Physics 323, Section 1, Fall Semester 2019
Instructor: Lance Nelson
FinalExam
Dec 16 – Dec 20
This exam is **OPENED BOOK** and untimed. Feel free to start and stop as often as you'd like.

1. (5 pts) Which of the following is *not* a lattice vector of an fcc lattice? You may give more than one response.

(a) a $(\hat{i} + 2\hat{j})$
(b) a $(\frac{1}{2}\hat{i} + \frac{1}{2}\hat{k})$
(c) a $(\frac{3}{2}\hat{i} - \frac{3}{2}\hat{j})$
(d) They are *all* lattice vectors of the fcc lattice.

2. (5 pts) The volume of a *primitive* unit cell in cesium chloride (CsCl) is.

(a) a^3
(b) $\frac{1}{2}a^3$
(c) $\frac{1}{4}a^3$
(d) $\frac{1}{8}a^3$

3. (5 pts) The number of atoms per unit volume in sodium (Na) is

(a) a^3
(b) $\frac{2}{a^3}$
(c) $\frac{4}{a^3}$
(d) $\frac{8}{a^3}$
(e) $\frac{1}{2a^3}$
(f) $\frac{1}{4a^3}$
(g) $\frac{1}{8a^3}$

4. (5 pts) Consider a crystal in the orthohombic crystal system. The [110] direction

(a) is
(b) is not

perpendicular to the (110) plane.

5. (5 pts) The space group of a certain crystal is in the crystal class 422 and is symmorphic. If there is an atom at ($\frac{1}{2}$,0,0), then there must be

(a) 1
(b) 2
(c) 3
(d) 4
(e) 6
(f) 8

atoms of that type in the primitive unit cell.

6. (5 pts) Consider x-ray diffraction from some set of planes n a crystal. If we use x rays of shorter wavelength, the Bragg angle will

(a) increase
(b) decrease
(c) remain the same

7. (5 pts) The reciprocal lattice of sodium chloride (NaCl) is

(a) sc (b) bcc

(c) fcc (d) None of the above.

8. (5 pts) In an fcc lattice, which of the following planes are spaced furthest apart?

(a) (100) (b) (110)

(c) (111)

9. (5 pts) A crystal with one atom in the primitive unit cell

(a) will always (b) may

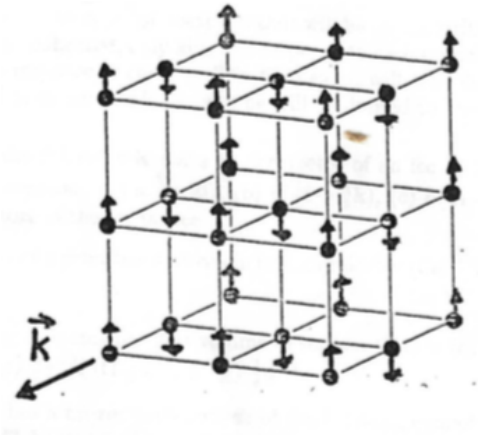
(c) will never

exhibit an optical branch in its photon dispersion curves.

10. (5 pts) Consider the lattice wave in the monatomic simple-cubic crystal shown below. The wave is

(a) transverse with k=0 (b) transverse with k=π/a

(c) longitudinal with k=0 (d) longitudinal with k=π/a



11. (5 pts) Consider a lattice wave with wave vector $k = (\pi/a)(\hat{i} + \hat{j})$ in a crystal of copper (Cu). Which of the following statements is true?

(a) All of the atoms are moving in phase with each other.

(b) Half of the atoms are moving 180° out of phase with the other half

(c) The is some other phase relationship between the atoms.

12. (5 pts) A certain crystal has a bcc lattice. A phonon in that crystal has a wave vector $k = (4\pi/a)(\hat{i} + \frac{1}{2}\hat{j} + \frac{1}{2}\hat{k})$. The wave vector of this phonon *in the first Brillouin zone* is equal to

(a) 0 (b) $(4\pi/a)(\frac{1}{2}\hat{j} + \frac{1}{2}\hat{k})$

(c) $(4\pi/a)(\frac{1}{2}\hat{i})$ (d) None of the above.

13. (5 pts) Consider the inelastic scattering of the photons in a crystal. If the photon absorbs a phonon, the wavelength of the photon will

(a) increase (b) decrease

(c) remain exactly the same

14. (5 pts) The average kinetic energy per conduction electron in a metal at room temperature is generally

(a) much greater than k_BT (b) much less than k_BT

(c) about the same as k_BT

15. (5 pts) Consider an electron state at an energy slightly below the Fermi energy. If we increase the temperature, the probability that this state will be occupied

(a) increases (b) decreases

(c) remains the same

Consider the Fermi energy to be independent of temperature.

16. (5 pts) For a real metal, the density of electron states *in k-space* is generally the greatest

(a) at the center of the first Brillouin zone (b) near the edge of the zone

(c) somewhere between the center and edge of the zone (d) the same everywhere in the zone

17. (5 pts) The volume of the first Brillouin zone in Si is

(a) $\frac{2\pi^3}{a^3}$ (b) $\frac{8\pi^3}{a^3}$

(c) $\frac{32\pi^3}{a^3}$ (d) $\frac{64\pi^3}{a^3}$

18. (5 pts) Consider a crystal of copper (Cu) of volume V. The number of electron states in one band is equal to

(a) $\frac{2V}{a^3}$ (b) $\frac{4V}{a^3}$

(c) $\frac{8V}{a^3}$ (d) $\frac{16V}{a^3}$

(e) $\frac{64V}{a^3}$ (f) $\frac{128V}{a^3}$

19. (5 pts) A crystal with an even number of electrons per primitive unit cell

(a) must be a metal (b) may be a metal

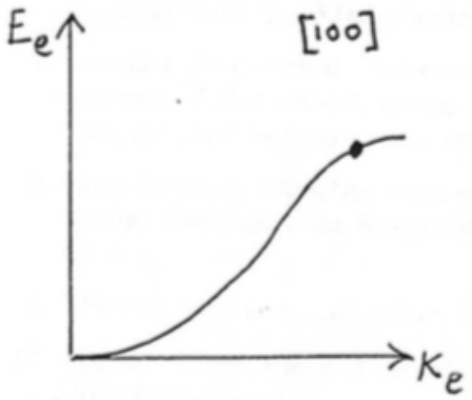
(c) cannot be a metal

20. (5 pts) If we increase the temperature, the average time between collisions of a conduction electron in a metal will

(a) increase (b) decrease

(c) stay the same

Note: For the next two problems refer to the figure below which depicts an electronic energy band in one dimension:



21. (5 pts) The effective mass of an electron occupying the state indicated by the dot is

(a) positive (b) negative

(c) infinite (d) zero

(e) cannot be determined from the information given

22. (5 pts) The velocity of an electron occupying the state indicated by the dot is

(a) zero (b) in the $+x$ direction

(c) in the -x direction

23. (5 pts) In an n-type semiconductor, the Fermi energy is generally

(a) above (b) below

the midpoint of the energy gap between the valence and conduction bands.

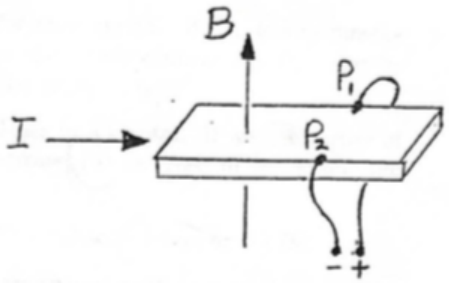
24. (5 pts) If we raise the temperature of an intrinsic semiconductor, its conductivity will

(a) increase (b) decrease

(c) remain the same

25. (5 pts) Consider a current I flowing through a semiconductor in a magnetic field B as shown in the figure below. We find that the voltage at point P_1 is positive with respect to the voltage at point P_2. This semiconductor is

(a) n-type (b) p-type



26. (5 pts) At 300 K, sodium (Na) has

(a) a much greater (b) a much smaller

(c) about the same

molar heat capacity as potassium (K).

27. (5 pts) At 100 K, silicon (Si) has

(a) a much greater (b) a much smaller

(c) about the same

molar heat capacity as germanium (Ge).

28. (5 pts) According to the classical model, the molar heat capacity of copper (Cu) is

(a) much greater than (b) smaller than

(c) about the same as

the molar heat capacity of sodium chloride (NaCl). (By molar heat capacity of NaCl, I mean the heat capacity per mole of atoms, not molecules. Also note that Cu is a metal and NaCl is not.)

29. (5 pts) Consider an ion with a magnetic moment. If we place this ion in a magnetic field **B**, the energy of the magnetic moment will be lowest when it is pointing

(a) in the same direction as **B** (b) in a direction opposite to **B**

(c) in a direction perpendicular to **B** (d) none of the above

30. (5 pts) According to the classical model, copper (Cu) should be

(a) paramagnetic (b) diamagnetic

31. (5 pts) Suppose we put a piece of metal in the path of an electromagnetic wave. If the frequency of the wave is *slightly* greater than the plasma frequency of the metal, the wave will be

(a) totally reflected (b) partially reflected

(c) not reflected at all

from the surface of the metal.

32. (10 pts) Consider a crystal with N_c primitive unit cells and p atoms in each primitive unit cell. How many vibrational modes are there in this crystal

33. (10 pts) Sketch a graph showing heat capacity as a function of temperature for a typical solid. What does classical theory predict the heat capacity to be? Indicate this on the graph. Over what temperature range does the classical model fail? Explain why briefly.

34. (10 pts) What two things contribute to the heat capacity of solids (In other words, what two things store the thermal energy). Does one dominate over the other at low temperature? high temperature?

35. (10 pts) Briefly define magnetic susceptibility (χ) (One short sentence)