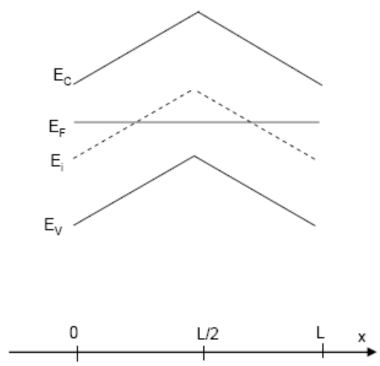
EECS 170A Section B
Homework Solution #3

1) Answer a-d for the figure shown below:



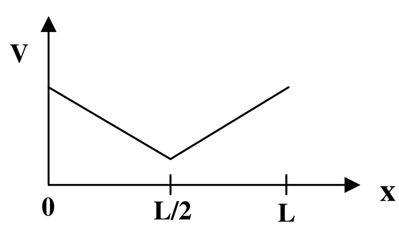
a. Do equilibrium conditions prevail? How do you know?

(2 pts) *Yes, the system is in equilibrium.*

(3 pts) *The Fermi energy is constant (i.e. $dE_F/dx = 0$). This means that any drift currents (J_{drift}) due to the internal electric fields will cancel out an equal but opposite diffusion current ($J_{diffusion}$). Consequently, the net current flow equals to zero, hence, the system is in equilibrium.*

b. Sketch the electrostatic potential (V) inside the semiconductor as a function of x.

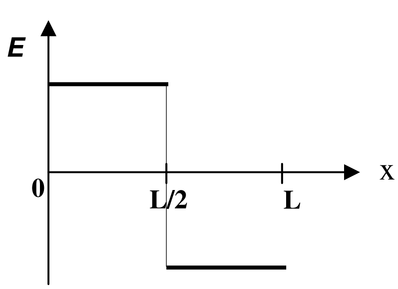
(5 pts)



The electrostatic potential can be expressed as $V = -E_C / q$. Remember that V is a relative quantity and can be scaled by any reference voltage.

c. Sketch the electric field (E) inside the semiconductor as a function of x

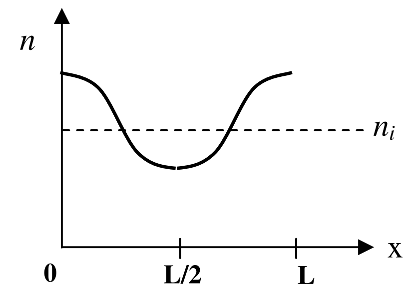
(5 pts)



The electric field (E) can be derived from the electrostatic potential (V) by $E = -dV/dx = 1/q\,(dE_C/dx)$.

d. Roughly sketch n and p versus x.

(5 pts)

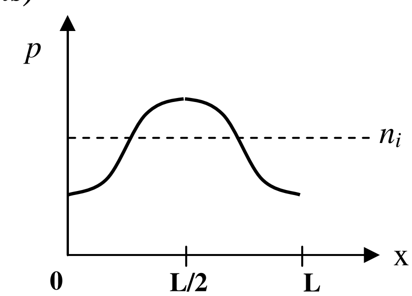


In equilibrium,

$$n = N_C e^{-(E_C - E_f)/KT} = N_i e^{(E_f - E_i)/KT}$$

Electrons accumulate at the lowest energy possible relative to the Fermi energy. Hence, the electron density (n) will be highest near x= 0 and x=L.

(5 pts)

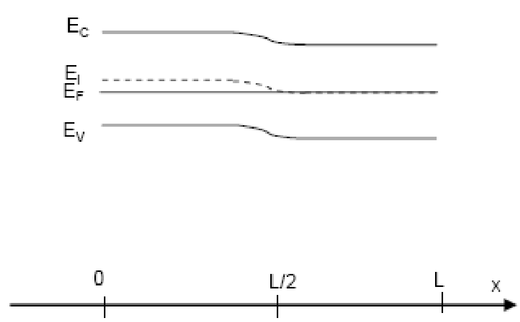


In equilibrium,

$$p = N_V e^{-(E_f - E_V)/KT} = N_i e^{(E_i - E_V)/KT}$$

When the Fermi energy for the intrinsic semiconductor (E_i) becomes greater than the Fermi level (E_f), then there is holes accumulation. The magnitude of p peaks at x= L/2.

2) Answer a-d for the figure shown below:



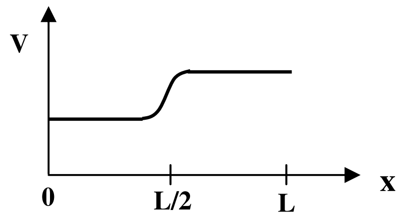
a. Do equilibrium conditions prevail? How do you know?

(2 pts) *Yes, the system is in equilibrium.*

(3 pts) *The Fermi energy is constant (i.e. $dE_F/dx = 0$). This means that any drift currents (J_{drift}) due to the internal electric fields will cancel out an equal but opposite diffusion current ($J_{diffusion}$). Consequently, the net current flow equals to zero, hence, the system is in equilibrium.*

b. Sketch the electrostatic potential (V) inside the semiconductor as a function of x.

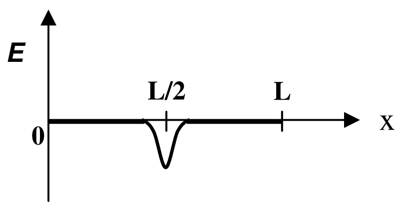
(5 pts)



The electrostatic potential can be expressed as $V = -E_c / q$. Center of the graph should be at x=L/2.

c. Sketch the electric field (E) inside the semiconductor as a function of x

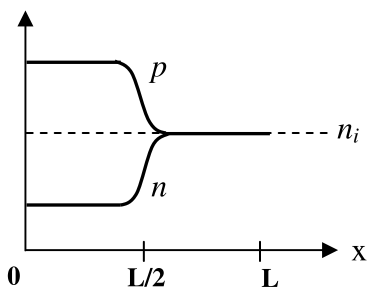
(5 pts)



The electric field (E) can be derived from the electrostatic potential (V) by $E = -dV/dx$.

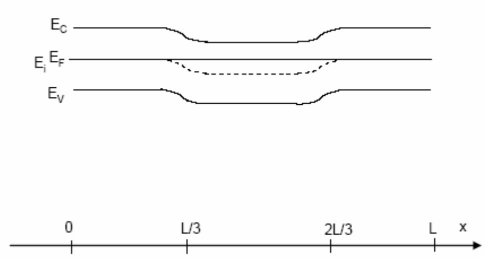
d. Roughly sketch n and p versus x.

(5 pts for n and 5pts for p)



When the Fermi energy for the intrinsic semiconductor (E_i) equals to the Fermi level (E_f), then the electron and hole concentrations equal to the intrinsic concentration (n_i).

3) Answer a-d for the figure shown below:



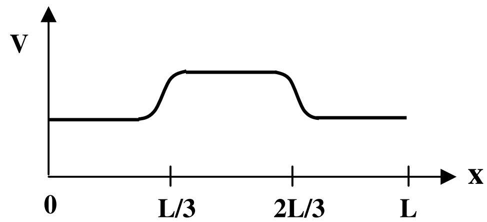
a. Do equilibrium conditions prevail? How do you know?

(2 pts) *Yes, the system is in equilibrium.*

(3 pts) *The Fermi energy is constant (i.e. $dE_F/dx = 0$). This means that any drift currents (J_{drift}) due to the internal electric fields will cancel out an equal but opposite diffusion current ($J_{diffusion}$). Consequently, the net current flow equals to zero, hence, the system is in equilibrium.*

b. Sketch the electrostatic potential (V) inside the semiconductor as a function of x.

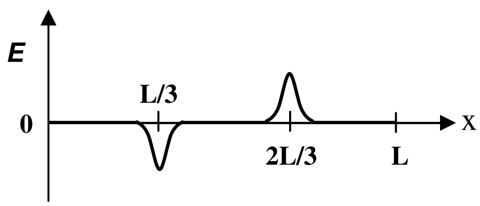
(5 pts)



The electrostatic potential can be expressed as $V = -E_c / q$. Center of the graph should be at x=L/3 and 2L/3.

c. Sketch the electric field (E) inside the semiconductor as a function of x

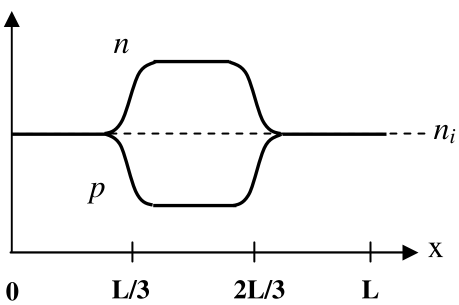
(5 pts)



The electric field (E) can be derived from the electrostatic potential (V) by E = -dV/dx.

d. Roughly sketch n and p versus x.

(5 pts for n and 5pts for p)



When the Fermi energy for the intrinsic semiconductor (E_i) equals to the Fermi level (E_f), then the electron and hole concentrations equal to the intrinsic concentration (n_i).

4) For Si at 300 K, calculate E_C-E_F and sketch E_C, E_F, E_i, and E_V as in figure 2.18 of the book for the following cases:

a. $N_D= 10^{18}$ cm^{-3}; $N_A =10^{12}$ cm^{-3}.

(3 pts) *Since $N_D >> N_A$ and $N_D >> n_i$,*

$\therefore n \approx N_D = 10^{18}\ cm^{-3}$

At 300K, $N_{C,V} = 2.510 \times 10^{19} \times (m_{n,p}^*/ m_0^*)^{3/2}$

From Table 2.1, for Si, $(m_n^*/ m_0^*) = 1.18$;

$(m_p^*/ m_0^*) = 0.81$

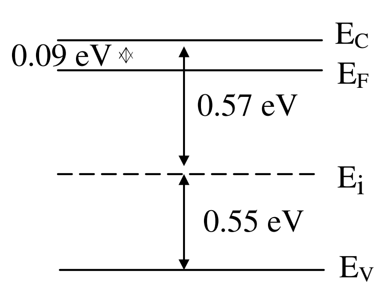
$N_C = 2.510 \times 10^{19} \times (1.18)^{3/2} = 3.217 \times 10^{19}\ cm^{-3}$

$N_V = 2.510 \times 10^{19} \times (0.81)^{3/2} = 1.83 \times 10^{19}\ cm^{-3}$

$E_C - E_F = KT \ln (N_C / n)$

$= 0.0259 \times \ln (3.217 \times 10^{19} / 10^{18}) = 0.09\ eV$

(2 pts for the sketch)



$E_C - E_i = KT \ln (N_C / n_i) = 0.0259 \times \ln (3.217 \times 10^{19} / 10^{10}) = 0.57$ eV
$E_i - E_V = KT \ln (N_V / n_i) = 0.0259 \times \ln (1.83 \times 10^{19} / 10^{10}) = 0.55$ eV

Or another approach:

$E_F - E_i = KT \ln (n/n_i) = 0.0259 \times \ln (10^{18}/10^{10}) = 0.477$ eV
$Ec - E_F = (E_C - E_i) - (E_F - E_i) = 0.57 - 0.477 = 0.093$ eV

Or another approach:

$E_C - E_i \approx Eg / 2 = 1.12 / 2 = 0.56$ eV
$Ec - E_F = (E_C - E_i) - (E_F - E_i) = 0.56 - 0.477 = 0.083$ eV

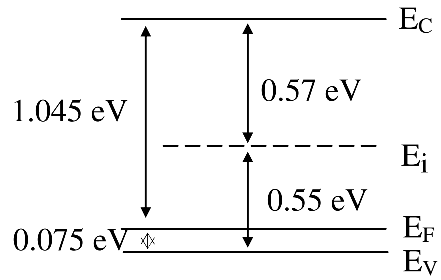
Acceptable ($Ec - E_F$) range = 0.08 ~ 0.095 eV

b. $N_A = 10^{18}$ cm^{-3}; $N_D = 10^{12}$ cm^{-3}.

(3 pts) $N_A >> N_D$ and $N_A >> n_i$
$\therefore p \approx N_A = 10^{18}$ cm^{-3}

$E_F - E_V = KT \ln (N_V / p)$
$= 0.0259 \times \ln (1.83 \times 10^{19} / 10^{18})$
$= 0.075$ eV
$E_C - E_F = (E_C - E_V) - (E_F - E_V)$
$= 1.12$ eV $- 0.075$ eV
$= 1.045$ eV

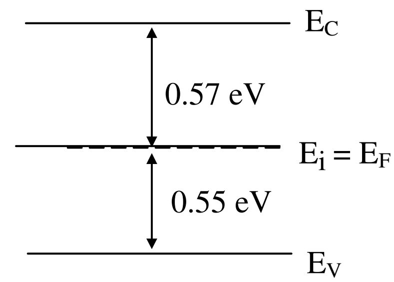
(2 pts for the sketch)



Acceptable ($Ec - E_F$) range = 1.03 ~ 1.05 eV

c. $N_A = 10^{18}$ cm^{-3}; $N_D = 10^{18}$ cm^{-3}.

(2 pts for the sketch)



(3 pts) $N_A - N_D = 0$
$n = p = n_i = 10^{10}$ cm^{-3}
$\therefore E_F = E_i$

At 300K, $N_C = 2.510 \times 10^{19} \times (m_n^*/ m_0^*)^{3/2}$
From Table 2.1, for Si, $(m_n^*/ m_0^*) = 1.18$;
$N_C = 2.510 \times 10^{19} \times (1.18)^{3/2} = 3.217 \times 10^{19}$ cm^{-3}

$E_C - E_i = E_C - E_F = KT \ln (N_C / n_i) = 0.0259 \times \ln (3.217 \times 10^{19} / 10^{10}) = 0.57$ eV

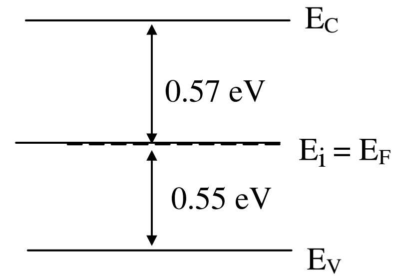
Or another approach:

$E_C - E_i = E_C - E_F \approx Eg / 2 = 1.12 / 2 = 0.56$ eV

Acceptable ($Ec - E_F$) range = 0.56 ~ 0.57 eV

d. $N_A = 10^{12}$ cm^{-3}; $N_D = 10^{12}$ cm^{-3}.

(2 pts for the sketch)



(3 pts) $N_A - N_D = 0$

$n = p = n_i = 10^{10}\ cm^{-3}$

$\therefore E_F = E_i$

At 300K, $N_C = 2.510 \times 10^{19} \times (m_n^*/ m_0^*)^{3/2}$

From Table 2.1, for Si, $(m_n^*/ m_0^*) = 1.18$;

$N_C = 2.510 \times 10^{19} \times (1.18)^{3/2} = 3.217 \times 10^{19}\ cm^{-3}$

$E_C - E_i = E_C - E_F = KT \ln (N_C / n_i) = 0.0259 \times \ln (3.217 \times 10^{19} / 10^{10}) = 0.57\ eV$

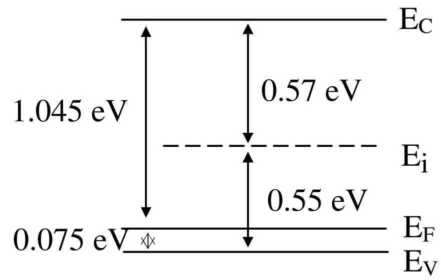
Or another approach:

$E_C - E_i = E_C - E_F \approx Eg / 2 = 1.12 / 2 = 0.56\ eV$

Acceptable ($E_c - E_F$) range = 0.56 ~ 0.57 eV

e. $N_A = 10^{18}$ cm^{-3}; $N_D = 10^{11}$ cm^{-3}.

(2 pts for the sketch)



(3 pts) $N_A >> N_D$ and $N_A >> n_i$

$\therefore p \approx N_A = 10^{18}\ cm^{-3}$

$E_F - E_V = KT \ln (N_V / p)$

$= 0.0259 \times \ln (1.83 \times 10^{19} / 10^{18})$

$= 0.075\ eV$

$E_C - E_F = (E_C - E_V) - (E_F - E_V)$

$= 1.12\ eV - 0.075\ eV$

$= 1.045\ eV$

Acceptable ($E_c - E_F$) range = 1.03 ~ 1.05 eV