Physics 323, Section 1, Fall Semester 2019
Instructor: Lance Nelson
Exam #3
Dec 11 – Dec 16

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.

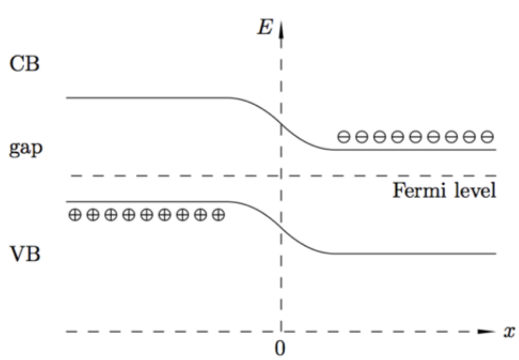
   (b) How many electronic states are contained in this sphere?

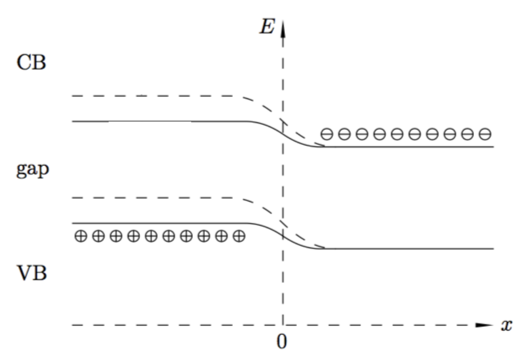
   Now we apply a $\mathcal{E} = 1.00$ V/m electric field, causing current to flow.

   (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





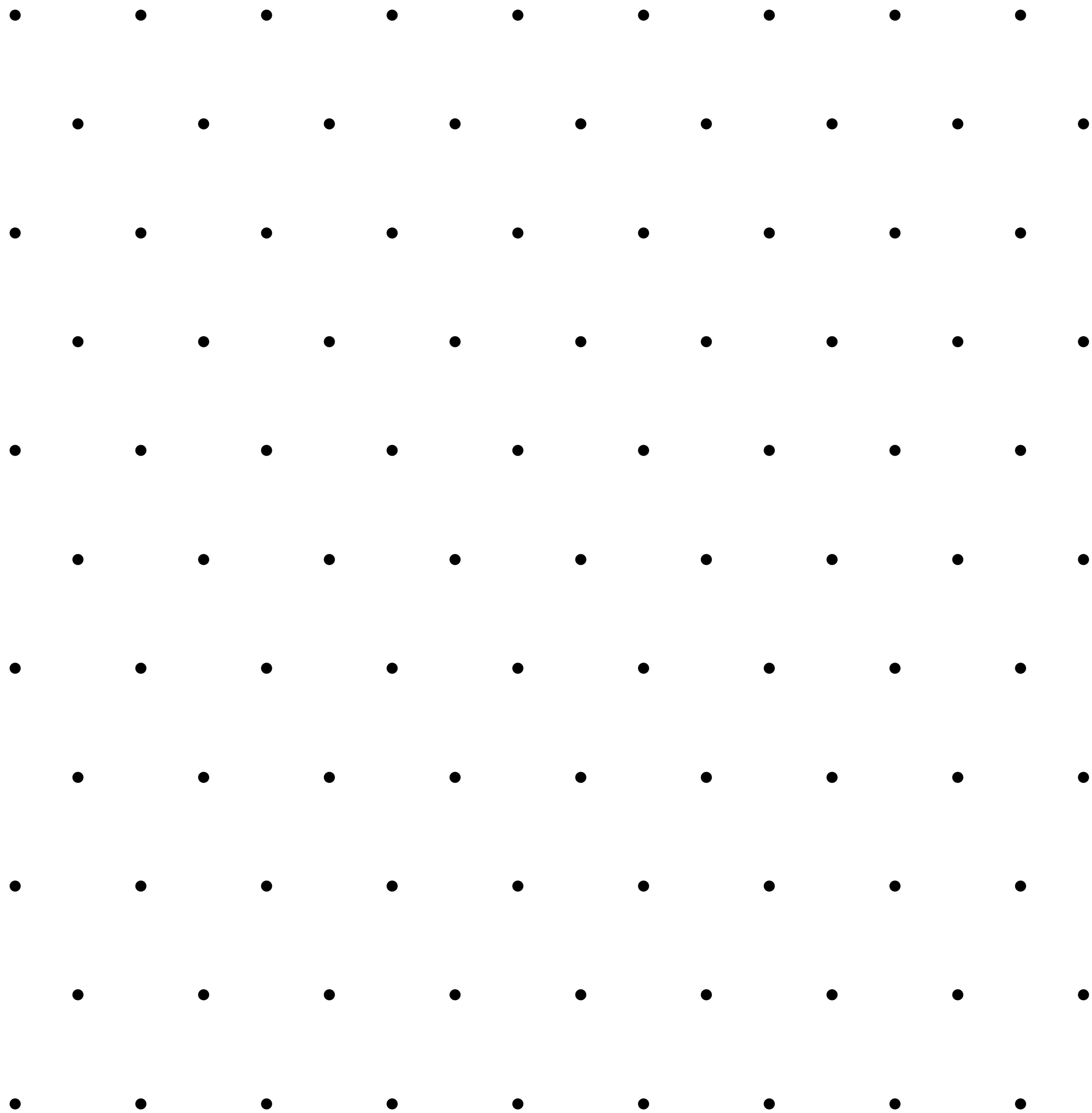
   (a) Indicate, on the left-most figure, which side of the junction is the n-side and which is the p-side.

(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 Brilliouin 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)

12. (10 pts)

    (a) Consider a monatomic crystal (contains only one type of atom). Each of these atoms has an *odd* number of electrons. We do not know the structure of the crystal, including how many atoms are in the primitive unit cell, and we do not know anything about its band structure. From this information, decide whether this crystal must be a metal, may be a metal, or cannot be a metal

    (b) Repeat if we know, in addition to the information in part (a), that there are 2 atoms in each primitive unit cell of the crystal

13. (5 pts) What is Pauli's exclusion principle? (one sentence)

14. (5 pts) What is an intrinsic semiconductor? (one sentence)

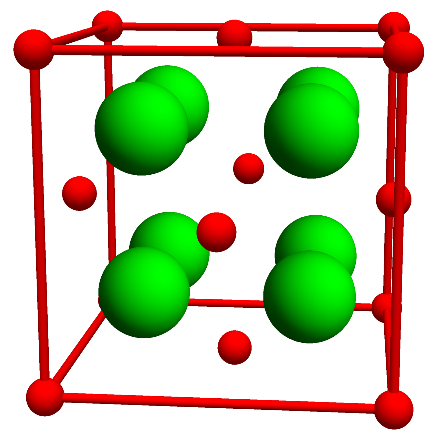
15. (5 pts) What experimental technique would you use to measure the Fermi surface for a metal?

16. (10 pts) How does the density of electrons in the conduction band (n) in a doped semiconductor vary with temperature. Make a sketch of the graph and explain why it has the shape that it does.

17. (10 pts) Sketch the resistivity vs temperature curve for a metal. Explain why it has this shape.

18. (10 pts) The electrical conductivity of Aluminum is about the same as that of Copper even though Aluminum has three times as many conduction electrons. Explain why.

19. (15 pts) Consider the unit cell (repeating unit) shown on the right. (look familiar?)
    (a) If the big atoms are Ag and the small atoms are Ni is this material a conductor or an insulator? Explain

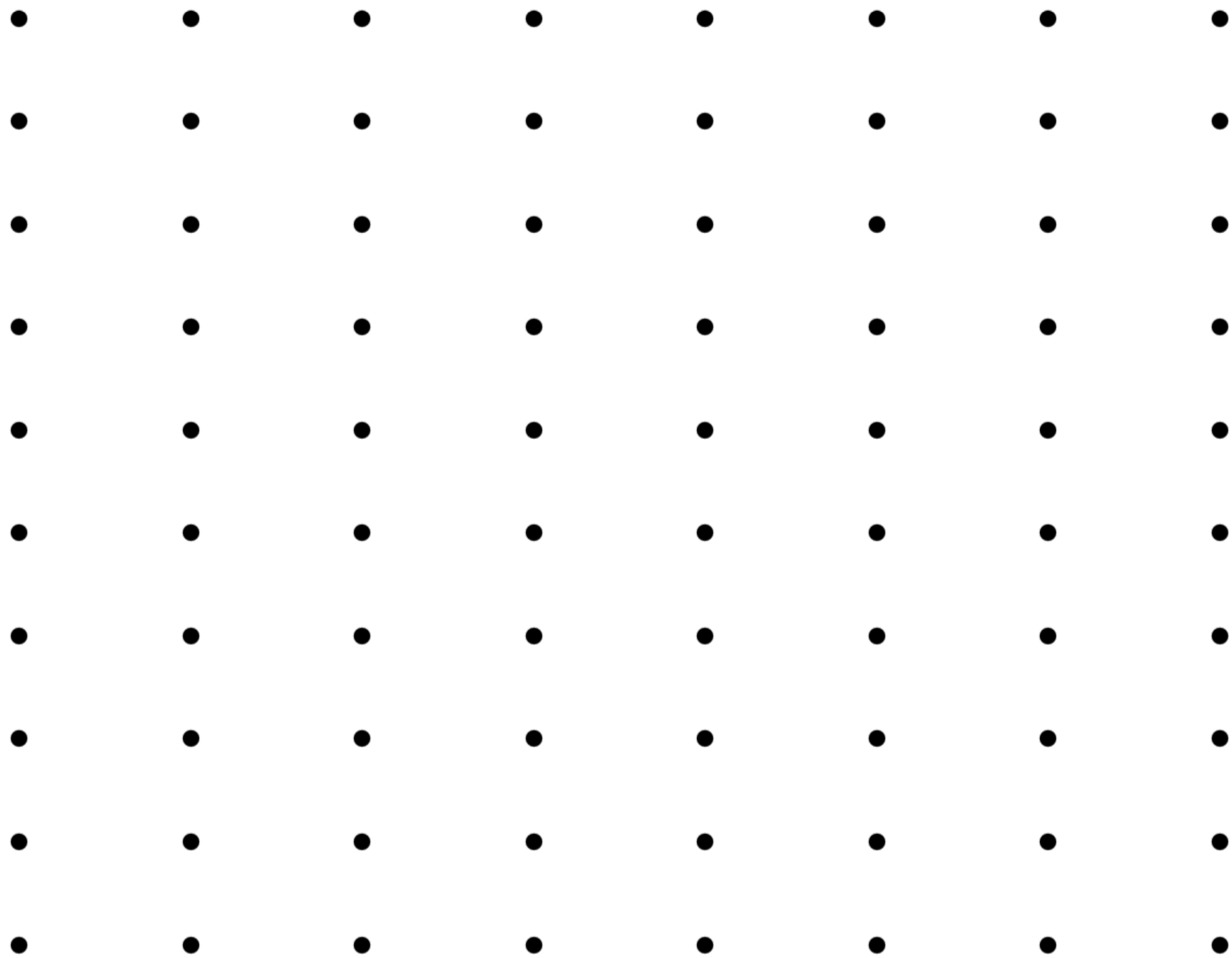


    (b) If the big atoms are Pd and the small atoms are Ni is this material a conductor or an insulator? Explain

    (c) If the big atoms are Cu and the small atoms are Pd is this material a conductor or an insulator? Explain

20. Consider a piece of sodium metal (Na) of mass 5.00 g. How many electronic states are in each band?

21. Consider the reciprocal lattice shown below. Find the first, second, and third Brilliouin zones



22. For the following questions, consider a piece of copper with mass $m = 5.00$ g. ($\sigma = 5.98 \times 10^7/\Omega\cdot$ m)

    (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.

(e) Discuss your results from part (c). Is it a big number or a small number relative to the atomic spacing? Why?

23. Consider a sample of p-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?

24. Explain the difference between generation and recombination current.

25. In a diode, current can flow in one direction but not the other. Explain why.

26. Explain how a solar cell works.