Problems 5.~~1~~, ~~2~~, ~~6~~, ~~8~~, ~~9~~, ~~10~~, ~~21~~, ~~23~~, ~~29~~, ~~30~~, ~~33~~

5.1:

Given $N_d = 10^{15}\ cm^{-3}$, $\mu_n = 1300\ cm^2/Vs$, $\mu_p = 450\ cm^2/Vs$

a, b) $\rho = \frac{1}{\sigma} = [e(\mu_n n + \mu_p p)]^{-1}$

here, $n = N_d \Rightarrow \sigma \simeq e\mu_n N_d = (1.602\times10^{-19}\ C)(1300\ \frac{cm^2}{Vs})(1\times10^{15}\ cm^{-3})$

$= .20826\ \frac{C}{V\cdot s\cdot cm}$, $\frac{C}{V\cdot S} = \frac{1}{\Omega}$

$\Rightarrow \boxed{\sigma = .20826\ (\Omega cm)^{-1}}$ b)

$\boxed{\rho = 4.802\ \Omega cm}$ a)

5.2: p-type Si. $\sigma = 1.80\ (\Omega cm)^{-1}$, $\mu_n = 1250\ cm^2/V\cdot s$, $\mu_p = 380\ cm^2/Vs$.

$N_a = ?$

$\sigma = e\mu_p N_a \Rightarrow \boxed{N_a = \frac{\sigma}{e\mu_p} = 2.957\times10^{16}\ cm^{-3}}$

5.6: GaAs, $T = 300K$, $N_d = 10^{16}\ cm^{-3}$, $N_a = 0$

a) $n_i^2 = n_o p_o = N_d p_o$, from Appendix B: $n_{i,GaAs} = 1.8\times10^6\ cm^{-3}$

$\Rightarrow p_o = \frac{n_i^2}{N_d} = \frac{(1.8\times10^6\ cm^{-3})^2}{1\times10^{16}\ cm^{-3}} = 3.24\times10^{-4}\ cm^{-3}$

b) $E = 10\ \frac{V}{cm}$, $J_{drift} = ?$ $\mu_n \simeq 8500\ cm^2/Vs$ (could use fig. 3 and get $\mu_n \simeq 7000\ cm^2/Vs$ $\Rightarrow J_{drift} \simeq 112\ \frac{A}{cm^2}$)

$\boxed{J_{drift} = e\mu_n N_d E = 136.17\ \frac{A}{cm^2}}$

c) $N_d = 0$, $N_a = 1\times10^{16}\ cm^{-3}$

$p_o = N_a$, $n_o = \frac{n_i^2}{N_a} = 3.24\times10^{-4}\ cm^{-3}$

(fig. 3 $\Rightarrow \mu_p \simeq 300\ cm^2/Vs \Rightarrow J_{drift} \simeq 4.8\ \frac{A}{cm^2}$)

d) $\boxed{J_{drift} = e\mu_p N_a E = 6.41\ \frac{A}{cm^2}}$, $\mu_p = 400\ cm^2/Vs$ – App. B

5.8: a) $R = \frac{L}{\sigma A} = \frac{L}{(e\mu_p N_a)A}$, $\mu_p = 400\ cm^2/Vs$, $N_a = 2\times10^{16}\ cm^{-3}$

$\Rightarrow R = 68.93\Omega \Rightarrow V = IR \Rightarrow I = \frac{V}{R} = 29\ mA$

b) $R = 3(68.93\Omega) \Rightarrow I = 9.67\ mA$

c) $J = eP_0 V_d$

a) $J = 34.12 \frac{A}{cm^2} \rightsquigarrow V_d = \frac{J}{eP_0} = 1.066 \times 10^4 \frac{cm}{s}$

b) $J = 11.38 \frac{A}{cm^2} \rightsquigarrow V_d = 3.55 \times 10^3 \frac{cm}{s}$

5.9: a) $N_d = 2 \times 10^{15}\ cm^{-3}$, $\mu_n = 8000\ cm^2/Vs$

$$R = \frac{V}{I} = 200\ \Omega$$

$$\to R = \frac{L}{(e\mu_n N_d)A} \Rightarrow L = A \cdot R \cdot (e\mu_n N_d) = .0256\,cm$$

b) $J = \frac{I}{A} = en_0 V_d \Rightarrow V_d = \frac{I}{A(en_0)} = 1.56 \times 10^6 \frac{cm}{s}$

c) $I = (en_0 V_d)A = 80\ mA$

5.10: a) $E = \frac{V}{L} = 3 \frac{V}{cm} \to V_d = \mu_n E \Rightarrow \mu_n = 3333\ cm^2/Vs$

b) $V_d = \mu_n E = 2.4 \times 10^3\ cm/s$

5.21:

a) $n_i^2 = N_c N_v e^{-E_g/kT} = 7.18 \times 10^{19}\ cm^{-6}$

$\Rightarrow n_i = 8.47 \times 10^9\ cm^{-3}$

for $N_d = 1 \times 10^{14}\ cm^{-3}$, $N_d \gg n_i \Rightarrow n_0 = N_d$

$$J = \sigma E = e\mu_n N_d E = 1.6 \frac{A}{cm^2}$$

b) $n_0 = 1.05 \times 10^{14}\ cm^{-3} = \frac{N_d}{2} + \sqrt{\left(\frac{N_d}{2}\right)^2 + n_i^2}$

$\Rightarrow 2.625 \times 10^{-12} = \left(\frac{T}{300}\right)^3 e^{-1.1/.0259\left(\frac{T}{300}\right)}$

solving graphically, $\boxed{T \simeq 456\,K}$

5.23:

a) $n_0 = N_d = 5 \times 10^{16}\ cm^{-3} \Rightarrow P_0 = \frac{n_i^2}{n_0} = \frac{(1.5 \times 10^{10}\ cm^{-3})^2}{5 \times 10^{16}\ cm^{-3}}$

$\Rightarrow P_0 = 4.5 \times 10^3\ cm^{-3}$

$P_0 = N_a = 2 \times 10^{16}\ cm^{-3} \Rightarrow n_0 = \frac{n_i^2}{P_0} = \frac{(1.5 \times 10^{10}\ cm^{-3})^2}{2 \times 10^{16}\ cm^{-3}} = 1.125 \times 10^4\ cm^{-3}$

compensated: $n_0 = N_d - N_a = 3 \times 10^{16}\ cm^{-3}$

$\Rightarrow P_0 = 7.5 \times 10^3\ cm^{-3}$

b) using fig. 5.3 : n - type : $\mu_n = 1100\ cm^2/Vs$

p - type : $\mu_p = 400\ cm^2/Vs$

compensated : $\mu_n = 1000\ cm^2/Vs$

c) n-type : $\sigma = e\mu_n n_o = 8.8\ (\Omega cm)^{-1}$

p - type : $\sigma = e\mu_p p_o = 1.28\ (\Omega cm)^{-1}$

compensated : $\sigma = 4.8\ (\Omega cm)^{-1}$

d) $J = \sigma E \Rightarrow E = \frac{J}{\sigma}$

n-type : $E = \frac{120\ A/cm^2}{8.8\ (\Omega cm)^{-1}} = 13.6\ \frac{V}{cm}$

p-type : $E = \frac{120\ A/cm^2}{1.28\ \Omega^{-1} cm^{-1}} = 93.75\ \frac{V}{cm}$

compensated : $E = \frac{120\ A/cm^2}{4.8\ \Omega^{-1} cm^{-1}} = 25\ \frac{V}{cm}$

5.29 :

$$J_n = e D_n \frac{dn}{dx} = e D_n \left[\frac{n(x+\Delta x) - n(x)}{\Delta x}\right] \quad , \quad x = 0, \quad \Delta x = .01\ cm$$

$$\Rightarrow \frac{J_n \Delta x}{e D_n} = n(\Delta x) - n(0) \quad \Rightarrow \quad n(0) = n(\Delta x) - \frac{J_n \Delta x}{e D_n}$$

$$\Rightarrow \boxed{n(0) = 2.56 \times 10^{13}\ cm^{-3}}$$

5.30 :

$$J_n = e D_n \frac{dn}{dx} \rightarrow e D_n \frac{\Delta n}{\Delta x} \quad , \quad \frac{\Delta n}{\Delta x} = \frac{5\times10^{15}\ cm^{-3} - 2\times10^{16}\ cm^{-3}}{.012\ cm}$$

$$\Rightarrow \boxed{J_n = -5.41\ A/cm^2}$$

5.33 : electrons :

$$J_n = e D_n \frac{dn}{dx} = e D_n \frac{d}{dx}\left(1\times10^{15}\ e^{-x/L_n}\ cm^{-3}\right) = \frac{-e D_n (1\times10^{15}\ cm^{-3})\ e^{-x/L_n}}{L_n}$$

at $x = 0$; $J_n = -2\ A/cm^2$

holes :

$$J_p = -e D_p \frac{dp}{dx} = -e D_p \frac{d}{dx}\left(5\times10^{15}\ e^{+x/L_p}\ cm^{-3}\right) = \frac{-e D_p (5\times10^{15}\ cm^{-3})\ e^{x/L_p}}{L_p}$$

at $x = 0$; $J_p = -16\ A/cm^2$

total : $\boxed{J = J_n + J_p = -18\ A/cm^2}$