4.48 Consider germanium with an acceptor concentration of $N_a = 10^{15}$ cm^{-3} and a donor concentration of $N_d = 0$. Consider temperatures of $T = 200$, 400, and 600 K. Calculate the position of the Fermi energy with respect to the intrinsic Fermi level at these temperatures.

Use MathCad for the necessary computations.

Define some constants

$kB := 1.380649 \cdot 10^{-23}$ J/K $kB\_eV := 8.617333 \cdot 10^{-5}$ eV/K

$h := 6.62607015 \cdot 10^{-34}$ J-s $m0 := 9.1093837015 \cdot 10^{-31}$ kg

Given $Na := 10^{21}$ m-3 $Nd := 0$

From Table B.4, germanium

$Eg := 0.66$ eV $mne := 0.55 \cdot m0$ $mpe := 0.37 \cdot m0$

200 K $kB \cdot 200 = 2.7613 \times 10^{-21}$ J $kB\_eV \cdot 200 = 0.017235$ eV

(4.10) $Nc200 := 2 \cdot \left(\frac{2 \cdot \pi \cdot mne \cdot kB \cdot 200}{h^2} \right)^{1.5}$ $Nc200 = 5.5716 \times 10^{24}$ m-3

(4.18) $Nv200 := 2 \cdot \left(\frac{2 \cdot \pi \cdot mpe \cdot kB \cdot 200}{h^2} \right)^{1.5}$ $Nv200 = 3.0742 \times 10^{24}$ m-3

(4.23) $ni200\_2 := Nc200 \cdot Nv200 \cdot e^{\frac{-Eg}{kB\_eV \cdot 200}}$ $ni200\_2 = 4.0036 \times 10^{32}$

$ni200 := \sqrt{ni200\_2}$ $ni200 = 2.00089 \times 10^{16}$ m-3

(4.62) $p0\_200 := \frac{Na - Nd}{2} + \sqrt{\left(\frac{Na - Nd}{2} \right)^2 + ni200^2}$ $p0\_200 = 1 \times 10^{21}$ m-3

(4.68) $EFi\_EF200 := kB\_eV \cdot 200 \cdot \ln\left(\frac{p0\_200}{ni200} \right)$ $\boxed{EFi\_EF200 = 0.18647}$ eV

400 K

$kB \cdot 400 = 5.5226 \times 10^{-21}$ J $\quad kB\_eV \cdot 400 = 0.034469$ eV

(4.10) $Nc400 := 2 \cdot \left(\frac{2 \cdot \pi \cdot mne \cdot kB \cdot 400}{h^2} \right)^{1.5}$ $\quad Nc400 = 1.5759 \times 10^{25}$ m^{-3}

(4.18) $Nv400 := 2 \cdot \left(\frac{2 \cdot \pi \cdot mpe \cdot kB \cdot 400}{h^2} \right)^{1.5}$ $\quad Nv400 = 8.6953 \times 10^{24}$ m^{-3}

(4.23) $ni400\_2 := Nc400 \cdot Nv400 \cdot e^{\frac{-Eg}{kB\_eV \cdot 400}}$ $\quad ni400\_2 = 6.6248 \times 10^{41}$

$ni400 := \sqrt{ni400\_2}$ $\quad ni400 = 8.13929 \times 10^{20}$ m^{-3}

(4.62) $p0\_400 := \frac{Na - Nd}{2} + \sqrt{\left(\frac{Na - Nd}{2} \right)^2 + ni400^2}$ $\quad p0\_400 = 1.45524 \times 10^{21}$ m^{-3}

(4.68) $EFi\_EF400 := kB\_eV \cdot 400 \cdot \ln\left(\frac{p0\_400}{ni400} \right)$ $\quad \boxed{EFi\_EF400 = 0.02003}$ eV

600 K

$kB \cdot 600 = 8.28389 \times 10^{-21}$ J $\quad kB\_eV \cdot 600 = 0.051704$ eV

(4.10) $Nc600 := 2 \cdot \left(\frac{2 \cdot \pi \cdot mne \cdot kB \cdot 600}{h^2} \right)^{1.5}$ $\quad Nc600 = 2.8951 \times 10^{25}$ m^{-3}

(4.18) $Nv600 := 2 \cdot \left(\frac{2 \cdot \pi \cdot mpe \cdot kB \cdot 600}{h^2} \right)^{1.5}$ $\quad Nv600 = 1.5974 \times 10^{25}$ m^{-3}

(4.23) $ni600\_2 := Nc600 \cdot Nv600 \cdot e^{\frac{-Eg}{kB\_eV \cdot 600}}$ $\quad ni600\_2 = 1.3223 \times 10^{45}$

$ni600 := \sqrt{ni600\_2}$ $\quad ni600 = 3.63632 \times 10^{22}$ m^{-3}

(4.62) $p0\_600 := \frac{Na - Nd}{2} + \sqrt{\left(\frac{Na - Nd}{2} \right)^2 + ni600^2}$ $\quad p0\_600 = 3.68666 \times 10^{22}$ m^{-3}

(4.68) $EFi\_EF600 := kB\_eV \cdot 600 \cdot \ln\left(\frac{p0\_600}{ni600} \right)$ $\quad \boxed{EFi\_EF600 = 7.1092 \times 10^{-4}}$ eV