Exercise 4.1

Electrons in semiconductors. A semiconductor has a parabolic band structure:

$$E - E_c = \frac{\hbar^2}{2m^*}(k_x^2 + k_y^2 + k_z^2)$$

The Fermi level in the semiconductor could be above or below the conduction band edge. Take the electron effective mass as the free electron mass. For $\mu - E_c = 0.05eV$ and $T = 300K$, do the following in the range $0.0eV < E - E_c < 0.1eV$:

a) Plot the Fermi-Dirac distribution as a function of E.

b) Plot the density of state as a function of E.

c) Calculate the product of $f(E,T)D(E)$, which means the average number of eletrons at each E, and plot the product as a function of E.

d) Calculate the product of $(E - E_c)f(E,T)D(E)$, which means the actual kinetic energy at each allowable energy level, and plot the product as a function of E.

e) Repeat the questions for $\mu - E_c = -0.05eV$.

Exercise 4.2

Chemical potential and dopant concentration. The number of electrons in the conduction band can be assumed to be equal to the dopant concentration. Calculate the chemical potential levels relative to the band edge for the dopant concentrations of $10^{18}\ cm^{-3}$ and $10^{19}\ cm^{-3}$.
Assume the effective electron mass is approximated to free electron mass at $T = 300K$.
It is given that the density of states for electron is $D(E)$, where

$$D(E) = \frac{1}{2\pi^2}\left[\frac{2m^*}{\hbar^2}\right]^{3/2}(E - E_c)^{1/2}$$

and , E_c is the energy of the conduction band edge.

Exercise 4.3

Blackbody radiation. Consider the Blackbody radiation at 300K.

a) Plot the Bose-Einstein distribution as a function of angular frequency ω

b) Plot the density of states as a function of ω

c) Plot fD as a function of ω

d) Plot $\hbar\omega fD$ as a function of ω

e) compute the emissive power as a function of temperature and the corresponding specific heat

f) Compare (a)-(e) for Photons and Phonons. Use Debye model with Debye velocity of 5000 m/s and Debye temperature 500 K

Exercise 4.4

Phonon specific heat Assuming that phonons obey the following dispersion relation (three-dimensional isotropic medium)

$$\omega = 2\sqrt{\frac{K}{m}}\left|sin\frac{|\mathbf{k}|a}{2}\right|$$

where a is the lattice constant, K the spring constant, and $\mathbf{k}$ the wavevector. Derive an expression for the phonon internal energy and specific heat.