1. (a) Determine the total number (#/cm³) of energy states in silicon between E_C and $E_C + 2kT$ at (i) T = 300K and (ii) T = 400K. (b) Repeat part (a) for GaAs.

$$g_c(E) = \frac{2 \cdot 2\pi (2m^*)^{\frac{3}{2}}}{h^3} \sqrt{E - E_c}$$

$$\#\text{ energy states}: \int_{E_c}^{E_c+2kT} g_c(E)\, dE = \frac{2 \cdot 2\pi (2m^*)^{\frac{3}{2}}}{h^3} \int_{E_c}^{E_c+2kT} \sqrt{E - E_c}\, dE$$

$$= \frac{2 \cdot 2\pi (2m^*)^{\frac{3}{2}}}{h^3} \frac{2}{3}(E - E_c)^{\frac{3}{2}} \Big|_{E=E_c}^{E=E_c+2kT}$$

(a) For Si: $\#\text{ energy states} = \dfrac{4\pi (2 \times 1.08 \times 9.11 \times 10^{-31})^{\frac{3}{2}}}{(6.625 \times 10^{-34})^3} \cdot \dfrac{2}{3} (2 \times 1.38 \times 10^{-23} \times T)^{\frac{3}{2}}$

(i) $T = 300 \Rightarrow \# = 5.99 \times 10^{25}$

(ii) $T = 400 \Rightarrow \# = 9.22 \times 10^{25}$

(b) For GaAs: $\#\text{ energy states} = \dfrac{4\pi (2 \times 0.067 \times 9.11 \times 10^{-31})^{\frac{3}{2}}}{(6.625 \times 10^{-34})^3} \cdot \dfrac{2}{3} (2 \times 1.38 \times 10^{-23} \times T)^{\frac{3}{2}}$

(i) $T = 300 \Rightarrow \# = 9.26 \times 10^{23}$

(ii) $T = 400 \Rightarrow \# = 1.42 \times 10^{24}$

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2. (a) For silicon, find the ratio of the density of states in the conduction band at $E = E_C + kT$ to the density of states in the valence band at $E = E_V - kT$. (b) Repeat part (a) for Ge.

(a) Density of states: $g(E)_1 = 2\dfrac{2\pi (2m_e^*)^{\frac{3}{2}}}{h^3} \underbrace{\sqrt{E - E_c}}_{=kT} \; (E > E_c)$, $g(E)_2 = 2\dfrac{2\pi (2m_h^*)^{\frac{3}{2}}}{h^3} \underbrace{\sqrt{E_v - E}}_{=kT} \; (E < E_v)$

$$\Rightarrow \frac{g(E)_1}{g(E)_2} = \left(\frac{m_e^*}{m_h^*}\right)^{\frac{3}{2}}$$

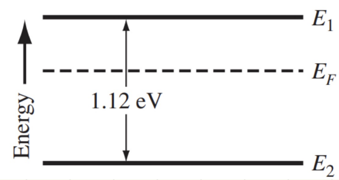
For silicon (Si): $m_e^* = 1.08\, m_0$, $m_h^* = 0.56\, m_0$

$\Rightarrow$ The ratio is $\left(\dfrac{1.08}{0.56}\right)^{\frac{3}{2}} = 2.678$

(b) Similarly, for germanium: $m_e^* = 0.55\, m_0$, $m_h^* = 0.37\, m_0$

$\Rightarrow$ The ratio is $\left(\dfrac{0.55}{0.37}\right)^{\frac{3}{2}} = 1.812$

3. Consider the energy levels shown in Figure 1. Let T = 300K. (a) If $E_1 - E_F = 0.20$eV, determine the probability that an energy state at $E = E_1$ is occupied by an electron and the probability that an energy state at $E = E_2$ is empty. (b) Repeat part (a) if $E_F - E_2 = 0.40$ eV.



(a)

$$f_F(E_1) = \frac{1}{1+\exp\left(\frac{E_1-E_F}{kT}\right)} = \frac{1}{1+\exp\left(\frac{0.2}{8.62\times10^{-5}\cdot300}\right)} \approx \exp\left(\frac{-0.2}{0.02586}\right) = 4.38\times10^{-4}$$

$$f_F(E_2) = \frac{1}{1+\exp\left(\frac{E_2-E_F}{kT}\right)} \approx 3.54\times10^{-16}$$

(b)

Similarly: $f_F(E_1) = 8.45\times10^{-13}$ $f_F(E_2) = 1.96\times10^{-7}$

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4. (a) The carrier effective masses in a semiconductor are $m_n^* = 1.21m_0$ and $m_p^* = 0.70m_0$. Determine the position of the intrinsic Fermi level with respect to the center of the bandgap at T = 300K. (b) Repeat part (a) if $m_n^* = 0.80m_0$ and $m_p^* = 0.75m_0$.

$$E_i = \frac{E_C+E_V}{2} + \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right)$$

$$\Rightarrow \text{(a) } E_i - \frac{E_C+E_V}{2} = \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right) = \frac{3}{4}\times1.38\times10^{-23}\cdot300\cdot\ln\frac{0.7}{1.21} \approx -0.01062\,eV$$

$\Rightarrow E_i$ is 0.01062 eV below the center of the bandgap

$$\text{(b) } E_i - \frac{E_C+E_V}{2} = \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right) = \frac{3}{4}\times1.38\times10^{-23}\cdot300\cdot\ln\frac{0.75}{0.80} = -0.00126\,eV$$

$\Rightarrow E_i$ is 0.00126eV below the center of the bandgap

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5. Semiconductor A has a band gap of 1 eV, while semiconductor B has a band gap of 2 eV. What is the ratio of the intrinsic carrier concentrations in the two materials (n_{iA}/n_{iB}) at 300 K. Assume any differences in the carrier effective masses may be neglected.

From $n_i = \sqrt{N_C N_V}\, e^{-\frac{E_g}{2kT}}$

we can know that: $$\frac{n_{iA}}{n_{iB}} = \frac{\sqrt{N_{CA}N_{VA}}\, e^{-\frac{E_{gA}}{2kT}}}{\sqrt{N_{CB}N_{VB}}\, e^{-\frac{E_{gB}}{2kT}}} = e^{\frac{E_{gB}-E_{gA}}{2kT}} = e^{\frac{2-1}{2\cdot8.617\cdot10^{-5}\cdot300}} = e^{19.35} = 2.3\times10^{8}$$

6. The value p_0 in Silicon at T = 300K is $2\times 10^{16}cm^{-3}$. (a) Determine $E_F - E_v$. (b) Calculate the value of $E_C - E_F$. (c) What is the value of n_0? (d) Determine $E_{Fi} - E_F$.

(a) $p_o = N_v \exp\left(\frac{E_v - E_F}{kT}\right) \Rightarrow E_F - E_v = -\ln\frac{p_o}{N_v} \cdot kT = 0.162\ eV$

(b) $E_c - E_F = E_c - E_v + E_v - E_F = E_g - (E_F - E_v) = 1.12 - 0.162 = 0.958\ eV$

(c) $n_o = \frac{n_i^2}{p_o} = \frac{(1.5\times 10^{10})^2}{2\times 10^{16}} = 1.125\times 10^4\ cm^{-3}$

(d) $E_{Fi} - E_F = \frac{E_c + E_v}{2} - E_F = \frac{1}{2}(E_c - E_F) + \frac{1}{2}(E_v - E_F) = \frac{0.958 - 0.162}{2} = 0.398\,eV$

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7. The electron concentration in silicon at T = 300K is $n_0 = 2\times 10^5 cm^{-3}$. (a) Determine the position of the Fermi level with respect to the valence band energy level. (b) Determine p_0. (c) Is it n- or p-type material?

(a)

$n_o = N_c \exp\left(\frac{E_F - E_c}{kT}\right) \Rightarrow E_F - E_c = kT \cdot \ln\frac{n_o}{N_c} \Rightarrow E_F - E_v = E_g + E_F - E_c =$

$= 1.12 + 300 \cdot 8.62\times 10^{-5} \ln\frac{2\times 10^5}{2.8\times 10^{19}}$

$= 1.12 - 0.842 = 0.278\ eV$

(b)

$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\times 10^{10})^2}{2\times 10^5} = 1.125\times 10^{15}$

(c)

Since $p_o >> n_o$, we can know that it's an n-type material