Lecture Outline:

Introduction.

Fixed V_i, Fixed R_L.

Fixed V_i, Variable R_L.

Zener effect

The **Zener effect is the breakdown mechanism if the** reverse bias required to force **breakdown occurs at low voltages.**

Consider the heavily doped p-n junction shown to the left and then apply a reverse bias to the junction.

Reverse bias brings the conduction band very close to the valence band.This brings many occupied states on the p-side into energetic alignment with vacant states on the n-side.Electrons **tunnel from the valence** band to the conduction band giving rise to a reverse current.

This is the **Zener effect.**

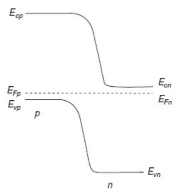
So what do we need to cause **Zener breakdown?**

The basic requirements to drive a tunneling current are:

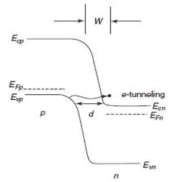
- A large number of electrons
- A large number of holes
- Separated by a narrow barrier of finite height.
- Tunneling depends heavily on the barrier width so we want to keep the junction sharp and doping high.
- This will ensure that the transition region W extends only a very short distance from each side of the junction.
- Failure to attain high doping or sharp junctions will result in no tunneling current.

Zener Breakdown

- Zener breakdown occurs when a sufficiently large reverse-bias is applied across a *p–n junction diode. The resulting* electric field at the junction imparts a very large force on a bound electron, enough to dislodge it from its covalent bond.
- The breaking of the covalent bonds produces a large number of EHP (electron–hole pairs). Consequently the reverse current becomes very large. This type of breakdown phenomena is known as ***Zener breakdown****.*



Energy band diagram of a Zener diode



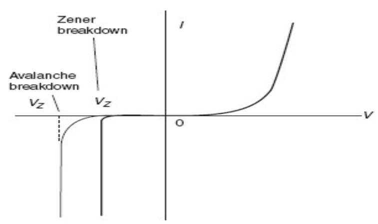
Reverse bias with electron tunnelling from *p to n leads to Zener breakdown*

When does it happen…

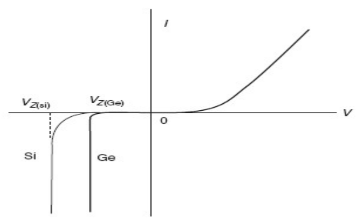
- Occurs in Si for fields ~ 106 V/cm
- Must have high impurity concentrations
- Occurs in general for reverse biases of less than 4Eg/q.

❖ Comparison between Zener and avalanche breakdown

Zener Breakdown	*Avalanche Breakdown*
1. Narrow depletion region and quantum mechanical tunneling takes place.	1. Higher Depletion region width and electron tunneling is negligible.
2. Highly doped diode with reverse-bias is required.	2. Low doped diode with reverse-bias is sufficient.
3. Operates at low voltage up to few volts reverse-bias.	3. Breakdown occurs at high reverse-bias from a few volts to thousands of volts.
4. Impact ionization does not occur in this case.	4. This breakdown mechanism involves the impact ionization of host atoms by energetic carriers.



The I–V characteristics comparison between Zener and avalanche breakdown

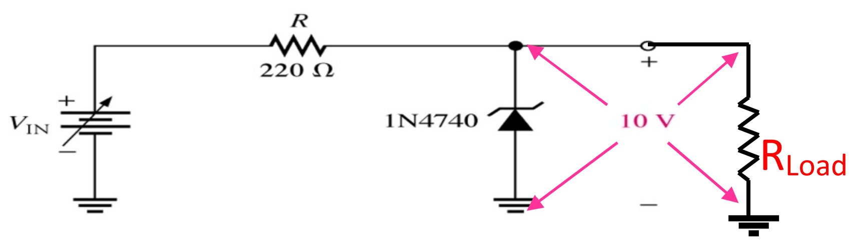


Comparison of Zener breakdown of Ge and Si semiconductor diodes with respect to I–V curve

Introduction

The basic function of **Zener diode** is to maintain a specific voltage across its terminals within given limits of line or load change.

Typically it is used for providing a stable reference voltage for use in power supplies and other equipments.

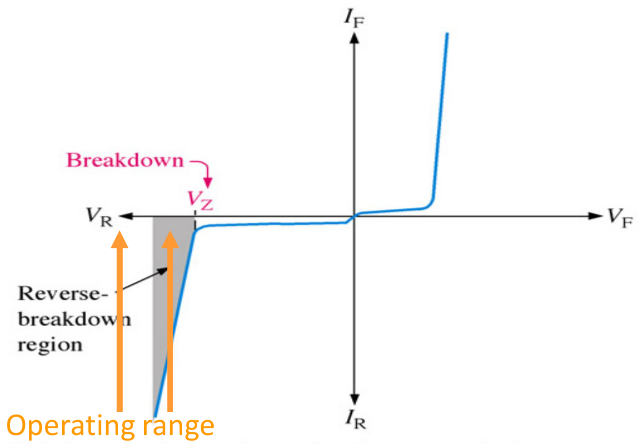


This particular Zener circuit will work to maintain 10volts across the load.

Zener Diode – Operating Range

A **Zener diode** is much like a normal diode (rectifier diode) when connected in forward bias, the exception being is that; it is placed in the circuit in **reverse bias** and **operates in reverse break-down region**.

This typical characteristic curve illustrates the operating range for a Zener diode. Note that its forward characteristics are same like a normal diode.



(b) The normal operating region for a zener diode is shaded.

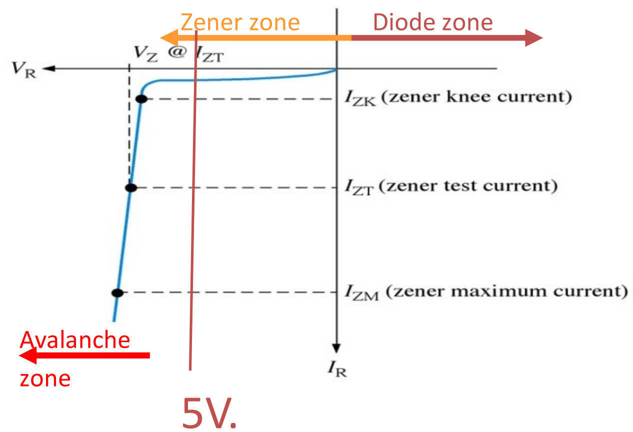
Zener Diodes – Regulation Ranges

The Zener diode's breakdown characteristics are determined by the doping process.

Low voltage Zeners (< 5V), operate in the Zener breakdown range.

Those diodes which are designed to operate (> 5V) operate mostly in avalanche breakdown range.

Zeners are available with voltage breakdowns of ***1.8V to 200V***.



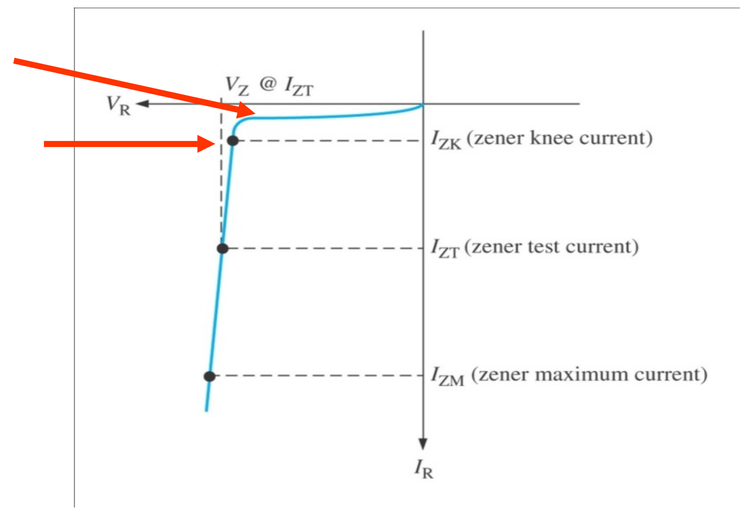
This curve illustrates the minimum and maximum ranges of current operation that the Zener can effectively maintain its voltage.

Zener Diode – Breakdown Characteristics

Note very small reverse current (before "knee").

Breakdown occurs @ knee.
Breakdown Characteristics:
V_Z remains near constant
V_Z provides:
- Reference Voltage
- Voltage Regulation

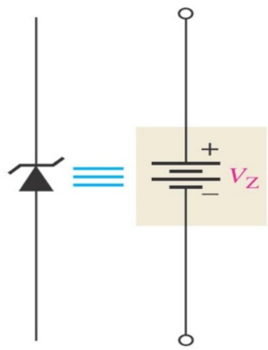
I_Z increases rapidly
$I_{Z_{MAX}}$ is achieved quickly
Exceeding $I_{Z_{MAX}}$ is fatal



Zener Diode – Equivalent Circuit

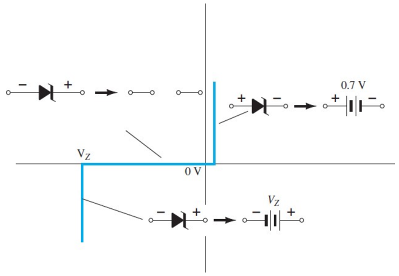
Ideal Zener exhibits a constant voltage, regardless of current draw.

Ideal Zener exhibits No Resistance characteristics.



(a) Ideal

- The Zener diode has three regions of operations. Each region has it own approximation model.
- It can be used as a part of protection circuit or as a voltage regulator.
- The use of the Zener diode as a regulator is so common that three conditions surrounding the analysis of the basic Zener regulator are considered:
  1. Fixed load and fixed supply voltage.
  2. Fixed supply voltage and variable load.
  3. Variable supply voltage and fixed load.
- The first case is already studied in the previous semester and will briefly reviewed.



Zener diode characteristics

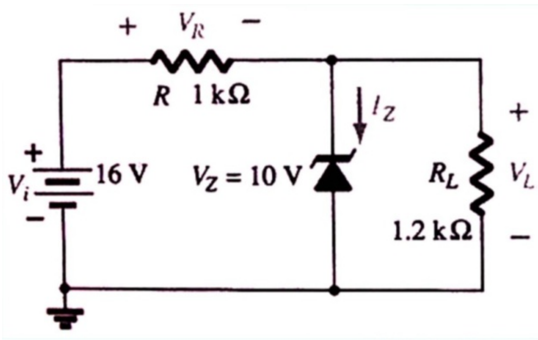
Fixed V_i, Fixed R_L:

Example

Example

For the Zener diode regulator,

1. Determine V_L , V_R , I_Z and P_Z.
2. If the load is changed to $R_L = 3\ k\Omega$, repeat the above problem.



Example

Fixed V_i, Fixed R_L:

Solution:

1. Determine the voltage across the Zener diode to determine its state:

$$V_{zener} = V_L = \frac{V_i \, R_L}{R_L + R} = 16\frac{1.2}{1 + 1.2} = 8.73 \ V$$

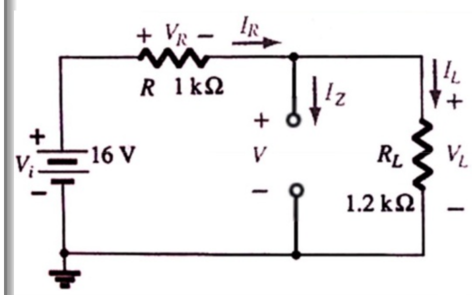
Since the voltage across the Zener is smaller than V_Z and the diode is reverse, then the Zener is OFF.

$$V_L = V_{zener} = 8.73 \ V$$

$$V_R = V_i - V_L = 16 - 8.73 = 7.27 \ V$$

$$I_Z = 0$$

$$P_Z = 0 \text{ Watts}$$



Example

Fixed V_i, Fixed R_L:

Solution:

2 If $R_L = 3\ k\Omega$:

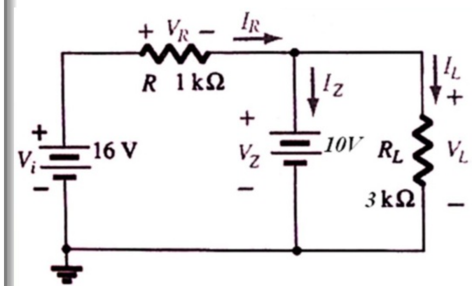
$$V_{zener} = V_i \frac{R_L}{R + R_L} = \frac{16 \times 3}{1 + 3} = 12\ V$$

Since the voltage across the zener is greater than V_Z then the zener is operating in the zener region and can be approximated as battery with V_Z :

$$V_L = V_Z = 10V$$

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

$$I_R = \frac{V_R}{R} = \frac{6V}{1\ k\Omega} = 6mA$$



Example

Fixed V_i, Fixed R_L:

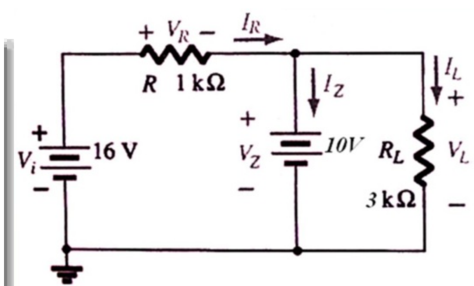
Solution:

$$I_L = \frac{V_L}{R_L} = \frac{10V}{3k\Omega} = 3.33\ mA$$

$$I_Z = I_R - I_L = 6 - 3.33 = 2.67\ mA$$

The power dissipated by the Zener diode is:

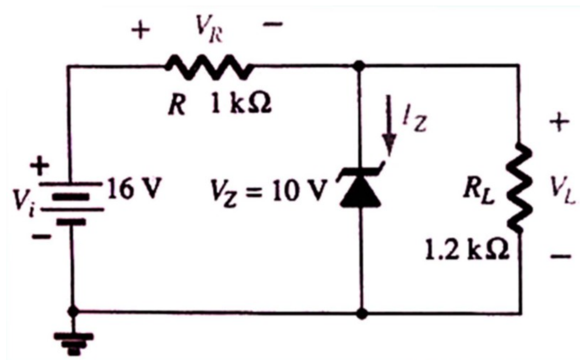
$$P_Z = I_Z \times V_Z = 26.7\ mW$$



Example

Fixed V_i, Variable R_L:

- The load resistance R_L determines the state of the Zener (on or off).
- Too small a R_L will result in a voltage V_L across the load resistor less than V_Z, and the Zener device will be in the "off" state.
- We need to find the range of load resistance that ensure the on state for the zener diode



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

Fixed V_i, Variable R_L:

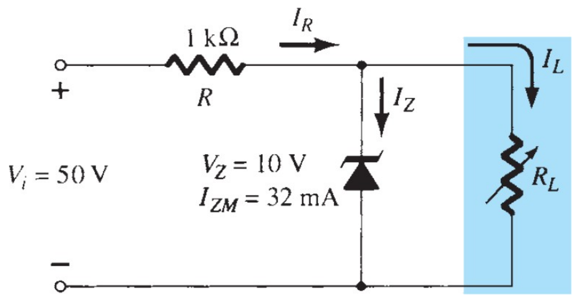
To determine the minimum load resistance, R_{Lmin}:
It is the resistance that will result in a lad voltage $V_L = V_Z$:

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

$$R_{Lmin} = \frac{R\,V_Z}{V_i - V_Z}$$

So, if a load resistance is grater than R_{Lmin} then the Zener will be on and:

$$I_{Lmax} = \frac{V_L}{R_L} = \frac{V_Z}{R_{Lmin}}$$



Fixed V_i, Variable R_L:

To determine the maximum load resistance, R_{Lmax}:

Once the diode is ON, the voltage across R is fixed at:

$$V_R = V_i - V_Z$$

and,

$$I_R = \frac{V_R}{R}$$

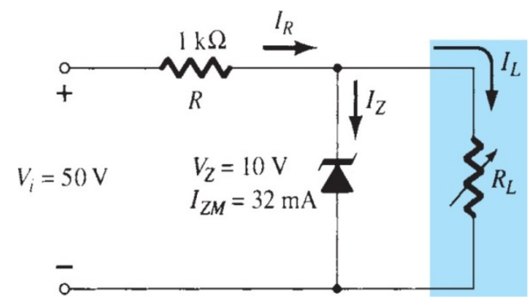
The Zener current is:

$$I_Z = I_R - I_L$$

I_Z is limited to the maximum zener current I_{ZM} from the data sheet.

$$I_{Lmin} = I_R - I_{ZM}$$

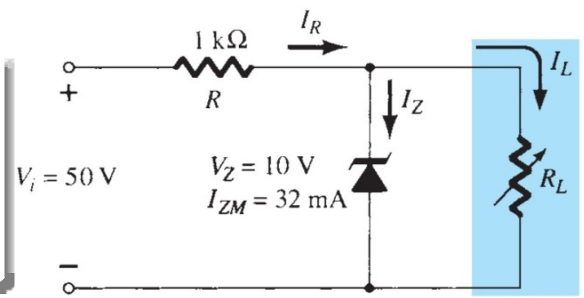
$$R_{Lmax} = \frac{V_Z}{I_{Lmin}}$$



Fixed V_i, Variable R_L:

Example:

1. For the shown network, determine the range of R_L and I_L that will result in V_L being maintained at 10 V.
2. Determine the maximum wattage rating of the diode.



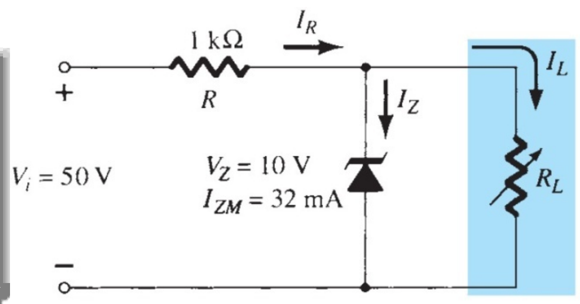
Fixed V_i, Variable R_L:

Solution:

$$R_{Lmin} = \frac{R\ V_Z}{V_i - V_Z} = \frac{1\ k\Omega\ 10V}{50V - 10V}$$

$$R_{Lmin} = 250\ \Omega$$

$$I_{Lmax} = \frac{V_L}{R_L} = \frac{V_Z}{R_{Lmin}} = \frac{10}{250} = 40mA$$



Fixed V_i, Variable R_L:

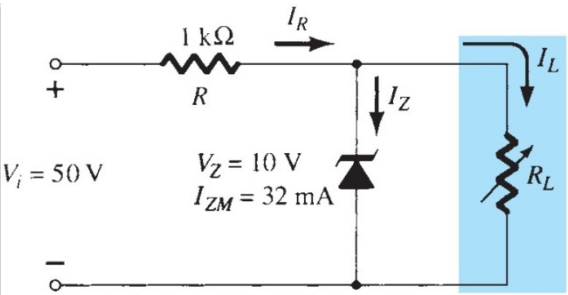
Solution:

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

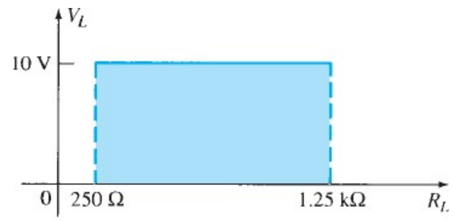
$$I_R = \frac{V_R}{R} = \frac{40V}{1\ k\Omega} = 40mA$$

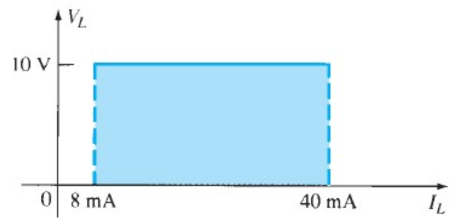
$$I_{Lmin} = I_R - I_{ZM} = 40 - 32 = 8mA$$

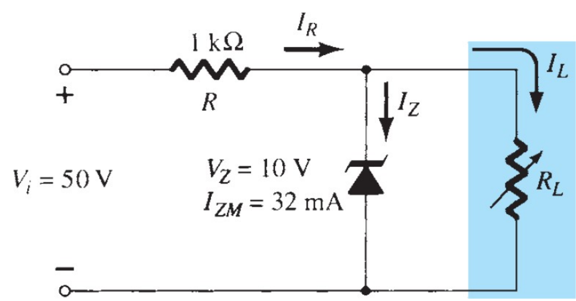
$$R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{10\ V}{8\ mA}$$



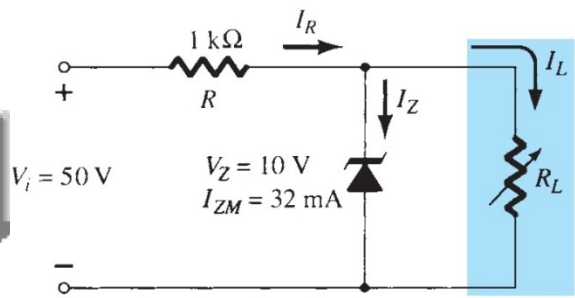
Fixed V_i, Variable R_L:







Fixed V_i, Variable R_L:



Solution:

$P_{Zmax} = V_Z\ I_{ZM} = (10\ V)(32\ mA) = 320mW$