Intro to Electronics (Practice Paper-1)

1. At thermal equilibrium, conductivity of a semiconductor is given by-

$$\sigma = nq\mu_n + pq\mu_p$$

$$= q\left(\frac{n_i^2}{p}\mu_n + p\mu_p\right)$$

For maximum resistivity (or min. conductivity).

$$\frac{d\sigma}{dp} = 0.$$

$$\therefore -\frac{n_i^2}{p^2}\mu_n + \mu_p = 0 \rightarrow p = n_i\sqrt{\frac{\mu_n}{\mu_p}}$$

as, $\mu_n > \mu_p$, $p > n_i$

i.e. the sample is slightly p-type.

2. At, 300K, n_i of Si is $1.5\times10^{10}\ cm^{-3}$

Electron mobility $(\mu_n) = 1350\ cm^2/V\text{-}s.$

Hole " $(\mu_p) = 480\ cm^2/V\text{-}s.$

So, resistivity of intrinsic Silicon is, $\rho = \frac{1}{qn_i(\mu_n + \mu_p)}$

$$\rho = \frac{1}{1.6\times10^{-19}\times1.5\times10^{10}(1350+480)} = \boxed{2.3\times10^{5}\ \Omega\text{-}cm.}$$

Doping

Assuming complete ionization,

$n = N_D = 10^{16}\ cm^{-3}$, n-type, $n \gg p$

Resistivity for this case, $\rho = \frac{1}{nq\mu_n} = 0.462\ \Omega\text{-}cm.$

So, by adding small amount of impurity (< 1 ppm), resistivity of Si can be changed by many orders.

(3)

Resistivity (ρ) $= 0.65\ \Omega$ - cm

mobility (μ_n) $= 1250\ cm^2/V\text{-}s$.

$$\rho = \frac{1}{\sigma} = \frac{1}{nq\mu_n} = 0.65 \quad ; \ \sigma = \text{conductivity}$$

$$n = N_D = \frac{1}{0.65 \times 1.6 \times 10^{-19} \times 1250} \quad ; \ N_D = \text{donor concentration.}$$

$$\boxed{N_D = 7.69 \times 10^{15}\ cm^{-3}}$$

Drift current density $(J) = nq\mu_n \mathcal{E}$; $\mathcal{E}$ = electric field.

$$160 = \frac{1}{\rho}\mathcal{E}$$

$$\boxed{\mathcal{E} = 160 \times 0.65 = 104\ V/cm.}$$

(4)

GaAs p-n junction, $N_A = 5\times10^{18}\ cm^{-3}$, $N_D = 5\times10^{16}\ cm^{-3}$ } Given, n_i of GaAs $= 1.8\times10^{6}\ cm^{-3}$ at 300K

Built-in potential, $V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)$; $V_T = 0.026\,V$ at 300K

$$V_{bi} = 0.026 \ln\left[\frac{5\times10^{18}\times5\times10^{16}}{(1.8\times10^{6})^2}\right] = \boxed{1.37\,V. = V_{bi}}$$

(5)

For diode, $I = I_s\left[\exp\left(\frac{V}{V_T}\right) - 1\right]$; assuming $\eta = 1$.

In reverse bias current is negative $(-I_s)$ and at that particular voltage

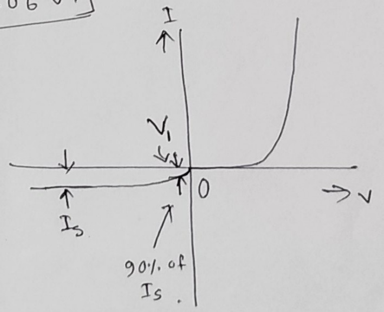
current $= -0.9\,I_s$; (90% of reverse saturation current)

From diode equation, $-0.9\cancel{I_s} = \cancel{I_s}\left[\exp\left(\frac{V_1}{V_T}\right) - 1\right]$

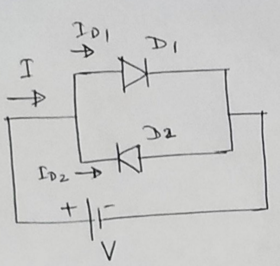
$$\therefore \exp\left(\frac{V_1}{V_T}\right) = 0.1$$

$$V_1 = V_T \ln(0.1)$$

$$\boxed{V_1 = -0.06\,V.}$$



6



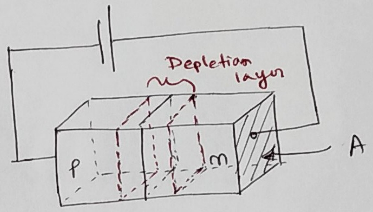
Here, D_1 is forward biased
D_2 is reverse biased.

Total current $I = I_1 + I_2$

$$I = I_S\left[\exp\left(\frac{V}{V_T}\right) - 1\right] + I_S$$

$$I = I_S \exp\left(\frac{V}{V_T}\right)$$

$$\boxed{V = V_T \ln\left(\frac{I}{I_S}\right)}$$



7

$$C = \frac{\epsilon A}{W}$$

$$C = \frac{\epsilon_0 \epsilon_r}{W} A.$$

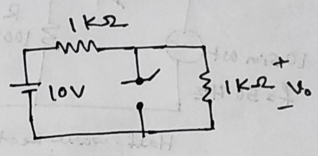
$$= \frac{11.7 \times 8.854 \times 10^{-12}}{10 \times 10^{-6}}$$; A = unit area (m^2).

$= 10.3 \, \mu F$

Introduction to

Electronics (Practice Paper-1)

(8) Given, $V_Z = 6\,V$.



The Zener diode is in reverse bias.

Voltage across the Zener diode is

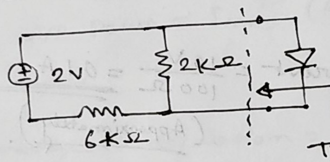
$$= \frac{1\,K\Omega}{1\,K\Omega + 1\,K\Omega} \times 10\,V$$

$$= 5\,V, \text{ but, } V_Z = 6\,V.$$

So, the Zener diode is in reverse bias, but not in breakdown.

So, $V_0 = 5\,V$.

(9) Let us redraw the circuit as

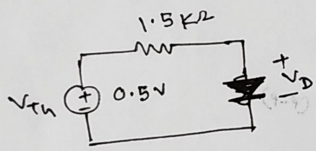


Thevenin equivalent

$$V_{Th} = 2 \times \frac{2}{2+6} = 0.5\,V$$

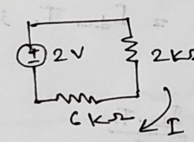
$$R_{Th} = 2\,K\Omega \parallel 6\,K\Omega$$

$$= 1.5\,K\Omega$$



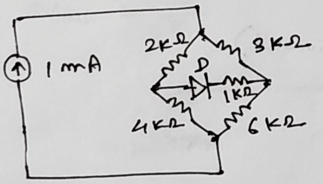
But, as $V_{on} = 0.7\,V$, the diode is OFF.

The circuit reduces to,



$$I = \frac{2}{2\,K\Omega + 6\,K\Omega} = 0.25\,mA.$$

(10)



This is a bridge circuit and the cross arm product is same

i.e. $2 \times 6 = 3 \times 4$

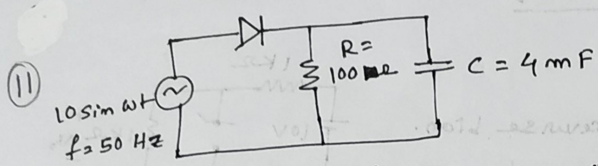
So, the bridge is balanced.

So, no current through the 1KΩ resistor.

Current through 4 KΩ resistor $= 1\,mA \times \frac{9}{9+6}$

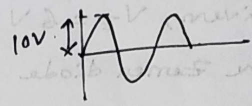
$$= 0.6\,mA.$$

(11)



Half-wave Rectifier.

Input signal = 10 Sin ωt.



Frequency = 50 Hz

Time period $(T) = \frac{1}{50} = 20$ m Sec

RC time const. = RC

$\cancel{= 100 \times 10^3 \times 4 \times 10^{-3}}$

$= 100 \times 4 \times 10^{-3}$

$\cancel{= 400}$

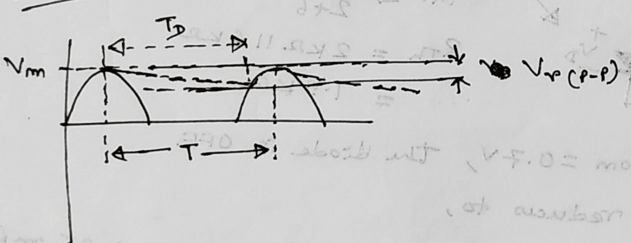
$= 400$ m Sec. $\gg T$.

So, we can say that voltage across the resistor is approximately ≈ 10 V (DC).

So, average stedy state current $= \frac{10\ V}{100\ \Omega} = 0.1$ A

(Approximately).

In more details



For half-wave rectifier, $V_{r\,(P-P)} \cdot C = I_{dc} \cdot T$;

[change balance]

$\therefore V_{r\,(P-P)} = \frac{I_{dc} \cdot T}{C}$.

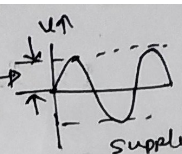
$V_{dc} = V_m - \frac{V_{r\,(P-P)}}{2}$ (approximated)

$\therefore I_{dc} \cdot R = V_m - \frac{I_{dc} \cdot T}{C}$.

$\therefore I_{dc}\left(R + \frac{1}{2fC}\right) = V_m$.

$\therefore I_{dc} = \frac{10}{100 + \frac{1}{2 \times 50 \times 4 \times 10^{-3}}} \approx 0.0976$ A.

Supply, $V_{rms} = 110\,V$, $V_m = 110 \times \sqrt{2} = 155.56\,V$



(12) $\therefore\ I_m = \dfrac{V_m}{R_L + r_f}$; $\quad r_f = 30\,\Omega$, $\quad R_L = 990\,\Omega$

$= \dfrac{155.56}{990 + 30} = \underline{0.152\,A}$ peak load current. — (a)

$I_{dc} = \dfrac{I_m}{\pi} = \dfrac{0.152}{\pi} = \underline{48.57\,mA}$. — (b)

$I_{rms} = \dfrac{I_m}{2} = \dfrac{0.152}{2}\,A = \underline{76\,mA}$. — (c)

$V_{dc} = I_{dc} \cdot R_L = 48.57 \times 990 = \underline{48\,V}$ — (d)

Total i/p power $= I_{rms}^2 (R_L + R_f) = (76 \times 10^{-3})^2 \times 1020$

$= \underline{5.89\,W}$. — (e)

Percentage of regulation $= \dfrac{V_{NL} - V_{FL}}{V_{FL}}$

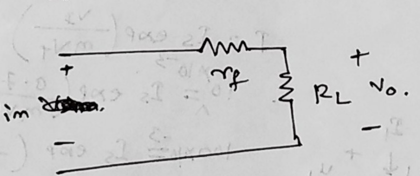
$= \dfrac{V_m/\pi - I_{dc} \cdot R_L}{I_{dc} \cdot R_L}$

$= \dfrac{\frac{155.56}{3.14} - 48.57 \times 10^{-3} \times 990}{48.57 \times 10^{-3} \times 990}$

$= \dfrac{49.54 - 48.08}{48.08} \simeq \underline{3.04\,\%}$. — (f)

For, half-wave rectifier,

(13) $V_{NL} = \dfrac{V_m}{\pi}$ and $V_{FL} = \dfrac{V_m}{\pi} \dfrac{R_L}{R_L + R_f}$



$\therefore$ percentage of regulation, $= \dfrac{V_{NL} - V_{FL}}{V_{FL}} = \dfrac{\frac{V_m}{\pi} - \frac{V_m}{\pi} \cdot \frac{R_L}{R_L + r_f}}{\frac{V_m}{\pi} \cdot \frac{R_L}{R_L + R_f}} \times 100\%$.

$= \underline{\dfrac{R_f}{R_L} \times 100\,\%}$.

For full-wave rectifier, V_{NL} and V_{FL} are double compared to that of half-wave rectifier.

Hence, % of regulation (full-wave) $= \dfrac{R_f}{R_L} \times 100\,\%$.

(14) $I = I_s\left[\exp\left(\frac{V_D}{\eta V_T}\right) - 1\right]$

Since, $\exp\left(\frac{V_D}{\eta V_T}\right) >> 1$; $\therefore I = I_s \exp\left(\frac{V_D}{\eta V_T}\right)$

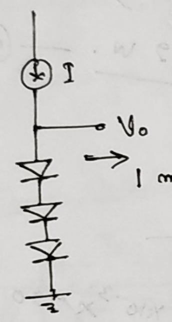
So, $\frac{15\ mA}{0.5\ mA} = \frac{\cancel{I_s}\exp\left(\frac{0.465}{\eta \times 0.025}\right)}{\cancel{I_s}\exp\left(\frac{0.340}{\eta \times 0.025}\right)} = \exp\left(\frac{5}{\eta}\right)$

$\therefore\ 30 = \exp\left(\frac{5}{\eta}\right)$

$\therefore \frac{5}{\eta} = 2.303 \log_{10}(30)$

$\therefore \eta = 1.47.$

(15)



Three diodes are identical.
So, drop across each diode $= \frac{V_o}{3} = \frac{2}{3}$ V.

$I = I_s \exp\left(\frac{V}{V_T}\right) = 10^{-14} \exp\left(\frac{2/3}{0.026}\right)$

$I = 1.366\ mA.$ — (a)

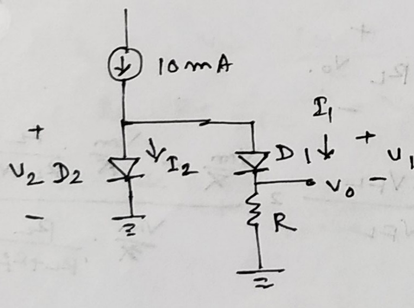
1 mA current is drawn by a load.

$\therefore \frac{1.366\ mA}{0.366\ mA} = \frac{\cancel{I_s}\exp\left(\frac{2/3}{0.026}\right)}{\cancel{I_s}\left[\exp\left(\frac{V'}{0.026}\right)\right]} = \exp\left(\frac{0.66 - V'}{0.026}\right)$

$\therefore 1.317 = \frac{0.66 - V'}{0.026}$

$\therefore$ change in o/p vol $\doteq (0.66 - V') = 0.034V = 34\ mV$ decrease (b)

(16)



$I = I_s \exp\left(\frac{V_D}{\eta V_T}\right)$

$\therefore 10 \times 10^{-3} = I_s \exp\left(\frac{0.7}{\eta V_T}\right)$ ← (1)

$100 \times 10^{-3} = I_s \exp\left(\frac{0.8}{\eta V_T}\right)$ — (2)

$\therefore$ From (1) & (2),
$\eta = 1.73$

$V_o = V_2 - V_1 = \eta V_T \ln\left(\frac{I_2}{I_1}\right) = 80\ mV.$

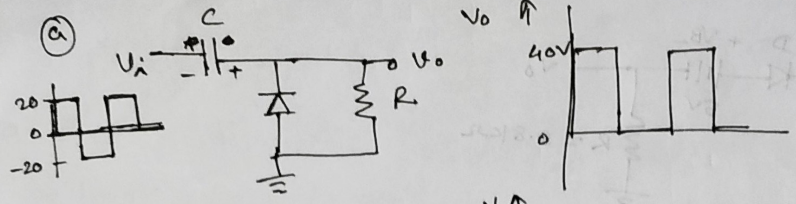
$\therefore 1.73 \times 0.025 \times \ln\left(\frac{I_2}{I_1}\right) = 80 \times 10^{-3}$

$I_1 + I_2 = 10\ mA. = 0.01\ A.$

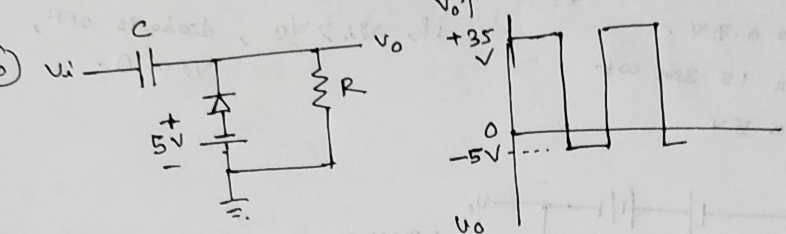
$\therefore I_1 \cong 1.4\ mA$

$\therefore R = \frac{80}{I_1} = 57.1\ \Omega$

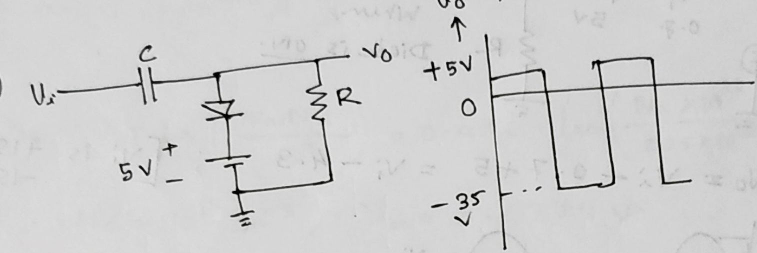
(17) (a)



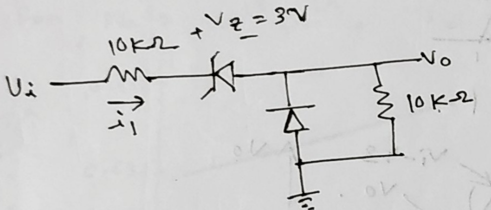
(b)



(c)



(18)



For $\underline{-10 < V_i < 0 \text{ V}}$, both diodes are conducting.

So, $V_o = 0$ V.; (as $V_\gamma = 0$)

for $\underline{0 < V_i \leq 3\text{ V}}$, Zener diode is not in breakdown.

(all voltage drop occurs across Zener and $I = 0$)

So, $V_o = 0$ V.

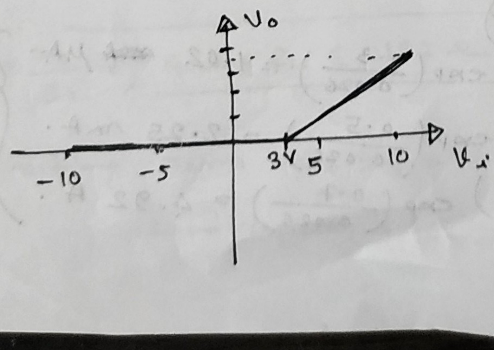
For $V_i > 3$ V, Zener is in breakdown and drop across it is:

$V_Z = 3$ V.

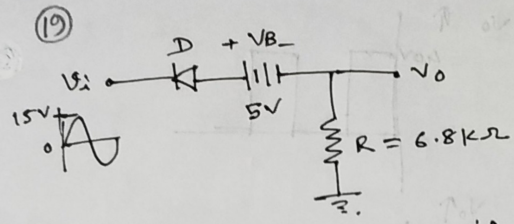
So, $i_1 = \dfrac{V_i - V_Z}{20\text{k}\Omega} = \dfrac{V_i - 3}{20}$ mA.

$\therefore V_o = 10\, i_1 = \dfrac{V_i - 3}{2}$ V.

at, $V_i = 10$ V, $V_o = 3.5$ V.



(19)

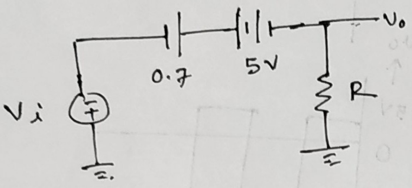


$V_\gamma = 0.7V.$

$V_i = 15 \sin \omega t$

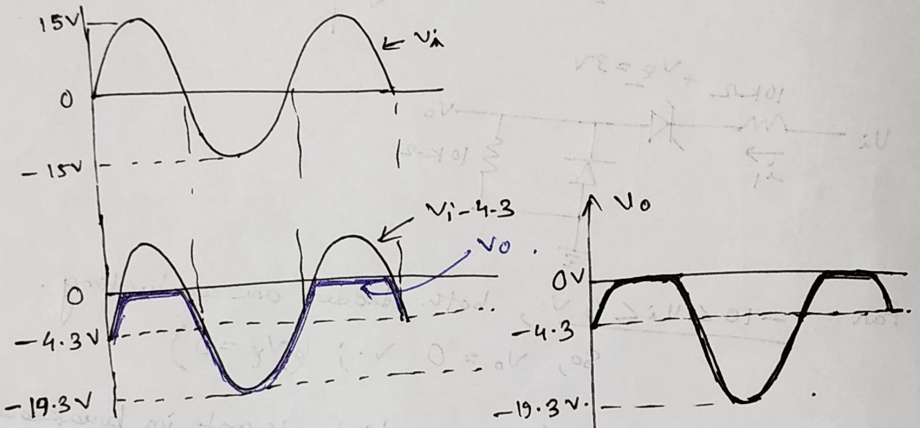
$V_B = 5V.$

if, $v_i > V_B$, diode is off,
$V_o = 0.$



When,
Diode is ON.

$V_o = V_i - 0.7 + 5 = V_i - 4.3$; [V_i is +15V −15V]



(20) $I = I_S \exp\left(\frac{V_D}{V_T}\right)$; $\eta = 1$

$\therefore 10I = I_S \exp\left(\frac{V_D + \Delta V}{V_T}\right)$

$\therefore \frac{10I}{I} = \frac{\exp\left(\frac{V_D + \Delta V}{V_T}\right)}{\exp\left(\frac{V_D}{V_T}\right)} = \exp\left(\frac{\Delta V}{V_T}\right)$

$\therefore \Delta V = V_T \ln 10 = 59.86\ mV \approx \underline{60\ mV.}$ → 10 times

$\therefore \Delta V = V_T \ln 100 = 119.73\ mV \approx \underline{120\ mV}$ → 100 times.

(21) In forward bias,

$I \approx I_S \exp\left(\frac{V_D}{V_T}\right)$

$I(0.3V) = (10^{-11}) \exp\left(\frac{0.3}{0.026}\right) = 1.02\ \mu A.$

$I(0.5V) = (10^{-11}) \exp\left(\frac{0.5}{0.026}\right) = 2.25\ mA.$

$I(0.7V) = (10^{-11}) \exp\left(\frac{0.7}{0.026}\right) = 4.92\ A.$

See the change in current.

In reverse bias..

$$I = I_s\left[\exp\left(\frac{V_D}{V_T}\right) - 1\right]$$

So, $I(-0.2V) = I_s\left[\exp\left(-\frac{0.2}{0.026}\right) - 1\right]$; $I_s = 10^{-11}$ A.

$I(-0.2V) \simeq -0.999 \times 10^{-11}$ A $\approx -I_s$.

$I(-2V) = 10^{-11}\left[\exp\left(-\frac{2}{0.026}\right) - 1\right]$

$I(-2V) \cong -10^{-11} \approx -I_s$.

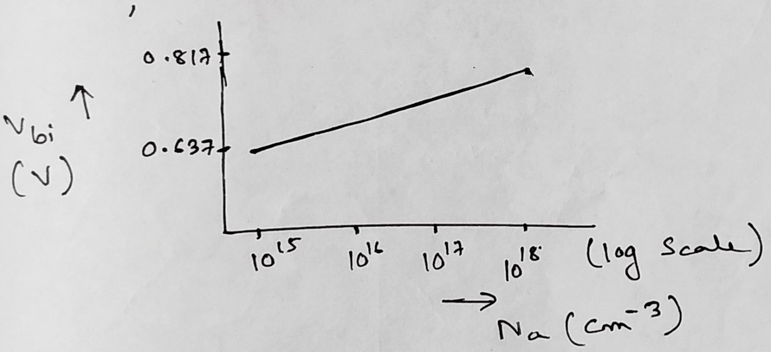
[Do for $I_s = 10^{-13}$ A.]

(22)

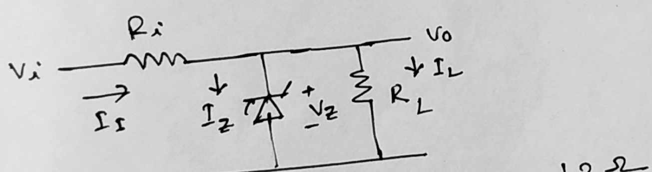
$$V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.026 \ln\left(\frac{N_a \times 10^{16}}{2.25 \times 10^{20}}\right)$$

For, $N_a = 10^{15}$ cm^{-3}, $V_{bi} = 0.6374$ V.

for, $N_a = 10^{18}$ cm^{-3}, $V_{bi} = 0.817$ V.



(23)



$V_i = 6.3$ V, $V_Z = 4.8$ V., $R_i = 12\,\Omega$

$\therefore I_I = \frac{6.3 - 4.8}{12} = 125$ mA.

$I_L = I_I - I_Z$, $5\text{mA} \le I_Z \le 100$ mA.

$\therefore$ $25\text{mA} \le I_L \le 120$ mA (Range of I_L)

$R_L = \frac{V_Z}{I_L}$; $40\,\Omega \le R_L \le 192\,\Omega$ (Range of R_L) } (a)

Power rating, Zener $= I_{Z\,max} \cdot V_Z = 480$ mW.

Load resistor $= I_{L\,max} \cdot V_Z = 576$ mW. } (b)