Name:

Exam 2 - Solid State Physics - Fall 2014

November 24, 2014

1:55-3:55PM

<u>Directions:</u> Please clear your desk of everything except for pencils and pens. The exam is closed book, and you are not allowed calculators or formula sheets. Leave substantial space between you and your neighbor. Show your work in the space provided on the exam. I can provide additional scratch paper if needed.

The entire exam is out of 100 points with each question (1,2,3,4) being worth 25 points. Each subquestion, (a)-(e), is worth 5 points unless noted otherwise.

1. **Short answer section**

   (a) What is the trial wave function for the Hartree-Fock approximation?

   (b) What is the basis of Thomas-Fermi screening?

   (c) Name 5 failures of the static lattice model.

   (d) What is the Debye model for phonons? What is a typical Debye temperature?

   (e) What are the conservation laws for neutron scattering from phonons?

2. **Lattice Vibrations**
Consider a one-dimensional Bravais lattice with ions that have positions na and mass M. The force between them is modeled by a springs with nearest neighbor atoms having force constant K_1 and next nearest neighbor atoms having force constant K_2.

   (a) Write down the equations of motion for the displacements, $u(na)$.

   (b) Solve for $\omega(k)$ within the first Brillouin zone. What is the wave vector range of the first Brillouin zone?

   (c) (3 points) What is the speed of sound in this model?

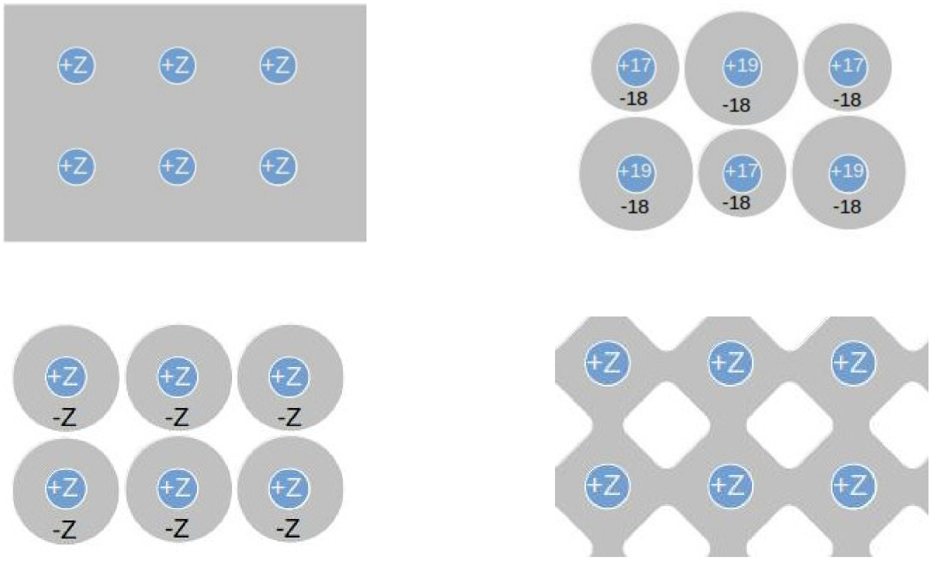
(d) Sketch $\omega(k)$ vs. k in the first Brillouin zone. Clearly label the axes. Label the acoustic and optical modes.

(e) (7 points) For the quantum version of this crystal calculate the low temperature and high temperature limits of the specific heat.

3. **Real Materials**

The following question contains several questions about real materials - mostly elements - from the more qualitative chapters of the book.

(a) The figures below illustrate the charge density for four different kinds of crystals. Label each crystal as either molecular, ionic, covalent, or metallic.



(b) Describe briefly the bond or forces which hold each of the above crystals together:

i. molecular crystals -

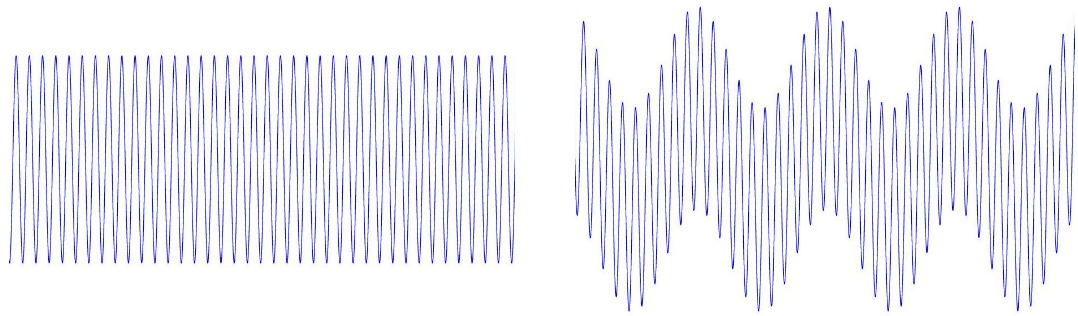
ii. ionic crystals -

iii. covalent crystals -

iv. metals -

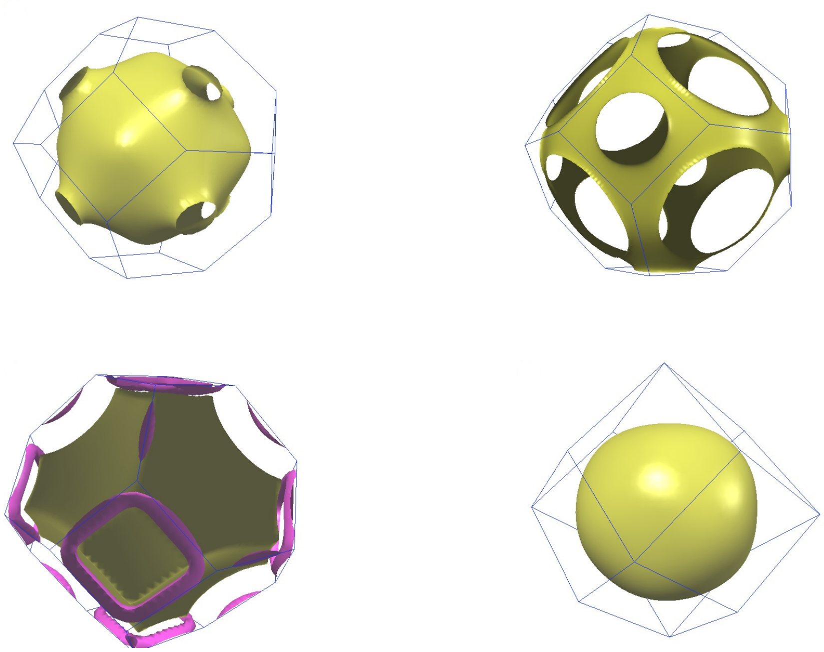
(c) What is the de Haas van Alphen effect and how is it used to map out the Fermi surface?

(d) The following shows the magnetization as a function of magnetic field for two different elements. Based on these plots, what do you think is the difference between the two Fermi surfaces?



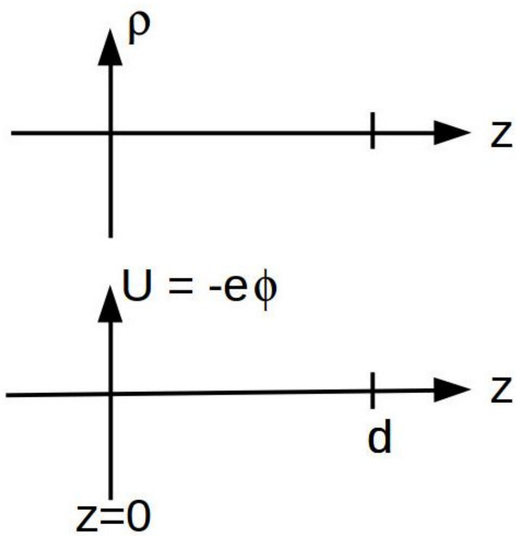
(A) (B)

(e) The figure has four different Fermi surfaces corresponding to an Alkali metal, a Nobel metal, a divalent metal, and a trivalent metal. Label each figure accordingly.

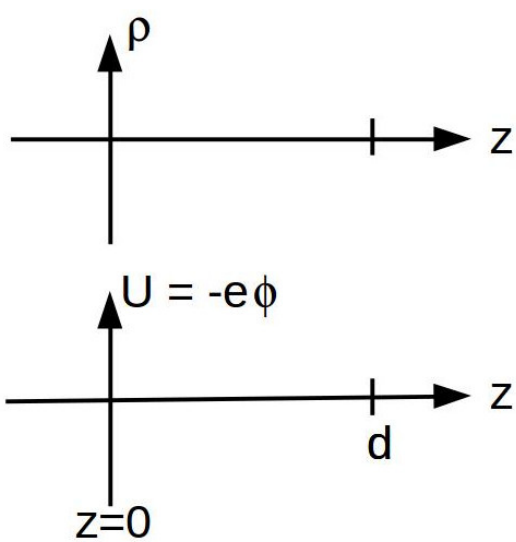


4. **Surfaces, Screening, and Scattering**

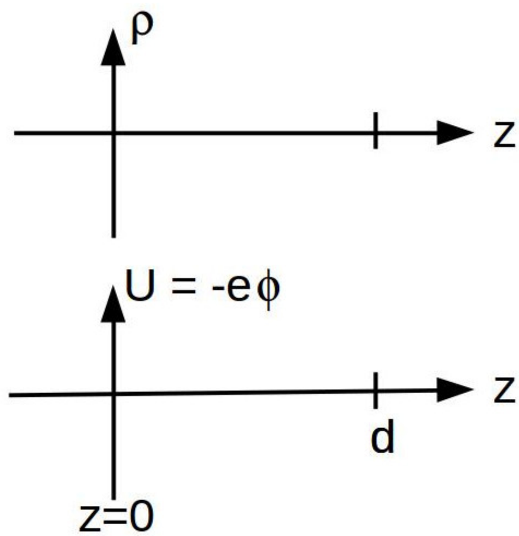
(a) A slab of metal exists between $z = 0$ and $z = d$. Sketch below the charge density, ρ, allowing for charge redistribution at the interface, and also the electrical potential energy, $U = -e\phi$. You may treat the positive ionic background as being uniform.



(b) Suppose an external electric field, $\vec{E} = E\hat{z}$ is applied perpendicular slab. Again sketch the charge density and the electrical potential energy. What is the characteristic length scale that the charge density relaxes to zero inside the metal?



(c) Redo the graph in part (b) for the case of a semiconductor, which has a much lower carrier density. How does the characteristic length scale that the charge density relaxes change?



(d) Write down the Boltzmann equation, including the scattering in terms of a rate to go from k to k': $W_{k,k'}$.

(e) Assuming that the scattering is elastic, derive a continuity equation for the energy density.