) remains constant. The Zener current may reach up to minimum Zener current(Iz-min). If the Zener current decrease below the rated minimum Zener current(Iz-min) the Zener diode behaves as a open circuit.

With decrease in the load current(I_L),the Zener current(Iz) gets increased and thus the total current(I) remains constant. The Zener current may reach up to maximum Zener current(Iz-max). If the Zener current increase above the rated maximum Zener current(Iz-max) the Zener diode may get permanently damaged.

Selection of Series Resistance:

$$R_{s(Max)} = \frac{V_{s(min)} - V_z}{I_L\,(max)}$$

Selection of Zener Diode:

The following data of the Zener diode should be known.

- Zener minimum current
- Zener maximum current
- breakdown voltage or Zener Voltage
- Power rating of the Zener diode