Ee40 HW 5 p1.

10.11

$$i_D = I_s\left[e^{v_D/nV_T} - 1\right]$$

$$\rightarrow I_s = \frac{i_D}{e^{v_D/nV_T} - 1} = \frac{0.2\times10^{-3}}{\left(e^{0.6/(2\times0.026)} - 1\right)} = 1.950\times10^{-9}\,A$$

for $v_D = 0.65V$:

$$i_D = 1.950\times10^{-9}\left[e^{0.65/(2\times0.026)} - 1\right] = \boxed{0.5321\,mA}$$

for $v_D = 0.70V$

$$i_D = 1.950\times10^{-9}\left[e^{0.70/(2\times0.026)} - 1\right] = \boxed{1.369\,mA}$$

10.13

When the switch is open:

$$I_s = \frac{i_{D1}}{e^{v/V_T} - 1} = \frac{10^{-3}}{e^{0.6/0.026} - 1} = 9.502\times10^{-14}\,A$$

When the switch is closed

$$i_{D1} = i_{D2} = 0.5\,mA$$

$$v = nV_T \ln\left[\frac{i_D}{I_s} + 1\right] = 0.026 \ln\left[\frac{0.5\times10^{-3}}{9.502\times10^{-14}} + 1\right] = \boxed{582.0\,mV}$$

For $n=2$:

$$I_s = \frac{10^{-3}}{e^{0.6/(2\times0.026)} - 1} = 9.748\times10^{-9}\,A$$

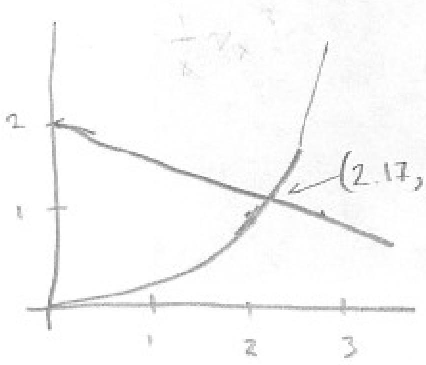
$$v = 2\times0.026 \ln\left(\frac{0.5\times10^{-3}}{9.748\times10^{-14}} + 1\right) = \boxed{1.163\,V}$$

10.16

Load line: $i_x = \frac{V_s}{R_s} - \frac{1}{R_s}v_x = 2 - \frac{1}{3}v_x$

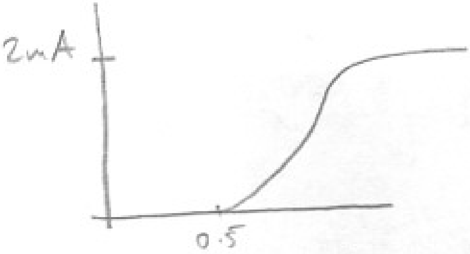
nonlinear: $i_x = \frac{1}{8}v_x^3$

$\boxed{\begin{array}{l} i_x = 1.28\,A \\ v_x = 2.17\,V \end{array}}$

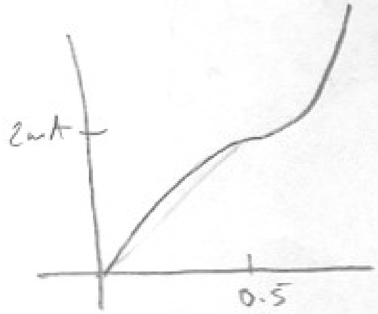


10.21

(a) $v_a(i_a) = v(i_a) + v_x(i_a)$ (series → same current, voltage adds)

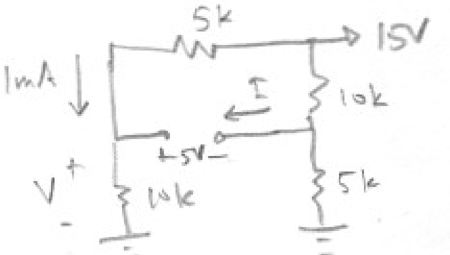


(b) $i_b(v_b) = i(v_b) + i_x(v_b)$ (parallel → same voltage, add current)



10.33

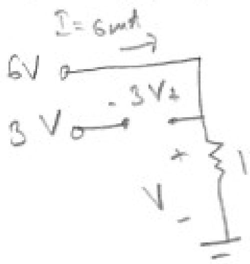
(a) D_1 on D_2 off



$V = \frac{10}{10+5} 15 = \boxed{10V}$

$I = \boxed{0A}$

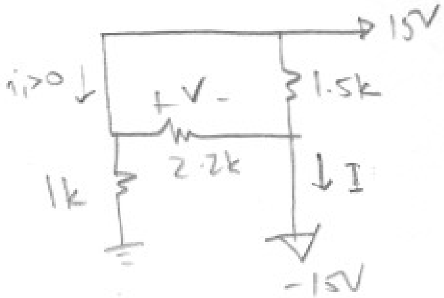
(b) D_1 on D_2 off



$V = \frac{6mA}{1k} = \boxed{6V}$

$I = \frac{6V}{1k} = \boxed{6mA}$

(c) Both on

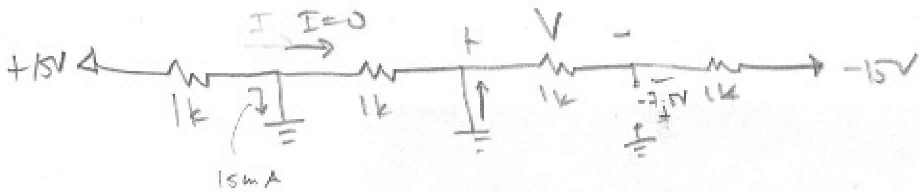


$V = \boxed{30V}$

$I = \frac{30V}{1.5k \| 2.2k} = 33.6\,mA$

10.34

(a) on/on/off

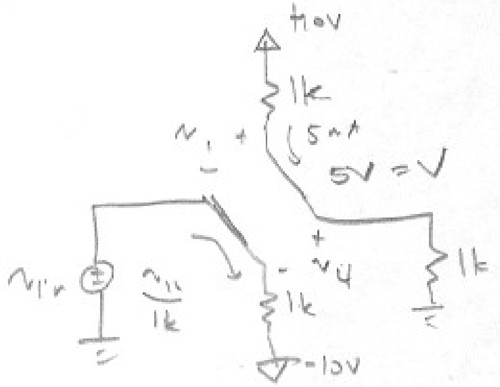


$V = \frac{1}{2}(15V) = \boxed{7.5V}$

$I = \frac{0V - 0V}{1k} = \boxed{0A}$

(b)

V_{in}	D_1	D_2	D_3	D_4	V	I
0	on	on	on	on	0	0
2	on	on	on	on	2V	2mA
6	off	on	on	off	5V	5mA
10	off	on	on	off	5V	5mA

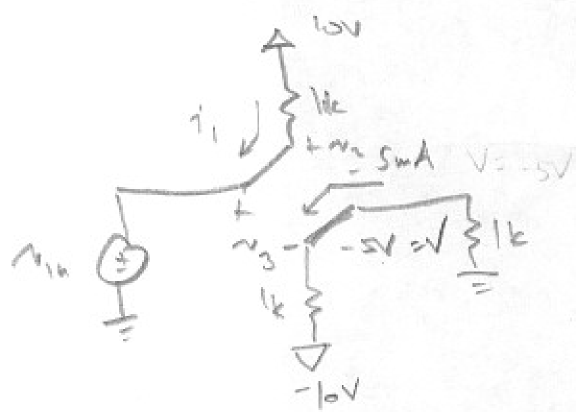


Need $v_1 < 0 \rightarrow v_{in} > 5V$

$i_3 = \frac{v_{in}}{1k} > 0 \rightarrow v_{in} > 0$

$v_4 < 0 \rightarrow v_{in} > 5V$

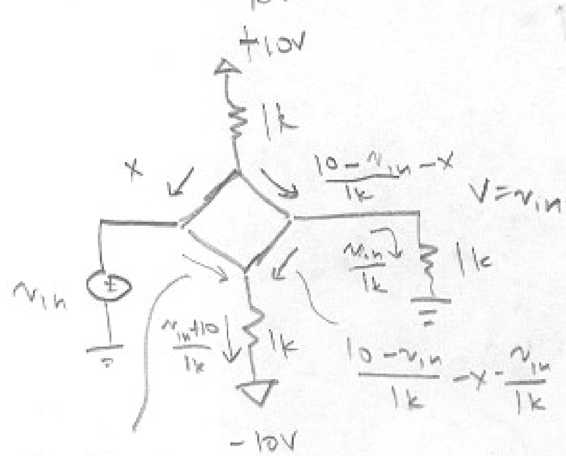
So for $v_{in} > 5V$ $V = 5V$



Need: $i_1 > 0 \rightarrow v_{in} < 10V$

$v_2 = v_3 < 0 \rightarrow v_{in} < -5V$

So for $v_{in} < -5V$ $V = -5V$



Need $x > 0$ (i)

$\frac{10 - v_{in} - x}{1k} > 0 \rightarrow x < \frac{10 - v_{in}}{1k}$ (ii)

$\frac{v_{in} + 10}{1k} - \left(\frac{10 - v_{in}}{1k} - x - \frac{v_{in}}{1k}\right) > 0 \rightarrow x > \frac{-3v_{in}}{1k}$ (iii)

$\frac{10 - v_{in}}{1k} - x - \frac{v_{in}}{1k} > 0 \rightarrow x < \frac{10 - 2v_{in}}{1k}$ (iv)

$\frac{v_{in} + 10}{1k} - \left(\frac{10 - v_{in}}{1k} - x - \frac{v_{in}}{1k}\right)$

By transitivity:

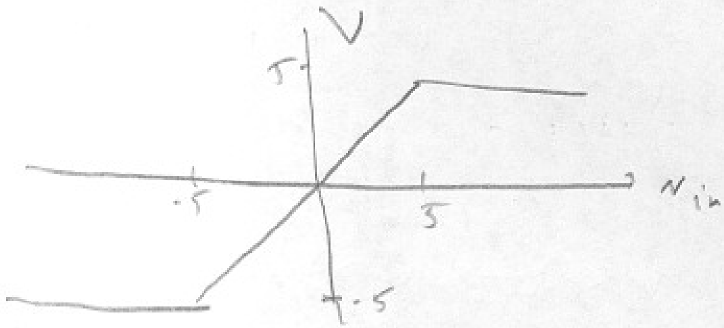
(i, ii) $0 < 10 - v_{in} \rightarrow v_{in} < 10$

(i, iv) $0 < 10 - 2v_{in} \rightarrow v_{in} < 5$

(iii, iv) $-3v_{in} < 10 - 2v_{in} \rightarrow v_{in} > -10$

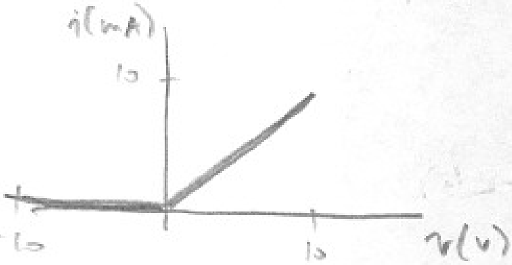
(ii, iii) $-3v_{in} < 10 - v_{in} \rightarrow v_{in} > -5$

So $V = v_{in}$ for $-5V < v_{in} < 5V$

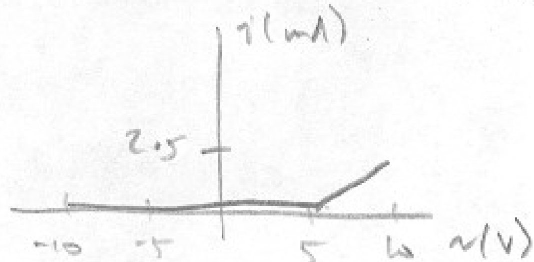


10.35

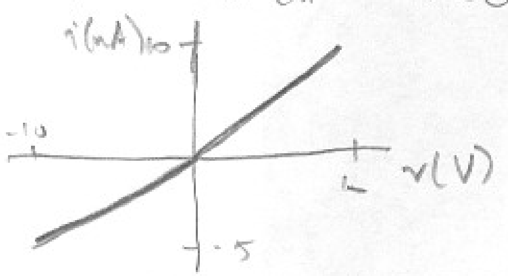
(a) $v < 0 \rightarrow$ off $v > 0 \rightarrow$ on



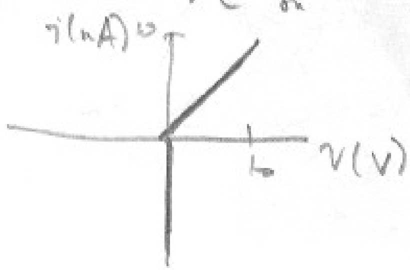
(b) $v > 5 \rightarrow$ on $v < 5 \rightarrow$ off



(c) $v > 0 \rightarrow$ A on $v < 0 \rightarrow$ B on



(d) $v > 0 \rightarrow$ C on $v < 0 \rightarrow$ D on



EE40 HW5

E2.4

(a) $N_a > N_d \rightarrow$ holes

(b) $p_0 = N_a - N_d = 5\times10^{16}\ cm^{-3}$

(c) $n_0 = \dfrac{n_i^2}{p_0} = 2\times10^{3}\ cm^{-3}$

E2.10

(a) $v_{dp} = \mu_p E = (150\ cm^2/Vs)(2\times10^3\ V/cm) = 3\times10^5\ cm/s$

(b) $J_p^{dr} = q p v_{dp} = (1.6\times10^{-19}C)(10^{18}cm^{-3})(3\times10^5 cm/s) = 4.8\times10^4\ A/cm^2$

(c) $\Delta t = \dfrac{\Delta x}{v_{dp}} = \dfrac{1\mu m}{3\times10^5 cm/s} = 3.333\times10^{-10}s = 333.3\ ps$

(d) $\#collisions = \dfrac{\Delta t}{\tau_c} = \dfrac{333.3\ ps}{0.5\ ps} = 666.7$

E2.11

(a) $N_a > N_d \rightarrow$ p-type

(b) $p_0 = N_a - N_d = 2\times10^{14}cm^{-3}$

(c) $E = \dfrac{v_{dp}}{\mu_p} = \dfrac{4\times10^6 cm/s}{475\ cm^2/Vs} = 8.421\times10^3\ V/cm$

(c) $J_p^{dr} = q p v_{dp} = (1.6\times10^{-19}C)(2\times10^{14}cm^{-3})(4\times10^6 cm/s)$

$= 128\ A/cm^2$

P2.2

$N_d = 10^{16}cm^{-3} + 2.5\times10^{15}cm^{-3} = 1.25\times10^{16}cm^{-3}$

$N_a = 1.15\times10^{16}cm^{-3}$

$n_0 = N_d - N_a = 1\times10^{15}\ cm^{-3}$

$p_0 = \dfrac{n_i^2}{n_0} = 5\times10^{5}\ cm^{-3}$

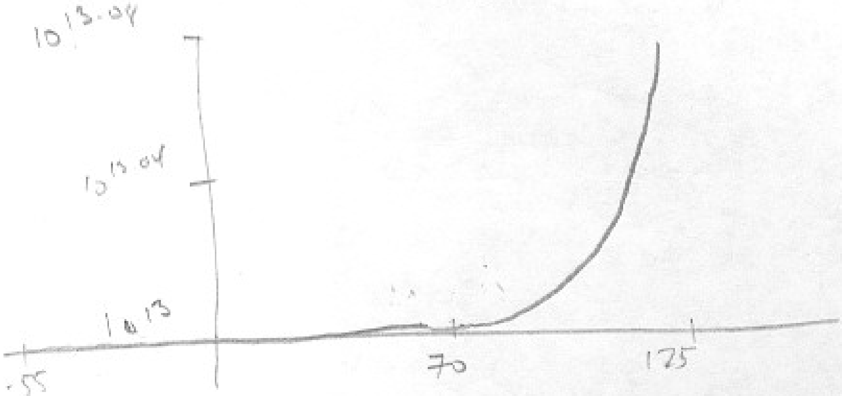
P2.5

P2.5

(a) $$n_o = \frac{N_d}{2}\left(1 + \sqrt{1 + 4\left(\frac{n_i}{N_d}\right)^2}\right)$$

$$n_i = A\,T^{3/2} e^{-6608.7/T} \qquad A = \frac{1.42\times10^9}{273^{3/2} e^{-6608.7/273}} = 1.026\times10^{16}$$

$$n_o = \frac{10^{15}}{2}\left(1 + \sqrt{1 + 4A^2T^3 e^{-(6608.7/T)2}}\right)$$



(b) $$\frac{p_o}{n_o} = \frac{n_i^2}{n_o^2} = 10^{-3} \rightarrow \frac{n_i}{n_o} = 10^{-3/2} \qquad \frac{AT^{3/2} e^{-6608.7/T}}{\frac{10^{15}}{2}\left(1 + \sqrt{1 + 4A^2T^3 e^{-(6608.7/T)2}}\right)} = 10^{-3/2}$$

$$\rightarrow T = 345\,K$$

P2.7

(a) $$E_x = \frac{2V}{24\mu m} = 8.333\times10^2\ V/cm$$

(b) $$v_{dn} = -\mu_n E_x = -(1450\ cm^2/Vs)(8.333\times10^2\ V/cm) = \boxed{-1.208\times10^6\ cm/s}$$

$$v_{dp} = \mu_p E_x = (500\ cm^2/Vs)(8.333\times10^2\ V/cm) = \boxed{4.167\times10^4\ cm/s}$$

$$\Delta t = \frac{\Delta x}{v_{dn}} = \frac{24\mu m}{1.208\times10^6\ cm/s} = \boxed{1.987\times10^{-9}\ s}$$

(c) $$J_n^{dr} = -q\,n\,v_{dn} = (-1.6\times10^{-19}C)(10^{13}\ cm^{-3})(-1.208\times10^6\ cm/s) = \boxed{1.933\ A/cm^2}$$

$$J_p^{dr} = q\,p\,v_{dp} = (1.6\times10^{-19}C)(10^7\ cm^{-3})(4.167\times10^4\ cm/s) = \boxed{6.667\times10^{-8}\ A/cm^2}$$

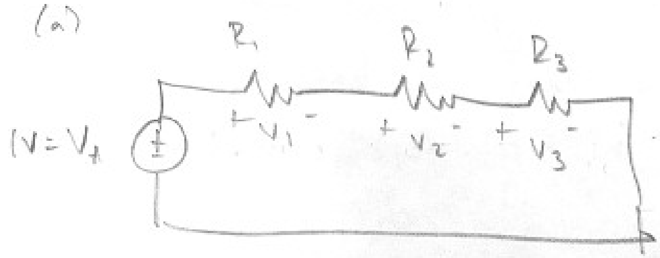
$$\%\text{error} = \left|\frac{J_p^{dr}}{J_n^{dr} + J_p^{dr}}\right| \times 100\% = \boxed{0.000003449\ \%}$$

(d) $$\sigma = \frac{J}{E} = \frac{1.933}{833.3} = 2.32\times10^{-3}\ \Omega^{-1}cm^{-1}$$

$$R = \frac{1}{\sigma}\frac{L}{Wt} = \left(\frac{1}{2.32\times10^{-3}\ \Omega^{-1}cm^{-1}}\right)\frac{24\times10^{-4}cm}{6\times10^{-4}cm\ 2\times10^{-4}cm} = \boxed{8.621\ M\Omega}$$

P2.10

(a)



$$R_1 = \frac{L}{q p \mu t W} = \frac{4\mu m}{(1.6\times10^{-19}\,C)(10^{15}\,cm^{-3})(480\,cm^2/Vs)(1\times10^{-4}\,cm)(2\mu m)} = 260.4\,k\Omega$$

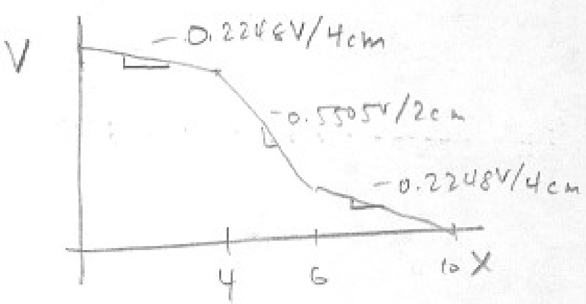
$$R_2 = \frac{2\mu m}{(1.6\times10^{-19}\,C)(2\times10^{14}\,cm^{-3})(490\,cm^2/Vs)(1\times10^{-4}\,cm)(2\mu m)} = 637.8\,k\Omega$$

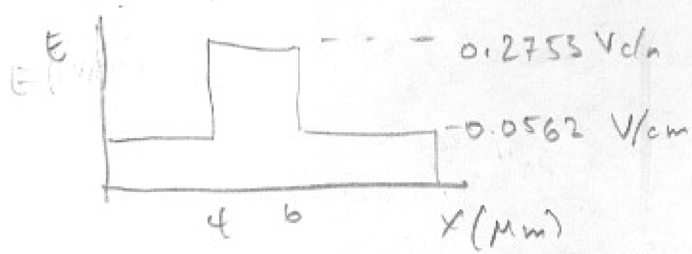
$R_3 = R_1 = 260.4\,k\Omega$

$I = \frac{V}{\Sigma R} = 0.8631\,\mu A$

$V_1 = V_3 = 0.2248\,V$

$V_2 = 0.5505\,V$





(b) $I_{max} = J_{max} Wt = q p v_{max} Wt$

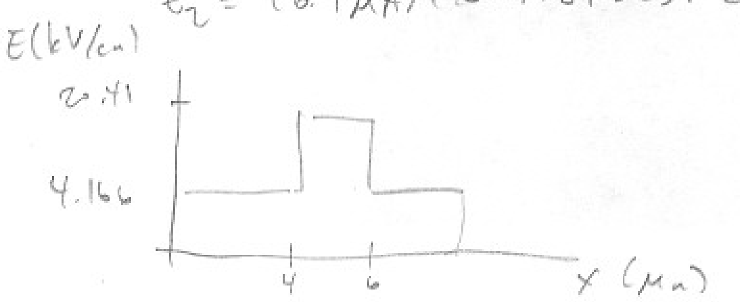
smallest p because all regions must satisfy

$= (1.6\times10^{-19}\,C)(2\times10^{14}\,cm^{-3})(10^{7}\,cm/s)(2\times10^{-4}\,cm)(10^{-4}\,cm) = 6.4\,\mu A$

(c) $V_{max} = I_{max} R_{tot} = 7.415\,V$

(d) $E_1 = E_3 = IR/\Delta X = (6.4\mu A)(260.4\,k\Omega)/4\mu m = 4.166\,kV/cm$

$E_2 = (6.4\mu A)(637.8\,k\Omega)/2\mu m = 20.41\,kV/cm$



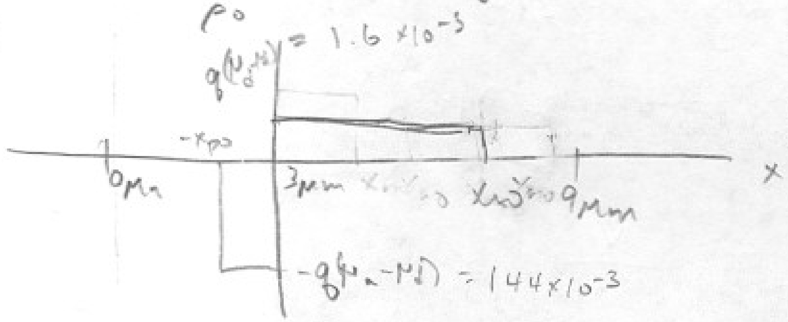
Problem 1

(a) The potential barrier is reduced and we get drift current

(b) The potential barrier is increased so that we have no drift current and are dominated by diffusion current.

(c) The acceptor doping is heavier → holes are majority carrier, electrons are minority

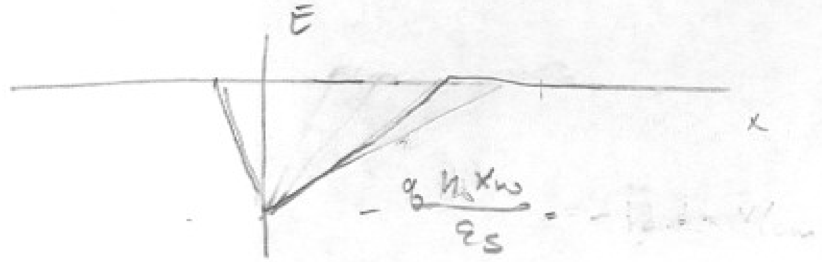
(d)

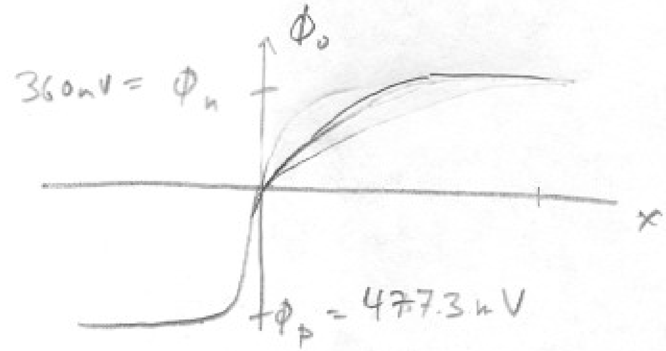


$$x_{no} = \sqrt{\frac{2\varepsilon_s\phi_B}{qN_d}\left(\frac{N_a}{N_d+N_a}\right)} = 7.165\,\mu$$

$$x_{po} = \sqrt{\frac{2\varepsilon_s\phi_B}{qN_a}\left(\frac{N_d}{N_d+N_a}\right)} = 1.187\,\mu$$

$$\phi_B = 360\,mV + 477.3\,mV = 837.3\,mV$$





(e) $W_j = x_{no} + x_{po} = 8.352\,\mu$

$$C = \frac{\varepsilon_s W L}{W_j} = \frac{(11.7\times8.85\times10^{-14})(5\times10^{-4})(1\times10^{-4})}{8.352\times10^{-4}} = 6.2\times10^{-17}\,F/cm$$

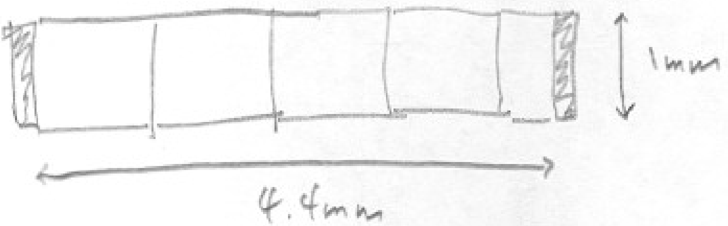
Problem 2

(a) n: $n_o = N_d = \boxed{10^{17}\ cm^{-3}}$

p: $p_o = N_a - N_d = 1.1\times10^{17} - 1\times10^{17} = \boxed{1\times10^{16}\ cm^{-3}}$

(b) $R_\square = \dfrac{1}{q p \mu_p t} = \dfrac{1}{(1.6\times10^{-19})(10^{16})(275)(100\times10^{-4})} = 227.3\,\Omega/\square$

(c) $\dfrac{1\,k\Omega}{227.3\,\Omega/\square} = 4.4\ \square$



(d) When we forward bias the pn junction

$\phi_B = 360 + 420 = 780\ mV$ (60 mV rule)

$V = 2V + 780\ mV = \boxed{2.78\ V}$

Problem 3

(a) n: $n_o = N_d = \boxed{10^{17}\ cm^{-3}}$

p: $p_o = N_a - N_d = 1.1\times10^{17} - 10^{17} = \boxed{10^{16}\ cm^{-3}}$

p+: $p_o = N_a - N_d = 10^{18} + 1.1\times10^{17} - 10^{17} = \boxed{1.01\times10^{18}\ cm^{-3}}$

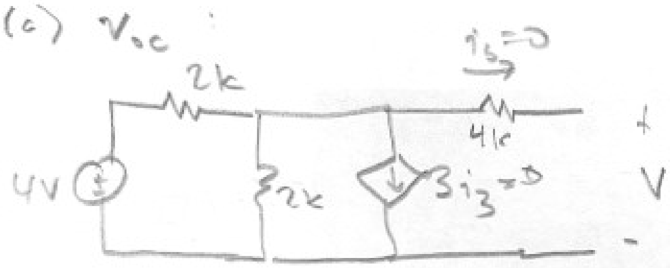
(b) $R_{\square p^+} = \dfrac{1}{q p_o \mu_p t} = \dfrac{1}{(1.6\times10^{-19})(1.01\times10^{18})(150)(1\times10^{-4})} = 412.5\,\Omega/\square$

(c) $R_{\square p} = \dfrac{1}{(1.6\times10^{-19})(1\times10^{16})(275)(2\times10^{-4})} = 11.36\ k\Omega/\square$

(d) $R_\square = R_{\square p^+} \parallel R_{\square p} = 398\,\Omega/\square$

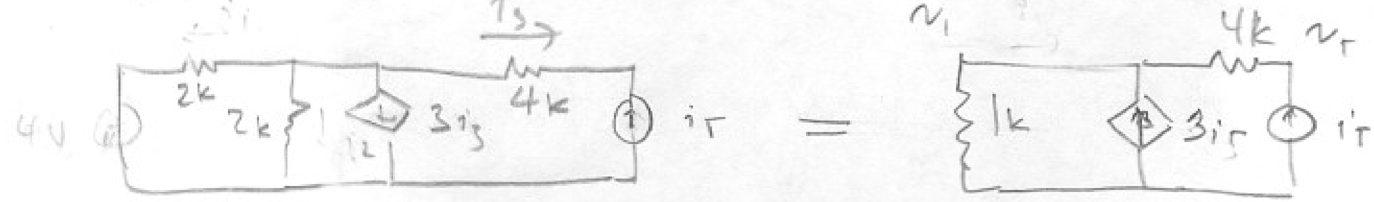
Problem 4

(a) v_{oc}



$$V_{oc} = V_{th} = \frac{1}{2} 4V = 2V$$

(b) Test current



$$i_3 = -i_T$$

$$\frac{v_1}{1k} = 4 i_T \qquad \frac{v_T - v_1}{4k} = i_T$$

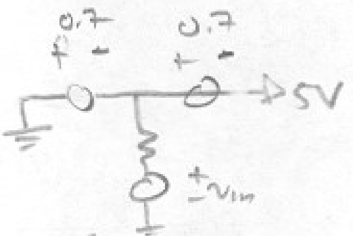
$$v_T - (4 i_T)(1k) = i_T (4k)$$

$$v_T = 8k (i_T) \rightarrow R_{eq} = 8k$$

Plotting this load line, we get $\boxed{V = 1.6V, I = 0.8mA}$

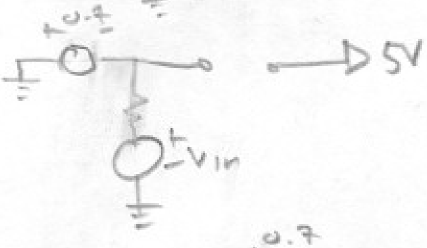
Problem 5

on/on $\rightarrow$



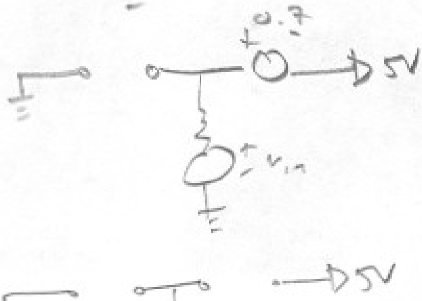
so $0 - 1.4 = 5V$ never

on/off $\rightarrow$



so $v_{in} < 0.7V \rightarrow v_o = 0.7V$

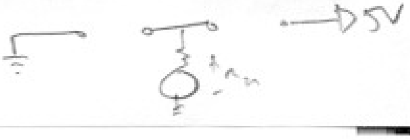
off/on $\rightarrow$



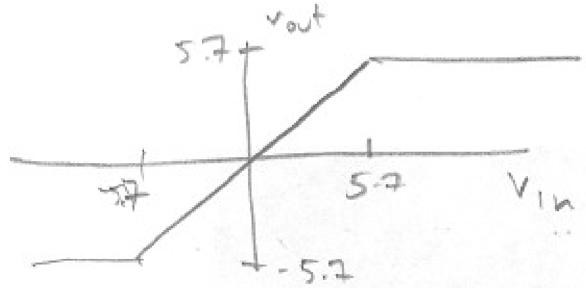
so $v_{in} > 5.7V \rightarrow v_o = 5.7V$

so $0.7 < v_{in} < 5.7V \rightarrow v_o = v_{in}$

off/off $\rightarrow$



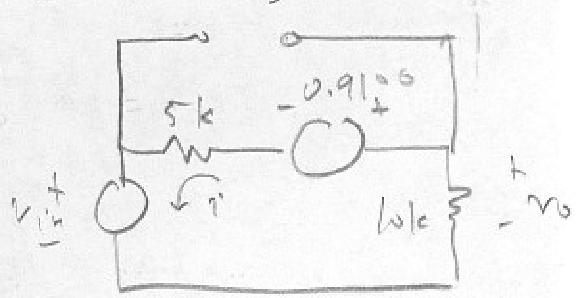
Problem 5 (cont'd)



Problem 6

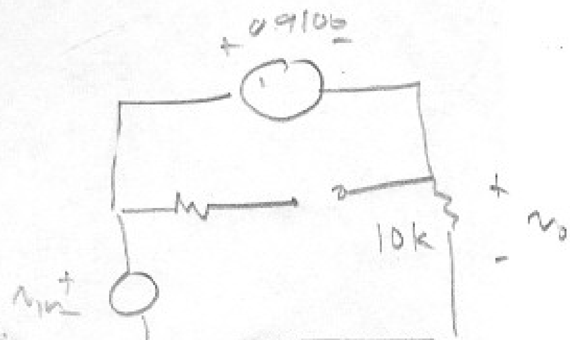
(a) $\phi_B = 60\,mV\left[\log\left(\frac{10^{18}}{10^{10}}\right) + \log\left(\frac{1.5\times10^{17}}{10^{10}}\right)\right] = 910.6\,mV$

(b) D_1 on:



$v_o = \frac{2}{3}(v_{in} + 0.9106V)$

$i > 0 \rightarrow v_o > 0 \rightarrow v_{in} < -0.9106$



D_2 on

$v_{in} - v_o \geq 0.9106$

$v_o \geq 0 \rightarrow v_{in} \geq 0.9106$

$v_o = v_{in} - 0.9106$

Both can't be on b/c $\rightarrow v_{in} \geq v_o$

So $-0.9106 < v_{in} < 0.9106 \rightarrow$ both off $\rightarrow v_o = 0$