Fall 2004: MtSE 719 Mid-Term Exam

Physical Principles of Solid-State Characterization

Name: **ID**

Take-home exam. Each problem is 15 pt. Solve any 7 problems for a full credit. Additional problems will be considered only for extra credit and will receive 8 points each. Solutions must be turned in before 4:00 pm next day after the exam.

1. Consider "slow" and "fast" neutrons with energies, respectively, of 1 eV and 1000 MeV. For each case calculate a) the speed of the neutron, b) de Broglie wavelength, c) equivalent temperature, d) wavelength and momentum of a photon with the same energy, e) energy and frequency of a photon with the same wavelength
   Extra credit: in a) and b) for fast neutrons take into consideration relativistic effects. How much are the results changed?

2. Using Bohrs model of a hydrogen atom (with ionization potential of 13.6 eV) estimate the ionization potential of a "muonium" atom. In such atoms the nucleus is a single proton, but the electron is replaced by a heavier particle with $m_\mu \simeq 207 m_e$.
   Extra credit: the mass of a muon is already non-negligible to the mass of a proton. Obtain a more accurate formula.

3. In 1913 H. Moseley observed a characteristic X-ray line (K_α line) with frequency f which varies smoothly with the atomic number Z as

   $$f = const \cdot (Z-1)^2$$

   (see Fig. 1). The value of *const* can be calculated from the following considerations Suppose one electron is knocked out of the K-shell ($n = 1$) leaving there one electron and one hole. An X-ray photon is emitted when an electron from the L-shell ($n = 2$) drops down to fill the hole. This electron is attracted to the nucleus, screened by the remaining K-electron. The Bohrs formula can be used with an effective charge of the nucleus $Z - 1$. Calculate the *const*.

4. For the previous problem, restore the labeling of the y-axis in Fig. 1 (the x-axes is the atomic number).

5. Describe qualitatively the structure of spectrum (i.e., possible energies) of a) free particle, b) particle which can perform only restricted motion, c) particle in a periodic potential

6. Consider the following hypothetical molecule: two nuclei of 30 a.u. each are separated by an equilibrium distance 0.5 nm. When nuclei are displaced from equilibrium their interaction can be modeled by a spring with a spring constant $k = 2000 N/m$. Calculate (in SI units) the rotational inertia and the vibrational frequency and determine a few vibrational energy levels in eV.

7. for the previous problem find the rotational energy levels (in eV) and give frequencies and wavelengths of a few rotational and rotational- vibrational spectral lines.

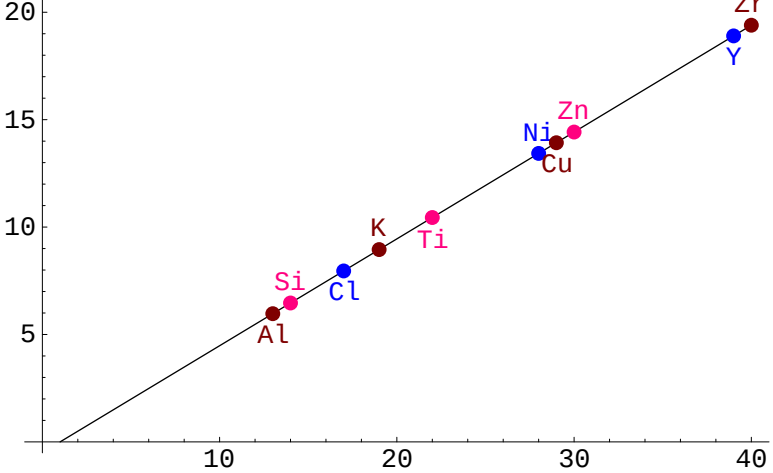

Figure 1:

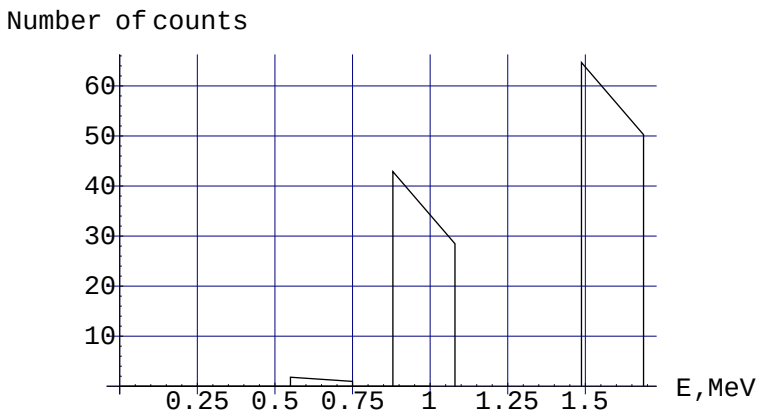

Figure 2:

8. Fig. 2 shows a RBS study of a certain thin film using 3.0 MeV α-particles. a) Identify every one of the three elements present in the film. b) Estimate the thickness of the film assuming an energy loss of 200 eV/nm for all energies.

9. For the previos problem estimate the relative concentrations. Try to guess the chemical composition of the film (i.e. the chemical formula for the main compound, and which element is the "impurity").