Physics 323, Section 1, Fall Semester 2019
Instructor: Lance Nelson
Exam #3
Dec 11 – Dec 14

This exam is **CLOSED BOOK**. All the information you need to solve a problem should be included in the problem statement or on the help sheet (found on the course website). You are welcome to use a help sheet that includes notes that you have added. If you believe that something has been unintentionally left off of the help sheet, explain and state how you would have solved the problem given the missing information.

1. (5 pts) What is a metal? (One short sentence) (Note: I can think of multiple one-sentence answers that are correct. Can you?)

2. (5 pts) What is the density of states $g(E)$? Make a sketch of the density of states for the free electron model of a metal.

3. (5 pts) What is the Fermi-Dirac distribution function $f_D(E)$? Sketch a graph of it for some temperature above 0 K.

4. (5 pts) What is the Fermi surface? (One short sentence)

5. (15 pts) Consider a sample of volume V containing N total atoms. Each primitive unit cell in the crystal contains p atoms. Each atom in the crystal has Z electrons.

   (a) Consider a sphere of radius k in k-space. Find the number of electronic states contained within the sphere. Your answer may contain only the symbols V, N,p,Z,k, and constants of nature. (Note: your answer doesn't necessarily involve *all* of the symbols)

   (b) How many electronic states are contained in a single energy band in this crystal. Your answer should contain only the symbols V, N,p,Z,k, and constants of nature. (Note: your answer doesn't necessarily involve *all* of the symbols)

6. (10 points)

   (a) Boron is a non-metal. Each boron atom has 5 electrons. What can we conclude (if anything) about the number of atoms in the primitive unit cell.

   (b) Arsenic is a metal. Each arsenic atom has 33 electrons. What can we conclude (if anything) about the number of atoms in the primitive unit cell.

7. (10 pts) Consider a sample of n-type silicon.

   (a) How many valence electrons does each impurity atom have?

(b) Compare the number of electrons in the conduction band to the number of holes in the valence band.

(c) Where is the Fermi energy?

8. (20 pts)For the following questions, consider a piece of sodium with mass $m = 8.00$ g. ($\sigma = 2.38 \times 10^7/\Omega\cdot$ m, $\rho = 968$ kg/m^3, $Z = 1$, $a = 4.30$ Å)

   (a) If we assume that the electrons are free, find the Fermi energy, the Fermi velocity, and the radius of the Fermi surface.

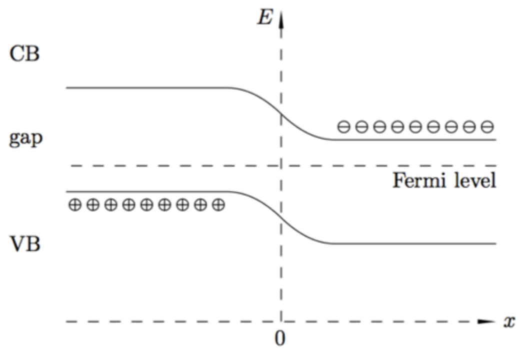
   (b) How many electronic states are contained in this sphere?

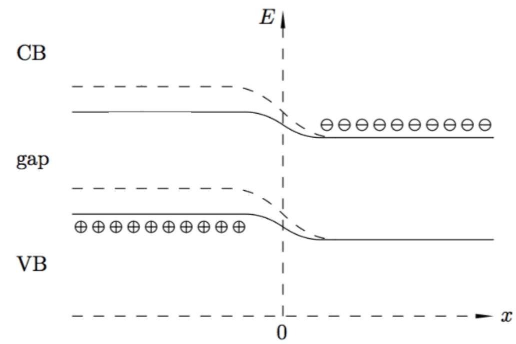
   Now we apply a $\mathcal{E} = 1.00$ V/m electric field, causing current to flow.

   (c) Determine the drift velocity of the electrons and the displacement of the Fermi surface (Δk). Is this displacement large or small relative to the radius of the Fermi sphere?

   (d) Determine the mean time between collisions (τ) and the average distance traveled between collisions. Is the distance between collisions big or small relative the the atomic spacing? Comments?

9. (10 pts) For the following questions, consider the p-n junctions shown below





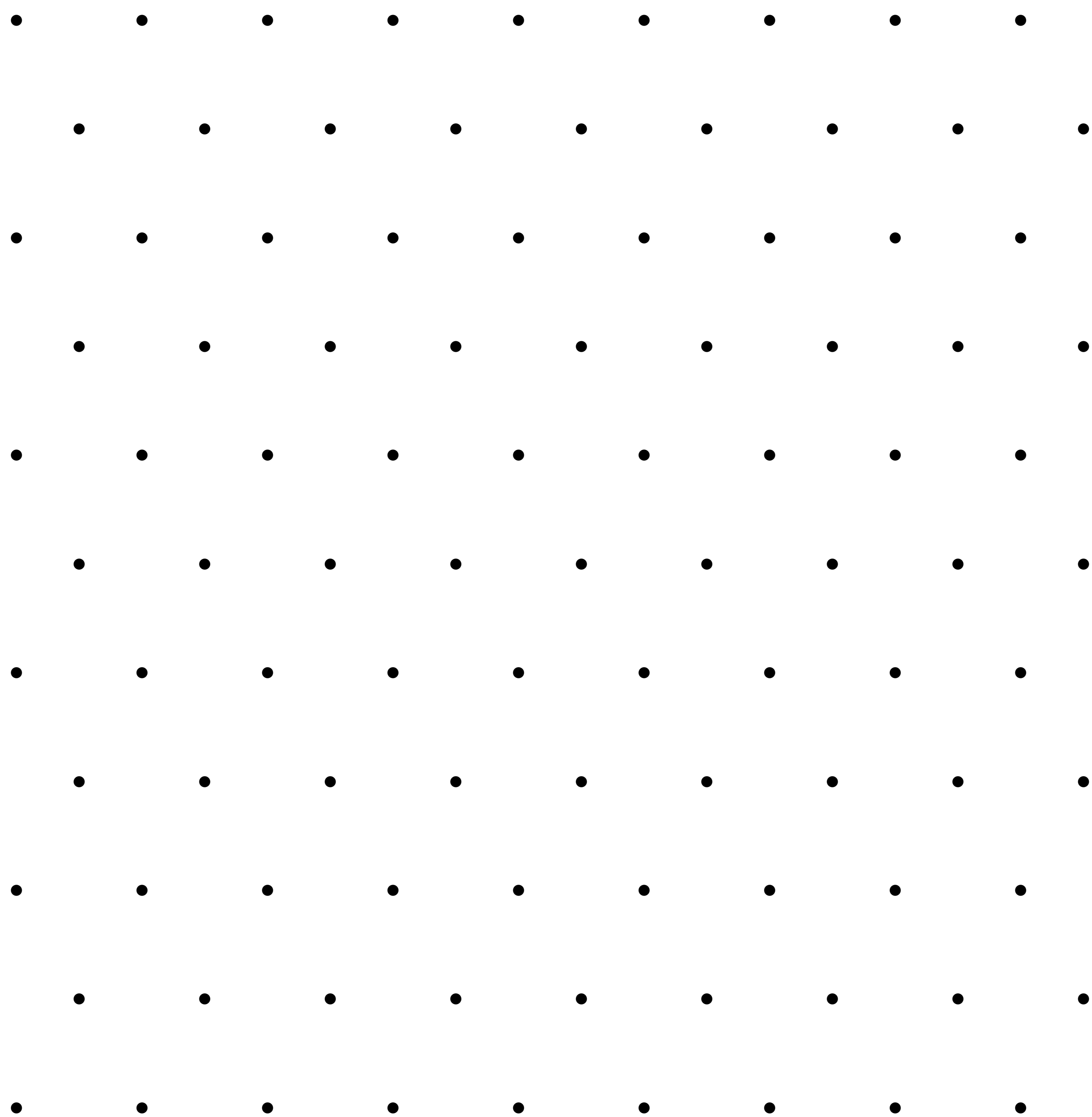
(a) Indicate, on the left-most figure, which side of the junction is the n-side and which is the p-side.

(b) The figure on the right is a biased p-n junction. Is it forward or reversed biased?

(c) For the bias shown, will the generation current increase, decrease, or stay the same? Explain

(d) For the bias shown, will the recombination current increase, decrease, or stay the same? Explain

10. (15 pts) Consider the reciprocal lattice shown below. Find the first, second, and third Brillouin zones. (Please use a ruler!)



11. (10 pts) Consider a piece of n-type silicon with $N_d = 1.56 \times 10^{21}$ m^{-3}. The effective mass of the holes in the valence band are $m_p^* = 1.00$m and the effective mass of electrons in the conduction band is $m_n^* = 1.09$m. Find the density of electrons in the conduction band (n) and the density of holes in the valence band (p) at 300 K. (The band gap for silicon is: $E_g = 1.124$ eV)