4.53 For a particular semiconductor, $E_g = 1.50$ eV, $m_p^* = 10\,m_n^*$, $T = 300$ K, and $n_i = 1 \times 10^5$ cm^{-3}. (*a*) Determine the position of the intrinsic Fermi energy level with respect to the center of the bandgap. (*b*) Impurity atoms are added so that the Fermi energy level is 0.45 eV below the center of the bandgap. (*i*) Are acceptor or donor atoms added? (*ii*) What is the concentration of impurity atoms added?

a) Per (4.26b), we get

$$E_{F,i} - E_{\text{midgap}} = \frac{3}{4} k_B T \ln\left(\frac{m_p^*}{m_n^*}\right) = \frac{3}{4}(8.617333 \times 10^{-5} \text{ eV/K})300 \ln\left(\frac{10 m_n^*}{m_n^*}\right)$$

$\Rightarrow$ <u>$\mathbf{E_{F,i} - E_{\text{midgap}} = 0.044645}$ **eV**</u>.

b)

(*i*) To move E_F <u>below</u> E_{midgap}, we'll need to <u>**add acceptor atoms**</u>.

(*ii*) $(E_{F,i} - E_{\text{midgap}}) + (E_{\text{midgap}} - E_F) = E_{F,i} - E_F = 0.044645 + 0.45 = 0.4946448$ eV.

Per (4.40), $p_0 = n_i\, e^{-(E_F - E_{F,i})/k_B T} = n_i\, e^{(E_{F,i} - E_F)/k_B T} = 1 \times 10^5\, e^{0.4946448/[8.617333 \times 10^{-5}(300)]}$

$\Rightarrow p_0 = 2.040175 \times 10^{13}$ #/cm^3.

Per (4.62), $$p_0 = \frac{(N_a - N_d)}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2}\ .$$

With $N_d = 0$ and $p_0 >> n_i$, this implies that $N_a >> n_i$.

Therefore, we can say that $N_a \approx p_0$ $\Rightarrow$ <u>$\mathbf{N_a \approx p_0 = 2.0402 \times 10^{13}}$ **#/cm^3**</u>.