PHYS 3202 QPII Mid-term examination (March 7, 2011)

11:30am – 1:15pm

Answer all questions.

(1) **(Vibrational-rotational spectrum)** (25 marks)

Fig. 1 shows the vibrational-rotational spectrum of HBr molecule.

(a) Determine the moment of inertia, bond length and the force constant of the molecule.

(Given: Mass of H atom = 1 u. Mass of Br atom = 80 u. u is the atomic mass unit.)

(Hint: Use the average separation of the spectral lines for calculation.) (15 marks)

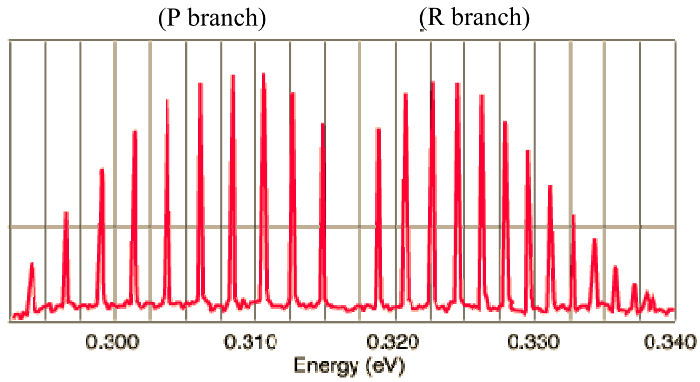

Fig. 1 The vibrational-rotational spectrum of HBr molecule.

(b) Fig. 1 is an absorption spectrum. Sketch an energy level diagram to show the transitions for the R branch. (10 marks)

(2) **(Giant helium molecule)** (15 marks)

(a) Usually, He_2 molecule does not exist, why? (5 marks)

(Hint: $|E_{-} - \varepsilon_0| > |E_{+} - \varepsilon_0|$ as shown in Notes.)

(b) Giant helium molecules, containing only two atoms "but assuming a size as large as a small virus", were created in 2003. Write down the Schrödinger equation for He_2 molecule. (Ignore the spin terms.) (10 marks)

(3) **(Energy band diagrams)** (10 marks)

(a) In Fig. 2 two energy bands of a hypothetical solid are represented. The bands are filled to level E_x, which may be in either band 1 and band 2. Indicate whether the solid is a conductor, insulator, or (intrinsic) semiconductor if

(i) $E_x = 3.00$ eV and $E_b = 9.00$ eV,

(ii) $E_x = 3.00$ eV and $E_b = 4.10$ eV,

(iii) $E_x = 1.49$ eV and $E_b = 9.00$ eV, or

(iv) $E_x = 4.40$ eV and $E_b = 4.10$ eV.

(2 marks each)

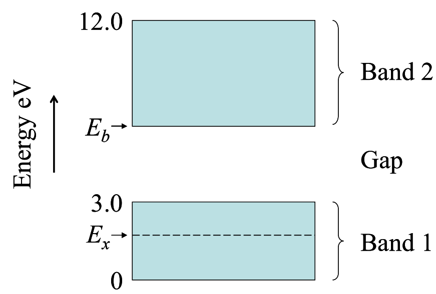

Fig. 2

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(b) Fig. 3 shows an energy band diagram of a solid assembled from N atoms. How many energy states are there in the 2s band for electrons? (2 marks)

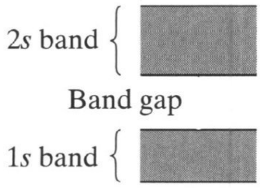

Fig. 3

(4) (**Cohesive energy)** (10 marks)

(a) NaCl crystal has a cubic structure with unit cell shown in Fig. 4.
Describe its crystal structure in terms of lattice type and basis. (2 marks)

(b) Consider the Na^+ ion at the center of the cube in Fig. 4.

(i) How many fourth-nearest neighbors does it have? (6 marks)

(ii) Are they Na^+ or Cl^-? (2 marks)

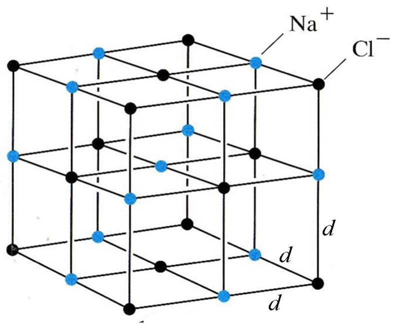

Fig. 4 The conventional unit cell of NaCl.

(5) **(Drude model)** (20 marks)

Silver (Ag) is a monovalent metal with density $\rho_m = 10.49$ g/cm^3, molar mass $M = 107.68$ g/mole, and resistivity $\rho = 1.62 \times 10^{-8}\ \Omega \cdot$ m.

Assume that quantum free electron model is used.

(a) Calculate the number of conduction electrons per unit volume. (4 marks)

(b) Calculate its Fermi energy at $T = 0$. (8 marks)

(c) Calculate the mean free path of conduction electrons at $T = 0$. (8 marks)

(6) **(Semiconductors)** (20 marks)

(a) An impurity atom donates one extra electron to the conduction band of silicon at room temperature. If these impurity atoms are added to silicon in the ratio of one impurity atom to 10^{10} silicon atoms, determine the conductivity of the doped silicon, assuming that the mobility of the donated electrons is the same as the mobility of the host electrons. The density of silicon is 2.42 g/cm^3. Molar mass of silicon is 28.1 g/mole and mobility:

$\mu_e = 1350$ cm^{2}V^{-1}s^{-1} & $\mu_h = 480$ cm^{2}V^{-1}s^{-1}. (18 marks)

(b) If a crystal of pure silicon is doped with atoms of phosphorus (Group V element), what type of semiconductor results, n or p? (2 marks)

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