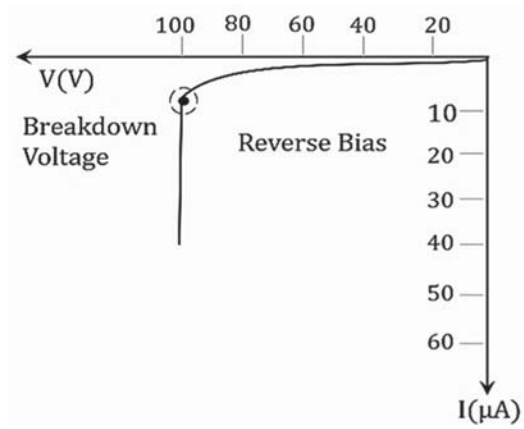
PN JUNCTION AND ZENER DIODE

Questions based on PN junction

Que.1. When the reverse bias in a p−n junction diode is significantly increased, the current.

(A) Remains fixed (B) Increases slowly
(C) Decreases slowly (D) Suddenly increases

Sol. Under reverse bias, the current remains nearly constant initially. However, at the breakdown voltage, there is a substantial surge in current due to the avalanche effect. Therefore, option (D) is the correct answer.



Que.2. In the configuration of a pn-junction diode under forward bias conditions,

(A) The direction of current is from n -end to p -end in the diode
(B) The p -end is connected to the negative terminal of battery
(C) The n -end is connected to the positive terminal of the battery
(D) The p -end is connected to the positive terminal of the battery

Sol. In the forward bias setup of a pn-junction diode, the positive terminal of the battery is linked to the p-end, whereas the negative terminal is linked to the n-end. When under forward bias, the flow of current within the diode moves from the p-side to the n-side.
Consequently, option (D) stands as the accurate choice.

Que.3. The primary mechanism governing the movement of charge carriers in forward and reverse-biased silicon pn-junctions is.

(A) Drift in both forward and reverse bias
(B) Drift in forward bias, diffusion in reverse bias
(C) Diffusion in forward bias, drift in reverse bias
(D) Diffusion in both forward and reverse bias

Sol. Under forward bias conditions, there is a reduction in the potential barrier, causing the depletion region to contract. Consequently, majority charge carriers can readily diffuse across the junction, leading to the dominance of diffusion current. Conversely, in reverse bias, the potential barrier escalates, resulting in the expansion of the depletion region. While the diffusion of majority charge carriers becomes negligible, the drift of minority charge carriers remains relatively constant. As a result, drift current prevails under reverse bias.
Consequently, option (C) emerges as the correct choice.

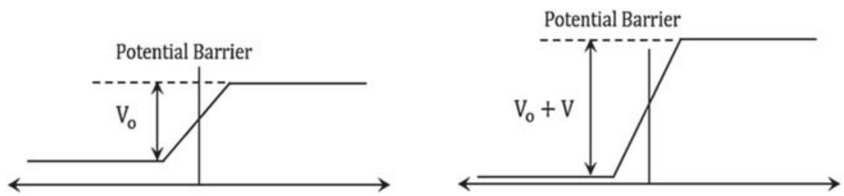
Que.4. Avalanche breakdown occurs as a result of.

(A) Decrease in depletion layer thickness (B) Collision of minority charge carrier
(C) Increase in depletion layer thickness (D) None of these

Sol. Under reverse bias conditions, when the breakdown voltage is reached, the electric field strength becomes exceptionally intense. Consequently, minority electrons attain significant velocities, leading them to dislodge bonded electrons through collisions. This process results in a rapid escalation of charge carrier concentration and consequently, a drastic increase in current flow occurs. Therefore, avalanche breakdown primarily arises from the collision of minority charge carriers. Consequently, option (B) stands as the correct response.

Que.5. The application of reverse bias to a pn-junction diode.
(A) Increases the potential barrier
(B) Decreases the potential barrier
(C) Increases the number of minority charge carriers
(D) Increases the number of majority charge carriers

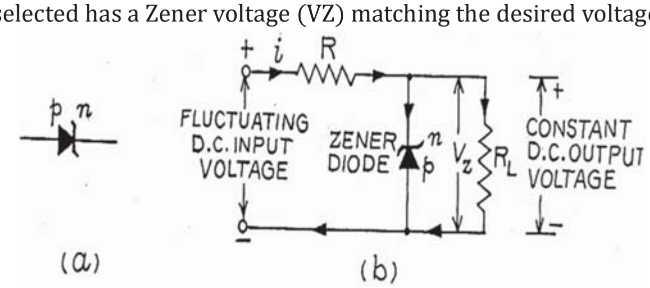
Solution.
Where a $p-n$ junction diode is reverse biased, p-end is connected to the negative terminal and pulls the holes away from the junction. Similarly, n-end is connected to the positive terminal and pulls the electrons. Therefore, the depletion region gets widen and this leads to the rise in the potential barrier.



Consequently, option (A) is the correct answer.

Different Types of Junction Diode
Several types of junction diodes exist, each tailored to fulfill particular functions. Notable examples include the Zener diode, photodiode, light-emitting diode (LED), and solar cell.

Zener Diode:
A Zener diode operates as a voltage regulator by exploiting the phenomenon of avalanche breakdown within a junction diode. As the reverse bias applied to the junction diode increases, there is a sudden surge in reverse current when the reverse bias attains a specific value, referred to as the 'breakdown voltage' or 'Zener voltage.' Within this region of the reverse characteristic curve, the voltage across the diode remains almost constant over a considerable range of currents. This characteristic enables the Zener diode to stabilize voltage at a predetermined level.
Zener diodes can be precisely engineered, using controlled doping, to stabilize voltage at any desired level ranging from 4 to 100 volts. The symbol of a Zener diode is represented in Fig. (a), while Fig. (b) illustrates a simple circuit for stabilizing voltage across a load RL. The circuit consists of a series voltage-dropping resistance R and a Zener diode connected in parallel with the load RL. The Zener diode selected has a Zener voltage (VZ) matching the desired voltage across the load.



When encountering fluctuating DC input voltage, such as the DC output of a rectifier, any rise in the input voltage results in an excess voltage drop across resistance R.
Consequently, the input current (i) rises, and this surge is diverted through the Zener diode. Consequently, the current flowing through the load, and thereby its voltage, remains consistent at VZ. Conversely, a decrease in the input voltage prompts a reduction in the input current, and the Zener diode modulates the current through the load to uphold a steady voltage.
The circuit's operation hinges on the input voltage not dipping below VZ, as resistance R absorbs fluctuations in input voltage to ensure a stable output voltage of VZ.

I-V characteristics

particularly in the reverse bias region where Zener breakdown occurs. Here's an overview of the key features:

- Zener diodes have a maximum power rating that determines how much power they can dissipate without being damaged. Exceeding this rating can lead to thermal runaway and device failure.
- The Zener diode's characteristics, especially its Zener voltage, can vary with temperature changes. The temperature coefficient indicates the rate at which the Zener voltage changes with temperature. It is usually expressed in mV/°C.
- The Zener resistance is the dynamic resistance exhibited by the Zener diode when it is conducting in the reverse breakdown region. It represents the change in voltage with respect to the change in current and is often used in circuit analysis.
- When the reverse bias voltage applied to the Zener diode exceeds the Zener voltage, the diode enters the reverse breakdown region. In this region, the Zener diode conducts heavily in the reverse direction while maintaining a relatively constant voltage across it.

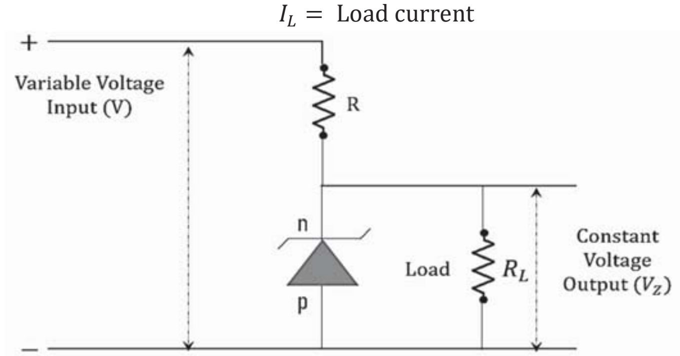
Voltage Regulation

which a Zener diode is utilized to maintain a stable output voltage across a load, despite variations in input voltage or load conditions. This regulation is achieved by operating the Zener diode in its reverse breakdown region, where it conducts heavily and maintains a nearly constant voltage drop across it, known as the Zener voltage (VZ). As a result, the Zener diode acts as a voltage reference, ensuring that the output voltage remains consistent and within a specified range, regardless of fluctuations in the input voltage or changes in the load.

The Zener diode is positioned in a reverse bias configuration, running parallel to the load, to ensure a stable voltage output. The current passing through resistor R is $I_R = I_Z + I_L$

$I_Z =$ Zener current

$I_L =$ Load current



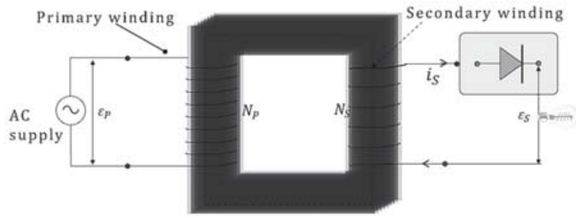
In order to achieve voltage regulation where a consistent voltage is necessary across the load, it is imperative that the current remains constant as well. Thus, the current passing through the load is

$$I_L = \frac{V_2}{R_1}$$

However, it's important to recognize that the current passing through the Zener diode can vary, and this specific current, denoted as I2, is determined by the equation: $I_2 = I_R - \frac{V_2}{R_2}$

Application of PN junction

A rectifier serves as an electrical apparatus designed to transform alternating current (AC), which cyclically changes direction, into direct current (DC).



The diode acts as a component that permits current flow in one direction and blocks it in the opposite direction. This functionality enables it to convert alternating current into direct current by allowing only the flow of current in one direction.

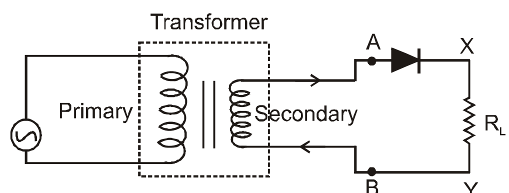
p-n Junction Diode as A Rectifier

A rectifier is a device engineered to convert alternating current (AC) or voltage into direct current (DC) or voltage. When a p-n junction diode is forward-biased, it presents a low resistance to current flow, facilitating efficient conduction. Conversely, when reverse-biased, it demonstrates a significantly high resistance. This behavior enables the diode to solely permit current flow in one direction, thus functioning as a rectifier. Depending on its configuration, the junction diode can operate as either a half-wave rectifier, allowing current flow exclusively during the positive half-cycles of the input AC, or as a full-wave rectifier, enabling current flow in the same direction throughout both half-cycles of the input AC.

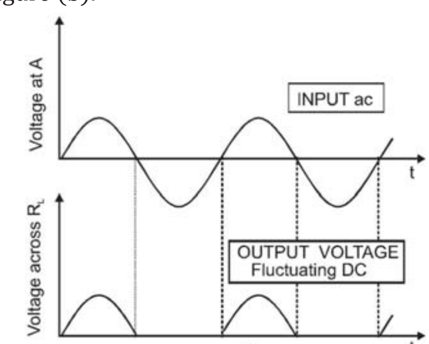
Half wave rectifier

Figure (a) depicts the configuration of a half-wave rectifier circuit, while Figure (b) illustrates the corresponding input and output waveforms. In this arrangement, the alternating input voltage is applied across the primary coil P_1 P_2 of a transformer. The secondary coil S_1 S_2 of the same transformer is connected to the p-type crystal of the junction diode at point S_1 and to the n-type crystal at point S_2 through a load resistance RL.

During the initial half-cycle of the alternating current input, when the secondary terminal S_1 is positive and S_2 is negative, the junction diode becomes forward-biased, allowing current to flow. As a result, current passes through the load RL in the direction indicated by the arrows. This current generates an output voltage across the load, with a waveform that mirrors that of the input voltage's half-cycle. Subsequently, during the second half-cycle of the AC input, S_1 becomes negative and S_2 becomes positive. At this point, the diode is reverse-biased, resulting in minimal current flow and negligible output voltage across RL. This process repeats, leading to a unidirectional but pulsating output current, as shown in the lower part of Figure (b).



(a)



(b)

Since the output current corresponds to only one half of the input voltage wave, with the other half absent, this technique is known as half-wave rectification. The transformer's function in this process is to supply the necessary voltage to the rectifier.

When the objective is to obtain high-voltage direct current from the rectifier, as required for power supply applications, a step-up transformer is utilized, as depicted in Figure (a). Conversely, in many solid-state devices, low-voltage direct current is necessary. In such cases, a step-down transformer is employed in conjunction with the rectifier.

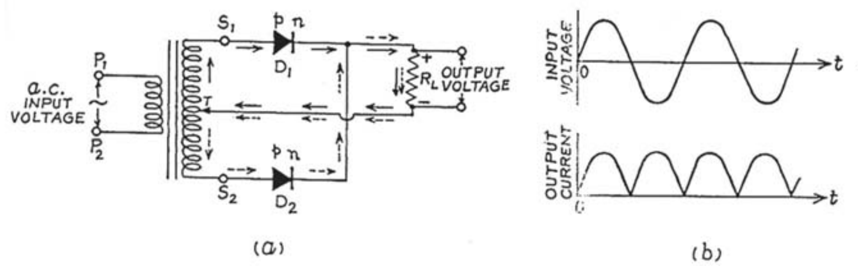
Note:

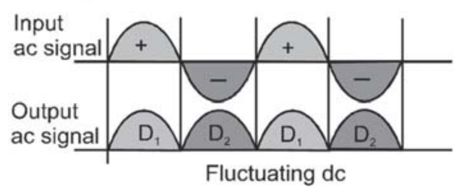
- During the positive half-cycle of the input signal, the diode undergoes forward biasing, resulting in the production of an output signal.
- Conversely, in the negative half-cycle, the diode experiences reverse biasing, leading to the absence of an output signal.

- Across the load resistance RL, there exists an output voltage. Although pulsating in nature, it comprises a combination of alternating current (AC) and direct current (DC).
- The root mean square (RMS) values for the output current and voltage are denoted by I_{rms} and V_{rms}, respectively.
- The efficiency of the half-wave rectifier stands at 40.6%.
- The ripple frequency (ω) for the half-wave rectifier matches that of the alternating current (AC).

Full wave rectifier

In a full-wave rectifier setup, a unidirectional and pulsating output current is produced for both halves of the alternating input voltage. This configuration necessitates the utilization of two junction diodes interconnected in a manner such that one diode rectifies the first half, and the second diode rectifies the second half of the input voltage. The circuit diagram for a full-wave rectifier is depicted in Figure (a), with corresponding input and output waveforms illustrated in Figure (b). The alternating input voltage is applied across the primary terminals P_1 P_2 of a transformer. The terminals S_1 and S_2 of the secondary are connected to the p-type crystals of junction diodes D_1 and D_2, while their n-type crystals are interconnected. A load resistance RL is linked across the n-type crystals and the central-tap terminal T of the secondary coil S_1 S_2.





During the initial half-cycle of the AC input voltage, when terminal S_1 is positively oriented with respect to T and S_2 is negatively charged, junction diode D_1 undergoes forward biasing, whereas D_2 experiences reverse biasing. As a result, D_1 conducts current, while D_2 does not. The conventional current flows through diode D_1, the load RL, and the upper half of the secondary winding, as indicated by solid arrows.

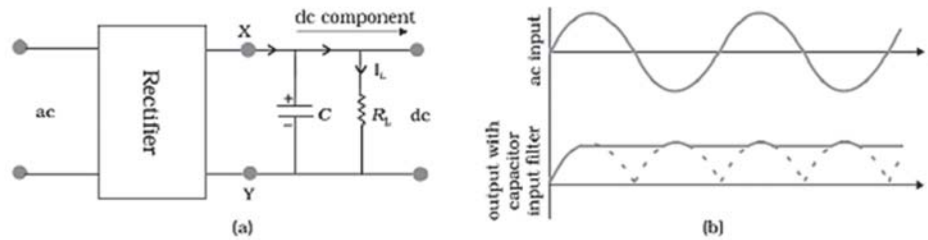
In the subsequent half-cycle of the input voltage, when S_1 becomes negatively charged relative to T and S_2 becomes positively charged, D_1 is now reverse-biased and ceases to conduct, while D_2 becomes forward-biased and allows current to flow through. The current now travels through D_2, the load RL, and the lower half of the secondary, as depicted by dotted arrows. It is evident that the current in the load RL consistently flows in the same direction for both half-cycles of the alternating input voltage. Consequently, the output current adopts the form of a continuous series of unidirectional pulses. However, to achieve a more stable output, smoothing filters can be employed.

Filter:

The rectified voltage, which exhibits pulsating waves resembling half sinusoids, lacks a stable, constant value despite its unidirectional flow. To stabilize this fluctuating voltage and obtain a steady DC output, a common approach involves connecting a capacitor across the output terminals, running parallel to the load RL. Alternatively, one can introduce an inductor in series with RL to achieve the same effect. These additional components, known as filters, effectively remove the AC ripple, resulting in a smooth, pure DC voltage.

Let's explore the role of the capacitor in this filtering process in detail. As the voltage across the capacitor increases, it undergoes a charging phase. In the absence of an external load, it retains a charge equivalent to the peak voltage of the rectified output. However, when a load is connected, the capacitor discharges through the load, causing its voltage to decrease. During the subsequent half-cycle of the rectified output, the capacitor recharges back to its peak value. The rate at which the capacitor's voltage decreases is determined by the inverse product of the capacitor's capacitance (C) and the effective resistance (RL) in the circuit, referred to as the time constant.

To optimize the time constant, it is beneficial to use a capacitor with a significant capacitance (C). Consequently, capacitor input filters often incorporate large capacitors. The output voltage obtained through a capacitor input filter closely tracks the peak voltage of the rectified input. This type of filter finds widespread application in power supply systems.



Notes:

- ➢ During the positive half cycle:
- ➢ Diode D1 is forward biased, while D2 is reverse biased.
- ➢ The output signal is solely a result of D1's operation.
- ➢ During the negative half cycle:
- ➢ Diode D1 is reverse biased, and D2 is forward biased.
- ➢ The output signal is solely attributed to D2's operation.
- ➢ The fluctuating DC signal is then passed through a filter to achieve a constant DC output.
- ➢ The output voltage is observed across the load resistance RL, which exhibits a pulsating, non-constant nature.
- ➢ The average output voltage and current are calculated as $V_{av} = 2/\pi\ V_m$ and $I_{av} = 2/\pi\ I_m$, respectively.
- ➢ The ripple frequency of a full-wave rectifier is twice the frequency of the input AC signal.
- ➢ The efficiency of the system is measured at 81.2%.

Full wave bridge rectifier:

In the circuit, four diodes, denoted as D_1, D_2, D_3, and D_4, are utilized. During the positive half cycle, D_1 and D_3 are forward biased, whereas D_2 and D_4 are reverse biased. Conversely, in the negative half cycle, D_2 and D_4 are forward biased, while D_1 and D_3 are reverse biased.