— Homework – 1

1) $n \cdot p = n_i^2$, $n = p = 4 \cdot 10^{10}$ for intrinsic silicon ①

After doping Boron;

$$p_p \approx N_A = 10^{11}$$

$$n_p = \frac{n_i^2}{N_A} = \frac{16 \cdot 10^{20}}{10^{11}} = 1{,}6\ 10^{10}$$

2) $\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$

$$\Rightarrow \mu_p = \frac{D_p}{V_T} = \frac{16\ cm^2/s}{0{,}025\ V} = 640\ cm^2/Vs$$

$$\mu_n = \frac{D_n}{V_T} = 1440\ cm^2/Vs$$

P type; $N_A >> n_p$ $\Rightarrow$ $p_p = \frac{1}{q(N_A \cdot \mu_p)} = 1{,}4 \cdot 10^{16}/cm^3$

↳ e^- density in p type

n type; $N_D >> p_n$ $\Rightarrow$ $n_n = \frac{1}{q N_D \mu_n} = 1{,}2 \cdot 10^{16}/cm^3$

↳ hole density in n type

Remark; $N_A > N_D$, $\mu_n > \mu_p$ (in a pn junction)

$$\Rightarrow V_0 = V_T \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right) = 0{,}025V \cdot \ln\left(\frac{1{,}4 \cdot 1{,}2 \cdot 10^{32}}{10^{20}}\right)$$

$$\simeq 0{,}704\ V$$

, $W = x_n + x_p$ depletion width

$$W = \sqrt{\frac{2 \cdot \varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_0 + V_e)}$$ zero bias $\Rightarrow V_L = 0$

$$W = \sqrt{\frac{2 \cdot 12 \cdot 8{,}85 \cdot 10^{-12}}{1.6 \cdot 10^{-19}}\left(\frac{1}{1{,}2 \cdot 10^{16}} + \frac{1}{1.4 \cdot 10^{16}}\right) \cdot 0{,}7V}$$

$$= \sqrt{\frac{2 \times 12 \times 8{,}85 \cdot 10^{-10}\ F/cm}{1.6\, 10^{-19}}\left(\frac{2{,}64}{1.4 \times 1{,}2 \cdot 10^{16}}\right) cm^3 \cdot 0{,}7V} = 3{,}8\mu m$$

c) $\tau_p = \frac{L_p^2}{D_p}$, $\tau_n = \frac{L_n^2}{D_n}$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{16\ cm^2/s \cdot 0{,}8 \cdot 10^{-6} s} = 3{,}6\ \mu m$$

$$L_n = \sqrt{\tau_n D_n} = \sqrt{36\ cm^2/s\ 0{,}8 \cdot 10^{-6} s} = 5{,}4\ \mu m$$

$$I = A\, q\, n_i^2 \left(e^{V/V_T} - 1\right)\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)$$

$$= 0{,}001 cm^2 \cdot 1.6 \cdot 10^{-19} \cdot 10^{20}/cm^6 \left(e^{0{,}7/0{,}025} - 1\right)\left(\frac{16\ cm^2/s}{3{,}6 \cdot 10^{-4} cm \cdot 1{,}2 \cdot 10^{16}/cm^3} + \frac{36 cm^2/s}{5{,}4 \cdot 10^{-4} cm\ 1{,}4 \cdot 10^{16}}\right)$$

$= 0{,}2\ A$

3

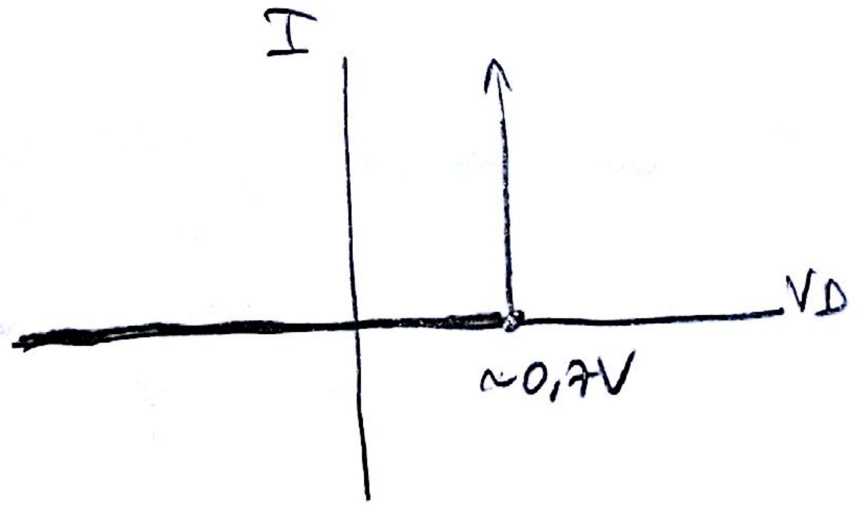
$$\frac{I_{D1} = I_s\left(e^{V_1/nV_T} - 1\right)}{I_{D2} = I_s\left(e^{V_2/nV_T} - 1\right)} \Rightarrow \frac{I_{D1}}{I_{D2}} \approx \frac{I_s}{I_s} \frac{e^{V_1/nV_T}}{e^{V_2/nV_T}}$$

$$\frac{I_{D1}}{I_{D2}} = e^{(V_1 - V_2)/nV_T}$$

$$\frac{7{,}2\,mA}{1{,}36\,mA} = e^{(0{,}05)/0{,}025 \cdot n}$$

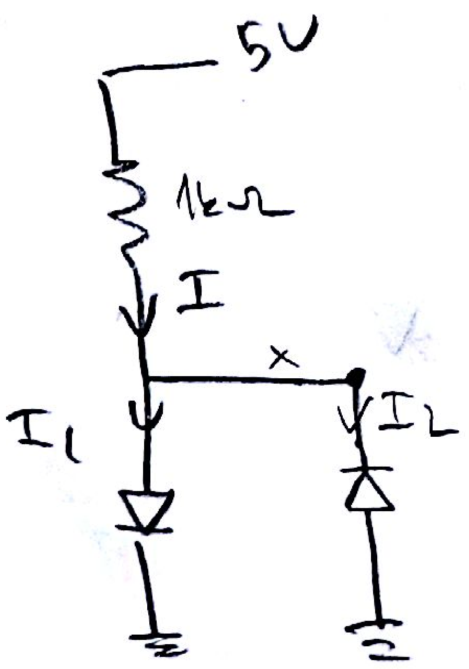
$$n = \frac{0{,}05}{0{,}025 \cdot \ln\left(\frac{I_{D1}}{I_{D2}}\right)} = 1{,}2$$

$$\Rightarrow 7{,}2^{mA} = I_s \cdot e^{0{,}05/1{,}2 \cdot 0{,}025} \Rightarrow I_s \cong 10^{-13} A$$



$\Rightarrow$ I–V characteristic of ideal diode.

a)

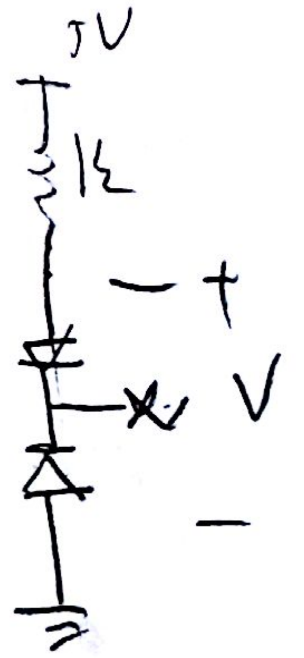


$V_x > 0 \Rightarrow I_2 = 0$

$V_x = V_D = 0{,}7V$

$5 - I_1 \cdot 1k\Omega - 0{,}7V = 0$

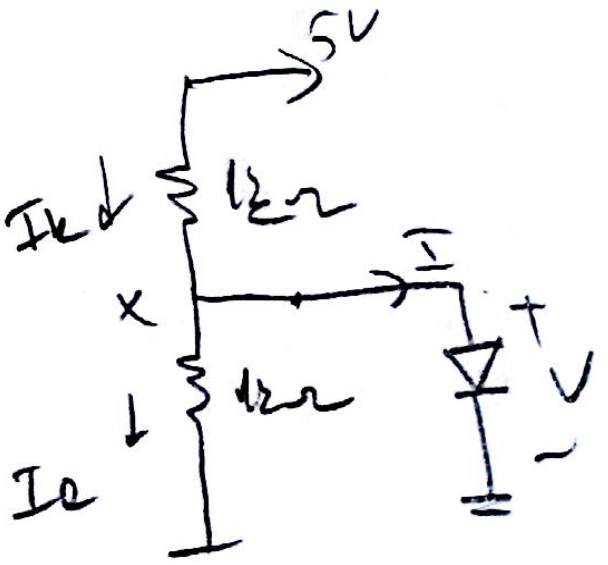
$I_1 = 4{,}3\,mA$



$V_x \geq 0 \Rightarrow I = 0$

$V = 5V$

c)



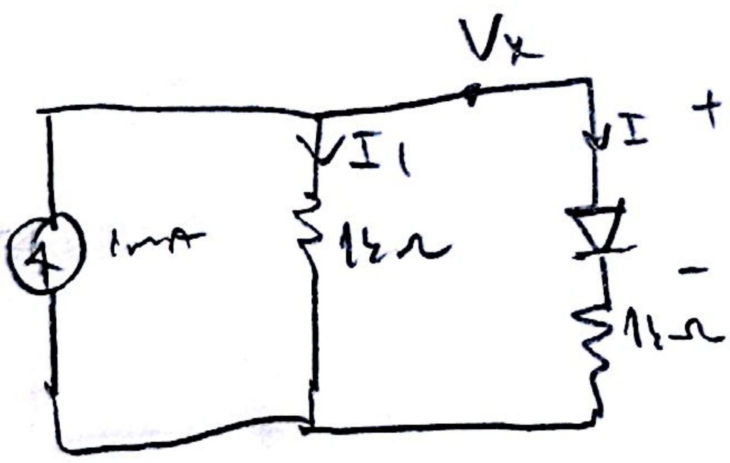
$V_{x\,min} = 0{,}7V$

$\frac{5 - 0{,}7}{1k} = I_k = 4{,}3mA$

$I_k = I_R + I = \frac{0{,}7V}{1k\Omega} + I = 4{,}3mA$

$I = 3{,}6mA$

d)



Assuming diode conducts

$1mA = I_1 + I$

$V_x = I_1 \cdot 1k\Omega = 0{,}7V + 1k\Omega I$

$(I_1 - I)\, 1k\Omega = 0{,}7V$

$I_1 - I = 0{,}7mA$

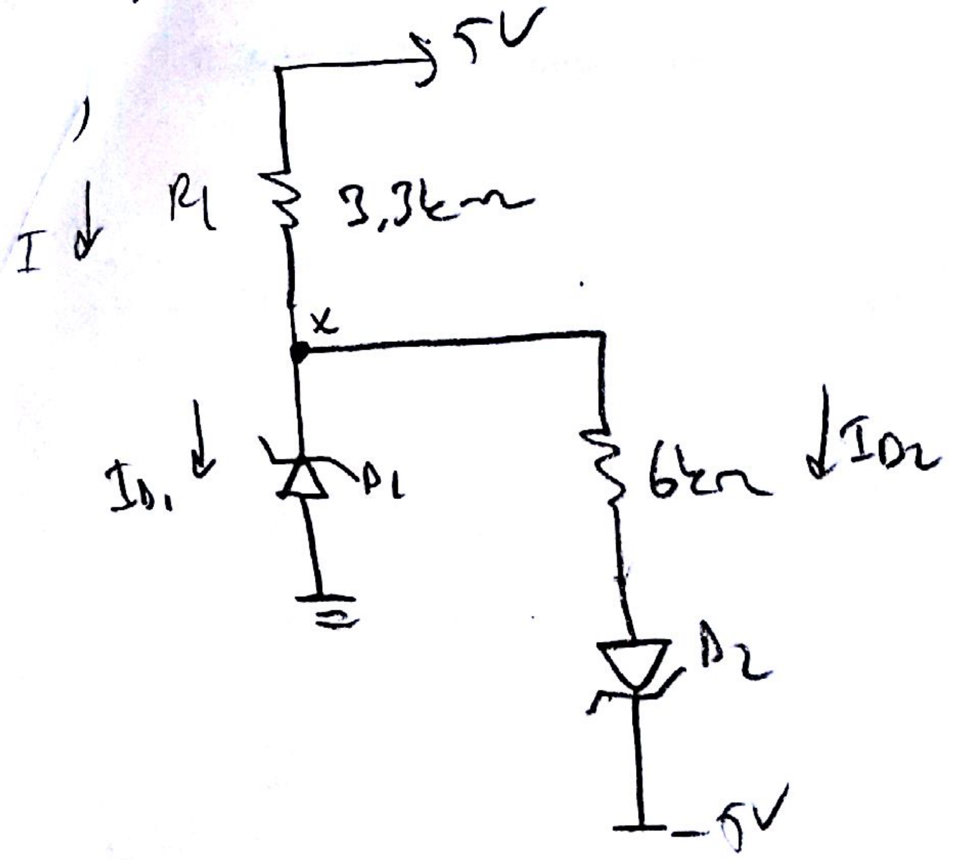
$I_1 + I = 1mA$

$I_1 = 0{,}85mA$

$I = 0{,}15mA$ ✓

$V = 0{,}7V$

(5)



If D_1, D_2 conducts, then $V_x \geq 3$

Assuming $V_x = 3V$

$$\Rightarrow \frac{3 - 0,7V + 5V}{6k\Omega} = I_{D2}$$

$$\frac{7,3V}{6k\Omega} = I_{D2} = 1,22\ mA$$

$$I = \frac{2}{3,3k\Omega} = 0,6\ mA$$

But I must be bigger than I_{D2}

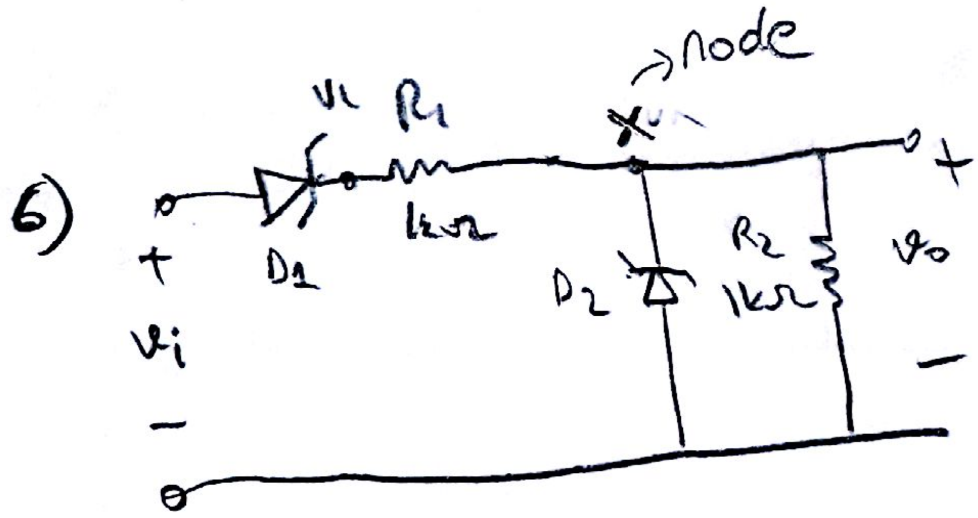
Therefore I_{D1} must be equal to zero.

Assuming only I_{D2} conducts;

$$I_{D2} = I = \frac{10 - 0,7}{3.3k\Omega} = 1mA \Rightarrow 5 - 3,3V \cdot \cancel{1mA} = V_x = 1,7V$$

Since $V_x = 1,7V < 3V \Rightarrow I_{D1} = 0$

6)



V_x: voltage of node X

i) Positive alternans;

Case-1

$0,7 > V_i > 0 \Rightarrow I_{D1} = 0, V_1 = 0, V_o =$

case 2

$4,7 > V_i > 0,7 \Rightarrow D_1$ conducts

$V_{1\,max} = 4,3V$

$V_{o\,max} = V_{Z_2} = 2V$

$I_{D1} = 2mA$ – 2,3m

Case-3

$V_i > 4,7V \Rightarrow I_{D1\,max} = 2,3mA$

ii) Negative alternans;

case 1;

$-2{,}7V < V_i < -0{,}7 \Rightarrow$ $I_{D2}=0$, $V_o=0$ up to $V_i=-2{,}7V$

case 2;

$V_i < -2{,}7 \Rightarrow$ $V_{o\,min} = -0{,}7V$

D_1 conducts $V_{x\,min} = -4{,}3V$

$I_{D_1 max} = I_{R_1 max} = \frac{4{,}3-2}{1k} = 2{,}3mA$

$I_{D_2 max} = 2{,}3mA - 0{,}7mA = 1{,}6mA$