

# Zener Diode

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Ordinary diodes are forward biased and work in the forward direction. They have a large forward current flowing through them with a negligible voltage drop across them. If we operate an ordinary diode in reverse biased, it conducts insignificant current until the voltage applied across them exceeds the reverse breakdown voltage. Once that happens, large current flows through the junction and the diode may get destroyed. The Zener diode is a particular type of diode that solves this problem.

Or we can say a Zener diode is a heavily **doped semiconductor device that is designed to operate in the reverse direction also known as a breakdown diode.**

## Working Principle

Zener diode allows electric current in **forward direction** like a normal diode but it 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.

However, when connected in **reverse biased** mode, a small leakage current flows through the diode. As the reverse voltage increases to the predetermined breakdown voltage ( $V_z$ ), current starts flowing through the diode. The current increases to a maximum, which is determined by the series resistor, after which it stabilizes and remains constant over a wide range of applied voltage.

There are two types of reverse breakdown regions in a zener diode:

- Avalanche Breakdown
- Zener Breakdown.

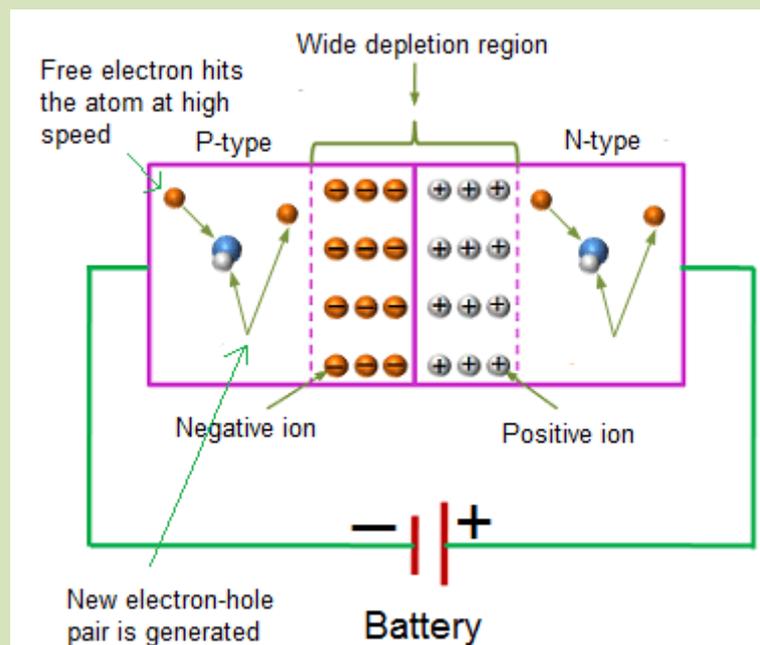
## Avalanche Breakdown

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**.

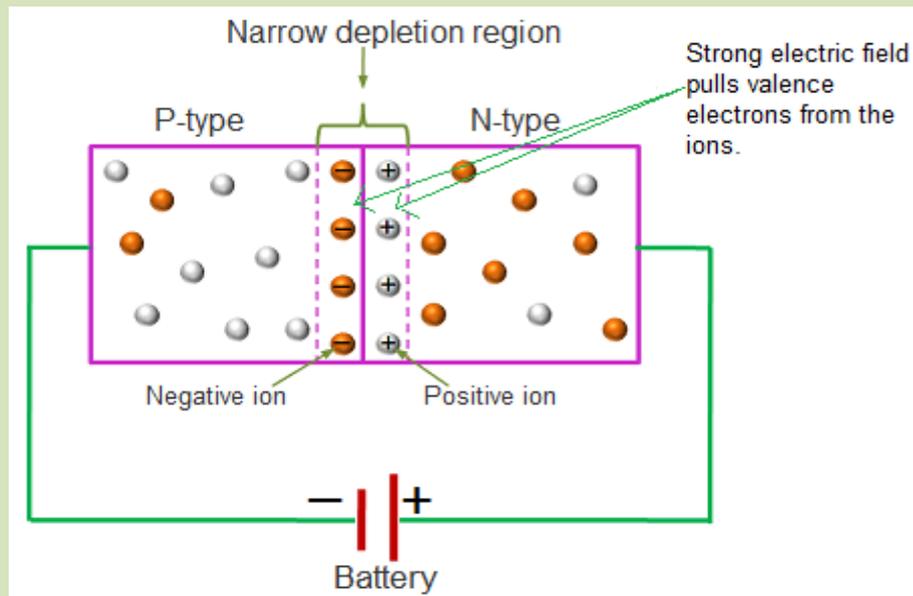
Further, these again collide with remaining stationary ions and this process continues it is referred to as **carrier multiplication**.

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**.



## Zener Breakdown

The zener breakdown occurs in heavily doped p-n junction diodes because of their narrow depletion region. When reverse biased voltage applied to the diode is increased, the narrow depletion region generates strong electric field.



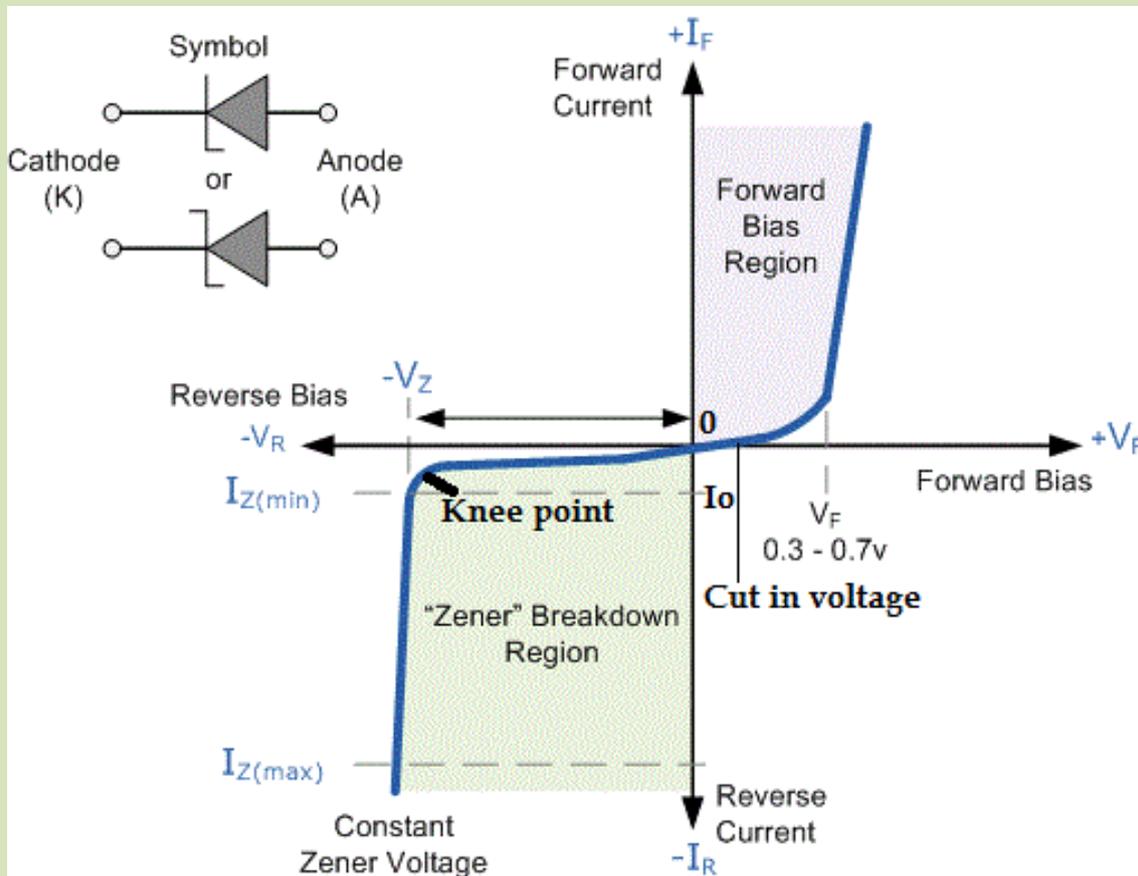
When reverse biased voltage applied to the diode reaches close to zener voltage, the electric field in the depletion region is strong enough to pull electrons from their valence band. The valence electrons which gains sufficient energy from the strong electric field of depletion region will breaks bonding with the parent atom. The valance electrons which break bonding with parent atom will become free electrons. These free electrons carry electric current from one place to another place. At zener breakdown region, a small increase in voltage will rapidly increases the electric current.

## V-I Characteristics of Zener Diode

The **first quadrant** is the **forward biased** region. Here the Zener diode acts like an ordinary diode. When a forward voltage is applied, current flows through it. But due to higher doping concentration, higher current flows through the Zener diode.

In the **third quadrant**, When a **reverse voltage** is applied to a Zener voltage, initially a small reverse saturation current  $I_0$  flows across the diode. This current is due to thermally generated minority carriers. As the **reverse voltage** is **increased**, at a certain value of reverse voltage, and current increases **drastically** and **sharply**.

This is an indication that the **breakdown** has **occurred**. Known as breakdown voltage or Zener voltage, it is denoted by  $V_Z$ .



The **zener breakdown** voltage of the zener diode is **depends** on the **amount** of **doping** applied. If the diode is heavily doped, zener breakdown occurs at low reverse voltages. On the other hand, if the diode is lightly doped, the zener breakdown occurs at high reverse voltages.

Zener diodes are available with zener voltages in the range of **1.8V to 400V**.

# Zener Diode as a Voltage Regulator

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## Voltage Regulator

A voltage regulator is a device that **regulates the voltage** level. It essentially steps down the input voltage to the desired level and keeps it at that same level during the supply. This ensures that even when a load is applied the voltage doesn't drop. The voltage regulator is mainly used for two main reasons, and they are:

- To vary or regulate the output voltage
- To keep the output voltage constant at the desired value in spite of variations in the supply voltage.

Voltage regulators are used in computers, power generators, alternators to control the output of the plant.

## Why Zener Diode used as a Voltage Regulator?

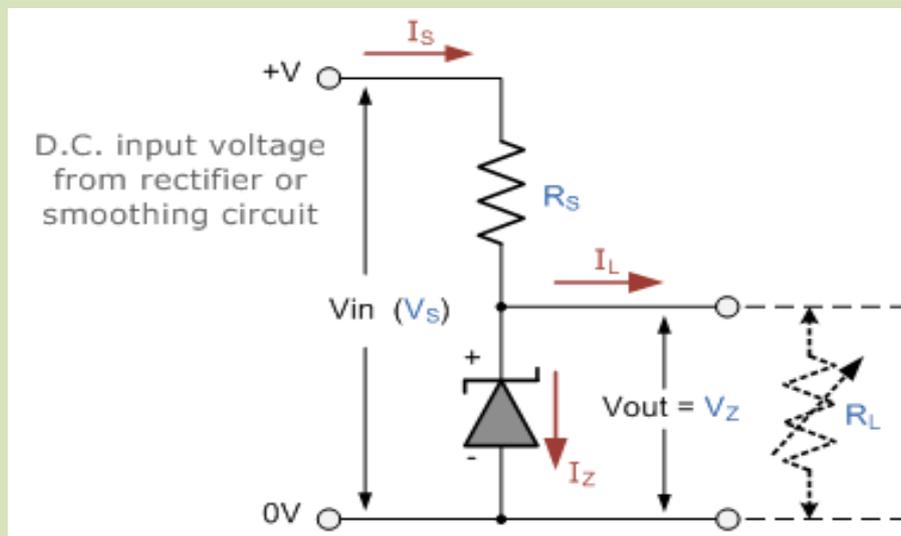
From the I-V characteristics curve above, we can see that the zener diode has a region in its reverse bias characteristics of **almost a constant negative voltage regardless** of the value of the **current flowing** through the diode. This voltage remains almost constant even with large changes in current providing the zener diodes current remains between the breakdown current  $I_{Zmin}$  and its maximum current rating  $I_{Zmax}$ .

This ability of the zener diode to control itself can be used to great effect to regulate or stabilise a voltage source against supply or load variations. The fact that the voltage across the diode in the breakdown region is almost constant turns out to be an important characteristic of the zener diode as it can be used in the simplest types of voltage regulator applications.

The **function of a voltage 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 variations in the load current. A zener diode will continue to regulate its voltage **until the diodes holding current falls below the minimum  $I_{Zmin}$**  value in the reverse breakdown region.

## Zener Diode Regulator

The source resistance  $R_s$  is connected in series with zener diode **to limit the maximum current flowing** in the diode with voltage source ( $V_{in}$ ) connected across the combination. The cathode terminal of zener diode is connected to the positive terminal of the voltage source so that the **zener diode is biased in reverse condition** and will be operating in breakdown region. The stabilised output voltage  $V_{out}$  is taken from across the zener diode.



Now to understand working of zener diode regulator considering two situations as:

- When **the load is not connected** across the zener diode, the load current will be zero, ( $I_L = 0$ ) mean **no load current will be conducted** and all the **current** due to the circuit will **pass through the zener diode** which **dissipating maximum** amount of **power** that causes overheating of the diode and **damages permanently**.

Selecting the appropriate values of series resistance  $R_s$  is also important because it also causes greater diode current, so that maximum power dissipation of the diode should not be exceeded under no load condition.

- Whenever a **load is connected in parallel** with zener diode, the voltage across  $R_L$  is always the same as the zener voltage, ( $V_R = V_Z$ ). But as there is a **minimum zener current** for which the **stabilisation** of the voltage is effective required thus the **zener current must stay above this value operating under load condition at all the time**. The upper limit of current is of course dependent upon the power rating of the device. **Thus the supply voltage  $V_S$  must be greater than  $V_Z$ .**

Then to **summarise** a little. A zener diode is always operated in its reverse biased condition. As such a simple voltage regulator circuit can be designed using a zener diode to maintain a constant DC output voltage across the load in spite of variations in the input voltage or changes in the load current.

The zener voltage regulator consists of a current limiting resistor  $R_S$  connected in series with the input voltage  $V_S$  with the zener diode connected in parallel with the load  $R_L$  in this reverse biased condition. **Thus the stabilised output voltage is always selected to be the same as the breakdown voltage  $V_Z$  of the diode.**