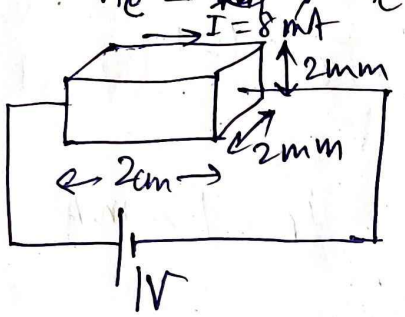
Basic Electronics

2024 – Autumn Mid Sem

1½ (a) $\mu_e = 1300\ cm^2/V\text{-}s$

$n_e = N_A$ $\quad n_e n_h = n_i^2 \Rightarrow n_h = \dfrac{n_i^2}{N_A}$



$I = n_e e A \mu_e E$

$I = N_A e A \mu_e \left(\dfrac{V}{l}\right)$

$\Rightarrow N_A = \dfrac{I l}{e A \mu_e V}$

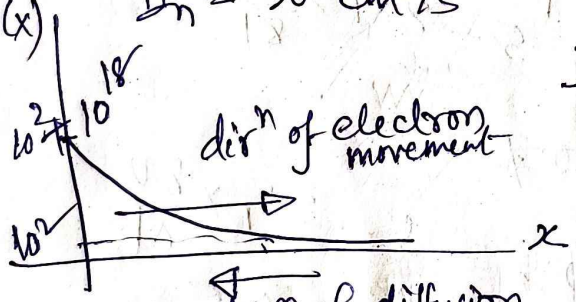
$= \dfrac{(8\times10^{-3})\times 2}{1.6\times10^{-19}\times(0.2\times0.2)\times1300\times 1}$

$= 0.19231\times10^{16}\ cm^{-3}$

$\boxed{N_A = 1.92\times10^{15}\ cm^{-3}}$

(b) $n(x) = 10^2 + 10^{18} e^{-x/L_n}$, $L_n = 20\ \mu m$

$D_n = 30\ cm^2/s$



$J_n = e D_n \dfrac{dn}{dx}$

$\dfrac{dn}{dx} = 10^{18} e^{-x/L_n}\left(\dfrac{-1}{L_n}\right)$

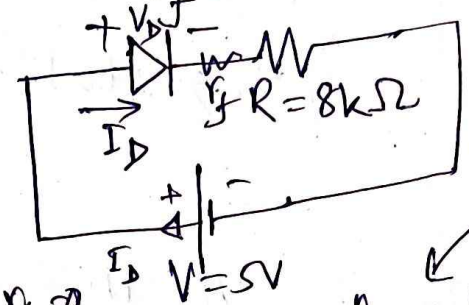
$J_n = -1.6\times10^{-19}\times 30\times\dfrac{10^{18}}{20\times10^{-6}\times10^2} e^{-x/L_n}$

$= -2.4\times10^3\, e^{-x/L_n}\ A/cm^2$

$\boxed{\begin{aligned}&\text{(i)}\ J_n = -2.4\times10^3\ A/cm^2\\ &\text{(ii)}\ J_n = -0.883\times10^3\ A/cm^2\\ &\text{(iii)}\ J_n = -0.535\times10^3\ A/cm^2\end{aligned}}$

2) (a) $V_\gamma = 0.6V$

$r_f = 20\Omega$



$$I_D = \frac{5 - 0.6}{20 + 8\times10^3}$$

$I_D = 0.549\ mA$

~~$V_D = 0.6V$~~

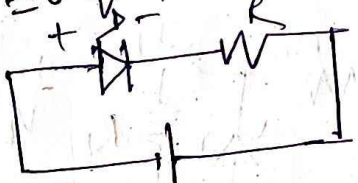
~~$P = 0.33mW$~~

$V_{D\text{on}} - V_\gamma - I_D r_f = 0$

$\Rightarrow V_D = V_\gamma + I_D r_f = 0.611V$

$P = I_D V_\gamma + I_D^2 r_f = 0.335mW$

forward bias



$I_D = 0$

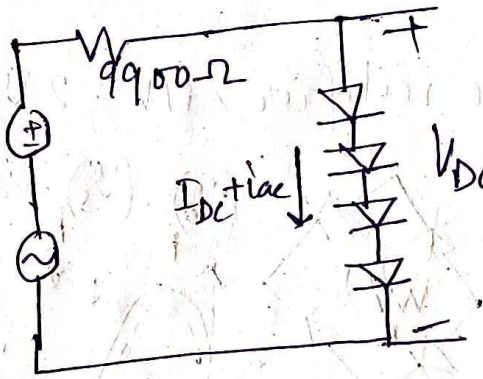
$V_D = -5V$

$P = 0$

→ reverse bias

$5 + V_D = 0 \Rightarrow V_\gamma = -5V$

(b)

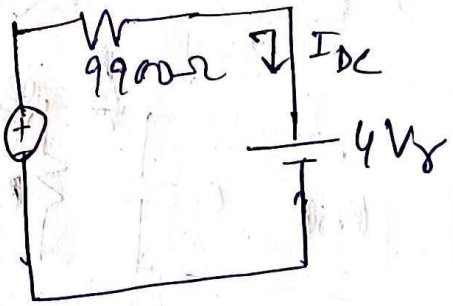


$V_\gamma = 0.7V$

$V_T = \frac{kT}{q} = 25mV$

$v_i = 100\cos\omega t\ mV$

~~$r_d = \frac{V_T}{I_{DC}}$~~



$$I_{DC} = \frac{12.7 - 4\times0.7}{9900}$$

$\boxed{I_{DC} = 1mA}$

$$r_d = \frac{V_T}{I_{DC}} = \frac{25}{1} = 25\Omega$$

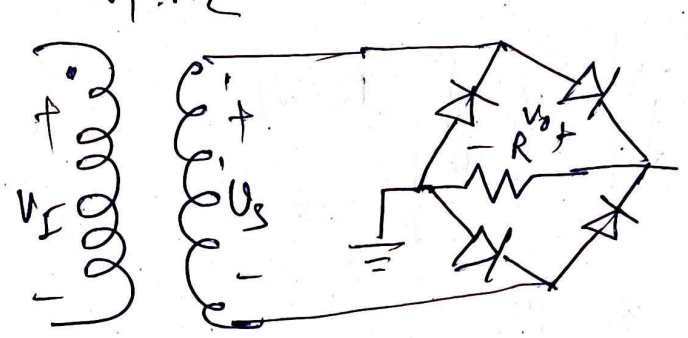
$$i_{ac} = \frac{(100mV)\cos\omega t}{9900 + 4\times25}$$

~~$V_t = V_0 (I_{DC} + i_{ac}) R$~~

$\boxed{v_{ac} = (1mV)\cos\omega t}$

$\boxed{i_{ac} = (0.01\ mA)\cos\omega t}$

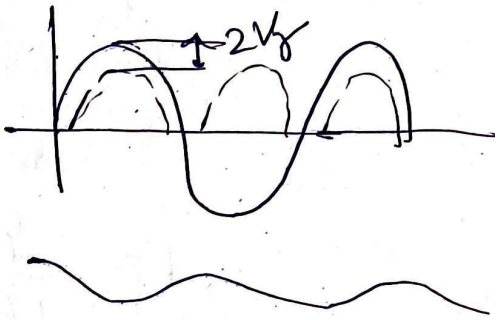
3)

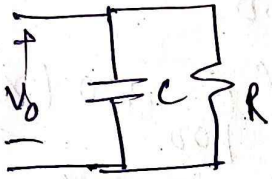


$$\frac{V_I}{V_s} = \frac{N_1}{N_2}$$

$$(PIV)_{bridge} = (V_s)_{max} - V_\gamma$$

$$(V_o)_{max} = (V_s)_{max} - 2V_\gamma$$





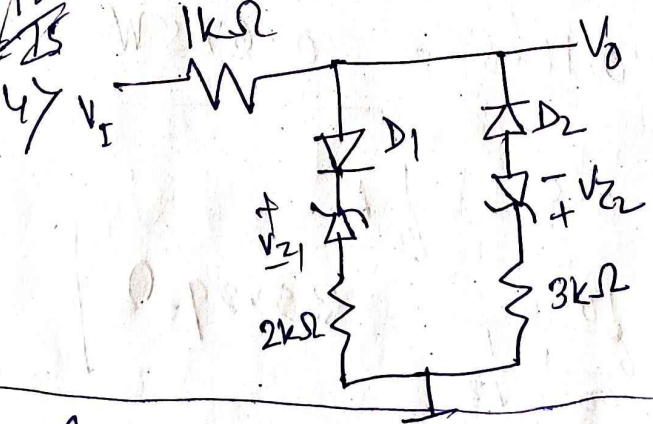
$(V_o)_{max} = 9V \Rightarrow (V_s)_{max} = 9 + 1.4 = 10.4\,V$

$$\text{turns ratio} = \frac{N_1}{N_2} = \frac{230\sqrt{2}}{10.4} = 31.3$$

$$PIV = 10.4 - 0.7 = 9.7\,V$$

$$C = \frac{0.1}{75} = 1.33\,mF$$

$I = \frac{9}{120} = 75\,mA$



$V_\gamma = 0.7V$

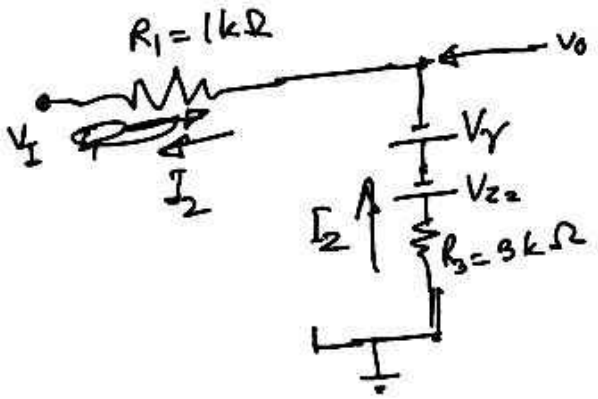
$V_{Z1} = 3V, V_{Z2} = 6V$

$-15V \le V_I \le 15V$

$$V_o = \begin{cases} V_I & \text{for } -6.7V \le V_I \le 3.7V \\ \frac{2V_I + 3.7}{3} & \text{for } V_I \ge 3.7V \\ \frac{3V_I - 6.7}{4} & \text{for } V_I \le -6.7V \end{cases}$$

2.

(4)



I_1, I_2, I_3 - mA

$V_I + I_2 \times 1 + V_\gamma + V_{z2} + I_2 \times 3 = 0$

$\Rightarrow 4I_2 = -V_I - 6.7$

$-V_I - 6.7 \geq 0$

$\Rightarrow V_I \leq -6.7V$

$V_o + V_\gamma + V_{z2} + I_2 \times 3 = 0$

$\Rightarrow V_o = -6.7 - \frac{3}{4}(V_I - 6.7)$

$= -6.7 + \frac{3}{4}(V_I + 6.7)$

$= \frac{3V_I + 3\times6.7 - 4\times6.7}{4}$

$= \frac{3V_I - 6.7}{4}$

$V_I - I_1 \times 1 - V_\gamma - V_{z1} - I_1 \times 2 = 0$

$\Rightarrow 3I_1 = V_I - 3.7$

for, $V_I \geq 3.7V$, $V_o = \frac{2V_I + 3.7}{3}$

for $V_I \leq -6.7V$, $V_o = \frac{3V_I - 6.7}{4}$

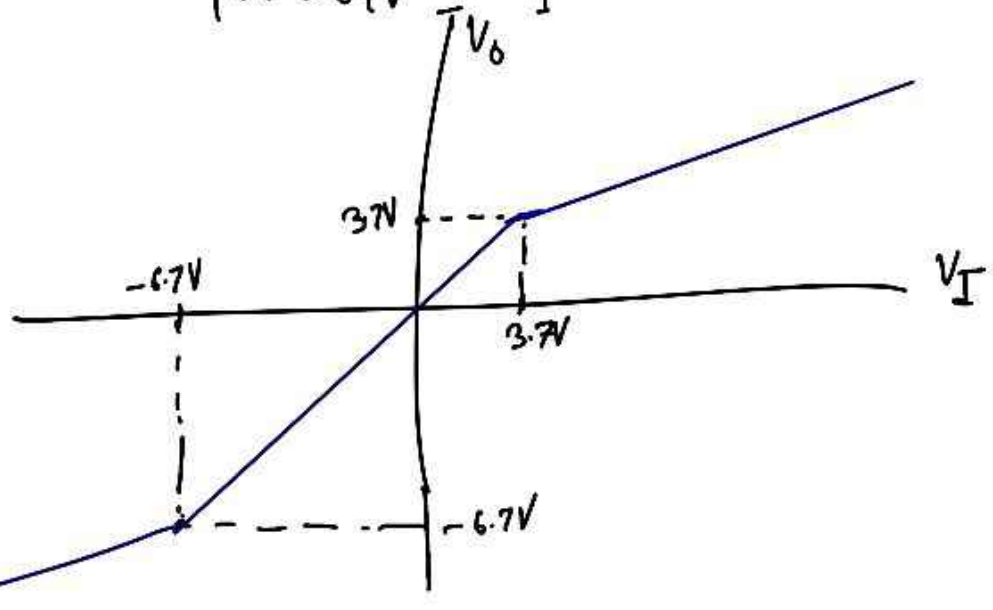
$V_o - V_\gamma - V_{z1} - I_1 \times 2 = 0$

$\Rightarrow V_o = 3.7 + \frac{2}{3}(V_I - 3.7)$

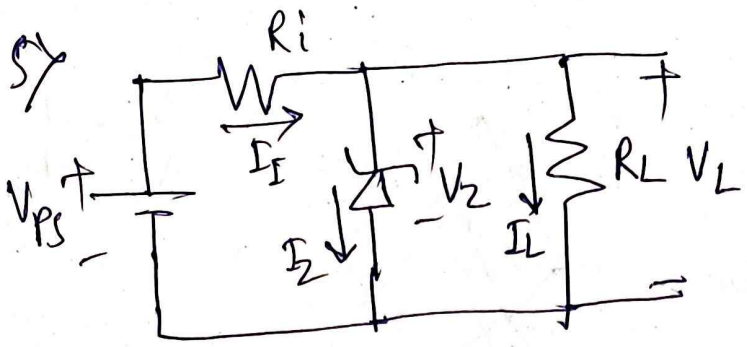
$= \frac{2V_I - 2\times3.7 + 3\times3.7}{3}$

$V_o = \frac{2V_I + 3.7}{3}$

for $-6.7V \leq V_I \leq 3.7V$, $V_o = V_I$



Sol



V_{PS} : 8V to 10V

$V_Z = 6V$

$(I_Z)_{min} = 0.1 (I_Z)_{max}$ $\qquad (I_Z)_{max} = x$

$$R_i = \frac{8-6}{\left(\frac{6}{100}\right) + 0.1x} = \frac{10-6}{\frac{6}{200} + x}$$

$$\Rightarrow 2\left(\frac{6}{200} + x\right) = 4\left(\frac{6}{100} + 0.1x\right)$$

$$\Rightarrow \frac{63}{200100} + x = \frac{12}{100} + 0.2x$$

$$\Rightarrow 0.8x = 0.12 - 0.03$$

$$= 0.09$$

$$\Rightarrow x = \frac{0.09}{0.8} A = 0.1125A$$

$$R_i = \frac{2}{0.06 + 0.1 \times 0.1125}$$

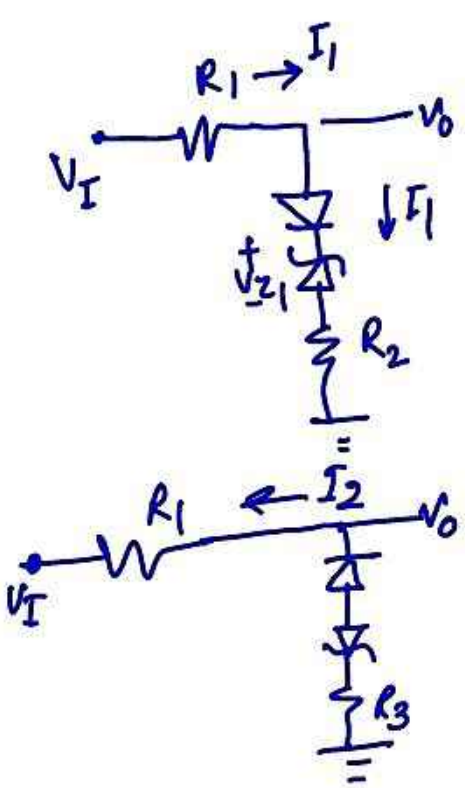
$$\boxed{R_i = 28.07\,\Omega}$$

$$\boxed{(P)_{max} = 6 \times 0.1125 = 0.675W}$$

(b) $(I_Z)_{max} = \frac{0.5}{6} = \frac{1}{12} A$

$$\boxed{R_i = \frac{10-6}{\frac{6}{200} + \frac{1}{12}} = 35.29\,\Omega}$$

(6)



$V_\gamma = 0.7V$

$V_I - I_1 R_1 - 0.7 - V_{Z_1} - I_1 R_2 = 0$

$\Rightarrow I_1 (R_1 + R_2) = V_I - 0.7 - V_{Z_1}$

$V_I \geq 0.7 + V_{Z_1}$

$0.7 + V_{Z_1} = 3$

$\Rightarrow \boxed{V_{Z_1} = 2.3V}$

$V_o - 0.7 - V_{Z_1} - I_1 R_2 = 0$

$\Rightarrow V_o = 3 + \frac{R_2}{R_1 + R_2}(V_I - 3)$

$\frac{R_2}{R_1 + R_2} = \frac{1}{3} \Rightarrow 3R_2 = R_1 + R_2$

$\Rightarrow \boxed{R_1 = 2R_2}$

$V_I + I_2 R_1 + 0.7 + V_{Z_2} + I_2 R_3 = 0$

$\Rightarrow I_2 (R_1 + R_3) = -V_I - 0.7 - V_{Z_2} \geq 0$

$\Rightarrow V_I \leq -0.7 - V_{Z_2} = -2$

$-0.7 - V_{Z_2} = -2$

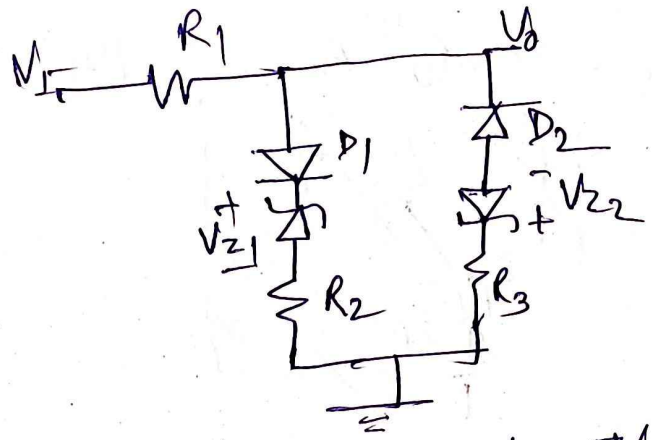
$\Rightarrow \boxed{V_{Z_2} = 2 - 0.7 = 1.3V}$

$V_o + 0.7 + V_{Z_2} + I_2 R_3 = 0$

$\Rightarrow V_o = -2 + \frac{R_3}{R_1 + R_3}(V_I + 2)$

$\frac{R_3}{R_1 + R_3} = \frac{1}{2} \Rightarrow \boxed{R_3 = R_1}$

6)



$V_{Z1} = 2.3V$, $V_{Z2} = 1.3V$

$R_2 = 1k\Omega$, $R_1 = 2k\Omega = R_3$

$R_1 = R_3 = 2R_2$

1) (a) $N_A = 1.92 \times 10^{15}\ cm^{-3}$

(b) (i) $J_n = -2.4 \times 10^3\ A/cm^2$

(ii) $J_n = -0.883 \times 10^3\ A/cm^2$

(iii) $J_n = -0.535 \times 10^3\ A/cm^2$

2) (a) forward bias → $I_D = 0.549\ mA$

$V_D = 0.611\ V$

$P = 0.335\ mW$

rev. bias → $I_D = 0$, $V_D = -5V$, $P = 0$

(b) $I_{DC} = 1\ mA$, $i_{ac} = (0.01\ mA)\cos\omega t$

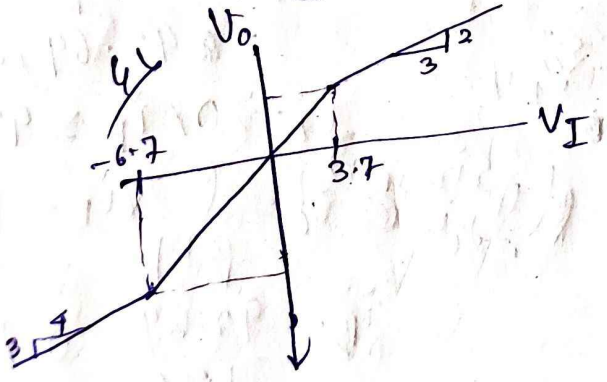
$v_{ac} = (1mV)\cos\omega t$

3) turns ratio = 31.3

PIV = 9.7V

C = 1.33 mF (doubt)

4)

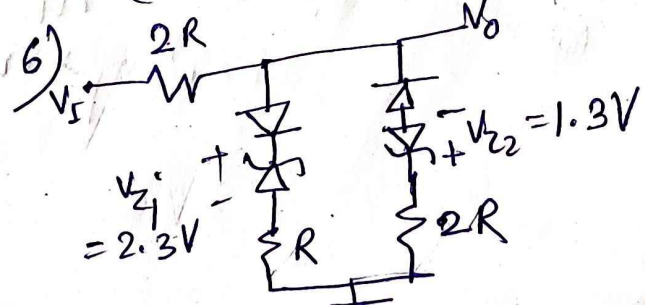


5) (a) $R_i = 28.07\ \Omega$

$(P)_{max} = 0.675\ W$

(b) $R_i = 35.29\ \Omega$

6)



2024 – Mid Autumn

PART B

	A_0	A_1
	$E_g = 1\,eV$	$E_g = 1.2\,eV$

1) (A) $n_i = BT^{3/2} e^{-E_g/2kT}$

$$\frac{(n)_{A_0}}{(n)_{A_1}} = e^{-\frac{E_{g_0} + E_{g_1}}{2kT}}$$

$$= \exp\left(\frac{-1 + 1.2}{2 \times 86 \times 10^{-6} \times 300}\right)$$

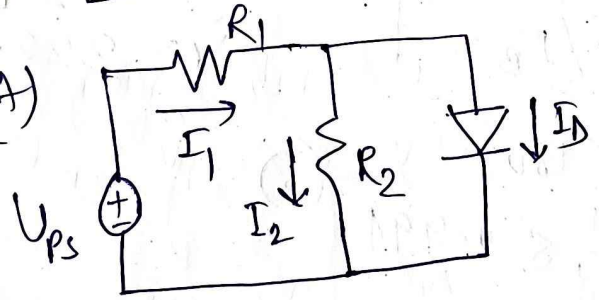
$$\boxed{\frac{(n)_{A_0}}{(n)_{A_1}} = 48.23}$$

(B) $J_n = e D_n \frac{dn}{dx}$

$$|J_n|_{diff} = 1.6 \times 10^{-19} \times 25 \times 10^{-3} \times 1250 \times 10^{21}$$

$$\boxed{(J_n)_{diff} = 5000\ A/cm^2}$$

2) (A)



$V_\gamma = 0.7V$

$6V \le V_{PS} \le 12V$

$(I_D)_{min} = 3mA$

$(P)_{max} = 15mW$

$I_D = I_1 - I_2$

$I_2 = \frac{V_D}{R_2}, \; I_1 = \frac{V_{PS} - V_D}{R_1}$

$I_D = \frac{V_{PS} - V_D}{R_1} - \frac{V_D}{R_2}$

$\frac{15}{0.7}$

$\frac{11.3}{R_1} - \frac{0.7}{R_2} = \frac{15}{0.7}$ — (ii)

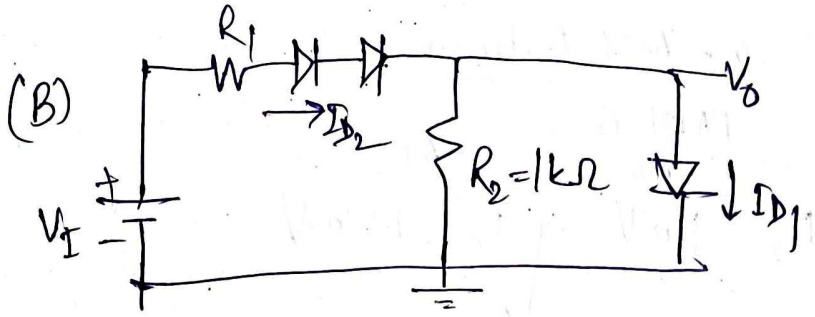
$3 = \frac{6 - 0.7}{R_1} - \frac{0.7}{R_2}$

$\Rightarrow \frac{5.3}{R_1} - \frac{0.7}{R_2} = 3$ — (i)

$\Rightarrow R_1 = 325.6\,\Omega$

$R_2 = 52.7\,\Omega$

(B)



$V_\gamma = 0.65V$

$V_I = 5V$

$I_{D_1} = \frac{1}{2} I_{D_2}$

$$I_{D_2} = \frac{5 - 0.65 \times 2 - 0.65}{R_1}$$

$$= \frac{5 - 0.65 \times 3}{R_1}$$

$$I_{D_1} = I_{D_2} - \frac{0.65}{1} = \frac{1}{2} I_{D_2}$$

$$\Rightarrow \frac{1}{2} I_{D_2} = 0.65$$

$$\Rightarrow \boxed{\begin{aligned} I_{D_2} &= 1.30\ mA \\ I_{D_1} &= 0.65\ mA \end{aligned}}$$

$$R_1 = \frac{5 - 0.65 \times 3}{1.30} \Rightarrow \boxed{R_1 = 2.35k\Omega}$$

3) (A) $I_C = \beta I_B$

(a) I_C / I_B

(B) $\beta + 1 = \frac{325}{2.8} \Rightarrow \beta \simeq 115$

$i_C = 322.2\mu A$ — (a)

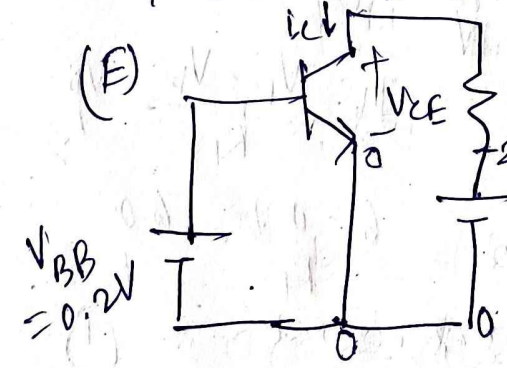
(C) $110 \leq \beta \leq 180$ — (b)

$0.991 \leq \alpha = \frac{\beta}{\beta+1} \leq 0.994$

(D) $i_E = 1.25\ mA$, $\beta = 150$

$1.25 = 151 \times i_B \Rightarrow i_B = 8.28\mu A$ — (a)

(E)



$i_C = 0$, $V_{CE} = 0.2V$

(a)

(E) $\beta = 125$, $v_{BE} = 0.615\,V$.

$$i_C = I_S e^{v_{BE}/V_T}\left(1 + \frac{v_{CE}}{V_A}\right)$$

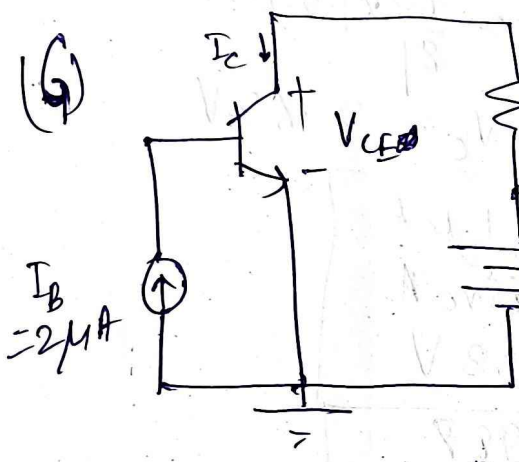
$$\simeq 5\times10^{-15}\, e^{0.615/0.026}$$

$$= 93.69\,\mu A$$

$$I_B = 0.75\,\mu A$$

$$I_E = 94.44\,\mu A \quad \Big] \text{—(b)}$$

(G)



$\beta = 120$

$I_C = \beta I_B$

$= 240\,\mu A$

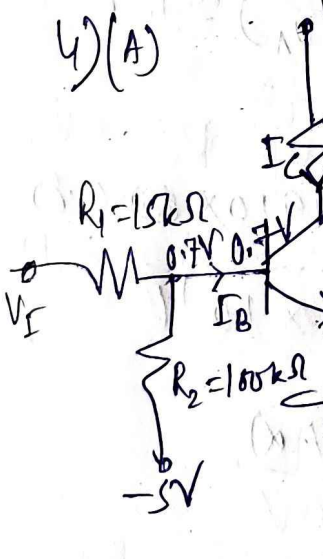
$$2 - \frac{240\times4}{1000} - V_{CE} = 0$$

$$\frac{0.7 - V_I}{15} + \frac{5.7}{100} \geq 0 \Rightarrow V_{CE} = 1.04\,V \quad \text{—(b)}.$$

$$\Rightarrow \frac{V_I}{15} \leq \frac{0.7}{15} + \frac{5.7}{100} \Rightarrow V_I \leq 0.7$$

$$\Rightarrow V_I \leq 1.555 + \frac{5.7}{100}\times15$$

4)(A)



$\beta = 25$ / $1.0V \leq V_{CE} \leq 4.5V$

$$5\left(\frac{0.7 - V_I}{15} + \frac{5.7}{100}\right) = \left(\frac{5 - V_{CE}}{1}\right)$$

$$\Rightarrow 5\left(\frac{20(0.7 - V_I) + 5.7\times3}{60}\right) = 5 - V_{CE}$$

$$\Rightarrow 14 - 20V_I + 17.1 = 60 - 12V_{CE}$$

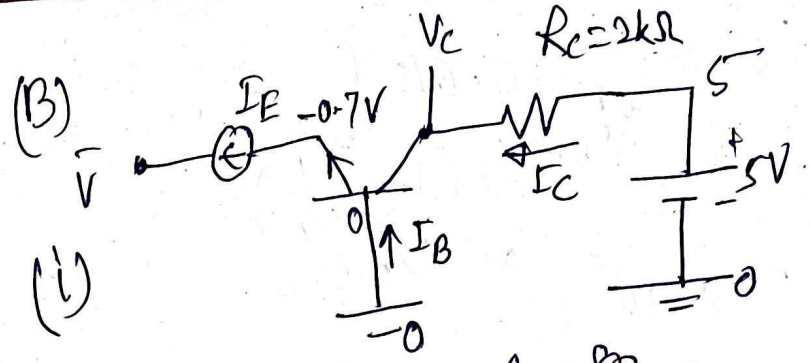
$$\Rightarrow 31.1 - 20V_I = 60 - 12V_{CE}$$

$$\Rightarrow 20V_I = 12V_{CE} - 28.9$$

$$V_I = \frac{12V_{CE} - 28.9}{20}$$

$$-0.845\,V \leq V_I \leq 1.225\,V$$

(B)



(i)

$\beta = 80$

$I_E = 1.2mA$

$I_B = \frac{1.2}{81}$ mA, $I_C = \frac{80}{81} \times 1.2$ mA

$5 - V_C = \frac{80}{81} \times 1.2 \times 2$

$\Rightarrow V_C = 2.63V$

$I_B = 14.81\,\mu A$
$I_C = 1.185mA$
$V_C = 2.63\,V$
$\alpha = 0.988$

(ii) $\alpha = 0.9910$, $I_E = 0.80mA$

$I_S = 5 \times 10^{-14} A$.

$I_C = \alpha I_E = I_S e^{V_{BE}/V_T}\left(1 + \frac{V_{CE}}{V_A}\right) \simeq I_S e^{V_{BE}/V_T}$

$\Rightarrow V_{BE} = V_T \ln\left(\frac{\alpha I_E}{I_S}\right)$

$\alpha = \frac{\beta}{\beta+1} \Rightarrow \beta = \alpha\beta + \alpha \Rightarrow \beta = \frac{\alpha}{1-\alpha}$

$= 0.026 \ln\left(\frac{0.9910 \times 0.80 \times 10^{-3}}{5 \times 10^{-14}}\right)$

$V_{BE} = 0.6107\,V$

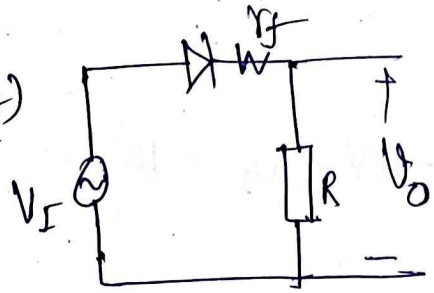
$1 - \alpha + \alpha$

$i_B = \frac{i_E}{\beta+1} = \frac{i_E}{1 + \frac{\alpha}{1-\alpha}} = \frac{i_E(1-\alpha)}{1}$

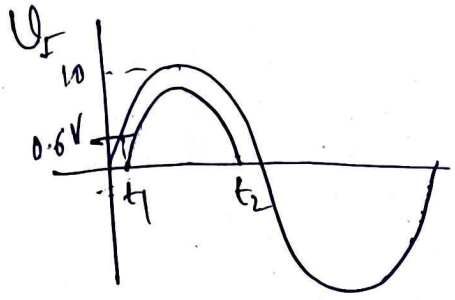
$\Rightarrow i_B = 7.2\,\mu A$

$i_C = 0.793\,mA$

5) (A)



$V_I = 10 \sin \omega t$
$R = 1\,k\Omega$
$V_\gamma = 0.6\,V$
$r_f = 20\,\Omega$.



$$V_0 = \frac{R}{R+r_f}(V_I - V_\gamma), \quad V_I \geq V_\gamma$$

$$\langle V_0 \rangle = \frac{R}{R+r_f} \frac{\int_{t_1}^{t_2} (V_I - V_\gamma)\, dt}{T}$$

$$= \left(\frac{R}{R+r_f}\right) \frac{\int_{t_1}^{t_2} (10 \sin \omega t - 0.6)\, dt}{T}$$

$10 \sin \omega t = 0.6$
$\Rightarrow \omega t_1 = 3.44^\circ$
$\omega t_2 = 176.56^\circ$

$$= \frac{R}{R+r_f} \times \frac{\frac{10}{\omega}[\cos \omega t_1 - \cos \omega t_2] - 0.6(t_2 - t_1)}{\frac{2\pi}{\omega}}$$

$$= \frac{R}{R+r_f} \times \frac{10(\cos \omega t_1 - \cos \omega t_2) - 0.6(\omega t_2 - \omega t_1)}{2\pi}$$

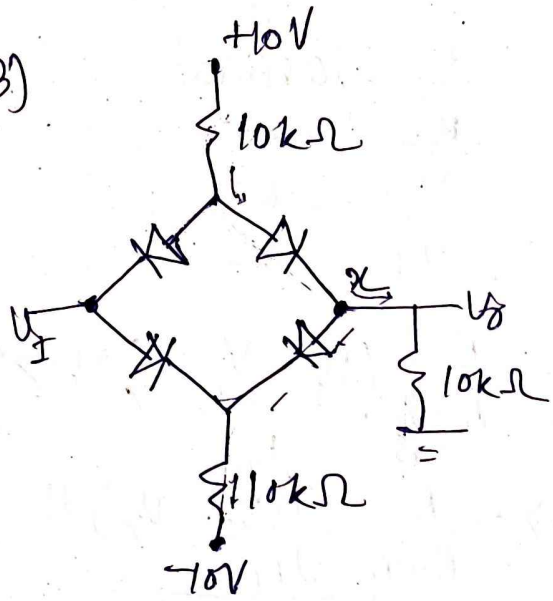
(i) $\boxed{\langle V_0 \rangle = 2.83\,V}$.

(ii) $\boxed{PIV = (V_I)_{peak} = 10\,V}$

(ii) $(I_D)_{peak} = \frac{10 - 0.6}{1020}\,A$

$\boxed{(I_D)_{peak} = 9.22\,mA}$.

(B)



$-10V \le v_I \le 10V$

for $v_I = 10V$,

$10 - i_1 \times 10 - 0.7 = x$

$x - 0.7 - 10i_1 = -10$

$\Rightarrow i_1 = \frac{9.3 + x}{10}$

$i_2 = \frac{x}{10}$

$\frac{9.3 - x}{10} = \frac{9.3 + x}{10} + \frac{x}{10}$

$\Rightarrow x = 0 \Rightarrow v_o = 0V$

$10 - 0.7 = 9.3$

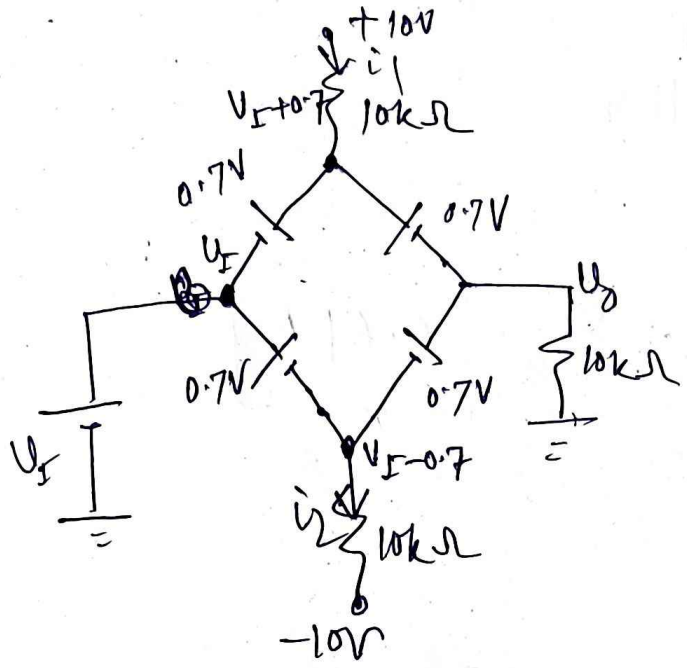
for $9.3 \le v_I \le 10V$, $v_o = 0V$

$10 - v_I \ge 0.7$

$v_I + 10 \ge 0.7$

$\Rightarrow -9.3 \le v_I \le 9.3$

for $-10V \le v_I \le -9.3V$, $v_o = 0V$

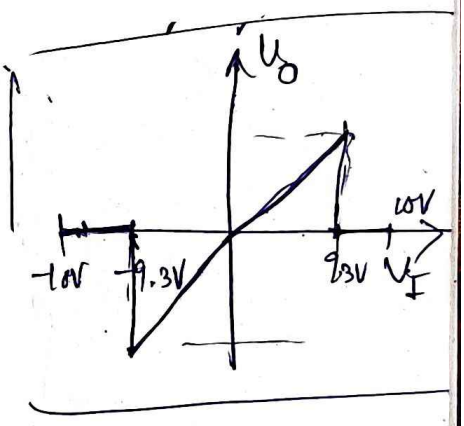


$10 - i_1 \times 10 - 0.7 - 0.7 - 10 i_2 = -10$

$\Rightarrow 10 i_1 + 10 i_2 = 18.6$

$\Rightarrow i_1 + i_2 = 1.86$ mA

$V_o = V_I$



b) (A) $f = 50$ Hz, $V_{D(on)} = 0.8$V

$V_{ripple} = 0.2$V, $V_m = 3.6$V

$V_s = V_o + 2V_r$

$PIV = V_s - V_r$

$= V_o + V_r$

$PIV = 4.4$V

$V_{ripple} = \frac{V_m}{2fRC}$

$P = \frac{V^2}{R} \Rightarrow R = \frac{3.6^2}{2}$

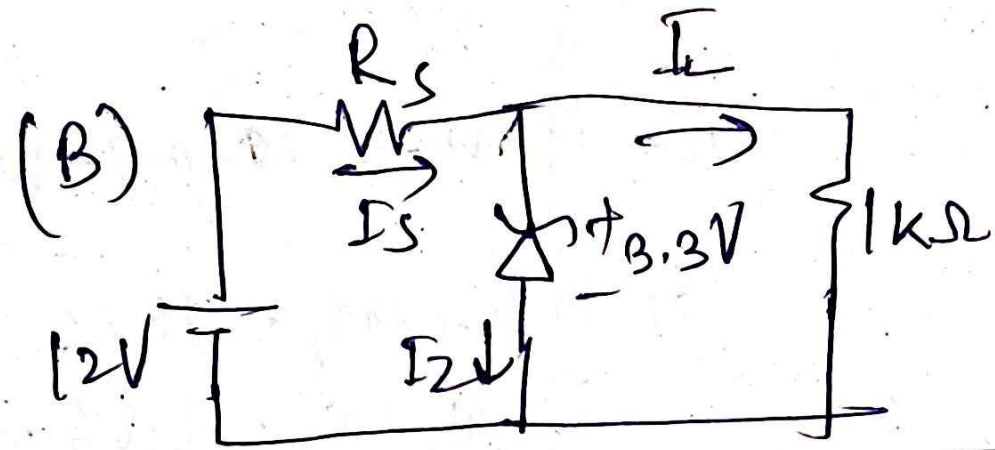
$= 6.48\,\Omega$

$C = \frac{3.6}{2 \times 50 \times 0.2 \times 6.48}$

$C = 27.78$ mF

3.6
0.8
4.4

(B)



$P_{max} = 2W \Rightarrow \boxed{(I_z)_{max} = \frac{2}{3.3} \simeq 0.61\ A}$

$$R_s = \frac{12 - 3.3}{I_z + I_L}$$

$$= \frac{12 - 3.3}{\frac{2}{3.3} + \left(\frac{3.3}{1000}\right)}$$

$$\boxed{(R_s)_{min} = 14.277\ \Omega}$$