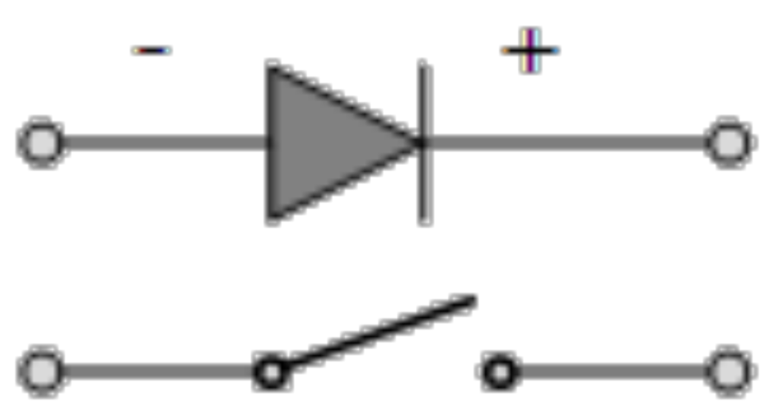
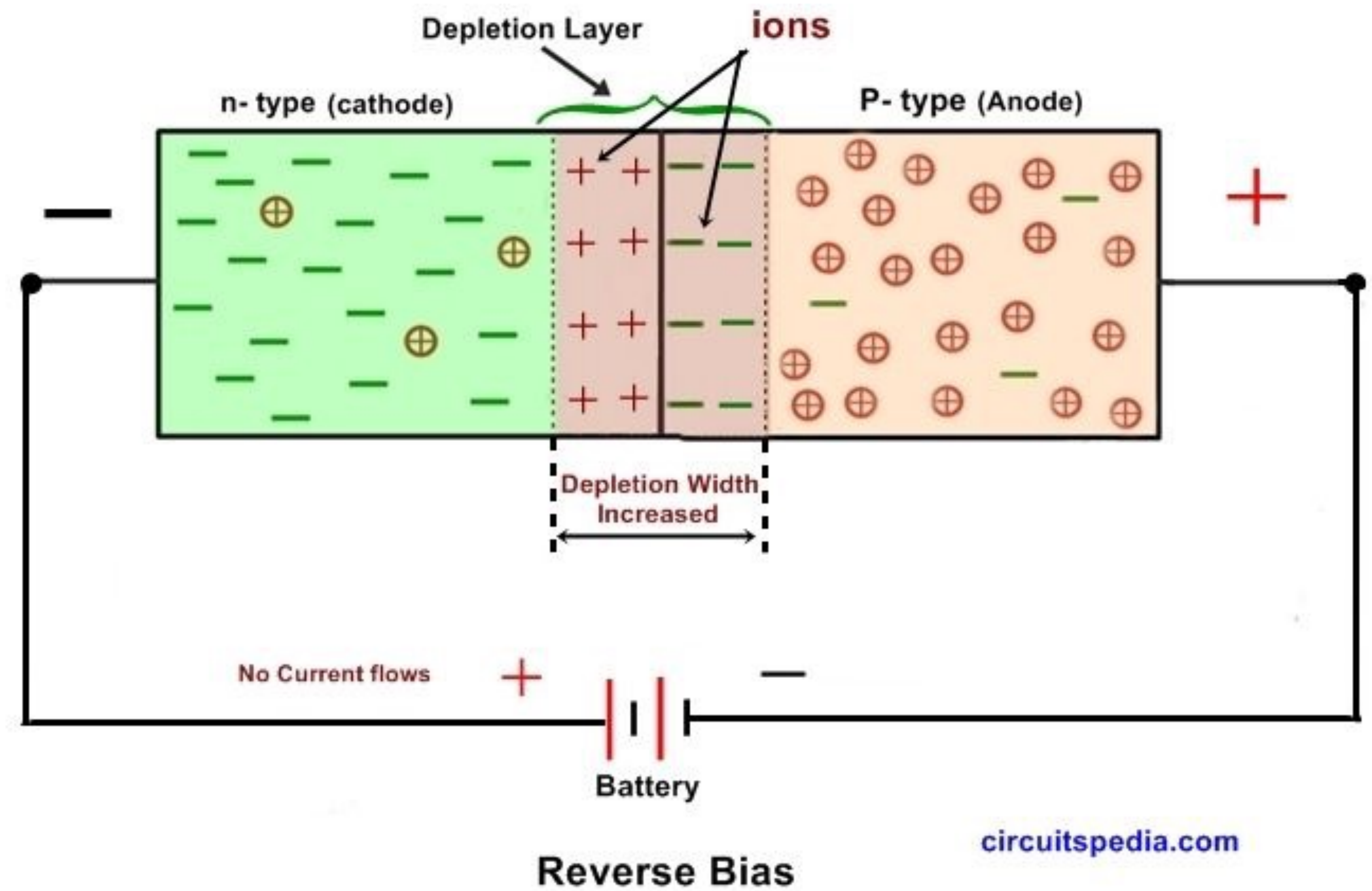
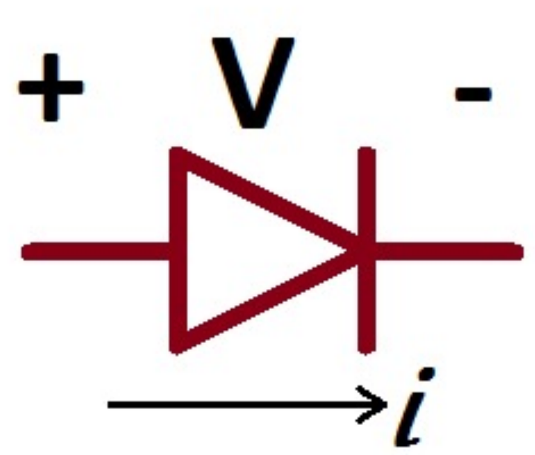
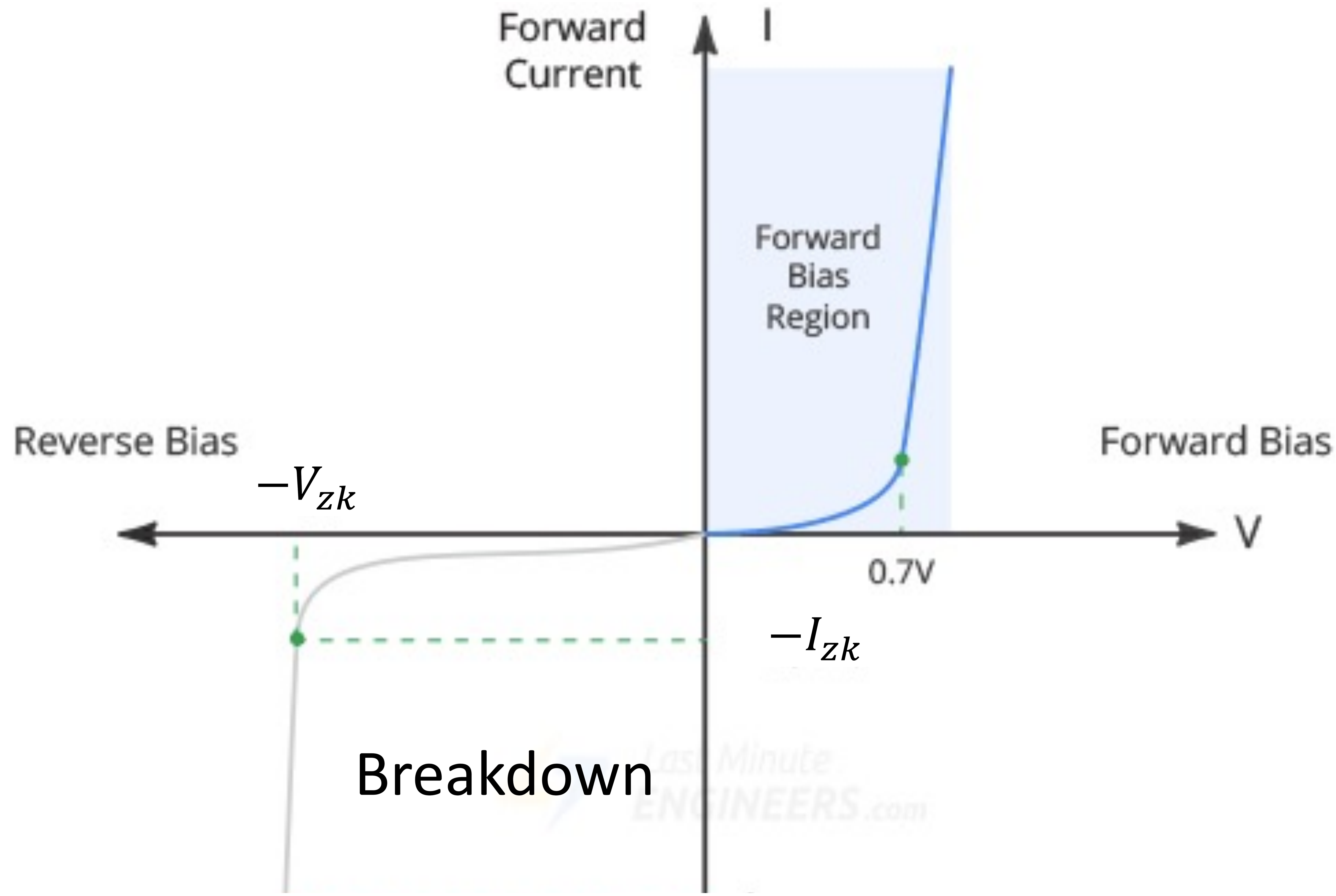
Diode in Reverse Bias



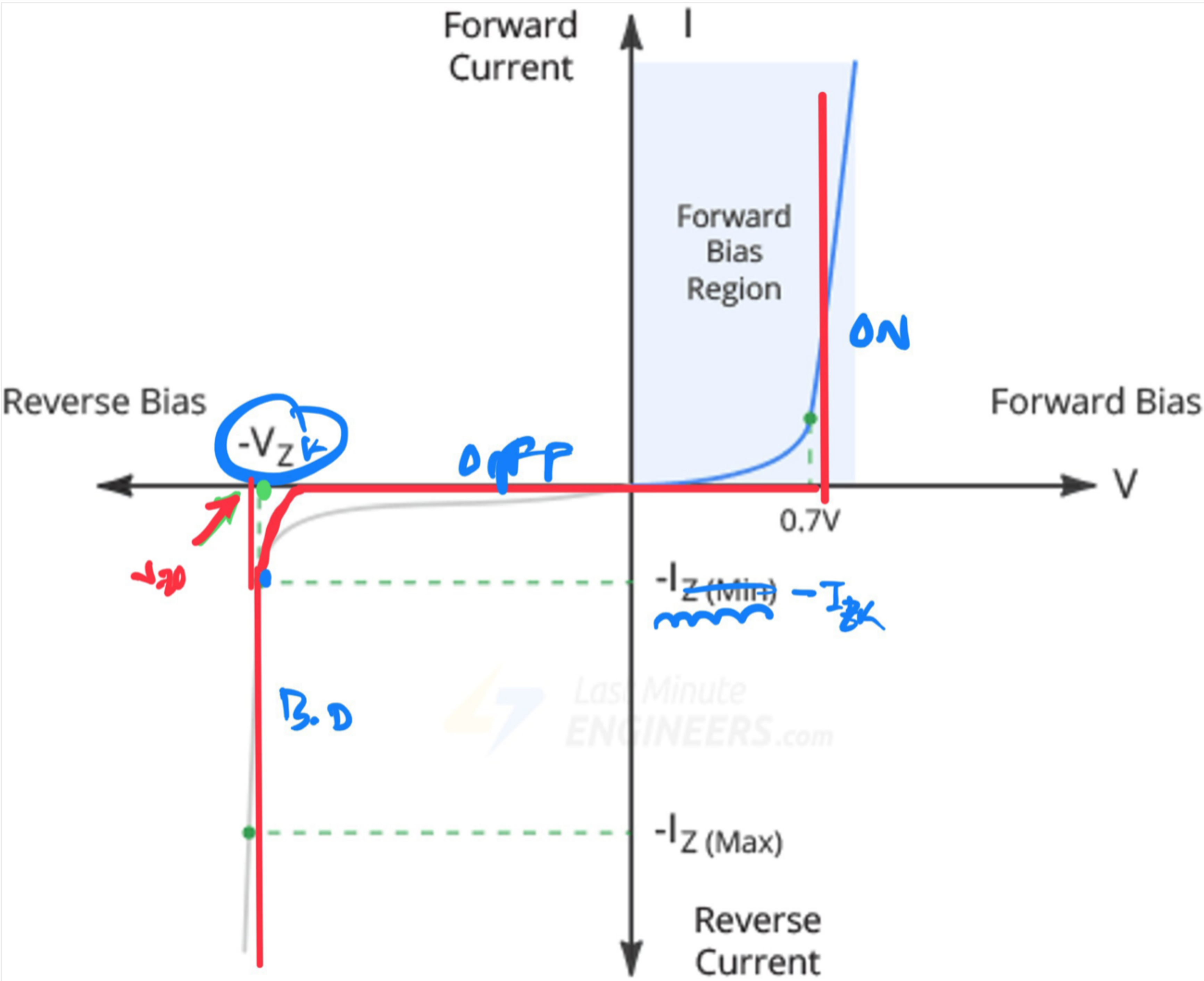


$$I = I_s\left(\exp\frac{V_d}{nV_T} - 1\right) \approx -I_s$$

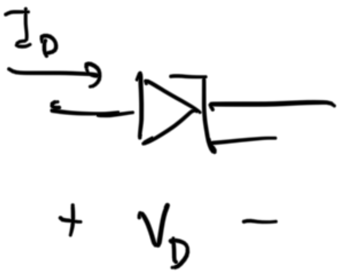

+ V -
i

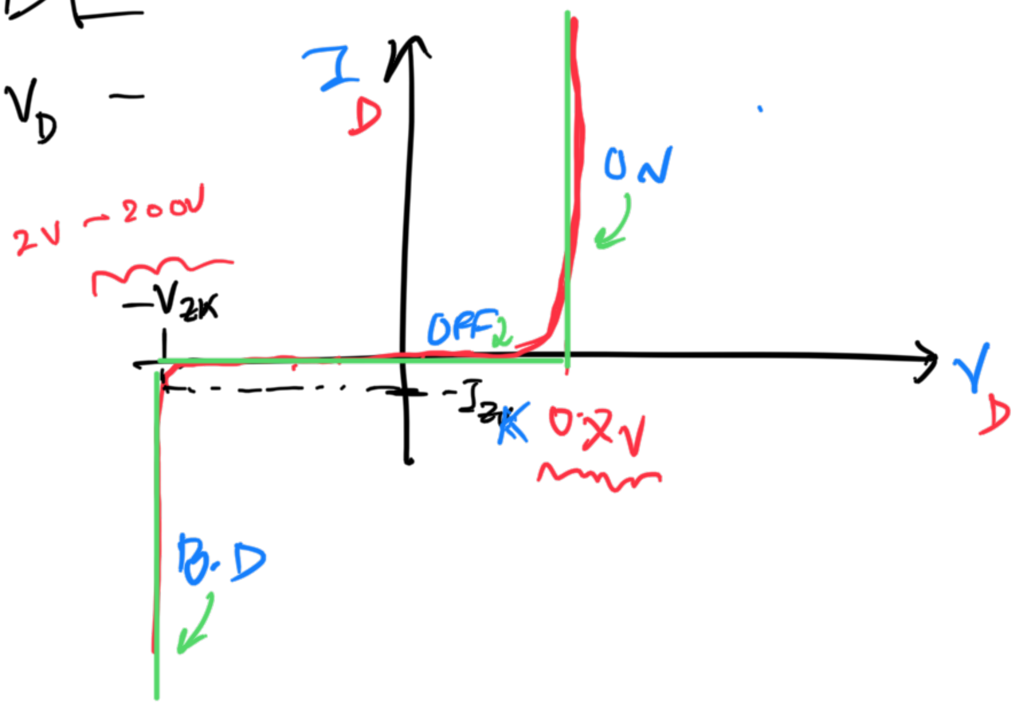

Forward
Current
I
Forward
Bias
Region
Reverse Bias
Forward Bias
$-V_{zk}$
V
0.7V
$-I_{zk}$
Breakdown

Zener Diode


Forward Current
I
Forward Bias Region
ON
Reverse Bias
-V_{Z}
K
OFF
Forward Bias
V
0.7V
-$I_{Z (Min)}$
$-I_{ZK}$
B.D
Last Minute ENGINEERS.com
-$I_{Z (Max)}$
Reverse Current

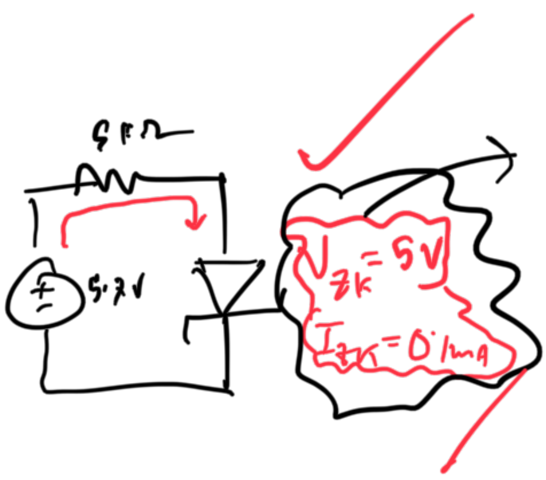
Zener diode



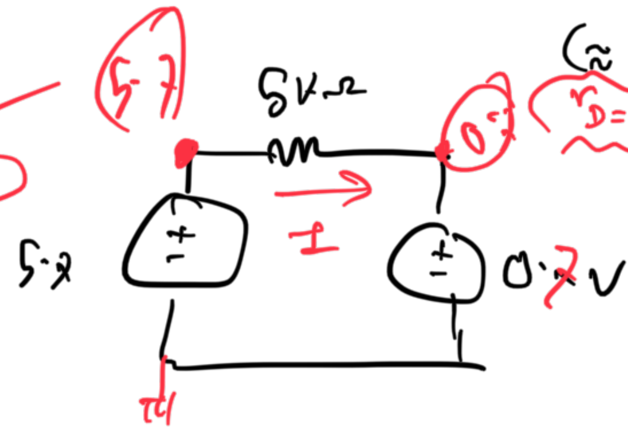


Operation mode	condition	eqn/model
ON	$I_D > 0$	A + V_D − C; $V_D = 0.7V$
OFF	$-V_{ZK} < V_D \leq 0.7V$	$I_D = 0$
B.D.	$I_D \leq -I_{ZK}$	A + V_D − C; V_{Z0} ($\approx V_{ZK}$)

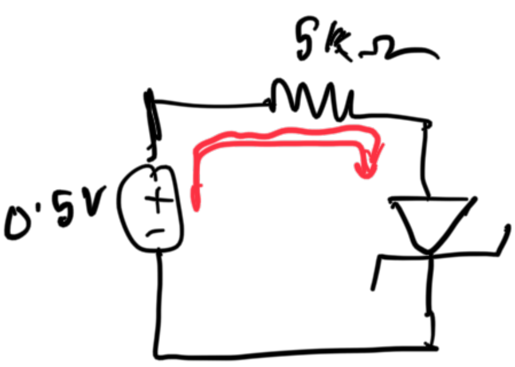
$r_D = - V_{Z0}$



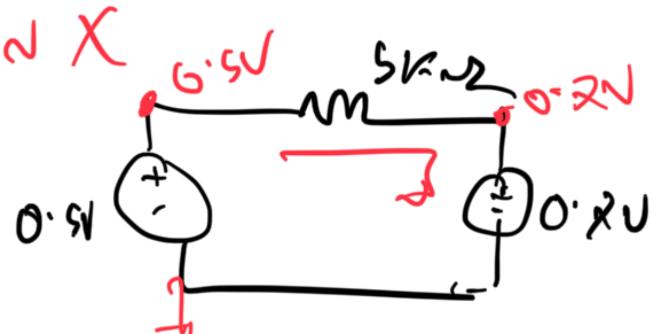
⇒ ON



$$I = \frac{5.7 - 0.7}{5k\Omega} = 1mA$$

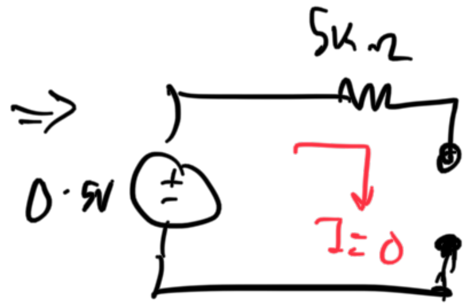


⇒ ON X



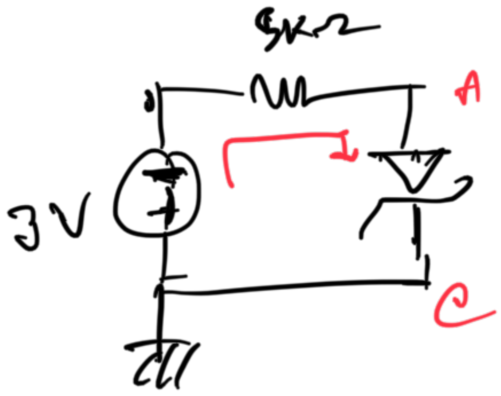
$$I = \frac{0.5 - 0.7}{5} = -0.04 \text{ mA}$$

OFF $\Rightarrow$

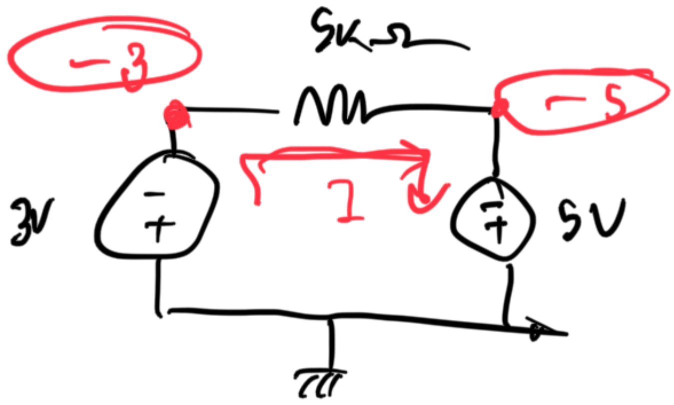


$V_D = 0.5V$

$\le V_{D0}$



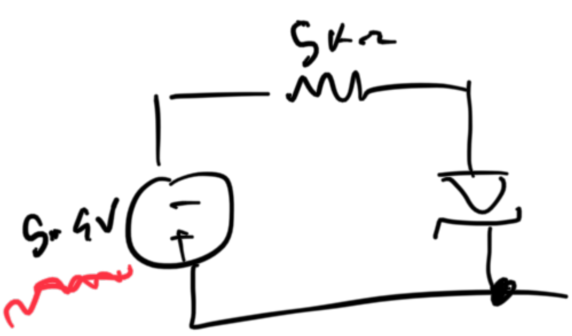
B.P. $\Rightarrow$



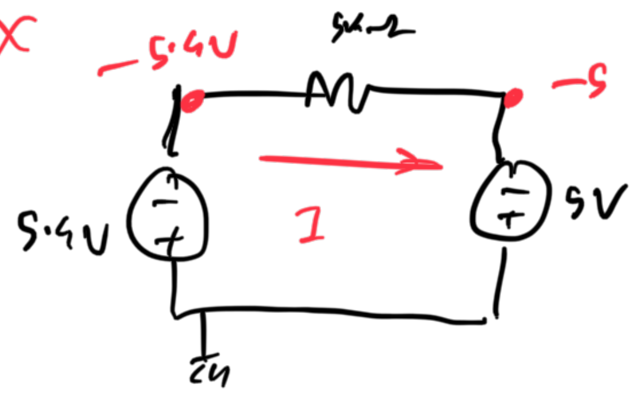
$$I = \frac{-3-(-5)}{5}$$

$$= 0.4\ mA$$

OFF



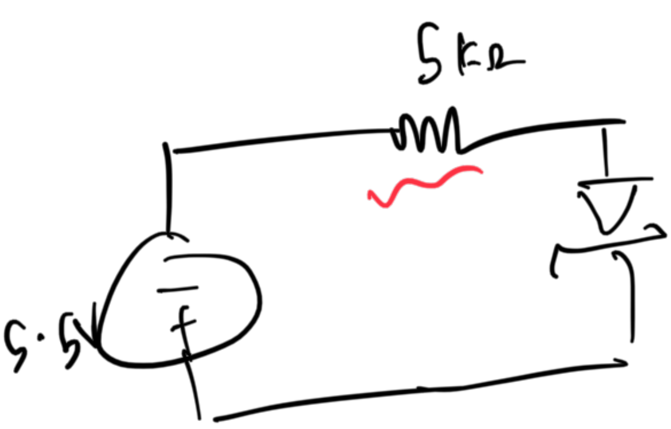
B.D $\Rightarrow$



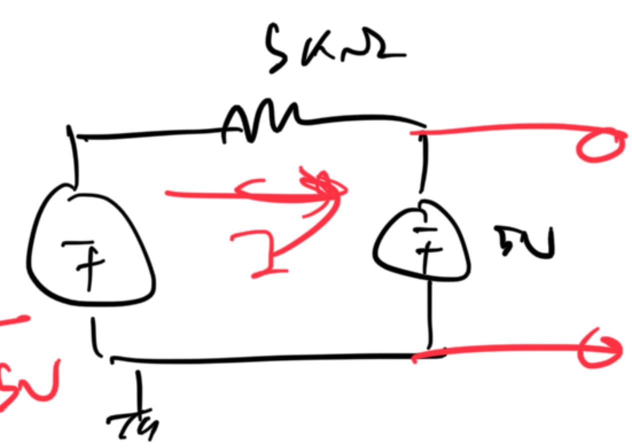
-0.08 -0.1

$$I = \frac{-5.4-(-5)}{5k} = -0.08mA$$

OFF!



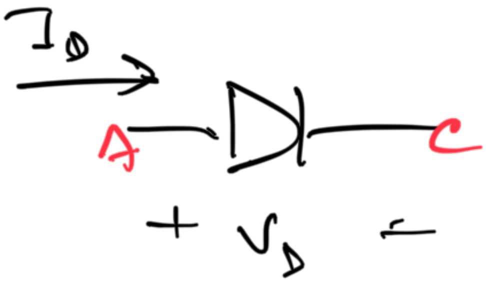
B.D $\Rightarrow$

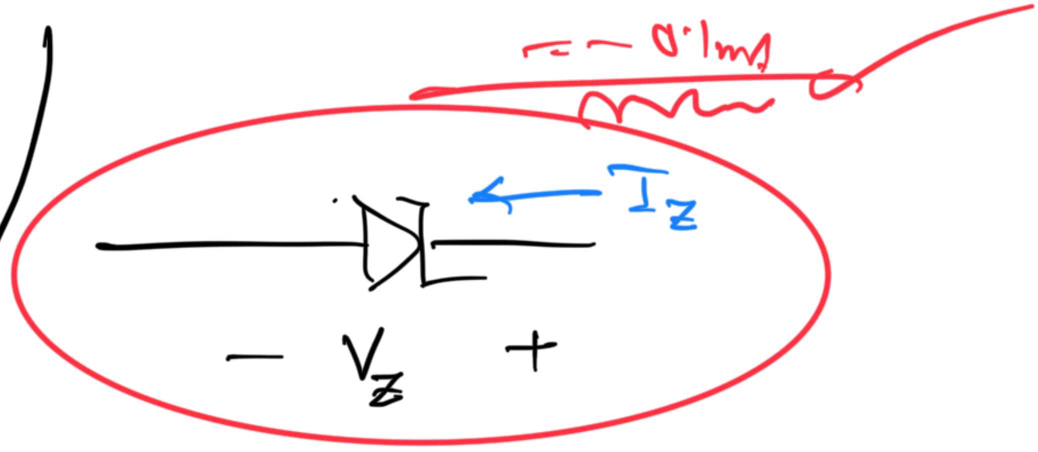


=6.5V

$$I = \frac{-5.5 - (-5)}{5k\Omega}$$

~~$= -0.1mA$~~

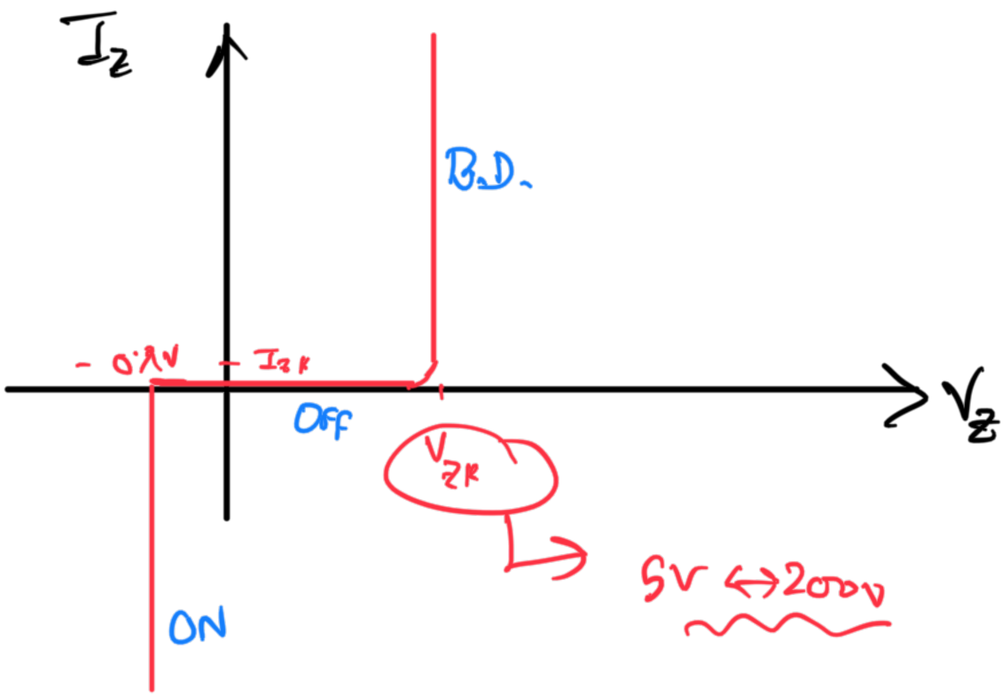


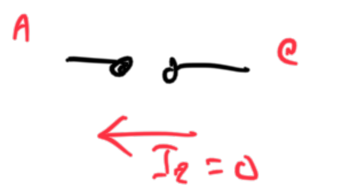
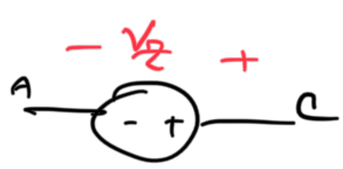


$V_Z = V_C - V_A$

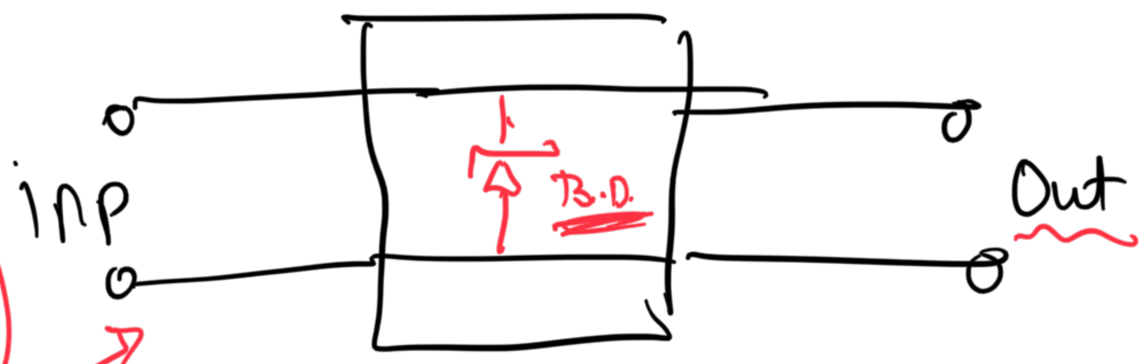
$I_Z = -I_D$

$V_Z = -V_D$



Operation mode	condition	eqn/mode
ON	$I_Z < 0$	 $V_Z = -0.7V$
Off	$-0.7 \leq V_Z < V_{ZK}$	 $I_Z = 0$
B.D	$I_Z \geq I_{ZK}$	 $V_Z = V_{Z0}$

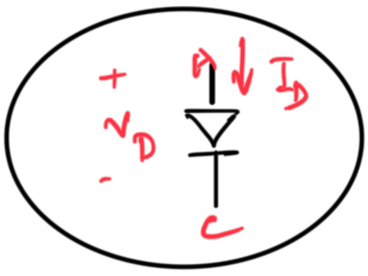
Regulator



$V_i = 5 \pm 1V$

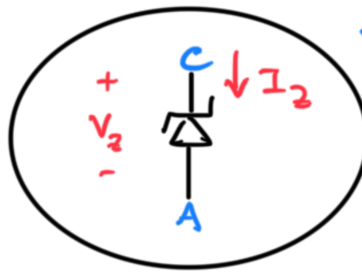
from a rectifier

$V_o = 4V \pm 0.01V$

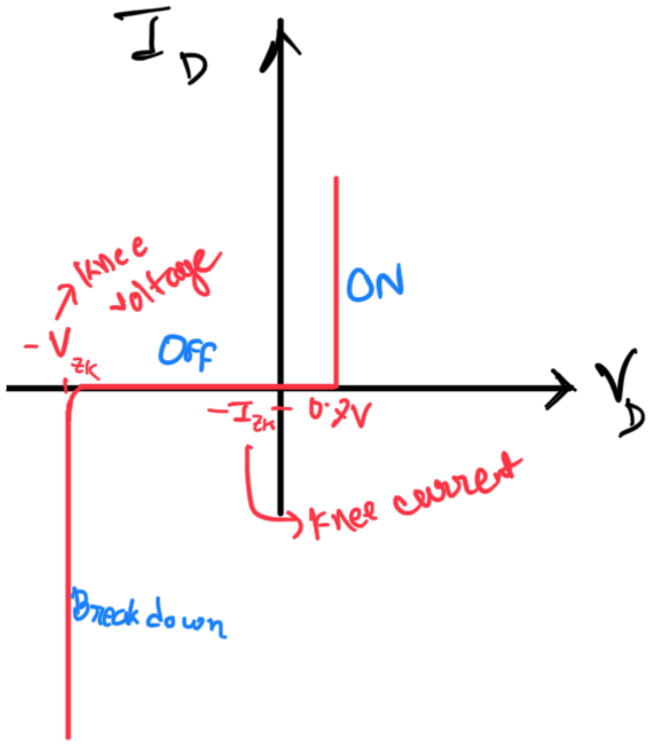


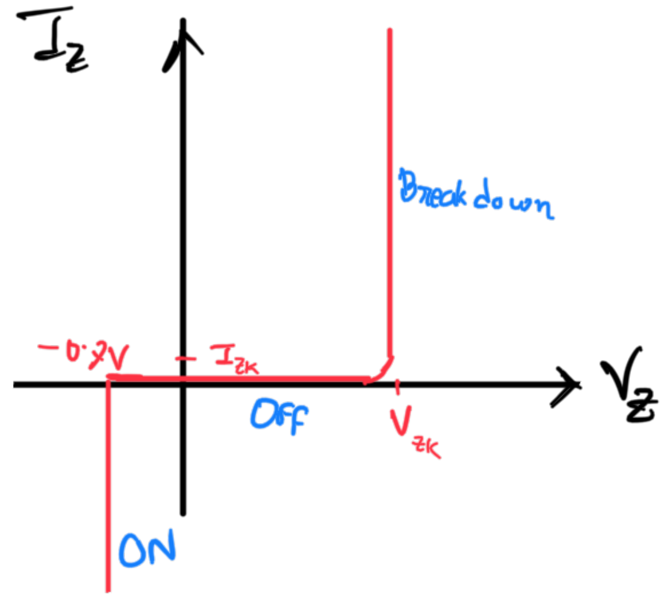
$I_Z = -I_D$

$V_Z = -V_D$

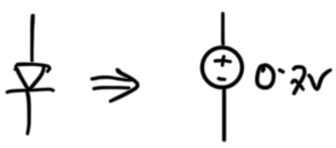


Zener Diode





ON when $I_D > 0$

⇒ 

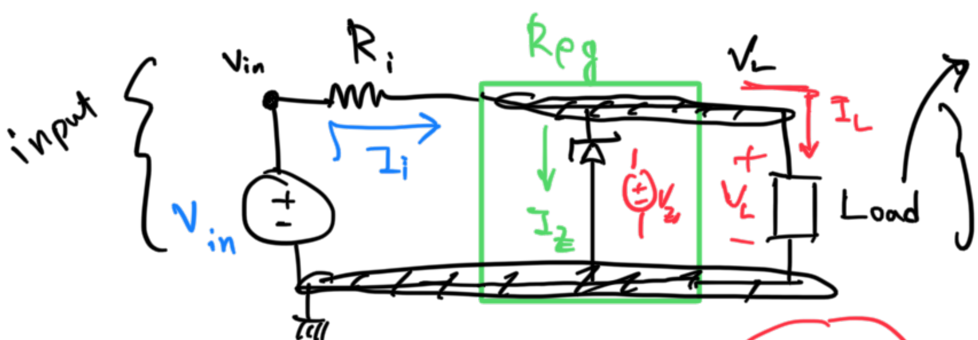
$V_D = 0.7V$

B.D. when $I_Z \geq I_{ZK}$

⇒ 

$V_Z = V_{Z0}$

Application ⇒ Voltage Regulator



→ current consuming device
RADIO, R, Is

Load side ⇒ works only when zener is in B.D

$\boxed{I_Z \geq I_{ZK}}$

$V_L = V_Z$

Eqn: $I_i = \dfrac{V_{in} - V_L}{R_i}$

$I_i = I_Z + I_L$

$\Rightarrow \boxed{I_Z = I_i - I_L = \dfrac{V_{in} - V_L}{R_i} - I_L}$

$V_{in} \uparrow\downarrow \Rightarrow I_Z \uparrow\downarrow$

$I_L \uparrow\downarrow \Rightarrow I_Z \downarrow\uparrow$

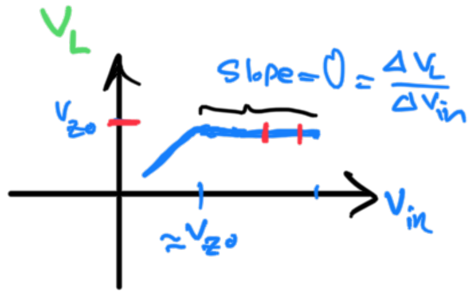
For regulator to work, zener MUST be in Breakdown

↳ $I_Z \geq I_{ZK}$

This means ⇒ ① V_{in} should be high

② I_L should be low

} For regulator to work properly



Design Guideline: Make sure regulator works even in the worst case scenario

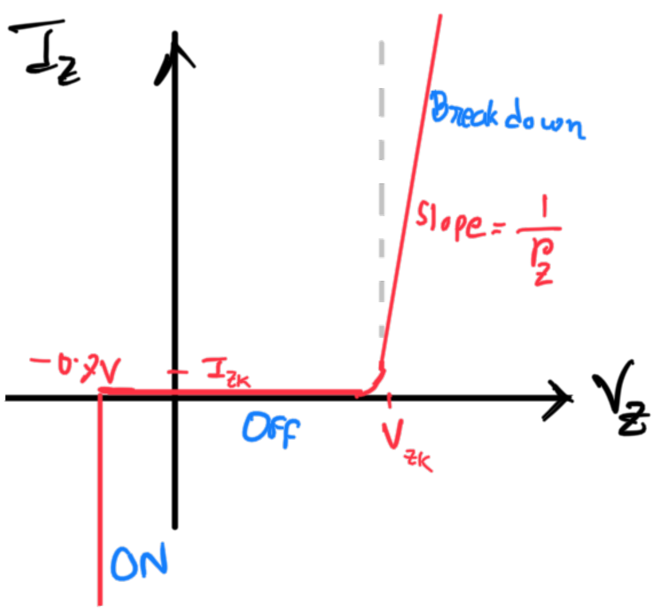
(i) $V_{in} = V_{in}(MIN)$

(ii) $I_L = I_L(MAX)$

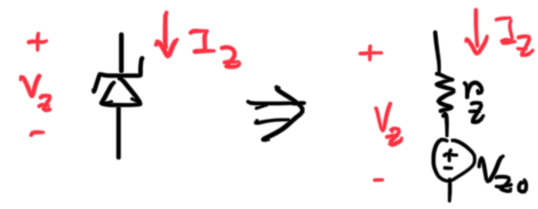
(iii) $I_Z = I_Z(MIN) = I_{ZK}$

$\boxed{I_Z \leq I_Z(MAX)}$

"REAL" Zener Diode



$I_Z > I_{ZK}$



$V_L = \boxed{V_z = V_{z0} + I_z r_z}$

This implies V_z changes with I_z

Reminder: $V_{in}\uparrow \Rightarrow I_z \uparrow$

$I_L \uparrow \Rightarrow I_z \downarrow$

line regulation

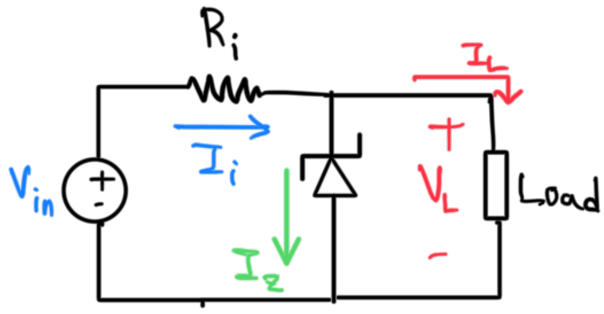
$\left[\frac{\Delta V_L}{\Delta V_{in}} \; (mV/V)\right]$

load regulation

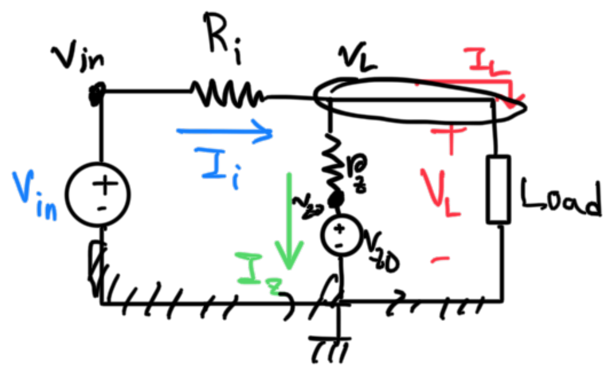
$\left[\frac{\Delta V_L}{\Delta I_L} \; (mV/mA)\right]$

What are the values of the slopes?

when the regulator is working



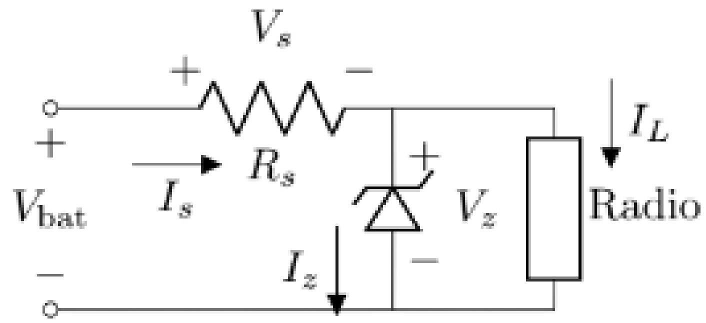
$\Rightarrow$



$$V_L = V_Z = \underbrace{\overbrace{\left(\frac{r_z}{R_i + r_z}\right)}^{\text{changes with } V_{in}}}_{\text{line}} V_{in} + \underbrace{\overbrace{\left(-\frac{r_z R_i}{R_i + r_z}\right)}^{\text{changes with } I_L}}_{\text{load}} I_L + \underbrace{\frac{R_i}{R_i + r_z}}_{\text{const.}} V_{Z0}$$

$\therefore$ Line regulation $= \dfrac{\Delta V_L}{\Delta V_{in}} = \dfrac{r_z}{R_i + r_z}$

$\therefore$ Load regulation $= \dfrac{\Delta V_L}{\Delta I_L} = -\dfrac{r_z R_i}{R_i + r_z}$



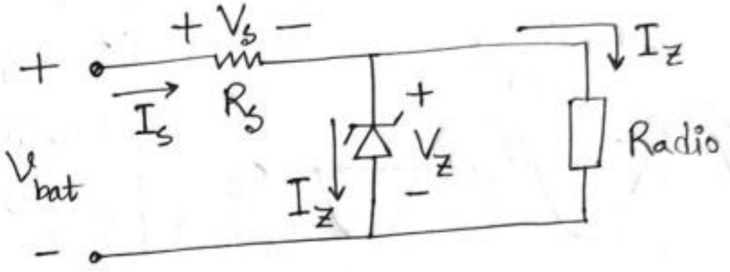
The circuit above is a voltage regulator used to power a car radio (which requires ≈ 9 V) from the car battery, V_{bat} whose voltage may vary between 11 and 13.6 V. The current in the radio, I_L, will vary between 0 (off) to 9 mA (full volume). The Zener diode in the circuit is specified with parameter $V_{z0} = 9$ V, $r_z = 0.05$ kΩ, and $I_{zk} = 1$ mA.

(a) **Identify** the worst-case conditions and **calculate** the Zener current (I_z), Zener voltage (V_z), the input voltage (V_{bat}), and the load current (I_L) in this worst-case scenario. [1+1+1+1+1]

(b) **Calculate** the current (I_s) and the voltage (V_s) the input resistor R_s in the worst-case scenario. [2]

(c) **Design** the circuit, i.e., find the value of R_s, such that even in the worst-case scenario voltage regulation is maintained. Calculate the line regulation for this circuit. [2+1]

⑤



Given that, $V_{bat} = 11v \sim 13.6v$

$I_L = 0 \sim 9\ mA$

$V_{Z0} = 9v$, $r_Z = 0.05\ K\Omega$, $I_{ZK} = 1\ mA$

ⓐ Worst case conditions:

① $V_{bat(min)} = 11v.$

② $I_{Z(min)} = I_{ZK} = 1\ mA.$

So, $I_Z = 1\ mA$. (Ans) $V_{bat} = 11v$. (Ans)

$V_Z = V_{Z0} + I_Z r_Z$

$\Rightarrow V_Z = 9 + 1 \times 10^{-3} \times 0.05 \times 10^{3}$

$\Rightarrow V_Z = 9.05v$. (Ans)

$I_L = I_{L(max)} = 9\ mA.$

(b) Applying KVL we get, $V_{bat} = V_s + V_z$

$\hookrightarrow V_s = V_{bat} - V_z$

$\hookrightarrow V_s = (11 - 9.05)\,v$

$\hookrightarrow V_s = 1.95\,v$. (Ans)

Applying KCL we get,

$I_s = I_Z + I_L$

$\hookrightarrow I_s = (1+9)\,mA$

$\hookrightarrow I_s = 10\ mA$. (Ans)

(c) $R_s = \dfrac{V_s}{I_s} = \dfrac{1.95}{10\times10^{-3}} = 195\,\Omega$. (Ans)

Line Regulation,

$$\frac{\Delta V_L}{\Delta V_{bat}} = \frac{r}{r+R}$$

$$= \frac{0.05\times10^3}{0.05\times10^3+195}\ V/V$$

$$= 0.20408\ V/V$$

$$= 204.08\ mV/V.\ \text{(Ans)}$$

here,

$r = r_z = 0.05\,K\Omega$

$R = R_s = 195\,\Omega$