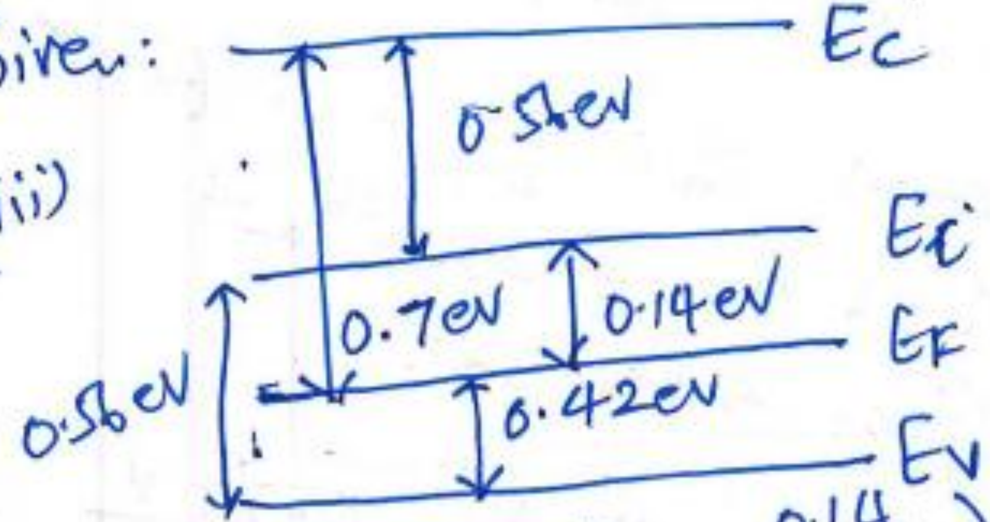
Solutions to Tutorial sheet 12

1) Given:

(iii)



$E_c - E_F = 0.7\,eV$

$p = n_i\, e^{\left(\frac{E_i - E_F}{kT}\right)}$

$kT = 26\ meV$

$n_i = 1.5 \times 10^{10}\ cm^{-3}$

(i) $p = 1.5 \times 10^{10}\left(e^{\frac{0.14}{.026}}\right) = \underline{3.27 \times 10^{12}\ cm^{-3}}$

$np = n_i^2 \Rightarrow n = 6.9 \times 10^{7}\ cm^{-3}$

(ii) $\sigma = q(n\mu_n + p\mu_p) = 2.61\ (\Omega\text{-cm})^{-1}$

$\rho = \frac{1}{\sigma} = 3.82\ k\Omega\text{-cm}$

2) (i) $\rho_p = 0.25\,\Omega\,cm \Rightarrow \sigma_p = \frac{1}{0.25} = 4\,(\Omega\,cm)^{-1}$

$\sigma_p = q p \mu_p$ ($\because$ $p\mu_p \gg n\mu_n$ for a p-type semiconductor and $n\mu_n \gg p\mu_p$ in a n-type semiconductor, ref. problem 1, 2).

$4 = 1.6\times10^{-19} \times p \times 500 \Rightarrow p = 5\times10^{16}\,cm^{-3}$

$n = \frac{n_i^2}{p} = 4.500\,cm^{-3}$.

$\rho_n = 0.1\,\Omega\,cm \Rightarrow \sigma_n = \frac{1}{0.1} = 10\,(\Omega\,cm)^{-1}$

$\sigma_n = q n \mu_n \Rightarrow n = 4.2\times10^{16}\,cm^{-3}$

$p = \frac{n_i^2}{n} = 5400\,cm^{-3}$.

(ii) $V_{bi} = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) = \underline{0.78\,V}$

3) Given I_s varies between 5×10^{-14} A to 5×10^{-12} A

$I_D = 2$ mA range A V_D ?

let $\eta = 1$

$$I_D = I_s\left(e^{\frac{V_D}{V_t}} - 1\right)$$

$$V_D = V_t \ln\left(\frac{I_D}{I_s} + 1\right) \qquad V_t = 26\text{ mV}$$

for $I_s = 5\times10^{-14}$ A $\quad V_D = 0.634$ V

$I_s = 5\times10^{-12}$ A $\quad V_D = 0.515$ V

V_D ranges from 0.515 V to 0.634 V

4)

Given $I_D = 150\mu A$ $I_S = 10^{-11} A$ $V_D = ?$

$$V_D = V_t \ln\left(\frac{I_D}{I_S} - 1\right) = \underline{0.43V}$$

$$R_D = \frac{V_D}{I_D} = \underline{2.86\,k\Omega}$$

$$r_d = \frac{V_t}{I_D} = 173\,\Omega$$

If V_D changes ~~from~~ by $0.1V$, $r_{av} = ?$

$$r_{av} = \frac{\Delta V_D}{\Delta I_D} = \frac{0.1}{(150\times10^{-6} - 3.3\times10^{-6})} = \underline{681\,\Omega}$$

5) Given $I_D = -0.9\, I_S$ $\quad V_D = ?$

$V_t = 0.026V$

$= 26\, mV$

$-0.9 I_S = I_S \left(e^{V_D/V_t} - 1 \right)$

$V_D = \underline{-0.06V}$

($\because$ in reverse bias I_D is opposite to that of original current direction)

$I_D = 0.9\, I_S$ results $V_D = +0.017V$ which is forward bias.

6)

$V_D = 0.2\,V \quad I_D = I_S\left(e^{V_D/V_t} - 1\right) = 2192.4\,I_S$

$V_D = -0.2 \quad I_D = -0.9995\,I_S$

$\left|\dfrac{I_D @ 0.2V}{I_D @ -0.2V}\right| = \underline{2193.4}$

7)

Given $V = 0.7V$

(i) Applying KVL, $V_{R_1} = 2 - 0.7 = 1.3V$

$V_{R2} = 0.7V.$

$$V_{R2} = \frac{2 \cdot R_2}{R_1 + R_2} = 0.7V$$

$$R_2 = 0.35 R_1 + 0.35 R_2 \Rightarrow \underline{R_2 = 538\ \Omega}$$

ii) $R_2 = 1k\Omega$

$$V_{R2} = 0.7V = \frac{2 \cdot R_2}{R_1 + R_2} \Rightarrow R_2 = 0.35 R_1 + 0.35 R_2$$

$$\Rightarrow R_1 = \underline{1.86\ k\Omega}$$

8)

$I = 15\,mA$

$I_0(D_1) = 5\,nA$

$I_0(D_2) = 10\,nA$

$I = I_0\left(e^{V_D/V_t} - 1\right) \Rightarrow V_D = V_t \ln\left(\frac{I}{I_0} + 1\right)$

$V_t = 26\,mV$ at $\underline{300K}$

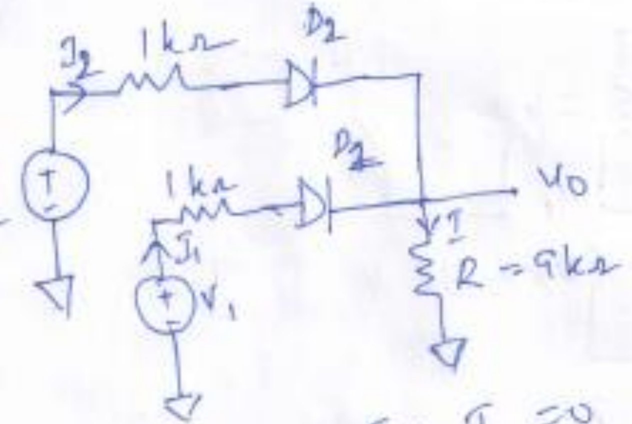
for D_1 : $V_{D1} = 0.026 \ln\left(\frac{15\times10^{-3}}{5\times10^{-9}} + 1\right) = 0.388V$

for D_2 : $V_{D2} = 0.37V$.

Applying KVL, $6 = 0.388 + 0.37 + I.R$

$\Rightarrow R = \underline{350\Omega}$

9)



$V_0 = IR$

$I = I_1 + I_2$

(i) $V_1 = V_2 = 0 \Rightarrow I_1 = I_2 = 0 \Rightarrow \underline{V_0 = 0V}$

(ii) $V_1 = 10V \quad V_2 = 0 \Rightarrow I_2 = 0. \quad I_1 = ?$

$I = I_1 + I_2 = I_1$

Applying KVL,

$$I_1 = \frac{10 - 0.6}{1k + 9k} = 0.94\,mA$$

$$V_0 = I_1 R = 0.94 \times 9k = \underline{8.46V}$$

(iii) $V_1 = 10V \quad V_2 = 10V.$

$I_1 = I_2 \qquad I = I_1 + I_2 \Rightarrow I_1 = I_2 = \frac{I}{2}$

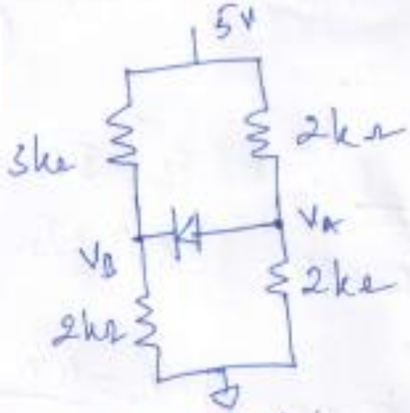
writing KVL,

$$10 = \frac{I}{2} \times 1k + 0.6 + I \cdot 9k$$

$$9.5k \cdot I = 9.4 \Rightarrow I = 0.989\,mA$$

$$V_0 = IR = 0.989 \times 9 = \underline{8.91V}$$

10)



KCL at node A:

$$\frac{5-V_A}{2k} = I_D + \frac{V_A}{2k} \quad -①$$

$$\frac{5-(V_A-V_D)}{2k} + I_D = \frac{V_A-V_D}{2k} \quad -②$$

① & ② $\Rightarrow$ $25 + 5V_D = 11V_A$

for $V_D = 0.6V$, $V_A = 2.545V$

$$I_D = \frac{5-V_A}{2k} - \frac{V_A}{2k} = (2.5 - V_A)\,mA$$

$$= -0.045mA$$

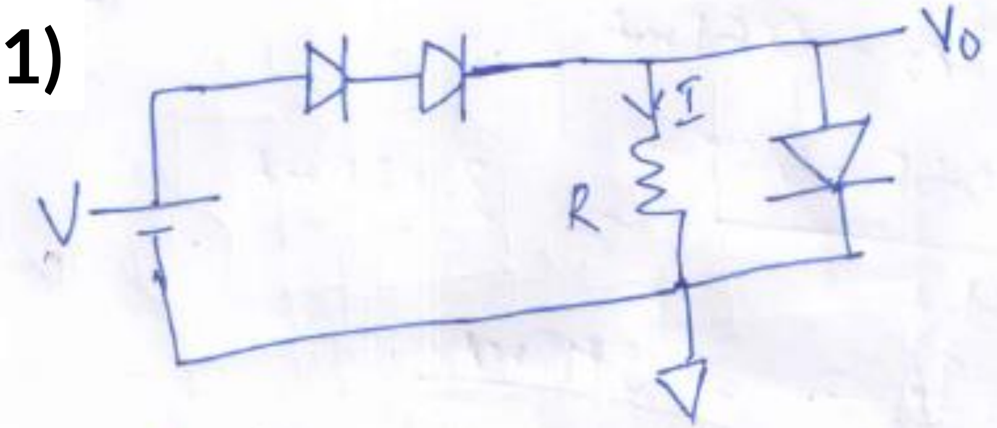
$I_D < 0 \Rightarrow$ diode is reverse biased.

So $I_D \simeq 0$

$V_A = 2.5V$ $\quad V_B = \frac{2k}{2k+3k} \cdot 5 = \underline{2V}$

$V_A - V_B = \underline{0.5V}$

11)



$I_0 = 2\times10^{-10}$ A

$V_t = 0.6$ V

$I = \frac{V_t}{1k\Omega} = 0.6$ mA

$I = I_0\left(e^{V_0/V_t} - 1\right) \Rightarrow V_D = V_t \ln\left(\frac{I}{I_0} + 1\right)$

$I = 0.6$ mA $\quad I_0 = 2\times10^{-10}$ A

$\Rightarrow V_D = 0.389$ V

KVL: $V = V_{D1} + V_{D2} + V_0 = \underline{1.378V}$

12)

given $I_{D1} = \frac{I_{D2}}{2} \Rightarrow I_{R2} = I_{D1} = \frac{I_{D2}}{2}$.

$I_{D1} = I_{R2} = \frac{0.65V}{1k\Omega} = \underline{0.65\,mA}$

$\therefore I_{D2} = \underline{1.3\,mA}$

(i) Applying KVL, $I_{D2} = \frac{V_I - 2V_D - V_O}{R_1}$

$\Rightarrow 1/R_1 = \frac{1.3\times10^{-3}}{5 - 2\times0.65 - 0.65} \Rightarrow R_1 = \underline{2.35\,k\Omega}$

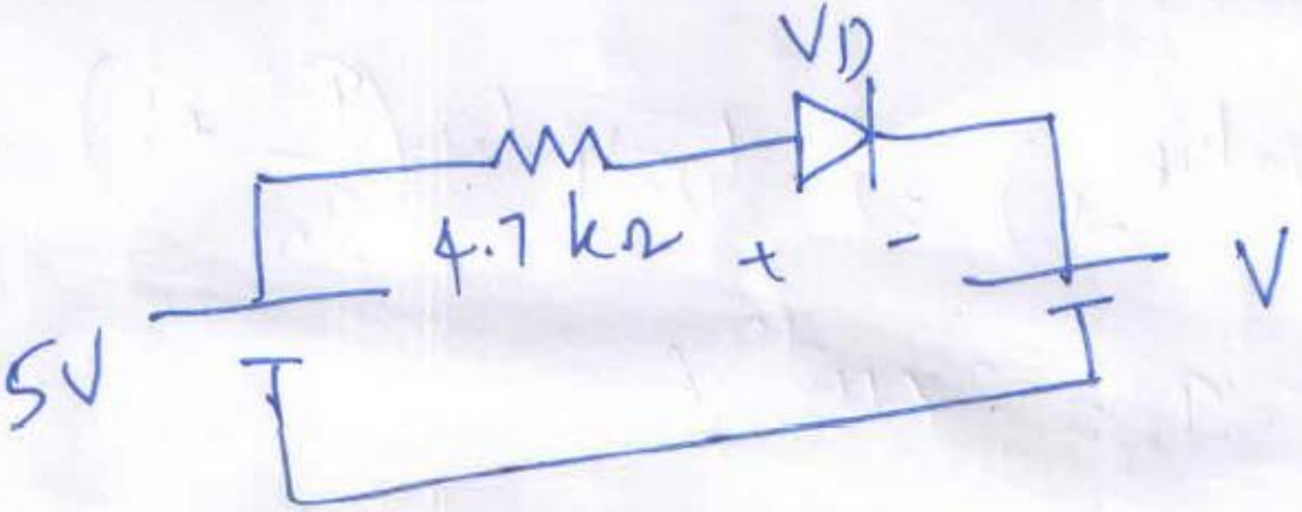
6

(ii) $V_I = 8V$ $I_{R2} = 0.65mA$

$I_{D2} = \frac{8 - 2\times0.65 - 0.65}{2k\Omega} = 3.025\,mA$

$I_{D1} = I_{D2} - I_{R2} = \underline{2.375\,mA}$

13)



$V_D = 0.7\,V$

$I_D = 0.4\,mA$

writing KVL,

$$5 = 4.7k\, I_D + 0.7 + V$$

$$\Rightarrow \underline{V = 2.42}$$

2.42 V