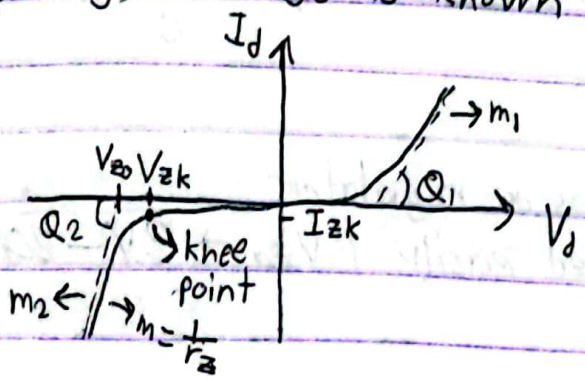
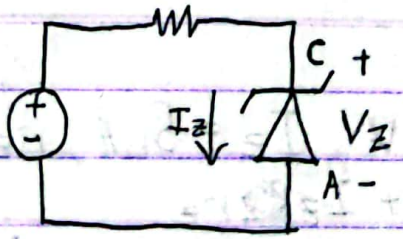
Breakdown Region:

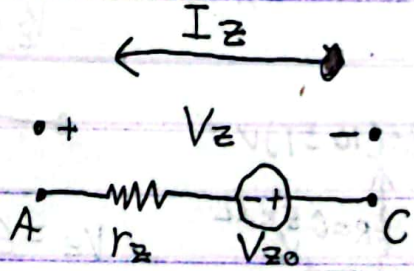
* In reality current does flow in the opposite direction of a diode but it is really small i.e. $10^{-9} \sim 10^{-12}$ A
* At a certain negative voltage, current starts to flow through a diode just like it does when the diode is on this ~~voltage~~ voltage is known as Breakdown region.



$Q_2 > Q_1$
$\tan Q_2 > \tan Q_1$
$m_2 > m_1$
$\frac{1}{r_2} > \frac{1}{r_1}$
$r_2 < r_1$

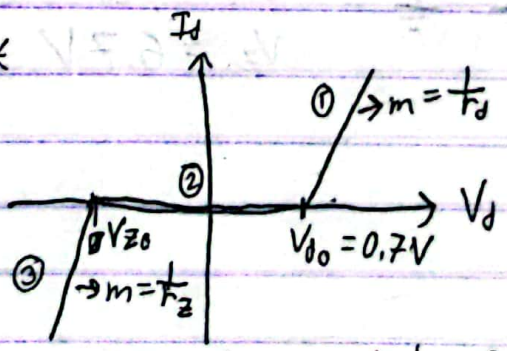
* Normal diodes become unusable if it goes to breakdown region once.
* Zener diodes can be used in the breakdown region.
* These diodes are better regulators because the value of r is smaller as $r_2 < r_1$.
* Zener diode symbol,





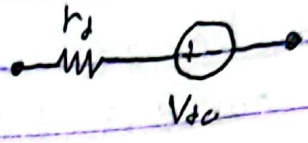
$$V_z = V_{z0} + I_z r_z$$

*

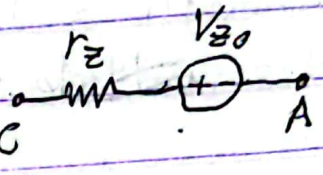


piecewise model of zener diode

- region - ①: $I_d > 0$ → ON →



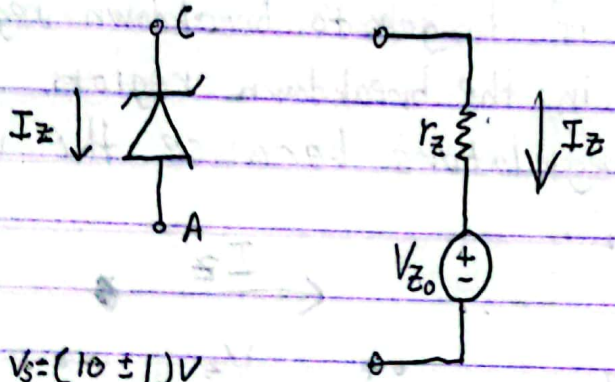
- region - ②: $-I_{ZK} \leq I_d < 0$ → OFF → open circuit
- region - ③: $I_d < -I_{ZK}$ → Breakdown Region →



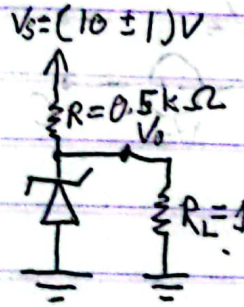
* Why use zener diode:

- $r_z < r_d$ → works better as a regulator
- V_{z_o} can be controlled easily ($V_{z_o} \rightarrow 2V - 200V$)

* Example:



$I_z > I_{ZK}$



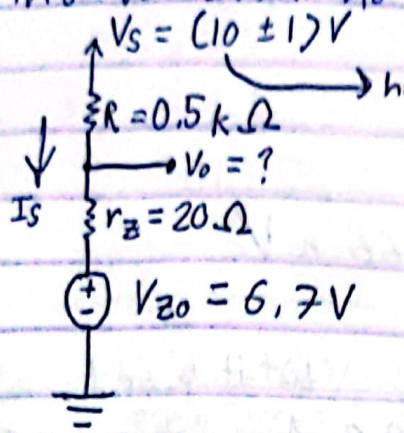
$V_z = 6.8V$, $I_z = 5mA$, $r_z = 20\Omega$, $I_{ZK} = 0.2mA$

$V_z = V_{z_o} + I_z r_z$

$6.8 = V_{z_o} + (5 \times 10^{-3} \times 20)$

$V_{z_o} = 6.7V$

① Find V_o with no load and V_s at it's nominal value.



$I_s = \frac{10 - 6.7}{500 + 20} = 6.34 \times 10^{-3} A$

$= 6.34 mA$

$I_{zk} = 0.2mA$ (I_s should be greater than I_{zk})

$V_o = V_{z0} + I_s r_z$

$= 6.7 + 6.34 \times 10^{-3} \times 20$

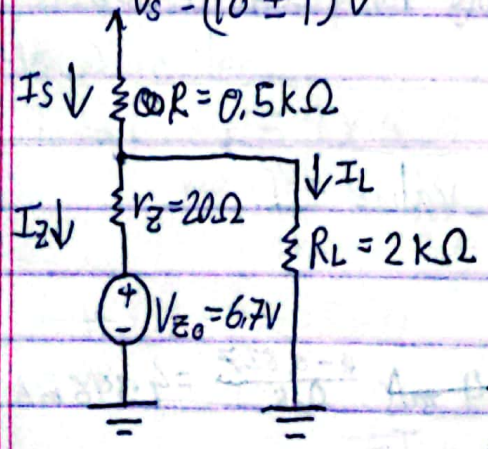
$= 6.827V$

② $\pm 1V$ change in $V_s \rightarrow \Delta V_o = ?$

$\frac{\Delta V_o}{\Delta V_s} = \frac{r_z}{R + r_z} = \frac{20}{500 + 20} = \frac{2}{52} = 0.038 \ V/V = 38 mV/V$

$\Delta V_o = \Delta V_s \times 38 \ mV/V = \pm 38 mV/V$ (Line regulation)

③



$V_o = 6.827V$

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

$= \frac{6.827}{2000}$

$= 3.413 mA$

Load Regulation $\rightarrow \frac{\Delta V_o}{\Delta I_L} = \frac{-R \| r_z}{R + r_z} = \frac{-500 \times 20}{500 + 20}$

$\frac{\Delta V_o}{\Delta I_L} = -19.27 \ V/A = -19.23 \ mV/mA$

$\Delta V_o = 3.413 \times -19.23 = -65.632 mV$

④ $R_L = 0.5\,k\Omega$

$I_L = \frac{V_o}{R_L} = \frac{6.827}{0.5} = 13.654\ mA$

$\Delta I_L = 13.654\ mA$

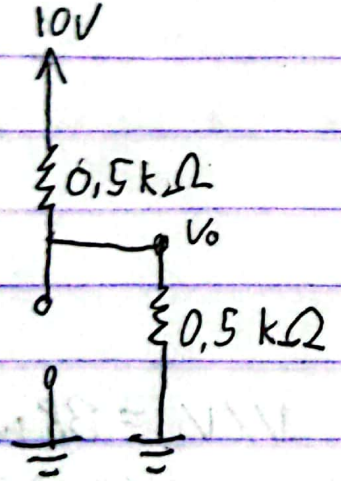
$\frac{\Delta V_o}{\Delta I_L} = -19.23\ mV/mA$

$\Delta V_o = 13.654 \times -19.23 = 262.566\ mV$

$I_S = I_Z + I_L$

$6.36 = I_Z + 13.654$

$I_Z = -7.35\ mA$ [$I_Z > I_{ZK} = 0.2mA$ but it is not so the zener diode will be off]



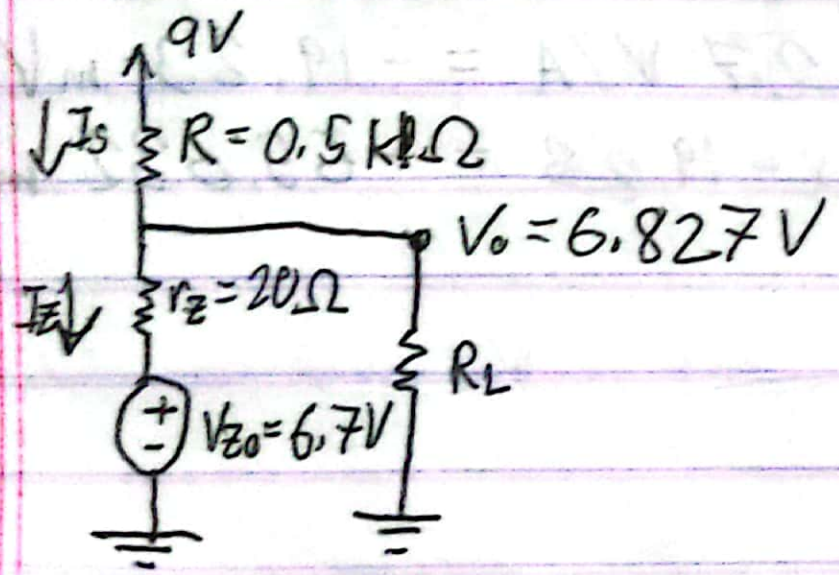
$V_o = 10 \times \frac{0.5}{0.5+0.5}$

$V_o = 5\ V$

* Load resistance should be kept big for zener diode to work.

⑤ Minimum possible Load resistance value = ?

- $V_S \rightarrow$ min
- $I_Z = I_{ZK}$



$I_S = \cancel{6.34\ mA}\ \frac{9-6.827}{0.5} = 4.346\ mA$

$I_S = I_Z + I_L$

$I_L = \cancel{6.34}\ 4.346 - 0.2 = \cancel{6.14}\ 4.146\ mA$

$R_L = \frac{V_o}{I_L} = \frac{6.827}{4.146} = 1.6466\ k\Omega$

* Ⅲ The output voltage (V_o) is constant because zener diode's purpose is to give a constant output voltage.