

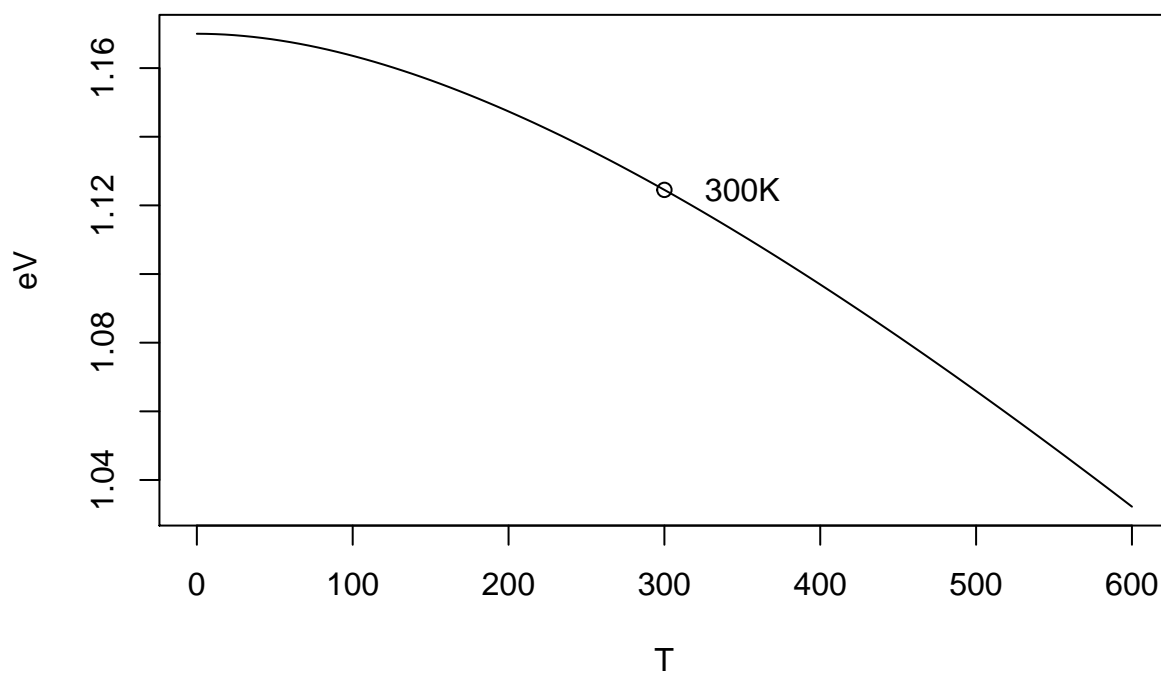
VE320 Homework2

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Ex 2.1

```
func <- function(x) {1.170-4.73e-4*x^2/(636+x)}  
curve(func, from = 0, to = 600, xlab = 'T', ylab = 'eV')  
points(300, func(300))  
text(350, func(300), labels = '300K')
```



Ex 2.2

For A, $E - E_v = -C_2 k^2$,

$$0 - 0.025 \text{ eV} \cdot 1.6 \times 10^{-19} = -C_2 \cdot (0.08 \times 10^{10} \text{ m}^{-1})^2$$

$$C_2 = 6.25 \times 10^{-39} \text{ V/m}^2$$

$$m^* = \frac{\hbar^2}{-2C_2} = \frac{(1.054 \times 10^{-34} \text{ J} \cdot \text{s})^2}{-2 \cdot 6.25 \times 10^{-39} \text{ V/m}^2} = -8.89 \times 10^{-31} \text{ kg} = -0.98 m_0$$

For B, $E - E_v = -C_2 k^2$,

$$0 - 0.3 \text{ eV} \cdot 1.6 \times 10^{-19} = -C_2 \cdot (0.08 \times 10^{10} \text{ m}^{-1})^2$$

$$C_2 = 7.5 \times 10^{-38} \text{ V/m}^2$$

$$m^* = \frac{\hbar^2}{-2C_2} = \frac{(1.054 \times 10^{-34} \text{ J} \cdot \text{s})^2}{-2 \cdot 7.5 \times 10^{-38} \text{ V/m}^2} = -7.41 \times 10^{-32} \text{ kg} = -0.08 m_0$$

Ex 2.3

$$E = \frac{p^2}{2m} = \frac{k^2 \hbar^2}{2m}$$

$$k = \sqrt{\frac{2mE}{\hbar^2}}$$

$$\frac{dk}{dE} = \sqrt{\frac{m}{2\hbar^2 E}}$$

$$g_T(k)dk = \frac{\pi k^2 dk}{\pi^3}$$

$$g(E)dE = \frac{2\pi mE}{\hbar^2 \pi^3} \sqrt{\frac{m}{2\hbar^2 E}} dE = \frac{2\pi m^{3/2} \sqrt{E}}{\hbar^3 \pi^3 \sqrt{2}} dE = \frac{4\pi (2m)^{3/2}}{\hbar^3} \sqrt{E} dE$$

$$g(E) = \frac{4\pi (2m)^{3/2}}{\hbar^3} \sqrt{E}$$

Ex 2.4

$$f_F = \exp \left[\frac{-(E - E_F)}{kT} \right] = \exp \left[\frac{-(E_c + kT - E_F)}{kT} \right]$$

$$1 - f_F = \exp \left[\frac{-(E_F - E_E)}{kT} \right] = \exp \left[\frac{-(E_F - (E_v - kT))}{kT} \right]$$

$$\exp \left[\frac{-(E_c + kT - E_F)}{kT} \right] = \exp \left[\frac{-(E_F - (E_v - kT))}{kT} \right]$$

$$E_c + kT - E_F = E_F - (E_v - kT)$$

$$E_F = \frac{E_c + E_v}{2}$$

Ex 2.5

(a)

$$kT = 8.62 \times 10^{-5} \text{ eV/K} \cdot 200 \text{ K} = 1.724 \times 10^{-2} \text{ eV}$$

$$f_F = 0.05 = \frac{1}{1 + \exp \left[\frac{E - E_F}{kT} \right]}$$

$$E - E_F = kT \ln 19 = 5.076 \times 10^{-2} \text{ eV}$$

$$f_F = 0.95 = \frac{1}{1 + \exp \left[\frac{E - E_F}{kT} \right]}$$

$$E - E_F = kT \ln \frac{1}{19} = -5.076 \times 10^{-2} \text{ eV}$$

$$\Delta E = 5.076 \times 10^{-2} \text{ eV} \cdot 2 = 1.016 \times 10^{-1} \text{ eV}$$

(b)

$$kT = 8.62 \times 10^{-5} \text{ eV/K} \cdot 200 \text{ K} = 3.448 \times 10^{-2} \text{ eV}$$

$$E - E_F = kT \ln 19 = 1.015 \times 10^{-1} \text{ eV}$$

$$E - E_F = kT \ln \frac{1}{19} = -1.015 \times 10^{-1} \text{ eV}$$

$$\Delta E = 1.015 \times 10^{-1} \text{ eV} \cdot 2 = 2.03 \times 10^{-1} \text{ eV}$$

Ex 2.6

$$E_{Fi} - E_{midgap} = \frac{3}{4} kT \ln \frac{m_p^*}{m_n^*}$$

For $T = 200 \text{ K}$, $kT = 1.724 \times 10^{-2} \text{ eV}$,

$$E_{Fi} - E_{midgap} = \frac{3}{4} \cdot 1.724 \times 10^{-2} \text{ eV} \cdot \ln \frac{0.56}{1.08} = -8.49 \times 10^{-3} \text{ eV}$$

For $T = 400 \text{ K}$, $kT = 3.448 \times 10^{-2} \text{ eV}$,

$$E_{Fi} - E_{midgap} = \frac{3}{4} \cdot 3.448 \times 10^{-2} \text{ eV} \cdot \ln \frac{0.56}{1.08} = -1.70 \times 10^{-2} \text{ eV}$$

For $T = 600 \text{ K}$, $kT = 5.172 \times 10^{-2} \text{ eV}$,

$$E_{Fi} - E_{midgap} = \frac{3}{4} \cdot 5.172 \times 10^{-2} \text{ eV} \cdot \ln \frac{0.56}{1.08} = -2.55 \times 10^{-2} \text{ eV}$$

Ex 2.7

$$\begin{aligned} n_0 &= \int g_c(E) f_F(E) dE = K \int f_F(E) dE \\ f_F(E) &= \frac{1}{1 + \exp\left[\frac{E - E_F}{kT}\right]} \approx \exp\left[\frac{-(E - E_F)}{kT}\right] \\ \int_{E_c}^{\infty} \exp\left[\frac{-(E - E_F)}{kT}\right] dE &= kT \exp\left[\frac{-(E_c - E_F)}{kT}\right] \\ n_0 &\approx K kT \exp\left[\frac{-(E_c - E_F)}{kT}\right] \end{aligned}$$

Ex 2.8

(a)

$$E_F - E_v = kT \ln \frac{N_v}{p_0} = 0.0259 \text{ eV} \cdot \ln \frac{1.04 \times 10^{19} \text{ cm}^{-3}}{2 \times 10^{16} \text{ cm}^{-3}} = 1.62 \times 10^{-1} \text{ eV}$$

(b)

$$E_c - E_F = E_g - (E_F - E_v) = 1.12 \text{ eV} - 1.62 \times 10^{-1} \text{ eV} = 9.58 \times 10^{-1} \text{ eV}$$

(c)

$$n_0 = N_c \exp \left[\frac{-(E_c - E_F)}{kT} \right] = 2.8 \times 10^{19} \text{ cm}^{-3} \exp \left[\frac{-9.58 \times 10^{-1} \text{ eV}}{0.0259 \text{ eV}} \right] = 2.42 \times 10^3 \text{ cm}^{-3}$$

(d)

$$n_i = \sqrt{p_0 n_0} = \sqrt{2 \times 10^{16} \text{ cm}^{-3} \cdot 2.42 \times 10^3 \text{ cm}^{-3}} = 6.96 \times 10^9 \text{ cm}^{-3}$$

$$E_{Fi} - E_F = kT \ln \frac{p_0}{n_i} = 0.0259 \text{ eV} \cdot \ln \frac{2 \times 10^{16} \text{ cm}^{-3}}{6.96 \times 10^9 \text{ cm}^{-3}} = 3.85 \times 10^{-1} \text{ eV}$$

Ex 2.9

(a)

$$E_F - E_v = kT \ln \frac{N_v}{p_0} = 0.0259 \text{ eV} \cdot \ln \frac{1.04 \times 10^{19} \text{ cm}^{-3}}{5 \times 10^{15} \text{ cm}^{-3}} = 1.98 \times 10^{-1} \text{ eV}$$

(b)

$$E_c - E_F = E_g - (E_F - E_v) = 1.12 \text{ eV} - 1.98 \times 10^{-1} \text{ eV} = 9.22 \times 10^{-1} \text{ eV}$$

(c)

$$n_0 = N_c \exp \left[\frac{-(E_c - E_F)}{kT} \right] = 2.8 \times 10^{19} \text{ cm}^{-3} \exp \left[\frac{-9.22 \times 10^{-1} \text{ eV}}{0.0259 \text{ eV}} \right] = 9.70 \times 10^3 \text{ cm}^{-3}$$

(d)

$p_0 > n_0$, holes.

(e)

$$n_i = \sqrt{p_0 n_0} = \sqrt{5 \times 10^{15} \text{ cm}^{-3} \cdot 9.70 \times 10^3 \text{ cm}^{-3}} = 6.96 \times 10^9 \text{ cm}^{-3}$$

$$E_{Fi} - E_F = kT \ln \frac{p_0}{n_i} = 0.0259 \text{ eV} \cdot \ln \frac{5 \times 10^{15} \text{ cm}^{-3}}{6.96 \times 10^9 \text{ cm}^{-3}} = 3.49 \times 10^{-1} \text{ eV}$$

Ex 2.10

(a)

$$p_0 = N_v \exp \left[\frac{-(E_F - E_v)}{kT} \right] = 1.04 \times 10^{19} \text{ cm}^{-3} \exp \left[\frac{-0.25 \text{ eV}}{0.0259 \text{ eV}} \right] = 6.68 \times 10^{14} \text{ cm}^{-3}$$

$$E_c - E_F = E_g - (E_F - E_v) = 1.12 \text{ eV} - 0.25 \text{ eV} = 0.87 \text{ eV}$$

$$n_0 = N_c \exp \left[\frac{-(E_c - E_F)}{kT} \right] = 2.8 \times 10^{19} \text{ cm}^{-3} \exp \left[\frac{-0.87 \text{ eV}}{0.0259 \text{ eV}} \right] = 7.23 \times 10^4 \text{ cm}^{-3}$$

(b)

$$N_v = 1.04 \times 10^{19} \text{ cm}^{-3} \cdot \left(\frac{4}{3}\right)^{3/2} = 1.60 \times 10^{19} \text{ cm}^{-3}$$

$$E_F - E_v = kT \ln \frac{N_v}{p_0} = 0.03448 \text{ eV} \cdot \ln \frac{1.04 \times 10^{19} \text{ cm}^{-3}}{6.68 \times 10^{14} \text{ cm}^{-3} \text{ cm}^3} = 3.48 \times 10^{-1} \text{ eV}$$

$$E_c - E_F = E_g - (E_F - E_v) = 1.12 \text{ eV} - 3.48 \times 10^{-1} \text{ eV} = 7.72 \times 10^{-1} \text{ eV}$$

$$N_c = 2.8 \times 10^{19} \text{ cm}^{-3} \cdot \left(\frac{4}{3}\right)^{3/2} = 4.31 \times 10^{19} \text{ cm}^{-3}$$

$$n_0 = N_c \exp \left[\frac{-(E_c - E_F)}{kT} \right] = 4.31 \times 10^{19} \text{ cm}^{-3} \exp \left[\frac{-7.72 \times 10^{-1} \text{ eV}}{0.03448 \text{ eV}} \right] = 8.14 \times 10^9 \text{ cm}^{-3}$$