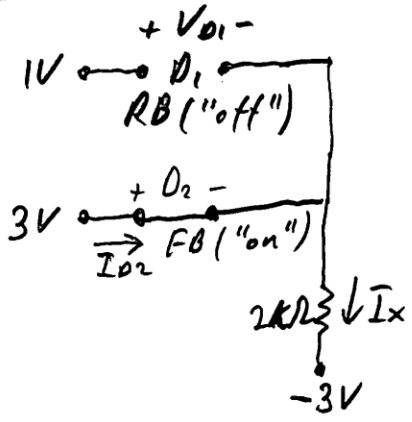
EECE 2412: HW3 Solutions

Problem 1:

$$I_x = \frac{3V-(-3V)}{2k\Omega} = \boxed{3mA = I_x}$$

a)



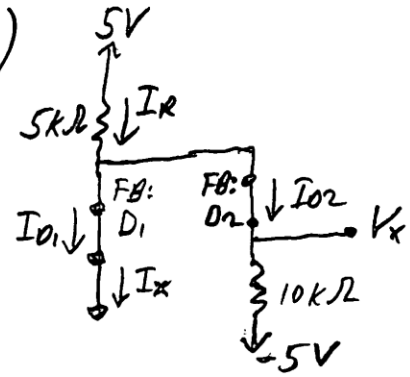
$\boxed{V_x = 3V}$

checks:

$V_{D1} = 1V - 3V = -2V < 0 \rightarrow$ D_1 is reverse-biased (RB)

$I_{D2} = I_x = 3mA > 0 \rightarrow$ D_2 is forward-biased (FB)

b)



$$I_R = \frac{5V-0V}{5k\Omega} = 1mA$$

$$I_{D2} = \frac{0V-(-5V)}{10k\Omega} = 0.5mA > 0 \rightarrow D_2 \text{ is forward-biased}$$

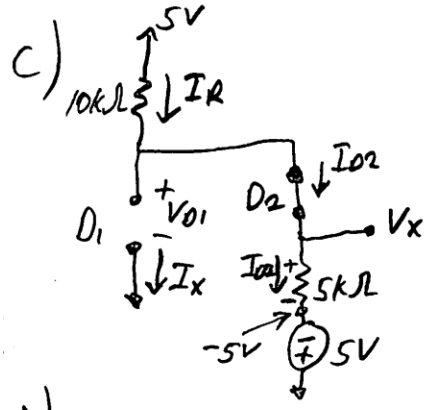
$0 = I_{D1} + I_{D2} - I_R$

$\hookrightarrow I_{D1} = I_R - I_{D2} = 1mA - 0.5mA = 0.5mA$

$I_{D1} > 0 \rightarrow D_1$ is forward-biased

$I_{D1} = \boxed{I_x = 0.5mA}$ $\quad \boxed{V_x = 0V}$

c)



$$I_{D2} = I_R = \frac{5V-(-5V)}{10k\Omega+5k\Omega} = 0.667mA > 0 \rightarrow D_2 \text{ is FB}$$

KVL: $0 = 5V - I_{D2} \cdot 5k\Omega + V_x$

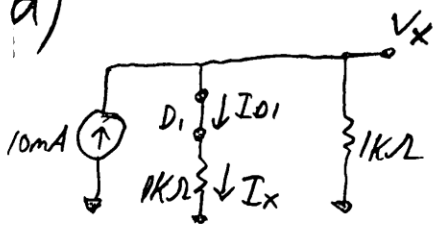
$\hookrightarrow V_x = (5k\Omega)(0.667mA) - 5V = \boxed{-1.667V = V_x}$

$\boxed{I_x = 0}$

check: $V_{D1} = V_x - 0V = -1.667V < 0$

$\hookrightarrow D_1$ is RB.

d)



$V_x = 10mA \cdot (1k\Omega \,\|\, 1k\Omega) = \boxed{5V = V_x}$

$$I_x = I_{D1} = \frac{V_x}{1k\Omega} = \frac{5V}{1k\Omega} = \boxed{5mA = I_x}$$

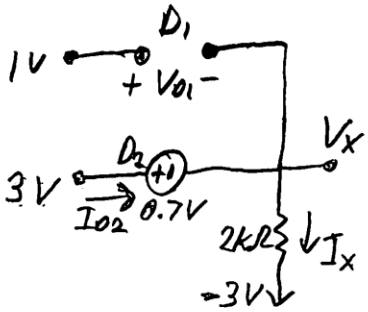
check: $I_{D1} > 0 \rightarrow D_1$ is FB.

Problem 2:

KVL: $0 = -3V + 0.7V + V_x \rightarrow \boxed{V_x = 2.3V}$

$$I_x = \frac{V_x - (-3V)}{2k\Omega} = \frac{5.3V}{2k\Omega} = \boxed{2.65mA = I_x}$$

a)

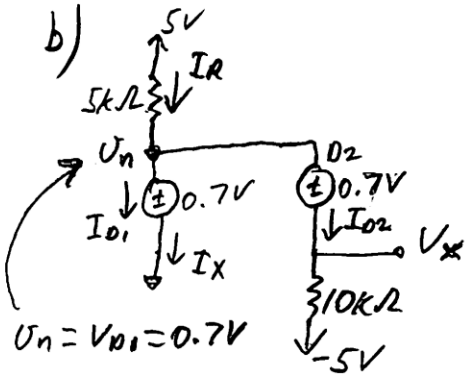


checks:

$I_{D2} = I_x = 2.65mA > 0 \rightarrow D_2$ is FB.

$V_{D1} = 1V - V_x = -1.3V < 0 \rightarrow D_1$ is RB.

b)



$$I_R = \frac{5V - 0.7V}{5k\Omega} = 0.86mA$$

KVL: $5V = I_R \cdot 5k\Omega + 0.7V + V_x$

$\hookrightarrow V_x = 5V - (0.86mA)\cdot(5k\Omega) - 0.7V = \boxed{0 = V_x}$

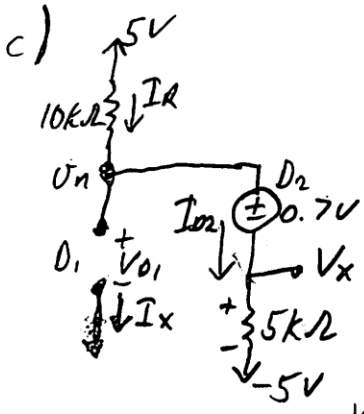
$$I_{D2} = \frac{V_x - (-5V)}{10k\Omega} = 0.5mA > 0 \rightarrow D_2 \text{ is FB.}$$

$I_x = I_{D1} = I_R - I_{D2} = 0.86mA - 0.5mA = \boxed{0.36mA = I_x}$

$\hookrightarrow I_{D1} > 0 \rightarrow D_1$ is FB.

$V_n = V_{D1} = 0.7V$

c)



$\boxed{I_x = 0}$ $\quad I_R = I_{D2}$

KVL: $5V = I_R \cdot (10k\Omega) + 0.7V + I_R \cdot (5k\Omega) - 5V$

$\hookrightarrow I_R = 0.62mA = I_{D2} > 0 \rightarrow D_2$ is FB.

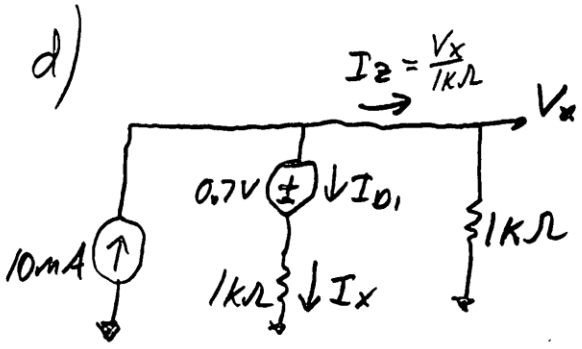
KVL: $-5V = -I_R \cdot 5k\Omega + V_x$

$\hookrightarrow V_x = -5V + (0.62mA)\cdot(5k\Omega) = \boxed{-1.9V = V_x}$

$V_{D1} = V_n = 5V - I_R \cdot 10k\Omega = 5V - (0.62mA)(10k\Omega) = -1.2V$

$V_{D1} < 0 \rightarrow D_1$ is RB.

d)



from KCL, ①: $I_x + \frac{V_x}{1k\Omega} = 10mA$

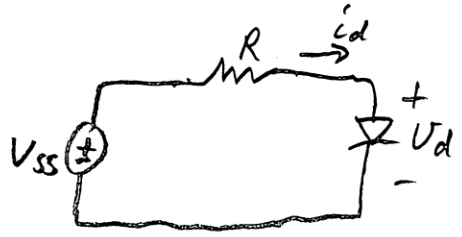
from KVL, ②: $-I_x \cdot 1k\Omega - 0.7V + V_x = 0$

Solving ① and ② simultaneously results in:

$\boxed{I_x = 4.65mA}$ $\quad \boxed{V_x = 5.35V}$

check: $I_{D1} = I_x > 0 \rightarrow D_1$ is FB.

Problem 3



KVL: $0 = -V_{ss} + R \cdot i_d + v_d$

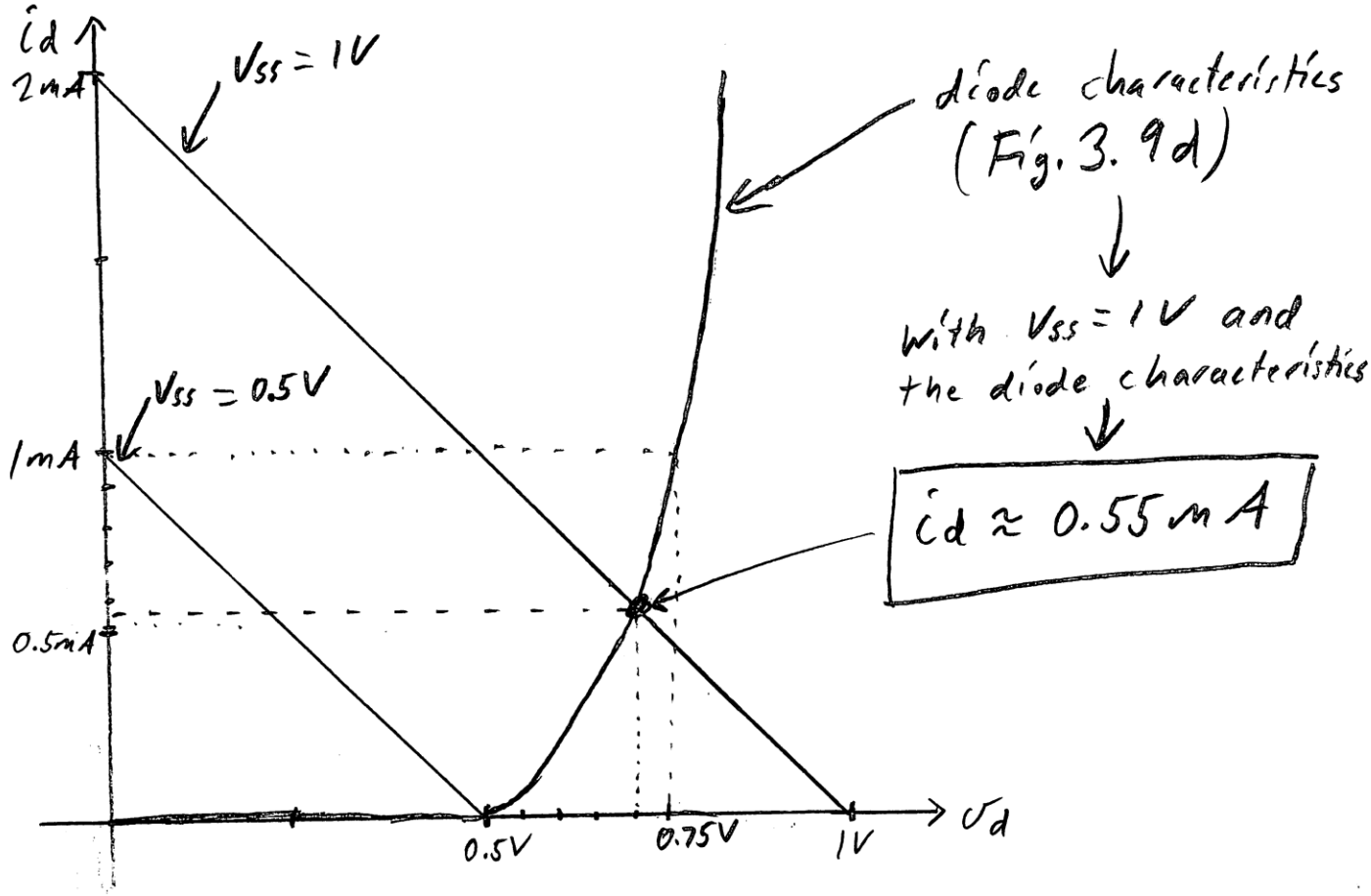
$\hookrightarrow i_d = \frac{V_{ss} - v_d}{R} = \frac{V_{ss}}{R} - \frac{v_d}{R}$

With $V_{ss} = 1\,V$ and $R = 500\,\Omega$: $i_d = \frac{1\,V}{500\,\Omega} - \frac{v_d}{500\,\Omega} = 2\,mA - v_d \cdot 2\,\frac{mA}{V}$

With $V_{ss} = 0.5\,V$ and $R = 500\,\Omega$: $i_d = 1\,mA - 2\,\frac{mA}{V}$

$\hookrightarrow$ <u>slope of the load line</u> in both cases: $-\frac{2\,mA}{V} = -\frac{1}{R}$

$\hookrightarrow$ No, the slope does not change when V_{ss} changes.



④ **Prob. 4**

a) $27°C = 300K$

equation 3.16 in the book:

$$V_T = \frac{k \cdot T}{q} = \frac{(1.38\times10^{-23})\cdot(300)}{1.60\times10^{-19}} = 25.875\ mV$$

equation 3.15 in the book:

$$I_D = I_S \cdot \left[e^{\left(\frac{V_D}{n\cdot V_T}\right)} - 1\right] \longrightarrow V_D = n\cdot V_T \cdot \ln\left(\frac{I_D}{I_S} + 1\right)$$

Since $\frac{I_D}{I_S} >> 1$ is assumed here:

①: $V_D \approx n \cdot V_T \cdot \ln\left(\frac{I_D}{I_S}\right)$

Using the two given measurement results to determine the emission coefficient:

$$V_{D2} - V_{D1} = n\cdot V_T \cdot \ln\left(\frac{I_{D2}}{I_S}\right) - n\cdot V_T \cdot \ln\left(\frac{I_{D1}}{I_S}\right)$$

$$V_{D2} - V_{D1} = n\cdot V_T \cdot \ln\left(\frac{I_{D2}}{I_{D1}}\right)$$

$$0.6 - 0.5 = n\cdot(25.875\times10^{-3})\cdot\ln\left(\frac{100\times10^{-6}}{5\times10^{-6}}\right)$$

$$\rightarrow \boxed{n = 1.29}$$

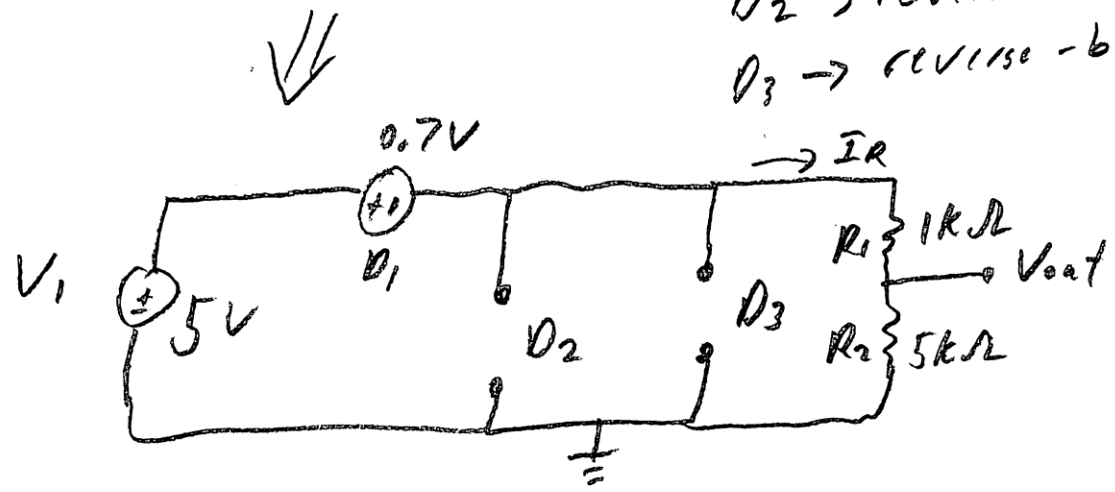
b) Rearranging equation ① above:

$$I_S = \frac{I_D}{e^{\frac{V_D}{n\cdot V_T}}} = \frac{5\times10^{-6}}{e^{\frac{0.5}{(1.29)\cdot(25.875\times10^{-3})}}}$$

$$\boxed{I_S = 1.561\times10^{-12}\ A = 1.561\ pA}$$

Problem 5

a) Equivalent circuit with: $D_1 \rightarrow$ forward-biased
$D_2 \rightarrow$ reverse-biased
$D_3 \rightarrow$ reverse-biased



KVL: $0 = -5V + 0.7V + I_R \cdot (R_1 + R_2)$

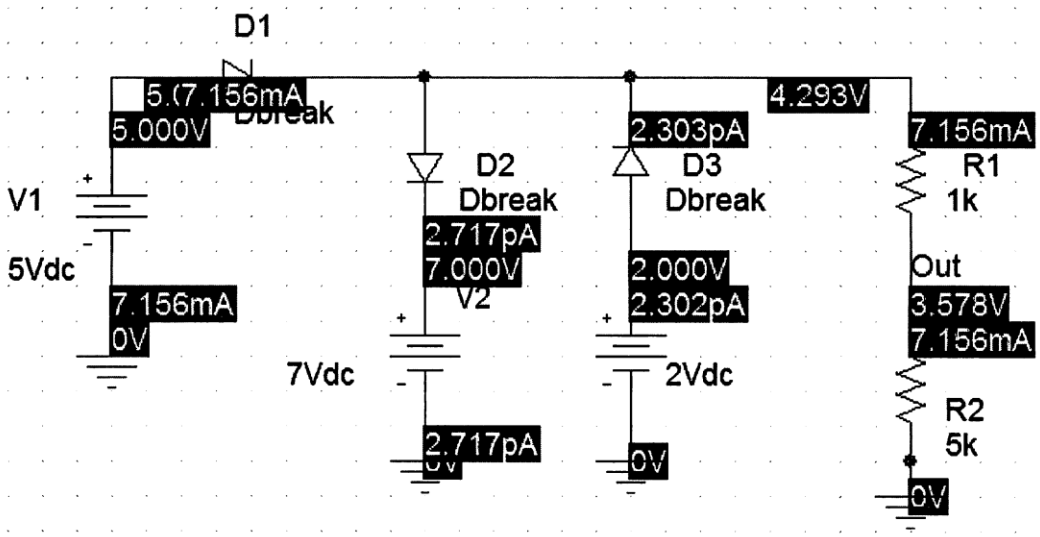
$\hookrightarrow I_R = \frac{5V - 0.7V}{1k\Omega + 5k\Omega} = 0.717mA$

$V_{out} = I_R \cdot R_2 = (0.717mA) \cdot (5k\Omega) = \boxed{3.583V = V_{out}}$

$\rightarrow$ The value is close to the simulation result of 3.578V (see next page).

Problem 5 , Part b)

Verification with V1 = 5V:



Part c) Transfer characteristic: