Introduction to Semiconductor Devices
(Purdue University EE 305/606)
Supplemental Homework Exercises

Tutorial questions based on *Carrier Statistics Lab v1.0* available online at https://www.nanohub.org/resources/3798/

Reference book: Semiconductor Device Fundamentals by Robert E. Pierret (Chapter 2)
FD: Fermi-Dirac MB: Maxwell-Boltzmann Ef: Fermi level above Ev

Q1. Find the occupation probability (value) for Fermi-Dirac distribution function for the following temperatures (i) 4 K (liuiqd helium temperature) (ii) 77 K (liquid nitrogen temperature) and (iii) 300K (room temperature) and at following energy values.
(Select Material = Si, Ef = 0.56eV (mid-gap))
(a) Ef
(b) Ef-3kT

(c) Ef+3kT
(d) Compare the results with Maxwell-Boltzmann distribution.

Q2. As shown in fig.1, for degenerate semiconductors properties are defined by FD statistics and not by MB, as MB overestimates the electron/hole densities when Fermi level is >Ec-3kT or <Ev+3kT. Now, comment on the following,

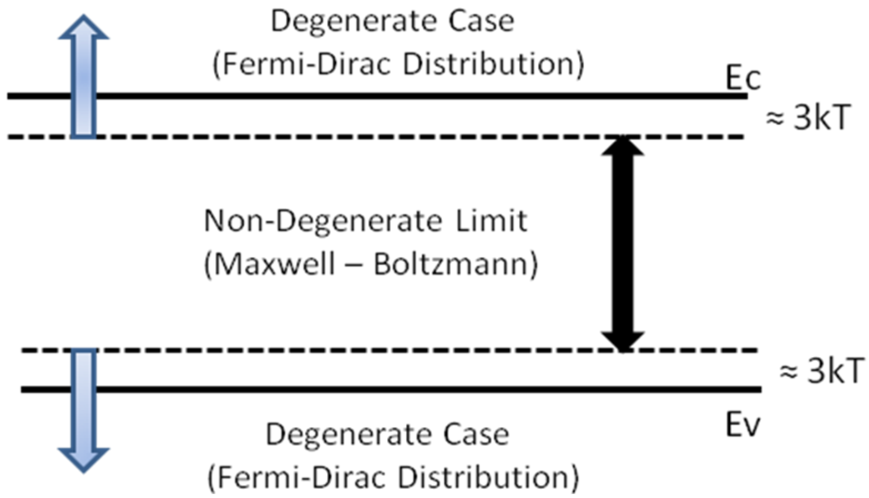

Figure1. Validity of Fermi-Dirac and Maxwell-Boltzmann distribution functions with fermi level.

(a) Compute electron and hole concentrations using FD and MB statistics for the following, (Material = Si)
(i) at T=100 K and Ef = Eg/2 ; Ef=Ec ; Ec+5kT ; Ef=Ev ; Ev-5kT
(ii) at T=200 K and Ef = Eg/2 ; Ef=Ec ; Ec+5kT ; Ef=Ev ; Ev-5kT
(iii) at T=300 K and Ef = Eg/2 ; Ef=Ec ; Ec+5kT ; Ef=Ev ; Ev-5kT
(b) Tabulate the above and show when MB statistics overestimate FD statistics.

(c) What is the physical insight related to your observation?

Q3. Obtain the following for Silicon using Fermi-Dirac statistics at T=300K. Vary Ef from Ev+5kT to Ec-5kT.
(a) Plot N vs Ef, P vs Ef, and Ni vs Ef. (Use minimum 10 data points), where N, P and Ni represent the mobile electron density, hole density and intrinsic density respectively.
(b) How does the carrier distribution curves change with variation in Fermi-level (Ef) and why?
(c) At what energy the peaks occur in (b) ?

Q4. Simulate for intrinsic Silicon using Fermi-Dirac statistics. Vary Temperature from T=200K to 700K. (Hint: Assume intrinsic Fermi level is at Eg/2)
(a) Plot N vs T, P vs T and Ni vs T.
(b) Do the same for intrinsic Ge and intrinsic GaAs. (Adjust energy range from -0.4eV to Eg+0.4eV)

Q.5 Simulate an n-type doped (Nd=1e15/cm3) (i) Si (ii) Ge and (iii) GaAs. (take Na=10/cm3)
(Hint: You can simulate different temperature ranges)
(a) Find the freeze out temperature. ($T_{freeze\text{-}out}$: N/Nd=0.99).
(b) Find the temperature at which extrinsic behaviour ceases to exist. Suppose extrinsic behavior is valid till N/Nd<=1.01.
(c) The difference of (a) and (b) is the working range for that material. Which material has highest working range and why?
(d) Plot Fermi level for the temperature range 300K-700K. What do you see and why? Find the slope in eV/K.