6.012 Problem Set #2 Solutions - Fall 2000

Problem #1 P2.7

a) $N_d = 10^{13}\ cm^{-3}$ $\mu_n = 1425\ cm^2/V{\cdot}s$ $\mu_p = 500\ cm^2/V{\cdot}s$

$E_x = \frac{V}{L}$ since V is linear

$E_x = \frac{2V}{24 \times 10^{-4}\ cm}$ = 833.33 V/cm

b) $v_{dn} = \mu_n E_x = -1425\ cm^2/V{\cdot}s \times 833.33\ V/cm$
$= -1.1875 \times 10^6\ cm/s$

$v_{dp} = \mu_p E_x = 500\ cm^2/V{\cdot}s \times 833.33\ V/cm$
$= 4.166 \times 10^5\ cm/s$

$\tau = 24 \times 10^{-4}\ cm \div 1.1875 \times 10^6\ cm/s$
$= 2.02 \times 10^{-9}\ s$

c) $J^{dr} = J_n^{dr} + J_p^{dr}$

since $N_d \gg n_i$ $n = N_d = 10^{13}\ cm^{-3}$

$p = \frac{n_i^2}{N_d} = \frac{10^{20}}{10^{13}} = 10^7\ cm^{-3}$

$J_n^{dr} = -q\, n\, v_{dn} = -1.60 \times 10^{-19}\ C \times 10^{13}\ cm^{-3} \times -1.1875 \times 10^6\ cm/s$
$= 1.9\ A/cm^2$

$J_p^{dr} = q\, p\, v_{dp} = 1.60 \times 10^{-19}\ C \times 10^7\ cm^{-3} \times 4.166 \times 10^5\ cm/s$
$= 6.6666 \times 10^{-7}\ A/cm^2$

$J^{dr} = 1.9000007\ A/cm^2$

percentage error $= \frac{J_p^{dr}}{J_n^{dr}} = 3.5 \times 10^{-5}\ \%$

d) $R = \frac{V}{I}$
$I = J \times W \times L = 1.9\ A/cm^2 \times 6 \times 10^{-4} \times 2 \times 10^{-4} = 2.28 \times 10^{-7}\ A$

$R = \frac{V}{I} = 8.77 \times 10^6\ \Omega$

problem #2 P2.14

a) $J_n^{diff} = q D_n \frac{dn}{dx}$

$\frac{D}{\mu} = \frac{kT}{q}$

$D_n = \frac{kT}{q} \times \mu_n = 25 \times 10^{-3} V \times 1200 cm^2/V \cdot s = 30 cm^2/s$

$\frac{dn}{dx} = \frac{10^4 cm - 10^{13} cm}{10^{-4} cm} = -10^{17} cm^{-4}$ since n is linear

$J_n^{diff} = 1.60 \times 10^{-19} C \times 30 cm^2/s \times 10^{17} cm^{-4} = -.48 A/cm^2$

b $J_p^{diff} = -q D_p \frac{dp}{dx}$

$D_p = \frac{kT}{q} \mu_p = 25 \times 10^{-3} V \times 460 cm^2/V \cdot s = 11.5 cm^2/s$

$\frac{dp}{dx} = \frac{10^{16} cm - (10^{13} + 10^{16})}{10^{-4} cm} = -10^{17} cm^{-4}$

$J_p^{diff} = -1.60 \times 10^{-19} C \times 11.5 cm^2/s \times -10^{17} cm^{-4} = .184 A/cm^2$

c) $J^{diff} = J_n^{diff} + J_p^{diff} = -.48 + .184 = -.296 A/cm^2$

$J = J^{diff} + J^{dr} = 0$

$J^{dr} = -J^{diff} = .296 A/cm^2$

d) $J_p^{dr} = q p \mu_p E$

$E = \frac{J_p^{dr}}{q p \mu_p} = \frac{.296 A/cm^2}{1.6 \times 10^{-19} C \times 10^{16} cm^{-3} \times 460 cm^2/V \cdot s}$

$= .402 V/cm$

problem #3

a) $R = \rho\left(\frac{L}{Wt}\right)$

$\rho = \frac{1}{qn\mu_n + qp\mu_p}$

since $n >> p$ $\quad \rho = \frac{1}{q n_o(x) \mu_n}$

$\sigma(x) = q\, n_o(x)\, \mu_n$

$G(x) = \frac{W}{L} \Delta x\, \mu_N\, q\, n_o(x)$

$G = \lim_{\Delta x \to 0} \sum_0^T \frac{W}{L} q\, n_o(x)\, \mu_N \Delta x$

$G = \int_0^T \frac{W}{L} q\, n_o(x)\, \mu_N\, dx$

$G = \frac{W}{L} q\, \mu_N \int_0^T n_o(x)\, dx$

$R = \frac{L}{Wq\mu_N} \times \frac{1}{\int_0^T n_o(x)\, dx}$

b) $\int_0^T n_o(x)\, dx = \int_0^T 10^{18} e^{-(x/L_x)} = 10^{18}\left(L_x - L_x e^{-T/L_x}\right)$

$R_\square = \frac{1}{q\mu_N 10^{18} L_x \left(1 - e^{T/L_x}\right)}$

$\mu_N = 320\ cm^2/V\cdot s$

$R_\square = \frac{1}{1.6\times10^{-12} C \left(320\ cm^2/V\cdot s\right)\left(2\times10^{-4} cm\right)\left(1 - e^{-\frac{500\mu m}{2}}\right)}$

$=$

c) $N_\square = .65\times2 + 19+3+17+3+19 + .56\times4 = 64.54$

$R = N_\square R_\square \quad =$

Problem #4 E 3.1

a) The sign is positive at −750nm and 250nm. An electric field points from positive charge to negative charge.

b) $E(-250_{nm}) - E(-1250\,nm) = \int_{-1250nm}^{-250nm} \frac{\rho}{\epsilon_s}$

$E(-1250_{nm}) = 0$

$E(-250\,nm) = \frac{1}{\epsilon_s}\left(3mC/cm^3(-500_{nm}+1250_{nm}) + 1\,mC/cm^3(-250_{nm}+500_{nm})\right)$

$E(-250\,nm) = \frac{1}{1.035\times10^{-12}\,F/cm}\left(3\times10^{-3}\frac{C}{cm^3}(750\times10^{-7}cm) + 1\times10^{-3}(250\times10^{-7}cm)\right)$

$E(-250\,nm) = 2.415 \times10^{5}\,V/cm$

c) $E(-500nm) - E(-1250\,nm) = \int_{-1250}^{-500} \frac{\rho}{\epsilon_s}$

$E(-1250nm) = 0$

$E(-500nm) = \frac{1}{1.035\times10^{-12}}\left(3\times10^{-3}\frac{C}{cm^3}(-500+1250)10^{-7}cm\right)$

$E(-500nm) = 2.174 \times10^{5}\,V/cm$

$E(250_{nm}) - E(-500nm) = \int_{-500}^{250} \frac{\rho}{\epsilon_s}$

$E(250\,nm) - E(-500\,nm) = \frac{1\times10^{-3}C \times (250+500)10^{-7}cm}{1.035\times10^{-12}\,F/cm}$

$E(250) - E(-500\,nm) = 7.246 \times10^{4}\,V/cm$

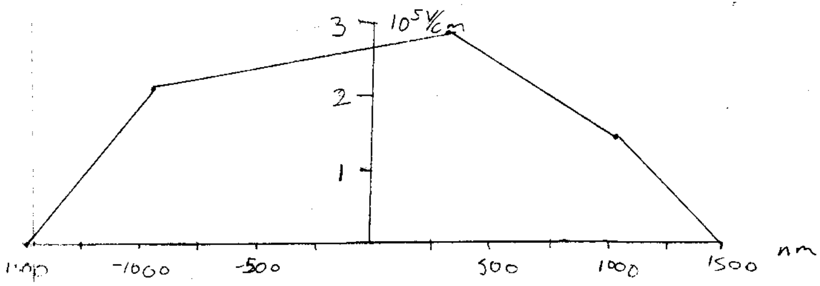
$E(250_{nm}) = 2.899 \times10^{5}\,V/cm$

$$E(1500nm) - E(1000nm) = \frac{1}{\epsilon_s} \int_{1000}^{1500} \rho$$

$$E(1500nm) = 0$$

$$-E(1000nm) = \frac{-3\times10^{-3} C \times (1500-1000)\times10^{-7} cm}{1.035\times10^{-12} F/cm}$$

$$E(1000nm) = 1.449\times10^{-4}\ V/cm$$



Problem # 5 E 3.5

a) $$\frac{dE}{dx} = \frac{\rho}{\epsilon}$$

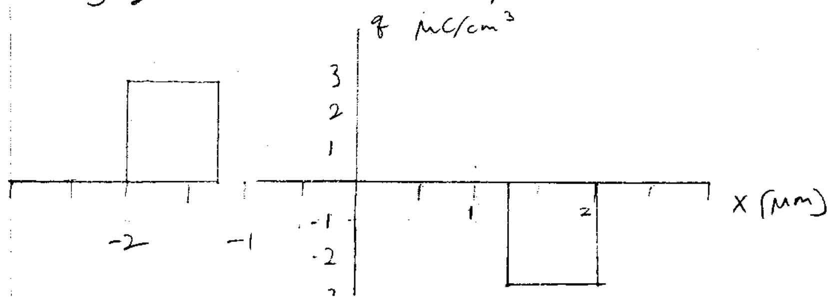
$$\rho = \epsilon \frac{dE}{dx}$$

$$\rho_1 = (1.035\times10^{-12} F/cm) \left(\frac{(2-0)10^3 V/cm}{(-1.25+2)10^{-4} cm}\right)$$

$$\rho_1 = 2.76\times10^{-6}\ C/cm^3$$

$$\rho_2 = (1.035\times10^{-12} F/cm) \frac{(0-.2)10^3 V/cm}{(2-1.25)}$$

$$\rho_2 = -2.76\times10^{-6} C/cm^3$$



b) $\phi(0) - \phi(-2\mu m) = \int_{-2\mu m}^{0} -E(x)\,dx$

$= \int_{-2}^{-1.25} -E(x)dx + \int_{-1.25}^{0} -E(x)\,dx$

$\phi(-1.25) - \phi(-2) = -\frac{1}{2}(.2\times10^3\ V/cm)(.75\times10^{-4}\ cm)$

$= -.0075\ V$

$\phi(-1.25) = -507.5\ mV$

$\phi(0) - \phi(-1.25) = -.2\times10^3\ V/cm\ (1.25\times10^{-4}\ cm)$

$= -.025\ V$

$\phi(0) = -532.5\ mV$

c) $\phi(1.25) - \phi(0) = -.2\times10^3\ V/cm\ (1.25\times10^{-4}\ cm)$

$= -.025\ V$

$\phi(1.25) = -557.5\ mV$

$\phi(2) - \phi(1.25) = -\frac{1}{2}(.2\times10^3\ V/cm)(.75\times10^{-4}\ cm)$

$= -.0075\ V$

$\phi(2) = -565\ mV$