ELECTRONIC DEVICES
ASSIGNMENT 1

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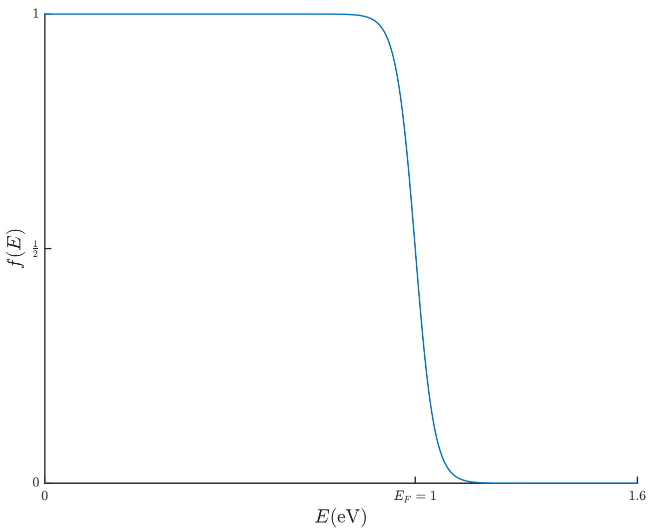
Exercise 1.

(1) Plot the Fermi function at room temperature for $E_f = 1\,\mathrm{eV}$. Plot over the energy range $0\,\mathrm{eV} - 1.6\,\mathrm{eV}$. Calculate data points every $0.2\,\mathrm{eV}$. Attach a table of calculated values along with your plot.
(2) Show that the probability of an occupied state ΔE above E_f is equal to the probability of an empty state ΔE below E_F, i.e.

$$f(E_F + \Delta E) = 1 - f(E_F - \Delta E)$$

Solution 1.

(1)



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E(eV)	$f(E)$
0	1
0.2	0.999999999999964
0.4	0.999999999916739
0.6	0.999999809324428
0.8	0.99956352640943
1	0.5
1.2	0.000436473590570019
1.4	$1.90675572317553 \times 10^{-7}$
1.6	$8.32612088642445 \times 10^{-11}$

(2)

$$\begin{aligned}
f(E) &= \frac{1}{1+e^{\frac{E-E_F}{kT}}} \\
\therefore f(E_F+\Delta E) &= \frac{1}{1+e^{\frac{E_F+\Delta E-E_F}{kT}}} \\
&= \frac{1}{1+e^{\frac{\Delta E}{kT}}} \\
\therefore f(E_F-\Delta E) &= \frac{1}{1+e^{\frac{E_F-\Delta E-E_F}{kT}}} \\
&= \frac{1}{1+e^{-\frac{\Delta E}{kT}}} \\
&= \frac{e^{\frac{\Delta E}{kT}}}{e^{\frac{\Delta E}{kT}}+1} \\
&= 1-\frac{1}{e^{\frac{\Delta E}{kT}}+1} \\
&= 1-f(E_F+\Delta E)
\end{aligned}$$

Exercise 2.
A N-type semiconductor has the following properties.

(1) $E_{\text{gap}} = 1.1\,\text{eV}$.
(2) $N_C = N_V$.
(3) $N_D = 10^{15}\text{cm}^{-3}$.
(4) $E_D = E_C - 0.2\,\text{eV}$.

Given that E_f is $0.25\,\text{eV}$ below E_C, calculate n_i, and the concentration of the electrons and holes in the semiconductor at $300\,\text{K}$.

Solution 2.

$$\begin{aligned}
n &= n_i e^{\frac{E_F - E_i}{kT}} \\
\therefore N_D &= n_i e^{\frac{E_F - E_i}{kT}} \\
\therefore 10^{15} &= n_i e^{\frac{0.3}{2585.1\times 10^{-5}}} \\
\therefore 10^{15} &= n_i e^{11.605} \\
\therefore n_i &= \frac{10^{15}}{e^{11.605}} \\
&= 9.12 \times 10^{9}
\end{aligned}$$

Therefore,

$$\begin{aligned}
p &= \frac{{n_i}^2}{n} \\
&= \frac{83.1744 \times 10^{18}}{10^{15}} \\
&= 83.174410^{3}
\end{aligned}$$

Exercise 3.
A semiconductor has an intrinsic carrier concentration of $10^{10}\mathrm{cm}^{-3}$ at 300 K, and its conduction and valence band effective densities of states are equal to $10^{19}\mathrm{cm}^{-3}$, i.e., $N_C = N_V = 10^{19}\mathrm{cm}^{-3}$.

(1) What is the band gap E_{gap}?
(2) If the semiconductor is doped with $N_D = 10^{16}\mathrm{cm}^{-3}$, what are the equilibrium electron and hole concentrations at 300 K?
(3) If the same piece of semiconductor, already having $N_D = 10^{16}\mathrm{cm}^{-3}$, is now also doped with acceptors with $N_A = 2 \times 10^{16}\mathrm{cm}^{-3}$, what are the new equilibrium electron and hole concentrations at 300 K? What is the Fermi level position with respect to the intrinsic Fermi level, i.e., what is $E_f - E_i$?

Solution 3.

(1)

$$
\begin{aligned}
n_i &= \sqrt{N_C N_V} e^{-\frac{E_{\text{gap}}}{kT}} \\
\therefore \frac{n_i}{\sqrt{N_C N_V}} &= e^{-\frac{E_{\text{gap}}}{kT}} \\
\therefore E_{\text{gap}} &= -kT \ln\left(\frac{n_i}{\sqrt{N_C N_V}}\right) \\
&= -(8.617)(300) \ln\left(\frac{10^{10}}{10^{19}}\right) \\
&= -\left(2585.1 \times 10^{-5}\right) \ln\left(10^{-9}\right) \\
&= -\left(2585.1 \times 10^{-5}\right)(-20.723) \\
&= 53571.0273 \times 10^{-5} \\
&= 0.53571\,\text{eV}
\end{aligned}
$$

(2)

$$
\begin{aligned}
n &= N_D \\
&= 10^{16}\text{cm}^{-3} \\
p &= \frac{{n_i}^2}{n} \\
&= \frac{10^{20}}{10^{16}} \\
&= 10^{4}\text{cm}^{-3}
\end{aligned}
$$

(3)

$$
\begin{aligned}
p &= N_A - N_D \\
&= 10^{16}\text{cm}^{-3} \\
n &= \frac{{n_i}^2}{p} \\
&= \frac{10^{20}}{10^{16}} \\
&= 10^{4}\text{cm}^{-3}
\end{aligned}
$$

Therefore,

$$
\begin{aligned}
n &= n_i e^{\frac{E_F - E_i}{kT}} \\
\therefore 10^4 &= 10^{10} e^{\frac{E_F - E_i}{\left(8.617 \times 10^{-5}\right)(300)}} \\
\therefore 10^{-6} &= e^{\frac{E_F - E_i}{2585.1 \times 10^{-5}}} \\
\therefore \ln\left(10^{-6}\right) &= \frac{E_F - E_i}{2585.1 \times 10^{-5}} \\
\therefore E_F - E_i &= (-13.8155)\left(2585.1 \times 10^{-5}\right) \\
&= -0.3571444905
\end{aligned}
$$