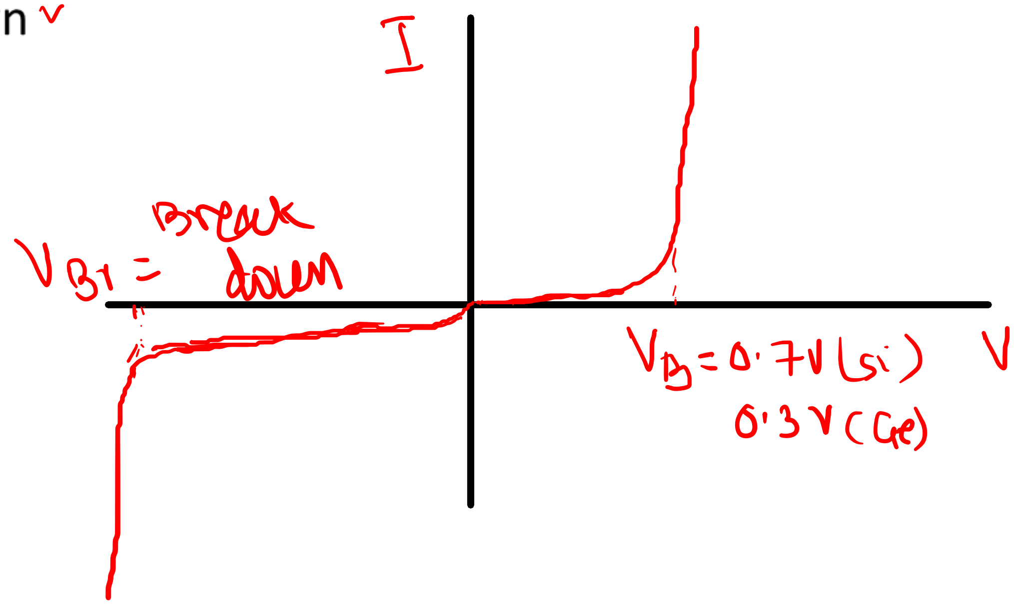
BREAK DOWN Mechanisms In PN Junction

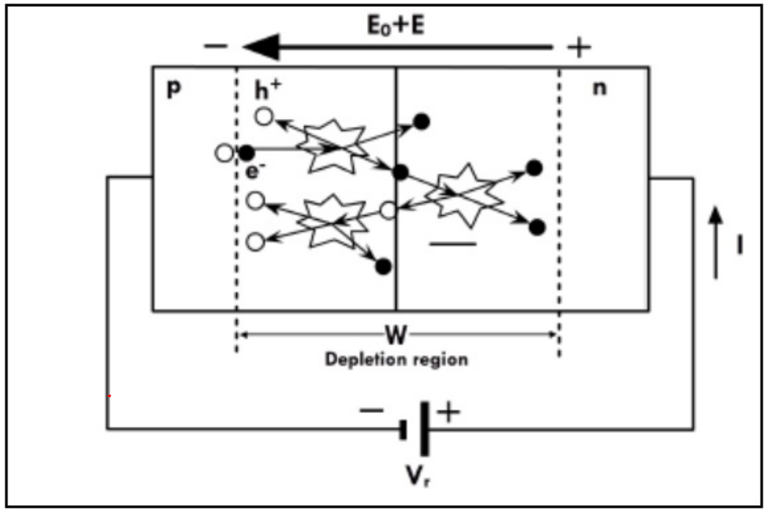
- Reverse bias voltage, at which the breakdown of a P-N junction diode occurs is called the *breakdown voltage.*

- The breakdown voltage depends on the width of the depletion region, which, in turn, depends on the doping level.

- There are two mechanisms by which breakdown can occur at a reverse biased P-N junction
  1. avalanche break down
  2. Zener breakdown.



Avalanche breakdown



- Avalanche breakdown occurs in moderately and lightly doped PN junctions with a wide depletion region.

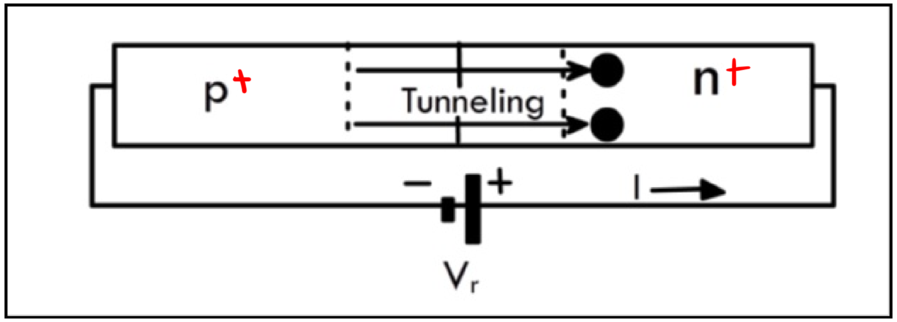
- Electron hole pairs thermally generated in the depletion region are accelerated by the external reverse bias. Electrons are accelerated towards the n side and holes towards the p side.

- These electron can interact with other Si atoms and if they have sufficient energy can knock out electrons from these Si atoms. This process is called impact ionization and leads to production of a large number of electrons.

- This causes the rapid rise in current. The breakdown voltage decreases with increase in dopant concentration.

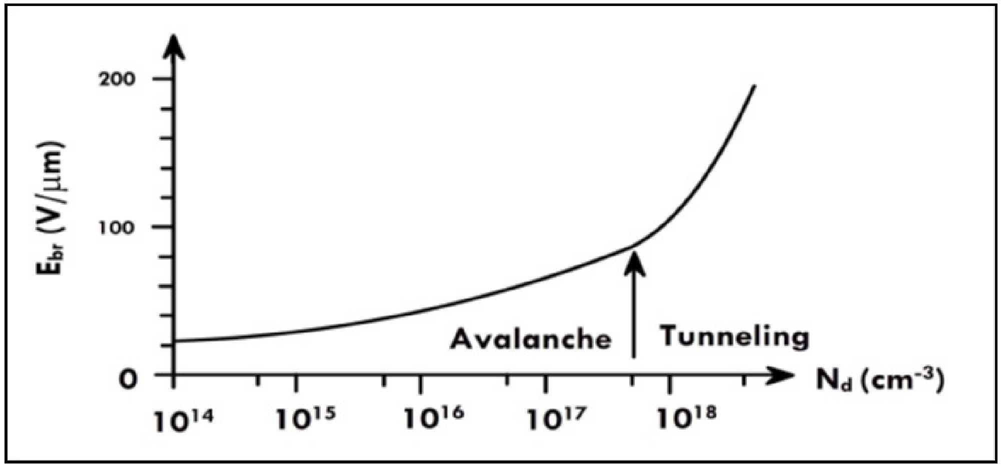
- The breakdown region is the knee of the characteristic curve. After breakdown the current is not controlled by the junction voltage but rather by the external circuit.

Zener breakdown

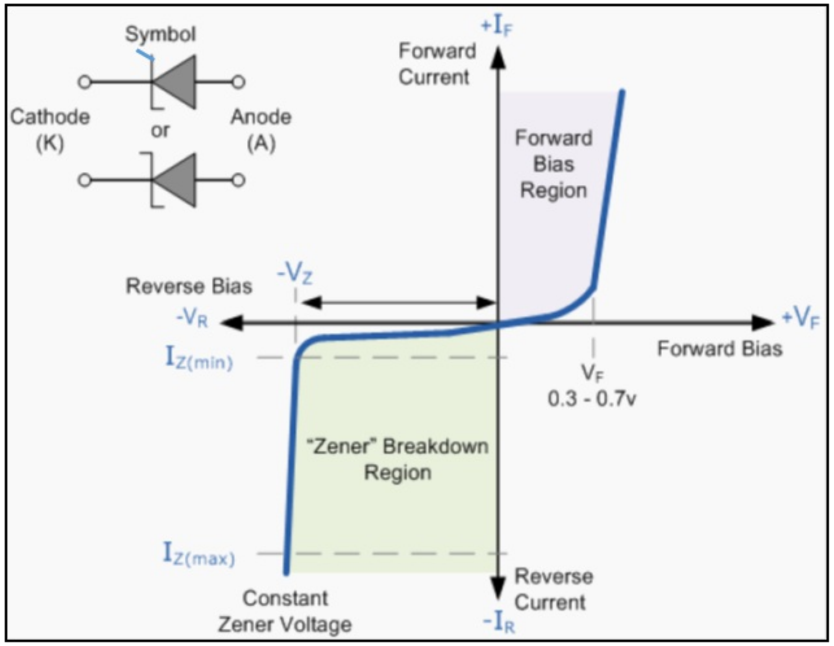


- With increase in doping concentration the breakdown mechanism, changes from Avalanche to a tunnelling mechanism. This is called a Zener breakdown.

- The depletion width decreases with dopant concentration.
- It is possible for carriers to tunnel across the narrow depletion region.
- The electrons tunnel from the valence band on the p side to the conduction band on the n side, driven by the externally applied reverse bias. Tunnelling also leads to a large increase in current.
- The transition from avalanche to Zener as the primary breakdown mechanism with dopant concentration is shown.



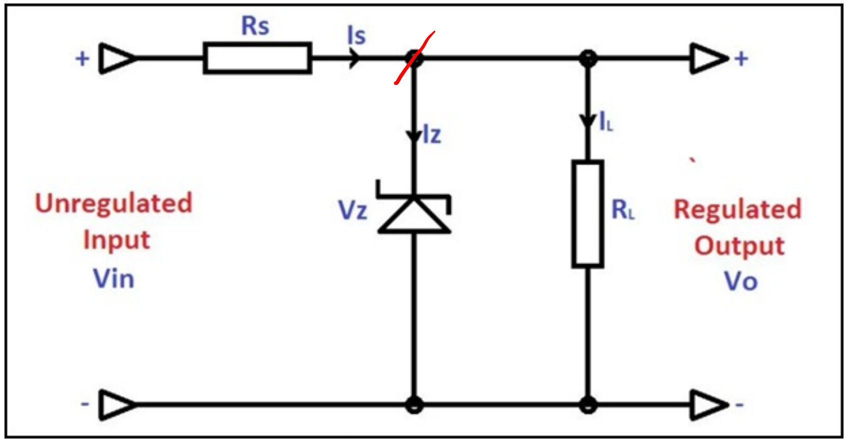
Zener Diode



- The Zener diode is like a general-purpose signal diode consisting of a silicon PN junction. When biased in the forward direction it behaves just like a normal signal diode passing the rated current.
- A reverse voltage applied across the Zener diode exceeds the rated voltage of the device, the diodes breakdown and high current flows through diode.

- Zener diodes are primarily used as surge protectors in circuits, since there is a rapid increase in current with a small change in voltage. Prior to breakdown there is a high resistance small reverse saturation current but after breakdown the resistance is very small.
- Zener diode is used as voltage regulators in circuits.

Zener Diode as Voltage Regulator

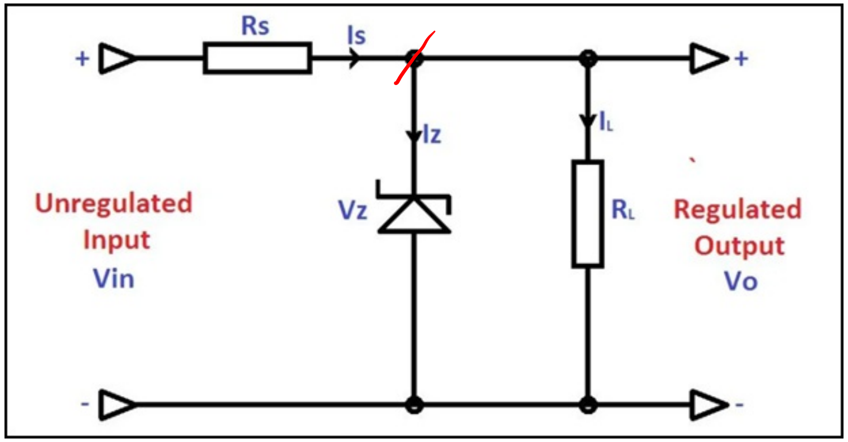


- Zener Diodes are widely used as Shunt Voltage Regulators to regulate voltage across small loads.
- Zener Diodes have a sharp reverse breakdown voltage and breakdown voltage will be constant for a wide rang of currents. Thus Zener diode parallel to the load such that the applied voltage will reverse bias it.

- If the reverse bias voltage across the Zener diode exceeds the knee voltage, the voltage across the load will be constant.

- The value of Rs must be small enough to keep the Zener Diode in reverse breakdown region. The minimum current required for a Zener Diode to keep it in reverse breakdown region will be given in its datasheet. For example, a 5.6 V, 0.5 W Zener diode has a recommended reverse current of 5 mA. If the reverse current is less than this value, the output voltage Vo will be unregulated.
- The value of Rs must be large enough that the current through the zener diode should not destroy it. That is the maximum power dissipation Pmax should be less than IzVz.

Zener Diode as Voltage Regulator



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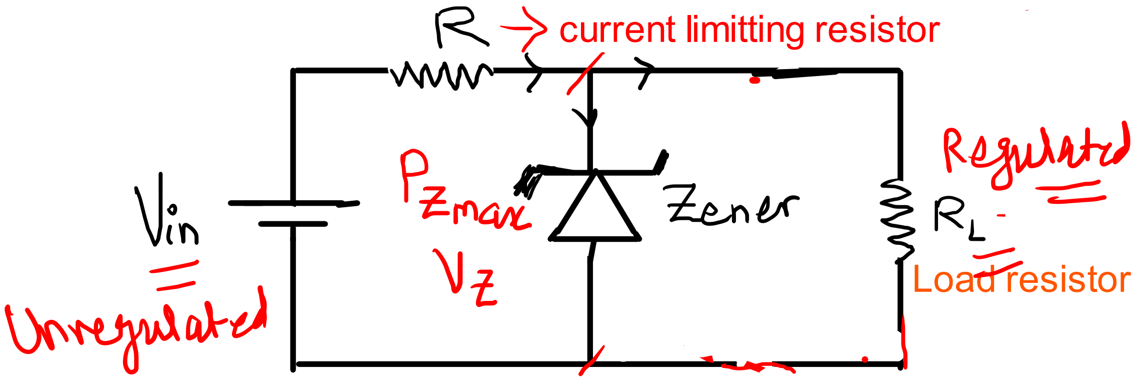
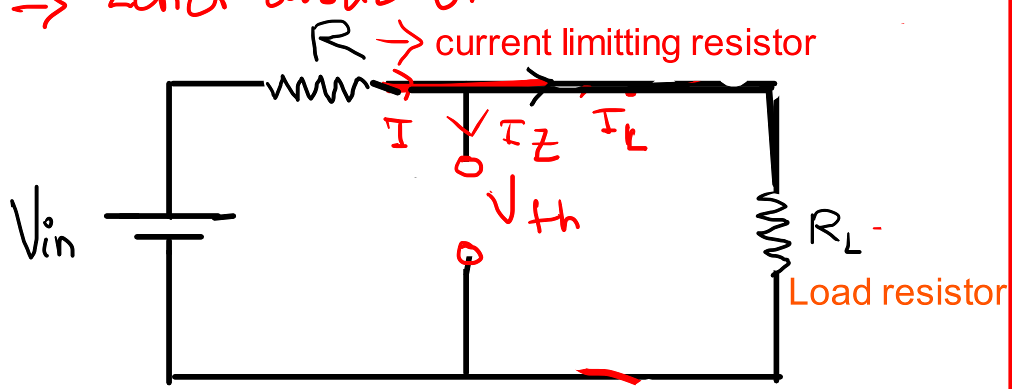
Zener diode as voltage regulator

1. If input voltage Vin and RL are constant



⇒ Zener diode OFF $|V_Z$



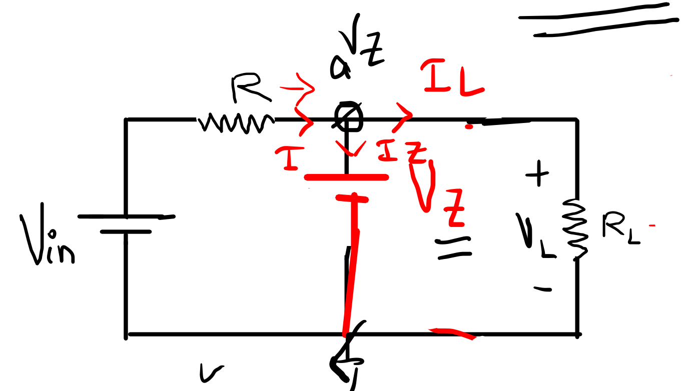
$$V_{th} = \frac{R_L \times V_{in}}{R + R_L}$$

$$|V_{th}| < V_Z$$

$$I_Z = 0$$

$$I = I_L = \frac{V_{in}}{R + R_L}$$

→ Zener ON ✓ $|V_{th}| > V_Z$



$$I = I_L + I_Z$$

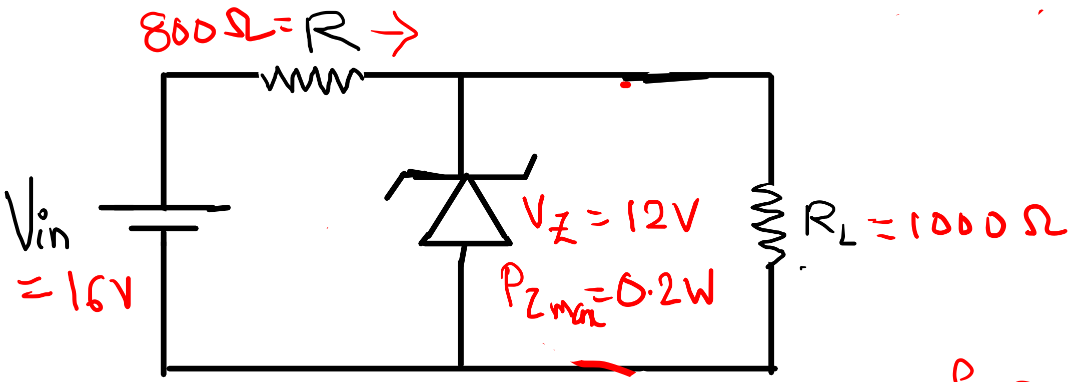
$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$$

$$I = \frac{V_{in} - V_Z}{R}$$

$$\boxed{I_Z = I - I_L}$$

Zener diode as voltage regulator

numerical 1. If input voltage Vin and RL are constant



Zener off

$$V_{th} = \frac{R_L \times V_{in}}{R + R_L}$$

Zener on

$$V_{th} = V_Z$$

$$\Rightarrow V_{th} = \frac{16 \times 1000}{800 + 1000}$$

$$V_{th} = \frac{16000}{1800} = 8.8V$$

$$|V_{th}| < (V_Z = 12)$$

So zener off

$$I_Z = 0, \quad I = I_L = \frac{16}{1800}$$

$$I_L = 8.8mA$$

So for $V_{th} \geq V_Z$ to ensure Zener breakdown

to find R

$$12 = \frac{1000 \times 16}{R + 1000} \qquad V_{th} = \frac{R_L \times V_{in}}{R + R_L}$$

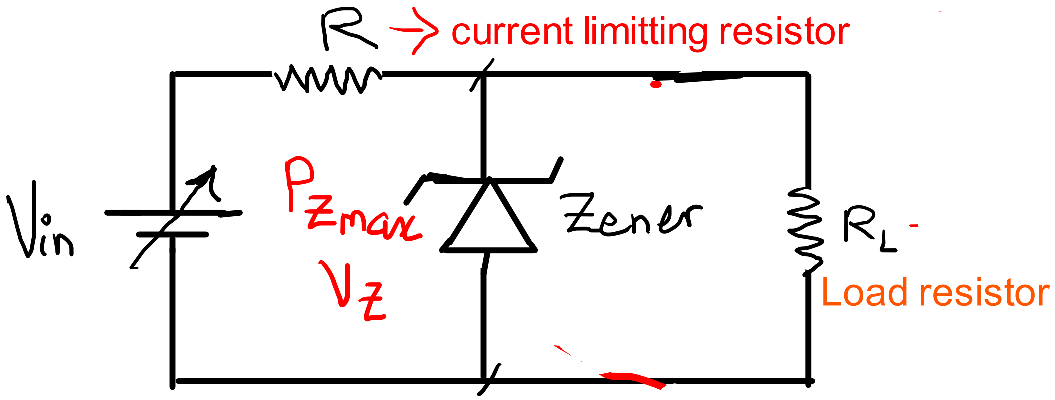
So

$$R \simeq 333\,\Omega$$

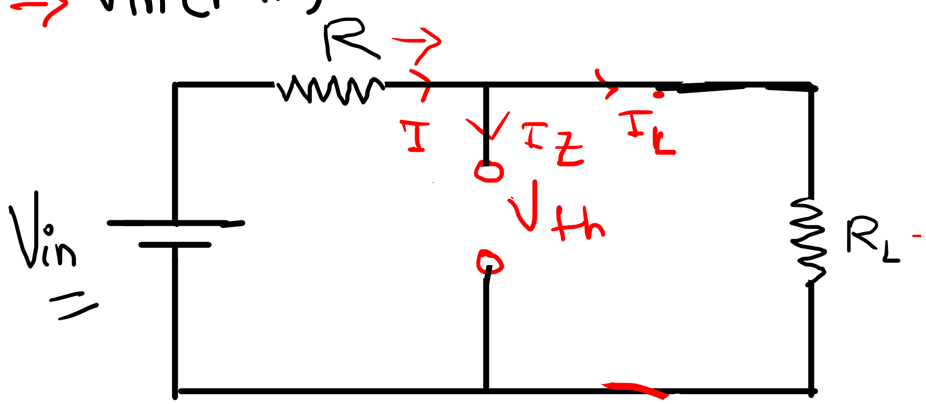
$$V_L = 12V$$

Zener diode as voltage regulator

2. If input voltage Vin variable and RL is constant



⇒ $V_{in}(min) = ?$

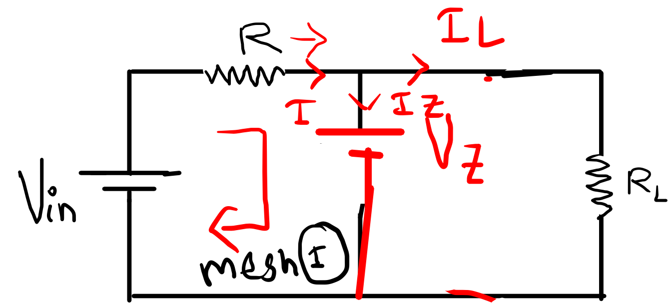


$$V_{th} = \frac{R_L \times V_{in}}{R + R_L}$$

$$|V_{th}| \geq V_Z$$

$$V_{in}(min) = \frac{(R + R_L) \times V_Z}{R_L}$$

→ $V_{in}(max) = ?$



Maximum current through Zener diode will Limit

$$I = I_Z + I_L$$

$$I = I_{Zmax} + I_L \quad \text{---} \; (1)$$

$$I_{Zmax} = \frac{P_{Zmax}}{V_Z} \quad \& \quad I_L = \frac{V_Z}{R_L}$$

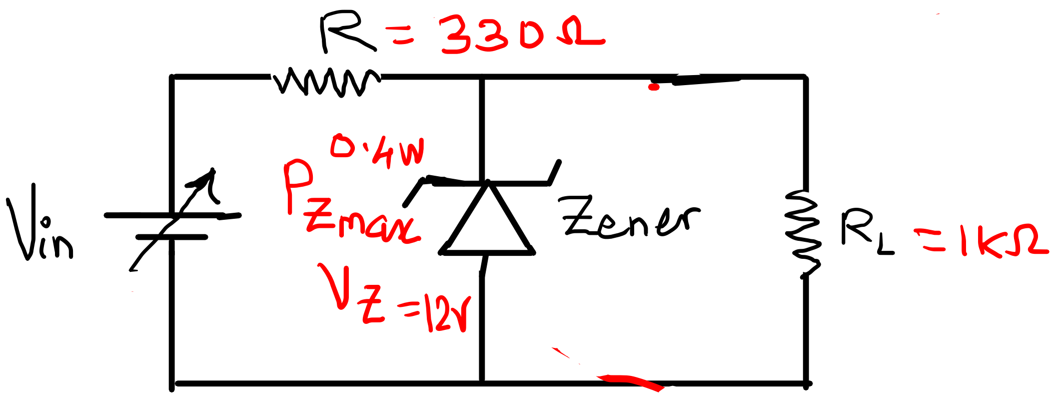
KVL to mesh I

$$V_{in}(max) - IR - V_Z = 0$$

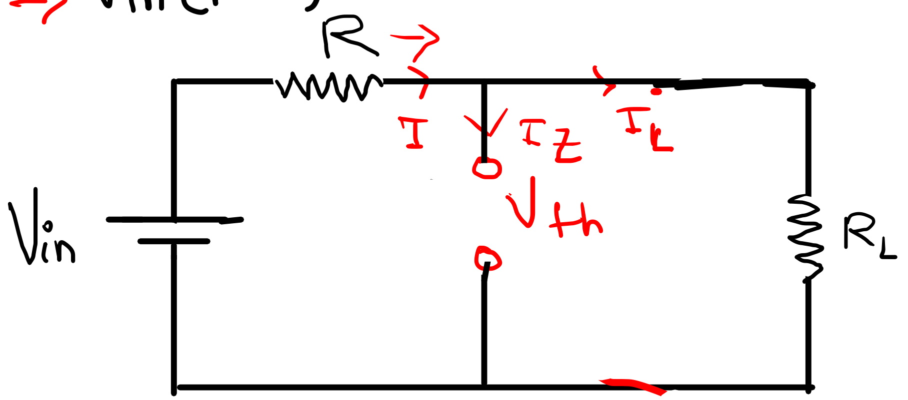
$$\boxed{V_{in}(max) = IR + V_Z}$$

Zener diode as voltage regulator

Numerical 2. If input voltage Vin variable and RL is constant



$\Rightarrow V_{in(min)} = ?$



$$V_{th} = \frac{R_L \times V_{in}}{R + R_L}$$

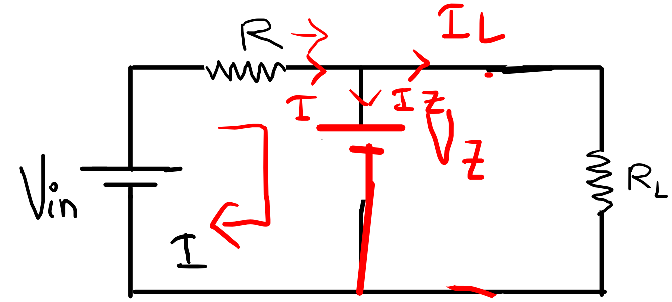
$$|V_{th}| \geq V_Z$$

$$V_{in(min)} = \frac{(R+R_L) \times V_Z}{R_L}$$

$$V_{in(min)} = \frac{(330+1000) \times 12}{1000}$$

so $\boxed{V_{in(min)} = 15.6V}$

$\Rightarrow V_{in(max)} = ?$



$$I_{Zmax} = \frac{P_{Zmax}}{V_Z} = \frac{0.4}{12} = 33.3mA$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{12}{1000} = 12mA$$

$$I = I_{Zmax} + I_L = 45.3mA$$

KVL to mesh (I)

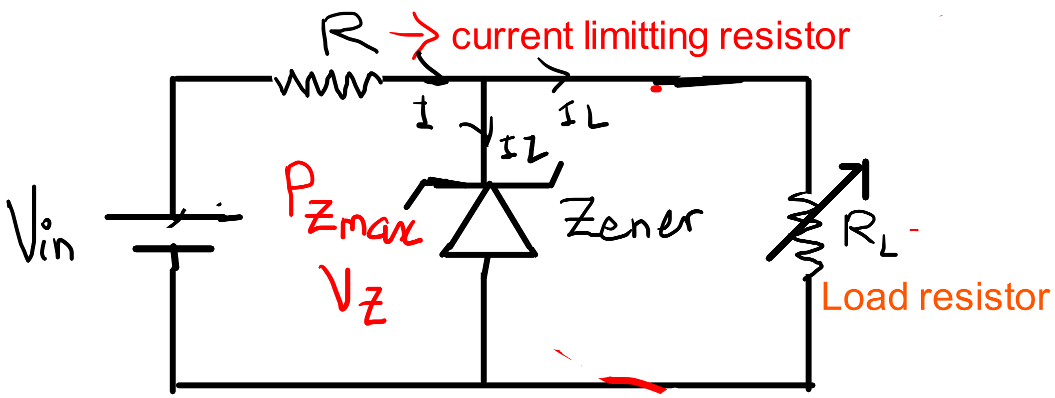
$$V_{in(max)} = I \cdot R + V_Z$$

$$V_{in(max)} = (45.3 \times 330) + 12$$

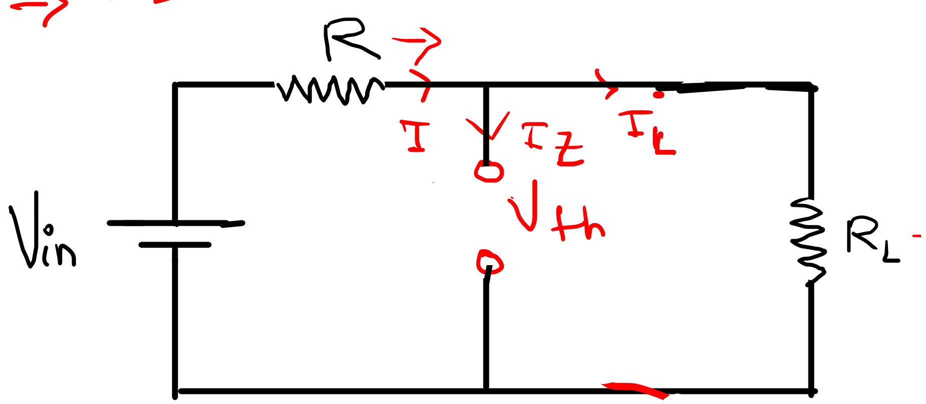
$\boxed{V_{in(max)} = 26.9V}$

Zener diode as voltage regulator

3. If input voltage Vin fixed and RL variable



$\Rightarrow R_L(min) = ?$



$$V_Z = \frac{R_L \times V_{in}}{R + R_L}$$

$$|V_{th}| \geq V_Z$$

$$V_Z R + V_Z R_L = R_L V_{in}$$

$$V_Z R = R_L (V_{in} - V_Z)$$

$$R_L(min) = \frac{V_Z \times R}{(V_{in} - V_Z)}$$

$\Rightarrow R_L(max) = ?$

$$P_{Z\,max} = V_Z \cdot I_{Z\,max}$$

$$I_{Z\,max} = \frac{P_{Z\,max}}{V_Z}$$

$$I = I_{Z\,max} + I_{L\,min}$$

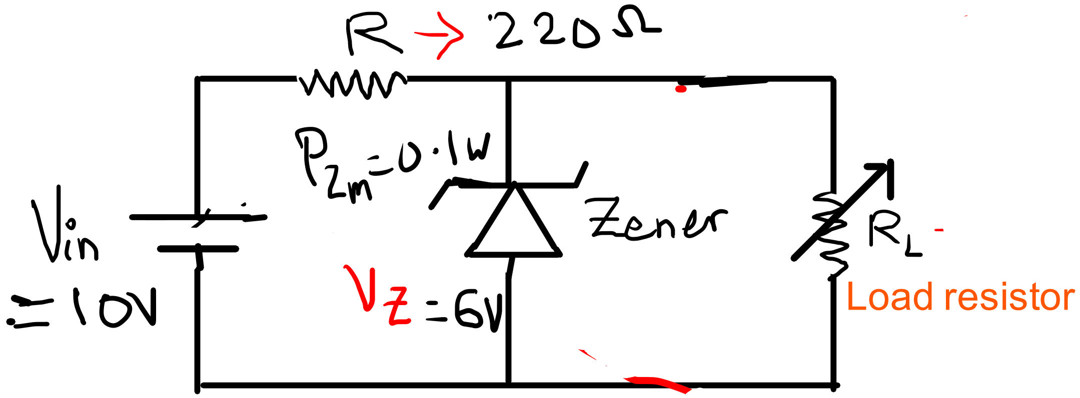
$$I_{L\,min} = I - I_{Z\,max}$$

$$I_{L(min)} = \frac{V_{in} - V_Z}{R} - \frac{P_{Z\,max}}{V_Z}$$

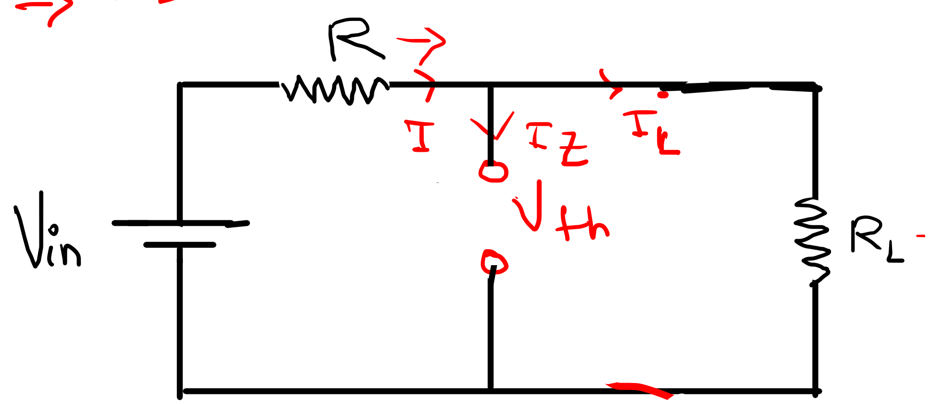
$$R_{L(max)} = \frac{V_Z}{I_{L\,min}}$$

Zener diode as voltage regulator

Example 3. If input voltage Vin fixed and RL variable



$\Rightarrow R_L(min) = ?$



$$R_L(min) = \frac{R V_Z}{(V_{in} - V_Z)} = \frac{220 \times 6}{10 - 6} = \underline{\underline{330\,\Omega}}$$

$\Rightarrow R_L(max) = ?$

$$P_{Zmax} = V_Z \cdot I_{Zmax}$$

$$I_{Zmax} = \frac{P_{Zmax}}{V_Z}$$

$$I = I_{Zmax} + I_{Lmin}$$

$$I_{Lmin} = I - I_{Zmax}$$

$$I_{L(min)} = \frac{V_{in} - V_Z}{R} - \frac{P_{Zmax}}{V_Z}$$

$$I_L(min) = \frac{10 - 6}{220} - \frac{0.1}{6} = \underline{1.51\,mA}$$

$$R_{L(max)} = \frac{V_Z}{I_{Lmin}}$$

$$R_L(max) = \frac{6}{1.51\,mA} \simeq \underline{3.9\,K\Omega}$$