4.1, 3, 4, 5, 7, 9, 10, 11, 12, 17, 18, 19, 20, 29, 30

4.1:

$$n_i^2 = N_c N_v \exp\left[\frac{-E_g}{k_B T}\right], \quad N_{c,v} = 2\left(\frac{2\pi m^*_{n,p} k_B T}{h^2}\right)^{3/2}$$

a) Si: $E_g = 1.12$ eV,

$T = 200$K: $N_c = 1.53 \times 10^{19}$ cm^{-3}, $N_v = 5.72 \times 10^{18}$ cm^{-3}

$$n_i = \sqrt{N_c N_v}\exp\left[\frac{-E_g}{2kT}\right] = 7.15 \times 10^{10}\ \text{m}^{-3} \rightarrow 7.15 \times 10^{4}\ \text{cm}^{-3}$$

$T = 400$K: $n_i = 2.32 \times 10^{19}$ m^{-3} $\rightarrow 2.32 \times 10^{12}$ cm^{-3}

$T = 600$K: $n_i = 9.59 \times 10^{14}$ cm^{-3}

b) Ge:

$T = 200$K: $n_i = 1.99 \times 10^{10}$ cm^{-3}

$T = 400$K: $n_i = 9.11 \times 10^{14}$ cm^{-3}

$T = 600$K: $n_i = 3.63 \times 10^{16}$ cm^{-3}

c) GaAs:

$T = 200$K: $n_i = 1.31$ cm^{-3}

$T = 400$K: $n_i = 3.3 \times 10^{9}$ cm^{-3}

$T = 600$K: $n_i = 5.93 \times 10^{12}$ cm^{-3}

4.3: a) $n_{i,max} = 5 \times 10^{11}$ cm^{-3}, $E_g = 1.12$ eV

$$n_{i,max}^2 = N_c N_v \exp\left[\frac{-E_g}{kT_{max}}\right]$$

$$N_c = N_{c,0}\left(\frac{T_{max}}{300}\right)^{3/2}, \quad N_v = N_{v,0}\left(\frac{T_{max}}{300}\right)^{3/2}$$

$N_{c,0} = 2.8 \times 10^{25}$ m^{-3} $\qquad N_{v,0} = 1.05 \times 10^{25}$ m^{-3}

$$N_c N_v = N_{c,0} N_{v,0}\left(\frac{T_{max}}{300}\right)^3$$

$$n_{i,max}^2 = N_{c,0} N_{v,0}\left(\frac{T_{max}}{300}\right)^3 \exp\left[\frac{-E_g}{kT_{max}}\right]$$

$$\Rightarrow n_{i,max} = \sqrt{N_{c,0} N_{v,0}\left(\frac{T_{max}}{300}\right)^3}\exp\left[\frac{-E_g}{2kT_{max}}\right]$$

Solving graphically, we find $\boxed{T_{max} \simeq 368\ \text{K}}$

b) $n_{i,max} = 5 \times 10^{12}$ cm^{-3}

$\boxed{T_{max} \simeq 418\ \text{K}}$

4.4: $n_i\,(T = 200\text{K}) = 1.4 \times 10^{2}$ cm^{-3}, $n_i\,(T = 400\text{K}) = 7.7 \times 10^{10}$ cm^{-3}

$n^2(400)$ $\quad [7.7 \times 10^{10}\ \text{cm}^{-3}]^2$

4.4: $n_i(T=200K) = 1.4\times10^{2}\ cm^{-3}$, $n_i(T=400K) = 7.7\times10^{10}\ cm^{-3}$

$$\frac{n_i^2(400)}{n_i^2(200)} = \frac{(7.7\times10^{10}\ cm^{-3})^2}{(1.4\times10^{2}\ cm^{-3})^2} = 3.025\times10^{17}$$

$$3.025\times10^{17} = \frac{N_{c,0}N_{v,0}\left(\frac{400}{300}\right)^3}{N_{c,0}N_{v,0}\left(\frac{200}{300}\right)^3}\frac{\exp[-E_g/.035]}{\exp[-E_g/.017]}$$

$$\Rightarrow 3.025\times10^{17} = 8\exp\left[\frac{-E_g}{.035}+\frac{E_g}{.017}\right] \Rightarrow \ln(3.78\times10^{16}) = \frac{E_g}{.017}-\frac{E_g}{.035}$$

$$\Rightarrow E_g\left(\frac{1}{.017eV}-\frac{1}{.035eV}\right) = \ln(3.78\times10^{16})$$

$$\Rightarrow \boxed{E_g = \frac{\ln(3.78\times10^{16})}{30.25\ eV^{-1}} \simeq 1.3\ eV}$$

$$(7.7\times10^{10}\ cm^{-3})^2 = N_{c,0}N_{v,0}\left(\frac{400}{300}\right)^3\exp\left[\frac{-1.3eV}{.035eV}\right]$$

$$\Rightarrow N_{c,0}N_{v,0} = \frac{27(7.7\times10^{10}\ cm^{-3})^2}{64\exp\left[\frac{-1.3eV}{.035eV}\right]} = 3.4\times10^{37}\ cm^{-6}$$

4.5:

$$\frac{n_i(B)}{n_i(A)} = \frac{\exp\left[\frac{-1.1}{kT}\right]}{\exp\left[\frac{-.90}{kT}\right]} = \exp\left[\frac{-.20}{kT}\right]$$

a) $\frac{n_i(B)}{n_i(A)} = 9.33\times10^{-6}$

b) $\frac{n_i(B)}{n_i(A)} = 4.43\times10^{-4}$

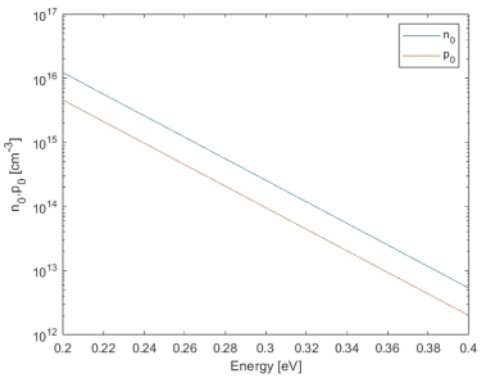
c) $\frac{n_i(B)}{n_i(A)} = 3.05\times10^{-3}$

4.7:

$$\frac{n(E_1)}{n(E_2)} = \frac{\sqrt{E_1-E_c}\exp\left[-\frac{(E_1-E_c)}{kT}\right]}{\sqrt{E_2-E_c}\exp\left[-\frac{(E_2-E_c)}{kT}\right]} = \frac{\sqrt{4kT}}{\sqrt{kT/2}}\exp\left[-\frac{\left[(E_c+4kT)-\left(E_c+\frac{kT}{2}\right)\right]}{kT}\right]$$

$$= 2\sqrt{2}\,e^{-3.5} = .0854$$

4.9:



4.10:

4.10:

$$E_{Fi} - E_{mid} = \frac{3}{4} kT \ln\left(\frac{m_p^*}{m_n^*}\right)$$

Si: $E_{Fi} - E_{mid} = -.0128\ eV$

Ge: $E_{Fi} - E_{mid} = -.0077\ eV$

GaAs: $E_{Fi} - E_{mid} = .0382\ eV$

4.11: $E_{Fi} - E_{mid} = \frac{1}{2} kT \ln\left(\frac{N_v}{N_c}\right)$

$T = 200K \quad E_{Fi} - E_{mid} = -.0086\ eV$

$T = 400K: \quad E_{Fi} - E_{mid} = -.0171\ eV$

$T = 600K: \quad E_{Fi} - E_{mid} = -.0257\ eV$

4.12:

a) $E_{Fi} - E_{mid} = \frac{3}{4} kT \ln\left(\frac{m_p^*}{m_n^*}\right) \rightarrow E_{Fi} - E_{mid} = -10.63\ meV$

b) $E_{Fi} - E_{mid} = 43.5\ meV$

4.17:

a) $E_c - E_F = kT \ln\left(\frac{N_c}{n_0}\right) = .2148\ eV$

b) $E_F - E_v = E_g - (E_c - E_F) = 1.12 - .2148 = .9052\ eV$

c) $p_0 = N_v \exp\left[\frac{-(E_F - E_v)}{kT}\right] = 6.9 \times 10^3\ cm^{-3}$

d) holes are minority carriers

e) $E_F - E_{Fi} = kT \ln\left(\frac{n_0}{n_i}\right) = .34\ eV$

4.19: a) $E_c - E_F = kT \ln\left(\frac{N_c}{n_0}\right) = .899\ eV$

$\rightarrow E_F - E_v = E_g - (E_c - E_F) = .276\ eV$

b) $p_0 = N_v \exp\left[\frac{-(E_F - E_v)}{kT}\right] = 2.419 \times 10^{19}\ cm^{-3}$

c) P-type

4.20: a)

$$n_0 = N_{c,0}\left(\frac{T}{300}\right)^{3/2} \exp\left[\frac{-(E_c - E_F)}{kT}\right] = 1.15 \times 10^{14}\ cm^{-3}$$

$E_F - E_v = E_g - (E_c - E_F) = 1.14\ eV$

$$p_0 = N_{v,0}\left(\frac{T}{300}\right)^{3/2} \exp\left[\frac{-(E_F - E_v)}{kT}\right] = 4.99 \times 10^3\ cm^{-3}$$

b) $E_c - E_F = kT \ln\left(\frac{N_c}{n_0}\right) = 0.2154\ eV$

$E_F - E_v = E_g - (E_c - E_F) = 1.205\ eV$

$\left[\frac{-(E_F - E_v)}{\quad}\right] = \quad \times 10^{-2} \quad cm^{-3}$

$$E_F - E_v = E_g - (E_c - E_F) = 1.205\ eV$$

$$p_o = N_{v,g} \exp\left[\frac{-(E_F - E_v)}{kT}\right] = 4.42 \times 10^{-2}\ cm^{-3}$$

4.29:

$$p_o = \frac{2}{\sqrt{\pi}} N_v F_{1/2}(\eta_F')$$

$$5 \times 10^{19} = \frac{2}{\sqrt{\pi}} (1.04 \times 10^{19}) F_{1/2}(\eta_F') \Rightarrow F_{1/2}(\eta_F') = 4.26$$

$$\eta_F' = \frac{E_v - E_F}{kT} \simeq 3 \Rightarrow \boxed{E_v - E_F \simeq .078\ eV}$$

4.30: a)

$$\eta_F = \frac{E_F - E_c}{kT} = 4 \Rightarrow F_{1/2}(\eta_F) \simeq 6$$

$$n_o = \frac{2}{\sqrt{\pi}} N_c F_{1/2}(\eta_F) \rightarrow n_o = \frac{2}{\sqrt{\pi}} (2.8 \times 10^{19}\ cm^{-3})(6)$$

$$\Rightarrow \boxed{n_o = 1.9 \times 10^{20}\ cm^{-3}}$$

b) $n_o = \frac{2}{\sqrt{\pi}} (4.7 \times 10^{17} cm^{-3})(6) \Rightarrow \boxed{n_o = 3.18 \times 10^{18}\ cm^{-3}}$