Chemistry 2720 Fall 2002 Test 3

Answer all questions.
Write all answers in the booklets provided.
Aids allowed: $8\frac{1}{2} \times 11$-inch information sheet, calculator.
Time: 75 min
Questions: 6
Marks: 60
Useful data:

$c = 2.997\,924\,58 \times 10^{8}\,\text{m/s}$
$e = 1.602\,176\,46 \times 10^{-19}\,\text{C}$
$\varepsilon_0 = 8.854\,187\,817 \times 10^{-12}\,\text{C}^2\text{J}^{-1}\text{m}^{-1}$
$h = 6.626\,068\,8 \times 10^{-34}\,\text{J/Hz}$
$m_e = 9.109\,381\,9 \times 10^{-31}\,\text{kg}$
$N_A = 6.022\,142\,0 \times 10^{23}\,\text{mol}^{-1}$
$R_H = 2.179\,871\,90 \times 10^{-18}\,\text{J}$

1. Atomic and molecular energies are often given in electron-volts (eV). The second ionization energy of helium is 54.416 eV. What is Rydberg's constant in eV? [3 marks]

2. In certain areas of chemistry, it is common to make solids or even molecular compounds which contain cavities large enough to hold one or a few molecules. Examples include fullerenes (carbon allotropes), zeolites (silicates) and clathrates (ices in which the crystal structure has large vacancies). Suppose that a methane molecule (molar mass 16.043 g/mol) is trapped in a cavity of radius 1.14 nm, the size of the cavities in zeolite A.

   (a) Estimate the minimum uncertainty in the velocity of the methane molecule. [6 marks]

   (b) Using the one-dimensional particle-in-a-box formula, calculate the minimum speed of the methane molecule.[1] [4 marks]

   (c) Are the results of the last two questions consistent with each other? Explain. [4 marks]

3. Spectroscopic equipment is frequently calibrated using the mercury green emission line at 0.4960 μm. If a gaseous ^{202}Hg atom emits a photon of this wavelength, by how much does its speed change? The mass of a ^{202}Hg atom is 201.970 617 amu. Typical speeds for gas-phase atoms or molecules at room temperature are in the range of a few hundred meters per second. Is the change in the speed due to the emission process significant? [8 marks]

[1] The cavity in a zeolite is not one-dimensional, but this will give a reasonable order-of-magnitude value.

4. Ionization energies can be measured by photoionization spectroscopy. In this technique, a sample is irradiated with monochromatic radiation. If the radiation is sufficiently energetic, electrons are ejected. Some of the photon energy goes into ionizing the atom or molecule, and the rest shows up as kinetic energy of the ejected electron.

   Helium has an ultraviolet emission line at 58.4 nm. When this wavelength of light is used to ionize krypton atoms in the photoionization experiment, the ejected electrons have a speed of $1.59 \times 10^6\,\mathrm{m/s}$. Calculate the ionization energy of krypton. [6 marks]

5. An orthorhombic lattice is one whose unit cell is a rectangular prism, but in which none of the lattice constants are necessarily equal. In an orthorhombic lattice, the distance between the crystallographic planes is given by

$$\frac{1}{d_{hkl}^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}.$$

   Nickel (II) sulfate forms orthorhombic crystals with $a = 634\,\mathrm{pm}$, $b = 784\,\mathrm{pm}$ and $c = 516\,\mathrm{pm}$.

   (a) If you were to study $NiSO_4$ by X-ray diffraction at a wavelength of 178.5 pm, at what angles would you expect to see the five lowest-angle reflections? Report your angles in degrees, to two decimal places, and indicate clearly the Miller planes to which each of these reflections corresponds. [16 marks]

   (b) Suppose that you wanted to repeat this experiment by neutron diffraction, keeping the same wavelength. What should the speed of the neutrons be? The mass of a neutron is $1.674\,927\,16 \times 10^{-27}\,\mathrm{kg}$. [4 marks]

6. The Humphreys series is a series of emission lines in the spectrum of hydrogen all of which share a common final quantum number n_f. The longest-wavelength line in this series occurs at $12.368\,\mu\mathrm{m}$. What is n_f? [9 marks]