Qualifying Exam - Introduction to Solid State Physics (2019)

This exam is closed-book. Please make sure that you put your name on all of your answer sheets and did not forget any question.

Crystal structure

1. What properties make a crystal different from a liquid? (5%)
2. Draw the lattice for a crystal with the three-atom basis A=(0,1), B=(1,1),C=(0,0) and the lattice vectors r=(2,1) and s=(1,3). (Draw in units of cm for an area of 6x6cm and label the atoms A,B,C) (10%)
3. Atoms in a crystal exhibit the energy-distance relation:
   $E(r) = \frac{16eV}{nm}(r^2 - 2r - 7\sqrt{r})$. (where r is in nm)
   a. How much energy does it take to remove an atom from rest position? (10%)
   b. Can this formula predict thermal expansion? Why/why not? (5%)

Diffraction

4. Electrons can be selectively transmitted through two closely spaced slits in the "double slit experiment". Assuming that electrons behave particle-like or wave-like, how would the electron distribution on a screen behind the double slit look like. (10%)
5. X-ray diffraction experiments analyze the intensity of electron diffraction from crystals. An intensity maximum is found to shift to larger angles after modification of a crystal. Explain the origin of this change and give two potential reasons. (10%)

Phonons

6. A phonon arises from collective vibrations of neighboring atoms in a crystal. Consider a 1D chain of identical masses connected by identical springs.
   a. What is the amplitude ratio and phase between neighboring masses? (10%)
   b. What is the speed of a phonon in this example? (10%)
   c. Sketch the relation between propagation speed and oscillation frequency. (10%)

Electrons

7. A 1D quantum well is a structure that restricts the wave functions of electrons and yields quantization of allowable states.
   a. Imagine a 1nm wide 1D quantum well that emits red light (E=1.9eV) when an electron relaxes from the second to the first state. What is the energy of an electron relaxing from the third to the first state? (10%)
   b. How would the emission energy of a 1D quantum well change if the well size was doubled? (5%)
8. How would the mean energy of electrons change if the band-gap in a crystal was somehow doubled? (5%)