

## ELECTRONIC DEVICES ASSIGNMENT 1

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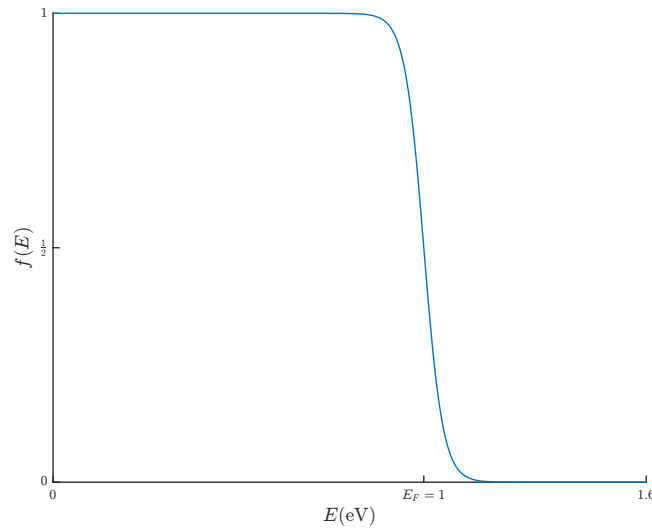
### Exercise 1.

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

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

### Solution 1.

(1)



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$E(\text{eV})$	$f(E)$
0	1
0.2	0.9999999999999964
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 eV below  $E_C$ , calculate  $n_i$ , and the concentration of the electrons and holes in the semiconductor at 300 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,

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

**Exercise 3.**

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

- (1) What is the band gap  $E_{\text{gap}}$ ?
- (2) If the semiconductor is doped with  $N_D = 10^{16} \text{ cm}^{-3}$ , what are the equilibrium electron and hole concentrations at 300 K?
- (3) If the same piece of semiconductor, already having  $N_D = 10^{16} \text{ cm}^{-3}$ , is now also doped with acceptors with  $N_A = 2 \times 10^{16} \text{ cm}^{-3}$ , 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)

$$\begin{aligned}
n_i &= \sqrt{N_C N_V} e^{-\frac{E_{\text{gap}}}{2kT}} \\
\therefore \frac{n_i}{\sqrt{N_C N_V}} &= e^{-\frac{E_{\text{gap}}}{2kT}} \\
\therefore E_{\text{gap}} &= -2kT \ln \left( \frac{n_i}{\sqrt{N_C N_V}} \right) \\
&= -(2)(8.617)(300) \ln \left( \frac{10^{10}}{10^{19}} \right) \\
&= -(5170.2 \times 10^{-5}) \ln (10^{-9}) \\
&= -(5170.2 \times 10^{-5}) (-20.723) \\
&= 107142.0546 \times 10^{-5} \\
&= 1.071420546 \text{ eV}
\end{aligned}$$

(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,

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