ECE 3030 - HW 3

1) $f(E) = \frac{1}{1+e^{(E-E_f)/kT}}$ $k = 8.62\times10^{-5}\ eV/K = 1.38\times10^{-23}\ J/K$

a) $E = E_f + kT \rightarrow f(E) = \frac{1}{1+e^{(kT)/kT}} = \frac{1}{1+e^{1}} = \boxed{0.26894}$ $e^{1} = 2.718$ $1-0.26894$

$\boxed{\text{Unoccupied probability}}$ $\boxed{0.73106}$

b) $E = E_f + 4kT \rightarrow f(E) = \frac{1}{1+e^{4}} = \boxed{0.07986}$ $e^{4} = 54.59$

c) $E = E_f + 9kT \rightarrow f(E) = \frac{1}{1+e^{9}} = \boxed{1.2339\times10^{-4}}$ $e^{9} = 8103.08$

2) $T = 300k$ $n_0 = 7\times10^{15}\ cm^{-3}$

a) $n_0 = N_c e^{-(E_c-E_F)/kT} \rightsquigarrow E_c - E_F = kT\ln\left(\frac{N_c}{n_0}\right)$

$E_c - E_F = (8.617\times10^{-5})(300)\ln\left(\frac{2.8\times10^{19}}{7\times10^{15}}\right) = \boxed{0.2144\ eV}$

b) $E_F - E_v = E_c - E_v - (E_c - E_F)$ and $E_G = E_c - E_v$

$E_F - E_v = E_G - (E_c - E_F) = 1.12 - 0.2144 = \boxed{0.906\ eV}$

c) $n_0 p_0 = n_i^2 \rightsquigarrow p_0 = \frac{n_i^2}{n_0} = \frac{(1.5\times10^{10})^2}{7\times10^{15}} = \boxed{3.2142\times10^{4}\ cm^{-3}}$

d) Since $p_0 < n_0$, the minority carriers are $\boxed{\text{holes}}$

e) $n_0 = n_i e^{(E_c-E_F)/kT}$ $n_0 p_0 = n_i^2 \longrightarrow E_F - E_i = kT\ln\left(\frac{n_0}{n_i}\right)$

$E_F - E_i = (8.617\times10^{-5})(300)\ln\left(\frac{7\times10^{15}}{1.5\times10^{10}}\right) = \boxed{0.3374\ eV}$

3) $n_o p_o = n_i^2 \quad n_o = N_d + \frac{n_i^2}{N_a}$

a) $T = 300k \quad N_d = 10^{15}\ cm^{-3} \quad N_a = 4 \times 10^{15}\ cm^{-3}$

$n_o = 10^{15} + \frac{(1.5\times10^{10})^2}{4\times10^{15}} = \boxed{1.00625 \times 10^{15}\ cm^{-3}}$ electron concentration

$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\times10^{10})^2}{1.00625\times10^{15}} = \boxed{2.236 \times 10^{5}\ cm^{-3}}$ hole concentration

b) $T = 300k \quad N_d = 3\times10^{16}\ cm^{-3} \quad N_a = 0\ cm^{-3}$

$n_o = \boxed{3\times10^{16}\ cm^{-3}}$ electron concentration

$p_o = \frac{(1.5\times10^{10})^2}{3\times10^{16}} = \boxed{7500\ cm^{-3}}$ hole concentration

c) $T = 300k \quad N_d = N_a = 2\times10^{15}\ cm^{-3}$

$n_o = N_d - N_a = \boxed{0\ cm^{-3}}$

No conduction carriers

$p_o = \boxed{0\ cm^{-3}}$

d) $T = 375k \quad N_d = 0\ cm^{-3} \quad N_a = 4\times10^{15}\ cm^{-3}$

$n_o = \frac{n_i^2}{N_a} = \frac{(1.5\times10^{10})^2}{4\times10^{15}} = \boxed{5.625\times10^{4}\ cm^{-3}}$ electron concentration

$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\times10^{10})^2}{56250} = \boxed{4\times10^{15}\ cm^{-3}}$ hole concentration

e) $T = 450k \quad N_d = 10^{14}\ cm^{-3} \quad N_a = 0$

$n_o = \boxed{10^{14}\ cm^{-3}}$ electron concentration

$p_o = \frac{(2.5\times10^{13})^2}{10^{14}} = \boxed{6.25\times10^{12}\ cm^{-3}}$ hole concentration

4) $E_G = 1.11 eV$ $n_i = 1.5\times10^{10}\ cm^{-3}$ $E_c - E_F = 0.20\ eV$

a) $n_0 = N_c\, e^{-(E_c - E_F)/kT} = 2.8\times10^{19} \cdot e^{(0.2)/(8.617\times10^{-5}\times300)} = 1.2222\times10^{16}\ cm^{-3}$

$N_c = 2.8\times10^{19}$

$N_d \approx n_0 \approx \boxed{1.2222\times10^{16}\ cm^{-3}}$

b) $N_a = 10^{16}\ cm^{-3}$

$n_0 = N_d - N_a \rightarrow N_d = n_0 + N_a = 1.2222\times10^{16} + 10^{16} = 2.2222\times10^{16}$

$\Delta N_d = N_d - N_a = 2.2222\times10^{16} - 10^{16} = \boxed{1.2222\times10^{16}\ cm^{-3}}$

5) The effective mass of electrons in the Γ-valley of GaAs is smaller and results in higher mobility.

If electrons are promoted from Γ to L valley, their effective mass increases, mobility decreases, and conductivity decreases.

6) $L = 2\,cm$ $A = 0.1\,cm^2$ $N_d = 10^{15}\,cm^{-3}$ $R = 90\,\Omega$ $v_{sat} = 10^7\,cm/s$ $E_{sat} = 10^5\,V/cm$

$v_d = \mu_n E$ $E = \frac{V}{L}$ $\mu_n = 1350\ cm^2/V\text{-}s$ $I = \frac{V}{R}$

a) $V = 100V$ $E = \frac{V}{L} = \frac{100}{2} = 50\ V/cm$ $v_d = 1350 \cdot 50 = \boxed{67500\ cm/s}$

$I = \frac{V}{R} = \frac{100}{90} = \boxed{1.11\ A}$

b) $V = 200V$ $E = \frac{V}{L} = \frac{200}{2} = 100\ V/cm$ $v_d = 1350 \cdot 100 = \boxed{135000\ cm/s}$

$I = \frac{V}{R} = \frac{200}{90} = \boxed{2.22\ A}$

c) $V = 10^6\ V$ $E = \frac{V}{L} = \frac{10^6}{2} = 5\times10^5\ V/cm$ ← above saturation ($10^5\ V/cm$) field $v_d = v_{sat} = \boxed{10^7\ cm/s}$

$I = \frac{V}{R} = \frac{10^6}{90} = \boxed{1.11\times10^4\ A}$

Current is linearly proportional to Voltage until the drift velocity reaches saturation