Ministry of Higher Education
University of Al-Maarif
Medical Instruments Engineering Techniques Department

# Medical electronic systems

*For*
*Students of Third class*

## Unit ONE
## Regulated power supplied (PART 3)
## Regulation Stage

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# The Regulator

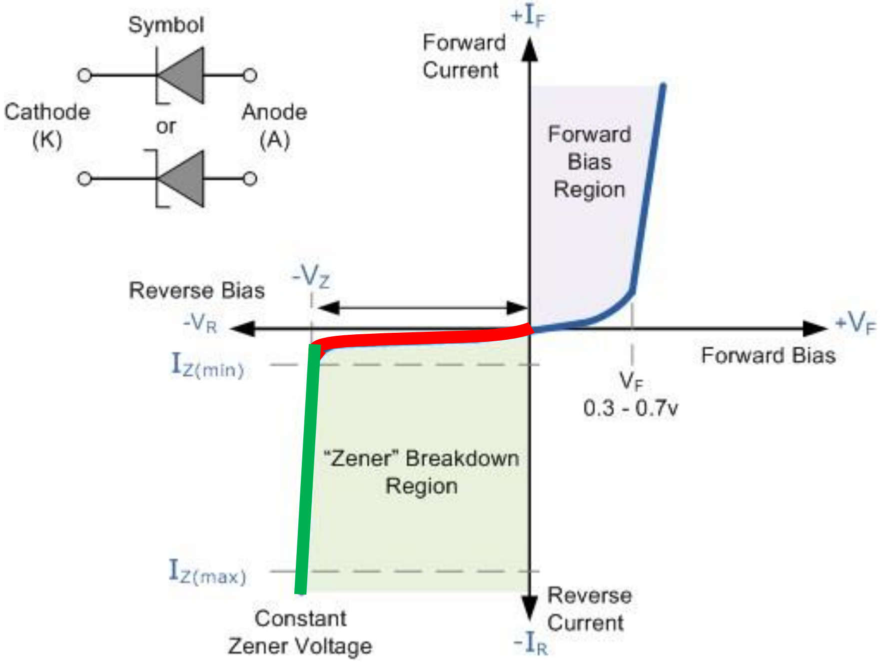
## Zener Diode Regulator

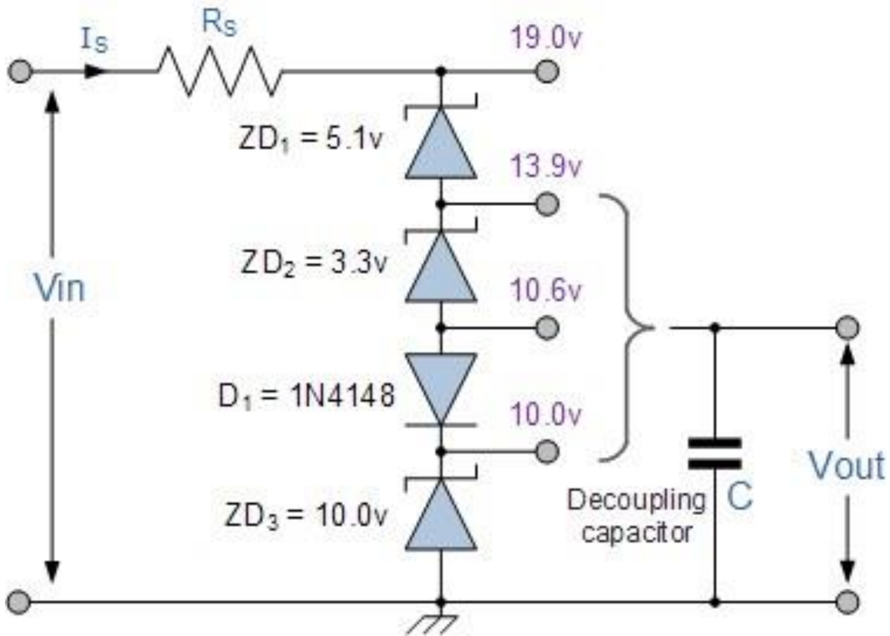
- **A Zener diode** allows current in the forward direction like a **regular diode**

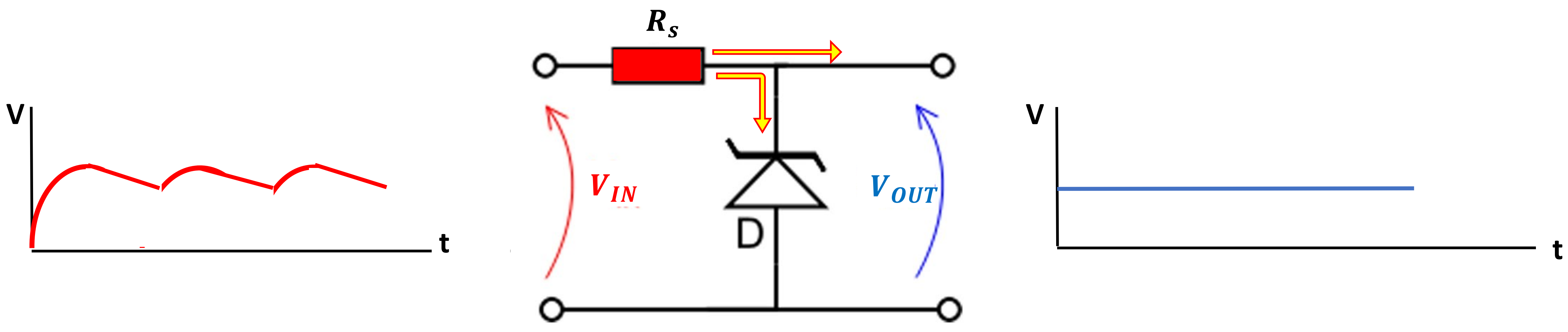
- but also **conducts in reverse** when the voltage **exceeds** a specific **Zener breakdown voltage** (Zener voltage).

- **Common Zener diodes**: 500mW BZX55 and 1.3W BZX85, like BZX55C7V5 (7.5V).

- Zener diodes can be **series-connected** with silicon diodes for various reference voltages.



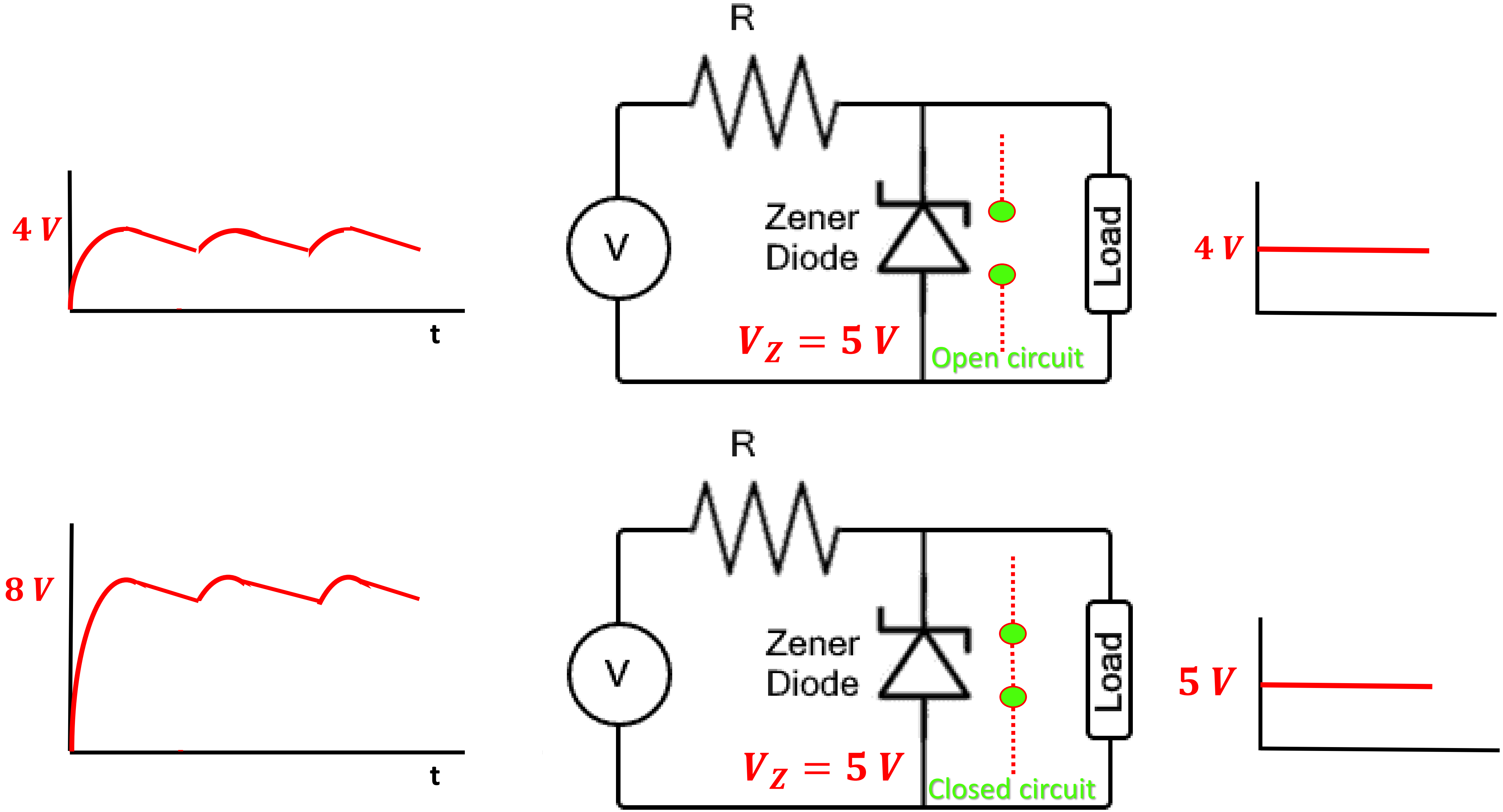



- Zener diodes provide a **stable out put voltage** with **low ripple** under varying load currents.

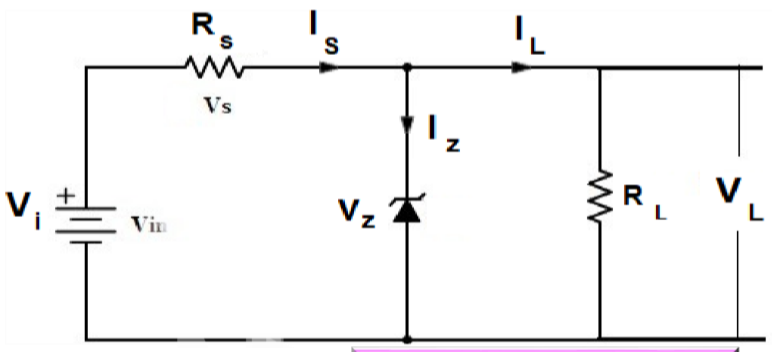
- A current-limiting resistor ($R_s$) ensures the Zener diode conducts enough current to maintain $V_{OUT}$.

- Rectifier DC output has a **ripple**; connecting a **Zener stabilizer** circuit to the rectifier generates a more **stable voltage**.

## Zener voltage $V_Z$



## Stage 1: Fixed $V_i$ and Fixed $R_L$




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

**When $V_L < V_Z$ Zener is OFF**

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

$$V_i - V_s - V_L = 0$$

$$I_S = \frac{V_S}{R_S}$$

$$I_z = 0$$

**When $V_L > V_Z$ Zener is ON**

$$V_Z = V_L$$

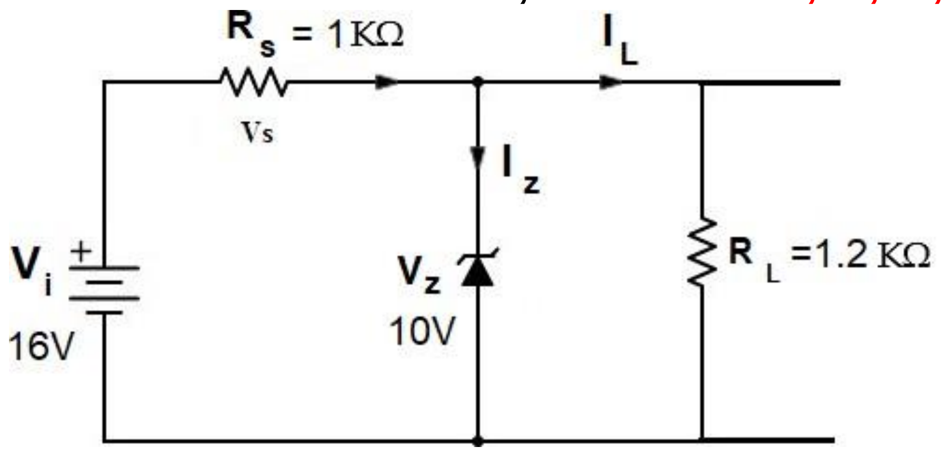
$$I_L = \frac{V_L}{R_L}$$

$$V_i - V_s - V_L = 0$$

$$I_S = \frac{V_S}{R_S}$$

$$I_Z = I_S - I_L$$

**EX:1** For the Zener circuit below, determine $V_L$, $I_L$, $V_S$, $I_s$ and $I_Z$




**Sol:**

**i**

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

$$= \frac{1.2}{1.2 + 1} * 16$$

$$V_L = 8.72\ V$$

$\because V_L(8.72V) < V_Z(10\ V)$

**Zener is oFF**

**ii**

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

$$= \frac{8.72}{1.2 * 10^3}$$

$$I_L = 7.27\ mA$$

**iii**

$$V_i - V_s - V_L = 0$$

$$16 - V_s - 8.72 = 0$$

$$V_s = 16 - 8.72$$

$$V_s = 7.27\ V$$

**IV**

$$I_S = \frac{V_S}{R_S}$$

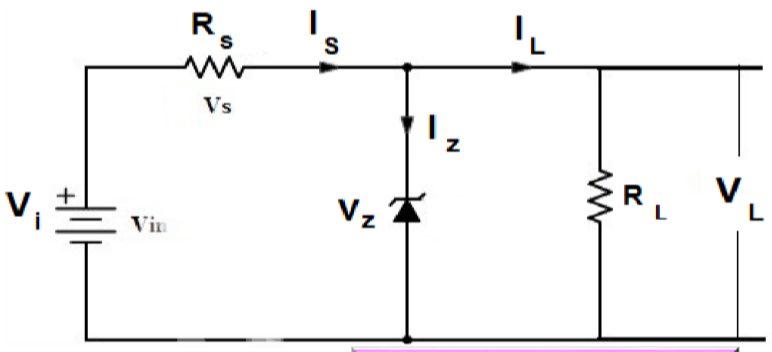
$$I_S = \frac{7.27\ V}{1\ k}$$

$$I_S = 7.27mA$$

**V**

$$I_z = 0$$

## Stage 1: Fixed $V_i$ and Fixed $R_L$




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

**When $V_L < V_Z$ Zener is OFF**

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

$$V_i - V_s - V_L = 0$$

$$I_S = \frac{V_S}{R_S}$$

$$I_Z = 0$$

**When $V_L > V_Z$ Zener is ON**

$$V_Z = V_L$$

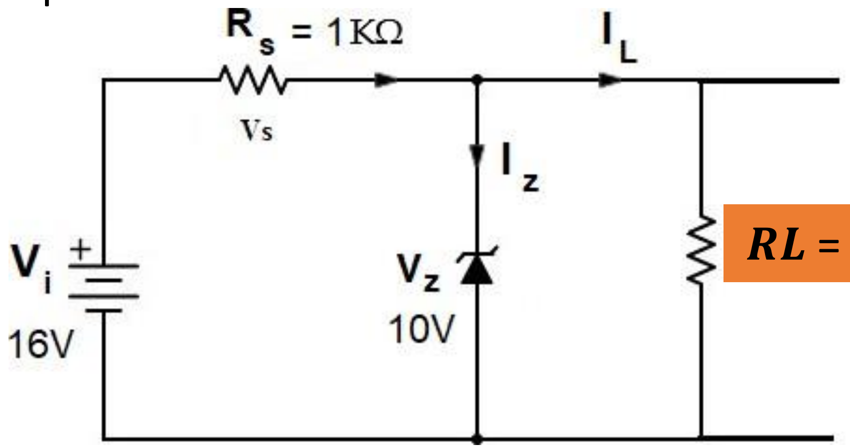
$$I_L = \frac{V_L}{R_L}$$

$$V_i - V_s - V_L = 0$$

$$I_S = \frac{V_S}{R_S}$$

$$I_S = I_Z + I_L$$

**EX:2** Repeat Ex.1 with $RL = 3\ K\Omega$




**Sol:**

i)

$$V_L = \frac{R_L}{R_L + R_S} V_i = \frac{3}{3+1} * 16$$

$$V_L = 12V$$

$\because V_L(12V) > V_Z(10V)$

**Zener is on**

$\therefore V_Z = V_L = 10V$

ii)

$$I_L = \frac{V_L}{R_L} = \frac{10}{3 * 10^3}$$

$$I_L = 3.33mA$$

iii)

$$V_i - V_s - V_L = 0$$

$$16 - V_s - 10 = 0$$

$$V_s = 16 - 10$$

$$V_s = 6V$$

IV)

$$I_S = \frac{V_S}{R_S}$$

$$I_S = \frac{6V}{1\ k}$$

$$I_S = 6mA$$

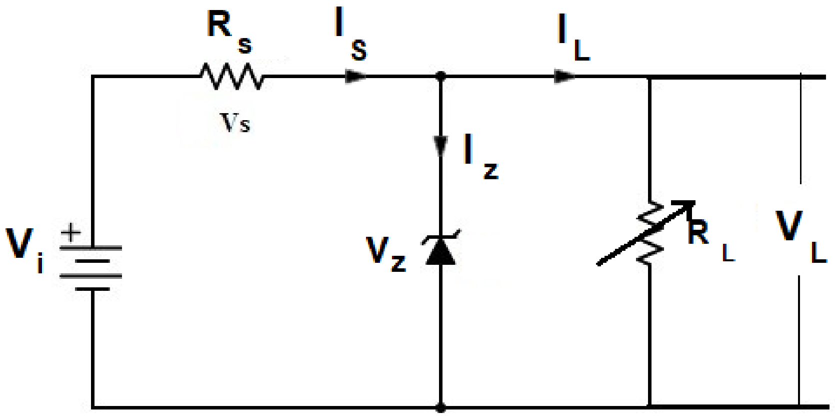
V)

$$I_S = I_Z + I_L$$

$$6 = I_Z + 3.33$$

$$I_Z = 2.67\ mA$$

## Stage 2: Fixed $Vi$ and Variable $RL$




$$R_{Lmin} = \frac{V_Z}{V_i - V_Z} R_s$$

$$V_L = V_Z$$

$$V_i - V_s - V_L = 0$$

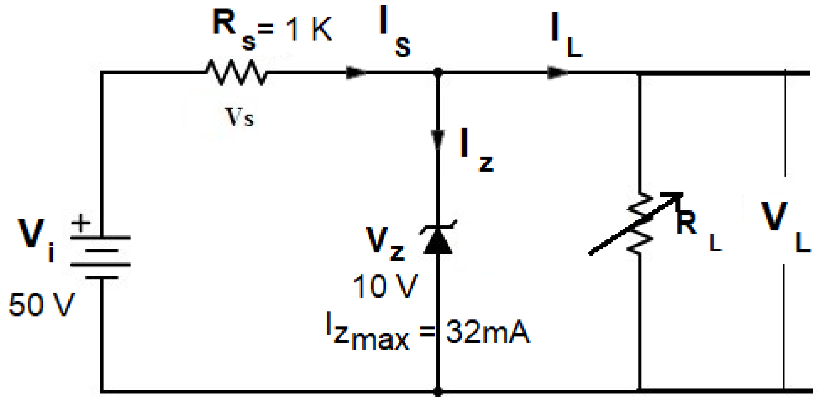
$$I_S = \frac{V_s}{R_s}$$

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

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

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

**EX:3** For the Zener circuit below, determine the range of $R_L$ and $I_L$




**Sol:**

**i**

$$R_{Lmin} = \frac{V_Z}{V_i - V_Z} R_s$$

$$= \frac{10}{50 - 10} * 1k$$

$$R_{Lmin} = 0.25\ k\Omega$$

**ii**

$$V_i - V_s - V_Z = 0$$

$$50 - V_s - 10 = 0$$

$$V_s = 40V$$

$$I_S = \frac{V_S}{R_S} \longrightarrow I_S = \frac{40}{1k}$$

$$I_S = 40\ mA$$

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

$$I_{Lmin} = 40mA - 32\ mA$$

$$I_{Lmin} = 8mA$$

**iii**

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

$$R_{Lmax} = \frac{10}{8mA}$$

$$R_{Lmax} = 1.25\ k\Omega$$

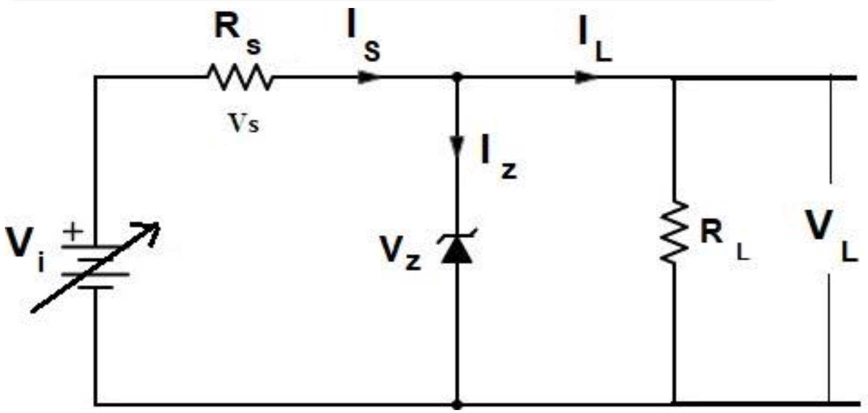
**IV**

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

$$I_{Lmax} = \frac{10}{0.25k}$$

$$I_{Lmax} = 40\ mA$$

## Stage 3: Variable $Vi$ and Fixed $RL$




$$V_{i\,min} = \frac{R_L + R_s}{R_L} V_Z$$

$$I_{S\,max} = I_{Zmax} + I_L$$

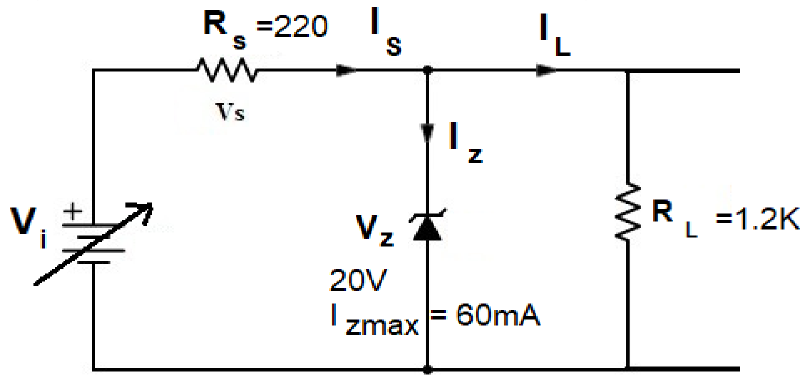
$$V_{i\,max} = I_{s\,max} R_s + V_Z$$

$$V_{smax} = I_{s\,max} R_s$$

$$I_{S\,min} = \frac{V_{i\,min} - V_Z}{R_s}$$

$$V_{s\,min} = I_{s\,min} R_s$$

**EX:4** For the Following circuit, determine the range of the input voltage and $V_s$




**Sol:**

**i**

$$V_{i\,min} = \frac{R_L + R_s}{R_L} V_Z$$

$$= \frac{1.2k + 220}{1.2k} * 20$$

$$V_{i\,min} = 23.67\ V$$

**ii**

$$I_L = \frac{V_L}{R_L} \rightarrow = \frac{20}{1.2k}$$

$$I_L = 16.6\ mA$$

$$I_{S\,max} = I_{Zmax} + I_L$$

$$I_{S\,max} = 60mA + 16.6mA$$

$$I_{S\,max} = 76.6mA$$

$$V_{i\,max} = I_{s\,max} R_s + V_Z$$

$$V_{i\,max} = (76.6mA)\ (220\Omega) + 20$$

$$V_{i\,max} = 36.86\ V$$

**iii**

$$V_{smax} = I_{s\,max} R_s$$

$$V_{smax} = (76.6mA)(220)$$

$$V_{smax} = 16.852\ V$$

**IV**

$$I_{S\,min} = \frac{V_{i\,min} - V_Z}{R_s}$$

$$= \frac{23.67 - 20}{220}$$

$$= 16.68\ mA$$

$$V_{s\,min} = I_{s\,min} R_s$$

$$V_{s\,min} = (16.68\ mA)(220\Omega)$$

$$V_{s\,min} = 3.67\ V$$