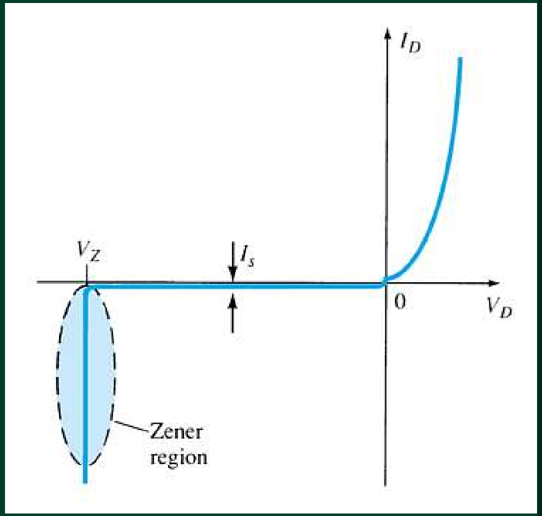
Zener Diode

Zener Diode and Avalanche Breakdown

Basics of Zener Voltage Regulator

Zener Region



- The Zener region is in the diode's reverse-bias region.
- At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.
- The maximum reverse voltage that won't take a diode into the zener region is called the peak inverse voltage or peak reverse voltage.
- The voltage that causes a diode to enter the zener region of operation is called the zener voltage (V_Z).

Zener Diode

- A **Zener diode** is a type of diode specifically designed to operate in the **reverse breakdown region**.
- Unlike ordinary diodes, which are damaged if the reverse voltage exceeds a certain threshold, Zener diodes are designed to withstand breakdown and maintain a stable reverse voltage.

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Zener Diode

- **Key Features of a Zener Diode**
  1. **Reverse Breakdown Operation**:
     1. The diode allows current to flow in the reverse direction when the reverse voltage reaches a specified level, called the **Zener voltage** (V_Z).
     2. This reverse breakdown does not damage the diode if operated within its power rating.
  2. **Voltage Regulation**:
     1. The Zener diode maintains a nearly constant voltage (V_Z) across its terminals even when the input voltage or load changes, making it useful as a **voltage regulator**.
  3. **Bidirectional Behavior**:
     1. In forward bias, it behaves like a regular diode.
     2. In reverse bias, it exhibits a sharp breakdown at V_Z, allowing significant current while holding the voltage constant.

Zener Diode

- **Construction and Working**
  - **Construction**:
    - Zener diodes are heavily doped to create a thin depletion region, enabling the **Zener breakdown mechanism** at low voltages.
    - They can also exhibit **avalanche breakdown** for higher voltage ratings (>6V).
  - **Working Principle**:
    - In forward bias: It behaves like a standard diode.
    - In reverse bias:
      - Below V_Z: Very little reverse current flows.
      - At V_Z: The diode enters breakdown and conducts a high current while maintaining the reverse voltage nearly constant.

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Zener Diode

- **Applications**
  1. **Voltage Regulation**:
     - Zener diodes are used in **power supply circuits** to stabilize voltage by providing a constant reference voltage.
  2. **Overvoltage Protection**:
     - Protects sensitive electronic components from voltage spikes by clamping the voltage to V_Z.
  3. **Waveform Clipping**:
     - Used to clip signals at a specific voltage, useful in signal processing.
  4. **Voltage Reference**:
     - Provides a stable reference voltage for precise applications, like in analog-to-digital converters.

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Zener Diode

- **Characteristics**
  1. **Zener Voltage (V_Z)**:
     - Defined as the reverse voltage at which the diode enters breakdown.
     - Can range from a few volts to hundreds of volts.
  2. **Power Dissipation**:
     - The maximum power the diode can dissipate, given by $P=V_Z \times I_Z$, where I_Z is the current through the diode.
  3. **Temperature Dependence**:
     - The Zener voltage changes with temperature.
     - Zener diodes below ~5.6V have a negative temperature coefficient, while those above ~5.6V have a positive coefficient.

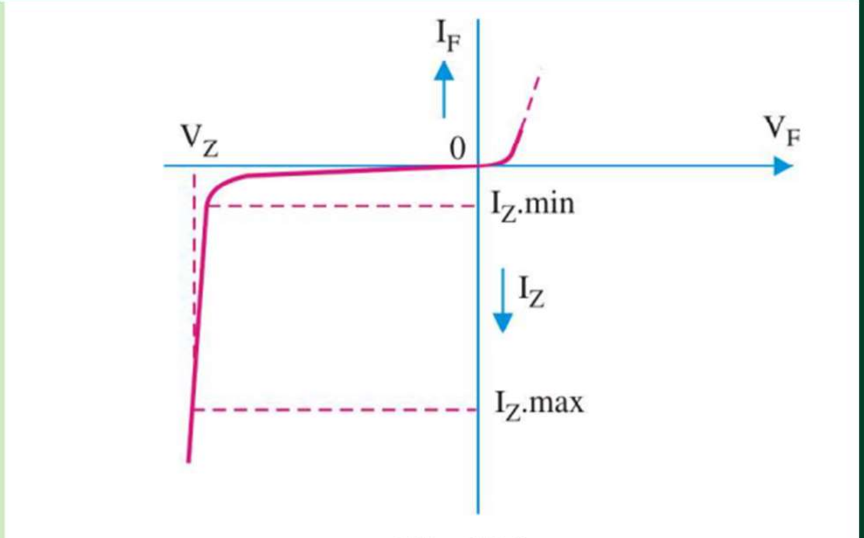

Fig. 15.1

Zener Diode

- **Example Circuit for Voltage Regulation**
  - **Components:**
    - Zener diode (V_Z=5.6V)
    - Resistor (R)
    - Input voltage source (V_{in})
  - **Operation:**

1. $V_{in} > V_Z$: The Zener diode breaks down and clamps the voltage across it to V_Z.
2. The resistor limits the current through the diode to prevent damage.

- This setup ensures a stable output voltage (V_Z) regardless of variations in V_{in} or load conditions.

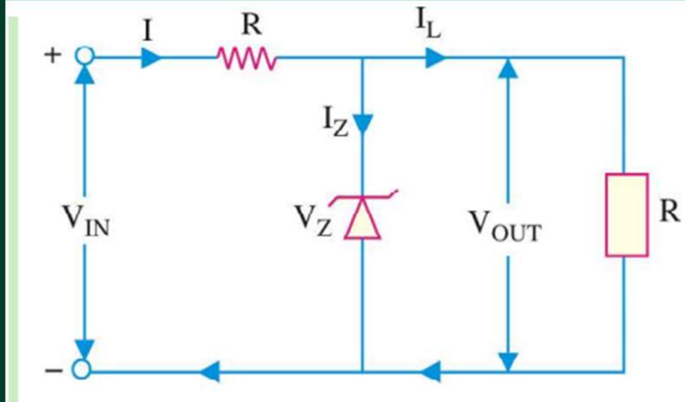

Fig. 15.6

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Zener Breakdown

- **Mechanism**:
  - Zener breakdown occurs due to quantum mechanical tunneling of electrons across a narrow depletion region in a heavily doped PN junction.
  - When the electric field across the junction becomes extremely strong (due to a high reverse voltage), it allows electrons to "tunnel" through the energy barrier.

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Zener Breakdown

- **Key Features**:
  - Happens in **heavily doped diodes** with thin depletion regions.
  - Dominates at **low reverse voltages** (typically less than 6V).
  - The breakdown voltage (Zener voltage) is well-defined and nearly constant for a given diode.
  - No significant damage to the diode if operated within the power ratings.
- **Applications**:
  - Used in **Zener diodes** for voltage regulation and reference voltage sources.

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Avalanche Breakdown

- **Mechanism**:
  - Avalanche breakdown occurs due to the impact ionization process.
  - In a less heavily doped PN junction, the depletion region is wider.
  - High reverse voltage accelerates free electrons, causing them to collide with lattice atoms and generate additional electron-hole pairs.
  - This multiplication leads to a large current.

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Avalanche Breakdown

- Key Features:
  - Happens in lightly doped diodes with wide depletion regions.
  - Occurs at higher reverse voltages (typically above 6V).
  - Dependent on temperature, as increased thermal energy aids the ionization process.
  - If the current is not limited externally, it can damage the diode.
- Applications:
  - Used in avalanche diodes for applications requiring high-voltage operation or protection circuits.

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Zener Vs Avalanche Breakdown

Feature	Zener Breakdown	Avalanche Breakdown
Doping	Heavy	Light
Depletion Region	Narrow	Wide
Voltage Range	Low (<6V)	High (>6V)
Mechanism	Quantum Tunneling	Impact Ionization
Temperature Dependence	Weak	Strong
Damage Risk	Low	High without current limiting

Zener Vs Avalanche Breakdown

- Quantum tunneling is a quantum mechanical phenomenon that occurs when particles pass through a potential energy barrier that they shouldn't be able to pass through according to classical mechanics.
- Impact ionization is a process that occurs in high electric fields when electrons or holes gain enough energy to break a bond and create electron-hole pairs.

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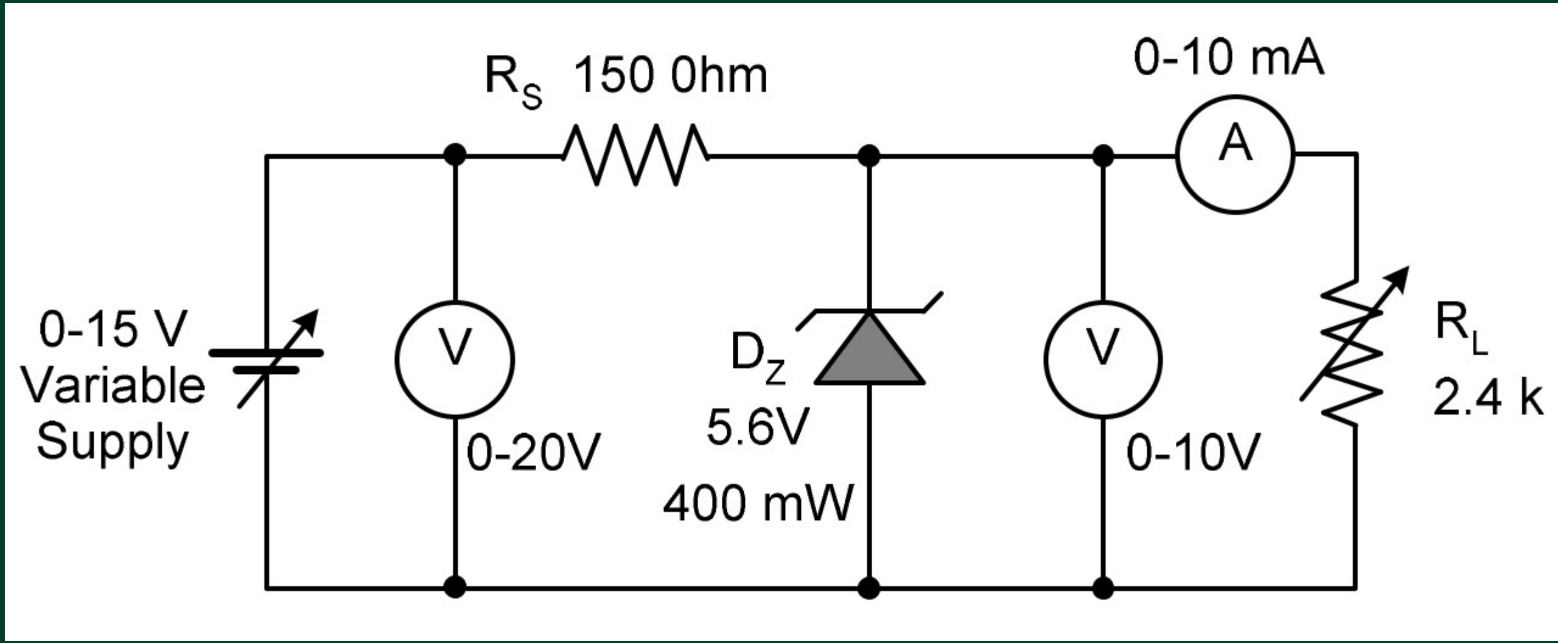
Zener Experiment Setup



Zener Experiment Setup

Output requirements

$V_O = 5.6V$, $I_L = 10mA$ When input is in the range $10 \pm 3V$

Select 5.6V Zener

$P_D = 0.25W$, $V_Z = 5.6V$, $I_{Zmax} = 45mA$, $I_{Zmin} = 5mA$

Design of load resistor, R_L

$$R_L = \frac{V_O}{I_{Lmin}}$$

$V_O = V_Z$. For a load regulation from 5mA to 15mA, $I_{Lmin} = 5mA$.

$$R_L = \frac{5.6}{5 \times 10^{-3}} = 1.12k\Omega$$

Zener Experiment Setup

Design of R_s

$$R_{smin} = \frac{V_{inmin} - V_Z}{I_{Lmax} + I_{Zmin}} = \frac{7-5.6}{(15+5) \times 10^{-3}} = 70\Omega$$

$$R_{smax} = \frac{V_{inmax} - V_Z}{I_{Lmin} + I_{Zmax}} = \frac{13-5.6}{(5+45) \times 10^{-3}} = 148\Omega$$

Take $R_{smin} < Rs < R_{smax}$

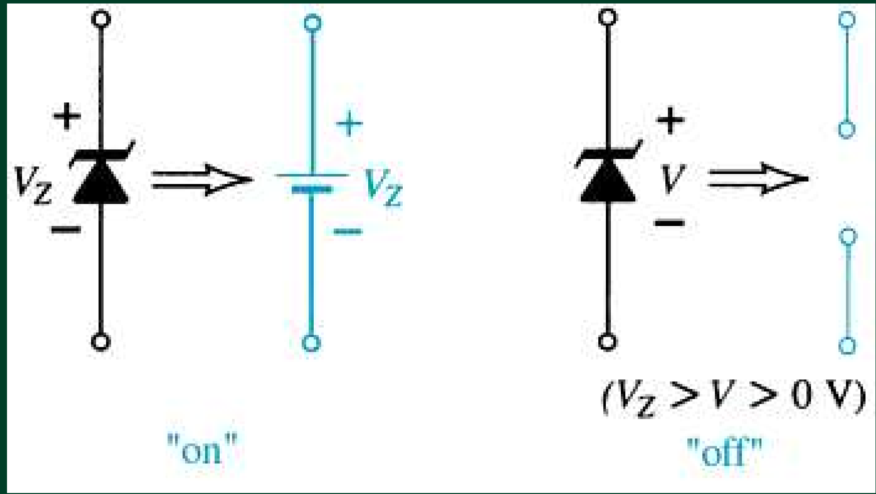
$R_s = 120\Omega$

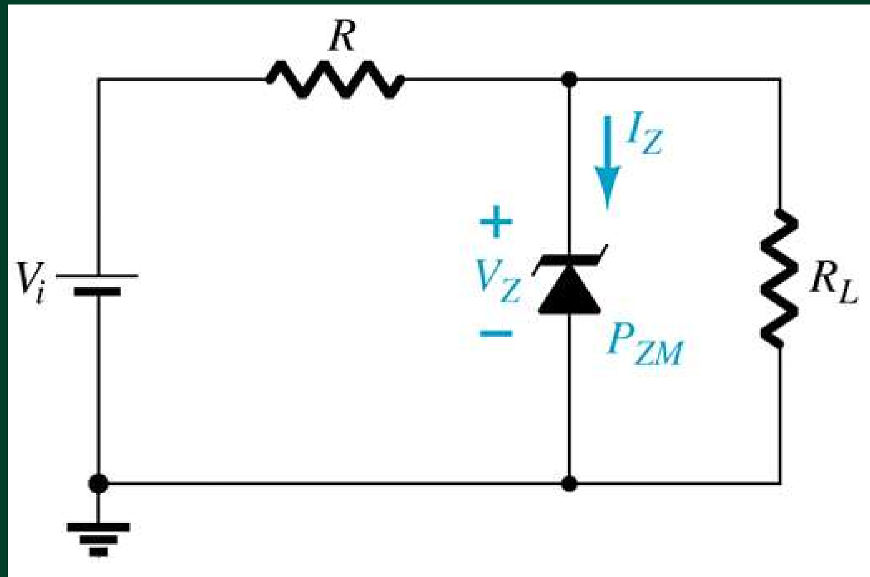
Power dissipation by $R_s = I_{smax}^2 \times R_s = (I_{Lmin} + I_{Zmax})^2 \times R_s = ((5 + 45)\times10^{-3})^2 \times 120 = 0.3W$

Take $Rs = 120\Omega$, 0.5W

347 Zener Diodes

- The Zener is a diode operated in reverse bias at the Zener Voltage (V_z).
- When $V_i \geq V_Z$
  - The Zener is on
  - Voltage across the Zener is V_Z
  - Zener current: $I_Z = I_R - I_{RL}$
  - The Zener Power: $P_Z = V_Z I_Z$
- When $V_i < V_Z$
  - The Zener is off
  - The Zener acts as an open circuit

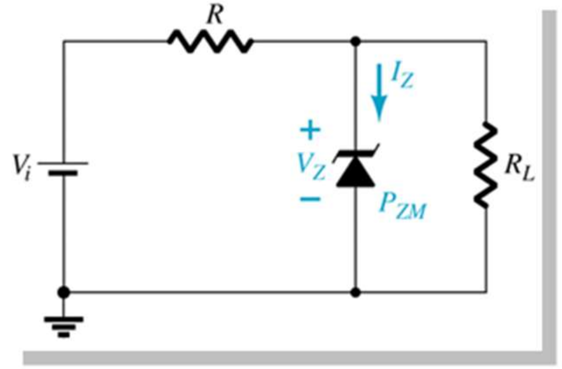




Zener Resistor Values

If R is too large, the Zener diode cannot conduct because the available amount of current is less than the minimum current rating, I_{ZK}. The minimum current is given by:

$$I_{L\min} = I_R - I_{ZK}$$



The *maximum* value of resistance is:

$$R_{L\max} = \frac{V_Z}{I_{L\min}}$$

If R is too small, the Zener current exceeds the maximum current rating, I_{ZM}. The maximum current for the circuit is given by:

$$I_{L\max} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L\min}}$$

The *minimum* value of resistance is:

$$R_{L\min} = \frac{RV_Z}{V_i - V_Z}$$

Practical Applications

- **Rectifier Circuits**
  - **Conversions of AC to DC for DC operated circuits**
  - **Battery Charging Circuits**
- **Simple Diode Circuits**
  - **Protective Circuits against**
  - **Overcurrent**
  - **Polarity Reversal**
  - **Currents caused by an inductive kick in a relay circuit**
- **Zener Circuits**
  - **Overvoltage Protection**
  - **Setting Reference Voltages**